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C.H. HUCKELBERRY
County Administrator

August 14, 2013

Jim Upchurch, Forest Supervisor
U. S. Forest Service
300 W. Congress Street
Tucson, Arizona 85701

Re: **Pima County Comments – Rosemont Copper Mine Preliminary Administrative Final Environmental Impact Statement**

Dear Mr. Upchurch:

Thank you for granting the time extension for providing comments. We appreciate this extra time.

Attached please find comments regarding the Rosemont Copper Mine Preliminary Administrative Final Environmental Impact Statement (PAFEIS) from Pima County and the Pima County Regional Flood Control District, collectively referred to as Pima County in this letter.

<u>Supplemental DEIS Requested</u>

Pima County previously provided comments on the Administrative version of the Draft EIS (DEIS) under our Cooperating Agreement with the Forest Service, as well as the public version of the DEIS. In those previous comments, we found the DEIS to be substantially flawed. We have requested previously and now repeat our request for a supplemental DEIS, since the version upon which public comment was based is so substantially different than the present version.

While this current version of the PAFEIS and associated reports contain considerably more information, the fact remains that this document fails to adequately address the primary purpose of the National Environmental Policy Act (NEPA), which is the full disclosure of impacts based on a thorough analysis of the proposal and its alternatives, including mitigation measures. Relying upon this document for your decision as to whether to permit the mine's destruction of thousands of acres of public Forest land, will surely result in lengthy challenges. Similarly, the US Army Corps of Engineers' (Corps') use of this document for their decision as to whether to approve a Clean Water Act (CWA) permit allowing Rosemont to fill, destroy and pollute area waterways, springs and seeps will also prove problematic.

Confusion Abounds Regarding Mitigation Measures and Requirements

An area of concern regarding the federal decision making process is confusion regarding what will be required mitigation or even offered mitigation. We understand the Forest Service, Corps and US Fish and Wildlife Service are limited in what they can require for mitigation. However, we were informed that if Rosemont voluntarily commits to mitigation measures, then those mitigation measures can become required conditions to the permits. Regardless of the distinction, the fact remains that the level of mitigation proposed is inadequate to offset the significant adverse and irreversible permanent impacts of the proposal or is described so vaguely it is confusing as to whether there is in fact a commitment.

Today, we still have no clear understanding as to what mitigation is either being voluntary provided or even required. We have read Appendix B, which is supposed to be a summary of the mitigation either provided or required. There are few, if any, declarative statements regarding specific, detailed mitigation.

There is also great confusion as to what is or will be a required response or condition of project approval or permitting. Saying the Forest Service cannot require a certain mitigation measure or project requirement and that the project proponent should volunteer compliance creates a loophole large enough to drive a mine truck through it. Without clear and concise requirements, every mitigation measure is questionable, setting up a scenario where the public will be left with a mess; and the taxpayers will be on the financial hook for corrective action.

Finally, the mitigation proposed also fails to recognize accepted local standards. Recommended mitigation measures proposed or suggested by the County have largely been ignored even though these measures are an accepted community standard.

No Clear Indication Local Code Compliance is Required

Neither the proposed action nor the project proponent has shown a willingness to or ability to comply with local codes and laws, such as the County Outdoor Lighting Code, the Floodplain Management Ordinance and other County Codes and Ordinances. The FEIS should provide a clear statement requiring local compliance. This is unacceptable and is either a federal oversight or simply ignoring legitimate local community concerns.

Major Areas of Concern

We take our role as a Cooperating Agency very seriously and to that end have contributed meaningful input we feel has and will continue to improve aspects of the project. As a County government, our role is also to assure public health, safety and welfare, as well as to protect taxpayers from adverse and costly impacts over the long run that could dwarf short-term benefits.

The comments attached reflect these roles and responsibilities, as well as the technical expertise of the staff that drafted them. Below are a few of the major concerns that continue to plague this NEPA review and process.

1. Water Supply Loss is not Mitigated

The proposed action relies on mined groundwater. The project proponents propose to recharge 105,000 acre feet (af) to offset this groundwater pumping and depletion. To date, they have recharged approximately 45,000 af of water in the Tucson Active Management Area (TAMA) but have done so in a location not hydrologically connected to the area of groundwater pumping and depletion.

The County has stated on numerous occasions our preference to have the mine rely on directly-delivered Central Arizona Project (CAP) water. If this water is not reliable on an annual basis, it could be supplemented with groundwater to augment the necessary mine water supply. This action would be preferred to groundwater mining and depletion. The balance of recharge from CAP water must be recharged in the area of hydrologic impact of groundwater pumping and depletion. Such should be required by the Forest Service.

In addition, there are vague references to offsetting groundwater pumping using CAP storage credits. However, there are no clear-cut statements or commitments to do so. The recharge credits obtained by Rosemont must be extinguished upon the pumping of groundwater. We recommend the Forest Service require that recharge credits be extinguished on an annual basis, with the number of acre feet of recharge credits being extinguished based on annual groundwater pumping by Rosemont. To not require these recharge credits to be extinguished potentially allows the groundwater overdraft to be doubled, instead of the proposed action, which is to offset groundwater pumping and depletion with recharge in the TAMA.

The County requests the Forest Service require further groundwater recharge to occur in the area of hydrologic impact of groundwater withdrawal and that recharge credits be extinguished on an annual basis in proportion to groundwater pumping by Rosemont.

2. Air Quality Impacts Are Underestimated

The potential adverse air quality impacts of the Rosemont proposal are underestimated due to incorrect assumptions used in the air quality modeling. These incorrect assumptions include the use of improper modeling inputs for estimating particulate matter; exclusion of elevated particulate matter data; underestimating background air quality data; incorrect nitrogen oxide emissions; and incomplete modeling for ozone.

When estimating the particulate matter (PM) arising from wind erosion of the tailings impoundments, the Forest Service relies on an assumed threshold friction velocity that is 2.5 times higher than the threshold actually measured for mine tailings at Hayden, Arizona. By using such a high threshold, the Forest Service has severely underestimated the ability of the wind to cause erosion, which would result in higher ambient PM levels that could exceed the National Ambient Air Quality Standards (NAAQS).

Rosemont excludes the highest PM value from the air quality modeling without thorough statistical analysis. When this high value is included, the 24-hour PM_{10} data exceeds (Proposed Action) or nearly exceeds (Barrel Alternative) the NAAQS.

US Environmental Protection Agency guidance requires modeled pollutant estimates to be added to current "background" levels found in the immediate area. Instead, Rosemont selected the lowest possible background pollutant level, sometimes from a monitor in a pristine area hundreds of miles away, to add to predicted Rosemont emissions. This mistake is made for PM and NO_x, thus calling into question all the air quality model results.

The incorrect nitrogen dioxide (NO_2) to nitrogen oxide (NO_x) ratios used result in an underestimation of NO_x concentrations. Even using the lower NO_2/NO_x ratio, modeled emissions for the Proposed Action and the Barrel Alternative exceed the NO_2 NAAQS.

Not only is Pima County likely to violate the NO_2 NAAQS, but also the ozone NAAQS. This is because NO_2 is a necessary ingredient for ozone formation and has a significant and complex effect on ambient ozone levels. Recognizing this, the Forest Service should have called for the use of a photochemical model to estimate the effects of Rosemont's activities on ambient ozone. The Forest Service claims that such modeling "is not typically performed..." but given the potential impacts of increased NO_2, a conservative approach to protecting air quality dictates the use of a photochemical model, especially since more than a million people live in the air shed.

Approving the Rosemont proposal based on flawed air quality modeling places Pima County closer to nonattainment of the NAAQS for multiple pollutants. Hence, the adverse cost of dealing with nonattainment potentially caused by Rosemont will be an economic burden placed on existing County businesses and residents.

The County requests the Forest Service require reanalysis of the air quality impacts of the Rosemont proposal related to conformance with the national ambient air quality standards of the CAA and demonstrate the County will not be placed in nonattainment if the Forest Service approves the proposed Rosemont action.

3. Wetland, Riparian, Seeps and Springs Loss not Mitigated

The proposed Rosemont action irreversibly impacts Waters of the United States (Waters) and seeps and springs that will be lost forever. Surface water captured by the Rosemont proposal will be diverted from replenishing Cienega Creek and Davidson Canyon, both designated Outstanding Waters of the State of Arizona. Over the life of the proposed action, in addition to surface water diversion, 18,000 af to 26,000 af of groundwater will be removed from the area around the proposed mining pit in the dewatering to facilitate safe excavation and operation of the pit. After mine closure, the pit lake will forever divert and evaporate natural groundwater flows that would otherwise replenish the Waters within the Cienega Basin. Long-term riparian restoration needs to be assured to offset the adverse impacts to Waters, springs and seeps that will be irreversibly impaired or destroyed.

Our concerns related to adverse impacts to Waters of the United States and the Outstanding Waters of the State of Arizona are based on our substantial public investments made to protect Cienega Creek and Davidson Canyon within the Cienega Basin. The County has already invested over $64 million in watershed and stream protection within the Cienega Basin. In addition, the Bureau of Land Management gave up thousands of acres of land to development in order to acquire Las Cienegas. The proponent's actions must not adversely impact these investments. We are not satisfied that the proposed mitigation measures regarding Waters of the United States impacts are adequate.

The PAFEIS fails to take into account the declining baseline conditions of natural water sources against which Rosemont's proposal must be evaluated. It is a well-known fact that dependable surface flows, as measured by the US Geological Survey in Cienega Creek, continue to diminish due to a variety of factors, including natural drought. The average dependable base flow of wet water at the Pantano Dam has been only 360af per year. The attached report entitled "Water Resource Trends in the Cienega Creek Natural Preserve" provides additional documentation of declines in surface water and groundwater conditions in the Preserve.

Rosemont has acquired a number of surface water rights dating from 1908 and proposes to use a portion or potentially all of these to satisfy the mitigation offsets to their impacts to Waters. They have acquired or have options to acquire 1,122 af of 1908, 1933 and 1935 surface water rights; however, the acquisition and dedication of these water rights can never be a real or dependable mitigation measure, since the base flow at the Pantano Dam may not much exceed 360 af in future years.

While acquisition of water rights, conveyance of those rights to the County, acquisition of the dam site, conveyance of the dam site to a third party or the County for conservation, and retiring the Vail Water Company well in the vicinity of the dam site will all be helpful actions, they will not fully mitigate the proponent's adverse impacts to Waters.

The County is willing to consider appropriate actions to improve the sustainability and development of riparian vegetation and aquatic habitat in the Cienega Basin; however, the responsibility to do so will be solely that of Rosemont. Rosemont must demonstrate clear and complete compliance with the CWA, and details of their mitigation proposals related to the impacts to Waters do not demonstrate such compliance at this time.

4. Habitat Losses not Mitigated

The PAFEIS disclosures that the Forest Service's preferred action will destroy up to 5,421 acres of functional ecosystem, about 1,000 acres more than was disclosed in the earlier DEIS and 1,000 acres more than the Silver Bell Mine. This substantial increase in disturbed area points to the need for a Supplemental DEIS. Pima County has an adopted local standard for mitigating the loss of ecosystem and habitats. This local standard would require around 12,900 acres of mitigation based on what we now know about how the project affects the County Conservation Land System that has been adopted and applied within Pima County for nearly 10 years. This local standard needs to be respected by federal agencies and is required to offset the loss of functioning ecosystems.

Under the present proposal, the project proponent is proposing to acquire approximately 3,300 acres of mitigation lands in Pima County, well below that required by the local standard. The project proponent has referenced the possible acquisition of Sonoita Creek Ranch. Even if this property is acquired, the proposal falls far short of meeting the local accepted standard for mitigation lands.

It should also be understood that the monetary fund being established for the Cienega Basin to "help restore the watershed to a functioning ecosystem" is grossly inadequate and represents a mere fraction of the cost of real restoration and mitigation.

Of most concern to the County is its exclusion from the interagency team responsible for identifying mitigation actions in the Cienega Basin. I assume this is an oversight. Given our $64 million investment in protecting the ecosystems and water resources within the Cienega Basin, the County requests it be a key member of the interagency mitigation team. The County also requests the federal decision-making agencies require the full mitigation obligation in accordance with local standards for acres of mitigation; a significant increase in the fund established for watershed and ecosystem restoration; and significant involvement with the interagency team responsible for identifying mitigation actions to be funded by Rosemont in the watershed.

The County has also suggested on numerous occasions the analysis of partial pit backfill to minimize the impact on the ecosystem by shrinking the footprint of the waste disposal site. Our requests have been largely discounted. It is only appropriate that full mitigation measures be imposed on Rosemont, given the County's suggested number of alternatives, including partial pit backfill to minimize these impacts.

5. Traffic Impacts not Mitigated

In the PAFEIS, the proponent inadequately and, in some cases, fails to reference any impact analysis or mitigation of adverse traffic impacts resulting from the proposed action. While there is some discussion regarding certain improvements to State Route (SR) 83, they are not clear, nor are the improvements quantified. For example, discussion has occurred regarding the paving of additional lanes on SR 83 in particular areas. However, there is no mention of the rural highway section being widened to accommodate this additional lane paving and shoulder. Without complete reconstruction of the roadway prism, adding a lane could make the roadway even more unsafe than it would be without improvements.

There are also impacts to County-maintained highways; i.e., Santa Rita Road, Sahuarita Road, Valencia Road and others that have not been analyzed or quantified. Full network transportation impacts need to be analyzed in order to validate the PAFEIS. Anything short of this is a significant flaw in the document. Traffic and transportation impacts do not stop at jurisdictional boundaries.

Certain roadway improvements, such as turning and passing lanes, shoulder stabilization and paving, and pavement overlay only on SR 83 could cost as much as $13 million. The mitigation measure suggested for heavy truck damage to the structural pavement section to "conduct the baseline analysis of road conditions along State Route 83" is wholly inadequate and will not result in any meaningful reductions of the impacts caused by the mine.

The proposal also locates a school bus stop in the vicinity of the mine entrance. Mixing school buses with heavy truck traffic and other mine traffic is unacceptable. Also, the location of the Vail School District bus turn around at Milepost 46.9 on SR 83 immediately south of the proposed Rosemont primary access is not disclosed in the PAFEIS. Finally, the proponent has indicated they intend to bus 1,250 workers to the site from staging areas along Interstate 10 or from the community of Sonoita, but there are no locations listed for these staging areas or statements of how employee bus travel will be enforced. If bus travel is not enforced, what would be the increased traffic impact to SR 83 and other local streets and highways maintained and operated by Pima County or the City of Tucson?

The PAFEIS states that gas tax revenues are available to pay for required roadway improvements and maintenance. A historical analysis of gas tax revenues in the State of Arizona shows they have been declining or stagnant for the last 10 years. Gas tax revenues will not be available to pay for needed roadway improvements or maintenance, and the cost burden of the transportation impacts caused by the proponent will be shifted to local taxpayers as gas tax revenues today are inadequate to maintain the existing streets and highways maintained by the State, County and City.

The PAFEIS is completely inadequate in evaluating and mitigating transportation and traffic impacts caused by the project. The document is significantly flawed in that it fails to disclose impacts to streets and highways maintained by the City and County. Further, the mitigation being required for improving SR 83 is unclear and nonspecific.

6. Mining Reclamation Plan is Inadequate

The Rosemont Copper letterhead contains the title: "Redefining Mining." The inadequacies of mine reclamation from past hard rock mining activities are well documented throughout the nation. Within a few miles of the Rosemont project area, legacies of periodic air quality violations of national ambient air quality standards, groundwater pollution, including the sulfate plume; and depleted groundwater along the Santa Cruz River remind us how important an adequate mine reclamation plan is to assure past mistakes will not be repeated. While a mine reclamation plan is proposed, it is not "Redefining Mining," since it does not contain detailed reclamation measures that assure the reviewer that reclamation will be assured, adequate and sustained in the long term.

A few simple examples demonstrate this reclamation plan is not better than those of the past. For example, there are no performance standards for the composition of the soil or "growth media" to be placed on the waste and tailings. Secondly, there are no success criteria for revegetation measures. Monitoring simply indicates that observations will be made, but it does not address what remedial actions will be taken to ensure revegetation will succeed.

Third, the plan relies heavily on natural soil availability. By 2015, natural soil borrow areas will have all been removed through excavation or covered by mine waste; and the amount of soil salvaged is, by our estimate, nearly 2.5 million cubic yards short of being able to plate the final mine waste landform with topsoil. Where will the additional topsoil come from for needed and complete reclamation?

The mine at closure will create a pit lake. No mitigation measures are proposed that would deal with a mine pit lake that does not meet water quality standards. The present lake pit water quality monitoring leaves out many sources of pollution and has made too many simplifying assumptions as we have previously commented. There is nothing in the reclamation plan that would assure us we will not be left with another polluted pit lake.

Finally, tens of thousands of native oak, juniper and mesquite trees will be destroyed as a result of the project proponent's actions. The final EIS must offset the impacts to these basic forest resources, either onsite or offsite. The Forest Service can, but has not, demanded this kind of mitigation; yet it is not only fundamental to the Forest Service's mission but also to Rosemont's visual mitigation goals for softening the blight of the mined landform.

In summary, it appears the reclamation proposed by the project proponent is nothing more than a dressed-up version of past methods that have failed.

7. <u>Future Impacts of Mining West of the Santa Rita Ridge Line not Addressed or Resolved</u>

The Green Valley community has been repeatedly assured that Rosemont has no planned mining activities west of the Santa Rita ridgeline; yet, there are no assurances from the project proponent that these deposits will also not be mined in the future.

Rosemont should be required to exchange mineral interests and fee simple estate of the Broadtop Butte and Copper World deposits with the Forest Service as partial mitigation and compensation for Rosemont's acquiring and using 3,670 acres of Forest Service land and 582 acres of State land to exploit the Rosemont deposit.

8. <u>Cultural Resources Impacts not Mitigated</u>

There have been ineffective consultations with Native American communities regarding the adverse impacts of the proposal on heritage resources that include traditional cultural places, sacred sites and landforms, and individual historic properties and archeological sites that comprise the entirety of the historic cultural landscape. There is a general lack of clarity when discussing critical issues related to Section 106 of the National Historic Preservation Act (NHPA), including assessment of the effect of mitigation of adverse effects, as well as monitoring programs designed to ensure damage to traditional cultural places, individual historic properties and archeological sites are minimized. Given the close locational association of historic properties, archeological sites and traditional cultural places to seeps, springs and Waters of the United States, any disruption or destruction of these Waters will proportionately destroy these cultural resources and have profound impacts to the cultural and spiritual fabric of traditional Native American communities that hold these places sacred. Mitigation of these greater impacts is not adequately addressed.

The PAFEIS indicates the Corps will defer to the Forest Service; however, the Forest Service's consultations appear to be rushed and without adequate consideration of the requests made by the Tohono O'odham Nation, Pascua Yaqui Tribe and other Native American tribes participating in the process. It is also troubling that the PAFEIS states that Section 106 of the NHPA has been concluded, when in fact it has not; and the draft Memorandum of Agreement (MOA) included in the PAFEIS is different from the version currently in review. Moreover, there are currently no assurances that the mitigation measures addressed in the draft MOA will be fully implemented. At present, these measures are not being considered in the reclamation bond that will provide financial assurances that the terms of the MOA and Historic Property Treatment Plan will be fulfilled. We recommend the Forest Service include this provision in the MOA and in the reclamation bond.

9. <u>Environmental Justice not Adequately Addressed</u>

With regard to environmental justice, the PAFEIS fails to address disproportionate impacts to the environmental justice communities of the Tohono O'odham Nation, Pascua Yaqui Tribe, or the Hispanic residents of Santa Cruz County. Federal agencies, in their conduct of this process, have failed to provide opportunities for meaningful involvement of these communities. The PAFEIS concludes the mitigation plan is unlikely to "relieve the disproportionality of the impacts to the Tohono O'odham Nation" or other consulting tribes. No additional mitigation is explored or proposed that might relieve this disparity in whole or in part. The process has failed to reduce or alleviate disproportionate impacts on minority communities.

Arizona Revised Statutes §45-2711 requires the Arizona Department of Water Resources (ADWR) director to conduct a hydrologic analysis of well impacts from nonexempt wells that may impact the Tohono O'odham Nation. The project proponent has indicated in their own studies that groundwater extraction will remove groundwater under the San Xavier District of the Tohono O'odham Nation, potentially reversing groundwater flow. The impacts of this action to a minority community need to be addressed.

10. <u>Fiscal Assurances are Inadequate</u>

Little to no information has been provided regarding the financial assurances to be provided by the project proponent to offset costs that would be incurred by the federal taxpayer if the project causes air and/or water pollution that endangers the public health.

No discussion has been completed that establishes any type of performance bond to assure mitigation and remediation of impacts should the project proponent fail to perform the mitigation or restoration actions stated.

Given the costly environmental remediation efforts necessary to correct hard rock mining pollution problems of the past, significant and substantial financial assurances must be provided by the project proponent. To date, little, if anything, has been provided.

Overall, the PAFEIS does include substantially more information than was included in the DEIS. It shows that the proposed mine would have high costs to the environment and the community, while providing inadequate mitigation; especially for the types of public health, safety, and welfare impacts that may be outside the regulatory framework of the Forest Service and the Corps. However, it is still incomplete in many ways and lacks information required to be included in a Final EIS.

The previous discussion summarizes our major concerns. Attached in your requested format are 164 pages of detailed comments organized by general subject matter. These comments constitute review of this subject that could be completed within the allotted timeframe.

We appreciate the ability to comment and the additional time afforded to us and other agencies. If, in fact, you do chose to pursue this substantially changed, but still flawed document as a Final EIS, as opposed to a Supplemental EIS, then these comments become all the more important as the process will not afford any further public comment. In addition to the comments attached, we restate all of our previous comments and concerns.

Sincerely,

C. Huckelberry

C.H. Huckelberry
County Administrator

CHH/mjk

Enclosures

c: The Honorable Chairman and Members, Pima County Board of Supervisors
The Honorable Raúl Grijalva, Congressional District 3, US House of Representatives
The Honorable Ron Barber, Congressional District 2, US House of Representatives
Nicole Fyffe, Executive Assistant to the County Administrator
Linda Mayro, Director, Sustainability and Conservation
Julia Fonseca, Environmental Planning Manager, Sustainability and Conservation

DOCUMENT REVIEW COMMENT FORM – PURPOSE AND NEED FOR ACTION

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Neva Connolly	1	Public Review	13-14	8-10	Based on the submission of 25,000 comments on the Draft EIS, there is significant public interest in the Rosemont Mine proposal. The Admin Final EIS contains substantial changes that the public should have opportunity to review and comment upon.
Julia Fonseca	1		1		The Forest Service has re-defined the mine life. The Forest should examine alternative operational time frames instead of re-defining the mine life from what was originally proposed in the MPO, and in the Draft EIS.
Julia Fonseca	1		1		What triggers closure as opposed to temporary cessation of operations? Who decides when closure occurs?
Julia Fonseca	1		1		Temporary closures have potential to significantly affect the human environment. Where is the effect of temporary closures analyzed?
Julia Fonseca	1		1		What are Rosemont's obligations during temporary cessation?
Julia Fonseca	1		2		Figure 1 does not show the proposed action (MPO footprint)
Julia Fonseca	1		3		The decision space has a significant effect on the human environment but needs no analysis? This chapter of FEIS does not disclose when decision space is discretionary e.g. validity exam
Julia Fonseca	1		4		Missing appendices were not reviewed by Pima County.
Julia Fonseca	1		10		No reclamation bond for review, nor even the components of such, however cited references include some preliminary identifications of these costs.
Julia Fonseca	1		14		Scoping issues—validity exam issue raised by public is not addressed in the FEIS
Julia Fonseca	1	Scope of Analysis			The analysis required by the National Environmental Policy Act was bifurcated by the Bureau of Reclamation's decision to treat Rosemont's Green Valley pipeline and recharge proposal as a separate action. The two should be regarded as connected actions by this later EIS because the recharge is mitigation for the impacts of the mine and would not be undertaken if Rosemont did not intend to operate mineral extraction wells. See September 8, 2008 letter from Pima County to Sandra Eto, USDOI-BOR.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	1	Purpose of and Need for Action	6	6 - 7	This should state '…applicable Federal, State, and local laws and regulations.'
Sarah Walters	1	Issues	15	15	The emissions of methane (CH4) and nitrous oxide (N2O) are known to have a greater impact on climate change when compared to the impact of CO2 emissions of the same magnitude. The PA-FEIS states that the emissions of these gases would be 'much smaller than the level of CO2 emissions associated with the project.' However, 'much smaller' is not defined. Given the potency of these gases the anticipated levels of CH4 and N2O emissions should be disclosed rather than excluded. The impact of these emissions should be evaluated along with the impact of the CO2 emissions using the CO2 equivalence of the anticipated emissions of CH4 and N2O.

DOCUMENT REVIEW COMMENT FORM – CHAPTER 2 ALTERNATIVES

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	2		22	15	Who would do this evaluation? Who would decide? Who would remove it?
Julia Fonseca	2		15		Why not minimize impacts to soils and air and other resources by NOT constructing a parallel service road the length of Santa Rita Road? Instead use stub outs to individual poles or booster stations. I realize that this area has to be disrupted for pipeline construction, but if it is only disturbed once, then the effects will be minimized. The service road is authorized but not required by the ACC order.
Julia Fonseca	2		15		I believe there is also a proposed fence that is not disclosed in this drawing or the text that would parallel the entire route across the Santa Rita Experimental Range.
	2		17		These figures are hard to read. Font size should be larger, and the overlap of the water line and transmission line appears to vary in the way it is depicted inconsistently over the length. What does that mean? For the road upgrade, the scale of the map is too small to be able to easily tell the differences.
Julia Fonseca	2		22-23		The text says there are 15 miles of new construction and 3 miles of reconstruction or upgrade. The more detailed GIS files that Mindy Vogel transmitted from SWCA show that the utility maintenance road and pipeline would follow the exact centerline of the existing road over the crest of the Santa Ritas. Can you provide details of the areas of disturbance across the crest? Is there a re-alignment of the road near the crest, or the existing bed simply getting widened? The word “upgrade” is not really communicating what is happening precisely. It could mean many things.
Julia Fonseca	2		78		The length of mine operations affects many resources and issues. A reduced mine operational period with the same operational intensity should have been examined. Also a longer operational time period with the same operational intensity should have been examined.
Julia Fonseca	2		NA		Identify methods and machinery to be used in transforming the rock into soils for reclamation and mixing in other “growth media”. What kind of volumes will be processed with this machinery? What materials or additives will be used in producing the soil, if any?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	2		8		The EIS should make clear what pit design the Forest is relying upon for each alternative. This page only says the forest supervisor is relying on a quotation by Rosemont that pertains to pit depth. By email of Mindy Vogel, July 29, 2013, I was told "It is not correct to state that "one pit is common to all alternatives". To answer this properly you really need to break the question down into what characteristics of the mine pit factor into the analysis. These are the characteristics I come up with: pit footprint, pit volume (i.e., amount of waste rock), and pit depth. Pit footprint – Yes, it is true that the footprint varies slightly between alternatives. You'll recall the briefing paper specifically about this issue. The differences are not significant (in our opinion), and the fact that there ARE slight differences just highlights the fact that slight variations can also be expected to occur when operations start. That's important to note, because we want to reflect in our NEPA disclosure what is likely to occur in reality. So we chose a strategy to avoid undercounting impacts. We chose to consistently use the largest of the footprints (which was the original MPO footprint) for all acreage calculations and on all figures. Pit volume/volume of waste rock – This differs between alternatives primarily because of slope changes within the pit. The different volumes are explicitly called out for each alternative in Chapter 2. Pit depth – This is important to the groundwater analysis, but the pit depth does not differ between alternatives. All have pit bottoms at an elevation of 3,050 feet amsl." If there is not one pit that is common to all alternatives, then this should be disclosed. If the Forest intends to allow any post-EIS modifications to the pit that fit within the width-depth-and volume parameters stated, then please make that apparent to the reader. I agree it's important to note. We have previously expressed to you our concerns that some of the pit designs could increase impacts to specific resources such as talus snails and visual resources.
Julia Fonseca	2		11		Can you provide an illustration like Figure 3 showing the processing for stockpiling and creation and emplacement of the "growth media"?
Julia Fonseca	2		17		Santa Rita South substation—Is it part of the project? The EIS should state whether this is an existing substation or proposed, and explain the difference between the substation and the proposed El Toro switchyard. Figure should show the new switchyard, which is part of this project.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	2		33-34		This is very helpful information about administrative process, but I suggest also providing public access to the monitoring and compliance information received by the Forest via posting to a website. This NEPA process has shown that there is an enormous public interest in the details of the mine, and that there are numerous people in the community with expertise to understand technical information. The community should not have to rely on an increasingly congested Freedom of Information Act process to obtain the monitoring and compliance data that would be required by law from the applicant.
Julia Fonseca	2				EIS fails to disclose any construction at the Port of Tucson that would be required as a consequence of the Rosemont mine. If none is needed, then stipulate that.
Julia Fonseca	2				Please clarify whether any exchange or acquisition of federal land by Rosemont is considered part of this NEPA evaluation.
Julia Fonseca	2		73		Since several different pit configurations have been proposed by Rosemont over the course of the project, it is difficult to understand what is meant by line 9. Did the Forest analyze a reduce pit size? If so, please cite a reference document.
J. Crowe	2	Alternatives	30	11	Pima County Department of Transportation has roadway right of way permitting authority and should be added to the list of agencies. This includes permits for the water supply pipeline that crosses or enters Santa Rita road way right of way.
J. Crowe	2	Alternatives	30	11	Pima County Department of Transportation has the authority to require a permit to move oversize or overweight vehicles on highways under its jurisdiction and should be added to the table. This applies to Kolb Road and Valencia Road in the vicinity of the Port of Tucson where the FEIS has stated railroad traffic to or from the Rosemont project will be transshipped to truck, among others. There is a formal application and fee for these permits (ref. Pima County Code Chapter 10.36).
J. Crowe	2	Alternatives	30	11	Pima County Department of Transportation has the authority to require a permit for any construction within roadway right-of-way under the authority of Pima County and should be added to the table. This applies to Santa Rita Road, the identified secondary access to the Rosemont project. Construction includes the activities of utilities (ref. Pima County Code Chapter 10.44)
J. Crowe	2	Alternatives	30	11	Pima County Department of Development Services also has permitting authorization concerning Scenic Routes (ref. Pima County Code Section 18.77.040. and should be added to the table.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 2	Water Supply	18	28	Rosemont has a Mineral Extraction permit from ADWR for the right to extract and use up to 6,000 acre-feet per year of groundwater, but the groundwater models and the estimated impacts are based on use of 5,400 acre-feet per year for the first eight years and 6,000 acre-feet after. The groundwater models and impacts should be re-evaluated and re-calculated based on the use of 6,000 acre-feet, including re-calculation of the drawdown and impact area. The groundwater models are based on a 20-year mine life, but the mine life, as cited in Chapter 1, page 1, line 23 is 24.5 to 30 years. The groundwater impacts should be recalculated.
Chavez	Chapter 2	Permits and Authorizations	31	Table 3-State Permit or Authorization	ARS45-2711 should be included as an applicable state requirement. This statute requires the ADWR director to conduct a hydrologic analysis of well impacts from nonexempt wells that may impact the Tohono O'Odham Nation. If the projected withdrawal from the initial five-year period of withdrawal will cause a water level decline of ten feet or more at any point on the exterior boundaries of the reservation, the application shall be denied. The estimated drawdown attributable to pumping will be up to 70 feet impacting an area of 3 to 4 miles from the pumping center This drawdown will reach into the San Xavier District and the impacts to the Tohono O'Odham Settlement Agreement should be addressed
Chavez	Chapter 2	Permits and Authorizations	31	Table 3-State Permit or Authorization	Table 3 does not list the need for a water recovery permit from ADWR. A recovery permit is required if Rosemont will be recovering stored CAP water from the Sahuarita well fields. The 2007 MOP (page 43) states that Rosemont has the option of modifying the ME permits wells to allow them to operate as recovery wells. If Rosemont is not planning to recover its stored water this should be made explicit in the FEIS and Rosemont should disclose what it plans to do with its long term storage credits. Selling or trading them to others who will recover them elsewhere in the TAMA will be a connected action and the impacts should be considered.
Chavez	Chapter 2	Water Supply	81	7	The FEIS notes 22 alternatives were evaluated, but the Review of Alternative Water Sources-Revised; SRK Consulting (Stone, 2011) reviewed 19.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 2	Water Supply	82	12	The FEIS discusses why effluent and brackish water were deemed infeasible, but there is insufficient discussion on why the other alternatives were not feasible or were impractical. The FEIS does not address the feasibility of CAP direct delivery or recharge and recovery at the proposed CWS CAP delivery system (Project Renews) The SRK report found direct delivery of CAP water to be not feasible for the following reasons: • Direct delivery requires construction of a treatment plant and delivery system. But no mention is made that ASARCO is successfully using CAP water. • SRK notes that a pipeline would cross private, state and CNF lands and cannot be buried along its entire length because of bedrock near the surface. However, Augusta is funding a CAP pipeline from the CAP terminus to the CWC recharge site. Rosemont is building a pipeline from the Sahuarita well fields to the mine site, demonstrating that construction of water delivery infrastructure is feasible • SRK notes limitations to the future use of direct CAP delivery due to drought, declining flows in the Colorado River, limited availability of excess CAP water, short-term planned CAP system outages and possible system failures. Yet, Rosemont is proposing to offset its groundwater pumping by recharging CAP water and has applied to ADWR for non-Indian agricultural priority CAP water that is being reallocated • SRK notes that direct delivery would require a cistern or reservoir for above-ground water storage and backup water supply, yet no mention of storing underground. Many of the largest water providers in the state are successfully using underground storage and recovery for CAP water. SRK also evaluated localized CAP recharge and recovery water and assessed the potential use of several recharge facilities in the Tucson Active Management Area including the proposed Community Water Company CAP delivery system. This option was found feasible, but SRK notes that the system is at least several years in the future and construction costs will require a substantial commitment of funds. This option should be included in the Water Supply Alternatives.
Chavez	Chapter 2	Alternatives Impact Summary	94	Table 12-Groundwater Quantity	Rosemont proposes to recharging 120,000 acre-feet of CAP water over the life of the mine and has recharged 42,593.02 acre-feet to date. The impacts of acquiring an additional 77,406.98 acre-feet CAP water should be evaluated in the context of the decreased availability of CAP water supplies to the TAMA region

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Tom Myers: Hydrologic Consultant for Pima County	2		4		*Quote from Myers Review on the DEIS* *The DEIS treated partial or complete backfilling of the pit as an alternative considered but eliminated from future study (DEIS, p 84-85). They eliminated backfill because they indicate that "maintaining a hydrologic sink" would capture any contaminants, which is "an acceptable and desirable condition … should pit water become contaminated" (DEIS, p 85). The FS argues that backfill would eliminate the hydraulic sink and increase "the risk of detrimental impacts to groundwater chemistry from potential contaminants in pit lake water" (Id.). Elsewhere in the DEIS, the FS indicates that seepage through the waste rock would be relatively clean. With backfill, any potentially acid generating (PAG) rock could be segregated and placed above the water level; alternatively, PAG rock could be placed very deeply so that it is submerged deeply so that oxidation, if it occurs, ends quickly. If seepage through the backfilled waste rock could be a problem, then it can also be a problem dumped on the ground surface.* *Additionally, the DEIS fails to analyze the advantage of backfilling the pit, and that is vastly decreased drawdown in the watershed and not creating a lake that essentially isolates almost 96,000 af of water (DEIS, p 291) in a dry desert region that is running low on water supplies. Other advantages include eliminating a visual blight on the land, the waste rock dump, and better containing potential seepage through the waste rock; if seepage does leach contaminants from the waste rock dumps, it could contaminate surface water.* The AFEIS has not considered partial backfill which could still maintain a hydraulic sink while substantially decreasing the volume of water locked up in a pit in the desert. Comments 11 through 13 in Myers (2012) specified the advantages of partial pit backfill that should be analyzed. The AFEIS has failed to consider all alternatives by not considering the advantages of partial pit backfill. The following are previous comments 11 through 13.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers					11. The DEIS should analyze and disclose the advantages of pit backfill so that the decision makers have both sides to consider. 12. The DEIS should consider the value of the water lost to the pit lake. 13. The DEIS should disclose the steps that the mining company would have to take if the pit lake did become contaminated to protect wildlife.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
RWRD - Staff	2	Removal of Heap Leach Facility from Barrel Alternative	4	31-34	The Forest Service response to both partial and complete waste rock pit backfill is: “Because of the extended environmental impacts, financial implications, and safety issues the responsible official has determined that complete (or partial) waste rock pit backfill is not technically feasible.” 1) The Forest Service created the Barrel Alternative because it is an approach that shifts the footprint of mine waste facilities in a way that certain land use areas are not affected. The EIS states, “The forest supervisor has chosen the Barrel Alternative to be the preferred alternative.” Factors influencing the decision include preservation of resource values in McCleary Canyon, including recreation, riparian areas, and wildlife species habitat and movement corridors, as well as avoidance of waters of the United States and cultural sites in McCleary Canyon and other areas. Backfill of the pit is an approach that has a profoundly different reduction in the surface footprint of mine waste facilities. 2) Backfill of the pit is an approach that has a profoundly reduced visual impact and offers opportunity for recovering much of the natural landform after temporary waste rock storage is eliminated from the surface at closure. 3) Backfill of the pit is technically practicable and may be economically feasible, since it has been practiced at other mine sites. This closure design is more frequently being incorporated into mine plans of operation because of more stringent regulations regarding mine pit lakes and water quality impacts, such as in California. Backfill of the pit is a reasonable alternative because it offers a rational method to significantly reduce the amount of waste that must be disposed at surface facilities at the proposed mine site. It logically follows that such an approach would lessen impacts in specifically identified areas of concern in the EIS, such as recreation and wilderness, cultural resources, livestock grazing, surface water quality, and visual resources.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
					4) Identifying the option of partial pit backfill as a mitigation measure should not preclude using full and/or partial backfill to formulate a reasonable alternative. The NEPA process is not so limiting that it excludes sound technical approaches from being used in whatever manner offers a full range of alternatives and the best options for mitigation. 5) The Forest Service contends that backfilling the pit and allowing groundwater to flow through pit material would increase the risk of detrimental impacts to groundwater chemistry from potential contaminants in pit lake water. However, if the pit is filled, there will never be a pit lake configuration to accumulate contaminated water. Also, literature on pit backfilling notes that one major advantage of filling a mine pit is that oxidation of surrounding wall rock is kept to a minimum, thereby reducing metal mobility in the environment, including groundwater. Recommendation: Clearly, extended environmental impacts are more probable with a pit lake compared to filled pit lake. Therefore the Forest Service should consider other backfill options in more detail, explore alternatives such as paste backfill, evaluate engineering options to reduce the safety risk, and weigh environmental risks and all impacts required in the EIS process against the cost considerations.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
RWRD - Staff	2	Stormwater Controls	42	4-22	If the Barrel Alternative is not selected it is a major impediment that there is not enough information about the construction of the Central Drain and flow-through drains supposed to convey stormwater under the tailings impoundment. It is unclear how tailing material will be kept out of this engineered drainage way. It is also unclear how it will remain unclogged during operation and in the post-closure period. The EIS should contain an explanation of how this drainage system is to remain clear and functioning as intended. Examples of mining facilities that have used this technology should be cited in the EIS so that it is clear that the technology is demonstrated. Simply put, implementation of the proposed Flow-Through Drain System at the proposed Rosemont Copper Mine is ultimately a Fatal Flaw. The design function of this earthen-material system will cease in the future – it is only a question of when, not if. The EIS should acknowledge that this may adversely impact streams and the ecosystem downstream of the mine site, in Barrel Canyon, Davidson Canyon and likely Cienega Creek. These comments were included in the January 18, 2012 comments to the Forest Service but not adequately addressed in the preliminary FEIS.
Neva Connolly	2	Alternatives Considered in Detail	3	37-42	The Barrel Alternative was refined and major elements removed from the proposed design, in part due to public comment received on the Draft EIS. The public should have the opportunity to review and comment upon these significant revisions.
Neva Connolly	2	Removal of Heap Leach	5	28	“copper’s” at the beginning of the line should be capitalized.
Neva Connolly	2	Water Control-Stormwater	21	18	“…exposed to precipitation only during operations.” should read, “..during the 24.5 to 30 year life of the mine.”

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Neva Connolly	2	Solid, Hazardous Waste	13	33-34	Please include the landfill location on the Alternative maps.
Neva Connolly	2	Barrel Alternative	56 and 57	n/a	Figure 18 depicts the primary crusher, conveyor, and several other facility components to the right of the mine pit. Figure 19 shows the crusher, conveyor and other components hovering over the pit. The scale or layout on Figure 19 needs to be adjusted.
Neva Connolly	2	Postclosure Monitoring	69	12-13	The life of the mine phasing for the action alternatives include a final reclamation and closure phase (3 years). Will the postclosure monitoring be included in the final reclamation phase? As yet, the postclosure monitoring period has not been determined…will it be less than or equal to the 3 years in the final phase, or will the final reclamation phase be extended to allow for over 3 years of postclosure monitoring? It is likely there will be a need for more than 3 years of postclosure monitoring.
Neva Connolly	2	Reclamation Bond	70-71	n/a	It is unclear whether the bonding for the revegetation and contouring will be placed in the Forest Service bond, State Mining bond, or CWA bond.
Julia Fonseca	2				This EIS proposes far higher amounts of land disturbance than does the previous DEIS. Table 7 of the DEIS documented over 3000 acres of impacts, and Table 8 of the same DEIS mentioned over 4000 acres of impacts for the Barrel Alternative. Now for the same alternative, we are told that impacts may be over 5000 acres. Why are the total acreages so much higher?

DOCUMENT REVIEW COMMENT FORM—DARK SKIES/LIGHTING

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Yves Khawam	2	Lighting	12	28-…	Lighting plans are discussed out of context of legal requirements to meet 2012 Pima County Outdoor Lighting Code for which no plans have to date met scope requisite for analysis.
Yves Khawam	2	Lighting	13	23	Lighting plans cannot be proposed or considered that do not meet the 2012 Pima County Outdoor Lighting Code.
Yves Khawam	3	Dark Skies	1	19	Lighting impact continues to reference plans not reflecting compliance with the 2012 Pima County Outdoor Lighting Code. This approach is prevalent throughout the Dark Skies section.
Yves Khawam	3	Pima County	8	1	Incorrect reference to enabling legislation for lighting at 11-830 as lighting regulating mines is enabled under §11-251(35).
Yves Khawam	3	Dark Skies	15	14	Concludes with a “mitigation plan” which has not demonstrated compliance with the 2012 Pima County Outdoor Lighting Code.
Yves Khawam	3	Affected Environ ment	63	19	Implementation of an outdoor lighting plan needs to capture that it requires compliance to the 2012 Pima County Outdoor Lighting Code.
Yves Khawam	3	Affected Environ ment	75I	1	Implementation of an outdoor lighting plan needs to capture that it requires compliance to the 2012 Pima County Outdoor Lighting Code.
Yves Khawam	3	Affected Environ ment	20	11-13	Impacts to dark skies are listed as “…being mitigated to the extent possible, given the mine’s need to operate 24 hours a day and safety requirements. Thus this conflict cannot be rectified.” Mitigating to the extent possible requires full compliance with the 2012 Pima County Outdoor Lighting Code which is again absent from this section. If safety requirements cannot be reconciled with outdoor lighting code compliance, then the mine should not operate 24 hours a day. 24 hours/day operation is a desire on the part of the mine and not a “need”.

DOCUMENT REVIEW COMMENT FORM—LAND OWNERSHIP

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Stofko	3	Landownership	5-6	31-13	Does "BLM Administered" in the context of the dependent resurvey mean that BLM personnel performed the survey? Or was it contracted out to an outside party? If the latter, to whom? Are the referenced "BLM's Field Notes of the Dependent Resurvey" a summary of the resurvey or are they the survey itself. Is the resurvey available for review?
Stofko	3	Landownership	5	3-6	The EIS states that 7 known mineral survey fractions would be impacted by the action alternatives and that they would be incorporated into the operations facilities during the construction and operation phases. However, Figure 77 appears to show only 2 of the 7 fractions within the proposed operations facilities. Which is it? If the latter, why not convey just the 2 within the operations facilities to Rosemont?
Stofko	3	Landownership	5	3-6	No information is provided describing any known mineral values of the 7 known mineral survey fractions. If 2 or all 7 fractions are conveyed to Rosemont, would they become mineable by Rosemont or its assignee? Or would they be conveyed subject to a restrictive covenant prohibiting mineral extraction in perpetuity?
Stofko	3	Landownership	6	16-28	States that Rosemont has agreed to purchase the currently known 7 mineral survey fractions, but that the NFS lacks the authority to require this purchase. It goes on to say, "Should Rosemont Copper choose not to purchase the mineral survey fractions, the NFS's ability to manage these fractions would be severely limited". What is the timing of the proposed purchase? This essentially states a potential problem and proposes a mitigation solution but does not guarantee that it will ever occur. If not, then there is effectively no mitigation of this problem,

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Stofko	3	Landownership	6	29-37	The same problem as stated in the comment directly above holds with Rosemont's expressed interest in placing a restrictive covenant on any privately held land within the footprint of the tailings and waste rock facilities to restrict potential future development. NFS admittedly lacks authority to require this. So the proposed mitigation may never come to pass.

DOCUMENT REVIEW COMMENT FORM - RECREATION

Commenter	Chapter	Section	Page	Line	Comment/Change requested
S. Anderson	3	Issue 9, Impact on Rec.	1-2	41, 1, 2	The mine ***will*** actually lead to permanent changes in recreational opportunities. The additional recreation opportunities Pima County will be making available *pale* in comparison to the opportunities on forest land, which is large and expansive in the area of the mine, and farther away from human habitation than we can provide.
S. Anderson	3	" "	2	4 - 15	What mitigation measures will be utilized to make sure that the opportunities lost (particularly miles of forest road and miles of trail) will be made up adequately elsewhere on forest land or on *other* lands?
S. Anderson	3	" "	6	16 - 19	Increased visitation to "…nearby lands" also include Cienega Creek Natural Preserve, Colossal Cave Mountain Park, the Bar V Ranch and the Arizona State Trust Land northeast of the CNF Nogales District (which all include parts of the Arizona National Scenic Trail), McKenzie Ranch, and the Santa Rita Experimental Range. Also, Pima County's Southeast Regional Park offers motorized recreation opportunities through its 400(+/-) acre Pima Motorsports Park property.
S. Anderson	3	Rec. Places	24	18-27	The relocation of the Arizona National Scenic Trail makes little sense in the discussion of the various Alternatives. The best alternatives from a recreation perspective are the Phased Tailings Alternative and the Proposed Action Alternative; they use the least amount of land and do the least damage to recreational opportunities, but their impacts on the Arizona National Scenic Trail are profound. I think *these* alternatives should be offered with the *12.8 mile* relocation of the trail (like in the Barrel Alternative); it insulates trail users from the worst overall effects on the trail (highly engineered, with *steps*?), and puts the most space between the trail and the mine. Can this 12.8/13 mile option be provided for the Arizona Trail with all the alternatives? The two crossings of the road aren't that bad compared to the effects the mine noise and the disconcerting views will have.
S. Anderson	3	Rec. Places	24	37-43	A direct loss in NFSRs would be regrettable for the motorized community. Have you thought about having the applicant buy some Arizona State Trust lands the motorized recreationists are not using now to make up for the losses to motorized users (and all users, for the matter) adjacent to the forest?
S. Anderson	3	Rec. Places	25	16-20	Sightseeing will undoubtedly be affected by the existence of the mine; I prescribe the acquisition of State Trust Land for this malady as well.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
S. Anderson	3	Scholef.-McCleary Alternative.	33 34 35	17-20 9-14	The Scholefield-McCleary Alternative is clearly the worst for the land from a total acreage perspective, and it's the worst alternative for the Arizona National Scenic Trail. It re-routes the trail, and goes right up next to it on the northeast side of the mine. Lots of bad views and mine noise with this one too. There are also major losses for roads (22.8 miles) with this alternative. The loss of motorized recreation opportunities in the Santa Rita Backcountry Touring Area will be profound.
S. Anderson	3	Cumula. Effects	35	30-41	The effects of fuels reduction is only temporary, and as such can be tolerated by the recreationists.
S. Anderson	3	Cumula. Effects	36	15 - 29	The Forest Service's policy toward the closing of roads is unfortunate, but if just ill-conceived roads are closed, we can live with it. What I didn't see was any reference to trails (not the Arizona National Scenic Trail). What are you going to do to replace the trails (if any) that are displaced by the mine? We'd want a "reclamation" fund for trails to replace the trails that are affected like the OHV plan for the replacement of roads.
S. Anderson	3	Mitigation And Mon.	38	21-22	The Forest Service has a dim view of road crossing of Hwy 83, but the Arizona National Scenic Trail will go under the roadway in box culverts, and the crossing is not that bad, comparatively. We don't mind the road crossings, and we would like to have the trail go this route to make it better.
S. Anderson	3	" "	38	29 - 40	It's good that Rosemont is attempting to address the OHV situation. Purchase of additional land would be good for that, and funding that would create new opportunities would be appreciated. The Forest Service and Rosemont should bring the OHV user group in to consult about the replacement of their opportunities.
S. Anderson	3	Mitigat. and Mining – Rosemont Copper	39	16 – 34	Rosemont clearly has some ideas for mitigation, but I would ask the people that live in the vicinity of the mine what they think would be acceptable mitigation measures.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
S. Anderson	2	Arizona National Scenic Trail	26	2-44	The trail is as described elsewhere; this chapter is more detailed, and it reads well. The standard quoted for the trail, and the trailheads as described, are sufficient. I think the Arizona National Scenic Trail *should be* away from the mine as much as possible. The 7.3-mile re-route (on the west side of Hwy 83) is an option, but not a very good option in any case; the mine's noise and questionable views make it a marginal solution. A better option would be to go with the 12.8 mile/13.0 mile relocation (east of Hwy 83) regardless of the alternative.

DOCUMENT REVIEW COMMENT FORM—HERITAGE RESOURCES

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Linda Mayro	1	Issue 6C: Sacred Sites	20	35-39	This section does not identify ***Ce:wi Duag*** (Santa Rita Mountains) as a traditional cultural property that is sacred to the Tohono O'odham; nor does it identify ***dzil enzho*** (Beautiful Mountain) as a site sacred to the Western Apache. The Hopi, Zuni, Apache, Pascua Yaqui, and Tohono O'odham all claim the Santa Rita Mountains as a traditional cultural place. **Huerfano Butte** is also claimed to be a TCP by the Tohono O'odham, but not identified. By only identifying the different property types found within the TCP, the very significance of a TCP and its importance the affected tribal groups is greatly diminished. A TCP is more than the sum of its parts.
Linda Mayro	1	Issue 6C: Sacred Sites	21	1 - 2	This section does not identify ***Ce:wi Duag*** (Santa Rita Mountains) as a traditional cultural property that is sacred to the Tohono O'odham; nor does it identify ***dzil enzho*** (Beautiful Mountain) as a site sacred to the Western Apache. The Hopi, Zuni, Apache, Pascua Yaqui, and Tohono O'odham all claim the Santa Rita Mountains as a traditional cultural place. **Huerfano Butte** is also claimed to be a TCP by the Tohono O'odham, but not identified. By only identifying the different property types found within the TCP, the very significance of a TCP and its importance the affected tribal groups is greatly diminished. A TCP is more than the sum of its parts.
Linda Mayro	3	Unavoidable Adverse Effects Cultural Resources	6	2	Impacts to the traditional cultural property **Ce:wi Duag** and **dzil enzho** need to be disclosed.
Linda Mayro	3	Irreversible and Irretrievable Commitment of Resources	11	22	"the area" needs to be replaced and disclosed as "the traditional cultural place known as **Ce:wi Duag** to the Tohono O'odham and **dzil enzho** to the Western Apache
Linda Mayro	3	Consultation under the National Historic Preservation Act	12	13-17	Consultation is not concluded, and SHPO has not entered into an MOA, which is still under review and revision.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Loy Neff	1	Issue 6A: Factors for Alternative Comparison	20	15-20	This section discusses Traditional Cultural Places (TCP) at same scale as individual Historic Properties (Sites), which minimizes assessment of effect on TCPs. The discussion should account for the difference in scale of the property types and identify range of resources within a Historic Property and the broad range of resources within a TCP for which effect must be assessed.
Loy Neff	2	Alternatives: removal of Heap Leach Facility from Barrel Alternative	4	18	The sentence on Line 18 includes the following segment, "…certain archaeological sites (particularly the 'Ballcourt Site') were to be avoided." The reference to certain sites is ambiguous and should be include specific information about the sites, or if they are discussed in more detail elsewhere in the document, indicate in this section that the specific sites are listed elsewhere and give reference.
Loy Neff	2	Ancillary Facilities and Activities: Utility Lines (Electrical and Water Supply): Power Supply and Water Supply	16; 18	20-26; Figure 5	The description of the TEP transmission line includes the statement that the power line , "…would generally parallel the existing South Santa Rita Road…" There is no additional discussion of Santa Rita Road. Figure 5 lacks details of the alignment, and Santa Rita Road is not shown. The discussion needs to include information about Santa Rita Road, including that it is a County maintained right of way subject to County permitting and compliance requirements. Any use of Santa Rita Road related to construction, use, repair & maintenance of the transmission line and associated water line in the designated utility corridor, including the 14-foot-wide unpaved maintenance road, or access to these components of the utility corridor from Santa Rita Road, will require a Pima County DOT Right of Way Use Permit. In addition to other requirements, this permit is subject to County cultural resources requirements. Table 3 includes this permit, but it lacks correct identification as a Pima County DOT permit. Figure 5 should depict Santa Rita Road and if the utility corridor or segments of the power or water line cross Santa Rita Road, these locations should be shown on the larger map, with detail insets depicting and clearly labeling each crossing.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Loy Neff	2	Utility Maintenance Road	23	21-22	This section refers to crossing Santa Rita Road; the water line, which "…travels under Santa Rita Road," and indicates that the utility maintenance road will intersect Santa Rita Road, which raises the question of access and/or use of Santa Rita Road during construction, use, repair & maintenance. The section should explicitly describe the crossing(s) of Santa Rita Road and whether or not access or use of the road is necessary. Also, there is a reference to Figure 5, which has already been commented on – does not provide sufficient detail to identify specific relationship between utility corridor and County road.
Loy Neff	2	Arizona National Scenic Trail	26 27	1-44 Figure 7	In the description of reroutes there is no discussion of potential effects on Historic Properties and avoidance, minimization and mitigation actions. Figure 7 does not provide sufficient detail to assess the trail alignment. Discussion should clarify the potential for impacts on Historic Properties and possible mitigation. Figure 7 should indicate relationship between the trail and Historic Properties affected. Detail insets should be included to show this, or specific reference to such detailed maps elsewhere, such as in HPTP.
Loy Neff	2	Reclamation and Closure	28	13-31	The discussion needs to include a general statement that any new ground disturbance from closure must consider and mitigate effects on Historic Properties.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Loy Neff	2	Permits and Authorizations;	30-32	Table 3	Table 3, Pima County Section: This section lists the Pima County right of way permit incorrectly. Identify as, Pima County DOT Right of Way Use Permit. Also note that the permit is subject to Pima County cultural resources requirements and that other ground disturbances on County lands are subject to County cultural resources requirements.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Loy Neff	2	Mitigation and Monitoring	66	11-18	General comment: The document combines mitigation and monitoring discussions for all types of effects, including environmental and cultural, which is unclear and does not make distinctions to allow a clear separation of the different categories of effects. The initial discussion appears to omit consideration of cultural resources and focuses on environmental effects. Cultural resources mitigation measures should be listed. The discussion switches between environmental and cultural resources, or omits cultural resources, resulting in confusion and an overall lack of clarity. The discussion needs to be restructured to distinguish between the two categories of mitigation and monitoring, with a section on cultural resources and an environmental section. The Monitoring section includes cultural resources, but the distinctions between environmental and cultural categories of effect, and consequent mitigation and monitoring need to be clarified. On P. 68, lines 14-20, cultural resources are included in the discussion of the MOA, but the previous section remains confusing and needs to be clarified.
Loy Neff	2	Mitigation and Monitoring: Evaluation and Reporting	68	14-28	Tribes are not included in the "Task Force" identified to assist in monitoring. Correct this to identify the Tribes with responsibility to assist with monitoring programs. Make distinction between environmental, cultural, and other monitoring programs.
Loy Neff	3	Cultural Resources, Existing Conditions, Description of the Historic Context	14	19, Table 199	The chronological table lists the "Silverbell Interval" in the Early Archaic without noting this identification is still under debate within the archaeological community and not universally accepted. The label should include a qualifying statement that it is a provisional identification.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Loy Neff	3	General Comment			A discussion of the Clean Water Act, Section 404 permitting requirements and process pertaining to cultural resources is absent from the cultural resources discussion. No maps are provided identifying relationships of Historic Properties and TCPs to Waters of the US, or of Jurisdictional Delineation(s) of Waters of the US relevant to the Rosemont project. Incorporate discussion of Section 404 permitting relevant to cultural resources, or reference this discussion if it is elsewhere in the EIS or in other documents.
Loy Neff	3	Mitigation and Monitoring – Forest Service	37	1-2	Inadvertent discoveries are defined as "previously unknown archaeological sites." Also include human remains, associated grave goods and ceremonial objects.
Loy Neff	3	Mitigation and Monitoring – Forest Service	37	9-11	In description of cultural resources protection training, contractors and their employees are omitted. Add "Contractors and their employees" to this section.
Loy Neff	Appendix B	Mitigation and Monitoring Plan	1-5	all	General Comment: The organization of the introductory discussion of the Mitigation and Monitoring Plan combines environmental, cultural, and other mitigation and monitoring tasks without regard for the nature of the affected resources. Instead, the very brief discussion is organized according to areas of designated responsibility and the Appendix is mostly a table listing mitigation and monitoring tasks. There are separately identified sections according to resources types, which tends to confuse issues related to specific programs for different resource types. The discussion needs to be organized to clearly distinguish between the mitigation and monitoring strategies according to resource types.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Loy Neff	Appendix B	Mitigation and Monitoring Plan: potential Future Mitigation Measures	3-4	20-36	This section includes a reference to the cultural resources MOA and HPTP but does not discuss where they are located, how to access them, what is the completion status of the documents, or other pertinent information. Some information is given in Lines 19-24, which include a disclaimer that some mitigation or monitoring plans are contingent upon which Alternative or combination of Alternatives is selected and will be required as part of the MOA or permit requirement of the appropriate regulatory agency. This section is too brief and needs additional explicit information about the MOA and especially the HPTP to provide information, at minimum, on where and how the reader can access them, and when to expect them to be executed or completed documents.
Loy Neff	Appendix B	Table: FS-CR-01	6		The description in this section states, “All archaeological sites within the areas of direct impact.” This does not account for indirect effect (impacts occurring later in time or with distance); for example, sites in proximity to the realigned segment of the Arizona Trail are subject to potentially significant indirect impacts, which need to be accounted for and mitigated. Add ”indirect impacts” to the phrase quoted above.
Loy Neff	Appendix D	MOA	6	1-3	This “Whereas” states that the Forest, “…consulted with Pima County and the Town of Sahuarita as part of the Section 106 process and has been invited to be a concurring party to this MOA; and” Add language similar to that used for the Tribes that have set forth resolutions in opposition to the Rosemont Mine Project, to the effect that, “Pima County has apprised the Forest, SHPO, Tribes, and other consulting parties of its opposition to the Project, and the Board of Supervisors has set forth a resolution, BOS Resolution 2007-15, January 16, 2007, in opposition to the project.
Loy Neff	Appendix D	MOA	10	17	Line 17 of Stipulation J has a typographical error, “Cultural-Sensitivity cultural sensitivity.” Delete the redundant clause.

DOCUMENT REVIEW COMMENT FORM – BIOLOGY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	NA- BO (This is not a comment on the BO, but what the FS has not chosen to consult on).	NA	NA	NA	The Forest has chosen not to consult with the USFWS on the yellow-billed cuckoo, northern Mexican gartersnake, or the Coleman's coralroot. These species are likely to be listed in the near future, and the Mexican gartersnake was proposed for listing on July 10, 2013. The FS should be working with the USFWS to consult on these (currently) unlisted species.
Brian Powell	3	Bio	NA	NA	No diagram of the Project area is provided in this section.
Brian Powell	3	Bio	2	38	The FS continues to use terminology like "have the potential" to "permanently impact vegetation, soils", etc. It is incumbent upon the FS, as part of the NEPA process, to fully disclose the impacts of the range of alternatives being considered. There is simple no doubt that the action alternatives will severely and permanently impact the vegetation and soils of the Rosemont site. The FS should be honest about this fact.
Brian Powell	3	Bio	4	30	Acknowledge Pima County's holdings and land management role within the analysis area.
Brian Powell	3	Bio	6	8	Wetlands administered by the BLM are acknowledged, but Pima County, which owns and manages the Cienega Creek Natural Preserve, are not acknowledged.
Brian Powell	3	Bio	10	1	The species of interest for Pima County are no longer referred to as PVS, which are a broader suite of species than are being proposed for coverage under the forthcoming MSCP (known as Covered Species). If PVS are to be used, should include, for the Rosemont area, the Arizona shrew.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	10	1	Relying on species that are "known to occur" in the project or analysis areas, yet not seeking more comprehensive and more current data (i.e., not relying to such an extent on work that was done in the 1970s) is unfortunate. More current and comprehensive surveys, at least in the project area, should be undertaken.
Brian Powell	3	Bio	10	1	It is improbable that the Arizona ridge-nosed rattlesnake does not occur in the analysis area, if not the project area. If they occur in Gardner Canyon (and they are well known to do so), then they have a very good likelihood of occurring in the analysis area.
Brian Powell	3	Bio	10	NA	The peregrine falcon is not considered in this analysis, but they are a species of concern for the AZGFD and they almost certainly occur in the project area
Brian Powell	3	Bio	10	NA	Sonoran desert tortoise is a PVS
Brian Powell	3	Bio	10	NA	Priority vulnerable species and MSCP Covered Species that occur in the Project and/analysis area, but which were not considered for impact; Birds: Bell's vireo likely occurs in the project area; Reptiles: the desert box turtle, which likely inhabits the project area; Mammals: Merriam's mouse is likely along Davidson and Cienega Creek (analysis area), southern yellow bat is likely in the analysis area, and California leaf-nosed bat has been confirmed in the analysis area (Cienega Creek Natural Preserve) and is likely in the project area. Clearly more work is needed to summarize the known distribution of these species and analyze the mine's impact upon them.
Brian Powell	3	Bio	14	NA	The document states that "Impacts to hydroriparian habitat along Cienega Creek Natural Preserve and Davidson Canyon are possible but not anticipated." We disagree and believe the impacts to surface water and groundwater continue to be minimized.
Brian Powell	3	Bio	15	Issue 5E.2	"Individuals may be impacted, but loss of population viability is not likely." This is not true for at least the Coleman's coralroot, which has approximately 40% of all known individuals occurring within the project area. This shows that the FS is not taking an objective view of mine impacts.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	17	20-22	The statement "Note that the term 'population' may have different connotations, but birds, in particular, are long-range migrants, so most often a population is considered a range-wide entity, rather than being composed of subpopulations, as is often true with smaller and less-mobile organisms". This statement is not supported in the scientific literature. Just a few sentences later (page 18, line 6) there is a cited need to manage and monitor populations of indicator species, some of which are birds.
Brian Powell	3	Bio	19	7	Update date of Pima County MSCP to 2012
Brian Powell	3	Bio	19	12-13	Not all of the private sector would be covered under the MSCP. For example, mining is not covered. A correct terminology would be "some, specific activities of the private sector".
Brian Powell	3	Bio	19	14	The permit area is much more broad than stated. Please review MSCP and report correct permit area, because it includes lands that will be impacted by the mine.
Brian Powell	3	Bio	29	42	The FS is poised to allow the permanent destruction of approximately 5,000 acres of land; it follows that the Service should be alarmed to write that "the latest botanical surveys by McLaughlin and Van Asdall (n.d. [1977])". Surely we can do better than to rely on old data such as this. In fact, later in the document, such as for giant sedge and for nearly all of the plant species analyzed, the Service notes the inadequacy of this earlier effort by way of the fact that later efforts consistently found these species.
Brian Powell	3	Bio (also seeps, springs, and riparian)	35	9	The level of detail with regards to the impact of the proposed mine on wildlife and plants is insufficient and based on generalities. (In this section—and with regards to impact on wildlife—the EIS addressed vegetation and information about impacts on species as "needs in terms of vegetation types.") Vegetation type change is certainly a possibility in some places, but in others it will be a loss of vigor over the short term and potential loss of species and vegetation structure. These changes were not analyzed as part of the EIS.
Brian Powell	3	Bio	35	1	Analysis for individual species (based on the number of acres) should be broken out separately by the 'analysis' and 'project' areas.
Brian Powell	3	Bio	36	26	No quantitative analysis of Pima Pineapple cactus was conducted. Certainly there have been surveys for this species in the pipeline and powerline corridors, but that should not preclude a large view of disturbance that will result from some of the connected actions.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	45	27	The level of detail for the Chiricahua leopard frog is excellent and certainly benefits from the fact that this species has a recovery plan. However, it underscores how little information is known for most of the other species that are analyzed and for which assumptions of available habitat are made. For many of these species, where does data come from that would enable modeling of habitat and what are the results of those modeling exercises? I can find no such information in any of the documentation from the FS. Reviewing these data is critical to understanding the validity of the models.
Brian Powell	3	Bio	49	2	For a species that is widespread in the analysis area ("all areas at elevations ranging from 2,350 to 4,800 feet above mean sea level and within all riparian habitats"), 963 acres is not a correct figure.
Brian Powell	3	Bio	49	26	For the Sonoran desert tortoise: "The most suitable habitat for this species, however, is largely to the west and north of the project area in Sonoran desertscrub." The area around Cienega Creek and Davidson Canyon are most certainly "suitable" habitat and Pima County has recoded many individuals in this area. This should be reanalyzed.
Brian Powell	3	Bio	60	20	It should be noted that annual monitoring has taken place for native fishes, including in 2011 and 2012. Arizona Game and Fish conducts those surveys, including at one site on Cienega Creek, downstream of the confluence with Davidson Canyon
Brian Powell	3	Bio	91	10	"100 additional species are growing in the revegetation plots" This is likely because the revegetation plots are small and are geographically close native plant communities. Natural seed dispersal from native species to the massive tailings piles is less assured. There are good models to test this potential and these should be employed before results from a small test plot can be extrapolated to the massive tailings piles being proposed.
Brian Powell	3	Bio	96	16-17	The line: "While the extent and degree of these impacts would depend on local climatic conditions and other factors that are difficult to quantify, mitigation measures to identify and control nonnative and invasive species are expected to be effective." This needs a citation and needs to have much greater clarification. Effective at what? Establishment of new species? Complete elimination?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	97	13	The EIS states that "population viability relates to the distribution of a species on lands managed by the Coronado—not rangewide." I am not aware of population viability being used in this manner. Usually population viability is determined through population viability analysis. Regardless, the use of distribution as a tool for viability determination is a flawed approach for those species for which we do not know the full (or even partial) distribution. This is the case for many of the species, especially plants.
Brian Powell	3	Bio	97	18-19	"A quantitative analysis using GIS was conducted to estimate the acreage of possible habitat for special status species within the analysis area and the expected direct impacts to possible habitat for these species." This is a positive addition to the EIS, but where is there greater detail about the GIS process? When Pima County did a GIS exercise for the Sonoran Desert Conservation Plan, it was an iterative and open process, with professional input and a document that could be viewed and critiqued by others. A similar approach should be taken here; otherwise it is just a leap of faith that that the FS team did things right. Based on the information presented, it also appears that these models are very coarse grained, as evidenced by the inclusion of "habitat types" as opposed to more specific resources. This is now common practice for site-specific impacts as opposed to landscape-level analyses, which the approach by the FS for the Rosemont mine is more suited.
Brian Powell	3	Bio	100	14-15	With regards to the needle-spined cactus, the EIS states that "Individuals of this species may occur near the reroute of the Arizona National Scenic Trail, but the trail is linear, requires a narrow corridor for construction, and allows for some flexibility in trail placement, so impacts to sensitive plants would be avoided to the extent practicable". This cactus can occur at quite high densities and therefore will be very difficult to avoid. Additional mitigation measures are needed.
Brian Powell	3	Bio	101	3-4	Over and over again for plant species such as the Huachuca golden aster, the Service indicates: "Direct impacts (i.e., crushing, clearing, trampling, etc.) to this species are not anticipated because there are no documented occurrence records for this species within the project area or the footprints of the connected actions." How can such a determination be made when no surveys have been undertaken to find the species? The FS needs to be honest when it does not know the extent or severity of impacts before making any such claim of effect.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	101	27	In chapter 2 of the document, the term “project area” is defined as the “area that is composed of the open pit, waste rock facility, tailings facility, heap leach facility, plant site and ancillary facilities, fenced area around the mine (perimeter fence), mine primary access road, and utility maintenance road.” However, with regards to the Coleman’s coral root, the document states that “there are individuals growing in McCleary Canyon in the analysis area outside the project area that could experience indirect impacts.” This is incorrect: the largest known population of the Coleman’s coral root—representing approximately 40% of known individuals— is inside of the project area boundary.
Brian Powell	3	Bio	101	27	The mitigation and monitoring plan claims that the plant site will be relocated so that there are not impacts on the plant, but this fact is unclear from the maps (chapter 2) and the County has not been provided GIS maps to verify this. However, assuming that the analysis is correct, the processing facilities will be *extremely close* to numerous known individuals in McCleary canyon. Here, the species’ host plant (presumed to be oak, in symbiosis with a fungus, but so much is still unknown) could be seriously impacted by plant operations, including fugitive dust and a higher likelihood for fire due to proximity to the plant. None of these impacts were given serious consideration. Instead, the FS declared that “because of the recent discovery of new populations, it has been determined that there would not be a loss of population viability across the Coronado National Forest.” It seems impossible to conclude that impacting approximately 40% of the known individuals of a species would not constitute loss of population viability. If there is one species that will be impacted by this proposed mine and that deserves special attention, it is certainly the Coleman’s coral root and sadly, such consideration was not afforded.
Brian Powell	3	Bio	101	27	By the Forest’s own definition of population viability (“the *distribution* of a species on lands managed by the Coronado—not rangewide” [italics added]), it seems unlikely that this species would not be determined to lose population viability. And if population viability is invoked, then a population viability analysis should be undertaken to determine factors such as minimum viable population.
Brian Powell	3	Bio	101	27	In each and every plant write-up in this section says “such as increased potential for competition from nonnative plant species.” Clearly this standard language does not take into account the actual life history of this species, because what exactly is the species in “competition” for? The fungus upon which it relies? Again, this language is clearly shoved into the account with little thought as to its meaning. Such facts offer little comfort, particularly for a species that could be driven toward the need to list under the ESA as a result of the mine.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	105	9	The analysis does not consider the impacts on the lowland leopard frog in the analysis area, which includes an important population in Cienega Creek below the confluence with Davidson Canyon. This is neither recognized nor seriously analyzed.
Brian Powell	3	Bio	106	2	No acknowledgement of the impacts on the Sonoran desert tortoise in the Cienega Creek area.
Brian Powell	3	Bio	106	36	The impacts of mine-generated noise on birds are not taken into account as it relates to singing and hearing territorial calls. This can be a significant impact in some areas and for some species.
Brian Powell	3	Bio	107	1	No determination of population viability for the rufous-winged sparrow is made.
Brian Powell	3	Bio	107	13	Northern grey hawk occurs at Cienega Creek, but that is not acknowledged, nor is the analysis area
Brian Powell	3	Bio	108	15	The Cienega Creek Preserve is an important site for the yellow-billed cuckoo, but impacts are not honestly stated. The document makes a point of stressing that the level of uncertainty over the impacts on Cienega Creek is high, but uncertainty calls for more information and a greater dose of caution.
Brian Powell	3	Bio	111	8	The EIS acknowledges that “groundwater drawdown is modeled to occur” (on Cienega Creek), but this is absent from evaluation of other aquatic and riparian obligate species except Gila topminnow
Brian Powell	3	Bio	111	24	Cienega Creek is one of the most important areas for the Gila topminnow and it is a creek system that has declined precipitously in the last few years. The determination of no effect on population viability is, at best, questionable.
Brian Powell	3	Bio	111	39	The EIS acknowledges that there will be direct loss of Sonoran talussnail and Santa Rita talussnail habitat (which is known to be occupied) but the EIS only suggests that individual could be crushed. An estimate of the number of individuals that would be killed would be honest. Because no mitigation efforts are proposed, will there be no attempt to minimize mortality for this species? No collection or relocation? What about impacts from loss of slope stability to the west of the pit

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	115	34	Regarding the jaguar, the FS Supplemental BA states: "Although the potential effects of roads have been discussed in the June BA and October SBA, the potential for road-mortality may have not been adequately addressed." In its determination in the EIS the FS also fails to take into account the fact that the mine, which will stretch from the ridge of the Santa Rita Mountains to the west to almost Highway 83 in east will significantly increase the potential for mortality of jaguars along Highway 83. This fact is acknowledged indirectly by way of a mitigation measure to use infrared triggered cameras as mitigation (a measure that I suggest is questionable). Nevertheless, this fact needs to be acknowledged and analyzed.
Brian Powell	3	Bio	116	1	The FS, by way of reports by SWCA (cited as SWCA 2012b), claims that "the Project will entail a perimeter fence encompassing approximately 6,990 acres that will likely exclude jaguars from the mine site…the perimeter fence of the Project will exclude jaguars, but will not preclude individuals from moving around the Project. Thus, the perimeter fence will not preclude the movement of jaguars within the northern Santa Rita Mountains". (Note that this is almost the exact same language used in the company's own report (via Westland). First, the confusing statement "will exclude jaguars, but not preclude individuals from moving around the Project" is interpreted to mean that jaguars can move around project areas (e.g., transmission lines, access roads) outside of the perimeter fence. Elsewhere in the document (Chapter 2) it is claimed that the perimeter fence will be a 4-strand wire fence and so will the security fence in areas outside of the main access and guard shack areas. Therefore, the two fences *will not exclude jaguars* from the project site and will therefore put an individual in danger of mine-related activities, equipment, and personnel.
Brian Powell	3	Bio	116	1	Based on the presence of a male jaguar near to (and possibly in) the project area, the FS classifies camera traps as a mitigation measure for this species. Aside from the idea that collecting information is important, in what meaningful way is taking photographs mitigation for the destruction of habitat? How would photographs lead to on-the-ground conservation action?
Brian Powell	3	Bio	116	1	Pima County also has concerns that the impact of the Sycamore Connector Road has not been analyzed as to its effect on the revised Critical Habitat designation. This road will further impact critical habitat, yet without proper analysis.
Brian Powell	3	Bio	116	1	Whether or not the proposed project impacts critical habitat for the jaguar is clearly up to the FWS, but how can the destruction of almost 4,000 acres of critical habitat for the jaguar be determined to "not destroy…critical habitat"?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Bio	117	5	Though most of the bats analyzed in the process eat insects, they are known to drink a lot of water from open sources. An analysis should be undertaken to determine what impact drinking pit water will have on these species. This fact has not been analyzed.
Brian Powell	3	Bio	117	41	Analyses based on old data (e.g., Botteri's sparrow, rufous-winged sparrow, and varied bunting…. have been documented in the proposed project area, but all are listed as rare to uncommon (Davis and Callahan n.d. [1977]) should be reevaluated.
Brian Powell	3	Bio	121	1	Disclose full impacts to Coleman's coralroot in other areas of McCleary.
Julia Fonseca	3	Biology	NA	NA	The EIS does not disclose that the project fails to meet the Sonoran Desert Conservation Plan's guidelines for mitigation of impacts to the Maeveen Marie Behan Conservation Lands System (CLS). The guidelines are not compulsory for the unregulated mining industry, but they are part of the County's land use plan and this was discussed in the biological mitigation group by the cooperators and the Forest Service staff. I estimate that at least 8700 acres of mitigation land in the CLS would be needed to offset disturbance for the Barrel Alternative under the CLS guidelines. Rosemont is offering around 3300 acres of land within the CLS as mitigation lands, well below the target of 8700 acres in the CLS. Even with the possible acquisition of Sonoita Creek Ranch outside the CLS, the acreage is still 4200 acres below the SDCP mitigation guidelines.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Biology	130 on		The analysis presented for cumulative effects is inconsistent with information from other regional plans and permit applications. For over a decade, Pima County and Pima County Regional Flood Control District have worked with other agencies and individuals on the Sonoran Desert Conservation Plan under the National Environmental Policy Act. The SDCP was an interagency planning effort in which the U. S. Fish and Wildlife Service, U. S. Forest Service, U. S. Bureau of Land Management and U. S. Environmental Protection Agency participated. That effort documented past loss of species habitats in the region, including many of the species analyzed in the Rosemont EIS. Of particular interest for cumulative effects analysis may be the impacts to species habitats and special elements that have been contributed by past urban development. See Table 4.5 of the November 2012 Environmental Impact Statement (see existing built environment) and Table 4.3 of same for existing built environment in the permit area, which includes the area outside, but adjacent to the Coronado National Forest and Santa Rita Experimental Range.
Julia Fonseca	3	Biology	130 on		The analysis presented for reasonably foreseeable actions is inconsistent with information from other permit applications. For over a decade, Pima County and Pima County Regional Flood Control District have worked with other agencies and individuals on an incidental take permit to cover activities relating to urban growth that is under the jurisdiction of the Pima County Board of Supervisors (and Flood Control District Board of Directors). The incidental take permit will cover impacts to 44 species in the permit area, which includes the area around the northern Santa Rita Mountains. The Rosemont EIS should include the issuance of this permit as a reasonably foreseeable action. Of particular interest for cumulative effects analysis may be the impacts to species habitat that are projected for future urban development and the projected impacted to special elements. See Table 4.5 of the November 2012 Environmental Impact Statement (see habitat loss by alternative). In this case the No Action Alternative would have the same effect as Alternative C. See Table 4.3 for projected impacts to special elements.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Linda Mayro	3	Biological Resources	4	24-29	This section correctly states that adverse impacts cannot be completely mitigated and is inconsistent with statement in Chapter 2 that "impacts will be short-term."
Julia Fonseca	Appendix B, and Chapter 3: Biology, Seeps and Springs, Livestock Grazing				Pima County should be on the interagency team overseeing the mitigation fund. Pima County has worked to protect and conserve natural resources in the Cienega basin since 1986, with the creation of the Cienega Creek Natural Preserve. According to the County Administrator's Office, total acquisition costs for lands in the Cienega Creek basin total nearly $64 million. Most notably, these include portions of lower Cienega Creek and Davidson Canyon, downstream of the proposed mine. The Cienega Creek Natural Preserve is a 4000-acre protected area owned by Pima County Regional Flood Control District containing intermittent and perennial flow reaches, and springs supported by a shallow water table. Acquisition costs total $8.6 million for the Preserve. Acquisition began in 1986 and was largely completed in the early 1990s. The Bar V Ranch, located along Davidson Canyon south of Interstate Highway 10 was acquired for $8.1 million in 2005. The State Transportation Board unanimously approved a contribution of $500,000 to acquire 600 acres of the ranch along Davidson Canyon to preserve viewsheds along state-designated scenic roads and highways. Bar V Ranch includes a vital wildlife linkage recognized by Arizona Game Fish Department along Davidson Canyon. In addition, the county also acquired 58 acres near the Empire Mountains at a cost of $190,000 called the Amadon and Nunez properties. These lands are located five to six miles east of the mine, and were purchased in conjunction consistent with the U. S. Bureau of Land Management's plan for Las Cienegas National Conservation Area.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Livestock Grazing	NA		Pima County's ranch conservation program depends on the use of groundwater wells, intermittent streams, and springs for livestock and domestic purposes (Exhibits A). In particular, Pima County has agreements with ranchers to use County land, springs, streams and grazing leases held by Pima County for ranch purposes at Bar V Ranch. The ability to maintain the ranch program depends on being able to provide the rancher a place to live and work on-site. This in turn depends on potable drinking water at the Bar V ranch house, which is supplied by a spring. Also, the wells used to water livestock must meet agricultural standards for livestock use

DOCUMENT REVIEW COMMENT FORM – GEOLOGY/SOILS

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Geology	1	15-16	Loss of federal mineral estate was an important public scoping issue. This EIS fails to acknowledge this, or discuss what the loss of the minerals will mean to future generations.
Julia Fonseca	3	Geology	1	32-33	Thank you for adding this statement
Julia Fonseca	3	Geology	1	34-38	This still does not disclose Forest Service decision not to exercise discretion to examine validity of lode claims to federal mineral estate that would lie under the proposed waste-tailings pile.
Julia Fonseca	3	Geology	2	17-18	What are the referenced alterations to the pit design? Which pit design is the Forest analyzing in this part of the EIS?
Julia Fonseca	3	Geology	5		FEIS does not disclose decision of Supervisor to not examine validity of exams.
Julia Fonseca	3	Geology	6		This part of FEIS does not disclose intent to alter surface management through boundary adjustments or land disposal.
Julia Fonseca	3	Geology	6-7		FEIS does not disclose intent to alter Forest Plan to allow mining.
Julia Fonseca	3	Geology	14, 15		Figure nor text does not disclose which pit and waste-tailing pile is being analyzed in this part of the EIS.
Julia Fonseca	3	Geology	22		Cutoff grade is relevant to the definition of waste and hence to the need to use Forest land for waste disposal. This FEIS discloses a cutoff grade. Is this cutoff grade the one that is the current basis for waste/tailings pile? Will Forest permit additional changes prior to ROD?
Julia Fonseca	3	Geology	24-25, 30		Analysis of seismicity fails to address questions about pit slope stability. EIS only disclosed values used for design of the waste-tailing pile.
Julia Fonseca	3	Geology	25		Potential for subsidence in Cienega Valley has not been addressed outside the mine operations area.
Julia Fonseca	3	Geology	30		Pratt 2007 referenced need for depressurization but most recent report by Call and Nicolas 2012 calls into question whether there will be sufficient dewatering to prevent slippage or rock bursts due to pore pressures. This should be disclosed.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Geology	30		Forest should require monitoring and mitigation of referenced pressures for stability of pit, with standards based on the pit configuration that is actually approved by the Forest in the approved Mine Plan of Operation. This requested monitoring and mitigation measure is different than and in addition to FS-SR-04. The current Call and Nicolas 2012 is for a different pit configuration than is referenced in the EIS, and for a different pit configuration than the Forest may ultimately approve.
Julia Fonseca	3	Geology	30		What response if any will be taken if rock bursts affect crest of Santa Rita mountains or affect pit operations?
Julia Fonseca	Appendix B		NA		Forest should require a contingent mitigation for rehabilitating areas of the crest of the Santa Ritas during and after operations.
Julia Fonseca	Appendix B		NA		Forest should require contingent mitigation for rehabilitating areas of the pit during operations.
Julia Fonseca	3	Geology	30		What are the limits of potential mass failures around pit wall before and after mine closure? How might this affect the functioning of stormwater controls, erosion, etc.? What measures would be taken in response after mine closure?
Julia Fonseca	Appendix B	Soils	14		Mitigation measure FS-SR-04 should provide for post-closure monitoring. The risks do not go away after operation ceases.
Julia Fonseca	3	Geology	33		Cumulative effects disclose fails to identify any impacts to geology and minerals in the region.
Julia Fonseca	3	Geology	34		Mitigation and monitoring should be added for pit wall stability, rock bursts, and seismic damage to pit. What measures will be required to reduce potential pit wall slope stability problems during operations and at closure? At closure, any berms and fencing around pit should be located beyond the limits of potential mass failure.
Julia Fonseca	3	Geology	34		Mitigation should require proper abandonment of any unused drill holes, existing shafts and adits. These should be identified in final MPO and bonded.
Julia Fonseca	3	Geology	NA		FEIS fails to address indirect or cumulative impacts to other mines in the area, including limestone and copper-moly mines, or on mineral supply, smelter availability or reagent availability.
Julia Fonseca	3	Soils	2 and ff		Analysis of stability fails to address pit. And which pit would be analyzed?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	Appendix B	Soils	Slope stability monitori ng p. 14		Pit slope stability should be monitored after closure. As written, this applied only throughout life of mine.
Julia Fonseca	Appendix B	Soils	Slope stability monitori ng p. 14		This monitoring should be tied to management actions in the event that there is the potential for collapse of any pit wall, not just collapse of “high wall”.
Julia Fonseca	3	Soils	2 and ff		Potential for increasing stability of pit walls should be addressed, and if possible, required as part of closure plan
Julia Fonseca	3	Soils	2 and ff		If no attempt will be made to reclaimed and revegetated pit wall benches, the text should explain why.
Julia Fonseca	3	Soils	2 and ff		What are Rosemont’s obligations with respect to reclamation, reclamation monitoring, and dealing with areas of erosion during temporary cessation of operations?
Julia Fonseca	Appendix B	Soils	NA		Pit wall benches above pit lake water surface elevation should be reclaimed as part of closure plan and as mitigation measure. And included in reclamation bond.
Julia Fonseca	3	Soils	14	19-20	Rosemont’s test plots show that the use of weathered bedrock has been successful only where native soil depths were adequate. Pima County staff visited the reclamation sites with Holly Lawson on August 16, 2012. We observed that where there was a high percentage of native soil admixed with bedrock, the plant cover was on the reclamation plots was very high, but on the portions of the Arkose plot where there was very little soil admixed into the Arkose, there was almost no plant cover. Thus, soil depth and composition is a critical factor for reclamation success. And yet the text does not mention the one-foot soil depth standard or provide any performance standards for soil particle size and depth, which are critical to success.
Julia Fonseca	3	Soils	15		FEIS should evaluate long-term impacts to surrounding soils due to pit wall instability.
Julia Fonseca	3	Soils	15 and ff		How much topsoil admixture (as opposed to bedrock) will be necessary to achieve the desired vegetation conditions? This is the critical factor for revegetation efforts.
Julia Fonseca	3	Soils	15		Please disclose whether any additional rock crushing will be needed to create the “soil” from onsite materials, where, and when this will occur.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Soils	15	7-8	Mesquite, acacia, mimosa and juniper all have heavy seeds that are seldom blown into sites by wind (see Laura Jackson's work in Pinal County abandoned farms for a reference as to the delay in revegetation). What is the basis for the Forest Service's belief that these species would readily colonize the reclaimed sites? The hydrology will not bring the seeds onto the reclaimed surfaces. By August 2012, tree species had not colonized the reclamation test plots in numbers sufficient to support this speculation. Even if they had, the reclamation plots are much smaller in size and less isolated from animals and adjacent seed materials than the large and highly elevated waste-tailings pile, and they had the advantage of abundant topsoil that had not been stockpiled. Some if not all soil that is used for reclamation will be stockpiled for long periods of time, a factor that may affect seed viability. Does the Forest Service have any data to cite for its conclusion?
Julia Fonseca	3	Soils	15		Table 23—Pima County continues to encourage the Forest Service to require a much more diverse seed mix than is shown here, inclusive of native annuals and including tree seeds.
Julia Fonseca	Appendix B	Soils	15		A more diverse seed mix to include more native trees should be considered a required mitigation measure. Trees have not been shown to establish significant cover.
Julia Fonseca	Appendix B	Soils	15		I encourage the Forest Service to consider adding some additional plant species that will tolerate high copper concentrations from the Arkose. During our visit in August 2012, we observed abnormally large and vigorous Eschscholzia plants on the Arkose plot. This is a species which is known to thrive in high copper concentrations. A special seed mix that is adapting to high copper and possibly other metals (arsenic comes to mind) is needed.
Julia Fonseca	3	Soils	27		Revegetation success criteria would be determined and specified in the final MPO, and thus are not available for our review. Omission of particle size standards, soil porosity, and soil depth is a fundamental flaw in this analysis—no one can predict capabilities of the soil without this fundamental information.
Julia Fonseca	3	Soils	27		The amount of soil (topsoil, not crushed rock) is likely to be a critical factor in revegetation, but no standards or reclamation success criteria have been provided by the Forest Service in the text. In lines 30-31, it says almost all slopes would receive either a cover of soil or a mixture of soil and rock cover. What is the basis for this statement? How much soil (soil depth) must slopes and flats receive to get to the desired vegetation?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Soils	32		The text should clarify that the vast majority of this volume is not soil derived from pedogenic processes but bedrock.
Julia Fonseca	3	Soils	34		Are there any restrictions on the range of materials that can be considered as "growth media"? The FEIS should disclose what materials will be added, and whether any of the growth media is to be imported to the site.
Julia Fonseca	3 and Appendix B	Soils	34		Will there be offsite excavations of alluvial materials in order to gain sufficient "growth media" for reclamation? This should be prohibited or disclosed, as the effects have not been analyzed in this EIS.
Julia Fonseca	3 and Appendix B	Soils	34		Please specify the methods, frequencies and action thresholds that would be used in monitoring required by the Forest Service.
Julia Fonseca	3 and Appendix B	Soils	35		What is the mechanism that would prevent future development of private lands on top of waste rock and tailings?
Julia Fonseca	3	Soils	35	29	What amount of cover is "sufficient cover"?
Julia Fonseca	Appendix B	Soils	FS-SR-01	7	The measure says it applies to all disturbed areas except the mine pit. Does this mean that there will be NO soil salvage for over one square mile that overlies the pit? The soils which overlie the pit should also be salvaged. The wording needs to be clarified as to applicability.
Julia Fonseca	Appendix B	Soils	FS-SR-01		What is the threshold for compliance with the NEPA decision? How will you know when adaptive management is within the NEPA decision?
Julia Fonseca	Appendix B	Soils	FS-SR-02		What is the threshold for compliance with the NEPA decision? How will you know when adaptive management is within the NEPA decision?
Julia Fonseca	Appendix B	Soils		10	Pit wall benches should be reclaimed and revegetated to enhance water quality protection and provide habitat.
Julia Fonseca	Appendix B	Sediment	FS-SR-05		Can you state how you would determine that erosion and downstream geomorphological changes exceed compliance with NEPA?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Soils and Revegetation	6	NA	On what basis is the following made: “Soil productivity would be reclaimed following placement of soil or soil/rock cover and revegetation”? Soils take thousands of years to build up productivity, but crushing rock and placing B, C, and R-horizon soils and rocks in its place, with little or no organic material will not reclaim soil productivity for many more hundreds or thousands of years (if ever). The FS need to be honest about this.
Brian Powell	3	Soils and Revegetation	15	38	Adaptive management is once again invoked as a tool for both refining success criteria and to “meet the revegetation criteria.” In the context of reclamation, adaptive management might otherwise be appropriate, but really this is a matter of experiments. The EIS outlines the results of the current experiment going on onsite, but we question the applicability of those results to future site conditions (this is partially acknowledged later in the Soils and Revegetation section) because the experimental sites had very few rock fragments and considerable amount of mulch.
Brian Powell	3	Soils and Revegetation	15	40	It is difficult to understand why the FS is waiting until the final MPO to unveil the success criteria for revegetation measures. That should be available now.
Brian Powell	3	Soils and Revegetation	22	11	Throughout the planning process, Rosemont touted reclamation drawings with large trees (presumably oaks). It is now clear, based on page 22, that trees are not part of the mix. How then, is the FS planning on mitigating for the loss of tens of thousands of oak trees that will be killed as part of this mine? The loss of these oak trees, which support wildlife and other species, is scarcely mentioned in any other part of the EIS.
Brian Powell	3	Soils and Revegetation	27	10	The EIS stated that “the Coronado would dictate the criteria that must be met for the revegetation to be considered successful and complete.” Later the document indicates that it is not reasonable to compel Rosemont to conduct reclamation far beyond the mines’ closure. But what contingencies would be put into place to ensure that success criteria are met if not to hold the company responsible beyond closure?
Brian Powell	3	Soils and Revegetation	NA	NA	The FS should require that Rosemont develop a rigorous and realistic revegetation experiment—one the uses growth medium that will represent the actual soil and groundcover conditions of the post-mine reclamation site.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Soils and Revegetation	34	7	I am not aware of any good climate models that predict “warmer and wetter conditions in the Southwest”. Please clarify.
Akitsu Kimoto	3	Soils and Revegetation	14	27-29	The studies conducted by the University of Arizona (Lawson, 2011) pointed out that the important factors for successful revegetation in the project area are to retain soil moisture and to prevent soil erosion. The FEIS does not describe the detail plan or studies to address those potential issues. Please explain what action would be taken for successful revegetation.

DOCUMENT REVIEW COMMENT FORM—GROUNDWATER QUANTITY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3-Groundwater Quantity	Analysis Methodology: Thresholds of Concern	6	18-23	FEIS states the threshold is a drop in water levels greater than ten feet over any period and that there is no regulatory mechanism prescribing a threshold. However, AAC R12-15-1302.B.1 limits the impact to ten feet of additional drawdown after the first five years of operation. A drawdown of ten feet is significant enough to cause affected well owners to replace groundwater wells with ones that reach deeper into the aquifer at a significant cost to affected well owners. This includes several wells owned by Pima County within the four-mile impact zone of the Rosemont well field.
Chavez	Chapter 3-Groundwater Quantity	Affected Environment	30	7-8; Table 54	ARS45-2711 should be included as an applicable state requirement. This statute requires the ADWR director to conduct a hydrologic analysis of well impacts from nonexempt wells that may impact the Tohono O'Odham Nation. If the projected withdrawal from the initial five-year period of withdrawal will cause a water level decline of ten feet or more at any point on the exterior boundaries of the reservation, the application shall be denied. The estimated drawdown attributable to pumping will be up to 70 feet impacting an area of 3 to 4 miles from the pumping center This drawdown will reach into the San Xavier District and the impacts to the Tohono O'Odham Settlement Agreement should be addressed
Chavez	Chapter 3-Groundwater Quantity	Affected Environment	30	7-8; Table 54	A recovery permit from ADWR should be included in the list of State Law/Regulation if Rosemont intends to replenish the groundwater it is withdrawing from the Sahuarita well field
Chavez	Chapter 3-Groundwater Quantity	Groundwater Recharge	31	22-32	The location of Rosemont's planned recharge should be identified, as this could be a connected action if it is within the groundwater impact area. Rosemont has submitted an application for 5,000 acre-feet per year of non-Indian agricultural pool CAP water that must be used by 2020. Of the 12,000 acre-feet of NIA pool water available for potential industrial subcontractors, there were applications for 17,000 acre-feet. NIA pool water will have a lower priority during shortage years, so its availability is not certain.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3- Groundwater Quantity	SAWRSA and Associated Litigation	31 and 32	35-41 and 1-6	Although modeling indicates that the Rosemont Copper water supply would violate the SAWRSA statutory restrictions, the modeling was based on withdrawals of 5,400 acre-feet, while the mineral extraction permit allows for withdrawal of 6,000 acre-feet. The estimated areal extend of the drawdown impacts is close enough to the Tohono O'odham lands that the analysis should be re-evaluated
Chavez	Chapter 3- Groundwater Quantity	Modeled and historic rates of water-level change for selected wells	48	17	Table 57. As described in Chapter 1, the active mining phase of the project is 20 to 25 years; the groundwater modeling for the water supply was conducted for only 20 years. If mining continues for longer than 20 years, which is a likely scenario, then additional water use and additional impacts to groundwater levels above and beyond those described by the modeling would occur.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3-Groundwater Quantity	Modeled groundwater-level drawdown for selected public supply, municipal or government wells	49 and 50	20	Table 59. Modeled groundwater-level drawdown for selected pubic supply, municipal, or government wells. Five Pima County wells were evaluated: D-17-13-25DAB This is an inactive non-exempt well. The ADWR registry says we acquired it 10/19/07 from Granite D-17-14-08ADD This non-exempt well managed by NRPR is used for irrigation at Sahuarita District Park. Well depth 500 feet; water level 330 D-17-13-14CAB This non-service industrial water production well managed by Solid Waste used for dust control at the Sahuarita landfill. Solid Waste reports the well depth is actually 470 feet and there will be no adverse impact D-17-13-36CDD ADWR well registry indicates this well is a piezometer used for monitoring, so it is not a valid well to evaluate for drawdown impacts D-17-13-36DAC This well is part of a group of shallow piezometers no longer used. Two wells used for compliance purposes at the Green Valley WRF would be impacted: • D17-13-36CAD (ADWR #55-509603) is 230 feet deep and screened from 170 to 225 feet. Recent water level readings were 175 feet. • D17-13-36BDD (ADWR #55-509604) is 230' deep and screened from 162 to 228 feet. Recent water level readings were 163 feet. Drawdown of 20 feet at these wells would still put the water level within the screened interval. Since Pima County maintains 15-20 feet of water above the pumps, the pumps need to be lowered to about 10-15 feet above the bottom of the well. The projected drawdown would put Pima County close to the limit of the usefulness of the well The 3-4 mile radius drawdown is based on groundwater modeling of 5,400 acre-feet per year, but the mineral extraction allow for withdrawal of 6,000 acre-feet and a projected mine life of 24 to 30 years. This is likely to affect county wells and some wells may need to be replaced.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3-Groundwater Quantity	Effect on Overall Groundwater Availability	50	1-7	Rosemont proposes to recharging 120,000 acre-feet of CAP water over the life of the mine and has recharged 42,593.02 acre-feet to date. The impacts of acquiring an additional 77,406.98 acre-feet CAP water should be evaluated in the context of the decreased availability of CAP water supplies to the TAMA region.
Chavez	Chapter 3-Groundwater Quantity	Effect on Overall Groundwater Availability	50	1-7	Rosemont evaluated the availability of CAP water in a report *The Potential for Future Colorado River Shortages to Impact Rosemont Operations* (Montgomery & Associates, January 13, 2012) and identified two alternatives should CAP supplies be curtailed during shortage: long-term storage credits and multi-year leases. The availability of long term storage credits is limited. Of the one million acre-feet of long-term storage credits accrued in the TAMA, a majority are held by the Arizona Water Banking Authority and the municipal water providers. The two entities that might be willing to consider sale of long-term storage credits, the Tohono O'odham Nation and Mohave Ventures, LLC, have a combined 96,446 acre-feet of long-term storage credits (see ADWR Long Term Storage Account Summary dated May 24, 2013).
Chavez	Chapter 3-Groundwater Quantity	Effect on Tohono O'odham Nation	50	14-19	The FEIS states that modeling shows no impacts that violate statutory restrictions. However, the modeling was based on withdrawals of 5,400 acre-feet, while the mineral extraction permit allows for withdrawal of 6,000 acre-feet. The estimated areal extend of the drawdown impacts is close enough to the Tohono O'odham lands that the analysis should be re-evaluated
Chavez	Chapter 3-Groundwater Quantity	Cumulative Effects	67	38	The FEIS notes that two proposed recharge projects, the Community Water Company recharge basins and the FICO groundwater savings facility, are not quantified as part of the modeling effort. It is clear that Rosemont intends to recharge at the CWC project, because the need for a water storage permit was noted in Table 3, page 30. Consequently the impacts of recharging should have been addressed in the groundwater models.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3-Groundwater Quality	Cumulative Effects	68	4-14	Current efforts to improve reduce pumping, conserve water, use renewable sources of water and improve groundwater levels are not acknowledged. Water providers and users are working to deliver renewable supplies to reverse groundwater declines. These efforts will be negated by the proposed mine water use. Agricultural lands are being converted to residential use and CAP allocations that are coming online need to be mentioned in predictions.
Chavez	Chapter 3-Groundwater Quantity	Mitigation and Monitoring	70	3-6	Rosemont is recharging 105 percent of the water pumped from the Santa Cruz Basin. However, it is accruing long term storage credits that can be sold, exchanged or traded to others to pump groundwater elsewhere in the TAMA. Consequently, it is not truly mitigating the groundwater pumped at the Sahuarita well fields. Rosemont should be required to recharge in the Green Valley area and to extinguish its accrued long term storage credits annually (not eventually) to replace the water pumped. This would leave Rosemont's CAP water in the Green Valley area.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3-Groundwater Quantity	Conclusion of Mitigation Effectiveness	70	41-44	Rosemont is proposing a mitigation measure that is not reliable. The availability of CAP water is uncertain. Ongoing drought conditions indicate a 45 percent chance that a shortage declaration will be made in 2016 (Don Gross, ADWR, Drought Interagency Meeting, May 20, 2013) triggering the 2007 shortage sharing agreement that will reduce the Arizona's allotment by 324,000 acre-feet. This will affect the availability of excess CAP water that Augusta Resource is planning to acquire. To date it has acquired 42,593.02 acre-feet in long term storage credits and an additional 77,406.98 acre-feet is yet to be recharged to meet the 120,000 acre-feet commitment. Rosemont has applied for a 5,000 acre-feet allotment of CAP water being made available under the non-Indian agricultural (NIA) priority reallocation process. Of the 12,000 acre-feet water being made available for industrial pool applicants, ADWR received requests of 41,248 acre-feet. It is doubtful that Rosemont will receive its full request, if at all. One of the evaluation criteria is that the applicant be an *existing* municipal or industrial user. Further, the NIA priority water has a lower priority than the Indian and Municipal and Industrial priority water and is expected to have reduced availability especially when Arizona is affected by shortage sharing curtailments.
Chavez	Chapter 3-Groundwater Quantity	Conclusion of Mitigation Effectiveness	71	1-8	Rosemont suggests is will recharge at the Community Water Company recharge area, however, elsewhere in the FEIS it is noted that the recharge site in unknown, the project is partially funded and the completion date is undetermined. Furthermore the FEA prepared by the Bureau of Reclamation in July 2010 concluded that the CWC delivery system is a separate utility from the proposed Rosemont mine, not a connected action and that Rosemont can meet its commitment to replenish water using other sources of CAP and other groundwater storage facilities.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Chavez	Chapter 3- Groundwater Quantity	Conclusion of Mitigation Effectiveness	71	9-11	Rosemont has made it clear it is using groundwater pursuant to its mineral extraction permit. If Rosemont intended to use storage credits to balance water pumped from the mine supply well field, it would have applied for a recovery permit from ADWR, which it has not. An appropriate mitigation measure to offset groundwater withdrawals from the mine supply well field is for Rosemont to extinguish its long term storage credits on an annually.
Chavez	Chapter 3- Groundwater Quantity	Conclusion of Mitigation Effectiveness	71	28-40	Rosemont's mitigation of the groundwater decline consists of an agreement with the Rosemont United Sahuarita Well Owners, CAP recharge and the Sahuarita Heights neighborhood agreement. These measures are inadequate- because recharge of CAP water will not be in the vicinity of the mine water supply wells.
Chavez	Chapter 3- Groundwater Quantity	Conclusion of Mitigation Effectiveness	71	12-14	Maintaining water storage and using inventory records to show that CAP recharge credits are balanced against groundwater removed is an ineffective mitigation strategy. Mitigation of groundwater pumped would entail acquisition of CAP water, storage in the area of hydrologic impact and extinguishment of the recharge credits annually by assigning them under ARS 45-854.01 to another party who would hold them for mitigation purposes to ensure that they are never recovered. Rosemont's reliable access to CAP water is questionable. Rosemont has stated it might not recharge at the CWC basins and may recharge at other recharge sites in the TAMA, and has no commitment to extinguish accrued long term storage credits. The FEIS itself notes (at line 19) that the exact recharge site is as of yet unknown.
Chavez	Chapter 3- Groundwater Quantity	Conclusion of Mitigation Effectiveness	72	13-17	Appropriate mitigation would be for Rosemont to commit to extinguish recharge credits annually, not voluntarily. If Rosemont were proposing to reclassify the Sahuarita well field as a recovery wells, it should list a recovery permit in Table 54, page 30.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Groundwater Quantity	7		The AFEIS responds to concerns about using less than the 5-foot drawdown to assess impacts by noting that it corresponds to natural variability (p 7). The AFEIS ignores two points here. Increased drawdown of any amount increases the time that a spring or stream would experience decreased flow or dried conditions. A spring only flows when the groundwater table is above the ground surface or when the hydrostatic pressure upgradient from the spring exceeds the elevation of the spring orifice. Drawdown of the controlling groundwater level adds to the period during which the spring is dry. It also ignores the fact that water can be drawn from a spring, decreasing its discharge, without any groundwater drawdown at the spring if drawdown away from the spring decreases the gradient controlling flow to the spring. A good comparative example is the Moapa Springs in southern Nevada from which the discharge is very sensitive to very small changes in upgradient water level (Mayer and Congdon 2007). At Moapa Springs, drawdown of less than one foot have observable impacts on the spring discharge. Another reason to consider smaller drawdowns is the lag time between the pumping which causes drawdown and it manifestation at the spring of interest. This is a bigger problem the further the spring is from the pumping because of the inherent momentum in the spread of a drawdown cone. As noted by Bredehoeft and Durbin (2008), once a trigger drawdown is detected at a given point, it is too late because the drawdown will continue to expand even after removing the stress. These considerations directly influenced Halford and Plume (2011) to use the one-foot drawdown contour in their analysis of the effects of pumping from Snake Valley on the Nevada/Utah border. This directly affects the results the AFEIS presents in Chapter 3 Seeps, Springs, and Riparian because the analyses rely on the plotted 5-foot drawdown contour. Pima County raised this issue previously and the AFEIS has not adequately addressed the concern. Mayer, T.D., and R.D. Congdon. 2007. Evaluating climate variability and pumping effects in statistical analyses. Ground Water 2007 doi:10.1111/j.1745-6584.2007.00381.x

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Groundwater Quantity	Groundwater Modeling		Pima County has submitted numerous comments regarding the groundwater model throughout the development of the EIS. The base model used in the AFEIS is the same as used in the DEIS and the model predictions presented in the AFEIS are the same, therefore those comments have not been applied to changed or improve the model. With some exception, the AFEIS does not reply or respond to the comments. The following sections repeat those comments with some additional discussion where appropriate.
Myers	3	Groundwater Quantity	Groundwater Modeling		One major assumption questioned by Pima County was the location of the western boundary of the model. Because of the intrusive rock massif forming the ridge of the mountain west of the proposed pit, simulating a boundary that will allow flow to cross the ridgeline is inappropriate. The sensitivity analysis discussed in the AFEIS (p 26) tests only the conductance of the boundary, not its location. The results of the AFEIS sensitivity analysis are not responsive to Pima County's comments.
Myers	3	Groundwater Quantity	Groundwater Modeling		Pima County questions the location of boundaries as used in both the Tetra Tech and Montgomery and Associates model, suggesting the agencies consider whether the flow across them is reasonable. The sensitivity analyses discussed in the AFEIS are not responsive to the County's comments regarding whether the boundaries are conceptualized properly. The agencies should make an independent estimate of flow across the boundaries and compare that to the simulated rate.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers			Groundwater Modeling		The Tetra Tech model includes a horizontal flow barrier (HFB) simulating the quartz-porphyry dike damming off the groundwater flow from the upper reaches of Davidson Canyon to the lower parts. Neither M&A nor Myers included this feature and it is not supported by the data. Comparisons of drawdown figures show that it limits the extent that drawdown reaches down Davidson Canyon Without specific data showing the hydraulic effect of this feature, Tetra Tech has not justified its use; at present, the model is a good interpretative model of what would occur if there were an impervious and horizontally and vertically continuous dike at that location. Specific data could include cores of the dike, geophysical tests, or aquifer tests with monitoring wells up- and downgradient of the dike. The AFEIS does present discussion on some sensitivity analysis that indicates the dike does affect the long-term response of the system to dewatering. The FS should require Rosemont to conduct hydrologic tests in and around the dike to improve its modeling.
Myers			Groundwater Modeling		Tetra Tech's model allows much more groundwater inflow through its boundaries than did M&A, although each model had boundaries in the same locations Tetra Tech did not appropriately constrain its calibration with flow data which allows this additional groundwater inflow. The simulation of this excess groundwater inflow is not supported by any data or geologic mapping. The inflow should be constrained by an estimate of recharge that would have occurred between the model domain boundary and the basin boundary. The excess groundwater inflow in the Tetra Tech model may limit the expansion of drawdown into the Cienega Basin. Boundary conditions should be supported by the conceptual model of the system with the flow across the boundary estimated independent of the numerical model. The AFEIS fails to do this.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers			Groundwater Modeling		Tetra Tech has much more steady state recharge near and above the pit than does M&A. They simulated in excess of 0.53 in/y all along the crest; they essentially forced water into non-receptive bedrock. M&A had simulated similar rates over the Backbone fault but near-zero rates over the granodiorite (pCb) outcrops along the crest of the Santa Rita Mountains. Myers' rates were high near the fault zone but very low south along the ridge near the granodiorite outcrops. The simulation of recharge near and through the mine facilities is a large difference between Tetra Tech's and M&A's model. Tetra Tech has reasoned there would be about 75 af/y more recharge after than before mining; M&A has reasoned that recharge will decrease by a similar amount. The extra recharge as simulated by Tetra Tech provides more water nearer to the proposed pit. This extra water entering the pit area from the west would limit help to fill the groundwater deficit created by dewatering and pit development. It may limit the extent that drawdown moves downgradient into Davidson Canyon. Both estimates are inaccurate, but Tetra Tech's estimate provides additional water that helps to satisfy the pit lake deficit which decreases the predicted impacts due to pit lake development downstream in Davidson Canyon. The AFEIS should present a sensitivity analysis of the recharge rates near the pit to show how sensitive the pit lake filling and dewatering rates are to the assumed recharge rates.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers			Groundwater Modeling		The Tetra Tech and M&A models used the same rectangular domain with head-controlled flux boundaries on most sides. Most modeling guidance suggests that the boundaries of a model should be at a point where conditions are known; usually this means the boundaries coincide with a topographic divide or significant change in formation. The ideal is for the boundaries to be a flow line, except for specified inflow and outflow reaches at locations where the flow is constrained. Myers had modeled the region between the topographic divides, and this would have been preferable for both Tetra Tech and M&A because it is preferable to simulate boundaries at locations where conditions are known. As in the comment above, boundary conditions should be supported by the conceptual model of the system with the flow across the boundary estimated independent of the numerical model. The AFEIS fails to do this. Alternatively, some modelers will set arbitrary boundaries at a distance from the area of interest with an expectation that the stresses will not change the flux across the boundary. The AFEIS does not provide any indication of whether these arbitrary boundaries are affected by the drawdown.
Myers	3	Groundwater Quantity	22, 25		Flow across the model boundaries differs substantially between the M&A and Tetra Tech models. The basic difference is that flow across the boundaries for the M&A model is on the order of a few thousand af/y and for the Tetra Tech model is around 25,000 af/y, inflow and outflow. It is obvious that the models have vastly different conceptualization, although neither model had an a priori estimate of flux across the boundary.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers			Groundwater Modeling 12	19-30	Drawdown in both the Tetra Tech and M&A models extends west of the Santa Rita ridge crest. Both the Tetra Tech and M&A models had conceptualized a connection with the west side, even though the granodiorite has low conductivity and the deeply dipping Paleozoic rock in which the pit is constructed may not be connected in a significant way to the formations on the west. Myers' model did not simulate this connection because it had set a boundary at the ridgeline based on the geology and topography. Allowing this connection allows the dewatering and pit lake development to draw water from areas west of the ridge that may not in reality be connected to the pit. This extra water provided to the pit introduces a bias in both models and limits the distance the drawdown extends down Davidson Canyon. The AFEIS discusses this boundary at the referenced lines and acknowledged there would be an effect but suggested it was far into the future and that the amount is a decrease in flow from the model domain. This is not responsive to the comment because it does not consider how much recharge, modeled to occur west of the ridge, flows across the ridge into the pit; if the granodiorite is essentially impermeable, this flow would not occur at all and the test presented in the AFEIS is not responsive to the concerns. If the models had not included this connection between the west and east sides of the ridge, the drawdown in Davidson Canyon may have been larger. The granodiorite intrusive rock west of the pit should be drilled to conceptualize the extent of fracturing. This would verify whether this area should be treated an impervious boundary or as a source of water to the model. Without such investigation, the model boundary west of the pit should be the ridgeline and should be no flow.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers			Groundwater Modeling		Myers' model simulated drawdown further into the Cienega basin than did either of the other models because he simulated more connection between the bedrock and basin fill in that basin; he also constrained the flows through that basin based on the flows through the Narrows – Tetra Tech did not. Because there are no hydraulic data showing no connection – the pump tests were much too short – impacts into Cienega basin could occur. This could be a substantial error in the primary modeling utilized in the AFEIS and could lead to insufficient monitoring and mitigation plans. The FS should require more extensive data gathering to test the hypothesis of a connection with the Cienega Basin. This could include drilling new wells and completing new, long-term pump tests. The FS should also require sensitivity analyses of the modeling to assess the potential for a connection between basins.
Myers					The DEIS does not consider different groundwater contours maps for different well depths. Such a map would show vertical gradients, which provides information on recharge and discharge areas. Such analysis is critical for writing a conceptual model of an area. The AFEIS did not respond or include such a map or analysis. The AFEIS should also include a map showing areas where groundwater may be perched. Perhaps this could be included with the Seeps, Springs, and Riparian section.
Myers					The ADEIS should provide estimates of the amount of groundwater in bedrock v. the amount in fill and alluvium. This would provide some context to the amount of water to be removed by dewatering The DEIS should also discuss how dewatering affects each of these aquifers, both qualitatively and quantitatively.

DOCUMENT REVIEW COMMENT FORM—GROUNDWATER QUALITY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
RWRD - Staff	3	Groundwater Quality and Geochemistry	18-20	14, 9, 20	Tables 71, 72, and 73 compare the expected seepage water quality from waste rock, heap leach, and tailings, respectively with numeric AWQSs and conclude that groundwater quality will comply. However, the values for selenium and perhaps some of the other metals may be a problem if discharge to the aquifer connects with surface water via spring flow downgradient of the facility. If this is the case, the narrative standard of R18-11-405(B) could apply, and the surface water quality standards, which are more stringent for some of these metals, could be applied at the point of compliance in the Aquifer Protection Permit. ADEQ has not taken this approach with their recently issued APP. There has been no analysis of fracture flow or karst development in the area. If fracture or karst are significant controls on subsurface flows, the groundwater modeling results are not a reliable prediction of the likely transport direction for seepage from the facility. The EIS identifies that there is little understanding of the relationship of groundwater levels and spring flow in the area. The Forest Service should make sure that appropriate study of spring flow and groundwater/surface water interaction through isotope studies, tracers, or geophysics, is conducted, so that the narrative standard can be applied where warranted. These comments were included in the January 18, 2012 comments to the Forest Service but not adequately addressed in the preliminary FEIS.
Julia Fonseca	3	Groundwater quality	8, Table 8	Issue 3C.2.	Table 8 is incorrect. Best available demonstrated control technology has not been accepted for all alternatives through the aquifer protection permit process. The APP issued is not for the Barrel Alternative, it is only for the mine plan of operations. This fact was disclosed by Rosemont letter dated February 20, 2012 to the Forest Service. The Letter notes that "once the Forest Service makes a decision on an alternative, Rosemont will make an application for an amendment to the permit…."

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Groundwater quality	Page 8, Table 8,	Last row	Impacts to the Sierrita plume should have been analyzed with respect to proposed Rosemont mitigation measures. It does not make sense to analyze the alternatives, since they are the same with respect to west-side water alternatives. The west-side recharge of CAP should be analyzed for its effects on the plume and disclosed in the EIS.
Julia Fonseca	3	Ground water quality	NA		Analysis of potential to contaminate aquifer does not appear to take into effect that soils underlying the waste/tailings landform will be removed as part of the effort to obtain sufficient “growth media”, which has the effect of removing the potential for soil adsorption and other geochemical processes that would otherwise attenuate contaminants prior to entering fractured bedrock.
Julia Fonseca	3	Ground water quality	NA		This chapter assumes the hydraulic sink will be effective even in the early years. But the groundwater models that are the basis for the Forest’s EIS indicates that the hydraulic sink effect would be limited in the early years of operation. Montgomery and Associates (2009) mapping shows the water table is within 30 feet of the current land surface underlying part of the mine facilities including waste and tailings. The ground above the shallow water table will be made more vulnerable to contamination because of the removal of soil and vegetation. Please address the potential for contamination in areas outside the hydraulic sink in the first ten years for each alternative, within particular emphasis on the contamination of areas where the depth to water is less than 50 feet.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Groundwater Quality	15-17		The DEIS had predicted there would be no seepage through the waste rock dumps, essentially because any water simulated as entering the soil would be captured and stored in the surface layer. Comments by Pima County had included that the modeling used inappropriate climate values, most especially using precipitation and evapotranspiration rates from the wrong place. In response, the AFEIS states that they considered an updated seepage model in which there were additional climate model scenarios were considered. The scenarios had to do with the length of simulation but with inappropriate climate values the antecedent conditions were never wet enough to allow additional seepage beyond the surface. The model used unsaturated conductivity values that never allowed seepage past the surface. Even the models that considered ponding simulate the water as remaining on the surface and never entering the waste rock. As noted, the presence of seepage through waste rock all over the country including in areas much drier than Rosemont demonstrates that seepage can occur. The AFEIS presents no discussion of the seepage model parameters, either soils or climate, and it still predicts no seepage. A brief review of the updated model shows that climate from inappropriate locations and soil parameters with such inappropriate parameter were still utilized. The AFEIS does not explain why these parameters were appropriate for use and is therefore unresponsive to previous comments. By using the inappropriate data as input, the AFEIS has not taken an appropriate or hard look at the potential for seepage through waste rock.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Groundwater Quality	17, 20		In the Barrel alternative, the heaps have been removed but they remain a part of the plan for all other alternatives. The plan as presented in the AFEIS for closure does not adequately describe the plan. The AFEIS describes a treatment system that would be established in the former pregnant leach pond. The AFEIS implies that the collection system and passive treatment system will also be buried because monitoring would occur through a "concrete riser piped to the surface of the waste rock"; the monitoring will verify that treatment is effective", however it does not indicate how the system would be maintained or fixed if it does not work adequately but is buried under an unspecified depth of waste rock (p 20). The need for this monitoring is apparent because at least some of the treatment, the passive treatment, will not fully treat the seepage; it is only with the "engineered biological system" that concentrations could be reduced below standards (p 20). The description herein does not meet the standards for specifying closure of the heap, as noted previously by Pima County, and does not qualify as a hard look at the plans for closing the facility.
Myers	3	Groundwater Quality	20		The AFEIS describes that heap drainage "would discharge from the sump to the ground via an open port". Throughout the AFEIS, seepage is considered to be spread over the area of the facility but in this case it is clearly a point discharge to the groundwater for which fate and transport has not been discussed.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Groundwater Quality	26		The pit lake modeling left out many sources and made too many simplifying assumptions, as indicated by Pima County on previous comments. The following is a list of those comments, with those accommodated in the AFEIS struck out. • Improved pit wall runoff estimates or better justification for the current assumptions • Estimates of water and chemical loading for pit wall interflow • Estimates of water and chemical loading for recharge to the groundwater table through the pit walls. • Loads from the leaching of the fractured rock subsequent oxidation in the pit wall • Differential inflow rates by geologic formation • Oxidation products due to dewatering the aquifers • Better justify their assumptions the pit lake will not stratify or they should include stratification in their model. • Run the model using the MWMP results rather than SPLP results because dissolution is the more important process. This could be considered to provide an upper bound on the pit lake chemistry. This might help to minimize the bias introduced by using unweathered rock in the tests. • Use input chemistry that varies with time based on the number of pore volumes of leachate that has passed the samples. • Description of how the model accounts for changing rock-type proportions. • The report should at a minimum discuss the evolution of water quality with time. The AFEIS is not responsive with respect to the previous comments, therefore they continue to apply.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Groundwater Quality			The AFEIS did not consider pit lake water quality at time periods on than 200 years. Pima County had requested this in previous comments. Because pit lake geochemistry can change considerably with time, this is a significant lack of disclosure; the pit lake may have much worse water quality at earlier or later times, but the AFEIS has not provided information or discussion regarding other time periods.
Chavez	NA	NA	NA	NA	Conveyance of CAP water to the Cienega basin: Although ADWR statutes address the transfer of groundwater out of the AMA (ARS 45-542), neither ADWR statutes nor rules prohibit the conveyance of CAP water outside the AMA. The Cienega basin is within Pima County which is part of the CAP three-county service area.

DOCUMENT REVIEW COMMENT FORM—SURFACE WATER QUANTITY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Canfield	3	Surface Water Quantity	5	4 to 43	The Golder Model report is not available as supporting data on the EIS report or the rosemonteis.us web site. Therefore, the conclusion that the 'Rosemont Copper modeling is reasonable and appropriate…' is unsupported in the analysis presented.
Canfield	3	Surface Water Quantity	5	25 to 34	The PAFEIS states that a minimum CN of 85 was used in the hydrologic analysis and notes that CN is the most sensitive parameter. However *the Preliminary Site Water Management Plan for the Barrel Alternative (TetraTech, July 2012)* includes areas with CN of 75 (Upper and Lower Barrel Canyon p. 7 of that report) and 74 for the Trail Creek Basin. Therefore, the discussion presented incorrectly asserts that higher runoff producing potential was assumed in the modeling.
Canfield	3	Surface Water Quantity	5	18 to 39	The analysis presents no actual values of runoff peak or volume and makes statements that could be interpreted either way (e.g. the 'model results' in lines 33 to 39 do not specifically state whether these results are measures of peak or volume). Therefore, it is impossible to assess the appropriateness of the analysis, when what is being compared (peak or volume) is not specifically stated. Furthermore, the 'percent difference' are of little help when the rainfall event used and the measure (peak or volume) is not specifically stated.
Canfield	3	Surface Water Quantity	5	18 to 22	The PAFEIS states that 24-hr rainfall values of 4.75 inch and 5.35 inches were compared. However, the return period of the event is not stated, so it is unclear how the findings should be interpreted.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Canfield	3	Surface Water Quantity	5	18 to 22	The PFAEIS uses 24-hr storms for all hydrologic analysis which may not address the storm of biggest concern. Sometimes shorter-duration higher intensity storms can cause higher flood peaks, so FEMA directs practitioners to consider the critical design storm for the basin. As we have demonstrated in previous comments, in some cases the 3-hr storm or shorter duration storms can produce higher flood peaks. By limiting analysis to the 24-hr event, the analysis underestimates the peak flood risk. Therefore, the hydrologic analysis should follow FEMA guidance to assess flood peak risk by determining the rainfall event duration and distribution that produces the highest flood risk for the return period of interest (e.g. 100-yr). By limiting the hydrologic analysis to the 100-yr storm Rosemont will undersize infrastructure by basing design on storm events that will not produce the critical storm on the watershed.
Canfield	3	Surface Water Quantity	5	18 to 22	The PFAEIS uses 24-hr storms for all hydrologic analysis which may not result in cumulative rainfall depths that can cause overtopping of ponds or soil moisture conditions that cause geotechnical failures. Therefore, the hydrologic analysis should consider rainfall depths for longer period events, such as the 7-day rainfall depth (e.g. 7-day 100-yr rainfall depths).
Canfield	3	Surface Water Quantity	5	6	The PAEIS erroneously states that Pima County recommends the PC-Hydro model for determining peak flows. Instead, RFCD Tech Policy 015 describes which hydrologic model should be used in different situations, and Tech Policy 018 describes how these models should be applied.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Canfield	3	Surface Water Quantity	10	8 to 16	The recognition that fires occur in the project area, that the largest burn areas have occurred since 2005 and that fires can dramatically impact the hydrologic regime should include a plan to address these concerns. There is no acknowledgment of associated hazards which occur in post-fire conditions including gullying/erosion and debris flows which could impact drainage infrastructure both during operations and post closure. There are many examples of gullying and post fire debris flows, including the Schultz fire that occurred near Flagstaff in 2010. Therefore, PAEIS does not offer a plan to address a likely hazard to occur in the project area during the operations and post-closure of the mine (i.e. fire and the associated flooding and debris flow hazard) and it should.
Canfield	3	Surface Water Quantity	25	19 to 21	The reduction of flows to downstream during the first 10 years of operations will put the offsite riparian areas at risk.
Canfield	3	Surface Water Quantity	30	11-31	The analysis of downstream water volume effects on Davidson Canyon and Cienega Creek is flawed, because *Predicting Regulatory (100-yr) Hydrology and Average Annual Runoff Downstream of the Rosemont Copper Project* (Zeller, 2011a) ignores the fact that greater rainfall occurs higher on the high elevations like the mine site, and will contribute more water to downstream areas than low elevation watersheds. By assuming that all areas contribute runoff equally underestimates the impact the mine site will have on surface water and riparian habitat in Davidson Canyon and Cienega Creek. Therefore, Rosemont should revise the analysis to more accurately reflect the effect the differences in rainfall depths on downstream runoff and its impact on riparian habitat.
Canfield	3	Surface Water Quantity	30	28-31	The SWCA Report (2012) is not provided in the PAEIS or on the rosemonteis.us website, so the finding that stormwater flow will be reduced by 4.3% (for the Barrel Alternative?) is unsupported and cannot be evaluated.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quantity	3	37	The Coronado Forest recognizes "change in recharge of the aquifer by runoff and the frequency of runoff" as "identified issues" The change in recharge could substantially affect the "Potential Waters of the United States" and Davidson Canyon. However, the FEIS did not clearly explain what action would be taken to prevent, minimize or address. Please explain.
Akitsu Kimoto	3	Surface water quantity	5	4-43	The Coronado Forest described that the Rosemont model results are reasonable, based on the Golder Associates' study. However, we found issues in the Golder's approach (Golder, 2012). Please address the issues cited below and explain why the Rosemont model results are reasonable based on the Golder's study.
Akitsu Kimoto	3	Golder (2012)	6		Golder (2012) stated that the sums of peak flow at SCS-1 were calculated by simply adding the peak flows at SCS-1 and 2. However, the timing of the peak is different between these locations. For example, the peak occurred at 35 min for SCS-1 (Run 1, Existing), while it occurred around 20 min for SCS-2. For the post-mining condition (Run 1), the time of concentration for BC is 25 min while it is 30 min for TC. This means that there is a significant difference in the timing of the peak. The peak cannot be simply added by simply assuming that the peak occurred at the same time. Please explain why this approach is reasonable.
Akitsu Kimoto	3	Golder (2012)	Appendix A		Vegetation cover density is 20% for both pre and post mining condition (Run1). The vegetation cover for the post-mining condition should be less. Please explain why the vegetation cover density would not be changed by mining activities.
Akitsu Kimoto		Golder (2012)	Appendix A		Impervious cover density is 10% for both pre and post mining condition (Run1). The impervious cover for the post-mining condition could be greater. Please explain why the impervious cover density would not be changed by mining activities.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quantity	5	11-17	The FEIS stated that the relative difference in percent change of peak flow was 13% for the Golder model, compared with 17% for the Rosemont model. The FEIS concluded that the Rosemont model was reasonable based on this comparison. Although the Golder's study has some technical issues, the study result actually showed why we concerned the Rosemont modeling result. Table 3 of the Golder's study (2012) showed that the percent change for Run 1 (high rainfall with high CN) could be 28% while it was 13% for Run 3 (low rainfall with low CN). Our previous comments for the Rosemont model are 1. the model should use higher rainfall, and 2. the model should use higher CN. The Golder's result clearly showed that the percent change (between pre- and post-mining) could be much less (13% versus 28%) if the morel does not use appropriate rainfall and CN. We believe that the Rosemont model used low CN with low rainfall (similar to Run 3 in the Golder's model), resulting in a smaller percent change. The Golder's study indicated that the Rosemont modeling study could underestimate the percent change because they used low rainfall with low CN. Apparently the Golder's study does not support the Rosemont modeling results. Please explain why the Rosemont model with low CN with low rainfall can be reasonable.
Akitsu Kimoto	3	Surface water quantity	5	11-17	The FEIS stated that the relative difference in percent change of peak flow was 13% for the Golder model, compared with 17% for the Rosemont model. The FEIS concluded 4% difference is insignificant. However, according to Table 76 (p.7), the peak difference is 22%, not 17%. It appears that the 17% difference is for average annual runoff (Table 76). The difference between 13% and 22% are not insignificant. Therefore the conclusion that the Rosemont model is reasonable and appropriate should be reconsidered.
Akitsu Kimoto	3	Surface water quantity	5	33-39	The Golder's study discussed about the difference in the peak discharge to justify the use of the Rosemont model. In addition to the difference in peak, the difference in runoff volume between the models should be discussed. The change in runoff volume could substantially affect the "Potential Waters of the United States" and Davidson Canyon.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quantity	5	29-32	The Rosemont and Golder models used soil type C for the peak and runoff calculations. The USDA SSURGO soil map shows that the project area is mostly soil type D. Please explain why soil type C was selected. As the draft FEIS pointed out, Curve Number (closely related to the selection of soil types) can significantly affect volume calculations. And, appropriate runoff volume calculation is important to estimate the impacts to the "Potential Waters of the United States" and Davidson Canyon.
Akitsu Kimoto	3	Surface water quantity	5	18-32	One of the previous comments has not been addressed. The rainfall value use to runoff calculation in the Golder model is based on the point rainfall at an elevation of 4429 feet. The elevation the Golder model used is the lowest end of the project site instead of the average elevation of the project area. The Forest should explain why the lowest elevation of the project site was selected to estimate rainfall value. The rainfall value affects runoff volume calculation. Appropriate runoff volume calculation is important to estimate the impacts to the "Potential Waters of the United States" and Davidson Canyon.
Akitsu Kimoto	3	Surface water quantity	25	20-21	Inconsistent results: The maximum runoff to the watershed during the first 10 yrs (the period with the max impact) is more than 30-40%? The table 90 shows the post closure runoff is over 45% in some cases.
Akitsu Kimoto	3	Surface water quality	P.25 L1-4, P.27 L.40-41, P.28 L.1-9		The Forest recognizes the ephemeral stormwater flow from the project area would change, primarily as a result of the retention of water at the project site. Although the FEIS acknowledged that several cooperating agencies expressed concerns of the amount of water removed and a resulting serious impact to downstream riparian resources, the FEIS did not evaluate how the water removal could impact downstream riparian resources over time (pre-mining, active mining and post-closure periods). Please disclose cumulative impacts of the reduction of storm water to riparian vegetation, channel geomorphology and groundwater drawdown.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quantity	30	Table 90	One of the previous comments has not been addressed. Orographic lifting causes precipitation in the Southern Arizona. As a result of the orographic effects, mountain areas receive more rain than downstream areas. The runoff volumes shown in Table 90 were calculated based on the assumption that runoff volumes would be reduced in proportion to the drainage area. The analysis of orographic effects on annual runoff volume should be included in the FEIS. This is because runoff volume is one of the most important factors for riparian vegetation in Davidson Canyon and Cienega Creek. In fact, the FEIS mentioned that the reductions in runoff are primarily important because they indirectly impact the water availability for downstream use (p. 30, Line 32-33). Reduction of annual post closure runoff volume could be larger due to the orographic effects. Annual Post Closure runoffs shown in Table 90 should be reevaluated. Appropriate runoff volume calculation is important to estimate the impacts to the “Potential Waters of the United States” and Davidson Canyon.
Akitsu Kimoto	3	Surface water quantity	30	32	The FEIS acknowledges that the modification of stormwater peak flows and volume is important in multiple aspects. However, the FEIS does not include any plans to address possible issues resulting from the modification of storm flow. For example, what would happen if the reduction of runoff volume significantly affects Davidson Canyon and Cienega Creek? The FEIS lacks a “backup” plan. Please explain what actions would be taken when problems are identified.
Akitsu Kimoto	3	Surface water quantity	31	L.17-23	The FEIS described that surface water rights beyond Davidson Canyon are unlikely to be impacted by changes in surface water hydrology in the project area based on the proportion of the area of the project site (p.31, L.20-23). Impacts of the reduction of storm flow from the project area on annual basis may not be substantial to downstream. However, cumulative impacts over time could be significant. Assessments of cumulative impacts of mining activities over time (pre-mining, active mining and post-closure periods) to downstream should be disclosed.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quantity	31	L.30-34	The FEIS acknowledges that some water sources would be impacted (p.31, L.30). However, the FEIS did not clearly explain who would be responsible of addressing issues. Please cite a responsible party to address potential issues, threat to health and natural resources and explain how to address issues when identified.
Akitsu Kimoto	3	Surface water quantity	37	27-29	Expansion of the limestone quarries in lower Davidson Canyon….this should be mentioned at p.3 Issue 3D; Surface Water Availability.
Akitsu Kimoto	3	Surface water quantity	37	1-32	Cumulative impacts of the reduction of storm flows downstream of the project site have not been evaluated. The FEIS focuses on the changes in either annual runoff or storm peak flow but ignored the cumulative impacts over the 20 years active mining life. Long-term, cumulative impacts of the reduction of flow from the project site on Davidson Canyon and Cienega Creek need to be evaluated.
Akitsu Kimoto	3	Surface water quantity	40	29-33	How will the monitoring data be used? What would happen if the monitoring data shows problems? The FIES should explain what actions would be taken when a problem arises.
Akitsu Kimoto	3	Surface water quantity	41	14-17	How long will the Rosemont Copper fund USGS to monitor the flow after the closure? The monitoring should continue after the closure to assess the mitigation effectiveness.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Postillion	3	Threshol ds of Concern	7	1-18	The EIS authors incorrectly claim that natural water-level fluctuations in wells make interpretation of the predicted draw downs from the mine pit more difficult and inaccurate, thus making the 5-foot predicted decline a better or preferred indicator. We believe that the impacts from the mine pit and all other sources are additive. This means that if seasonal changes currently lower the water levels below stream channels and occasionally affect riparian trees and other vegetation, the drawdown from the pit will increase the time and magnitude of these impacts and will be superimposed upon the current impacts. Thus, a one-foot decline contour will show an ADDITIVE effect on the currently documented declining water levels and base flows of the Cienega and Davidson Basins. A recent study we can supply, statistically documents the 15-year drought in the Cienega Creek Nature Preserve, and can serve as a baseline for any potential mine activity (Powell, 2013). The study uses statistics to show the long-term trends and allows for seasonal variability. This justification should be dropped. Also, substantial natural fluctuations observed in deep bedrock aquifers as opposed to basin fill aquifers could indicate that impacts from a large open pit will move through these aquifers much more quickly than predicted with the groundwater model. This could result in larger draw downs manifesting faster during and after pit construction. Natural and seasonal variability can be evaluated over time.
Postillion	3	Quantity-Threshol ds of Concern	7	14-18	The statement “there is no reliable method for separating out ongoing seasonal or annual variation from impacts of the mine” has little basis when significant baseline data has been collected by Pima County and statistical analyses have been performed evaluating seasonal and annual trends in the Cienega Creek Nature Preserve and Davidson Canyon. Continued pre-mining monitoring will allow for separating the mining effects by comparing the historical data to assess the additive effects of the mine. Typical ADWR Assured Water Supply studies are mandated to superimpose the projected modeling results from a large pumping well over the current and historical water-level trend in an area to show the long-term impacts of the land use. We know there has been a historical downward trend the last 15-17 years for water levels in this area. There is no reason why the effects of the pit cannot be superimposed over this.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Postillion	3	Quantity	13	18	Add 170 to 370 AF/year. In addition, The 170 AF/yr amount appears low based upon some basic water balance information. The final diameter of the lake based on Tetra Techs Geochemical Report is about 3000 feet, and the size of the lake would be about 162 acres. Rainfall in would be approximately 20 inches. Evaporation in this area is estimated at 48 inches. The net difference in water lost to the atmosphere is about 28 inches or 2.33 feet. Thus the water lost annually would be more like 380 AF. Tetra Tech in their Geochemical modeling report came up with 288 AF of net loss which is also probably too low.
Postillion	3	Quantity	39	35	Table 55 begins with “Estimate” Why does the Myers Column need “Estimated” in front of the values for rows of Recharge from Precipitation and Evaporation? This is redundant and unnecessary, and implies that the Montgomery and Tetra Tech values are better.
Postillion	3	Quantity	64	19-24	This discussion appears to be very down played. Equilibrium is over 1000 years away. What really needs to be emphasized is the loss from years 0-20 and 20-200. These impacts are far greater than at equilibrium and will affect the downstream well users and riparian vegetation. Tetra tech estimates at year 200 that 517 AF is evaporated and lost at the pit and that amount will rise as the pit lake grows. Over the 20-year mining period as much as 925 AF/year is lost due to pit dewatering. These are the amounts that need emphasis, not at equilibrium when the current generations are gone. In addition, little discussion regarding water availability for the downstream riparian community is mentioned. This needs elaboration and is an omission.
Postillion	3	Quantity	65	1	A more significant reference for table 67 is at year 20 and 200, not equilibrium. As discussed above, the largest impacts regarding water availability are years 20-200 and maybe slightly beyond. This omission does not emphasize the more near generational impacts of water availability. Equilibrium is only a snapshot of the impact and how many years is that-greater than 1000.
Postillion	3	Quantity	69	9	Monitoring is a good thing to assess the impacts from pit dewatering to downstream wells and vegetation. However, a mitigation opportunity overlooked is the ability of the mine to take the 18,000-26,000AF dewatered from the pit and discharge it downstream to replenish the water that would have eventually gone downgradient to begin with. It is understood that the pit water would have to be monitored for water quality. But if the report such as Tetra Tech’s (2010b) geochemical model predicts, the quality should meet water quality standards. This mitigation is truly mitigation at the area of hydrologic impact.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Postillion	3	Quantity	70	3	Numerous people have asked why Rosemont could not use CAP directly when a pipeline is built that far south. ASARCO is currently using 10,000 AF/yr at their facility based upon the SAWARSA settlement. So legal issues aside, this can be done with cooperation of Rosemont and a willing provider. Why not use imported CAP with a poorer quality for mining processing? Is this too sensible a mitigation measure?
Postillion	3	Quantity	70	7	Documentation is needed that states the amount and time Rosemont has funded the 7- mile CAP extension. Again, direct use of CAP by Rosemont is a better option. Leaving the higher quality groundwater with lower TDS for potable supply is a more sensible option.

DOCUMENT REVIEW COMMENT FORM—SURFACE WATER QUALITY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Surface Water Quality	NA		The EIS fails to analyze effects of SR 83 roadway alternations including drainage alterations resulting from the SR83 connected action.
Julia Fonseca	3	Surface Water Quality		35	A separate contingency fund should be established to deal with mitigation of impacts to surface water quality. The Cienega Creek Watershed Conservation Fund should not be used for dealing with surface water quality impacts caused by the mine, as that fund is inadequate for mitigating other impacts.
Julia Fonseca	3	Surface Water Quality		31	The secondary standards for total dissolved solids do have relevance for the character of the riparian vegetation and macroinvertebrate communities. Excessive salinities in particular can be damaging and encourage the growth of tamarisk. TDS levels at Oracle Ridge mine monitoring wells and tailings seep have been as high as 1200 mg/l. The Oracle Ridge mine is a skarn deposit similar to the Rosemont mine. The EIS should disclose the degree to which TDS will be affected in the Outstanding Waters, and provide for monitoring of such.
Julia Fonseca	3	Surface Water Quality	NA		EIS fails to disclose WUS impacts associated with the SR 83 roadway improvements
Julia Fonseca	3	Surface Water Quality	NA		EIS fails to disclose Rosemont's obligations for surface water quality maintenance during temporary cessation of operations.
Julia Fonseca	3	surface water quality	NA	NA	The waste and tailings will create unplanned surface water bodies around the perimeter of the site where natural flows are blocked or where drainage collects. In addition, the mine plan of operations propose the creation of PCAs (perimeter containment areas) that may retain water periodically. Effects on surface water quality have not been analyzed.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quality	21	10-21	One of the previous comments has not been addressed. The Forest assumes that sediment transport linearly increase/decrease with changes in a watershed area. The assumption is inadequate because high elevation areas receive more rain than downstream areas due to orographic effects. The project area is located upstream of the Davidson Canyon. The FEIS described that changes in sediment load would not significantly impact the fluvial geomorphology of the stream system because the area affected by the proposed mine is relatively small. However, the Forest admitted that "the reach of Barrel Canyon could be affected… (p.23, L8), and "This reach of Barrel Canyon …could be impacted by the reduction of sediment load." Also, as shown in Table 104 (p. 22), the reduction of contributing watershed area can be more than 50%. Because the project site is located at upstream area with high elevation, the reduction of contributing area could have much more significant impacts on the annual sediment delivery than the Forest's estimates summarized in Table 104. The appropriate sediment delivery analysis is important because it could affect geomorphology, vegetation and fluvial system of the "Potential Waters of the United States".
Akitsu Kimoto	3	Surface water quality	23	8-13	The impacts of mining activities on sediment transport could change over time during the active mine life and after the closure. The FEIS reported that the reach of Davidson Canyon is currently a sediment transport-limited system. However, with a reduction in sediment load from the project area over time, it is possible that loose sediment is washed out and as a result the sediment transport system could be changed. The changes in sediment balance could affect the fluvial geomorphology of the Davidson Canyon and Cienega Creek. Appropriate sediment transport analysis is necessary to estimate long-term impacts of mining activities on channel geomorphology, vegetation and fluvial system of the "Potential Waters of the United States". Cumulative impacts of possible changes in sediment transport system on "Potential Waters of the United States" over time should be disclosed.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	3	Surface water quality	22	22-30	The FEIS acknowledged that there will be a reduction in sediment yield from Barrel Canyon watershed but no change in the geomorphology of the channel is expected. The FEIS only discusses about annual average sediment delivery. The FEIS did not consider cumulative impacts of sediment delivery change over the active mine period and post-closure. Considering the proposed active mine life is over 20 years, the FEIS should assess long term impacts on sediment yield, delivery and channel geomorphology.
Akitsu Kimoto	3	Surface water quality	32	14-15	One of the previous comments has not been addressed. The FEIS mentioned about the best management plan, but the plan was not provided. Therefore it is not possible to assess the effectiveness.
Akitsu Kimoto	3	Surface water quality	33	8-9	Who is responsible repairing and rebuilt the dam if damaged?
Akitsu Kimoto	3	Surface water quality	34	32-35	If severe scour or aggradation is identified, how to address the issue?
Akitsu Kimoto	3	Surface water quality	35	21-28	What action would be taken if water quality exceeds the standard or contamination of surface or groundwater is detected? Is there a public notification system if monitoring data shows that the level of contamination is above the standard or could potentially risk human health?
Akitsu Kimoto	3	Surface water quality	38	6-9	What action would be taken if monitoring data shows the impacts to surface water quality in the Davidson Canyon during active period and post-closure?

Canfield	3	Surface Water Quality	3	19-22	*The method used to estimate erosion is not appropriate to evaluate the impact of mining alternatives and is far below industry standards.* While Rosemont's consultant, Tetra Tech, has justified their use of the PSIAC method (Tetra Tech, August 18, 2011, comment 2), the two studies cited by Tetra Tech (Rasely, 1991; Renard *and Stone* 1982 [Tetra-Tech neglected to mention the co-author Stone]), clearly state that the PSIAC method is inappropriate for site level assessment: *'The method developed by the Water Management Committee of PSIAC (1968) was intended for broad planning rather than specific project formulation where more intensive investigations are required.'* p. 130 in Renard KG and Stone JJ. 1981 *"Estimating Erosion and Sediment Yield from Rangeland."* Proceedings of the Symposium on Watershed Management, ASCE, Boise, Idaho, July 21-23, 1980 *'It should be emphasized that the PSIAC sediment yield procedure is quite different from the Universal Soil Loss Equation, USLE, (Wischmeier and Smith, 1978) because the USLE evaluates on-site soil disturbance in relationship to agricultural cropland, which is the gross soil erosion in an individual soil and farm field setting, while the PSIAC sediment yield procedure rates sediment delivery from rangeland and mountainland which is net soil loss in a watershed hydrologic unit setting.'* p. 6 in Rasely, RC. 1991. *"Proposed Revision of the Sediment Yield Procedure Pacific Southwest Interagency Committee Report of the Water Management Subcommittee, 1968."* Upper Colorado River Basin Rangeland Salinity Control Project, Salt Lake City, UT. U.S. Department of Agriculture, Natural Resources Conservation Service, 17 p This quote from Rasely, 1991 clearly indicates that PSIAC is meant to be used on undisturbed rangelands and mountainlands, while other methods, such as USLE, are appropriate for assessing the impacts of disturbance. Therefore, the two sources identified by Tetra Tech as justification for the use of PSIAC method for evaluating the impact of the Rosemont mine actually state that PSIAC is an inappropriate method for evaluating impacts of mining on erosion and sediment transport and soil loss.

DOCUMENT REVIEW COMMENT FORM—(SEEPS/SPRINGS/RIPARIAN)

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Springs, Riparian	8	15	The FS expanded their analysis to a larger set of springs for this version of the EIS. That is good, but in analyzing the effects of the mine, it was not recognized that baseline conditions were taken during the height of one of the most severe droughts of recorded history. Data from elsewhere in the watershed (e.g., Cienega Creek Preserve) support this, but again, this is not taken into consideration
Brian Powell	3	Springs, Riparian	11	20	The report cited is the wrong study (what was cited was a fact sheet) and the correct report was not provided.
Brian Powell	3	Springs, Riparian	15	27	The FS cites long-term uncertainty about impacts to water and vegetation resources as being largely shaped by externalities ("Long-term impacts are less certain or even speculative, not only because the uncertainty of the model results increases with time but because the cumulative effects from other future actions and climate change are entirely unpredictable during these long time frames"). These factors are certainly important, but this is the wrong approach; what is before the FS is a mine proposal that will have impacts on geological time scales and this should compel the FS to invoke the precautionary principle.
Brian Powell	3	Springs, Riparian	23	1	Pima County has collected baseline data at Bobo, Mescal, Davidson, and Becky spring (indicated as #92; this is important spring for Bar-V Ranch and is an important source of domestic water for the ranch). We can provide these data to the FS for their analysis and we would welcome data collection at these sources. In fact, it is surprising that we were not contacted by the FS or Rosemont consultants about these springs. All of them are very accessible (i.e., not "too remote").
Brian Powell	3	Springs, Riparian	54	1	Further development in Davidson Canyon and the installation of more wells seems to be a reasonably foreseeable action that should be analyzed based on population projections for the area and the fact that there is no other water supply for future growth.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	3	Springs, Riparian	55	19	The document claims that the BLM/AZGFD action of reintroducing beaver to Cienega Creek will have a beneficial impact on riparian resources. This is a very simplistic assessment and will require more attention, because although these impacts may be beneficial in some areas of upper Cienega Creek, Pima County has serious concerns that this action will negatively impact the County's Cienega Creek Natural Preserve.
Brian Powell	3	Springs, Riparian	56	9	There is no clear connection between a number of the mitigation and monitoring activities in this section (e.g., perimeter buttresses, growth media salvage) to seeps, springs, and riparian areas. Document should be explicit about how some of these mitigation measures would impact these resources.
Brian Powell	3	Springs, Riparian	58	1	The document states "revegetation of disturbed areas would also reduce impacts to riparian resources by allowing more water to flow downstream as soon as possible during the active mining phase." It is not clear how more vegetation, which holds and uses water, would allow more water to flow downstream.
Brian Powell	3	Springs, Riparian	58	19	"The new riparian habitat that would be created downstream of Pantano Dam would replace hydroriparian habitat if any is lost." Has this been evaluated? If so, how much hydroriparian habitat would be created?
Brian Powell	3	Springs, Riparian	NA	NA	There is no analysis of the impact of fire and/or pests on these resources. As springs and shallow groundwater areas are dewatered, they will be more susceptible to wildland fire and/or pathogens. This is an important indirect effect.
Brian Powell	3	Springs, riparian	NA	NA	A large body of evidence from regional studies of riparian and aquatic plants points to thresholds as systems respond to changes in groundwater levels. Crossing these thresholds does not always result in replacement with another communities, but can (at first, or over a very long period time) result in reduced vigor (particularly in riparian trees) and loss of grasses and forbs. This has not been analyzed for springs (and their associated plant communities), nor has such analysis been extended to Davidson Canyon and Cienega Creek.
Carla Danforth	3	springs	15	8-9	Important Riparian Areas (IRA) are mapped based on many factors including landscape linkages, wildlife corridors, and hydrologic connectivity, as well as vegetation. IRA boundaries are not subject to amendment under the Pima County Floodplain Management Ordinance. Due to the ecological importance of the function of IRA, why does the IRA classification not factor into the assessment of riparian impacts in the FEIS?

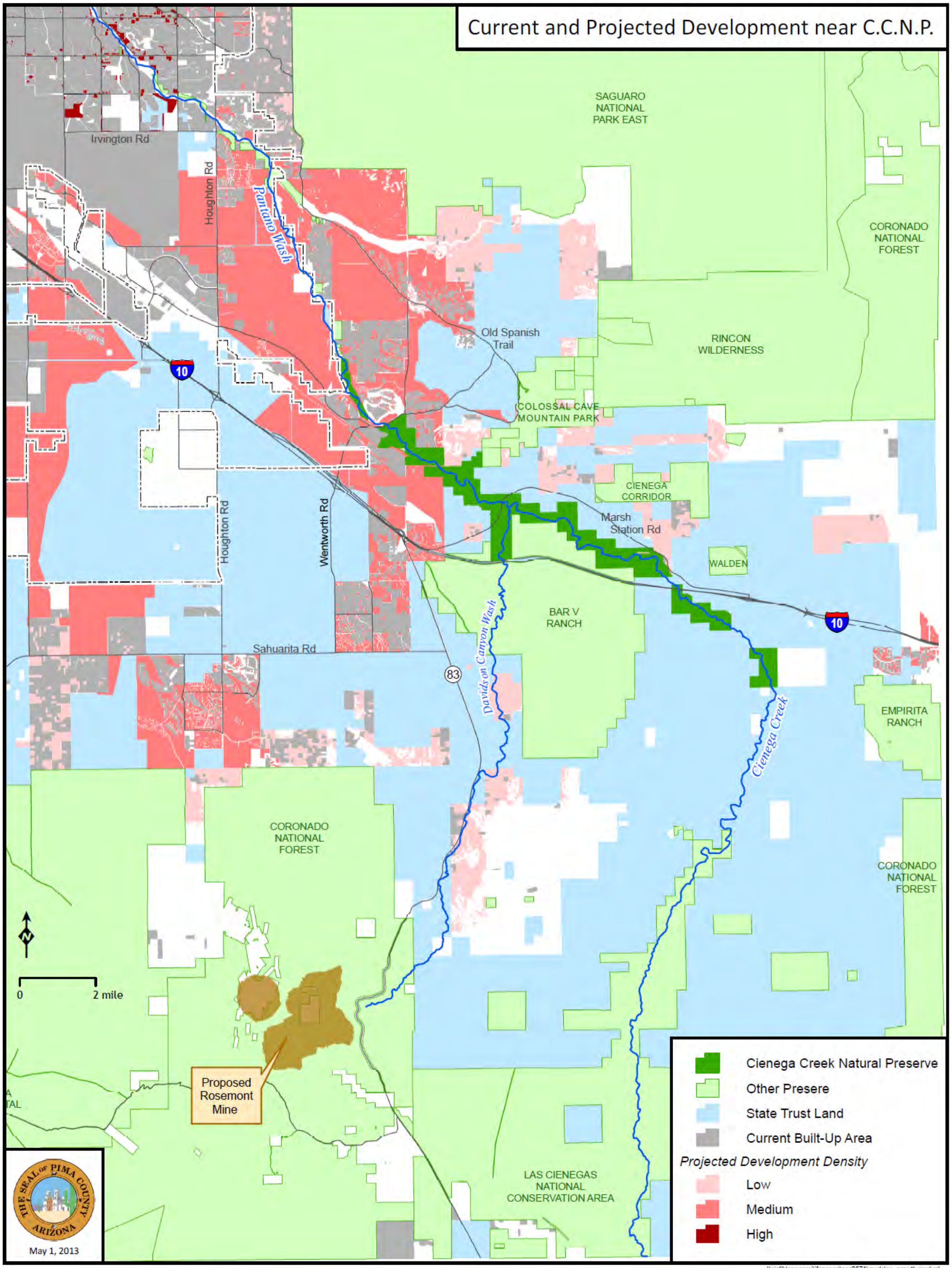
Commenter	Chapter	Section	Page	Line	Comment/Change requested
Carla Danforth	3	springs	31	20-21	Hydroriparian and Mesoriparian habitat are subject to the same regulations under the Pima County Floodplain Management Ordinance. No regulatory distinction is made between the two classes. These stream reaches have intermittent flow, a criteria of mesoriparian habitat. If an applicant seeks to amend the riparian classification, plant surveys and documentation will be required and is subject to Pima County review and approval to issuance of a Floodplain Use Permit (FPUP)
Carla Danforth	3	springs	31	28-29	These stream reaches have intermittent flow, a criterion of mesoriparian habitat.
Carla Danforth	3	springs	41	11-27	Monitoring to assess impacts to streamflow is incorporated into the mitigation plan but what measures will be taken to reduce impacts if monitoring shows negative impacts on stream flow and groundwater levels? Monitoring is not valuable unless measures are identified to be undertaken should monitoring data show negative impacts on resources.
Carla Danforth	3	springs	46-56	all	Given the large number of acres of riparian habitat and streams that will be impacted by the proposed actions, how and where can these impacts be adequately mitigated?
Carla Danforth	3 & Appx B	springs	56 & 58 21 (B)	29-30 & 14-20	If the surface water rights are transferred to an entity which allows the water to flow downstream of the dam, Del Lago Golf Course (current user of the surface water diverted from Cienega Creek) will need to find an alternative irrigation source. What will this alternative water source be? No plans exist for a reclaimed or CAP water line to be constructed to the golf course, have the effects on Cienega Creek of pumping a new well for golf course irrigation been analyzed? The water rights severance and transfer process is a lengthy legal process, which is likely to be protested, and the applicant has no guarantee it will occur. The amount of water physically available through the severing and transferring senior water rights for in-stream flow along Lower Cienega Creek is limited and decreasing, water rights do not equal wet water. The trend in streamflow of Cienega Creek is declining water levels, the median annual flow has decreased from 1.5 cfs to 0.4 cfs between 1984-2012 (Powell 2013). This declining flow due to climate change and the effects on the stream reach should be addressed in the FEIS.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Carla Danforth	3	springs	53-54	36-38/ 1-2	The FEIS states springs & seeps will be monitored to determine impacts due to dewatering of the regional aquifer in vicinity of the mine pit but does not state what actions will be taken if the water levels are negatively impacted..
Carla Danforth	3	springs	55	16-18	How will the enhancement of the Sana Cruz River near Sahuarita be accomplished and by whom?
Carla Danforth	3	springs			How will reintroduction of beaver into Cienega Creek offset “any” impact due to dewatering of the regional aquifer, offsets should be quantified. If flows are diverted into upper Cienega Creek how will the diversion affect the biologically rich reaches of lower Cienega Creek?
Carla Danforth	3 & Appx B	springs	57 & 35(B)	24-29	$2 million endowment is not sufficient to mitigate the large number of acres being impacted by the proposed actions. $2 million spread over 10 years will not finance many acres of mitigation. Restoration of functional streams and ecosystems is very costly, in the range of $80,000 – $200,000/acre or more including long-term monitoring and maintenance.
Carla Danforth	3	springs	4	9-17	Rosemont Copper has *“agreed to consider”* implementing mitigation measures? Shouldn’t all of these mitigation measures be a requirement of any permits issued to Rosemont Copper for the proposed actions?
Myers	3	Seeps, Springs, and Riparian	57		The AFEIS does not provide mitigation beyond monitoring springs in Barrel and Davidson Canyon (p 57). The AFEIS does not indicate what would be done to mitigate a reduction in flows at these specific springs. The creation of artificial sources in other areas is not a substitute. The AFEIS has failed to provide adequate mitigation for specific springs that may go dry due to the proposed project.
Myers	3	Seeps, Springs, and Riparian	8	8-10	The AFEIS has not considered isotope data as had been requested by Pima County in several previous filings. Isotope data for the springs would help to identify their source.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Myers	3	Seeps, Springs, and Riparian	General		This section discusses changes in ephemeral flows on the washes due to changes in topography around the mine site, as requested. However, the AFEIS does not discuss changes in recharge due to changes in ephemeral flow. Mountain front recharge is primarily the recharge of ephemeral runoff and should be considered as such. The AFEIS also has not considered how the changed location of recharge affects drawdown or pit refill, as requested by Pima County in previous comments.
Julia Fonseca	3	Springs	7	33-37	Illogical reasoning. Although perennial springs are likely to be fed by regional aquifer, it does not follow that a non-perennial spring is NOT related to the regional aquifer. In some areas, groundwater observations indicate that there have been declines in the regional aquifer, therefore cessation of flow at a nearby spring WOULD BE CONSISTENT with a connection to the aquifer.
Julia Fonseca	3	Springs	6	Table 106 and rest of the chapter	Your definition of ephemeral fails to take into consideration whether depth to groundwater is shallow. This is information that has been made available to the Forest and Corps through this EIS process, but the analysis in this chapter is very inconsistent with respect to the impacts that will have on the vegetation along ephemeral streams, which can be greatly influenced by the water table.
Julia Fonseca	3	Springs	2	1-6	I Some of the existing aquatic and riparian resources that are analyzed in this latest EIS are located in the Upper Santa Cruz basin (Tucson Active Management Area). The Tetratech groundwater model assumes that groundwater from the Upper Santa Cruz Basin can move from that area into the Cienega groundwater basin to fill the aquifer drawdowns that the mine would create around the pit. The analysis is made in this version of the EIS for some of the springs in the Upper Santa Cruz Basin, so the EIS contradicts the statement made here that the analysis remains absent and that there are no resources in the Upper Santa Cruz basin.
Julia Fonseca	3	Springs	1	NA	As a general comment, the discussion in the rest of the chapter does not live up to the definition of riparian that is on page 1. Functional values of ephemeral streams, in particular, receive scant discussion in the chapter. Most of the chapter focuses on perennial streams and hydromesoriparian vegetation.
Julia Fonseca	3	Springs	8	1-7	Discounting the standard industry practice of relying upon spring discharges as indication of the regional aquifer does not make sense in those Rosemont mine areas where the water-level elevation of the aquifer is known.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Spring	8	8-10	Why do you state that isotopic data have not made available? These data are posted on the Forest EIS website. See Montgomery and Associates 2009 Hydrogeologic Characterization.
Julia Fonseca	3	Spring	8, 10		The County's 2005 mapping considered shallow groundwater areas underlying riparian areas, to the extent they were known. Where it was known that shallow groundwater areas existed at the time of the classification, then the riparian areas above the shallow groundwater table were classified as hydromesoriparian, indicating their potential to support such vegetation, even if the vegetation did not exist at that time. It was not known until later that shallow water tables underlie part of the Rosemont waste-and-tailings disposal area.
Julia Fonseca	3	Spring	Table 108		What is the duration of the impacts? I saw the earlier discussion about near/far term and uncertainty, but it's unclear what time frame was used for this table.
Julia Fonseca	3	Spring	Table 108	Issue 3D.2	With reference to no action, the Assessment of Climate Change in the Southwest US Summary for Decision Makers by Jonathan Overpeck and others (2013) notes observed recent climate change includes reduced flows in four major drainage basins of the Southwest, and declines in river flow and soil moisture will continue.
Julia Fonseca	3	Spring	Table 108	Issue 3D.2	With reference to action alternatives, why do you predict no impacts? I disagree with the conclusion. Box Canyon, Box Canyon tributary called Sycamore on USGS topo, Barrel, Sycamore in Santa Cruz Basin, Adobe Tank Wash and Mulberry have intermittent flow reaches and are within 5 mile zone. Impacts to Box Canyon, in particular, were a topic of discussion at the third cooperator meeting on biological mitigation held July 24, 2012 and this was identified for follow-up by Forest Service personnel according to the meeting notes in the EIS references.
Julia Fonseca	3	Spring	Table 108	Issue 3D.2	With respect to the No Action alternative, the table says no impacts are predicted. Please reconsider the evidence for a declining baseline. PAG monitoring data show that the number of flowing stream miles and ground water levels along lower Cienega Creek and Davidson Canyon have been declining. See http://www.pagnet.org/Programs/EnvironmentalPlanning/Water/HydrologicResearch/CienegaCreekProjects/CienegaCreekHydrologicResearchandFindings/tabid/1012/Default.aspx.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Spring	Table 108	Issue 3D.3	With respect to the No Action alternative, the table says no lowering of the water table is predicted. There is a prediction that increased water demands in the Cienega groundwater basin could exceed the amount of groundwater discharged annually. See http://azconservation.org/downloads/sustainable_water_management_in_the_southwestern_united_states
Julia Fonseca	3	Spring	Table 108	Issue 4.1	With respect to the No Action Alternative, no loss of riparian areas is predicted due to disturbance. However, for the Pima County Multi-species Conservation Plan, we use a spatially explicit projection of where losses due to future residential and commercial development will occur. The attached excerpted figure for the Cienega-Rosemont vicinity shows that even without the mine, we expect impacts at the periphery of the National Forest and along the length of Davidson Canyon. This development projection, which is being used for a habitat conservation plan under the Endangered Species, should be taken into consideration in the EIS analyses of impacts to biological resources, including riparian areas. We can provide you the GIS data files so you can calculate how many acres of riparian or upland losses would occur in your area of analysis.
Julia Fonseca	3	Spring	Table 108	Issue 4.3	With respect to the No Action alternative, U. S. Geological Survey's Miguel Ponce has detecting some trends in vegetation in the entire Cienega Creek watershed that include the loss of riparian vegetation in the lowlands, and loss of woodlands in favor of grasslands at middle elevations of the Cienega Creek Watershed that have not been taken into account by this EIS No action alternative. Miguel Villareal has also provided me the attached photos showing the declining condition of riparian trees along Davidson Canyon. These repeated photos are part of a series of USGS photographs that go back decades, having been started by the Raymond Turner at USGS. The Forest Service and Corps should take advantage of the USGS information about riparian vegetation trends in this watershed.

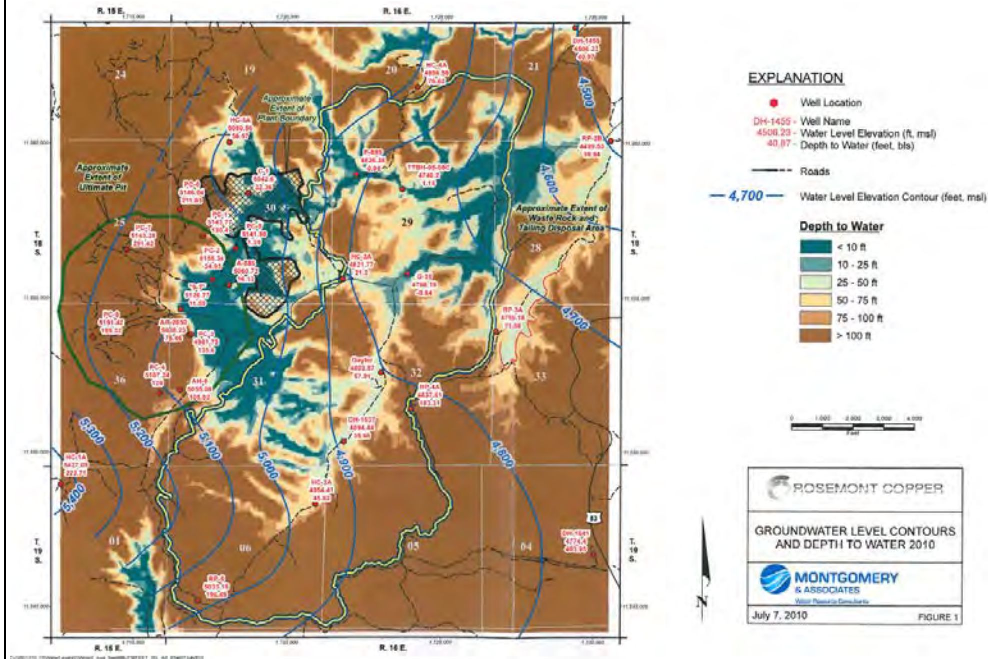

Current and Projected Development near C.C.N.P.
SAGUARO NATIONAL PARK EAST
CORONADO NATIONAL FOREST
RINCON WILDERNESS
Irvington Rd
Houghton Rd
Pantano Wash
Old Spanish Trail
COLOSSAL CAVE MOUNTAIN PARK
CIENEGA CORRIDOR
Marsh Station Rd
WALDEN
Houghton Rd
Wentworth Rd
10
BAR V RANCH
Davidson Canyon Wash
Sahuarita Rd
83
Cienega Creek
EMPIRITA RANCH
CORONADO NATIONAL FOREST
CORONADO NATIONAL FOREST
0
2 mile
Proposed Rosemont Mine
LAS CIENEGAS NATIONAL CONSERVATION AREA
Cienega Creek Natural Preserve
Other Presere
State Trust Land
Current Built-Up Area
Projected Development Density
Low
Medium
High
THE SEAL OF PIMA COUNTY ARIZONA
May 1, 2013

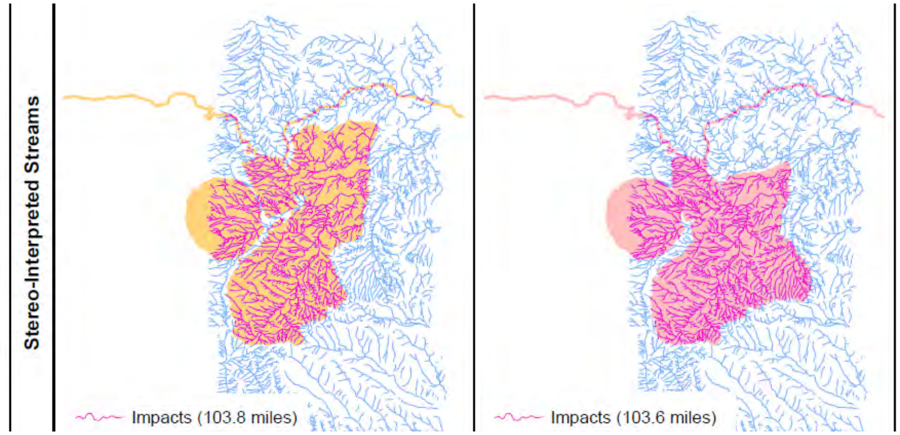
Photographs for comment from Julia Fonseca re: Table 108, Issue 4.3.

The first photo is from USGS Stake 41 in Davidson Canyon. This 2011 shows dead or moribund cottonwood and mesquite.

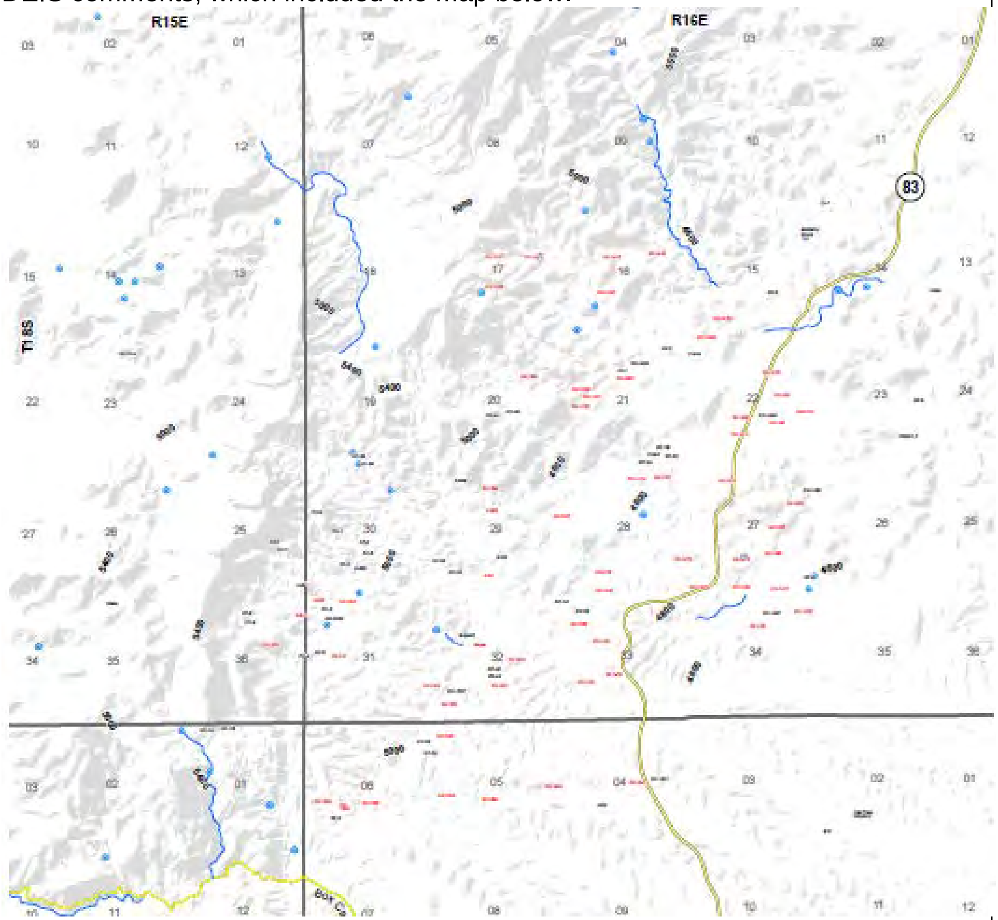
The second photo is from the same location but in 1994.

Julia Fonseca	3	Spring	NA	NA	Effects analysis does not take into account the impairments that failure of the stormwater controls will have. Pima County Flood Control has serious concerns about the ability of the stormwater controls to handle multi-day storms, and after closure there is no plan to maintain anything.
Julia Fonseca	3	Spring		39-40	Davidson Canyon has experienced declining groundwater conditions and declining length of intermittent flow from the evidence that PAG has gathered over the years. From Miguel Villareal's work, we see declining condition in riparian vegetation. The record supports the notion that whatever the complexity of the links, vegetation and streamflow has responded in a way that is consistent with the declines in the regional aquifer.
Julia Fonseca	3	Spring	NA	NA	As far as I can tell, the EIS does not address altered riparian processes like dissipation of energy, cycling of nutrients, removal of elements and compounds, retention of particulates, export of organic carbon and maintenance of animal communities. These would be needed for the Corps permit, at the minimum, but also for understanding other effects on the human environment.
Julia Fonseca	3	Spring	NA	Table 110	The footnote referring to the difference between the habitat designation and the field descriptions would not be necessary if WestLand understood the classification system.

Julia Fonseca	3	Spring	40		The belief that the shallow water table under Barrel is somehow separate from the rest of the aquifer and will not be affected by the drawdown seems speculative and unsupported by Montgomery and Associates mapping and interpretation.  Areas of shallow water table may be located in alluvial deposits, but they may be fed by fracture flow from older, underlying bedrock or consolidated basin fill units. There is evidence in the well data for upward gradients from older units.

Julia Fonseca	3	Spring	NA	NA	Neither the Springs Chapter nor the issues selected in Table 108 treat the functional values of the headwaters streams. Many first- and second-order streams are visible in an independently mapped stream delineation presented below and in our 2012 DEIS comments.  The MPO in orange at left, Preferred (Barrel) Alternative in pink at right. Although many of these headwater ephemeral streams were not included in the jurisdictional determinations of the U.S. Army Corp, the loss of their functional values should not be ignored in the FEIS. Over 100 miles of streams would be directly affected by the MPO, shown at left above. An equal number of stream-miles would be affected by the Forest's Preferred Alternative (Barrel), shown at right. To what degree will the new mine landform replace these functional values?
Julia Fonseca	3	Spring	31		Surface flow analysis fails to address evidence of intermittent flows reported by Westland in various years of surveying intermittent streams for leopard frogs occurrence.
Julia Fonseca	3	Spring	31	10-21	This discussion in the EIS reflects WestLand's misunderstanding of the County's classification and mapping.

Julia Fonseca	3	Spring	32		The No Action alternative discussion in the EIS ignores the evidence for declining baseline conditions in the area. Many intermittent to perennial springs and streams are currently dry or intermittently dry. Water tables that used to be shallow enough to support denser vegetation or hydromesoriparian vegetation are dropping, and the condition of this vegetation is declining in a consistent manner. Climate change projections, coupled with projected population growth and water use suggest that this trend will continue.
Julia Fonseca	3	Spring	Table 102		This Table and this EIS fail to analyze all intermittent streams within the analysis area. Where in the EIS can I find the rest of the intermittent streams analyzed?
Julia Fonseca	3	Spring	NA	NA	Has a Corps-approved functional/condition assessment been performed for this project? I did not see any information about this referenced. It would be a good source of information, if it were available.
Julia Fonseca	3	Spring	NA	NA	The Corps developed an hydrogeomorphic model that was used for six different locations in the Gila River basin, including the Santa Cruz watershed. Contact Kelly Burks-Cope at ERDC for more information.
Julia Fonseca	3	Spring	NA	NA	Please discuss any temporal losses of aquatic resource functions that could be caused by the permitted impacts and the replacement of aquatic resource functions at the compensatory mitigation site.
Julia Fonseca	3	Spring	NA	NA	Perhaps I missed it, but where do you draw conclusions about whether we are going to see an increase in tamarisk or other invasive non-native species affecting adjacent riparian areas because of the mine?
Julia Fonseca	3	Spring	1, 15		It really does not make sense to say on p. 1 that you are using the County maps because of their value in defining habitat corridors, and then on p. 15 to say that IRAs are not important. The reason that the Science Technical Advisory Team included the “important” riparian designation on top of some of the mapped polygons was to identify watercourses thought to be important for connectivity in that region. The IRA is not a meaningless regulatory definition of the County’s, it was developed with input from a broad array of professional biologists with field experience in our area, and it included at the time the first and only Coronado National Forest plant ecologist.

Julia Fonseca	3	Spring	NA	NA	You have the information on the distribution of more intermittent streams than are discussed in this chapter. On August 6, 2012, at your request, we transmitted to Melinda Roth and Chris Garrett our GIS files of intermittent streams and shallow groundwater areas. This should have been used in the analysis. See also 2012 DEIS comments, which included the map below.  This included new intermittent streams that were derived from information provided for the EIS process by Rosemont consultants, as well as the Barrel Canyon intermittent flow reach which was originally mapped by PAG (2000).

Julia Fonseca	3	Spring	6		How would the effects on intermittent streams affect their values for landscape connectivity?
Julia Fonseca	3	Spring	NA	NA	The EIS does not disclose impacts to Box Canyon, which is an important Forest resource identified in the Forest Plan. It should continue to be managed for the unique wildlife and vegetative resources per the current Forest plan.
Julia Fonseca	3	Spring	6	Barrel 2	Barrel Canyon 2 has an intermittent flow reach within the area you classify as ephemeral. See PAG (2000) report that we transmitted on August 6, 2012 to Melinda Roth and Chris Garrett of streams and shallow groundwater areas—this report indicates an intermittent flow reach occurred on Barrel Canyon. This reported reach was based on field observations by PAG staff and US Forest Service RASES, which are riparian assessments provided by USFS for the Sonoran Desert Conservation Plan.
Julia Fonseca	3	Spring	11-14		I support the use of the referenced sources. This is a good general description of the relationships among hydrological variables and riparian vegetation response for perennial and intermittent streams with a shallow water table.
Julia Fonseca	3	Spring	12	Table 107	There are a few parts of table 107 that do not conform with the cited reference, for instance stem density of Goodding's willow did correlate with permanence whereas cottonwood did not, and mesic competitor tree basal area did not correlate with permanence
Julia Fonseca	Appendix B	Springs	21	FS-SSR-01	As written, this measure depends on the cooperation of Pima County Regional Flood Control District with respect to the severance and transfer to areas within the Preserve. Likewise, the measure also depends on the willingness of other agencies to accept the transfer, whether it is protested, and whether ADWR will grant the in stream flow.
Julia Fonseca	Appendix B	Springs	NA	NA	Rosemont also holds an option to acquire a diversion dam and a well site, totaling some two acres in size that is next to Cienega Creek. Forbidding that this wellsite ever be pumped would remove or prevent the decline of the aquatic resource due to the threat of pumping the well. This is a mitigation measure that does not depend on any agreement with Pima County, and should be considered a pre-requisite to any other type of mitigation involving the water rights at the dam.
Julia Fonseca	Appendix B	Springs	41	FS-BR-24	Please describe the thresholds that Forest will use for determining NEPA compliance. I can't tell what is meant by this phrase.

Julia Fonseca	Appendix B	Springs	53		Please disclose how the level of uncertainty of impacts that was described in the text will be dealt with ensuring the mandatory mitigation measures are effective. I see that there will be monitoring, but it does not address how they will be used to ensure mitigation is effective.
Julia Fonseca	3	Springs	58	14-20	Proposals to sever and transfer could be protested. Our experience has been that ADWR does not act on protested proposals. I am unaware of any successful sever-and-transfers to in-stream flow; SRP has been waiting for years for ADWR to approve theirs on the San Pedro,. These are facts which must be disclosed in the EIS.
Julia Fonseca	3	Springs	54		This cumulative effects analysis only considered other proposed projects. Doesn't really take into account cumulative effects of past and present actions that have already degraded the riparian environment in the analysis area, nor does it take into consideration the reasonably foreseeable actions of Pima County in terms of future development (see previous comment).
Julia Fonseca	3	Springs	54		The Andrada mine is included but not the one in Davidson Canyon proper? I don't understand the omission.
Julia Fonseca	3	Springs	54		What about the ADOT improvements to SR83 and their impacts to Davidson?
Julia Fonseca	3	Springs	57	30-34	Why can't monitoring results be used to make mitigation more effective by including responsive management measures?
Julia Fonseca	3	Springs	58	25-29	Why can't monitoring results be used to make mitigation more effective by including responsive management measures?
Julia Fonseca	3	Springs	58	9-10	Says Conservation Easements but I saw restrictive covenants in the Appendix B? RCs are much less effective.
Julia Fonseca	3	Springs	58	14-20	This discussion does not acknowledge the uncertain outcome. SRP has been trying to sever-and-transfer to instream flow as a mitigation measure on the San Pedro, and the state has yet to approve such a measure. I'd love to see ADWR move ahead with type of action, but the record to support this as an effective mitigation measure is not yet established.
Julia Fonseca	3	Springs	58	18-19	I've heard Westland and Rosemont refer to legal obstacles on Upper Cienega Creek. The sever-and-transfer does not resolve legal obstacles on lower Cienega Creek. I think you should confirm with BLM that there are legal obstacles on Upper Cienega Creek, if you have not already done so.
Julia Fonseca	3	Springs	58	18-20	Placing this statement in the same paragraph as the sever-and-transfer is confusing the two different strategies.

Julia Fonseca	3	Springs	57-58		Need to clarify in the final version which are mandatory and which are not, and what the relationships are between BO and Corps decisions.
Julia Fonseca	Appendix B	Springs	24	FS-WUS-01	A conservation easement with a third party beneficiary is a more effective conservation measure than a restrictive covenant because there is monitoring and rights of enforcement, and often an endowment for stewardship. If a restrictive covenant is used, there should be an endowment established for monitoring, and provisions for enforcement. EIS should either provide these additional features or acknowledge the deficiencies of a restrictive covenant.
Julia Fonseca	3	Springs	NA	NA	What are the effects, duration of effects, and mitigation with respect to Traditional Cultural Property values? Or is that dealt with somewhere else?
Julia Fonseca	3	RC-SW-01			Stream gage will not be useful for monitoring intermittent along Barrel, because most of the intermittent reach of Barrel Canyon is downstream of the gage. But it could be useful for understanding the overall volume and magnitude of flow. The mitigation measure should disclose what data will be collected here. There is a big difference between operating this as a crest-stage gage, a bubbler, or a water quality sampling site, etc.
Postillion	3	Seeps, Springs etc.	16	16	Upper and Lower Cienega Creek and Davidson Canyon needs to be correlated to the Reaches defined in Table 106, p.6 and Figure67, p.5. All one can do is assume that Cienega Creek 1,2 and 3 is upper Cienega and Cienega 4 and 5 is Lower Cienega; Davidson 1 &2 is upper Davidson and Davidson 3 is Lower Davidson. That assumption may be incorrect unless the document correlates the terminology.
Postillion	3	Seeps, Springs etc.	16	14	“All three reaches” needs to be defined. Cienega Creek has 5 reaches and Davidson has 4,. According to Table 106, p.6.
Postillion	3	Seeps, Springs etc	33	35-36	The last sentence leaves one hanging and begs the question: Why would this be any different from short-term results? The models are using the same data but just projecting further out in time. More explanation is needed to discuss the reasoning behind this statement. The sentence may imply that short-term data is also speculative because of the models' inherent uncertainties with dealing in fractured bedrock, fissures and other non-Basin groundwater issues.
Postillion	3	Seeps Springs, etc	34	36-39	This is an admission of an omission. Clearly the contribution of Empire Gulch stream flow is an appreciable amount and no work has been done to estimate that amount. This needs to be rectified by evaluation and analysis to estimate the loss in stream flow to Upper Cienega Creek by impacts of the Mine activities on Empire Gulch.

Postillion	3	Seeps, Springs, etc	36	36	Catalo does a survey of the entire United States! This reference is misquoted and unacceptable first, and second it should reference watersheds closer to the Davidson watershed. Not sure where the reference to 17,000AF/mi was, but it appears incorrect. Table 3, p.31 of Catalo,2004 references transmission losses from tributaries to the Tucson Basin (Burkam, 1970) and this is another omission. Tributaries to Patano (sic) Wash, more characteristic of the Davidson were estimated at 43-49 AF/mile/yr and 31-57% of transmission loss as percentage of upstream flow (Table 3, p.32).
Postillion	3	Seeps, Springs, etc	36	37-39	Another omission is the lack of discussion of subflow. Even if the upstream Barrel Canyon contribution from stream flow is recharged, that water continues to move along the shallow alluvium downstream and contributes to the subsurface alluvial water movement into Davidson Canyon. Some of that water may be captured by meso-riparian plants, but most will travel along the alluvial-bedrock interface downstream. Any lost available surface water due to mining activities is a loss to Davidson Canyon and springs/seeps, and should not be down played by this transmission loss discussion.
Postillion	3	Seeps, Springs, etc	37	1	Again, this discussion downplays the effect of alluvial subflow and should not be added. Discussion of subflow is an omission and needs rectification. The lateral movement of upstream recharged water because of the hydraulic gradients and sub-surface bedrock underlying the shallow alluvium in Barrel and Davidson mean it will move downstream subsurface and eventually contribute to base flow and springs.
Postillion	3	Seeps, Springs, etc	42	1-2	Table 111. Two Criteria appear problematic: Riparian Vegetation and Subflow, and they are related. The reduction of surface flow from Barrel Canyon and the mine are quantified reductions and adds to the cumulative reduction in subsurface flow, gradients and thus the amount of water reaching an already diminishing base flow in Cienega Creek. To say these impacts are “muted” is unclear and obfuscatory. Bottom line is the Davidson Canyon subflow will be affected based on the estimated reduction in flow permanently intercepted by the mine. Less water WILL be unavailable to riparian vegetation as it moves subsurface in the alluvial aquifer. This obfuscatory language must be removed. Effects are cumulative from upper to lower watershed and propagate downstream.
Postillion	3	Seeps, Springs, etc	56	34-35	The well near the Pantano Dam is currently a monitor well. It has not been equipped and pumped for many decades. Please rephrase indicating that the retirement of the pumping rights would occur for this inactive well.

Postillion	3	Seeps, Springs, etc	57	30-34	Monitoring is a good thing to assess the impacts from pit dewatering to downstream wells and vegetation. However, a mitigation opportunity overlooked is the ability of the mine to take the 18,000-26,000AF (900-1300AF/yr) dewatered from the pit and discharge it downstream to replenish the water that would have eventually gone downgradient to begin with. This water would also help to mitigate for the reduction in surface water recharge due to mining activities. It is understood that the pit water would have to be monitored for water quality. But if the report such as Tetra Tech's (2010b) geochemical model predicts, the quality should meet water quality standards. This mitigation is truly mitigation at the area of hydrologic impact. The mitigation would also provide propagative effects farther downstream in the Davidson Canyon watershed to help compensate for an already significantly decreased base flow and contribution to Cienega Creek.
Julia Fonseca	3	Springs	NA	NA	The idea of consolidating analysis of riparian effects into a single chapter is a good change from 2011 DEIS.
Julia Fonseca	3	Springs	1	23	I agree that the use of the Pima County riparian maps for this EIS is appropriate, as compared to the maps used in the 2011 DEIS.
Julia Fonseca	3	Seeps and Springs			This analysis should take into account that the ecological and recreational significance of Cienega Creek is amplified because it is one of a very few remaining examples of a desert riparian environment. Environments of this type once paralleled many of the water courses and drainages in southern Arizona such as the Santa Cruz River near Tucson. During the past century, the extent of these riparian areas has been greatly reduced.

DOCUMENT REVIEW COMMENT FORM—REQUIRED DISCLOSURE

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Akitsu Kimoto	Chapter 3	Required Disclosures	2	11-15	"Desert washes in the footprint of the pit, tailings facility, and…..(P.2, L11-15)" should be mentioned in Chapter 3, Surface Water Quantity.
Akitsu Kimoto	Chapter 3	Required Disclosures	8	12-16	"With respect to surface water quality, the resources that…" should be mentioned in Chapter 3, Surface Water Quality.
Julia Fonseca	3	Required Disclosures	1	Geology	EIS fails to disclose that the proposed short-term uses would provide largely for the mineral interests of other nations due to off-take agreements and other financial obligations. This section should address the availability of mineral for future generations of Americans.
Julia Fonseca	3	Required Disclosure	2	Groundwater Quantity, Surface Water Quantity	Says what the impacts are, but fails to address what this means to future generations of Americans or even residents.
Julia Fonseca	3	Required Disclosure	2	Groundwater Quantity	Line 7-8 beginning "Pumping…" is unclear as to reference. You mean pumping on which side of the mountain? There is pumping on both sides.
Linda Mayro	3	Required Disclosures Biological Resources	2	24 - 25	Impacts to wildlife and habitat will be permanent. Reclamation is not likely to allow habitat to reestablish itself to pre-mine conditions.
Linda Mayro	3	Required Disclosures Cultural Resources	3	10 -14	Desecration and permanent loss of sacred sites is not disclosed.

DOCUMENT REVIEW COMMENT FORM—SOCIOECONOMICS

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Craig Horn	3	Socioeconomics	51	2 - 4	The cited $3.5 million annual direct local property taxes paid by the company dates to a reference in the *Rosemont Copper Project Feasibility Study*, Volume 1, August 2007, which noted this tax amount was based on "a study performed by Donald Ross Consulting." The same $3.5 million annual property tax projection has been used in all economic impact analyses, even though Arizona subsequently decreased the property tax assessment ratio for mining from 24% (in 2007) to 20% (in 2011 and 2012). Beginning with 2013, the assessment ratio for mining will further decrease by 0.5% each year until it reaches 18% in 2016. With a lower assessment ratio (i.e., a decreased taxable value for the mine), actual property tax revenues collected by local governments and school districts would be only 75% of the amount cited in the economic impact analyses and accepted by the USFS.
Craig Horn	3	Socioeconomics	47 51	30 – 32 14 - 17	On Page 47, USFS concludes employment would have "minimal demands on the local housing supply during the operational phase of the mine" because the number of employees would be far below the number of vacant housing units in the study area. This conclusion, which could very well be accurate, implies there will be no (or little in the way of) new property tax revenue collected by local governments and school districts because the necessary housing stock to support mining operations already exists and is already being taxed. Indirect Revenue Impacts of $107.6 million from the Applied Economics study are cited on Page 51. Property tax revenues collected by local governments and school districts comprise $58.19 million of the $107.6 million. Based on the USFS conclusion that essentially all needed housing already exists, the $58.19 million of local property tax revenue reported by Applied Economics would not represent new, additional property taxes from new housing construction. Instead, this would be the amount of taxes paid by direct, indirect and induced employees who live in already existing homes and apartments. Thus, the overall tax revenue impact associated with mining operations is actually less than the impact amount reported by Applied Economics, as the term "impact" means this is new, additional revenue that would not exist without the project being analyzed.

J. Crowe	3	Socioeconomics and Environmental Justice	63	1	This section, in general, does a poor job of identifying and determining the costs of roadway impacts resulting from the project. Specifically, it fails to list the cost to Pima County taxpayers of public roadway improvements, repairs, maintenance, and replacement that will be required as a result of this project. Besides State Route 83, impacts are anticipated on County roadways such as Sahuarita Road and Santa Rita Road, which will provide secondary access to the project. All affected roadways should be listed and costs estimated for project-related roadway costs. Specifically, costs for required roadway improvements should be distinguished from roadway maintenance costs.
J. Crowe	3	Socioeconomics and Environmental Justice	63	1	This section documents known historical roadway maintenance costs, but it fails to also estimate *future* roadway maintenance costs which will likely exceed historical expenditures. Future maintenance costs should be estimated and provided.
J. Crowe	3	Socioeconomics and Environmental Justice	63	1	This section fails to include the costs of required roadway improvements such as turning and passing lanes, shoulder stabilization and paving, and pavement overlay. This cost information can and should be provided. Pima County estimates the cost of constructing truck lanes along State Route 83 to be as much as $13 million.
J. Crowe	3	Socioeconomics and Environmental Justice	63	1	The report states that “damages resulting from … (heavy truck traffic) … would be difficult to quantify”, but roadway maintenance costs can be estimated. Pima County estimates that a structural overlay of all affected roadways would cost as much as $14.6 million. A mitigation measure of simply “conducting a baseline analysis of road conditions along State Route 83” is wholly inadequate and is only the first step in providing roadway mitigation for the project.
J. Crowe	3	Socioeconomics and Environmental Justice	63	1	Gas tax revenues are stated as a way of paying for required roadway improvements and maintenance. However, gas tax revenues alone resulting from vehicle fuel purchases will be wholly inadequate to pay for all roadway improvements and maintenance as required for this project. Gas tax revenues from project-related truck traffic and vanpools should be estimated and then compared to anticipated roadway expenditures described in the comments above. Unless the project sponsor agrees to pay the full cost of required roadway improvements, the burden will be shifted to Pima County taxpayers to pay for needed roadway improvements and maintenance that will occur during the lifetime of the project.

Chavez	Chapter 3-Socioeconomics	Table 238-Potential environmental justice impacts	70	Water Quantity	The FEIS states there would be an adverse impact to water quantity, but no disproportionate impact because wells experiencing drawdown would not extend to environmental justice communities. We disagree. Many well owners experiencing the impacts of drawdown would be affected. Potential impacts of the projected drawdown to the Tohono O'odham Nation are not adequately addressed.

DOCUMENT REVIEW COMMENT FORM—HAZARDOUS MATERIALS

Commenter	Chapter	Section	Page	Line	Comment/Change requested
John Wisner	3-Hazardous Materials	Table 156	6	19	Add: 40 CFR 300 to 313 – Emergency Planning & Community Right-to-Know Act…The commodities and quantities fall under these additional sections.
John Wisner	3-Hazardous Materials		7 & 29		NO mention is made of the following items during a Potential Release: Notifications-on & off site (including the Local Emergency Planning Committee (via Pima County OEM) & the National Response Center; Activation of Response Teams-facility or local responders; creation & activation of a Facility Emergency Response Plan and Hazardous Waste Plan; means to alert the Public & employees of a release;
John Wisner	3-Hazardous Materials		25	7	Potential Releases within the mine: no mention of any detection systems to be in place to detect & report a release of a hazardous material at the mine.
John Wisner	3-Hazardous Materials		7	27.5	6. Appropriate annual reporting of hazardous materials and hazardous waste on-site. NOTE: This information is used in Community Planning for Emergencies.
John Wisner	3-Public Health		22	41	Pima County Office of Emergency Management, Local Emergency Planning Committee, Fire Chief's Association & Sheriff Department should be included in the planning process for the response plans, at least for review and comment, indicated in this section along with additional plans required by law, statute and local ordinances.

DOCUMENT REVIEW COMMENT FORM—TRANSPORTATION

Commenter	Chapter	Section	Page	Line	Comment/Change requested
J. Crowe	3	Transportation/Access	1	8	The FEIS fails to present any quantified discussion of impacts to Santa Rita Road, yet this Pima County maintained unpaved road is planned to be used as a secondary access to the project site.
J. Crowe	3	Transportation/Access	1	14	The FEIS fails to present any quantified discussion of impacts to Sahuarita Road, yet this Pima County maintained road is the most direct access from any points south of downtown Tucson. This road will serve as a key secondary access road to the project site.
J. Crowe	3	Transportation/Access	9	1	The FEIS fails to provide any quantitative discussion of potential usage or impacts from traffic generated by the proposed project on Sahuarita Road, a Pima County-maintained paved roadway classified as a Rural Principal Arterial under USDOT / FHWA criteria.
J. Crowe	3	Transportation/Access	13	15, 37	Lines 14-15 state that heavy-duty vehicles account for 6-12 percent of the traffic load according to the manual counts, but lines 37-38 state that heavy-duty vehicles account for only 4 per cent of the traffic load according to the ADOT counts. This is a difference of 50 to 200 per cent – which is correct? An accurate presentation of the heavy truck component is critical to subsequent discussions of the comparative increase in heavy trucks generated by the proposed project both during construction and operations. Heavy trucks are a key component of level of service, highway safety and traffic noise analysis.
J. Crowe	3	Transportation/Access	14	3	The FEIS fails to provide any traffic data on Sahuarita Road and Santa Rita Road, which will carry project traffic.
J. Crowe	3	Transportation/Access	14	3	The FEIS fails to provide any traffic counts nor level of service data for SR 83 from the proposed mine entrance north to I-10, where the majority of mine traffic is expected to travel.
J. Crowe	3	Transportation/Access	17	19	The *Highway Capacity Manual* states "…all grades of 3 percent or more with a length of 0.6 mi or more must be analyzed as specific upgrades or downgrades" (page 20-1, *Highway Capacity Manual 2000*). State Route 83 in the vicinity of Greaterville road meets the conditions of this restriction but there is no indication that such an analysis was made. There is no discussion of how the variations in conditions along the segments were averaged into a single value applicable to miles of roadway.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
J. Crowe	3	Transportation/Access	19	20	The FEIS fails to include any discussion of bicyclists and pedestrians which are both common and legal modes on S.R. 83 and all other public roadways except the controlled access portions of I-10. Bicyclists present special issues for level of service (overtaking and passing) and safety.
J. Crowe	3	Transportation/Access	19	20	The FEIS fails to disclose that the Vail School bus turn around at milepost 46.9 on SR 83 is immediately south of the proposed Rosemont Copper primary access road at milepost 46.82. The fact that both school busses and heavy truck traffic converge at this one location increases the potential for school bus and mine truck conflicts. The FEIS fails to address this potential conflict or suggest possible mitigation measures to ensure safety.
J. Crowe	3	Transportation/Access	19	20	The FEIS fails to address how the increased number of heavy trucks traveling to and from the mine site will impact the safety of school busses stopping within the travel lanes of SR 83. Neither does the FEIS address how school busses stopping will affect level of service under increased mine traffic.
J. Crowe	3	Transportation/Access	21	30	Table 169 states that all 1,250 workers will commute in 37 buses. How will this be organized and enforced? If not required, there will be much more commuter traffic using SR 83 and local roadways and the traffic impacts would be much greater than what was assumed for the traffic impact analysis.
J. Crowe	3	Transportation/Access	23	34	Although it is impossible to predict how much commuter and mine-related traffic will use Sahuarita Road, it is highly likely that some traffic will use this route because it is the closest arterial roadway to the proposed mine. It provides the most direct access to Green Valley, Sahuarita and southern Tucson. The current pavement condition is poor so any additional traffic will further deteriorate this roadway and accelerate the need for improvements.
J. Crowe	3	Transportation/Access	26	1	There is no discussion of level of service impacts on roadways under the jurisdiction of Pima County (Sahuarita Road, Santa Rita Road, and Valencia Road adjacent to the Port of Tucson which will have increased traffic, especially heavy trucks, due to Rosemont mine construction and operations.
J. Crowe	3	Transportation/Access	28	19	The secondary access road connection to Santa Rita Road will require a Right-of Way Permit from Pima County. A similar permit or permits would be required for any utility facilities that are located within the Santa Rita Road right-of-way.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
J. Crowe	3	Transportation/Access	30	16	The FEIS states that during construction of the mine as many as 1,250 workers will be bussed to the site (37 busses) from staging areas along I-10 or in Sonoita. Where will these "staging areas" (parking lots) be located, will they involve permitting (ADOT, local jurisdictions), and will they disturb new ground not accounted for in the FEIS? Construction is stated to occur in one shift; what will be the impacts on State Route 83 traffic and level of service from the platoons of busses headed to the mine at about the same time? If the busses leave the project site after delivering workers there will be up to 148 additional bus trips per day on S.R. 83. at the height of the construction activity. This is not addressed in the FEIS.
J. Crowe	3	Transportation/Access	30	24	The 100-150 estimated daily heavy truck traffic during the 20 year mine production life will have a greater impact on level of service on State Route 83 and other affected roadways than the simple number would indicate. How are the effects of heavy vehicles in the traffic stream taken into account in the estimation of level of service impacts?
J. Crowe	3	Transportation/Access	32	20	This section fails to address impacts to bicyclists and pedestrians, both common on S.R. 83, especially in relation to safety, overtaking and passing and the increase in truck traffic.
J. Crowe	3	Transportation/Access	32	12	If copper concentrate is shipped via rail to Nogales, the projected train traffic would impact several Pima County at-grade roadway crossings including Hughes Access Road, Old Vail Connection Road, and Whitehouse Canyon Road. These impacts have not been addressed.
J. Crowe	3	Transportation/Access	34	31	Constructing bus pullouts would not improve traffic flow because school children may still need to cross the street to board or depart the bus. Given the additional truck traffic, school children may require the bus to stop traffic so that they can safely cross the street. The bus pullouts will therefore not improve student safety.
J. Crowe	3	Transportation/Access	34	39	The proposed mitigation measure requiring truck traffic to avoid times of high commuter or school bus traffic conflicts with the statement on page 31 line 4 that "the largest volume of mine traffic…would occur…between 6-8 a.m. …" This timeframe coincides with school bus traffic and morning peak hour traffic. How would this measure be accomplished?

DOCUMENT REVIEW COMMENT FORM—ENVIRONMENTAL JUSTICE

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Leslie Nixon	3	Environ mental Justice	43 68 69, Table 238	14-17 31-36	The archeological/cultural resources mitigation plan is incomplete. The Draft Final EIS recognizes the mining project creates a disparate negative impact on the Tohono O'odham Nation "and other tribes" The Native tribes expressed concern about potential impacts of the project on ancestral villages, human remains, sacred sites, and traditional resource collecting areas. In response, the DFEIS presents an archeological and cultural resources mitigation and monitoring plan. However the DFEIS concludes that the mitigation plan is unlikely to "relieve the disproportionality of the impacts to the Tohono O'odham Nation" or other consulting tribes. No additional mitigation is explored or proposed which might relieve this disparity in whole or in part. This could include relocation of structures, modification of the project, or financial mitigation. The potentially serious cultural damage to two of the three protected groups merits this additional consideration and planning.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Leslie Nixon	3	Environmental justice	68-69, Table 238		Other than the archeological/cultural resource impact described above, the DFEIS includes no recognition or mitigation of any additional potential disproportionate impacts to the environmental justice communities of the TO Nation, Pascua Yaqui Tribe, or Hispanic residents of Santa Cruz County. By definition, these communities are economically disadvantaged, with inadequate housing, insufficient employment opportunities, a high rate of single parent families, and lower educational achievement. Sociologists, health care agencies, government, and social service providers recognize that environmental conditions have a more serious impact on the poor than on more affluent citizens due to fewer resources, less mobility, inadequate job training and education options, and minimal political influence on policymakers. These factors are relevant to the environmental justice evaluation in this case, specifically because the three protected groups share the following characteristics -less mobility due to fewer resources (cannot move away from community with increased air pollution) -minimal or no health insurance (wait until environmentally caused illness, e.g., asthma, is serious before seeking medical care; less resources to purchase medication) -poor access to adequate education and job training (more vulnerable to employment supply fluctuations, such as loss of tourist and recreation jobs) -ineffective political influence to obtain government remediation (road repair for damage caused by mining trucks) These examples demonstrate the fallacy of the conclusion that the three protected communities will suffer no exceptional negative consequences from the mine project other than the archeological impact on the Tohono O'odham Nation and Pascua Yaqui Tribe The DFEIS's failure to address these disproportionate impacts renders this section of the DFEIS insufficient under the Environmental Justice Executive Order.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Leslie Nixon	3	Environ mental justice	39	28,31-32	In spite of Pima County's comments to the Draft EIS, the DFEIS omits any strategy to satisfy the "meaningful involvement" legal standard, which mandates that environmental justice communities merit special outreach efforts in order to ensure they are active stakeholders regarding conditions which will impact their families and communities. In Pima County's previous comments, the following were suggested as appropriate examples of outreach to the protected classes: -small local meetings chaired by community leaders -workshops with participants selected from the protected groups -use of local media (e.g., monthly newsletters or newspapers) -attendance and participation at the impacted community's events and gatherings It may seem expeditious to move forward on a project without comprehensive community participation and the complications and delays that may arise. Historically, however, the failure to effectively integrate impacted low income and minority groups in the EIS process has resulted in alienation of the communities, incomplete and ineffective environmental impact statements, and expensive and protracted litigation. The DFEIS should not move forward without remedying this situation.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Leslie Nixon	3	Environ mental Justice	43 68 69, Table 238	14-17 31-36	The archeological/cultural resources mitigation plan is incomplete. The Draft Final EIS recognizes the mining project creates a disparate negative impact on the Tohono O'odham Nation "and other tribes" The Native tribes expressed concern about potential impacts of the project on ancestral villages, human remains, sacred sites, and traditional resource collecting areas. In response, the DFEIS presents an archeological and cultural resources mitigation and monitoring plan. However the DFEIS concludes that the mitigation plan is unlikely to "relieve the disproportionality of the impacts to the Tohono O'odham Nation" or other consulting tribes. No additional mitigation is explored or proposed which might relieve this disparity in whole or in part. This could include relocation of structures, modification of the project, or financial mitigation. The potentially serious cultural damage to two of the three protected groups merits this additional consideration and planning.

DOCUMENT REVIEW COMMENT FORM—PUBLIC HEALTH AND SAFETY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
J. Crowe	3	Public Health and Safety	4	27	Table 192, Issue 10.5 fails to mention the anticipated increase in traffic-related deaths and injuries that are predicted to occur on area public roadways as a direct result of project -related traffic. The DEIS indicated that fatal traffic deaths are expected to increase from once every three years to between three to six deaths every three years with the project (see DEIS page 652).
J. Crowe	3	Public Health and Safety	4	27	The statement in Table 192 that hazardous material spills during transport would only affect a radius of up to 0.5 mile and 1.0 mile for explosives is false – the affected radius could be as much as 25 miles and involve a detour of more than 50 miles. Any hazardous material spill as described on a highway would close the road or highway. The effect will propagate back to the available detour routes. The magnitude of a diversion will depend on the duration and the location of event on the highway. For example, in the case of an event on Sonoita Highway north of the proposed mine entrance; the detour routes are south on S.R. 83 to S.R. 82 (Sonoita), to S.R. 90, to I-10 (Benson), or south on S.R. 83 to S.R. 82, to I-19 (Nogales), to I-10 (Tucson). Either route entails a distance in excess of 50 miles. An event or crash at the S. R. 83 / I-10 interchange could potentially propagate over several states.
J. Crowe	3	Public Health and Safety	18	28	The report fails to mention that the nearest fire station to the mine site is over 10 miles away (near the junction of I-10 and SR 83). Any hazardous spill response on or adjacent to State Route 83 will be compromised by this distance.
J. Crowe	3	Public Health and Safety	18	28	The discussion of hazardous material spills during transport fails to include any mention of roadway closures and traffic impacts that could result from a roadway spill. With an estimated 32 trips per day of hazardous materials, the possibility of a spill appears to be significant. The referenced emergency response guidelines are insufficient and inadequate to address roadway and transportation impacts resulting from a spill.
J. Crowe	3	Public Health and Safety	23	42	There is no mention of truck passing lanes for safety mitigation. Given the expected increase in traffic deaths and “substandard tight, horizontal curves” on State Route 83, widening the roadway shoulders and providing truck-passing lanes should be proposed to address the anticipated increase in traffic deaths and accidents and in particular the need for truck passing lanes between mileposts 44 and 46.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Julia Fonseca	3	Public Health	7		Pima County has a responsibility to the citizens to abate public nuisances, sources of filth and causes of sickness under our health authority. ARS 36-602 is the statute that would apply where groundwater essential for domestic cleanliness and drinking water purposes is no longer available or polluted. 36-602. Abatement of nuisances, sources of filth and causes of sickness; civil penalty; property assessment; procedure A. Notwithstanding any other provision of this title, when a nuisance, source of filth or cause of sickness exists on private property, the county board of health, the local health department, the county environmental department or the public health service district shall order the owner or occupant to remove it within twenty-four hours at the expense of the owner or occupant. The order may be delivered to the owner or occupant personally, or left at the owner or occupant's usual place of abode or served on the owner or occupant in the same manner as provided for service of process under the Arizona rules of civil procedure. If the order is not complied with, the board or department may impose a civil penalty pursuant to section 36-183.04 and shall cause the nuisance, source of filth or cause of sickness to be removed, and expenses of removal shall be paid by the owner, occupant or other person who caused the nuisance, source of filth or cause of sickness. B. A city or county may prescribe by sanitary ordinance or regulation a procedure for making the actual cost of this removal or abatement, including the actual costs of any additional inspection and other incidental costs in connection with the removal or abatement, an assessment on the lots and tracts of land on which the nuisance, source of filth or cause of sickness was abated or removed, subject to the following: 1. Any such ordinance or regulation shall include a provision for appeal of the assessment to the governing body or the board of supervisors or its designee. 2. The assessment, from the date of its recording in the office of the county recorder in the county where the lot or tract of land is located, is a lien on the lot or tract of land until paid. 3. Any assessment recorded is prior and superior to all other liens, obligations or other encumbrances, except liens for general taxes and prior recorded mortgages. 4. The city or county may bring an action to enforce the lien in the superior court in the county in which the property is located at any time after the recording of the assessment, but failure to enforce the lien by this action does not affect its validity.

DOCUMENT REVIEW COMMENT FORM — AIR QUALITY

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	2	Introduction	1	7	This should state '…Federal, State, and local laws and regulations.'
Sarah Walters	2	Introduction	1	14	"project area" - Linear water and electricity utility corridors, new roads, and modification of existing roads (including improvements to SR 83 required by AZ Department of Transportation) that are not within the perimeter area covered by the AZ Department of Environmental Quality (ADEQ) issued Class II Air Quality Permit will require compliance with Pima County Code Title 17, including, but not limited to: any required Fugitive Dust Activity Permit(s) (PCC 17.12), and compliance with Visible Emission Standards (17.16).
Sarah Walters	2	Alternatives Considered in Detail	2	40	This should state '…Federal, State, and local agencies'
Sarah Walters	2	General Overview of Mining Operations: Stormwater	21	8	Stormwater control system – Diversion channels, any perimeter ditches, and peripheral detention basins, as well as the on-surface evaporation ponds should be included as potential sources of particulate matter and as such the potential particulate matter emissions from these areas should be disclosed.
Sarah Walters	2	General Overview of Mining Operations: Utility Maintenance Road	22	35	Grading operations conducted for regular maintenance of the Utility Maintenance Road should be included as a source of fugitive dust emissions and as such the potential particulate matter emissions from these areas should be disclosed.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	2	General Overview of Mining Operations: Utility Maintenance Road	23	4	Grading operations conducted for regular maintenance of the gravel road to Lopez Pass would also need to be included as a source of fugitive dust emissions and as such the potential particulate matter emissions from these areas should be disclosed
Sarah Walters	2	General Overview of Mining Operations: Other Area Roads	24	4	This sentence refers to Table 11; however, Table 11 does not define what is meant by 'disturbance elements' there are no units or means of determining the potential fugitive dust emissions from the various 'disturbance elements' listed in the table. The table should contain the units of measure of the values that are presented in the Table. If each number in the Table is the acreage associated with that 'disturbance element' then the Table should specify that. Also, any disturbance element outside of the proposed mine site (i.e. outside the area covered by the ADEQ Class II Air Quality Permit) will require compliance with Pima County Code Title 17, including, but not limited to: any required Fugitive Dust Activity Permit(s) (PCC 17.12), and compliance with Visible Emission Standards (17.16). Also, the potential fugitive dust emissions from regular maintenance, development, and regular use of all the disturbance elements should be disclosed.
Sarah Walters	2	Reclamation and Closure	28	1	Any demolition of mine buildings and other structures would need to comply with Federal Asbestos National Emissions Standards for Hazardous Air Pollutant (NESHAP) requirements.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	2	Permits and Authorizations	30	10	Table 3 – ADEQ does not have jurisdiction for 'Air Activity Permit' outside the footprint of the mine site; Pima County Department of Environmental Quality would have jurisdiction over Fugitive Dust Activity Permits for activities such as earth moving, trenching, road building, blasting, etc. for any areas outside the actual boundary of the planned mine site. Any peripheral roads (such as the Utility Maintenance Road and similar off-site roads), trenching, etc. will require compliance with Pima County Code Title 17, including, but not limited to: any required Fugitive Dust Activity Permit(s) (PCC 17.12), and compliance with Visible Emission Standards (17.16). This would need to be added to Table 3, on Page 32 under Pima County and add Pima County Department of Environmental Quality - Air Quality Fugitive Dust Activity Permit(s).
Sarah Walters	2	Detailed Description of Alternatives: Action Alternatives	37	22	Table 4: potential particulate matter emissions from the soil salvage stockpiles should be disclosed. Also, the EIS should specify whether the air quality emissions from soil salvage, transport, and stockpiling were identified and evaluated in the air quality modeling.
Sarah Walters	2	Mitigation and Monitoring – Evaluation and Reporting	68	29	Along with the monitoring results the following should also be included in the quarterly and annual report in order to relay to the Forest Service any contributions from the mine (including pre-mining activities) to air pollution within Pima County: permit deviations, excess emissions, deficiencies, and/or enforcement actions associated with the ADEQ Class II Air Quality Permit; deficiencies, and/or enforcement actions associated with the PDEQ Fugitive Dust Activity Permit(s); and deficiencies, and/or enforcement actions related to PCC Title 17 including, but not limited to Visible Emission Standards. This would be especially significant for events related to non-compliance with requirements set forth in the Mitigation and Monitoring Plan.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	2	Alternatives Impact Summary	91	24	Table 11: The units associated with the numbers in this table are unclear. In Chapter 2, in the 'General Overview of Mining Operations: Other Area Roads' section (page 24, line 4), there is a mention of acreages, but the Table itself also has feet, and miles within certain 'disturbance element' descriptions. This Table should be modified to clearly state what is being presented.
Sarah Walters	2	Alternatives Impact Summary	93	N/A	Table 12: Exceedances of the PM_{10} NAAQS at the perimeter fence for the Barrel Trail and Scholefield - McCleary Alternatives is unacceptable as the cost associated with a PM_{10} Nonattainment Designation for Pima County would be significant for the health and welfare of Pima County residents, businesses within Pima County, and the effects of transport of air pollution to other areas within the State of Arizona. Please see comment below regarding Nonattainment Designation.
Sarah Walters	2	Alternatives Impact Summary	94	N/A	Table 12: the potential for future exceedance of the Ozone NAAQS due to the associated increase in NO_x with All Alternatives is unacceptable as the cost associated with an Ozone Nonattainment Designation for Pima County would be significant for the health and welfare of Pima County residents, businesses within Pima County, and the effects of transport of air pollution to other areas within the State of Arizona. Please see comment below regarding Nonattainment Designation.
Sarah Walters	2	Alternatives Impact Summary	94	N/A	The potential for degradation of air quality related values in the Saguaro National Park East, Saguaro National Park West, and Galiuro Wilderness Class I airsheds needs further consideration, and further analysis.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	3	Changes from the Draft Environmental Impact Statement	1	31	Lines 31 – 41 describe that the restart options in the CALPUFF modeling had not been set to the preferred settings. The results of the sensitivity analysis are not fully presented and an increase in the modeled criteria pollutant concentrations as well as deposition and visibility impacts should be thoroughly discussed and not simply ignored. The 'slight increase' is not defined and warrants statistical analysis, discussion, and thorough explanation. If the 'slight increase' causes exceedance of the NAAQS, or exceedance of NAAQS threshold values for criteria pollutants, a full re-run of all CALPUFF modeling affected by this oversight is warranted.
Sarah Walters	3	Changes from the Draft Environmental Impact Statement	2	7	The EPA has not acted on the Exceptional/Natural Events and thus the data have yet to be excluded as such. This warrants including these values in the modeling, at least as a consideration for the effects of natural events on the emissions from the Rosemont project.
Sarah Walters	3	Changes from the Draft Environmental Impact Statement	2	13	Any mitigation and Monitoring measures added to reduce modeled emissions such that the NAAQS or thresholds were reached need to be addressed in the ADEQ Class II Air Quality Permit in order to ensure that those measures are required, not optional. Exceedances of the NAAQS, or air quality thresholds, could have significant impacts on the health and welfare of Pima County residents, businesses within Pima County, and the effects of transport of air pollution to other areas within the State of Arizona. Please see comment below regarding the cost of Nonattainment Designation.
Sarah Walters	3	Changes from the Draft Environmental Impact Statement	3	15	If PDEQ understands correctly the Tier IV engines in six of the haul trucks would only be implemented in year 10 of operations. This should be clearly discussed, including the reasoning behind waiting until year 10 of operations before requiring the switch to this emissions control. Is the switch required by the ADEQ Class II Air Quality Permit, if so why, or is it due to modeled exceedances of the NAAQS in that year if the operational changes are not implemented at the proposed mine?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	3	Analysis Methodology, Assumptions, Uncertain and Unknown Information	6	1	A detailed description of how the potential emissions from the surface disturbance from these activities were addressed in the air quality modeling should be included. On Page 6, Lines 34 – 43 and Page 7, Lines 1-3 the 'Fugitive dust emissions associated with mine development' are discussed, however, it is not discussed how the per acre-month is calculated, nor does this section discuss how the use of separate emission factors (one emissions factor for 25% of the time, and a separate emission factor for 75% of the time) was determined. Were the 'disturbance elements' in Table 11 (Chapter 2, Page 91 Line 24) included in this?
Sarah Walters	3	Air Quality Analysis Methodology: Tailpipe Emissions	7	14	At such a time that Rosemont reaches employment of at least 100 full time equivalent employees Rosemont will be considered a 'Major Employer' and compliance with the Travel Reduction Program (TRP) requirements set forth in PCC 17.40.070.
Sarah Walters	3	Air Quality Analysis Methodology: Tailpipe Emissions	7	36	This section describes the Global Warming Potential for CO_2 versus N_2O, and states that the 2 percent of global warming potential is insignificant, however, there are conversion factors to convert the global warming potential of gases to a CO2 equivalent and this should be disclosed, and accounted for, as stated in previous comments. To reiterate: The emissions of methane (CH_4) and nitrous oxide (N_2O) are known to have a greater impact on climate change when compared to the impact of CO_2. The PA-FEIS states that the emissions of these gases would be 'much smaller'. Given the potency of these gases the anticipated levels of these emissions should be specified rather than excluded for disclosure. The impact of these emissions should be evaluated along with the impact of the CO_2 emissions using the CO_2 equivalence of the anticipated emissions of CH_4 and N_2O.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	3	Air Quality Analysis Methodology: Point and Fugitive Emissions Associated with Active Mining	8	36	This section should also disclose the character of the tailings. The EIS should disclose that the tailings will be a non-plastic sandy silt, with an average of 63 percent No. 200; these characteristics dispose the material to wind transport.
Eric Betterton	3	Air Quality Analysis Methodology: Point and Fugitive Emissions Associated with Active Mining	8	36	Particulate matter emissions from the Tailings Storage areas have been grossly underestimated. If the correct Tailings Storage emissions factor were to be used in the AERMOD projections then the modeled particulate matter levels would be greater than predicted. Comments on the Draft EIS previously submitted to PDEQ by Eric Betterton in January 2012 that are relevant to this PA-EIS are included and reference the PA-FEIS Chapter, Page Number, and Line Number, 'Eric Betterton Comments of Draft EIS – 12-01-12' PDF attached.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	Air Quality Analysis Methodology: Point and Fugitive Emissions Associated with Active Mining	9	3	When estimating the dust arising from wind erosion of the tailings impoundments the Forest Service relies on an assumed threshold friction velocity of 0.43 m/s. This is two-and- a-half times higher than the threshold actually measured for mine tailings at Hayden, Arizona, of 0.17 m/s (Evaluation of Aerosol Production Potential of Type Surfaces in Arizona, W. G. Nickling and J. A. Gillies, 1986). By using such a high threshold, the Forest Service has severely underestimated the ability of the wind to cause erosion. They have set the bar unreasonably high and again, they have failed to take a conservative approach. The Forest Service claims that perimeter buttresses of waste rock will “break up the air flow”. They ignore the possibility that the buttresses will instead induce strong turbulent eddies and thereby actually promote wind erosion. Please see attached PDF titled ‘13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013’
Eric Betterton	3	Air Quality Analysis Methodology: Point and Fugitive Emissions Associated with Active Mining	9	4	The highest wind speed recorded over the three year period is listed as 10.7 m/s, to represent the effective observed wind speed. This value is twice as high as the threshold wind speed reported by Nickling and Gillies (1987) for Hayden mine tailings (5.11 m/s). Comments on the Draft EIS previously submitted to PDEQ by Eric Betterton in January 2012 that are relevant to this PA-EIS are included and reference the PA-FEIS Chapter, Page Number, and Line Number, ‘Eric Betterton Comments of Draft EIS – 12-01-12’ PDF attached.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	3	Air Quality Analysis Methodology: Point and Fugitive Emissions Associated with Active Mining	9	5	The wind speed should also be presented in 'miles per hour'.
Sarah Walters	3	Climate Change Methodology	11	14	To reiterate: The emissions of methane (CH_4) and nitrous oxide (N_2O) are known to have a greater impact on climate change when compared to the impact of CO_2. The PA-FEIS states that the emissions of these gases would be 'much smaller'. Given the potency of these gases the anticipated levels of these emissions should be specified rather than excluded for disclosure. The impact of these emissions should be evaluated along with the impact of the CO_2 emissions using the CO_2 equivalence of the anticipated emissions of CH_4 and N_2O.
Sarah Walters	3	Summary of Effects by Issues Factor by Alternative	13	1	Table 28: there are multiple places in this table where it appears information is missing, i.e. Issue 2.1: $PM_{2.5}$ versus background and threshold – under the Proposed Action column '…Active mining: 4 increase…' what value does the 4 go with, i.e. is it a 4 percent increase? Earlier in the document it specifies a '4 X increase', but in this section it is not specified
Sarah Walters	3	Local and Regional Air Quality: National Ambient Air Quality Standards	21	7	The air quality section should disclose the assumptions regarding where smelting will occur (within Arizona or northern Mexico) and implicate the impacts to air quality for the SO_2 NAAQS.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	AERMOD Modeling of Compliance with NAAQS at the Perimeter fence for the Action Alternatives	41	21	The statistical analysis to “prove” that the highest measured PM_{10} value (71.3 µg/m^3) is an “outlier” is fundamentally flawed. Rosemont suggests that the reading might have been impacted by a regional dust storm, in which case they should have analyzed the frequency of regional dust storms, not the frequency of high readings at their lone PM_{10} monitor in order to determine the probability of a recurrence. Indeed, the National Weather Service has stated that the frequency of dust storms in Tucson and Phoenix has increased substantially over the past few years, and so the “high” PM_{10} value is likely to be repeated or even exceeded in future. When the Forest Service includes the high value in their analysis they predict that the 24-h PM_{10} exceeds (Proposed Action) or nearly exceeds (Barrel Alternative) the NAAQS of 150 µg/m^3. Nevertheless, they arbitrarily dismiss this troubling result and instead accept a lower modeled value. In other words, they failed to err on the side of caution. Please see attached PDF titled ‘13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013’
Eric Betterton	3	AERMOD Modeling of Compliance with NAAQS at the Perimeter fence for the Action Alternatives	41	40	The EPA default value of the crucial NO_2/NO_x ratio is 0.5. Instead of using this value the Forest Service used a ratio of just 0.05, one tenth the recommended value, to demonstrate NAAQS compliance in the AERMOD model. When they use a ratio of 0.1, which is still only one fifth the recommended value, their own model shows that both the Proposed Action and the Barrel Alternative will exceed the NAAQS. The Forest Service again accepted the lowest predicted value and failed to err on the side of caution. Please see attached PDF titled ‘13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013’

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	AERMOD Modeling of Compliance with NAAQS at the Perimeter fence for the Action Alternatives	41	3	Rosemont is required to model future pollutant levels and then add the future pollutant estimates to the existing pollutant levels, i.e. in addition to the current "background" levels found in the immediate area. Instead, Rosemont selects the lowest possible pollutant level, and then adds this "background" level to predicted Rosemont emissions. This mistake is made PM and for NOx, thus calling into question all the air quality model results. Comments on the Draft EIS previously submitted to PDEQ by Eric Betterton in January 2012 that are relevant to this PA-EIS are included and reference the PA-FEIS Chapter, Page Number, and Line Number, 'Eric Betterton Comments of Draft EIS – 12-01-12' PDF attached.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	AERMOD Modeling of Compliance with NAAQS at the Perimeter fence for the Action Alternatives	41	3	Rosemont monitored PM_{10} at the proposed mine site for three years in order to establish the background level. EPA requires that the average of the highest 24-hour values recorded during each of three years is to be used as the 24-hour maximum PM_{10} background level. However, Rosemont ignored its highest observed PM_{10} value declaring it to be an anomalously high outlier. Justification for ignoring its own data is erroneous. Rosemont's own statistical analysis (a linear regression with a R2 value of unity) shows that the high value is not an outlier. It is clearly a valid member of the normal population distribution of natural PM_{10} observations. The high value may not be ignored simply because it will occur only infrequently, any more than one ignore the risk of a flood simply because it will occur once every hundred years. To reiterate, the high value is a naturally occurring value that is expected to occur again and that must be included when calculating the 3-year average background PM_{10}. The National Ambient Air Quality Standard (NAAQS) maximum 24-hour PM_{10} of 150 µg/m3 will be exceeded when the correct average PM_{10} is added to Rosemont's predicted PM_{10} emissions (which are erroneously low anyway, see above). The EPA provides no guidance for selecting outliers. Indeed, their guidance makes it clear that a high background should be used to provide for a worst case analysis. Rosemont may not simply ignore inconvenient observations. Comments on the Draft EIS previously submitted to PDEQ by Eric Betterton in January 2012 that are relevant to this PA-EIS are included and reference the PA-FEIS Chapter, Page Number, and Line Number, 'Eric Betterton Comments of Draft EIS – 12-01-12' PDF attached.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	AERMOD Modeling of Compliance with NAAQS at Saguaro National Park East for the Action Alternatives	46	28	Not only is Pima County likely to violate the NO_2 NAAQS but also the ozone NAAQS. This is because NO_2 is a necessary ingredient for ozone formation, and has a significant and complex effect on ambient ozone levels. Recognizing this, the Forest Service should have called for the use of a photochemical model to estimate the effects of Rosemont's activities on ambient ozone. The Forest Service claims that such modeling "is not typically performed…" but given the potential impacts of increased NO_2 a conservative approach to protecting air quality dictates the use of a photochemical model, especially since more than a million people live in the air shed. Please see attached PDF titled '13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013'

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	CALPUFF, AERMOD, and VISCREEN Modeling for Projected Impacts to Air Quality Related Values at Class I Areas	50	15	A crude, EPA-approved model called VISCREEN was used to estimate the effects of mine emissions on visibility at Saguaro National Park East, which is within the 30-mile range of this model. The “Level 1” calculation provides a quick and dirty look at the worst case scenario. If possible visibility impairment is indicated then a “Level 2” screening is conducted under more realistic conditions. The Forest Service predicts that the mine will indeed adversely impact visibility at SNPE (Table 49, page 53). According to the EPA Workbook for Plume Visual Impact Screening and Analysis (Revised), a more detailed “Level 3” study should then be conducted using a model such as PLUVUE II. The Forest Service did not do this, and thus failed to take the conservative approach to protecting visibility. In order to model the effects of the Rosemont mine alternatives on visibility at more distant Class I areas (including Saguaro National Park West, the Galiuro Wilderness, Chiricahua National Monument, and the Chiricahua Wilderness), the Forest Service appropriately switched from VISCREEN to CALPUFF. The EPA classifies the effects of pollutants on visibility in two ways: those that “contribute”, and those that “cause” impairment. According to the Forest Service “all action alternatives could contribute to noticeable impairment at each of the Class I areas analyzed” (emphasis added), and the Proposed Action, and the Barrel Alternative could “cause” impairment at Saguaro National Park West, and at the Galiuro Wilderness. (Table 50, page 55). Any “maximum dv impact” greater than 0.5 “contributes” and any “maximum dv impact” greater than 1.0 “causes” visibility impairment. It is remarkable that the “Proposed Action” would even be noticeable in the Superstition Wilderness Area some 150 miles away. Yet the Forest Service simply states what the modeled impacts might be without further comment. It does not discuss the effects on human welfare or on the tourism industry. Please see attached PDF titled ‘13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013’

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Eric Betterton	3	Projected Effects on Deposition of Sulfates and Nitrates on Class I Areas	57	1	CALPUFF was also used to estimate nitrogen deposition to the Class I areas. The Forest Service shows that nitrogen deposition will exceed the threshold at Saguaro National Park (East and West) and at Galiuro Wilderness (Table 51, page 58). They simply ignore the potential impacts, including the response of vegetation. Overall, it is troubling that the Forest Service appears to have worked so hard to minimize the modeled impacts of the proposed Rosemont mine on human health and welfare, when instead they should be taking a conservative approach to protect the region for the next three decades. Please see attached PDF titled '13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013'
Eric Betterton	3	Air Quality and Climate Change	1	1	Comments specific to the Rosemont Air Quality Permit are also in the attached PDF document titled '13-07-22 Eric Betterton Comments on ADEQ Permit Application and Mining Plan Revision Final Draft July 19 2013'.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Ursula Kramer	3	Air Quality and Climate Change	1	1	When an area is designated nonattainment, the agency which oversees the area must submit a state implementation plan (SIP) to the U.S. EPA. Through the SIP, an air quality agency will design an approach to reducing the pollutant levels in the air and, if appropriate, any emissions of precursor pollutants. Precursors are those pollutants which can form another pollutant in the atmosphere. For example, Volatile Organic Compounds (VOCs) and Nitrogen Oxides (NOx) are precursor pollutants for ozone. This provides for a comprehensive approach to reducing criteria air pollutants taken by the Clean Air Act which covers many different sources and a variety of clean-up methods. These air pollution control programs could include the nonattainment New Source Review permit program and Federal General Conformity and Transportation Conformity programs. SIPs can affect sources such as power plants, manufacturing, automotive repair and detailing as well as other pollution sources. Working with the EPA, a state or local authority will also implement programs to further reduce emissions of pollutant precursors from sources such as means of transportation (cars, buses, trucks, etc.), fuels, and consumer/commercial products and activities. After the area is designated as nonattainment, the area must meet the federally mandated deadlines established by the 1990 Amendment to the Clean Air Act for compliance with the National Ambient Air Quality Standards. In the interim, it must be demonstrated to the EPA that reasonable further progress toward improving the air quality is being made in the nonattainment area. …continued on next row…

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Ursula Kramer	3	Air Quality and Climate Change	1	1	Continued…Economic development would not be impacted directly by a nonattainment designation, but there could be indirect, costly consequences due to the designation. Sources could be required to install pollution control equipment, take limits on their production, or otherwise find reductions in emissions by “offsetting” in order to expand. New facilities wanting to locate in a nonattainment area will most likely be required to install pollution controls or take stringent operational limits. Additional requirements may be needed for different vehicle fuels and consumer/commercial products. Any of these requirements would likely be more expensive than the current status. Such costs will be borne by the various affected industries and ultimately by the area residents who rely on such products.

DOCUMENT REVIEW COMMENT FORM—VISUAL RESOURCES

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Neva Connolly	3	Visual Resources	39	Figure 86	Figure 86: The proposed project area does not include the utility corridor, though corridor impacts were discussed in this chapter. The acres of potential seen area will increase greatly if the visibility analysis included the utility corridor.
Neva Connolly	3	Visual Resources	30-31	43-3	Viewpoint 9 along Sahuarita Road is said to be representative of views from the Tucson area. It is not in the Tucson metropolitan area and it is not representative geographically. It is miles closer and on an opposite aspect (angle of repose) and lower elevation than much of the Tucson residential population.
Julia Fonseca	3	Visual	NA		EIS should disclose whether Forest will take any measure to response to damage of crest of Santa Ritas during operations and after mine closure.

DOCUMENT REVIEW COMMENT FORM—APPENDIX B

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Postillion	Appendix B	Mit. And Mon.	4	39	Please indicate the agency responsible for the Stormwater Pollution Prevention Plan. Is it Pima County? ADEQ? EPA? Disclosure of the regulatory Authority is needed. It appears to be a general AZPDES SWPPP
Postillion	Appendix B	Mitigation and Monitoring	11	3	Anchoring of the growth medium will be essential, yet it is not emphasized. A sentence needs addition to state "sufficient growth medium and anchoring of that medium to ensure re-vegetation success"
Postillion	Appendix B	Mitigation and Monitoring	22	Timing	For both FS-SSR-01 and 02 the timing aspect of 5 years post mining is insufficient. Effects of the mine pit on drawdown and reduction of runoff volume for many of the springs will not show effects until many more years after mine closure. Who will monitor and bear the cost of monitoring these springs after 5 years post closure. Knowing that the long-term effects of the pit will have long-term water-level declines, the mine must leave a mitigation fund to compensate for the loss of the springs and potential base flow loss in Cienega Creek.
Postillion	Appendix B	Mitigation and Monitoring	28	3-4	The long-term management and maintenance fund needs to be specified with initial monies based on predicted impacts to affected springs as per the FEIS. Estimates of cost need to be established so Rosemont is held responsible for an initial fund to be adjusted as mining proceeds.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Postillion	Appendix B	Mitigation and Monitoring	21	NA	An additional mitigation measure that will significantly contribute to downstream subflow and spring and seep restoration would be controlled discharge of the water derived from pit dewatering to locations downstream of the mine. Based on Tetra Tech's modeling, the pit dewatering is predicted to be of good quality. In addition, good quality groundwater from the Upper Santa Cruz Basin is scheduled for use at the Mine. If additional makeup water or dust control water is needed, then Santa Cruz groundwater (or better yet, CAP) should be used since the groundwater removed from the pit through dewatering would have eventually moved down-gradient to the Davidson and Cienega Creek Basins, absent the mine. This mitigation would be fundamental in providing the wet water so critical to the downstream riparian areas and to restoring an already reduced base flow on Cienega Creek.
Postillion	Appendix B	Mitigation and Monitoring	74	NA	RC-GW-03 could go further to allow for the pipeline to come to the Rosemont supply line and Rosemont directly use CAP, when available, instead of groundwater which is a lower TDS and could be better utilized as a potable source. In addition, this would help mitigate impacts to adjacent well owners and loss of their wells. This is currently being implemented at ASARCO Mine as they use 10,000 AF/yr of CAP for mine process water. We understand that CAP will not always be available. However, when it is available, Rosemont needs to use CAP instead of groundwater and allow for flexibility in its infrastructure to accomplish this action.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	All	Most	NA	Appendix B outlines a host of monitoring and mitigation measures that Rosemont is agreeing to or is willing to consider. Key, general points about the entire document are: • There is scant detail on what action(s) would ensure if a threshold has been reached. Monitoring is fine, but without locking into place at least a process and (bonded) funding or operational penalties for exceeding those thresholds, the proposed (or suggested) thresholds and monitoring have very little meaning. This is a critical and it bolsters a common argument against monitoring that does not lead to meaningful outcomes. • There is insufficient information to properly critique most aspects of the mitigation and monitoring plan, such as: what thresholds will be used (and associated confidence intervals on estimates and their associated Type I and Type II errors) , what, where, when, and how often will monitoring take place, and (as mentioned earlier), what will be done when significant change occurs. The FS indicates that more information is forthcoming and will be part of the ROD, but the lack of specifics in this document is troubling.
Brian Powell	Appendix B	FS-GMP-1	6	NA	Putting Rosemont in the position of suspending operations after discovery of “significant” paleontological resources puts an unreasonable expectations and charge of responsibility on the company and their staff. What is “significant” and how will untrained staff know when this resource (and threshold from “insignificant”) has been discovered? What is involved in this “after action review” and for how long will work stoppage take place? More details and guidance is needed.
Brian Powell	Appendix B	FS-GMP-2	7	NA	Again, having Rosemont report on these resources is unrealistic. Further, the document states that “Upon discovery of such resources, Rosemont Copper would suspend work at that site and notify the Forest Service, and the site would be investigated in the same 24-hour period by the Forest Service before work resumes.” This means that, for example, if a cave resource is discovered at midnight on a Saturday night that an investigation would be completed (not started) by Sunday night. This is not realistic. Instead, an independent entity should be brought in to oversee work and this type of investigation because it is simply not in the company’s interest to report these resources.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-SR-01	8	NA	Success criteria for growth media should be established prior to final approval. It should be made more clear exactly what will be accomplished by "refining" success criteria. In fact, the document claims already that reference sites will be used for this purpose.
Brian Powell	Appendix B	FS-SR-01	8	NA	The document cites the use of an adaptive management approach to refine those success criteria. This is not an appropriate use of adaptive management, which (according to the very source that is being cited) seeks to reduce uncertainty of management actions and not (as proposed) to develop criteria for success. This is just one small part of the adaptive management cycle.
Brian Powell	Appendix B	FS-SR-01	8	NA	Recommended that the FS have a very strict standards for soil particle size, soil stability, etc as reclamation progresses. Certainly some areas will need additional work, but for the FS and Rosemont to go back to previously reclaimed areas and enhance elements such as soil particle size is simply unrealistic; standards should be well articulated and they should be met as work progresses.
Brian Powell	Appendix B	FS-SR-01	8	NA	With regards to bonding (which we are not privy to reviewing), sufficient money should be allocated for erosion repair and vegetation establishment for years after mine closure.
Brian Powell	Appendix B	FS-SR-01	8	NA	Identify "established" NRCS protocols for growth media.
Brian Powell	Appendix B	FS-SR-01	8	NA	The document indicates that "Available, onsite woody debris from clearing of the mine site would be used on the reclaimed growth medium surfaces to provide stability, organic matter, and microhabitats for seed germination, invertebrates, and small vertebrate species." This may not be realistic for more than a few years out from the initial vegetation clearance action because these woody elements will decompose. What, then, will be the plan for woody components at the time of mine closure?

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-SR-01	8	NA	If the success criteria are matched to areas of natural vegetation and that standard cannot be met, there is no indication in the document as to what action the FS would take other than "determine the need for additional mitigation measures for more successful revegetation and increased soil stability", which of course is referring to on-site actions. The FS should include a provision (and appropriate bonding) for off-site mitigation if the on-site actions are not sufficient.
Brian Powell	Appendix B	FS-SR-01	11	NA	As with the soil metrics, the FS is not using adaptive management in the right context for the revegetation success. Adaptive management should not be used to adjust success criteria, which can be articulated now.
Brian Powell	Appendix B	FS-SR-01	11	NA	There is a reference to "three types of plots" but no definition of what this means.
Brian Powell	Appendix B	FS-SR-01	11	NA	The number, location, and frequency of monitoring plots (or transects) can be established now- there is no justification for waiting on this, especially if natural reference conditions are used as baseline
Brian Powell	Appendix B	FS-SR-01	11	NA	Livestock grazing on reclaimed sites should be addressed explicitly. Given the steep slopes and potential for erosion, grazing should not be allowed until after success criteria are met.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-SR-01	11	NA	Controlling invasive species is generally a good thing, but more detail is needed. In the document there is a justification for using a National Park Service protocol for invasives, but that protocol is for natural areas, and surveys are targeted on areas with some level of disturbance. In contrast, the entire Rosemont reclamation site is disturbed land and therefore far more susceptible for the establishment of invasive weeds. In addition, it might be prudent not to view all invasive species as harmful. For example, on areas that have no vegetation and are susceptible to erosion, the presence of some species such as Lehman's lovegrass may not be as undesirable as at times and locations where erosion is not a significant concern. Therefore, an invasive species management plan should be developed that is explicit about goals and objectives related not only to the actual species present, but also to the associated soil and hydrological considerations. Development of such an approach is ideally suited to a structured decision making process, which is increasingly being used by Federal land management agencies.
Brian Powell	Appendix B	FS-SR-01	11	NA	There is no explicit consideration of the tens of thousands of oak trees that will be impacted by this project. Specific targets should be set for these trees and if on-site revegetation will not work, then off-site should be found.
Brian Powell	Appendix B	FS-SR-03	13	NA	Conformance with many of the mitigation measures is monitoring using "visual inspections" to ensure, for example, that "surfaces would be stable and excessive erosion would not occur." The mitigation plan should articulate what constitutes these thresholds. Better yet, do not rely on qualitative measures, like aerial LiDAR.
Brian Powell	Appendix B	FS-SR-03	14	NA	Specify location and distance: "Activities near known lesser long-nosed bat roosts"
Brian Powell	Appendix B	FS-SR-04	14	NA	"Rock slopes within the mine pit would be remotely monitored for movement." Monitoring is good, but the document fails to identify what measures would be put in place if movement does happen. Aside from obvious human safety issues, there are also biological concerns, such as impacts to talus snail habitat. Bonding should be identified for potential slope movement.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-SR-05	14	NA	Sediment transport monitoring stops at SR 83 bridge, but what about downstream? The County has great concern for sedimentation into Bar-V Ranch and Cienega Creek.
Brian Powell	Appendix B	FS-SR-05	14	NA	Thresholds have not (but need to be) identified and this can be done by conducting baseline assessment and pairing Barrel with nearby, unimpacted sites to determine the relative contribution of sediment in Barrel Canyon.
Brian Powell	Appendix B	FS-SSR-01	22	NA	With regards to timing of purchase of water rights, the document says: "throughout the life of the project (pre-mining through final reclamation and closure phases) and for 5 years following mine closure." Clarify what this is referring to and if water rights would be reversionary.
Brian Powell	Appendix B	FS-BR-2	25	NA	As part of the avoidance of Coleman's coralroot plants, it is imperative that the host trees be monitored for vigor and condition; if they die, so too will the orchids. Specify what contingencies would be put in place if the plants are impacted. (Note: what constitutes "impact" needs to be defined).
Brian Powell	Appendix B	FS-BR-3	26	NA	There is an assertion that the security fence will be equipped with a frog barrier fence, but the security fence (Chap 2, page 14) is only chain-link near access roads; everywhere else it will be barbed wire. Specify how such a fence will be amenable to a frog barrier.
Brian Powell	Appendix B	FS-BR-3	26	NA	Because the security fence will be barbed wire, wildlife will be able to enter the site, but there is an assumption that wildlife will not be able to enter the site. This should be clarified.
Brian Powell	Appendix B	FS-BR-4	27	NA	Replacing up to 300,000 agaves with approximately 35,000 individuals should not be allowed; there should be greater emphasis on this species.
Brian Powell	Appendix B	FS-BR-4	27	NA	Monitoring of agaves should set number of plots and sites, and how often.
Brian Powell	Appendix B	FS-BR-4	27	NA	Planting of agaves should be staggered across years to ensure a good interannual distribution of flowing plants

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-BR-4	27	NA	Plant stock grown in nurseries should be from or very near to the site.
Brian Powell	Appendix B	FS-BR-5	28	NA	It needs to be determined what the trigger will be that would compel Rosemont to construct artificial waters. Without such a trigger, it could be very easy for Rosemont to stall implementation.
Brian Powell	Appendix B	FS-BR-6	29	NA	Qualified biologists need to be on hand during construction of power lines to ensure that talus are not disturbed.
Brian Powell	Appendix B	FS-BR-7	29	NA	Conservation easement on the Helvetia ranch should preclude mining as an activity and all valid mining claims relinquished.
Brian Powell	Appendix B	FS-BR-9	31	NA	A camera study is not a meaningful mitigation effort.
Brian Powell	Appendix B	FS-BR-10	31	NA	Transplanting Pima pineapple cactus has proven to be quite ineffective.
Brian Powell	Appendix B	FS-BR-10	31	NA	Helvetia North is showing as having Pima pineapple cactus, but how many? If it is mitigation land, then disclose the number of PPC on site.
Brian Powell	Appendix B	FS-BR-14	33	NA	A significant population of yellow-billed cuckoos is found downstream of the confluence of Cienega Creek and Davidson Canyon, but no mitigation actions are proposed there. That should be addressed, as the mine will likely impact their habitat there.
Brian Powell	Appendix B	FS-BR-14	33	NA	Buffer around nests needs to be larger-this species is notorious for spooking easily. At least a 100 m buffer should be afforded the species.
Brian Powell	Appendix B	FS-BR-15	34	NA	The plan for the Coleman's coral root is survey for known individuals and mark those. This is not sufficient, as we know (based on our limited knowledge of the biology of the species), that individuals only flower every 3-6 years. By only marking individuals that flower in a particular year, up to 85% of the population may not be accounted for. Modifications to this plan need to be made.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-BR-16	35	NA	A fund for $2M will do very little to "help restore the watershed to a functioning ecosystem." The ecological repair needs of the Cienega Watershed—over and above the mitigation activities committed to by Rosemont—will far exceed the amount pledged for this conservation fund.
Brian Powell	Appendix B	FS-BR-16	35	NA	The document states that BLM and AZGFD will be responsible for identifying mitigation actions. Pima County would like to be involved in those decisions.
Brian Powell	Appendix B	FS-BR-18	37	NA	Plans to "addressing [plant and 1 invertebrate] species that are found in disturbance areas, such as but not limited to documentation, collection, translocation, seed collection". This should be done before approval because it is unclear what mitigation measure would actually work for each of these species. Is translocation really possible for these species? (Probably not). We should already know the answer to this question, but the FS has not attempted to address this question for these species and has chosen to put off that work until after mine approval. However, it means that a complete analysis of the mine's impact has not been undertaken because we don't know what mitigation measures are possible.
Brian Powell	Appendix B	FS-BR-18	38	NA	Monitoring for effects of pit dewatering is fine, but what do we do with this information? There needs to be a reasonable response. This should tie into release from bonding issue.
Brian Powell	Appendix B	FS-BR-20	38	NA	Monitoring roadkill of jaguar, ocelot, and their prey base is because the mine effectively cuts off the northeastern portion of the Santa Rita Mountains to the movement of animals (the mine is placed from ridgeline to the west, Highway 83 to the east.) So yes, mortality will increase due to funneling animals onto the highway (which of course also creates a safety hazard for motorists). But what management actions will this invoke? Will there be changes to Highway 83 to allow for safe passage of animals? If not, then this is another example of collecting data for the sake of collecting data and pretending it is mitigation.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Brian Powell	Appendix B	FS-BR-21	38	NA	Describe what "ascertain whether shielding from artificial night light emitted by the mine is possible or prudent" means.
Brian Powell	Appendix B	FS-RW-03	49	NA	Moneys will be given to the Forest to study and improve conditions from ORVs, but studies and subsequent mitigation should take place on other parcels, closer to Tucson, such as the County's Bar-V and Cienega Creek Natural Preserve, both of which will likely receive more ORV traffic as a result of the loss of the Rosemont site.
Iris Rodden	Appendix B		27		Part of the proposed mitigation to Palmer's agave includes "seasonal grazing restrictions to increase flowering success of agave". There should be more details about this proposal as agave stalks grow throughout most of the spring and summer months – are they proposing to only graze in fall and winter? This could impact native grasses and other plants by focusing grazing pressures after summer rains when the plants are trying to reproduce. Continuously grazing in the fall is something we actively avoid doing on our own ranches.
Sarah Walters	Appendix B	Air Quality	60	N/A	To reiterate: Roads not directly on the mine site are not under the jurisdiction of the ADEQ Air Quality Permit and will require compliance with Pima County Code Title 17, including but not limited to: any required Fugitive Dust Activity Permits (PCC 17.12), and compliance with Visible Emission Standards (17.16).
Sarah Walters	Appendix B	Air Quality	61	N/A	The Dust Control Plan should contain enforceable dust control measures, and requirements for implementation of dust control measures prior to high wind events. The Dust Control Plan should also include visual monitoring of the open areas and storage piles such that vulnerable areas are identified prior to high wind events.
Sarah Walters	Appendix B	Air Quality	64	N/A	The use of Tier IV engines is specified as only occurring at, and after year 10 of operations; this does not apply as a mitigation measure during any other years, and as such this should be specified in the ADEQ permit and in the EIS.

Commenter	Chapter	Section	Page	Line	Comment/Change requested
Sarah Walters	Appendix B	Other Monitoring Items for Air Quality	65	N/A	Opacity Monitoring should be required during high wind events. Also, monitoring of property boundary should be conducted to ensure compliance with PCC Title 17 Visible Emission Standards that should be included within the ADEQ Air Quality Permit.
Sarah Walters	Appendix B				The ADEQ Air Quality Permit should require the Dust Control Plan to be updated as needed if the Mine Site has repeated deficiencies and/or enforcement actions associated with fugitive dust emissions. The Dust Control Plan should include visual inspections of the surface of the tailings to determine areas vulnerable to windblown dust, and action plan to address these vulnerable areas prior to high wind events.
Julia Fonseca	Appendix B	OA-GW-05			What is being measured for NEPA compliance? How much deviation is tolerated before monitoring results are deemed “out of compliance” with NEPA decision?
Julia Fonseca	Appendix B	FS-BR-05			The water features described herein are unlikely to replace the functional values of the springs and streams that would be impacted to wildlife. The Forest and Corps should consider adding the mitigation measure described by Frank Postillion, which would involve discharging pit water for recharging selected aquifers. This could reduce the short-term indirect impacts to streams and springs, and buy time to ensure that other offsite mitigation measures can really succeed.
Julia Fonseca	Appendix B	OA-GW-07			The threshold for NEPA compliance should be clearly stated in performance criteria. The ADWR permit allows 6000 acre-feet per year pumping, but the NEPA analysis says they will only pump up to 5400 acre-feet per each of the first eight years. But the performance criteria is “as specified by ADWR permit”, which means that the pumping could exceed the NEPA assumptions for 600 acre-feet per year, or a total of 4800 acre-feet. The threshold that the Forest will use for NEPA compliance should be the ones used for the groundwater analysis, not the limits stated in the ADWR permit.
Julia Fonseca	Appendix B	FS-SSR-02			The Cienega Creek Watershed Conservation Fund is inadequate for all of the stated purposes. Also, need to disclose how you determine an “effect”, particularly if you are allowing discontinuance when “observations indicate the absence of standing water...” etc. This mitigation measure is really not thought out well.

Julia Fonseca	Appendix B	Ground Water quality	FW-GW-02		This mitigation measure and the EIS fail to disclose which water quality constituents will be monitored. This disclosure is needed not only for anyone to understand what is being monitored, but also for quantifying costs in the reclamation bond. The mitigation measure should specify that monitoring will encompass constituents and characteristics comprising both the narrative and quantitative surface water quality standards for aquifer uses in the Forest (livestock and wildlife, primarily). The measure should disclose what actions the Forest Service is prepared to take if the standards are not met.
Julia Fonseca	Appendix B	Groundwater Quality	FS-GW-01		How many pans or lysimeters will be deployed? This is needed to quantify costs. The mitigation measure also needed to state what the threshold will be for determining that seepage is occurring.
Julia Fonseca	Appendix B	Groundwater	NA		The Forest Service should also use visual evidence of seepage around the margins of the waste rock and tailings a separate monitoring measure.
Julia Fonseca	Appendix B	Groundwater quality	NA		Mitigation should require proper abandonment of any unused drill holes, existing shafts and adits on Forest lands and on Rosemont's lands within the pollutant management area before the operations begin to protect ambient groundwater. These sites should be identified in final MPO and bonded. If there are sites that have already "treated", these should have been identified in the PA FEIS.
Julia Fonseca	Appendix B	Ground Water quality	NA		Mitigation measure is needed for require proper abandonment of any unused drill holes, wells, and piezometers as part of reclamation and closure plan to protect groundwater quality and quantity.
Julia Fonseca	Appendix B	Groundwater Quality	NA		Forest Service should require that all existing wells have been evaluated for proper wellhead protection to ensure ground water quality is not impaired where the continued use of wells for drinking water, stock, monitoring and wildlife uses is proposed in this EIS. If deficiencies are found, these should be rectified. This mitigation measure would protect groundwater uses in the area.

S. Anderson	Appendix B. Mitigation and Monitoring Plan	FS-RW-01 Relocation…	47-48	No line	You didn't put specific information about the trailheads in the Mitigation and Monitoring Plan; that's probably on purpose. Talk to the Arizona Trail Association to get their current standards.
S. Anderson	Appendix B.	FS-RW-02 AZ Trail Esmt	48	No line	How wide is the easement going to be? It should be, at a bare minimum, 15' in width or greater, and nothing should be developed or placed on the land on either side for at least 500'. The exception would be existing structures, such as Hwy 83 or the box culvert under the highway, or a trailhead. Those can stay, but nothing new can be placed in proximity to the Arizona Trail that is not trail-related. The easement should be non-terminable, and everything should be spelled out in the document. You should reference the Arizona Trail Association on these pages too.
S. Anderson	Appendix B.	FS-RW--03 Mitigate …	49	No line 49	The OHV Recreation Plan that will be funded by Rosemont to replace the displaced OHV opportunities should consider lands outside, but abutting, the forest. Arizona State Trust Lands could be used for this purpose.
S. Anderson	Appendix B.	RC-GW-03 Extension..	74	No line	If the CAP is extended 7 miles to the south, we're going to want the CAP Trail extended as well. The CAP is a National Recreation Trail, and it goes everywhere the CAP goes. I will advise the BOR as to Pima County trail desires.
Julia Fonseca	Appendix B	Biology			A new monitoring requirement should be in place to detect inadvertently formed surface water bodies within the mine perimeter fence as a protection for Forest land, water, and wildlife resources. Detection should trigger monitoring for maintenance of narrative and quantitative surface water quality standards for wildlife, and contingent provisions for fencing. (Monitoring measure FS-GW-01 is not intended to identify unplanned surface water bodies, and thus will not address this issue.) (Monitoring measure FS-BR-03 does not address protection of wildlife from inadvertently formed ponds).

Julia Fonseca	Appendix B	Surface Water Quality			The Forest and Fish and/or Wildlife Service should require monitoring narrative and quantitative surface water quality standards for Aquatic and Wildlife (warm-water) at the locations of all new planned surface water bodies, to include arsenic, selenium, copper and mercury. This should include any new mitigation waters created for wildlife or stock, the existing water bodies at mitigation areas, stock tanks, and the pit lake, which would provide an attractive nuisance. Big Pond, a livestock and wildlife watering site on State Trust land east of the facility; East Dam, a livestock and wildlife watering site located less than one miles east of the facility, on Forest land, an important site for the Chiricahua leopard frog; Adobe Tank, a livestock and wildlife watering site, located less than two miles east of the facility on State Trust land in the upper; Highway Tank and Oak Creek Canyon Tank, livestock and wildlife watering site located one to two miles east-southeast of the facility, on Forest land and habitat for the Chiricahua leopard frog; 4066 Tank, a livestock and wildlife watering site on Forest land southeast of the facility; McCleary stock tank; Greaterville area tanks which harbor Chiricahua leopard frogs may receive airborne contaminants from the mine site; Cienega Creek base flows restored at the Pantano dam should also be monitored (if part of the mitigation for this project)
Julia Fonseca	Appendix B	surface water quality	FS-GW-03		EIS fails to disclose what analytes will be monitored. There is no reason that these cannot be disclosed at this time, and in fact this is needed for any estimate of cost and for a basic understanding of the monitoring proposal.

Julia Fonseca	Appendix B	surface water quality			The pit lake that would be created by this permit would have a volume of 96,000 acre-feet, making it one of the largest water bodies in southern Arizona. The pit lake would be accessible to wildlife, and would reflect primarily the characteristics of the aquifer at the mine site but would be influenced by inflows from the pit walls and drain-back from other parts of the mining facilities under plans discussed in the APP. The APP provides no monitoring for the pit lake. The Forest and Fish and Wildlife Service must require post-mining water quality monitoring to assess potential toxicity to wildlife and minimize potential take under the Migratory Bird Treaty Act.
Julia Fonseca	Appendix B	Biology	24	FS-WUS-01	The EIS should disclose the restrictions on water use within the easement, and other restrictions that may apply.
Julia Fonseca	Appendix B	Biology	24	FS-BR-01	This mitigation relies on initial review of plans and weekly visual inspections to ensure that plans and execution conform with the footprint of the final MPO and closure and reclamation plan. The Forest should be provided with shapefiles representing the MPO and plans to facilitate the Service's review of plans.
Julia Fonseca	Appendix B	Biology	24	FS-BR-01	The Forest should require that limits of disturbance be marked in the field with orange field barricade to facilitate the weekly inspections, and to reduce the likelihood of accidental incursions into areas that were intended not to be disturbed.
Julia Fonseca	Appendix B	Biology	24	FS-BR-02	What is the frequency of monitoring? .
Julia Fonseca	Appendix B	Biology	24	FS-BR-02	The Forest should require that limits of disturbance be marked in the field to facilitate inspections, and to reduce the likelihood of accidental incursions into areas that were intended not to be disturbed

Julia Fonseca	Appendix B	Temporary Cessation of Operations			Notification of temporary cessation is not addressed by the Monitoring or Mitigation Plan. Section 2.8 of the APP permit, Temporary Cessation, provides requirements to Rosemont Copper should they cease operations of the facility for a period of 60 days or greater: "the permittee shall submit for ADEQ approval a plan for maintenance of discharge control systems and for monitoring during the period of temporary cessation." And "During the period of temporary cessation, the permittee shall provide written notice to the Water Quality Compliance Section and the Southern Regional Office of the operational status of the facility every three years." The Forest must be made aware immediately of Rosemont's plans during any period of temporary cessation, regardless of how short or long the duration might be. The Forest should not have to rely on ADEQ for this information.
Julia Fonseca	Chapter 3	All	NA	NA	EIS should analyze or disclose what effects temporary cessation or interim shutdowns would have in terms of the Forest permit to operate and identified impacts.
Julia Fonseca	Appendix B	Biology	29	FS-BR-07	The restriction should be in the form of a conservation easement held by a second party, with the USFWS as a third party beneficiary. This would increase the effectiveness of the measure. There should be an endowment established for monitoring, and rights to access and enforce the restrictions to someone other than the owner.
Julia Fonseca	Appendix B	Biology	29	FS-BR-07	The EIS should disclose the restrictions on water use within the easement or covenant, and other restrictions that may apply.
Julia Fonseca	Appendix B	Visual	46	FS-VR-03	Mitigation for visual impacts to crest or west side of the Santa Ritas due to inadvertent cuts, fills, or collapses should be specified. Monitoring for these impacts is needed.
Julia Fonseca	Appendix B	Surface Water	70	OA-SW-01	EIS should disclose the analytes that will be monitored and what kind of triggers or responses would be taken. Without this information, it is impossible to evaluate effectiveness.
Julia Fonseca	Appendix B	Surface Water	70	OA-SW-01	How would this monitoring affect (mitigate) sediment load? Given this purpose, there should be a threshold and a mitigation measure attached to this item that would control sediment loads.
Julia Fonseca	Appendix B	Surface Water	70	OA-SW-01	There should be effectiveness monitoring by Forest to ensure that construction of all stormwater facilities in the final MPO are constructed in a timely manner. This was an issue at the Carlota mine, where lack of effective phasing of stormwater facilities resulted in pollution during runoff events.

Julia Fonseca	Appendix B	Land Ownership	76	RC-LO-01	This is a federal action that could have significant impacts on the human environment. This EIS has not analyzed the impacts of transferring ownership on natural and cultural resources. This should not be considered a mitigation measure. If it is to be considered, it should be analyzed as a connected federal action, not a voluntary mitigation measure of Rosemont's. This measure cannot be implemented without federal action.
Julia Fonseca	Appendix B	Land Owner ship	76	RC-NA	Rosemont should make good on its promise to Green Valley that neither Broadtop Butte nor Copper World is ever mined by placing a conservation easement on the deeded lands that comprise these ore bodies.
Julia Fonseca	Appendix B	Land Ownership		Figure 77	This figure fails to disclose the majority of the mineral survey fractions fall in what Rosemont has defined as the Broadtop Butte mineral resource. Also fails to show location relative to mine facilities other than the perimeter fence.

Julia Fonseca	Appendix B	Water Quality	FW-GW-02		Forest Service should require monitoring of streams around of the facility and in the National Forest to verify that such Forest streams continue to meet surface water quality standards. The proposed FS-GW-02 does not address intermittent streams located on Forest lands. In mineralized areas, it is critical to collect such baseline data so that impacts during operation and post-closure may be distinguished from pre-mining ambient conditions. This monitoring measure lacks an implementation or response—what happens if there is non-compliance? Surface water quality monitoring should be required at springs or intermittent flow reaches at locations listed below, inclusive of mitigation lands in the area: • Box Canyon and Box Canyon tributary called Sycamore Canyon, important site for Chiricahua leopard frog and other species, as well as recreation on Forest land • Sycamore Canyon north of the facility on Forest land, important for wildlife and recreation; • Papago Canyon north of the facility on Forest land, important for recreation and wildlife; • Mulberry Canyon northwest of the facility, on Forest land, important for wildlife and recreation, and part of the mitigation lands; • Intermittent reach on Barrel Canyon located downstream and east of the facility on Rosemont's land; important for recreation and wildlife, and inclusive of the mitigation land there; • East Fork Davidson Canyon, an intermittent and ephemeral stream important for recreation and wildlife, located east of the facility on Forest, state trust and Rosemont land, including mitigation land; Upper McCleary Canyon, located one mile or less northwest and upstream of the facility, used for recreation, wildlife and stock purposes

Krieski	Appendix B	FS-SR-02 FS-SW-02	12 – 13 21		Specifications / Bonding Requirements Needed for Postclosure – Continuing Operations and Responsibilities after Reclamation: Soil Loss, Slope Stability, Revegetation Operations, Maintenance of Facility Stormwater Systems Within the section *Soil Development and Productivity Lost to Erosion after Reclamation* (PA EIS Chapter 3, Soils and Revegetation, p 15), the following is noted: *"Postclosure, reduction of soil loss from the watershed would be dependent on structural and engineered sediment controls and on revegetation of the site to prevent erosion from occurring. Reduction of the actual erosion of soil from surfaces can only be accomplished through revegetation of the site or the use of protective rock cover, which is generally undesirable with respect to recovery of soil productivity."* As stated, following the conclusion of Reclamation activities and well into the Postclosure period, reduction of soil loss / soil erosion is dependent upon sediment controls and successful revegetation of the site. Clearly, soil loss through downslope movement and rilling/gullying will continue unabated into the post-reclamation (postclosure) period as vegetation plantings try to take root and survive. Slope surface rehabilitation operations, including replacement of lost soil, and revegetation of unsuccessful zones of initial plantings, may require decades of time. As noted in Appendix B, FS-SW-02 (Stormwater Diversion … downstream drainages postclosure), monitoring and maintenance of site stormwater management systems / engineered sediment controls in the postclosure period will also be an essential site operational activity: "*Monitoring postclosure for a period of time to be determined ensures that facilities would operate with no or minimal maintenance."* Within the PA EIS Appendix B, FS-SR-02, p 12, Responsible Party, Implementation and Effectiveness, the following are noted: "The Forest Service would spot check revegetation success …… determine whether acceptable soil stability has been achieved; and determine the need for additional mitigation measures for revegetation and soil stability. Rosemont Copper is responsible for monitoring, treatment, follow-up treatments, and reporting to the Forest Service."

					Within the PA EIS Appendix B, FS-SR-02, p 13,Timing, the following are noted: "Implementation: Monitoring would begin …….. and would continue until the Forest Service determines that no further revegetation efforts (seeding, planting, site stabilization, etc.) are necessary to meet the revegetation plan and final reclamation and closure plan and objectives during final reclamation and closure and postclosure phases." In summary, postclosure facility operations required for soil replacement, slope stability, revegetation and maintenance of facility stormwater management systems may be required for many years, and possibly decades, following "final reclamation" activities at the end of mining. From the above statements from the PA EIS, the Forest Service will monitor the closed facility. <u>However, the question remains</u>: who is responsible for funding and executing postclosure operations required for necessary revegetation, soil replacement, and slope stability activities, including monitoring and maintenance of site stormwater management systems, until such time that the closed mine site reaches functional equilibrium with the surrounding natural environment? The Forest Service has not specifically stated that Rosemont Copper is responsible for these operational activities in the postclosure period (until such time the Forest Service approves the final product and Rosemont Copper is allowed to "Walk Away"). Per 36 CFR 228 Part A and in 2800 Section of the Forest Service Manual, "To the extent practicable, reclaimed National Forest System land shall be free of long-term maintenance requirements." To the contrary, however, per documents prepared by Rosemont Copper, the mining company intends to "walk away" from the mine site following the conclusion of reclamation activities. According to information contained in Chapter 13 (Reclamation and Closure Costs) of the CDM Smith *Preliminary Reclamation and Closure Plan for the Barrel Alternative* (July, 2012), no cost / bonding provisions are included for facility postclosure

					revegetation, soil replacement, slope stabilization, and/or maintenance of stormwater control systems. Table 13-4 (Reclamation Cost Summary per Activity Area) contains no costs for long-term operation, maintenance and monitoring associated with the surfaces of the Waste Rock or Tailings facilities. Changes Requested: 1. Specifically state in the PA EIS that Rosemont Copper is responsible for soil replacement, slope stability, and revegetation operations in the postclosure period, until such time the Forest Service determines the facility is stable and revegetation is successful. Specifically acknowledge in the PA EIS that soil replacement, slope stabilization, and revegetation operations in the postclosure period may require many years, or even decades, of time following final reclamation. 2. Specifically state in the PA EIS that Rosemont Copper is responsible for monitoring and maintenance of site stormwater management systems, including sideslope benches, perimeter stormwater systems, Sediment Control Structures 1 and 2, etc. until such time the Forest Service determines the facility can operate with essentially no maintenance. 3. Specifically include financial provisions within the mine bond which cover estimated costs associated with all postclosure operations for soil replacement, slope stability, activities required for successful revegetation, and monitoring and maintenance of site stormwater management systems. These postclosure bond requirements can be modified during final reclamation activities based upon the results of concurrent reclamation activities to date. Should Rosemont Copper, for any reason, not be capable of performing these required activities, then the Forest Service shall enlist a 3rd party contractor to perform these vital postclosure operations.

RWRD - Staff	App. B	Mitigation & Monitoring Plan	16-17	All	It is critical to monitor ground water quality conditions for this site. However, in FS-GW-02, "Water Quality Monitoring beyond Point-of-Compliance Wells" there is no mention of a data management plan, which should include statistical analysis, trending, and outlier examination. Gathering a huge amount of data is only valuable if the data is managed and presented in a way where trends in pollutant concentration can be examined. The Forest Service should require a Data Management Plan to include periodic statistical analysis, trending and conclusions based on data summaries.
Linda Mayro	Appendix B	Mitigation and Monitoring Plan	3	20-36	This section includes a reference to the cultural resources MOA and HPTP, but does not discuss their purpose and relatedness, consulting parties, concurring parties, and whether completed, and is generally too brief.
Linda Mayro	Appendix B	Table: FS-CR-01	53-58		This does not address or explore any mitigation for the loss of integrity of the overall traditional cultural property and its impacts to social and cultural fabric of the tribal communities affected. To give the appearance of mitigating impacts to the entire TCP, only mitigation of impacts to its component parts – springs, archaeological sites, gathering sites, etc. is proposed. This is inadequate. A TCP is more than its component parts, and may be likened to the premise that desecrating the cathedral is OK provided the statues and candles are removed.
Linda Mayro	Appendix B	Entire			The issue of Social Justice is not addressed. While impacts to the human environment are addressed under NEPA, the FEIS recognizes the mining project will have a disparate negative effect on the Tohono O'odham Nation, other tribes and communities, and concludes that "the archaeological/ cultural resources mitigation plan is unlikely "to relieve the disproportionality of these impacts." There is also the issue of how to mitigate impacts to the social and cultural fabric of the Tohono O'odham and other affected communities. Other than the cultural resources mitigation plan (HPTP), no other mitigation measures are considered or offered or explored.

Linda Mayro	Appendix D	MOA			The draft MOA in Appendix D is different from the current version under review. Neither version includes a provision that the FS will ensure that the Historic Properties Treatment Plans (HPTP) and all mitigation tasks for the mine and for the utilities will be implemented in their entirety, especially if the mine ceases operations. A clear statement is required in the MOA that states the FS will ensure there will be adequate funding included in the Financial Assurances and Reclamation Bonding to complete all elements of the HPTP in the event the mine ceases to operate. This issue can be addressed in the STIPULATIONS: ROLES AND RESPONSIBILITIES Section I.A The Forest shall…
Akitsu Kimoto	Appendix B	Soil and Revegetation	8		What corrective actions would be taken if revegetation and soil stability are unsuccessful?
Akitsu Kimoto	Appendix B	Soil and Revegetation	9		No explanation about the best management practices that will be implemented for sediment control. What practices will be implemented? This information is particularly important for revegetation and soil stabilization on steep slopes. Pelase disclose the information.
Akitsu Kimoto	Appendix B	Soil and Revegetation	9		"The Forest Service is responsible for establishing success criteria to determine whether the growth media is sufficient to support revegetation objectives of the final reclamation and closure plan and soil stability requirements". The success criteria should be clearly defined.
Akitsu Kimoto	Appendix B	Soil and Revegetation	9		It is not clear that the number of reclamation monitoring sites (plots? How many?). It is important to have multiple monitoring sites with different conditions to assess the mitigation effectiveness. Please disclose detail monitoring plans and sites.
Akitsu Kimoto	Appendix B	Soil and Revegetation	10		The FEIS cited that "Monitoring would begin when salvage of soil (growth media) begins to ensure that storage pile(s) are stable and do not contribute large quantities of dust during wind events; continuing through placement of growth media to ensure that it is stable, placed according to final reclamation plan, and does not erode excessively". However, it is not clear how to monitor the impacts of storage piles on wind erosion or dust. Please explain.

Akitsu Kimoto	Appendix B	Sediment transport monitoring	14-15		More frequent and quantitative sediment transport monitoring (e.g. suspended sediment concentration) is required in Barrel Canyon. Quarterly visual inspections proposed in the FEIS are not enough to assess the impacts of mining activities on sediment transport. Especially frequent monitoring is necessary during a monsoon season. Please consider additional monitoring.
Akitsu Kimoto	Appendix B	Surface Water Quantity and Quality	20		“Structures would be stable and would show no excessive erosion, settling, slumping, or deformation that could affect water routing. Water would be routed to desired natural features (washes) in an efficient manner. Permanent facilities would be designed to minimize the need for long-term maintenance post-closure.” The FEIS describes the effectiveness of the mitigation but it does not explain what actions would be taken if mitigation does not achieve the expected or required level. Please explain.
Chavez	Appendix B	RC-GW-02 Recharging of the aquifer	74		Performance Criteria: Rosemont’s accrued storage credits should be extinguished annually to offset the groundwater pumped at the Sahuarita well field.

Krieski	Appendix B	FS-SR-01	7 - 10		Develop Specifications for Soil Availability for the Final Reclamation Operation According to Figure 6 (Soil Stockpile at End of Operation Year 15) of the CDM Smith *Preliminary Soil Salvage Management Plan* (July 2012), two soil salvage stockpiles are located on the surface of the Tailings and Waste Rock mound. Stockpile 3 has a capacity of 335,000 cy, and Stockpile 4 has a capacity of 283,000 cy, for a combined total capacity of 618,000 cy. Chapter 3, Figure 36 of this PA EIS depicts the area which remains to be reclaimed for Years 16-22 Reclamation Work. This figure corresponds to Figure 12 (Composite of Yearly Reclamation Areas) contained in the CDM Smith *Preliminary Reclamation and Closure Plan for the Barrel Alternative* (July, 2012). Information in this report indicates some 57% of the Tailings and Waste Rock mound (approximately 1,990 acres) remains to be reclaimed in the period of Years 16-22. Table 4-1, Concurrent Reclamation Areas (Year Pre – Post Production), of the CDM Smith *Preliminary Soil Salvage Management Plan* (July 2012) provides similar reclamation information. At the end of Year 15 in the mine's life, and probably closer to Year 10, there are no longer any areas available on-site from which to borrow soils. At this time, potential soil borrow areas have already been removed through excavation or covered by mine waste materials. Any removal of soils from undisclosed off-site locations would itself trigger the formal reclamation of these same areas. With a minimum specification of 1 ft of soil cover needed for the 1,990 acres which remain to be reclaimed at the end of Year 15, soil quantities required for this operation alone require some 3,200,000 cy. With stockpiles 3 and 4 containing the only remaining available soil for final reclamation, there appears to be a deficiency of about 2,500,000 cy for final reclamation of the landform (3,200,000 cy - 618,000 cy).

					Changes Requested: 1. Clarify the apparent, significant discrepancy of 2,500,000 cy of soil needed for final reclamation of the Tailings and Waste Rock mound for Years 16-22. For final reclamation purposes, where will additional soils be obtained, either on-site or off-site, for reclamation of the mine waste disposal landform? 2. For soils obtained from additional on-site or off-site areas, identify these general soil borrow areas and provided specifications for how these areas themselves will be reclaimed. 3. Include within the Final Reclamation and Closure Plan specific *Mine Reclamation Soil Management Maps* which clearly show, for the life of the mine through Final Reclamation, were soil would be obtained (Soil Borrow Areas) and stockpiled (Soil Stockpile Areas) to provide complete site reclamation activities for the period of Year 10 – Final Site Reclamation. Include annual estimated volumes which are expected to be obtained from each Soil Borrow Area, and annual estimated volumes which are expected to be stored in each Soil Stockpile Area, for the period of Years 10 – Final Site Reclamation. 4. Provide specifications in the Final Reclamation and Closure Plan to formally update the *Mine Reclamation Soil Management Maps* every 2 years during the life of the mine and through Final Reclamation.

Krieski	Appendix B	FS-SR-01	7-10		Recalculate Soil Volume Needed for Final Reclamation and Postclosure Table 3-1 (Reclamation Needs) of the CDM Smith *Preliminary Soil Salvage Management Plan* (July 2012) includes estimates of the volume of soil needed for total site reclamation. A nominal depth of 12 inches is used to calculate soil needs for reclaimed areas. However, a nominal depth of 12 inches results in a significant underestimation of actual soil needs due to three primary reasons: 1. Placement of Soil on Waste Rock Surfaces 2. Uniform Soil Loss through Downslope Movement / Slope Rehabilitation 3. Soil Needed for the Post-Reclamation (Postclosure) Period Placement of Soil on Waste Rock Surfaces The vast majority of landform slopes and surfaces to be covered with a minimum of 1 ft of growth media salvage consist of a waste rock application surface. The placement of soil on an irregular waste rock surface, inherently irregular and pocked with void spaces, will required considerably more soil than a nominal 1 ft calculated thickness in order to physically construct a 1 ft minimum thickness layer. A significant amount of soil will be required to first fill in the many voids and irregularities of a waste rock surface, prior to the construction of a 1 ft minimum thickness growth media layer. Uniform Soil Loss through Downslope Movement / Slope Rehabilitation during the MPO Reclamation Period No calculated soil loss quantities have been included within the volume estimate of growth media salvage soil for the approximately 2,500+ acres of sideslopes to be reclaimed as part of Concurrent Reclamation, and from additional landform surfaces covered during Final Reclamation activities. Successful revegetation of these reclaimed surfaces will take tens of years; significant uniform loss of soil will occur during Concurrent and Final Reclamation activities. In addition, localized slope rilling and gullying will occur on all landform sideslopes, requiring additional soil materials for slope rehabilitation.

					Soil Volume Requirements for the Postclosure (Post-Reclamation) Period Following the conclusion of Final Reclamation activities and during the Post-Closure Period, until such time that the Forest Service approves the success of the vegetation over the total landform reclamation area (~2,700 acres), soil loss through downslope movement and area-specific rilling/gullying will continue unabated. Surface slope soil needs for rehabilitation activities during this time period, particularly in the decades following "Final Reclamation", may be significant. Under *Timing – Effectiveness,* "Monitoring would begin ….; continuing through placement of growth media to ensure that it is stable, placed according to the final reclamation plan, and does not erode excessively." Change Requested In order to quantify more realistic soil volumes which will be required for placement of soil growth salvage media for total landform reclamation activities, in contrast to the nominal 1 ft thickness presented in the PADF EIS, provide specifications in the Final Reclamation and Closure Plan for determinations of the following: 1. The anticipated additional soil volume requirements for construction of a minimum 1 ft thick soil growth media surface on top of an irregular waste rock surface. 2. The estimated volume of annual soil loss from reclaimed sideslopes during the period of Concurrent and Final Reclamation of the site. 3. In conjunction with an associated comment regarding the preparation and updating of *Mine Reclamation Soil Management Maps* every 2 years, update soil volume calculations for site reclamation needs every 2 years. 4. Soil volume needs for slope rehabilitation activities during the Postclosure (Post Reclamation) period, until such time the Forest Service can definitively state the site is "stable". Specify the locations of Soil Borrow Areas to be utilized for these Postclosure soil needs? 5. Include Bonding requirements for Postclosure soil obtainment and placement operations, to ensure sufficient funds to perform necessary site stabilization operations of eroding, rilling, and gullying landform surfaces.

Krieski	Appendix B	FS-SR-01	8		Create Specifications within the Final Reclamation and Closure Plan for the Systematic Monitoring and Reporting of Volumes of Soil Growth Media Utilized This Monitoring / Reporting mitigation measure should specify requirements for the systematic monitoring and documentation of all Soil Borrow Areas from which soils are obtained, the quantity of soils obtained, and the quantity of soils utilized in relation to applications on specific acreages of reclaimed surfaces. These activities should correspond to requirements raised in related PA DEIS comments, including the preparation and updating of *Mine Reclamation Soil Management Maps* every 2 years, and updating soil volume calculations for site reclamation needs every 2 years. The Forest Service recognizes the importance of the systematic collection of this data as part of monitoring the concurrent reclamation activity: As noted in the *Training Guide for Reclamation Bond Estimation and Administration, For Mineral Plans of Operation authorized and administered under 36 CFR 228A, USDA-Forest Service, April 2004* within <u>*Earthwork*</u>*:* *"The operator should be required in the POO to regularly submit an accounting of stockpiled materials such as subsoil, and topsoil so that the reclamation review calculations are based on factual data rather than conjecture. It is incumbent on FS personnel to ensure that the operator is stockpiling any such materials as the mine is developed and that the stockpile volumes are accurate. We do not want to have to 'mine' needed reclamation materials from another site in order to reclaim the mine."* Change Requested: 1. Include formal specifications within the Final Reclamation and Closure Plan for requirements for systematic monitoring and reporting of the Soil Borrow Areas from which the soils were obtained, the quantity of soils obtained, the quantity of soils utilized for reclamation and slope rehabilitation, and the acreages of reclaimed and rehabilitated surfaces.

Krieski	Appendix B	FS-SW-02	20 – 21		Need to Release Additional Surface Water into Downstream Drainages Postclosure 1. Eliminate Perimeter Containment Areas - Release Surface Water Downstream As shown in the PA DEIS (Chapter 2, p57, Figure 19 – Barrel Alternative Stormwater Concept) and on Figure 13 (Barrel Alternative Landform) of the CDM Smith *Preliminary Reclamation and Closure Plan* (July 2012), two Perimeter Containment Areas (PCA2 and PCA3) are located around the southern boundary of the Waste Rock disposal mound. The PCAs are stormwater retention basins, intended to capture and hold all incoming surface water, with no release to downstream drainages. As shown on Comment Figure 1, stormwater collected in the two PCAs include contributions from the lower slopes of the Waste Rock mound and adjacent upper slopes of the Barrel Canyon watershed (Area 1), and the entire watershed area associated with the Pit Diversion Channel (Area 2). Area 1 has a surface area of about 335 acres; Area 2 has a surface area of about 240 acres, with an approximate 100-yr discharge of 1800 cubic feet per second. Combined, Areas 1 and 2 have a watershed surface area approaching 1 square mile in size. As noted in Chapter 3 of the DEIS under *Barrel Alternative-Stormwater Management after Closure*, "The diversion channel west of the pit would collect precipitation in stormwater retention ponds along the southern toe of the waste rock facility and would be allowed to infiltrate as aquifer recharge, but it would not be able to flow downstream as surface water due to topography". The "topography" referenced here is simply the geometric result of the intersection of the graded waste rock pile and existing slopes of upper Barrel Canyon (the remnant surface of the large graded pile superimposed on hilly topography nearby the upper watershed boundary). As a result, stormwater collected in Area 1 is trapped between the lower slopes of the Waste Rock mound and the existing topography at the head of Barrel Canyon. As noted on Figure 1, Rosemont Copper has named the two main areas of trapped water PCA2 and PCA3. In addition to the capture of all waters from the Area 1 watershed, all water collected from the Area 2 watershed and transmitted by the Pit Diversion Channel is also captured and held without release in these two large surface water trapping areas.

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>Stormwater retained in PCA2 and PCA3 is problematic both during mining operations and throughout the postclosure period. Stormwater ponded against waste rock, to depths of about 50 ft, will cause leaching of contaminants into the groundwater as the ponded water moves laterally into and through the waste rock mound. Instead, stormwater should be transferred around the Waste Rock mound for release into downstream drainages for perpetuity.

Surface waters collected in Areas 1 and 2 certainly do <u>not</u> have to be captured and held in PCA2 and PCA3. These waters can, and should, be collected and transferred via a continuous perimeter drainage channel, and released downstream into the Trail Creek - Barrel Canyon drainage system as fundamental stormwater management component of the facility operational and postclosure condition. This can be accomplished by integrating and implementing the following operations:
A. Design minor modifications to the geometry of southern Waste Rock mound side slopes to facilitate passage of perimeter stormwater.
B. Perform excavations through the hilly topography of the upper Barrel Canyon watershed, as required, for construction of the perimeter stormwater management system.
C. Utilize abundant waste rock materials for construction of the perimeter stormwater management channel, including placement of waste rock materials adjacent to the toe of the Waste Rock slope to construct a stormwater transfer system designed to function in perpetuity.

There is sufficient grade for a continuous perimeter stormwater channel from PCA2 all the way around to the Trail Creek outlet. As shown on Figure 1, the Waste Rock mound perimeter distance from Point SW-1 (elev ~ 5220 msl) to Point SW-2 (elev ~ 4820 msl) is about 20,000 ft, with an elevation drop of about 400ft. This corresponds to an average slope of approximately 2% for the perimeter system.

Design and construction of a continuous perimeter stormwater system is doable, and constitutes a minor part of these primary mining operations:
- Excavation and disposal of 1.9 billion tons of waste rock and tailings
- Creation of a permanent 4.5 square mile waste products landform on Federal and State lands</td></tr>
</table>

2. Release Additional Surface Water from the Lower Tailings Mound Sideslope

An additional wraparound or perimeter channel should be constructed along the northeastern side of the Tailings mound. As shown on Figure 1, there is no collection channel planned to transfer water collected at the bottom of the Area 3 sideslope interval. Instead, stormwater collected on this lower sideslope ponds along the base of the sideslope within three primary headwater areas below the adjacent north-trending ridgeline. This situation is similar in nature to the trapped water in the PCAs noted in Part 1 above.

As indicated on Figure 1, a perimeter channel should be designed and constructed to collect and transfer stormwater from the base of the subject sideslope, by utilizing the same techniques noted above in Part 1 (operations A, B and C). Collected stormwater should be routed into the lowest planned bench at the northeast corner of the Tailings mound, for transmission release into the wraparound channel and release in

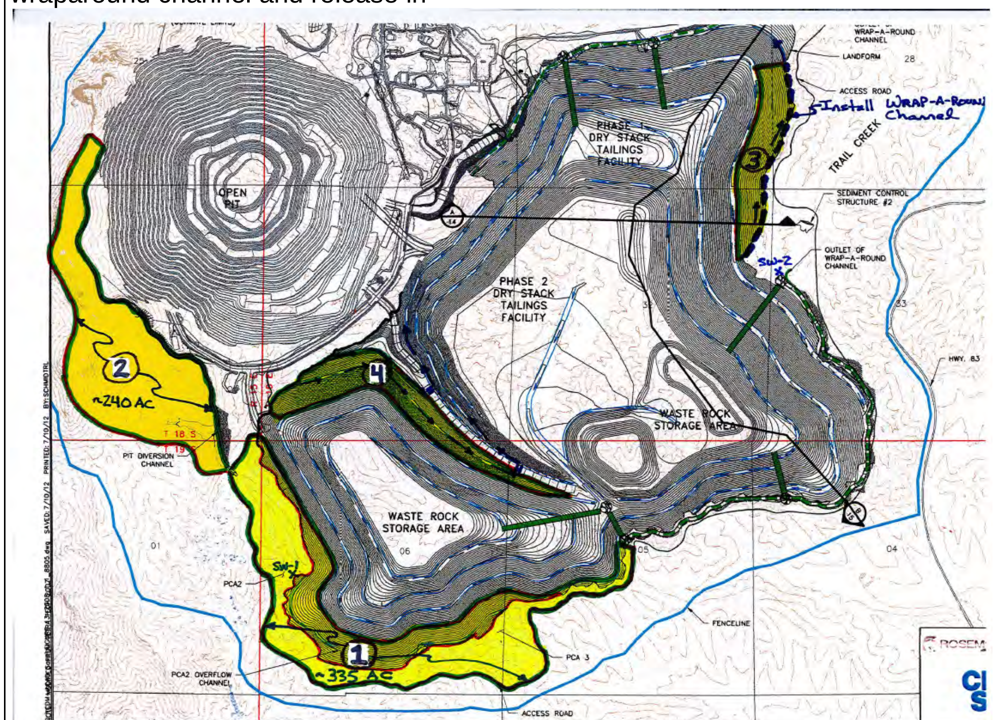


FIGURE 1. Post-closure Stormwater Issues – Appendix B: FS-SW-02

to Barrel Canyon.

3. Release Additional Surface Water from the Lower Waste Rock Mound Sideslopes

Surface water collected on a portion of the lower sideslopes of the Waste Rock

Julia Fonseca	Appendix B mitigation, Chapter 3 mitigation effectiveness	Pantano Dam, Del Lago water rights			The mitigation and mitigation effectiveness are affected by the means of diversion. According to Jonathan Garrett, ADWR, personal communication April 24, the amount diverted and reported to ADWR for the Del Lago golf course use was 461.75 acre-feet in 2010, 352.62 acre-feet in 2011, and 347.5 af in 2012. These amounts are far lower than the 1100 acre-feet that may be available in any given year. See also Powell (2013, attached to these comments) for more information about flows delivered to the site and for photographs of the means of diversion.
Julia Fonseca	Appendix B mitigation				Pima County requests that Rosemont voluntarily provide mitigation for impacts to the Maeveen Marie Behan Conservation Lands System (CLS), which is part of the County's land use plan, and an adopted part of the Sonoran Desert Conservation Plan. The CLS represents the biological reserve design that was adopted by Pima County after years of development by many technical studies and an interagency Science and Technical Advisory Team which included the Coronado's plant ecologist, as well as representatives of US Fish and Wildlife Service, as well as Arizona Game and Fish Department If the impacts for the Barrel alternative are as described in the EIS, then Rosemont should acquire approximately 12,900 acres of mitigation in the CLS to offset the loss.

PRELIMINARY ADMINISTRATIVE (PA) FINAL EIS REVIEWERS

Steve Anderson
Planning Division Manager
MPA in Public Administration; BA in Political Science, minor in Public Administration

Produced a countywide update of the Eastern Pima County Trail System Master Plan in 1996 and a new Pima Regional Trail System Master Plan in 2011. Contributions to the Sonoran Desert Conservation Plan in 1998 and 1999. Bought the corridor and built 32 miles of the Arizona Trail up to the boundary of the forest from 2004 to 2012. Served as a board member for the Arizona Trail Association since 1993.

Thomas M. Berry
Permit & Regulatory Compliance Officer
Pima County Regional Wastewater Reclamation Department
M.S. Nutrition & Food Science, B.S. Microbiology, B.S. Fisheries Science

Mr. Berry has worked for Pima County for the last 20 years in various capacities, having been responsible for permit and regulatory compliance and compliance reporting for the last 10 years.

Eric Betterton

University of Arizona Distinguished Professor in the Department of Atmospheric Sciences and in the Institute of Atmospheric Physics, Currently the Head and Director, respectively. Also holds courtesy appointments in the Department of Chemical and Environmental Engineering, and in the Division of Community, Environment and Policy, Zuckerman College of Public Health. His research in the laboratory and in the field is focused on environmental pollutants, especially those found in the air and water that might affect people. For example, he studies toxic metals in airborne dust, the chemistry of rain and snow, and the environmental fate of sodium azide, the propellant used in certain automobile airbags. He teaches a large introductory course in weather and climate, and smaller, more advanced courses in atmospheric physics, atmospheric chemistry, and atmospheric particulate matter (dust and aerosols).

Evan Canfield
Chief Hydrologist
PhD in Agricultural Engineering, Minor Hydrology; MS and BS Geology

Involved with Rosemont review since 2006. Reviewed Surface Water Hydrology report and APP permit report. Over 25 years experience working in hydrology and water resources, the last 15 in Pima County. Arizona Professional Civil Engineer with specialty in water resources. ASFPM Certified Floodplain Manager. Extensive experiences in hydrologic modeling, analysis and reviewing hydrology and hydraulic studies. Familiar with the Pima County Title 16, Floodplain and Erosion Hazard Management Ordinance. Developed technical policies (hydrology, hydraulic) and guidance for the Pima County Regional Flood Control to be used in all hydrologic and hydraulic analysis for development in Pima County. Supervise the section of the Flood Control District that maps floodplains. Experience evaluating extreme hydrologic events such as the 2006 floods in Pima County and the flooding following the Los Alamos Fire.

Kathleen M. Chavez, P.E.
Water Policy Manager
BS Civil Engineering

Daily job responsibilities include the review of regional water policy and water resource issues; evaluation of water resource impacts to county facilities. Involved in the CAP water issues in Green Valley.

Neva Connolly
Senior Planner, Office of Sustainability and Conservation
BS Biology, Masters in Landscape Architecture

County responsibilities include contributions towards planning efforts for the Sonoran Desert Conservation Plan, Section 10 permit, and comprehensive NEPA training in 2007. Involved in review of the Rosemont proposal since 2006.

Jonathan L. Crowe
Principal Planner
M.S Urban and Regional Planning
B.A. Geography and Environmental Studies

Over 20 years experience preparing or reviewing traffic forecasts, traffic impact analysis, traffic safety reviews, roadway improvement project development, regional and local long and short-range transportation plans, public transit service plans and budgets, and bicycle and pedestrian improvements within Pima County.

Carla Danforth
Environmental Planning Manager
Pima County Regional Flood Control
Water Resources Division

Responsible for developing and implementing the Pima County Riparian Habitat Mitigation Ordinance. Implements and manages riparian restoration projects such as Swan Wetlands and Cortaro Bosque.

Andrew D'Entremont
Emergency Management Coordinator
Pima County Office of Emergency Management and Homeland Security

My primary function is emergency operations planning for Pima County OEMHS. Also have 30+ years of prior law enforcement experience with the Pima County Sheriff's Department, including several years of service in the Green Valley District supervising emergency response to local mining operations.

Tom Drzazgowski
Deputy Chief Zoning Inspector, Development Services Department
BA in Geography, Minor Math and Finance

County responsibilities include Executive Secretary for the Board of Adjustments, processing all conditional use permits for Pima County. Extensive knowledge and work experience with Title 18 - Pima County Zoning Code. Involved in review of Rosemont proposal since 2013.

Benjamin H. Goff, P.E.
Deputy Director
B.S. College of Engineering
Registered Professional Engineer

Over thirty years of experience preparing or reviewing traffic forecasts, traffic impact analysis, traffic safety reviews, roadway improvement project development, public transit service plans and budgets, and bikeway improvement plans within Pima County. Co-authored NEPA environmental documents related to roadway projects including:
Kolb Corridor, Draft and Final EIS
Palo Verde Corridor, Draft and Final EIS
Campbell Corridor, Draft and Final EIS
Kino Parkway Noise Analysis Report (principal author)
River Road – La Cholla to Thornydale Section 4f Mitigation Report (principal author)

Craig Horn
Financial Projects Coordinator
Pima County Finance & Risk Management Department's Budget Division since April 2006, is responsible for tax revenue projections, including property taxes, assessing impacts of legislative changes on County revenues, and performing economic and financial analysis for County administration. Prior to employment with Pima County, Mr. Horn was a financial and economic consultant conducting market analysis and industry studies for litigation, businesses and government agencies. His expertise includes preparation and analysis of economic and tax revenue impact studies associated with new business activities.

Julia Fonseca
Environmental Planning Manager, Office of Sustainability and Conservation
M.S. Geology, 26 years experience in inventory and protection of natural resources in Pima County Arizona. Julia was a principal hydrologist and project manager at Pima County Flood Control for groundwater recharge and riparian restoration. Julia developed natural resource inventories, plans and policies for the Sonoran Desert Conservation Plan. She currently oversees the development of a multi-species habitat conservation plan under the Endangered Species Act, and a related Environmental Impact Statement under the National Environmental Policy Act. In 2004 she evaluated the natural resources of Rosemont Ranch as a potential County acquisition. She later participated in NEPA scoping, and defining work objectives for staff and consultants.

Nicole Fyffe
Executive Assistant to County Administrator
Masters in Public Administration

Administers Pima County's Conservation Acquisition Program since 2004
Coordinated the purchase of 50 properties totaling almost 50,000 acres
Involved in reviewing the Rosemont Mine proposal since 2006

Yves Khawam
Pima County's Chief Building Official.

Dr. Khawam possesses over twenty years of building administration experience in various capacities including as a designer, builder, and code official.

Akitso Kimoto
Principal Hydrologist
PhD Agricultural Science

Review Hydrology sections of EIS and APP permit report. Extensive experiences in hydrologic modeling, analysis and reviewing hydrology and hydraulic studies. ASFPM Certified Floodplain Manager, Responsible for managing a floodplain mapping project in Pima County, Familiar with the Pima County Title 16, Floodplain and Erosion Hazard Management Ordinance, Experiences in reviewing applications for developments in regulated floodplain and riparian areas, Developed technical policies (hydrology, hydraulic) for the Pima County Regional Flood Control

Ursula Kramer
Director, Pima County Department of Environmental Quality
B.S. Civil Engineering

Involved in air quality regulatory issues for more than 25 years. Oversees all air quality permitting for projects within Pima County.

Mark Krieski, P.E., Civil Engineering Manager
Pima County Regional Flood Control District

B.S. - Geology, 1979, University of Arizona
M.S. - Geological Engineering, 1984, University of Arizona

Mark Krieski is an Engineer and Geologist, and a registered professional Geological Engineer in the state of Arizona. He is currently employed as a Civil Engineering Manager for the Pima County Regional Flood Control District, where he has managed the Major Watercourse Program for five years, including watercourse management, infrastructure development and maintenance, and associated regulatory programs. Mr. Krieski previously spent 3 ½ years as Pima County's Solid Waste Manager, where he was responsible for siting, design, permitting, construction and closure services for a variety of solid waste management facilities. Prior to joining Pima County, Mr. Krieski served as a consultant with SCS Engineers for 14 years, performing geological engineering, geology, hydrogeology and environmental engineering services in Arizona and California. Investigation, design, permitting, construction, closure, compliance monitoring, and remediation services were performed for numerous waste management, mining, industrial, Superfund, and community facilities and contamination sites. Previously, Mark worked for 4 ½ years with Woodward-Clyde Consultants in California and Arizona, performing similar consulting work with an emphasis in earth hazards, foundation and earthquake engineering, and assessment and remediation of contaminated industrial facilities. After receiving his B.S. degree, Mr. Krieski also worked for 2 ½ years as an exploration geologist for Amax Exploration in Arizona, Nevada and California. During his undergraduate studies program, Mark performed a variety of geophysical surveys for both Mining Geophysical Surveys and Zonge Engineering throughout the western United States.

Tom Myers, Ph.D.
Hydrologic Consultant
PhD Hydrology/Hydrogeology

Preparation of a conceptual and numerical groundwater model for the Rosemont area Review of hydrology studies and ground model reports completed by Tetra Tech and Montgomery and Associates. Specializes in groundwater modeling, hydrogeology, environmental forensics, regulatory compliance, water rights, NEPA analysis, and environmental and water policy. He focuses on mining and water resource development issues, coal-bed methane development and groundwater contamination.

L**inda Mayro**,
Director, Office of Sustainability and Conservation
Loy Neff
Program Manager
Office of Sustainability and Conservation
Co-manager, Cultural Resources and Historic Preservation Division
Responsible for overseeing cultural resources compliance for County private sector development review and other permitting, as well as external agency/jurisdiction compliance issues. Participated in the County's Rosemont review team from its inception, representing the Office of Cultural Resources and Historic Preservation. First involvement with Rosemont was review and comment of the proposed Mine Plan of Operations, 9/26/2006.

Leslie Nixon, J.D.
Program Manager
Neighborhood Reinvestment Program
Pima County Community Development and Neighborhood Conservation Department

Responsible for Pima County community revitalization initiatives, neighborhood reinvestment bond program, and outreach to stressed communities. Attorney/Administrator with 23 years of litigation, legislative, and executive experience on behalf of Arizona's low income, minority, and tribal populations. First involvement with Rosemont Copper Project was review and comment on the Environmental Justice section of the draft EIS in July, 2011.

Frank Postillion
Chief Hydrologist, Section Manager, Water Resources
MS, Watershed Management and Hydrology

Responsible for coordination of review for impacts to water supply, water resources, shallow groundwater for this projects (2006). 35 years of experience in water resource and water quality evaluations in the public and private sectors. Evaluated the effects of Tucson Copper Mining District copper mining and the effects tailing pond recharge on the ground-water quality of the Upper Santa Cruz Basin. His affiliation and management of the Upper Santa Cruz Basin Mines Task Force led to modeling and management recommendations to pump interceptor wells at a sufficient rate to contain the mineralized sulfate and TDS plumes, and to avoid contamination of public supply wells. Evaluated the effects of coal mining on the hydrology of Black Mesa in Northern Arizona.

Brian Powell
Program Manager
M.S. in Wildlife Ecology from the University of Arizona School of Natural Resources and the Environment
B.S. in Ecology and Wildlife

Responsible for implementing the effectiveness ecological monitoring program for the County's forthcoming Section 10(a)1(A) permit from the U.S. Fish and Wildlife Service. Expert on wildlife habitat assessment and enumeration.

Greg Saxe
PhD, M.R.P., B.A., Environmental Planning Manager

Reviews rezoning, comprehensive plan amendment, variances, special use permits, ROW permits and any other Planning and Zoning Commission actions for compliance with Floodplain and Erosion Hazard Management and Riparian Habitat Ordinances. Pima County NFIP CRS Coordinator. Former Planning Director for the Tohono O'odham Nation and the Town of Sahuarita, Water Resources Planner for the Martha's Vineyard Land and Water Commission and consultant on Arizona/Sonora border area water and economic development issues. PhD in Geography and Regional Development, Master of Regional Planning, Bachelor of Arts in Environmental Science and Public Policy. 25 years experience in review of EIS and involved with Rosemont Review and monitoring since 2006. Involvement with Forest Service procedures includes developing impact analysis on behalf of the service for growth around the Cape Cod National Seashore and identification/evaluation of Roadless Areas and their impact on local economies and natural resources. 2000 Census Tribal Liaison and nationally recognized for census outreach efforts.

Michael Stofko
Special Projects Manager, Real Property Department

Michael Stofko is an attorney with over 31 years' experience in Arizona. He is employed as Special Projects manager for Pima County Real Property Services section and has handled numerous complex land acquisitions for the County's bond-funded Open Space Program.

John Wisner, Jr.
Program Coordinator for the Pima County Office of Emergency Management

John also serves as the District Emergency Coordinator for the Arizona State Emergency Response Commission in Pima County. His role is to work with the businesses, responders, and citizens on issues relating to Hazardous Materials in Pima County. He is the liaison to the Pima County Local Emergency Planning Committee (LEPC) , ensuring that the committee, businesses, and the county is compliant to roles and responsibilities as outlined in the Superfund Amendment and Reauthorization Act (SARA) Title III and the Arizona State Statutes.

Water Resource Trends in the Cienega Creek Natural Preserve, Pima County, Arizona

August 2013

Brian Powell
Pima County Office of Sustainability and Conservation

Suggested Citation: Powell, B. F. 2013. Water resource trends in the Cienega Creek Natural Preserve, Pima County, Arizona. An unpublished report to the Pima County Flood Control District, Tucson, AZ.

Table of Contents

Executive Summary

The Cienega Creek Natural Preserve is the "crown jewel" of the County's extensive land holdings for natural resource conservation. The Preserve contains some of the region's most important aquatic and riparian habitat and is home to a number of threatened and endangered species. Because of its regional importance, and in consideration of the importance of water in maintaining and promoting the aquatic and riparian habitat, Pima County began monitoring water resources soon after the establishment of the Preserve in the 1980s. Since that time a number of monitoring efforts have resulted in a wealth of water-related data from the preserve, including data on precipitation, streamflow volume, extent of surface flow, and depth to groundwater. Though data have been collected and reported in annual reports and periodic assessments, there has not been a recent effort to thoroughly analyze these data or to use statistics to investigate the significance of the observed trends. This report addresses this need and does so using data collected principally from 1990-2011.

With the exception of precipitation, all water resources analyzed have shown declines since monitoring efforts began. In most cases, these declines have been both statistically and ecologically significant. Between 1990 and 2011, streamflow discharge (a measure of surface water volume) declined by 83%. Similarly, streamflow extent (i.e., the length of stream channel with surface water) declined by 88%. For many of the parameters, the hot, dry period prior to the monsoons was a period of extreme decline, such as for streamflow discharge, which declined by 97% when comparing June 1990 to June 2011 (Pantano Wash gage). Depth to groundwater, which is measured in a number of monitoring wells, declined less than other measures, yet declines were as much as 44%.

The causes for the observed declines are not entirely known because many factors are likely acting in concert. First, drought conditions were in place for much of the time period covered by the report; in some years precipitation was as little as 50% of normal. To compound the effects of the drought, there has seen a sharp rise in the number of new groundwater wells drilled for domestic and commercial use. In addition to these factors is the amount of water being withdrawn from the system by way of evapotranspiration, as well as the underlying hydrological and physical characteristics of the aquifer.

Water is the ingredient that makes the Cienega Creek Natural Preserve so special, yet water will become even more vulnerable in the future. Chief among the threats to water is a climate, which will be hotter and most likely drier. Development pressure will continue to impact the Preserve by way of more groundwater wells that take water from the natural system. The proposed Rosemont Mine will also impact water resources in Davidson Canyon, a key tributary to Cienega Creek. All of these factors speak to the need for proactive management actions such as purchasing water rights and protecting upland areas of the Cienega Creek watershed.

Introduction

Figure 1. The lush aquatic and riparian resources of the Cienega Creek Natural Preserve provide habitat for endangered species are an important drinking water source for Tucson.

The Cienega Creek Natural Preserve (Preserve) is the most significant aquatic and riparian property in Pima County's extensive preserve network. The Preserve was established in 1986 and is more than 4,000 acres in size (over 6 square miles) and stretches along the last 12 miles of Cienega Creek before the creek drains into the Pantano Wash.

The Preserve contains some of the region's best examples of mesic riparian forest, with its associated tall cottonwood, willow, and mesquite trees that were once abundant along streams and rivers of southern Arizona. Unlike the nearby Santa Cruz River, which is much different now than it was historically, Cienega Creek retains some characteristics of its former hydrological and ecological function. The precious open water and lush marsh and mesic riparian vegetation along Cienega Creek (Figure 1) provide habitat for two species of endangered fishes (the Gila topminnow and Gila chub), one endangered plant (Huachuca water umbel), species of interest such as the Mexican garter snake (Rosen and Caldwell 2004) and lowland leopard frog, and hundreds of other plants and animals that rely on this rare resource. What is perhaps most unique about the Preserve is that all of these resources occur in such close proximity to the Tucson metropolitan area (Figure 2). Because of its perennial flow, good water quality, and role as wildlife habitat, Cienega Creek has been designated one of Arizona's "Outstanding Waters" by the Arizona Department of Environmental Quality (Fonseca 1993).

The Preserve was established for "the purposes of the preservation and protection of the natural and scenic resources of the property…for the benefit and protection of the County, its resources, residents, and visitors". Specifically, the management objectives (from McGann and Associate Inc. 1994; Pima County Regional Flood Control District 2009) for the Preserve are to:

1. Preserve and protect the perennial stream flow in Cienega Creek;
2. Preserve and protect the existing natural riparian community along the stream corridor;
3. Provide opportunities for public use of the Preserve for recreation, education, and other appropriate activities.

Since its establishment, the Preserve has undergone significant changes, due in part to management actions such as the exclusion of cattle soon after its establishment. Since that time, the lush cottonwood and willow gallery forest has returned to the Preserve (Figure 3).

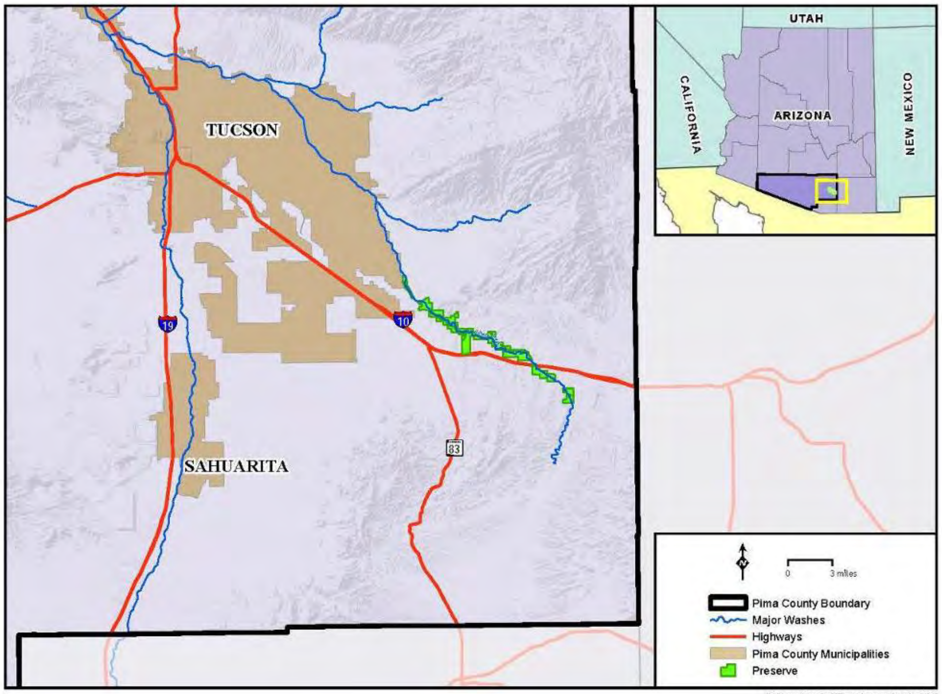


Figure 2. Location of Cienega Creek in relationship to Tucson and the southwestern U.S.

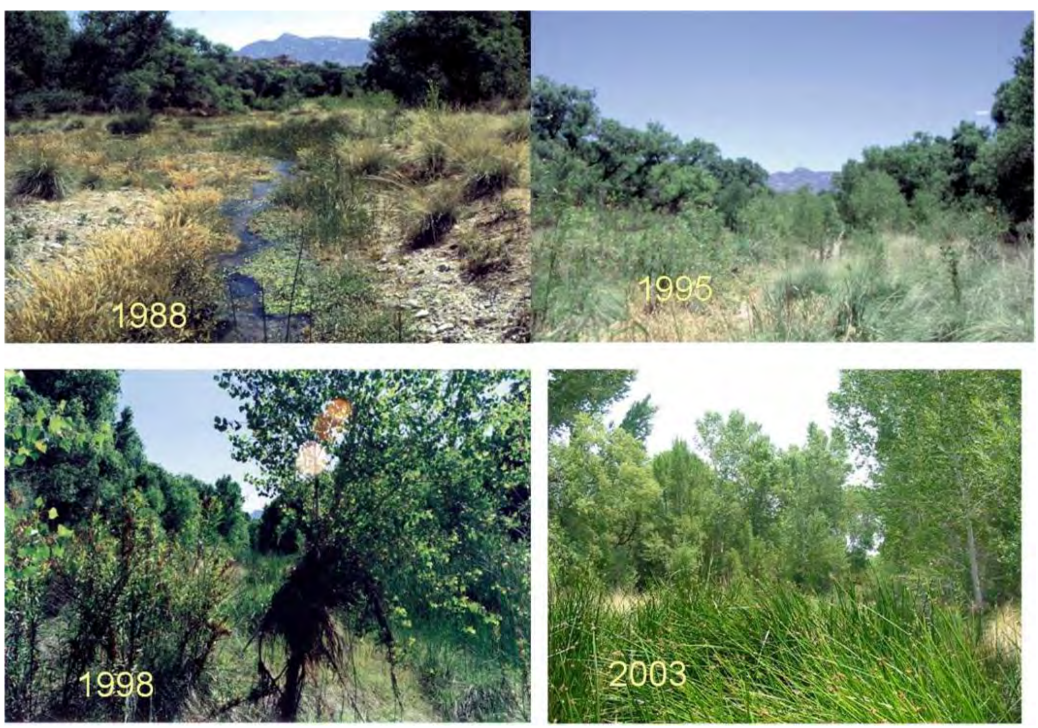


Figure 3. Changes in the vegetation community at the Cienega Creek Natural Preserve following the removal of cattle, which began in 1988 (photographs by the Pima County Regional Flood Control District).

The key resource in the Preserve is water, and without it, the Preserve would be like so many dry and shrub-lined washes of the region. Pima County has focused increasing effort toward the monitoring and enhancement of water and associated aquatic and riparian resources. This focus is all the more important given the Preserve's close proximity to Tucson and the associated development pressures.

These pressures have become a considerable concern for the long-term health and vibrancy of the Preserve considering the reliance of many exurban development projects on pumping groundwater for domestic use. The Pima County Regional Flood Control District (RFCD) began monitoring water and associated resources in 1987 because of planned development within the Cienega Creek watershed and the County pursuit of Outstanding Waters designation for Cienega Creek (Fonseca 1993). Though some of the planned development was never realized, maintaining water monitoring at the Preserve became a top priority for the RFCD and the Pima County Natural Resources, Parks, and Recreation Department (NRPR), which co-manage the Preserve (Pima County Regional Flood Control District 2009). Currently, water monitoring at the Preserve is funded by RFCD and is carried out by the Pima Association of Governments (PAG).

The purpose of the current monitoring effort is to establish baseline hydrologic conditions for comparison purposes, in the event that future groundwater development or land-use changes occur in the vicinity of Cienega Creek (Pima Association of Governments 2011). Though this monitoring effort is ongoing and PAG regularly provides the RFCD and NRPR with annual updates on monitoring activities (e.g., Pima Association of Governments 2011), there has not been a thorough review of the long-term datasets since 1998 (Pima Association of Governments 1998).

This report provides a summary of much of the water data that has been collected at the Cienega Creek Preserve, and—if applicable—elsewhere in the Cienega watershed. I look specifically at: 1) precipitation, 2) streamflow and discharge, 3) surface water extent, and 4) depth to groundwater. I also put precipitation data from the Cienega watershed in a regional context. I do not summarize or investigate trends in water quality data. The period of interest varies by the parameter being investigated because of when monitoring began, but for all parameters the analysis period ends in 2011, the last complete year of data that was available when this project began (October 2012).

For parameters that are included in this report, I investigate trends and correlations among monitoring parameters, potential threats to those resources, and what (if any) management action can be taken to address these trends. Specifically, the goals of this report are to:

- Summarize most of the water-related monitoring data that has been collected at the Preserve and elsewhere in the watershed;
- Where feasible and appropriate, identify statistically and ecologically significant trends in those data;
- Provide potential explanations of observed trends;

Methods

The level of data summary and analysis for this effort depends on the data themselves. For some data, I summarize observations in graphical format, but do not perform statistical analyses because such an approach may not be statistically valid, either because the data were not collected using the same method or at the same location over time or because the data were too sparse for statistical analyses. For most data, the methods of collection and length of collection were sufficient to investigate long-term trends. In these instances, I always checked the distribution of observations before any statistical analyses to ensure that parametric assumptions of normality were met. If not, I transformed the data to meet these assumptions and in all cases, used the natural logarithm.

The type of statistical analysis varies by the parameter of interest. For many of the parameters, I investigated long-term trends by way of a linear function and for many parameters I used the Seasonal Kendall test, which was developed by the USGS in the 1980s and has become the most frequently used test for trends in the environmental sciences (Yue et. al. 2002; Hensel and Frans 2006) including river flow data (Douglas et. al. 2000). The Seasonal Kendall test performs separate tests for trends in each season (months, unless otherwise noted), and then combines the results into one overall linear trend result. The Seasonal Kendall test accounts for seasonality by computing the Mann-Kendall test on each season separately, and then combines the results blocks out all seasonal differences in the pattern of change (Hensel and Frans 2006). No comparisons are made across seasonal boundaries and this is important because water resources in our region often change within a year based on the bimodal precipitation patterns of the area. I note the results of the Kendall test in the text of the document, but also show the results graphically and report the linear (monthly) trends and the associated statistics from linear regression analysis. In each section, below, I provide further details and justifications for the data summary and analysis method(s) used.

Precipitation Data

Data Collection. The primary focus of this report is on water resources, so it is appropriate to begin with an analysis of precipitation. The Pima County RFCD operates and maintains a network of real-time sensors used to collect data on precipitation, stormwater runoff, and other meteorological conditions. The precipitation gages are tipping buckets, which measure rainfall depth in 1mm increments (but reported values are in inches). Using radio telemetry, sensors report data in the National Weather Service Automated Local Evaluation in Real Time (ALERT) format. ALERT system sensors are event driven and transmit data in real-time to base station computers at the District's office and the Tucson National Weather Service office. Currently, the ALERT system includes 93 precipitation, 36 stream, and 4 weather station sites located in Pima and adjacent counties. There are seven precipitation gages in the Cienega watershed (numbers 4410, 4310, 4320, 4290, 4250, 4270, 4280; Figure 4). For this report, precipitation data are summarized for the period January 1990 through December 2011. Data gaps exist for some gages. For example, gages 4410, 4290,

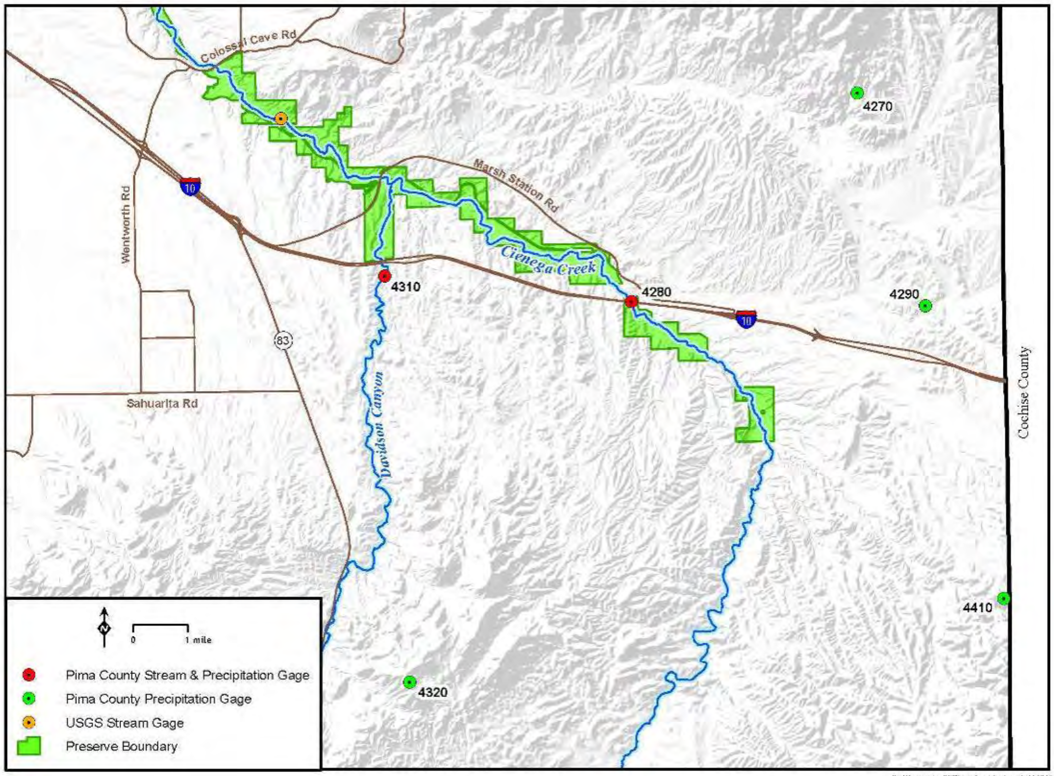


Figure 4. Location of precipitation and/or stream gages in relation to the Cienega Creek Natural Preserve. The USGS Stream Gage is the "Pantano Wash Near Vail, AZ" (site #09484600).

and 4270 were not in operation until 1993, while some gages were inoperable for a few time periods from 1990-2011. In general, the precipitation record for the Cienega Creek watershed is fairly robust and informative.

Analysis. Raw data are collected continuously at these gages, but for this analysis I obtained a monthly precipitation total for each gage. Using these data I first summarized mean annual precipitation $\pm$ 1 SD across all seven sites to understand the spatial distribution of precipitation in the watershed. I tested for linear trends in annual rainfall from 1990 through 2011 using linear and polynomial regression. Polynomial regression is a form of linear regression in which the relationship between the independent variable *x* and the dependent variable *y* is modeled as an *n*th order polynomial. I tested for 2^{nd} and 3^{rd} order polynomials and looked for the combination of variables that explained the most variation in the data, as expressed by R^2. Polynomials are useful for data such as precipitation, which can be cyclical among years. I also investigated seasonal precipitation patterns using one-way analysis of variance (ANOVA), where seasons were noted as: Winter (October-April) and Summer (May-September), which correspond to annual precipitation regime of our region (i.e., winter precipitation patterns come primarily from the Pacific Ocean and summer monsoon moisture comes primarily from the Gulf of Mexico). I also looked for spatial trends in precipitation; that is to determine if there were differences in precipitation over time among the different gages. I used multiple regression for this using gage, year, and gage*year interaction. I also tested for differences in monthly precipitation data among gages using the Tukey-Kramer, which is used in conjunction with an analysis of variance to look at differences among groups (in this case, gages).

Finally, precipitation data was used as a key explanatory variable throughout this document; in other words to explain observed changes in other parameters. Where precipitation was used for this purpose, it is explained in the appropriate section, below.

Streamflow

Streamflow in Cienega Creek was measured using two primary methods: 1) a hand-held flow meter, 2) continuous discharge measurements from the permanent USGS stream gage at Pantano and 3) during discrete flooding events at two stream gages located near I-10 (at Davidson Canyon and Cienega Creek; see Figure 4).

Flow Measurements Using Hand-held Meter

Streamflow volume is the quantity of surface water and is typically measured in cubic feet/second (CFS). Direct measures of streamflow have been taken at various times and using various methods since 1979. Data were collected sporadically and with unknown equipment during the late 1970s and early 1980s. Because no information is available on these methods of data collection, they are not included in this report. Instead, I summarize the two efforts that are well documented and that collected data at the same two sites over time at: 1) Marsh Station Road Bridge, downstream from the Cienega/Davidson confluence, and 2) Tilted Beds, several miles upstream from Marsh Station; Figure 5).

Arizona Outstanding Waters effort, Arizona 1987-1993. The RFCD, PAG, and the Arizona Department of Environmental Quality (ADEQ) collected baseline data for the designation of Cienega Creek as an Arizona Outstanding Waters. It is not known what specific instruments were used, but Fonseca (1994) indicates that a current meter was used. Measurements were made on a single occasion for an instantaneous measurement of flow, which is assumed to represent the baseflow for that sampling period. The number and timing of sampling was inconsistent, especially at the Tilted Beds site (Table 1).

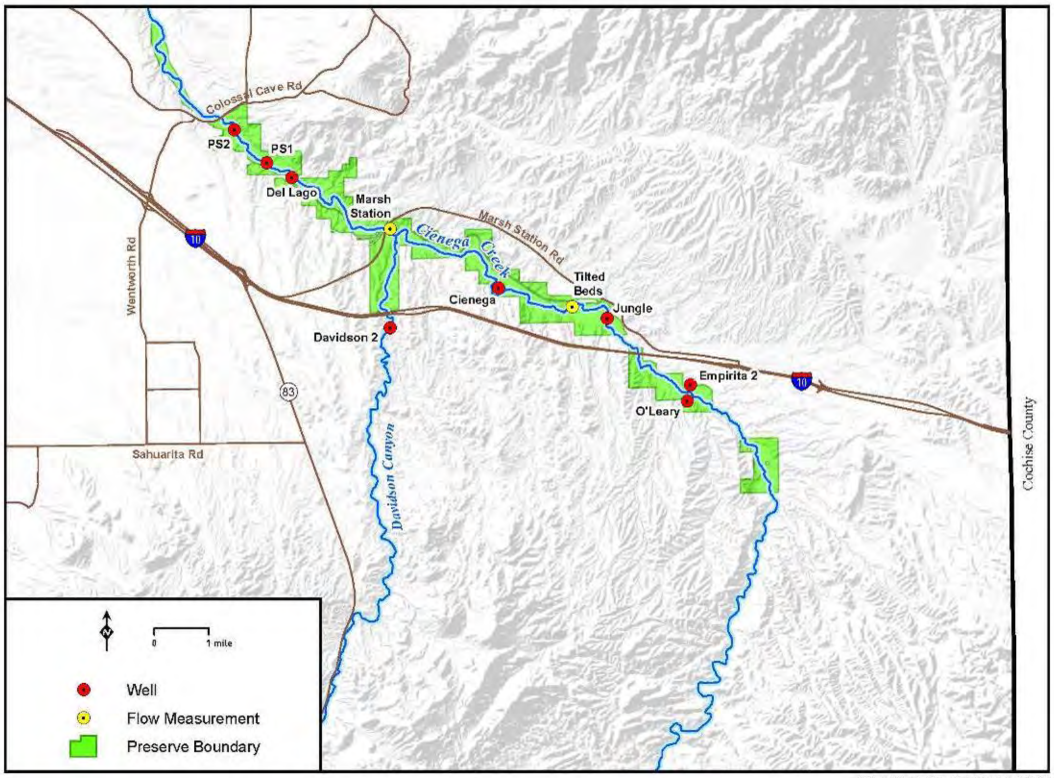


Figure 5. Location of flow measurement and well monitoring sites in the Cienega Creek Natural Preserve.

Table 1. Number of stream flow sampling events in support of the Arizona Outstanding Waters designation at two sites along Cienega Creek at the Cienega Creek Natural Preserve.

	Site	
Year	Tilted Beds	Marsh Station
1987		3
1988		5
1989	5	6
1990	2	6
1991	0	6
1992	1	6
1993	1	2

Pima Association of Governments, 1993-2011. PAG continued the previous effort starting in 1993, though sampling events were inconsistent until 1996. Since that time, PAG has consistently monitored flow at the two monitoring sites in each month of the year. PAG used a pygmy flow meter (Qualimetrics brand, Model 6660) and calculated discharge in CFS. To accurately represent baseflow, monitoring did not take place if a significant rainfall event occurred within three days prior to a scheduled field event. If a precipitation event did occur within three days, sampling was postponed until drier conditions prevailed. (However, a review of the data for both sites revealed that on a few occasions flood events were occurring. Data were recorded noted as "flood event", but these data were excluded for this analysis.) Streamflow measurements were taken at a location along the stream where the channel was relatively straight and streamflow was fairly uniform. When possible, points of converging and diverging flow paths were avoided. Because stream form can change between monthly visits, the actually monitoring locations varied by up to 10 m. The pygmy meter was sometimes employed at the Tilted Beds site, but the stream velocities at that site were often too low to be accurately measured using this method. Therefore, most discharge measurements at the Tilted Beds site were made by catching the flow into a 22-quart bucket. The volume collected and the time required for the volume to be collected were measured. The waterfall usually included most, if not all, of the discharge.

Data Analysis. For the Marsh Station Bridge site, I performed a seasonal Kendall test from 1990-2011. I also used logistical regression for each of the 12-months of sampling, with the total number of years in each monthly test dependent on the start of sampling in that particular month. That is, because some years and months did not have data, logistical regression was performed starting at the first month and year of data collection. Because of the high number of visits with no flow at the Titled Beds site, I did not perform statistical analyses on these data, but I present them in box plots to show the distribution of information. Box plots are a convenient way of graphically depicting groups of numerical data using 5-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and sample maximum.

Baseflow Volume: Stream Gaging Stations

Summary of the Data. Permanent stream gaging stations are one of the most important tools in the U.S. for measuring and monitoring streamflow. Streamflow is measured via a float device within the steel housing of the gage (Figure 6). This float marks the stage height, which is converted to cubic feet/second by way of calculating the stream channel characteristics. Technicians periodically visit the site to check for problems and recalibrate the flow measurements. Data are collected approximately every 15 minutes, though it can be more frequently during high-flow events. There are three stream gages within the Preserve. The primary gage is administered by the USGS (gage #9484600) and is located along the Pantano Wash near Vail (Figure 4). Two other gages are run by the Pima County Regional Flood Control District and the gages are located near to I-10 in both Cienega Creek (gage #4283; see Figure 4) and Davidson Canyon (gage #4313). Those gages differ somewhat from the USGS gage in that the RFCD gages consist of a pressure transducer within a conduit housing to measure stream height in real time and on an event-driven basis. For analysis, I

Figure 6. The permanent USGS stream gage at the Pantano Wash site, 2010.

used data from all three rain gages from January 1, 1990 through-December 31, 2011 and obtained mean daily discharge (cubic feet/second) measurements for each of the >8,000 days during this time period.

The two gages located along Davidson Canyon and Cienega Creek are located along currently ephemeral reaches of the two creeks. Because the gages record streamflow only during a flood, there were few measurements from these gages. From 1990-2011, the Davidson Canyon gages recorded data on 95 days and the Cienega Creek gage on 160 days during the same period.

The Pantano gage, an official USGS streamgage, is located in a perennial-flow section of the Pantano Wash before the water is diverted to Del Lago golf course (Figure 6). This gage recorded a continuous baseflow measurement record from 1990-2011. Observations are reported as mean daily CFS.

Analysis. I summarized the number of days in each year where data were recorded at each of these gages and calculated total annual discharge in acre-feet. I did not test for trends in the actual discharge measurements (i.e., mean daily discharge) because of the high number of days with no measured streamflow (i.e., many 0 values). By contrast, the Pantano Wash gage had a continuous streamflow and therefore the opportunity to discover trends was greatest. For the analysis of the Pantano gage, I first summarized the mean + SD for each month over the 21-year record to test for the seasonality of streamflow among months.

The overall Seasonal Kendall trend slope for data from the Pantano Wash gage was computed as the median of all slopes between data points within the same season (month). To prepare the data for the Seasonal Kendall test, I obtained the median monthly flow rate, because the median rate better reflects baseflow conditions (as opposed the mean, which can be influenced by extreme flooding events). I also plotted median annual discharge from 1990-2011 to graphically show the trends in baseflow conditions over time.

Comparison of Flow Measurements and the Pantano Stream Gage

Analysis. I sought to understand two sets of relationships between data sets to better understand the dynamics of the system and to inform the efficiency of monitoring in the future. The two comparisons of Streamflow were: 1) Tilted Beds to Marsh Station Road and 2) Marsh Station Bridge to the Pantano gage. I used a pairwise correlation comparison. This is matrix of correlation coefficients that summarizes the strength of the linear relationships between each pair of response (*y*) variables, in this case monthly streamflow measurements. For these analyses, I included only those observations from January 1995 to December 2011, which represented the most continuous period of record. I excluded those pairs of observations for which there was no flow at the Tilted Beds site. In the comparison of Marsh Station Bridge to the Pantano gage, I used the median measurement at the Pantano gage to represent the baseflow conditions of the stream. I also used the median flow for the first 10 days of each month, because no data existed on which day discharge data were collected by PAG, though the data collection period for PAG was approximately in the first week of each month. After performing an overall correlation analysis, I sought to understand seasonal differences in these observations. Therefore, I performed separate analyses for each month of the year, irrespective of trend over time.

Comparison of Flow to Precipitation

I used the monthly rainfall totals, averaged among all seven precipitation gage sites within the watershed, to determine the influence of precipitation on streamflow discharge, as measured at the Pantano gage. For the Pantano gage I used the mean daily flow measurement from the last day of each month from 1990-2011. I used the last day because precipitation totals for each month go through to the last day of each month. For this analysis I used multiple regression and in addition to precipitation measurements, I also included other variables to explain variations in the data. Specifically, I tested for the effect of year, month, and year*month interactive effect.

Extent of Streamflow (Wet/Dry Mapping)

Methods. Wet/dry mapping has a relatively long history at Cienega Creek, with the first data collected in 1908 (Fonseca 1993). The next mapping efforts in the mid and late-1970's and early 1980's were sporadic, but from late 1984-1991, there was a consistent record of sampling 4-5 times per year (Table 2). Data during this period were collected by way of aerial photography over the creek, which was paid for by a company seeking approval of a proposed development near the Preserve (Julia Fonseca, *personal communication*). Julia Fonseca interpreted these aerial images as part of the County's instream flow application for Cienega Creek (Fonseca 1993). The survey area for this effort was from just downstream of where Cienega Creek crosses under Interstate 10 (east side) to the Pantano Dam (west side). As part of the current reporting effort, Mike List (Pima County IT department) translated the Data from Fonseca 1993 and input these data into a GIS layer for this analysis. These data will be posted to the County's GIS library for future reference. On three occasions (one occasion in 1974 and two occasions in 1988) there was an incomplete survey of the creek; those data were excluded from this analysis.

From 2001-present, the PAG has carried out quarterly monitoring (March, June, September, and December) at much the same location as previous efforts, except they exclude a 1.5 mile stretch starting downstream of the confluence of I-10 and Cienega Creek. That stretch is included in this analysis as "dry" because repeated surveys along that stretch have found this to be the case; the last time it was known to have baseflow was in the 1980's. The PAG effort involves mapping by way of walking the length of the creek channel and marking the location (or start/stop points) of surface water in the creek. PAG has also conducted walk-throughs on Lower Davidson Canyon near its confluence with Cienega Creek since 2001 and in upper Davidson Canyon, south of Interstate 10 on the County's Bar V property, since 2005. Those data are not summarized in this report. Also not summarized are data from March, September, and December 2010 and 2011; those data were collected, but have not been analyzed by PAG.

Table 2. Summary of perennial surface mapping at the Cienega Creek Preserve since 1974. Because sampling occurred at different months and dates over time, seasons are defined as: Winter: 11/15-1/31, Spring: 2/1-3/31, Pre-monsoon: 4/1-7/1, Monsoon: 7/2-10/1.

	Season			
Year(s)	Spring	Pre-monsoon	Monsoon	Winter
1975			X	
1976-77		No surveys		
1978			X	
1979				X
1980-81		No surveys		
1982				X
1983		No surveys		
1984			X	X
1985		X	X	X
1986	X	X	X	X
1987	X	X	X	X
1988	X	X	X	X
1989	X	X	X	X
1990	X	X	X	X
1991	X	X	X	X
1992-98		No surveys		
1999		X		
2000		X		
2001		X	X	X
2002	X	X	X	X
2003	X	X	X	X
2004	X	X	X	X
2005	X	X	X	X
2006	X	X	X	X
2007	X	X	X	X
2008	X	X	X	X
2009	X	X	X	X
2010	X	X	X[a]	X[a]
2011	X[a]	X	X[a]	X[a]

X[a] Data collected but not analyzed.

Analysis. The total length of streamflow for each sampling event was determined through GIS analysis of the data and summarized as number of miles with perennial flow. I performed linear regression analysis using all observations and seasons, but also separated analyses for each season. I used the monthly rainfall totals, averaged among all seven sites within the watershed, to determine the influence of precipitation on surface water extent. For this analysis I used multiple regression included other variables to explain variations in the surfacewater data. Specifically, I tested for the effect of year, month, and year*month interactive effect, and precipitation from the previous month because of the time lag between precipitation and flow extent conditions.

Depth to Groundwater

Methods. Depths to groundwater were measured at eight wells with either a Solinst Water Level Meter or with in situ transducers. The monitoring wells are distributed throughout the Preserve but occur in different geological contexts. On a monthly basis and when accessible, PAG monitored the O'Leary, Jungle, Cienega, Del Lago 1 and Empirita 2 well sites. The Davidson 2 was monitored on a quarterly schedule. The PS-1 and PN-2 wells were monitored four times a day by ADWR transducers and the data was summarized as the mean measurement per month.

Analysis. I tested for linear trends for each of the 8 wells using linear regression. I used the monthly rainfall totals, averaged among all seven sites within the watershed, to determine the influence of precipitation on depth to water in the wells that were mentioned previously. For these analyses I used multiple regression. Precipitation was for the one and two months prior to measurement of depth to groundwater. I also included other variables to explain variations in the data, specifically, I tested for the effect of year, month, and year*month interactive effect.

Drought: A Look at Regional Climate

Methods and Analysis. Changes in water characteristics at Cienega Creek such as streamflow and volume are the result of a host of site-specific factors such as rainfall and land-use within the watershed. Broader-scale climate factors are also key to understanding changes at Cienega Creek and a key dataset is the Palmer Drought Severity Index. The index was developed by Wayne Palmer in the 1960s and uses temperature and rainfall information in a formula to determine dryness. It has become the semi-official drought index and is most effective in determining long term drought—a matter of several months—and is not as good with short-term forecasts (a matter of weeks). It uses a 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is moderate drought, minus 3 is severe drought, and minus 4 is extreme drought. I summarized data from "southeastern" Arizona, which includes Pima, Santa Cruz, and Cochise counties. Data are summarized monthly from 1895-2011 and from 1990-2011, the focal period for this report. These data were used to understand if the observed patterns at the Preserve could be explained, in part using the broader, regional trend in the Palmer index.

Results

Precipitation

From 1990-2011, mean annual precipitation was 11.2 inches and ranged from 6.5 inches in 2009 to 15.1 inches in 2000 (Figure 7), which was similar to areas around the Tucson basin. As was expected, precipitation varied by month, when averaged across all seven sites within the Cienega watershed (Figure 8), with July and August having the greatest total rainfall of any other month and together accounting for one half of the average annual rainfall.

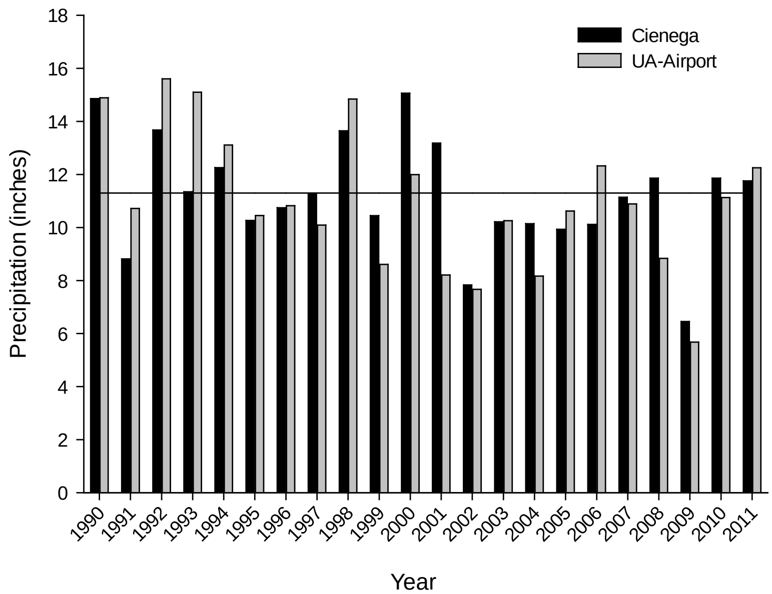


Figure 7. Total annual precipitation averaged among all seven sites in the Cienega Valley and compared to the mean annual precipitation, averaged for both the University of Arizona (UA) and the Tucson International Airport. Solid line is the long-term average at the Tucson International Airport.

There was considerable inter-site variation in rainfall during the period of record, with sites varying in total annual rainfall (one-way ANOVA; $F_{6,126}$ = 9.28, *P* = <0.001), after accounting for the effect of year. Mean annual rainfall was highest for the Davidson Canyon gage (site 4310; 13.9 $\pm$ 3.8 [SD] inches) and lowest for the Empire Peak gage (site 4310; 7.5 $\pm$ 2.6 [SD] inches). The other four sites were not statistically different (based on Tukey-Kramer HSD test at 95% difference) and all had mean annual precipitation measurements of approximately 10.5 inches. Taken together, the combination of site and year was a good predictor of mean annual rainfall (multiple linear regression; $F_{27, 117}$ = 9.3, *P* = <0.001, R^2 = 0.64).

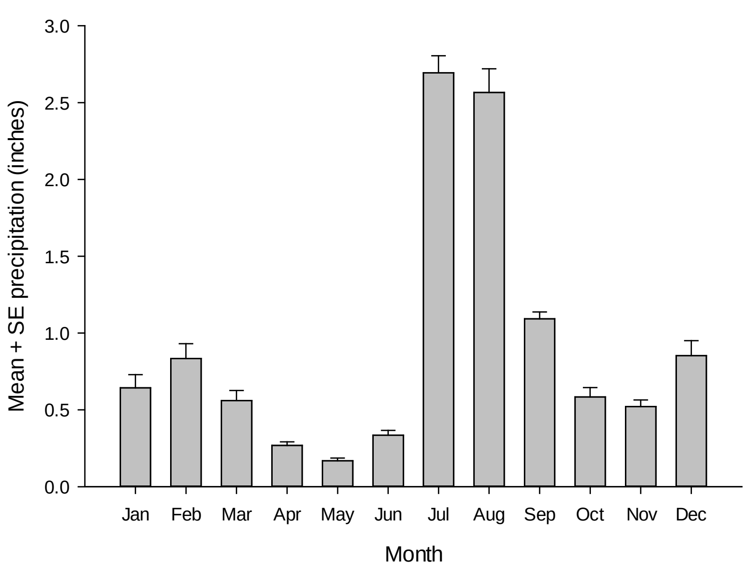


Figure 8. Mean monthly precipitation ($\pm$ 1SE), averaged across the seven gage sites in the Cienega watershed, 1990-2011.

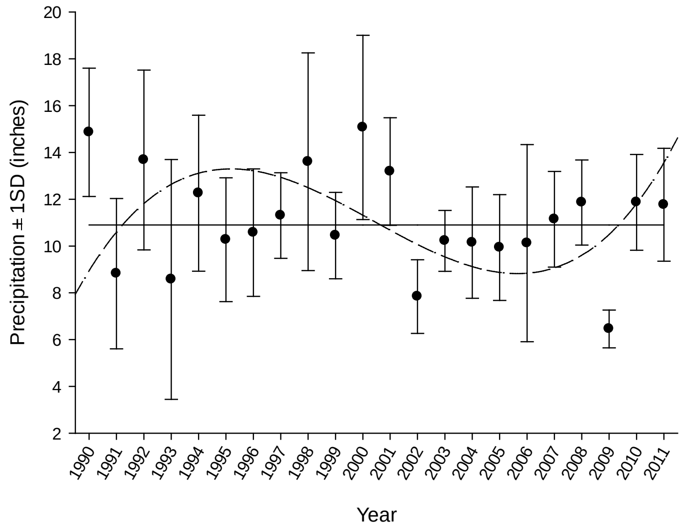


Figure 9. Mean precipitation from seven precipitation gages near the Cienega Creek Natural Preserve. Solid line is the mean annual precipitation for this period of record. Dashed line is the 3rd order polynomial that maximizes the amount of variation explained in the data. Error bars are larger for 1993 in part because data existed for only 5 sites.

From 1990-2011, there was a negative trend in precipitation, but after taking into account the effect of the precipitation gage, there was no statistically significant linear trend (multiple regression $F_{1,131}$ = 0.57, P = 0.45, R^2 = -0.003). I also fit a set of polynomial models to help explain variation in the data (Figure 9). The model that explained the most variation in the data was a 3rd order polynomial (Figure 9; $F_{3,56}$ = 3.5, P = 0.02, R^2 = 0.06), which shows the cyclical nature of wet and dry periods in the Cienega watershed during this period. There was no spatial trend in precipitation among sites (multiple regression $F_{6,6}$ = 0.53, P = 0.77).

Mean monthly summer rainfall (June-October) averaged 6.8 inches, while winter rainfall (November-May) averaged 4.1 inches (*t*-test for difference among group; t_{263} = 11.2, P = <0.0001). Despite seasonal changes in mean monthly precipitation totals from 1993-2011, there was no statistically significant trends within the summer (linear regression on log-transformed data; $F_{1,82}$ = 1.5, P = 0.21, R^2 = 0.006; Figure 10) nor the winter months ($F_{1,82}$ = 1.7, P = 0.17, R^2 = 0.007; Figure 10).

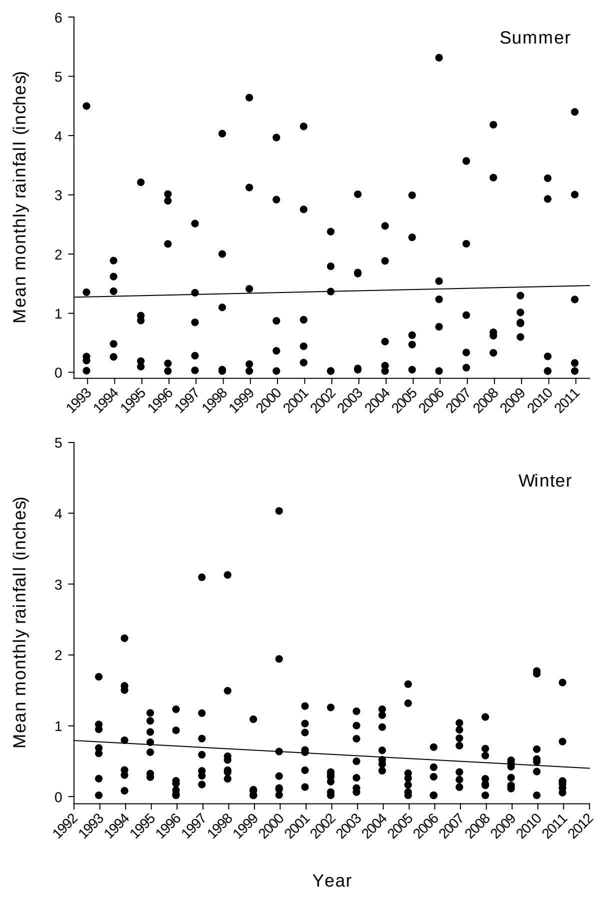


Figure 10. Seasonal differences in precipitation within the Cienega watershed, 1993-2011. Seasons: Winter (October-April) and Summer (May-September). Trends are not statistically significant.

Streamflow: Baseflow and Discharge

Baseflow measured using hand-held meters. Baseflow at the Tilted Beds site was sporadic (Figure 11); from 1996-2011, there was no flow in five of the years and in many years, flow was restricted to only a few occurrences.

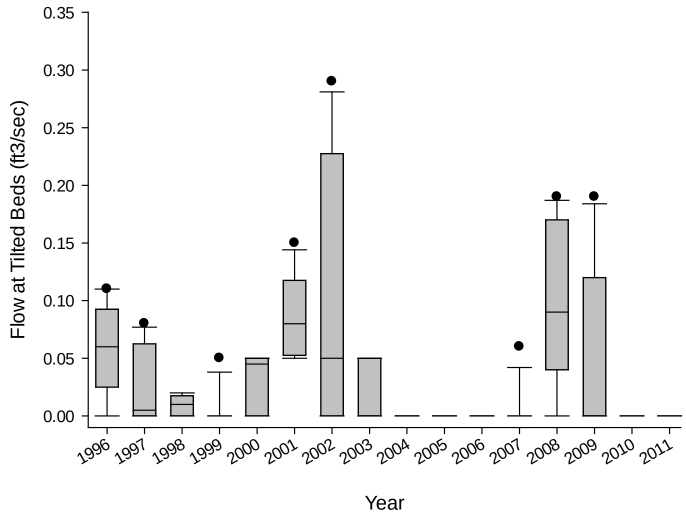
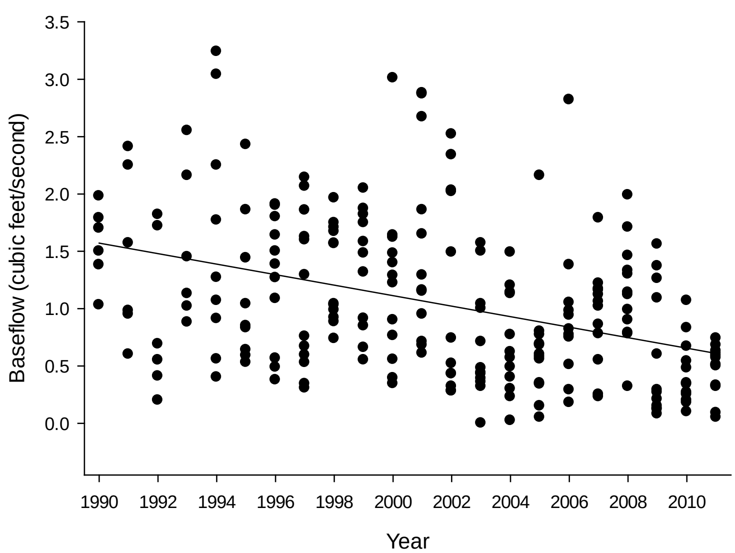


Figure 11. Box plot showing baseflow at the Tilted Beds site. The site was visited in each month during this period of observation, so missing data is the result of no flow observations. Statistical analyses were not performed on these data due to lack of flow at this site over time. Box plots show the variability of flow measurements at these sites.

Baseflow at Marsh Station Bridge showed a significant decline from 1990-2011. This declining trend is confirmed by the Seasonal Kendall Trend Test (slope = 1.485 + -0.05*Time[year]; tau correlation =-0.417, z = -8.68, P = 0.0003). A similar trend was found using linear regression ($F_{1,242}$ = 53.4, P = <0.0001, R^2 = 0.18; Figure 12). On one sampling occasion (in 2003) there was no recorded flow at the Marsh Station Bridge site.



linear regression analysis. In addition to a decline, the intra-annual dispersion of measurements over time also declined, especially in the last few years of record.

In all but one month there was a negative trend across the period of record (Figure 13). Negative trends in baseflow were statistically significant (i.e., P<0.05) for nine of the 12 months, which also demonstrates important seasonal differences; the months with no statistically significant trend represent the monsoon season (July, August, and September).

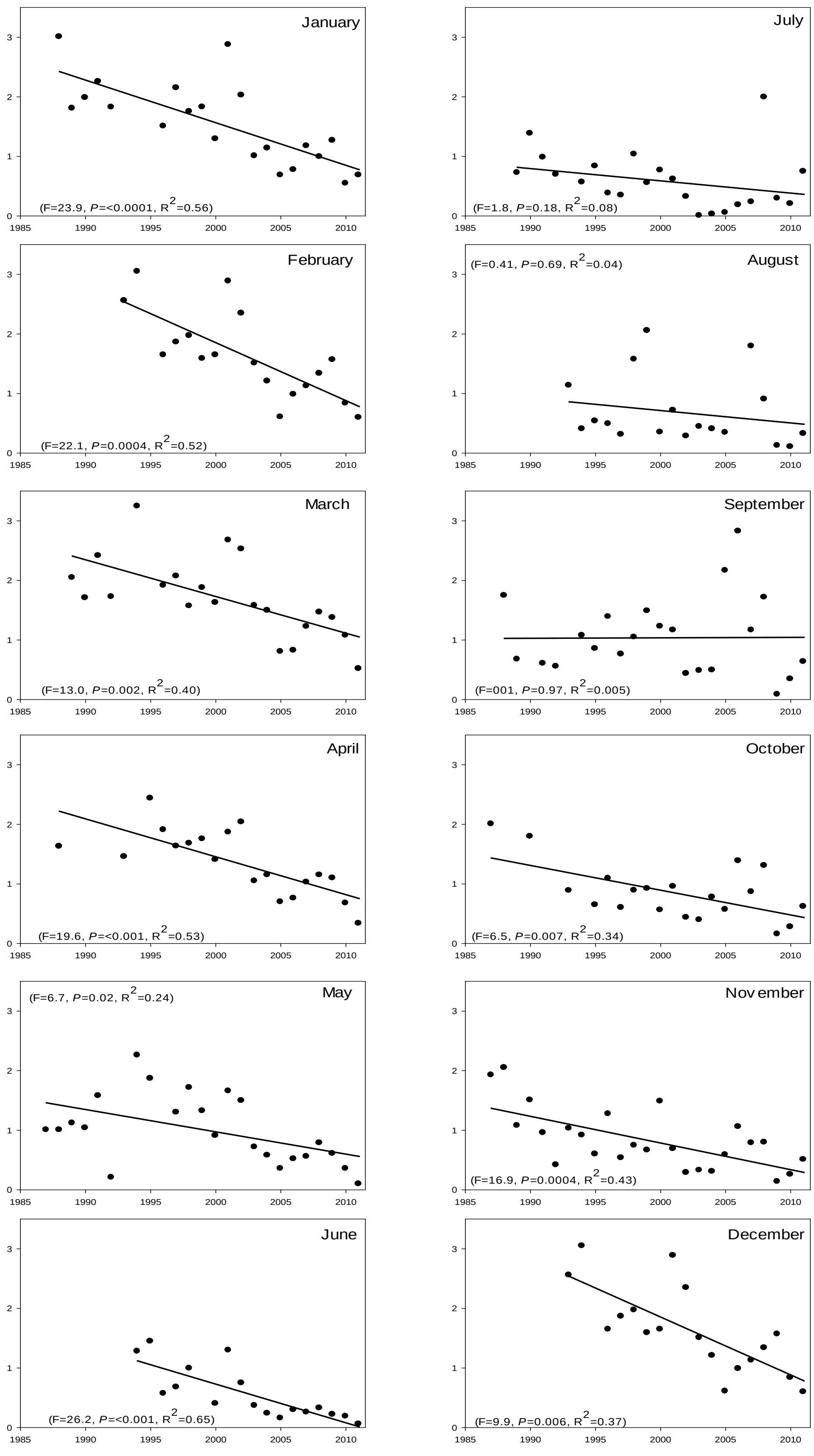


Figure 13. Baseflow measured at the Marsh Station Bridge by month. Statistics and trend lines are from linear regression analysis. Note that the period of record is different for some months.

Discharge measured at gaging stations. The number of days in a calendar year with discharge measurements at the Davidson Canyon gage ranged from zero days (for four years) to a high of 11 days in 2008 (Figure 14). The number of days with measurable flow was highest in 1990 and 2000, with each year having a total of 10 days of recorded flow. These data showed an increasing trend over time, but these trends were not statistically significant (logistic regression, $F_{1,20}$ = 0.88, P = 0.35, adjusted R^2 = -0.005). The Davidson Canyon gage had its highest discharge in 2003, a year when the Davidson gage recorded more water than the Pantano and Cienega gages combined (Figure 15). (Over 60% of the total discharge for the Davidson gage for 2003 was from three days in August 2003 and one day in particular had a total discharge of 603 acre feet, or 31% of the total discharge). Though total annual discharge increased at the Davidson Canyon gage from 1990-2011, the results were not statistically significant (logistic regression, $F_{1,16}$ = 2.4, P = 0.14, adjusted R^2 = 0.13).

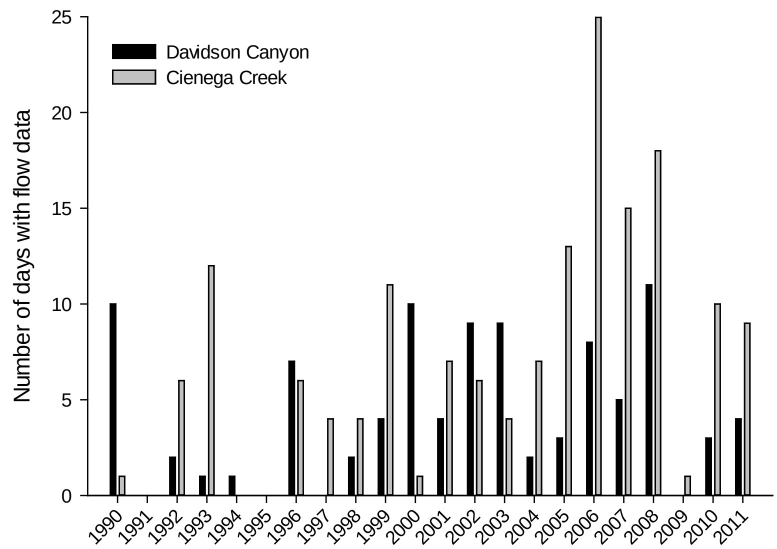


Figure 14. Number of days of measured flow at the Davidson and Cienega Creek gaging stations.

The Cienega Creek site had four years with no measureable discharge, but had seven years with $\geq$10 days of recorded discharge, including one year (2006) with 25 days of discharge measurements (Figure 14). Discharge at the Cienega Creek gage was highest in 2007 and had a number of years with none or very little measureable discharge, but there was an increasing and statistically significant trend from 1990-2011 (Figure 15; logistic regression, $F_{1,17}$ = 9.3, P = 0.007, adjusted R^2 = 0.31).

For the Pantano Gage, discharge was highest in 1998 with approximately 11,100 acre feet and lowest in 2009 with less than 500 acre feet (Figure 15). There was a significant decline in median monthly discharge from 1990-2011 at the Pantano Wash gage (Figure 16). This declining trend is confirmed by the Seasonal Kendall Trend Test (slope = 0.66 + -0.83*Time[year]; tau correlation =-0.4, z = -5.32, P <0.0001). I also adjusted the model for the effects of precipitation on streamflow, though that did little to improve the model (Seasonal Kendall Trend test with LOWESS smooth; tau correlation =-0.43, z = -5.6, P <0.0001). For graphical purposes, I also plotted the median annual discharge at the Pantano Wash gage (Figure 17).

There was considerable variation in the mean daily discharge by month (Figure 18), with the months representing the monsoon (July, August, and September) having the most variation. This variation may explain why these months were the only months that did not have a statistically significant decline from 1990-2011, which was the case for the other months of the year (Figure 19).

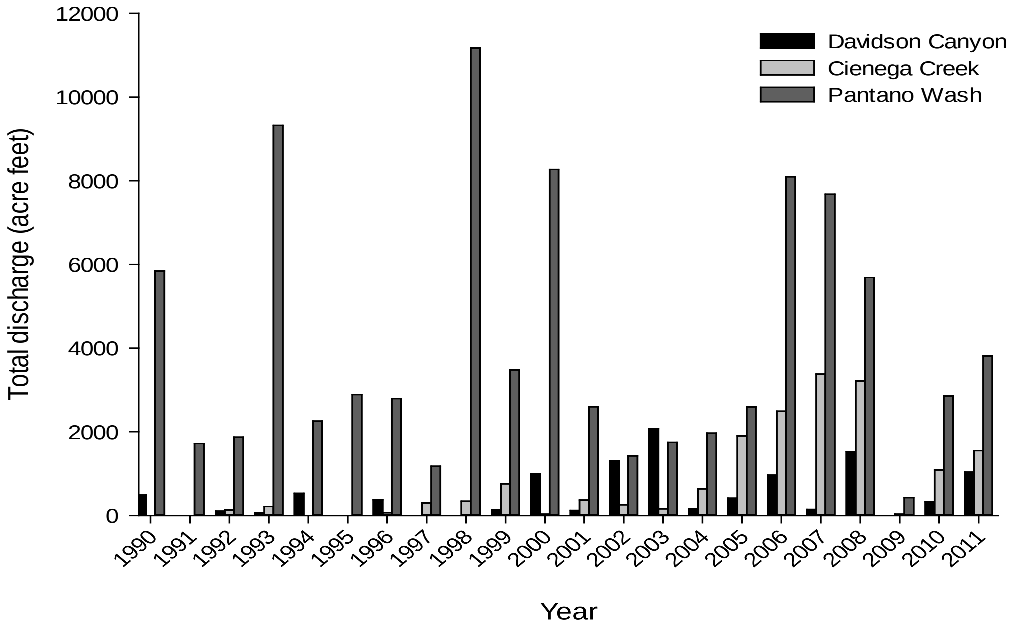


Figure 15. Total annual discharge at the three gages within the Cienega Creek Natural Preserve. Discharge at the Cienega and Davidson gage represented stormflow, whereas at the Pantano gage, total discharge represented both stormflow and baseflow. Stormflow discharge has increased at the Cienega Creek gage despite the drought.

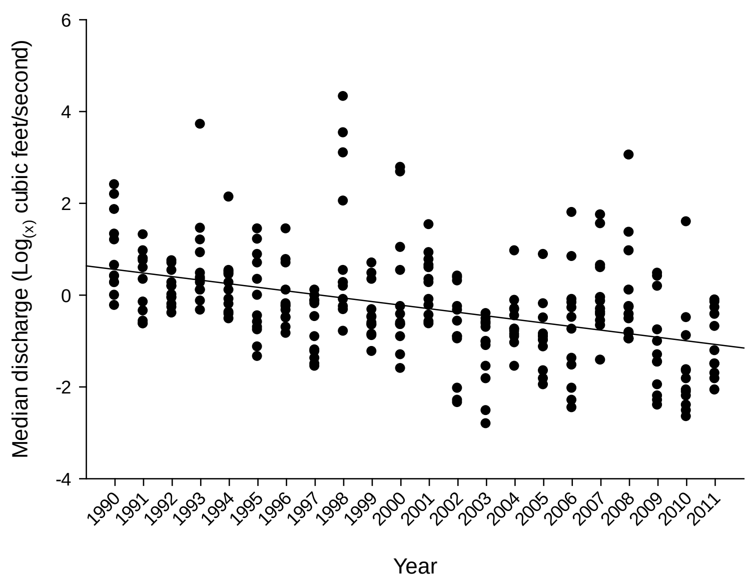


Figure 16. Median monthly discharge (natural log of cubic feet/second) measured at the Pantano Wash gage. Data and linear trend line are for graphical purposes; trend is tested for using the Seasonal Kendall test for trend and reported in the text.

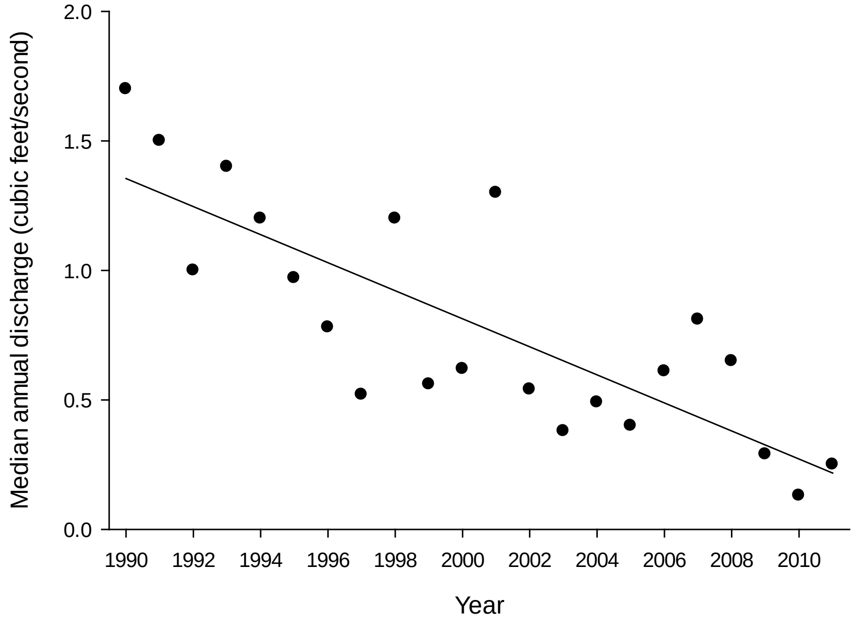


Figure 17. Median annual discharge at the Pantano Wash gage. This is a summary of the data in Figure 16, but data are not log-transformed.

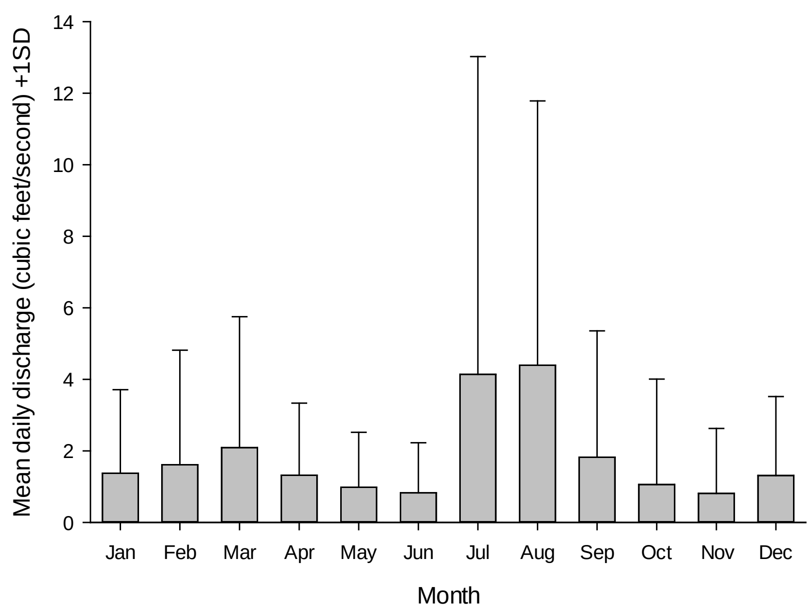


Figure 18. Mean daily discharge by month, in cubic feet/second +1 standard deviation (SD) at the Pantano Wash gage. Notice the variability of measurements in July and August, which are during the monsoon season.

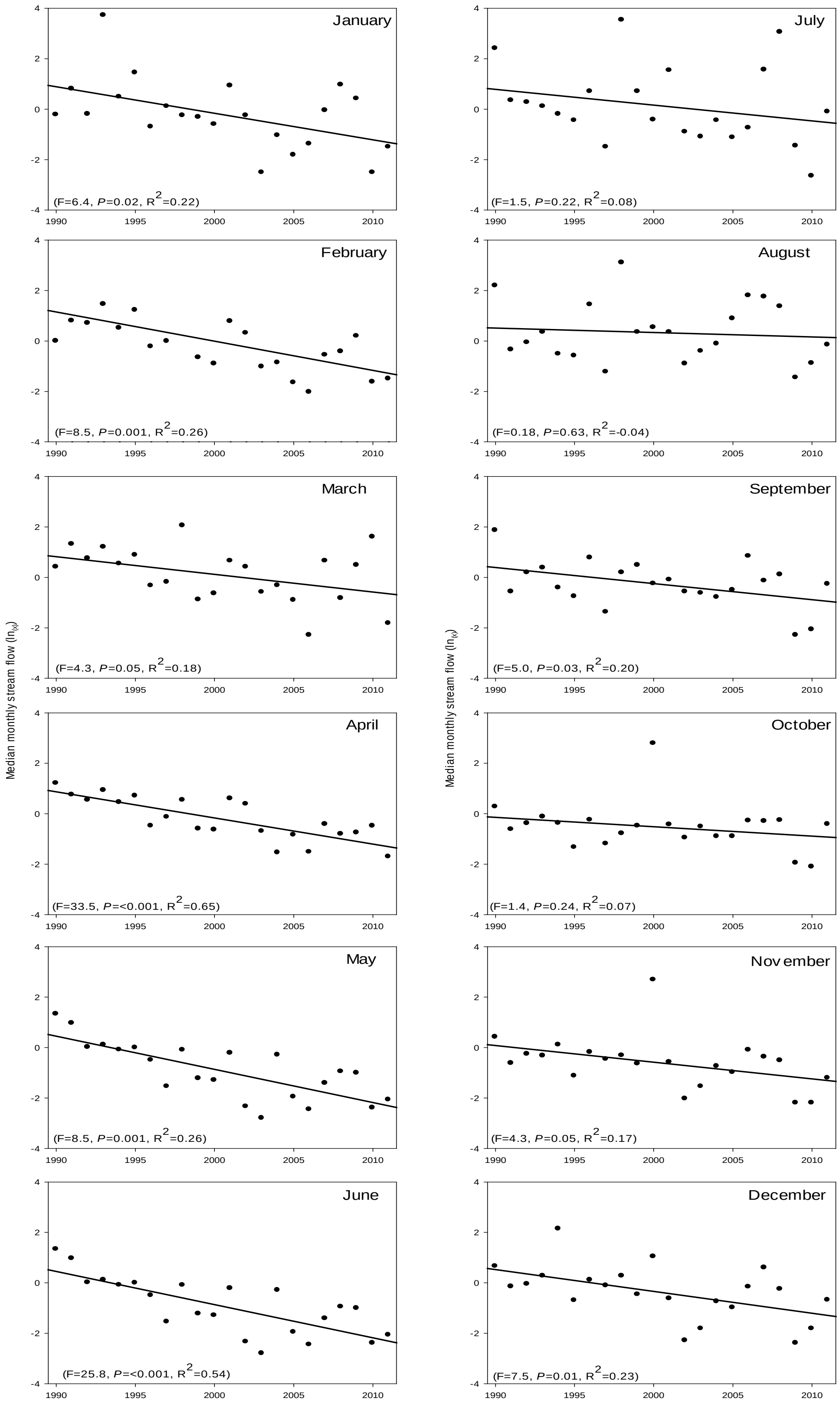


Figure 19. Discharge (natural log) measured at the Pantano gage for each month. Lines and statistics are from linear regression analysis.

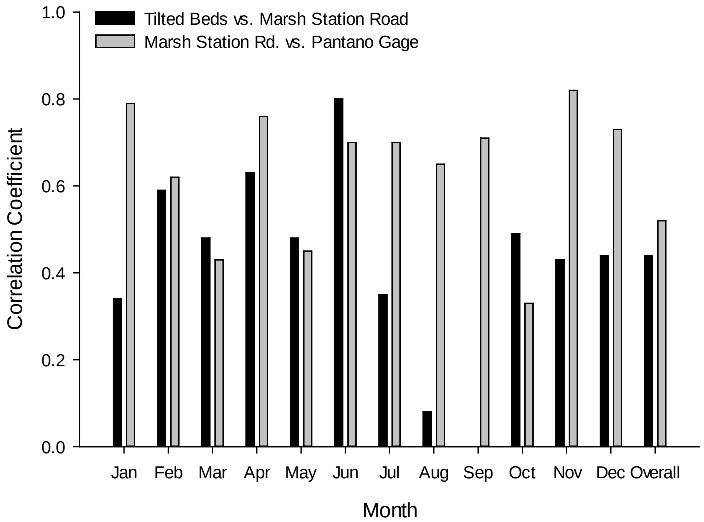


Figure 20. Pairwise correlation between flow measurements taken at the at Tilted Beds and Marsh Station Road and flow measurements at Marsh Station Rd and the natural log of median monthly flow

Influence of Precipitation on Streamflow: Pantano Gage

Mean streamflow discharge at the Pantano gage were most heavily influence by precipitation and year ($F_{4,259}$ = 33.9, *P* = <0.0001, R^2 = 0.34; Table 3).

Comparison of Streamflow Measurement Data

I compared results of Streamflow monitoring at the Tilted Beds and Marsh Station Bridge sites and found only slight correlation between the two sampling locations (total correlation coefficient = 0.45). However, there were significant differences among months, from a maximum correlation of 0.81 in June to no correlation in September (Figure 20). Comparison of the Marsh Station Bridge and the Pantano gage found a closer overall correlation (correlation coefficient = 0.52) and less monthly variation in the coefficients over time (Figure 20).

Extent of Streamflow

The extent of streamflow declined from a high of 9.5 miles from 1984 through late 1986 to a low of 1.25 miles in June of 2011 (Figure 21). The decline in extent was significant for all four seasons, but greatest in the pre-monsoon (June) and less in the winter (December; Figures 22, 23, 24; Appendix A-D). The variability of flow has also changed during the period of record (1974-2011), from relatively stable flows in the 1980s and early 1990s to highly variable flows from 2001-2009 (Figure 25).

Table 3. Results of multiple regression analysis on the relationship between streamflow discharge (natural log) and other variables thought to influence flow.

Effect	Estimate	F	df	P
Precipitation	0.66	101.9	1	<0.001
Year	-0.06	25.9	1	<0.001
Month	-0.06	6.3	1	0.012
Year*month	0.004	1.3	1	0.25

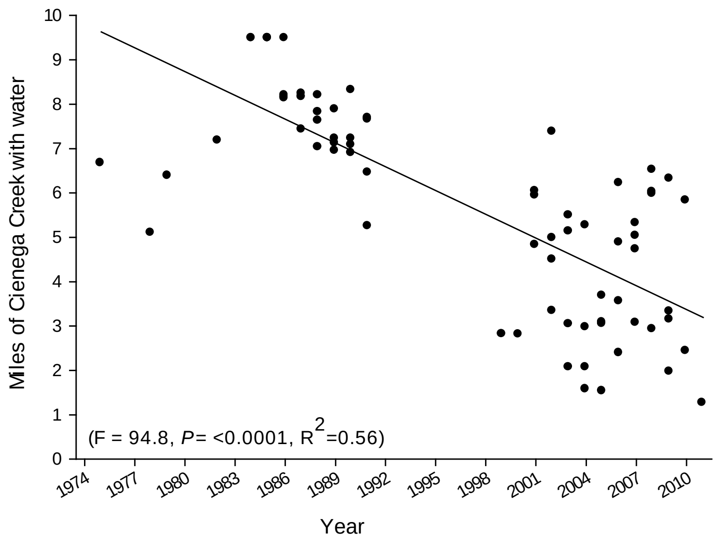


Figure 21. Extent of streamflow at the Cienega Creek Natural Preserve, using all observations. See Figure 22 for summary by season. Maximum flow extent is 9.5 miles. Solid line is from linear regression analysis.

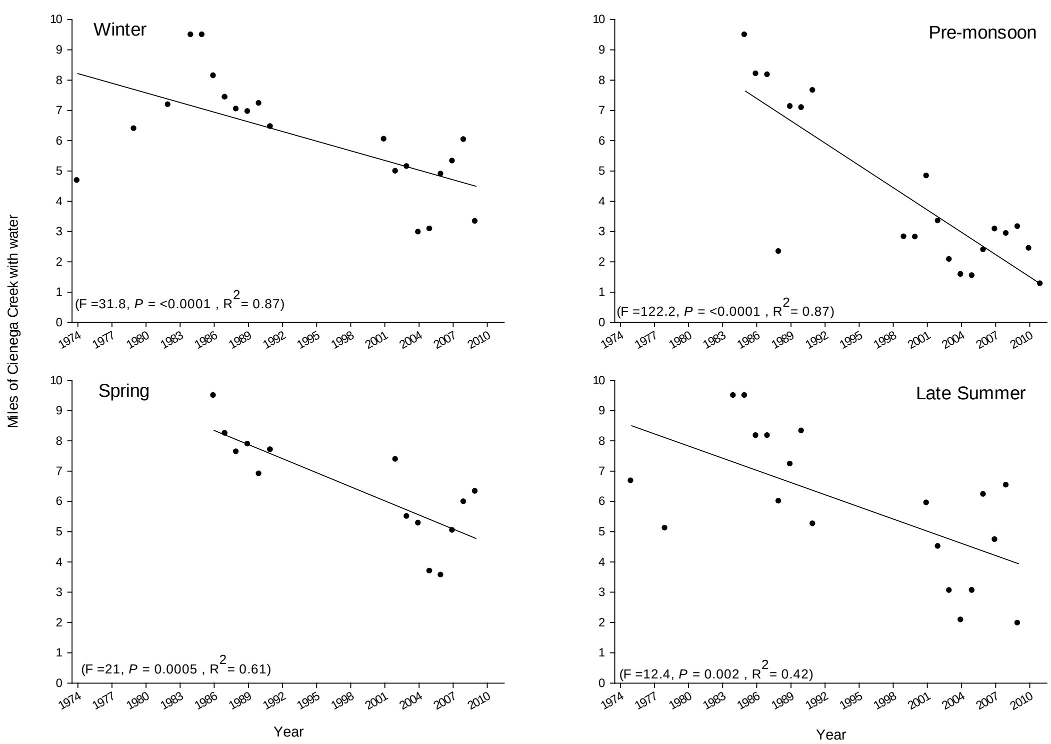


Figure 22. Extent of stream flow at the Cienega Creek Natural Preserve, by season. Maximum flow extent is 9.5 miles. Seasons are defined as: Winter (Nov 15-Jan31); Spring: (Feb 1- March 31); Pre-monsoon: Apr 1-June 30); Late summer (July 1- Nov 1).

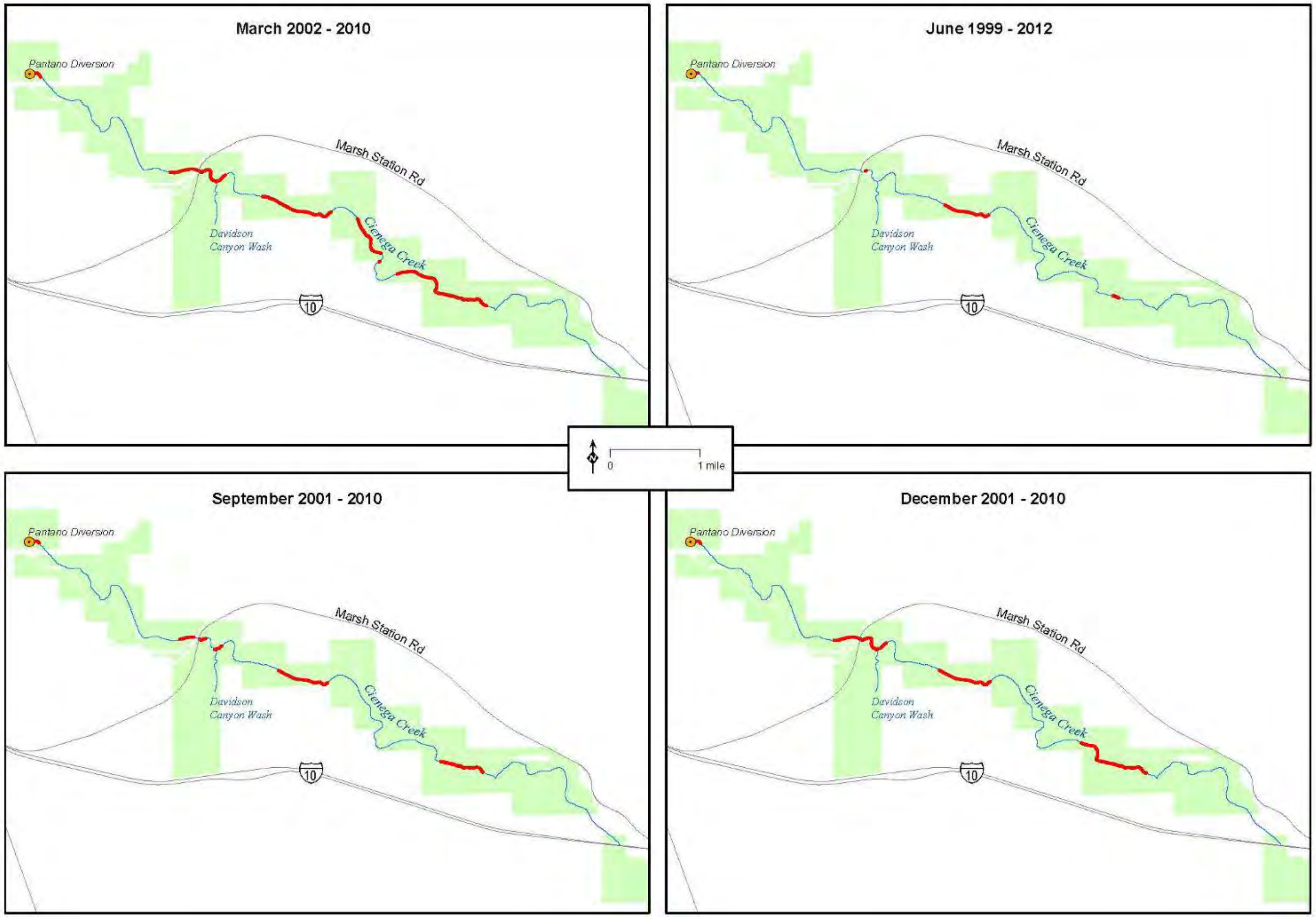


Figure 23. Minimum extent of streamflow at the Cienega Creek Preserve for the four, quarterly sampling events each year, 1999-2012.

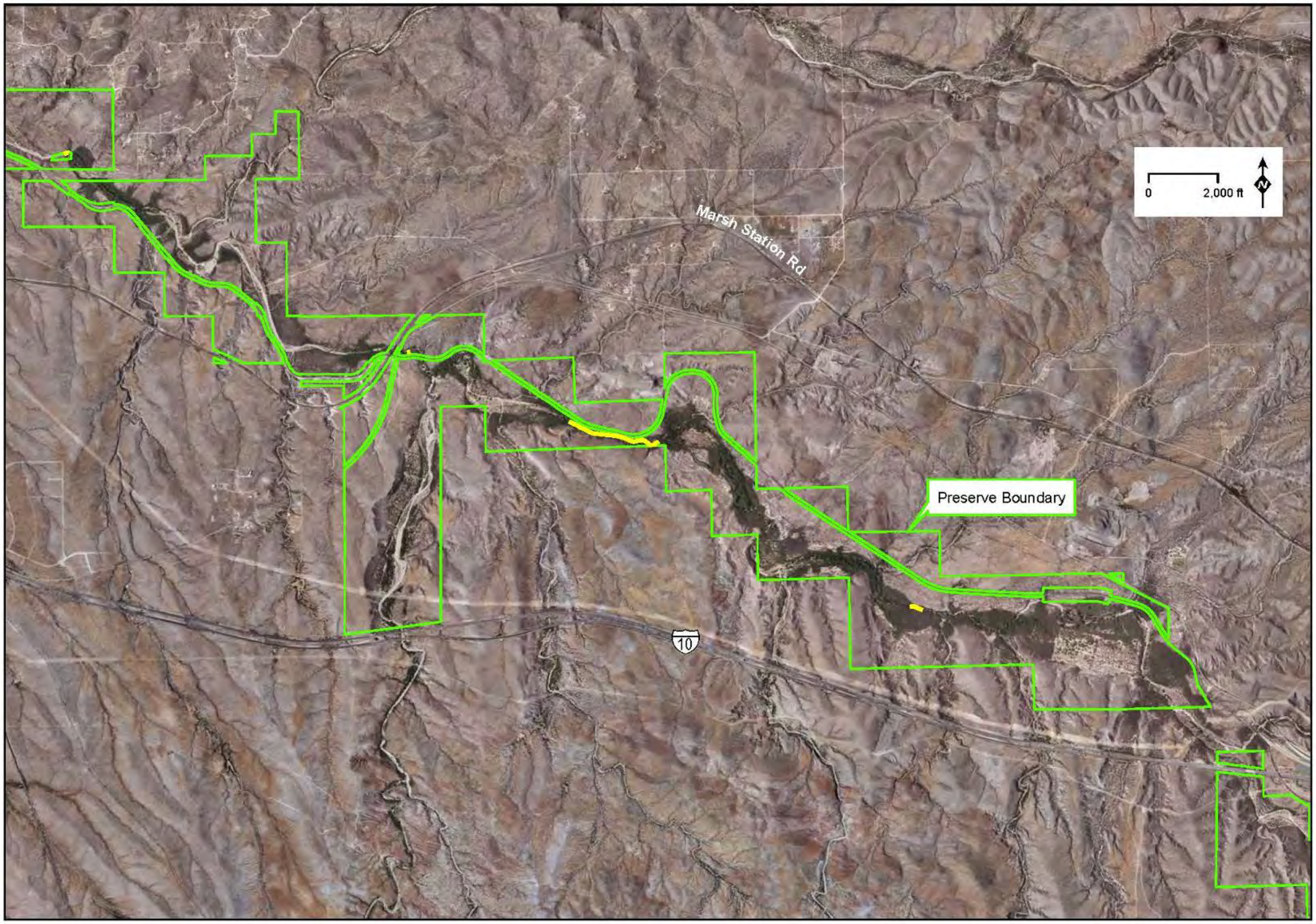


Figure 24. Minimum extent of streamflow at the Cienega Creek Preserve (noted as yellow lines or dots) for all sampling periods combined, 1999-2012.

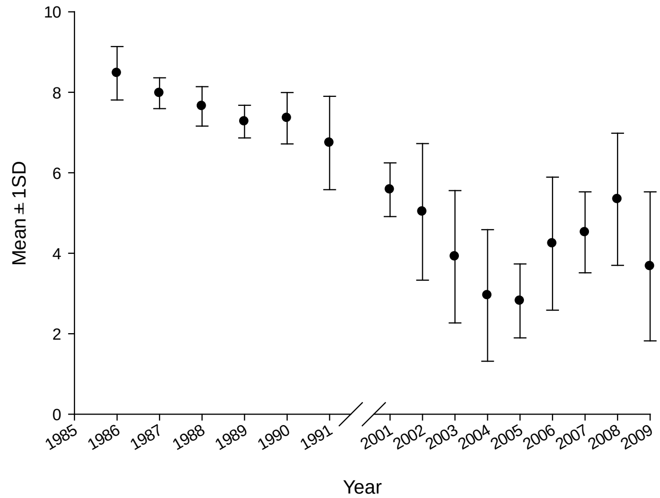


Figure 25. Mean and standard deviation of miles of streamflow for years with at least 4 seasonal measurements, Cienega Creek Natural Preserve. Note both the mean decline and the increase in variability over time.

Influence of Precipitation on Streamflow Extent

Mean streamflow extent was most influenced by year but no other factors (multiple regression, $F_{6,39}$ = 3.3, P = 0.01, R^2 = 0.34; Table 4). Flow extent did not appear to be influenced by rainfall in the one and two months prior to sampling.

Depth to Groundwater

Depth to groundwater in wells declined in all eight wells during the period of record for each well (Figure 26). The decline was most pronounced in the Empirita and Jungle wells and less pronounced in the PS-1 and PN-2 wells, which had the shorted period of record and the most intra-annual variation. Del Lago 1 also had a lot of intra-annual variation, while Empirita and Jungle has less variation (Figure 26).

Table 4. Results of multiple regression analysis on the relationship between surface flow extent other variables thought to influence extent.

Effect	Estimate	F	df	P
Precipitation from 1 month prior	0.19	0.19	1	0.6651
Precipitation from 2 months prior	0.14	0.33	1	0.5705
Year	-0.16	13.42	1	0.0007
Month	-0.05	0.47	1	0.4932
Year*month	-0.0005	<0.01	1	1.0000

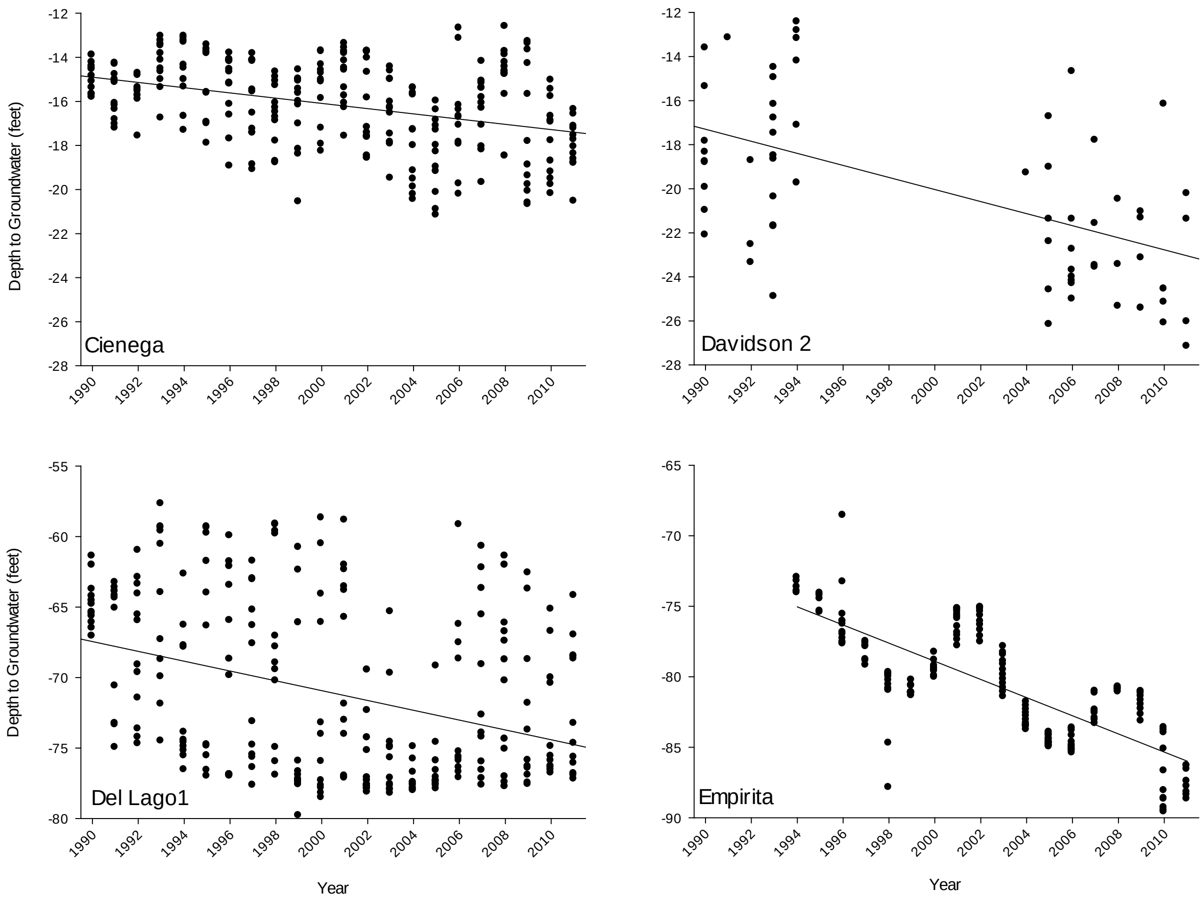


Figure 26. Depth to groundwater from monthly measurement and linear regression analysis by well, Cienega Creek Preserve. Note scale differences in vertical (X) axes.

Total precipitation and lag (in months) did not have high correlation with depth to water measurements (Table 5). Depth to water at the various wells were associated with different explanatory variables (Table 6), but the influence of year was consistently strong (i.e., P<0.01) for all but one well. The association between depth to water and precipitation varied among wells.

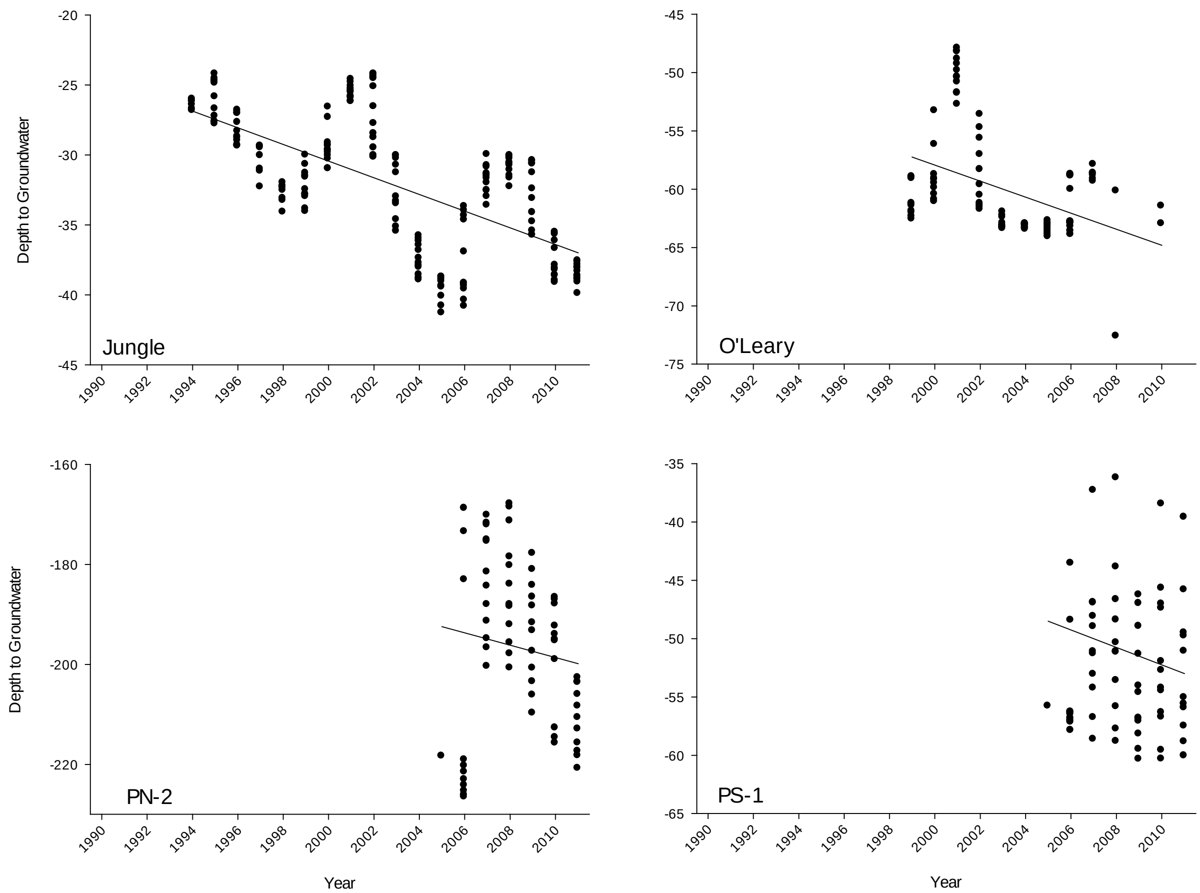


Figure 26, cont.

Table 5. Correlation coefficients between various measures of flow (Pantano Gage) and precipitation and groundwater levels at wells within or near to the Cienega Creek Natural Preserve. Data from 1990-2011. Correlations in bold show a $\geq$50% correlation. "Totals from previous number of months" is a measure of past precipitation. For example, "2" is the sum of the rainfall from previous two months.

	Flow at the Pantano Gage		Precipitation					
			Lag (Months)			Totals from previous number of months		
Well	1 month prior	2 months prior	1	2	3	1	2	3
Cienega	0.45	0.31	0.22	0.12	-0.02	0.22	0.21	0.16
Davidson #2	**0.61**	**0.54**	0.48	**0.50**	0.09	0.48	**0.58**	**0.57**
Del Lago #1	**0.60**	0.41	0.49	0.34	0.10	0.49	0.52	0.47
Empirita 2	0.18	0.18	0.01	-0.02	0.00	0.01	0.00	0.00
Jungle Well	0.27	0.27	0.06	0.06	0.04	0.06	0.08	0.08
O'Leary Windmill	0.15	0.18	0.11	0.07	0.10	0.11	0.11	0.14
PN-2	0.31	0.42	0.05	0.32	0.48	0.05	0.23	0.43
PS-1	**0.70**	0.47	0.71	**0.59**	0.12	**0.71**	**0.82**	**0.74**

Table 6. Results of multiple regression analysis on the relationship between depth to groundwater and other variables thought to influence that parameter.

Well	Effect	Estimate	Model R2	F	P
Cienega			0.37	29.7	<0.001
	Year	-0.11		54.4	<.0001
	Month	-0.24		71.2	<.0001
	Year*month	-0.006		2.9	0.13
	Precipitation from 1 month prior	0.11		0.5	0.45
	Precipitation from 2 months prior	0.294		9.9	0.001
Davidson 2			0.68	23.6	<0.0001
	Year	-0.25		36.7	<0.0001
	Month	-0.20		4.4	0.04
	Year*month	0.05		13.4	0.0005
	Precipitation from 1 month prior	-0.12		0.1	0.78
	Precipitation from 2 months prior	1.14		22.4	<.0001
Del Lago#1			0.42	36.7	<0.0001
	Year	-0.31		41.7	<.0001
	Month	-0.35		15.0	0.0001
	Year*month	0.02		2.1	0.1521
	Precipitation from 1 month prior	0.96		4.6	0.0332
	Precipitation from 2 months prior	1.47		25.7	<.0001
Empirita2			0.59	50.1	<0.0001
	Year	-0.65		248.33	<.0001
	Month	-0.02		0.13	0.7170
	Year*month	-0.01		0.01	0.9829
	Precipitation from 1 month prior	-0.03		0.01	0.9222
	Precipitation from 2 months prior	-0.22		1.22	0.2708
Jungle			0.42	28.4	<0.0001
	Year	-0.60		134.17	<.0001
	Month	-0.15		3.47	0.0638
	Year*month	-0.01		0.33	0.5633
	Precipitation from 1 month prior	-0.04		0.01	0.9094
	Precipitation from 2 months prior	0.20		0.62	0.4329
O'Leary			0.12	2.8	0.02
	Year	-1.60		11.66	0.0009
	Month	-0.07		0.04	0.8514
	Year*month	0.14		1.04	0.3109
	Precipitation from 1 month prior	0.24		0.02	0.8998
	Precipitation from 2 months prior	0.50		0.16	0.6917
PN-2			0.15	2.5	0.04
	Year	-1.18		1.16	0.2849
	Month	0.53		0.8	0.3614
	Year*month	-0.48		2.36	0.1294
	Precipitation from 1 month prior	-4.98		3.3	0.0732
	Precipitation from 2 months prior	4.180		5.62	0.0207
PS-1			0.71	33.2	<0.0001
	Year	-0.70		5.74	0.0194
	Month	-0.16		1.04	0.3118
	Year*month	-0.07		0.64	0.4277
	Precipitation from 1 month prior	1.05		2.01	0.1607
	Precipitation from 2 months prior	3.08		41.84	<.0001

Palmer Drought Severity Index and Regional Rainfall patterns

Pima County is in an increasingly severe drought (Figure 27). From 2000-2011, there have been only 3 years with conditions that would be considered not to be drought, while 7 years during this time have been in moderate to extreme drought. Looking at a longer view, there have been long-term droughts in the past century, most notably from the late 1930s through the late 1950s (Figure 28).

Precipitation in the Tucson basin from 1970s through 2011 also shows that drought conditions of the last 10 years have been below the long-term average (Figure 29).

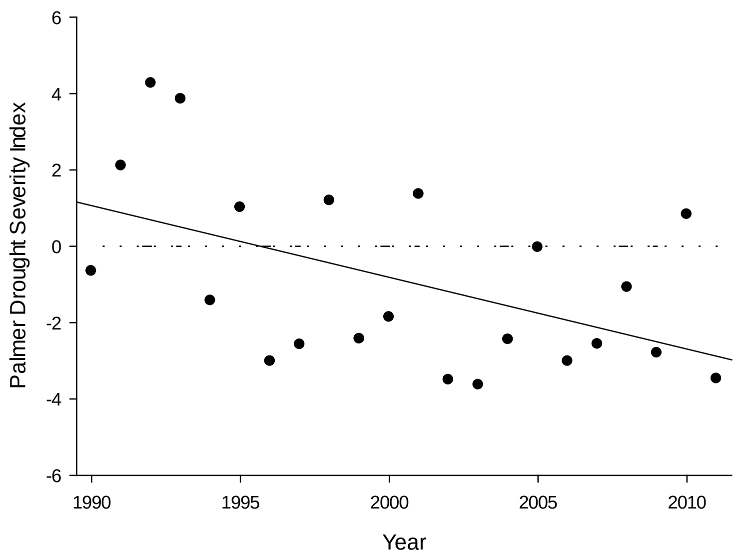


Figure 27. Palmer Drought Severity Index for Pima County, 1990-2011, showing an increase in drought severity in the region, as indicated by the linear trend line. Values below the dashed line indicate drought conditions.

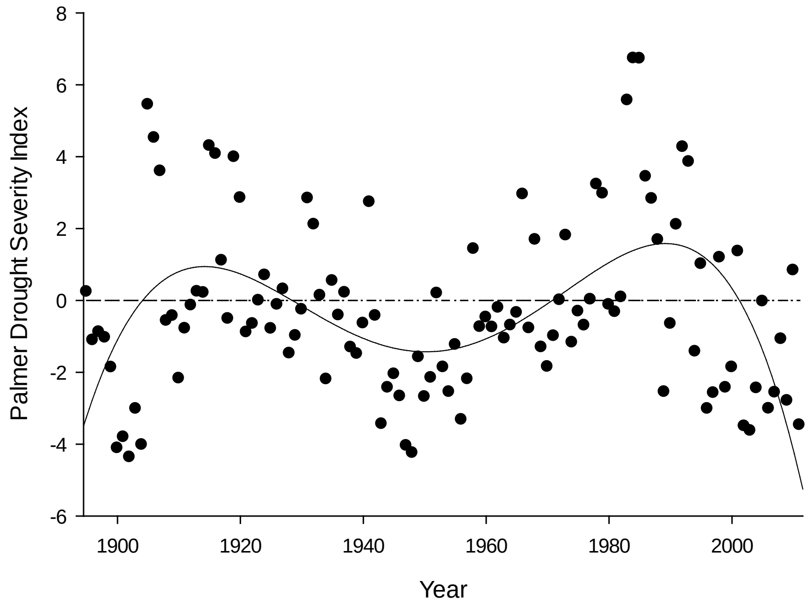


Figure 28. Palmer Drought Severity Index for Pima County, 1891-2011, showing the cyclical nature of droughts in our region. Values below the dashed line indicate drought conditions. Solid line is a 6th order polynomial that maximizes the variation in the data.

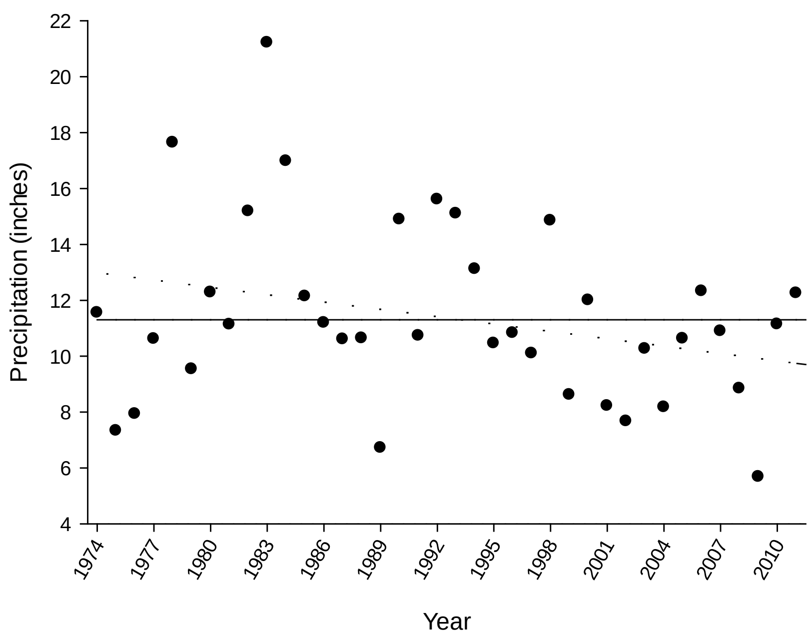


Figure 29. Precipitation measured at the Tucson airport also shows a decreasing trend over time, 1973-2011 (dashed line). Solid line is the long-term average (1891-2012).

Discussion

Summary of Trends and Regional Context

All water resources within the Preserve that are summarized in this report showed a decline over time. Streamflow and discharge were among the parameters that showed the greatest decline; between 1990 and 2011, the mean value of these two measures declined by 68% (Figure 12) and 83% (Figures 16 and 17), respectively. Similarly, the geographic extent of surface water flow decreased from a high of 9.5 miles in the 1980s to a low of 1.1 miles in 2011 (Figure 21), a decline of 88% during that time. The change was less pronounced, but still significant, from 1999-2011 during which time it declined by 63%. Changes in depth to groundwater varied among wells, but declines were as much as 44% (Jungle Well from 1994-2011; Figure 26).

Identifying the underlying cause(s) of the observed declines in these critical water resources is beyond both the scope of this report and the data themselves, but it is instructive to speculate on likely causes and identify key uncertainties. This section discusses the host of potential causes for this decline, including the hydrogeological setting, recent history of downcutting, followed by discussions of the input (precipitation) and output (evapotranspiration and groundwater pumping). By comparing data associated with each of these input and outputs, a narrative develops that may help explain the changes to the invaluable water resources of the Preserve.

The underlying hydrogeology of the Preserve and watershed is critical starting place for the discussion of observed changes. The area in and around the Preserve has been the subject of a number of hydrology and geological studies (Kennard et. al. 1988; Fonseca 1993; Ellett 1994; Chong-Diaz 1995; Pima Association of Governments 2003). Four hydrogeologic units occur in the Cienega Creek basin: younger alluvium, basin-fill alluvium, Pantano Formation, and bedrock complex (Kennard et al. 1988). The younger alluvium is up to 105 feet thick, consisting of unconsolidated silt, sand and gravel and found along the geologic flood plain of Cienega Creek and its tributaries, thereby forming the major aquifer under the Preserve. The younger alluvium has higher transmissivity and specific yield than the basin-fill alluvium, which is found upstream of the Preserve. The basin fill alluvium consists of loosely to moderately lithified sedimentary rocks, ranging in grain size from clay to boulders. It is the major water-bearing unit within the Cienega Creek basin, and acts as a semi-confined aquifer due to the presence of interbedded, fine-grained material that acts as a confining medium (Kennard et al. 1988).

Also important to understand is how the aquifer recharges and discharges. Groundwater recharge occurs primarily along the slopes of the surrounding mountains, and from infiltration of ephemeral flows along Cienega Creek and its tributaries (Figure 30). Baseflows at the Preserve are derived from upstream basin groundwater (Grahn, 1995) and present themselves at locations with shallow bedrock, where groundwater is forced to the surface, creating perennial streamflow (Chong-Diaz 1995). This is particularly true in areas where the

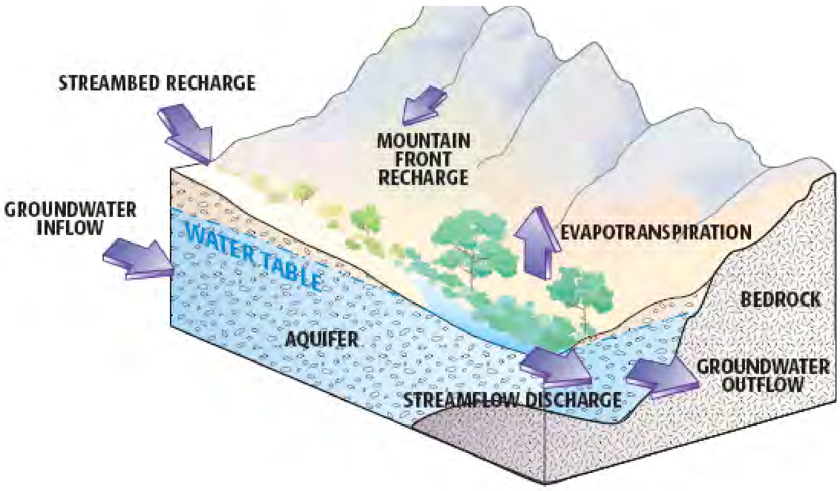


Figure 30. Sources of water inflow and outflow to a basin. A high water table can support streamflow discharge, but less recharge can lead to a lower water table and subsequently less streamflow. Figure from Fonseca (2008).

alluvium is restricted to relatively narrow bands (see Appendix E) bordered by consolidated rock units (Bisbee Formation, lower Pantano formation, the andesite, and the Paleozoic limestone). An exception to this can be found near the Tilted Beds site, which has a broader floodplain (Appendix E), a fact that may help explain why this site has only intermittent surface flow (Figure 11). Many of the areas where surface flow terminates are associated with fault zones with transitions from highly consolidated rocks to less well consolidated rocks (Pima Association of Governments 2003), though it appears that the fault zones are not contributing new sources of water to Cienega Creek from deeper within the earth. A number of questions about the role of the underlying geology of the area remain unanswered and doing so could lead to a better understanding of the influences of the geology on surface and groundwater resources (see PAG 2003 for more information).

It is also important to note that what is now Cienega Creek at the Preserve was historically a large cienega system with year-round water and marshy conditions. As happened in many other cienegas in the region, overgrazing and subsequent loss of vegetative cover and groundwater pumping have led to massive arroyo downcutting (Hendrickson and Minckley 1984; Turner et. al. 2003). The result is that the current channel elevation of Cienega Creek is far below that of its position of approximately 150 years ago (see Figure 31).

Fonseca (1990) estimated that a minimum of 4 million tons of sediment was removed from the Preserve between the 1880s and the mid 1930s; historically this sediment would have acted to capture and release water from the shallow aquifer. Downcutting of the stream channel started again in 1999 and accelerated from 2001-2009 (Pima Association of Governments 2010). This event was caused by a lowering of the groundwater table with the erosion taking place because the system was attempting to find an equilibrium. These successive downcutting events have had an important impact on the flow and length of flow within the Cienega Creek. However, the headcutting that took place from 1999-2009 cannot explain the changes to surface water resources observed during this study (Figures 12, 21), in part because that headcutting actually restored base flow in some parts of the creek (though dried others). The headcutting did, however, reduce the long-term storage capacity of the shallow groundwater aquifer by washing sediments downstream.

Figure 31. The current level of the creek sits below its historic floodplain in the Cienega Creek Natural Preserve, 2012. Note the two people in the foreground for scale.

Streambed aggradation and degradation will be an important attribute to monitor over time. As noted, streambed degradation has been a conspicuous feature at the Preserve, but it has not been uniform. In fact, there are areas of aggradation downstream of the headcut area that threaten the few, deep water pools that are critical to the persistence of Gila chub, in particular. Clearly aggradation and degradation are important and historically have been difficult to monitor without considerable field effort. Now, airborne LiDAR technologies are providing a new and efficient tool for measuring aggradation and degradation along entire stretches of rivers, thereby giving new possibilities for monitoring this change. In fact, Tyson Swetnam at the University of Arizona is currently analyzing LiDAR data from the Preserve for aggradation and degradation as well as canopy cover.

Precipitation. Though past land-use history and the underlying geology of an area provide a foundation of understanding current conditions in water resources of Cienega Creek, clearly precipitation is a key determinant of trends in these resources, and this report specifically targeted the role of precipitation in understanding the trends in many of the water resources of interest (Tables 3-6). With the exception of a few years with above-average rainfall, the 1990s and especially the 2000s in southern Arizona were historically very dry (Figures 7, 9, 28, 29). Precipitation totals have been especially low since 2002 compared to the long-term mean within the Cienega watershed and Tucson (Figure 7). In fact, in seven of the years between 2002 and 2011 recorded precipitation totals were below the long-term average, but the decline in the key measures of water resources at the Cienega Creek Preserve (i.e., flow, extent, groundwater) do not directly follow trends in precipitation. For example, comparing the mean annual flow extent between 1990 and 2011 shows a 50% decline (Figure 21), but comparing precipitation between those two years shows a 16% decline (Figure 29). Clearly precipitation plays an important role in determining the condition of water resources in Cienega Creek, but other factors are also at play.

The spatial pattern and seasonal timing of precipitation falling within the watershed may be important to consider, and though there are some among-site differences in these measures based on their position within the watershed, among-site precipitation totals did not change from 1993-2011. There were, of course, seasonal differences in precipitation with a greater percentage of precipitation falling during the summer rather than the winter season (Figure 8). This was true for all seven precipitation gages, and though there was a change in the mean seasonal precipitation (averaged among sites; Figure 10), these changes were not statistically significant. If spatial changes were seen, then runoff and infiltration characteristics of certain watersheds that contribute to Cienega Creek might partially explain changes detailed in this report. (It is important to note that changes in the spatial patterns of precipitation may not have been picked up by this study; the precipitation gages were not spread about the entire watershed). This finding of insignificance is important, because runoff and infiltration vary among seasons. More research is needed to determine the relative contributions of summer and winter precipitation to the shallow aquifer within Cienega Creek.

Patterns in change in baseflow and discharge are some of the most important and interesting patterns in the data summarized in this report (Figures 11-19). These data show both statistically and environmentally significant declines over time, but it is not the same when compared by months (Figures 13, 19). Those months that represent the monsoon (July, August, and September) do not show statistically significant declines for baseflow (Figure 13). The August and September flow measurements are also highly variable, indicating that they are likely responding to high rainfall events that can temporarily increase baseflow, but which may not have lasting impacts on baseflow. Baseflow conditions in June are perhaps the most important to monitor because they represent the time of year when water is most scarce and the demands on the water resource (by way of groundwater pumping and evapotranspiration) the greatest. June shows a declining trend over time with very little variation that is not explained by the linear trend (Figures 13, 19). Streamflow extent is also most restricted in June, a sampling period that shows a steady and rapidly declining trend (Figure 22). Further discussion about this trend can be found in the section about the ecological significance of the observed changes.

Streamflow extent is an important monitoring parameter at the Preserve. This monitoring is also undertaken at other sites in the Cienega watershed and at other rivers and streams in southeastern Arizona. In closest proximity to the Preserve is the effort along Cienega Creek at Las Cienega National Conservation Area, which is upstream of the Preserve. There, June mapping efforts have shown a marked decrease in flow extent, from 9.5 miles in 1990 to a low of 4.8 miles in 2012 (Jeff Simms, *unpublished data*), a 50% reduction. However, from 2006-2011, a period that is directly comparable with data from this report, the extent of surface water actually increased, whereas it decreased markedly at the Cienega Creek Natural Preserve (Figure 32). On the nearby San Pedro River, Turner and Richter (2011) summarize 12 years of data from along approximately 80 km of the river and found no statistically significant declines during that time. The drought conditions that were experienced in the Cienega watershed were also taking place in the San Pedro River watershed, the next large watershed to the east of Cienega (Figure 33).

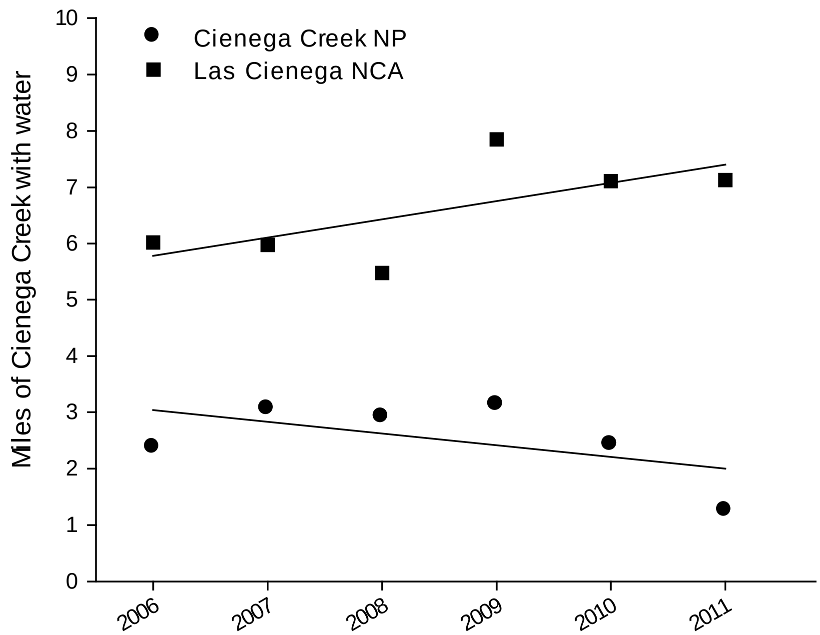


Figure 32. Length of streamflow at the Cienega Creek Natural Preserve (NP) and Las Cienegas National Conservation Area (NCA), as measured in June of each year.

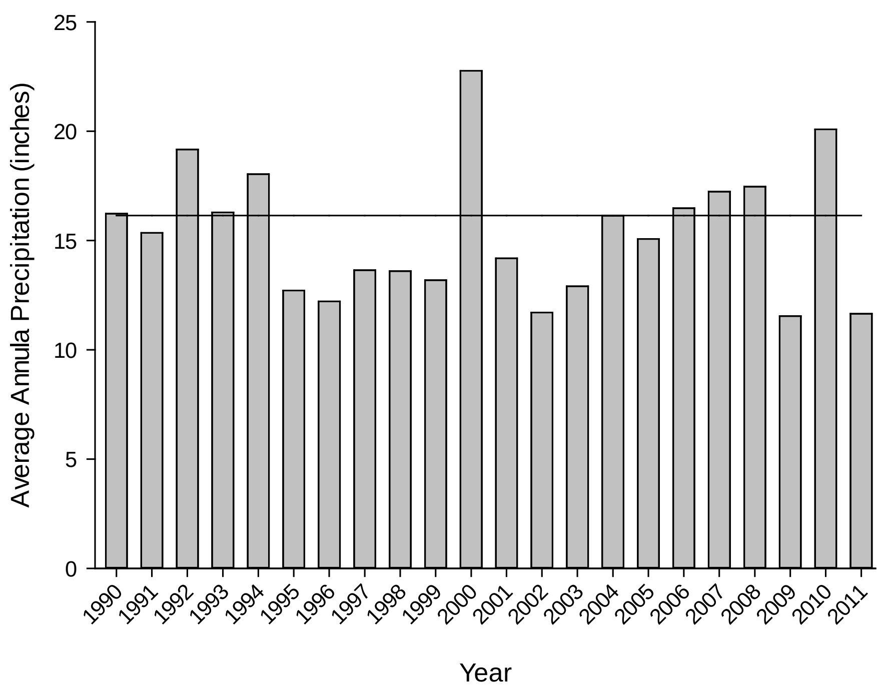


Figure 33. Annual precipitation averaged among 4 sites on the San Pedro National Conservation Area, east of the Preserve (Data obtained from Russ Scott, USDA Agricultural Research Service). Solid line is the average from 1971-2000.

Precipitation clearly plays a critical role in determining stream discharge (Table 3), streamflow extent (Table 4), and groundwater levels (Tables 5,6). Yet, the precipitous decline in these water parameters cannot solely be attributed to changes in precipitation totals . The fact that surface water resources (and to a lesser extent, groundwater resources) of lower Cienega Creek declined more precipitously than either the upper Cienega Creek or the San Pedro River bolsters this perspective.

<u>The Role of Evapotranspiration</u>. Large riparian trees can use a significant amount of water to support photosynthesis; a process known as evapotranspiration. A large cottonwood tree can use as much as 200 gallons/day, so it stands to reason that greater evapotranspiration rates from the Preserve's gallery riparian forest may be responsible for a reduction of the streamflow extent and volume. Early results from a study by Tyson Swetnam (*unpublished data*) does not lend strong support to this hypothesis, at least in regards to changes observed in the last decade (Figure 34). It is important to note that prior to the establishment of the Preserve there was extensive cattle grazing on the site, but once cattle were removed from the system, vegetation height and volume increased significantly (see Figure 2) and likely plateaued in the early 2000s (*unpublished data*). Vegetation often responds positively to removal of cattle (Krueper et. al. 2003), but since 2005 there has only been a slight increase in the extent of cottonwood canopies in the Preserve (Figure 34), though this analysis does not address the density of vegetation within the canopy. It is also important to note that the extent and vigor of mesquite trees has declined during this time. Another line of evidence that does not support the evapotranspiration hypothesis can be found in the fact that both the extent of streamflow and flow volume also declined in December (Figures 13, 19, 22), a month when there would be no evapotranspiration. However, the decline in streamflow extent (Figure 22) and discharge (Figure 19) was greatest during the June sample period, a time when evapotranspiration is probably the greatest. Clearly more research is needed to understand the role of evapotranspiration in the water budget of Preserve.

<u>Groundwater Pumping</u>. Another key factor to consider in regards to the water resources at the Preserve is the pumping of shallow groundwater. Identifying the quantity of water withdrawn by wells can be very difficult to determine because pumping records do not exist for any exempt wells or for non-exempt wells outside of Active Management Areas (only portions of the Cienega Creek watershed is within the Tucson Active Management Area; therefore records are incomplete for non-exempt wells). Nevertheless, some data are available and they show an increase in both the number of new wells drilled (Figures 35, 36) and amount of pumping near to the Preserve (Figure 37). Both of these measures have increased significantly since 2000.

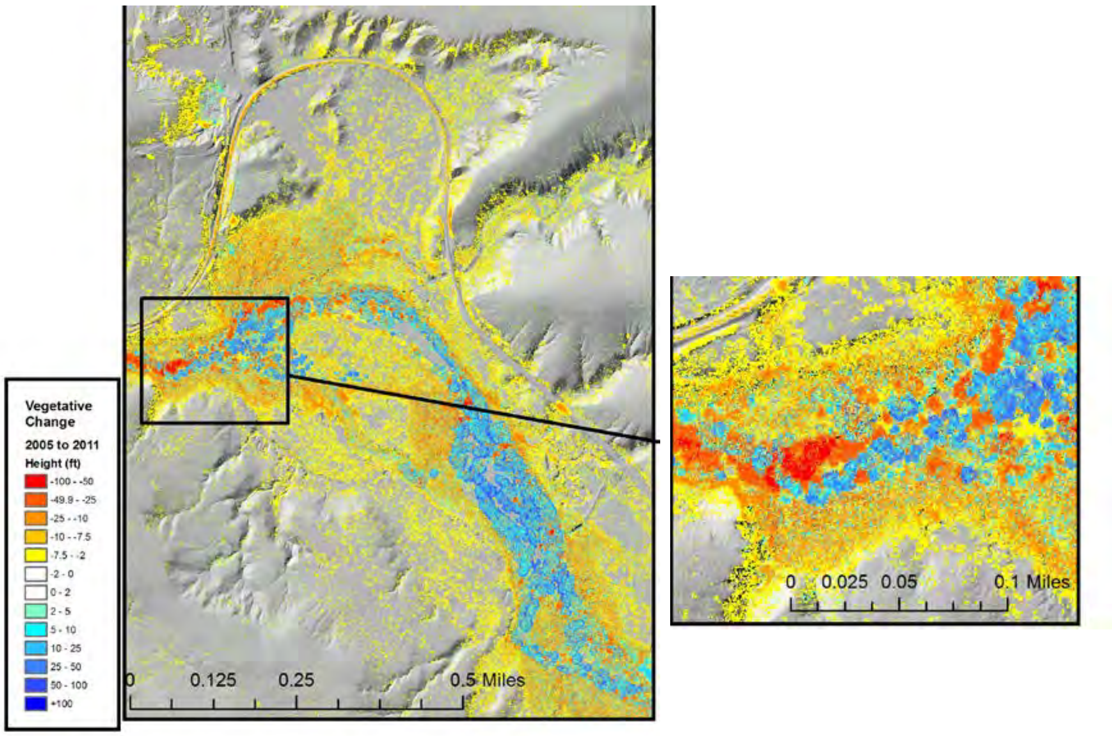


Figure 34. Change in vegetation between 2005 and 2011 at the horseshoe area of the Cienega Creek Natural Preserve. Most of the vegetation away from the active channel had declined, whereas there has been a slight but not significant increase in cottonwood/willow increase along the active channel. Note that much of the dark blue is because of a growth on the outside of the canopies. Zoomed in area is from the loss of cottonwood and mesquite from the recent headcut. Unpublished data from Tyson Swetnam.

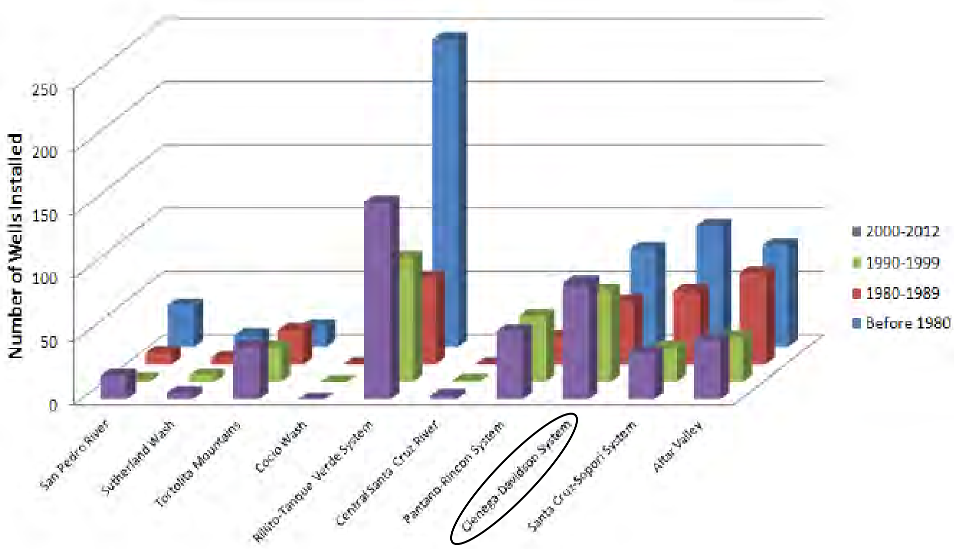


Figure 35. The number of exempt wells drilled within 1 mile of groundwater basins of eastern Pima County. Note that the Cienega-Davidson basin had the second-highest number of wells drilled from 2000-2012. Data and figure from Pima Association of Governments (2012).

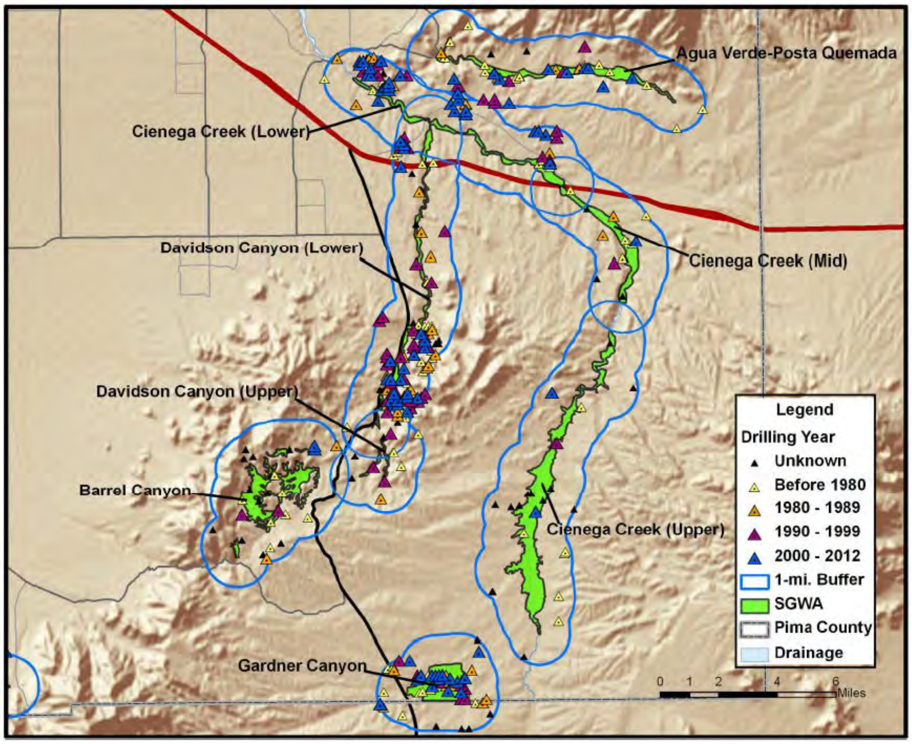


Figure 36. Wells within the shallow groundwater areas (SWGA; in green) of the Cienega-Davidson basin. Cienega Creek Natural Preserve is located in the area shown as Cienega Creek (Lower). Note the relatively narrow shallow groundwater area in the preserve compared to the areas shown as Cienega Creek (Upper); which is located at Las Cienega National Conservation Area. Figure from Pima Association of Governments (2012).

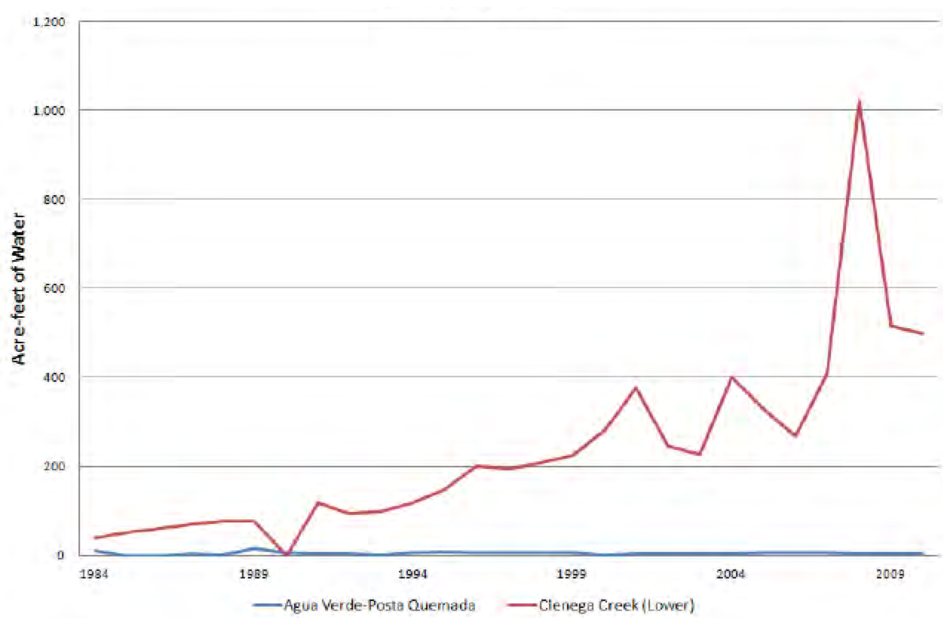


Figure 37. Total water withdrawals from non-exempt wells in the Cienega-Davidson shallow groundwater area. Data and figure from Pima Association of Governments (2012).

Data collected at the Preserve was not collected to specifically investigate direct, cause-and-effect relationship between groundwater pumping and a decline in measures such as streamflow length and depth to water (Figure 26). As noted earlier, a decline in precipitation has played a role in the decline of these resources, but the increased groundwater pumping cannot be eliminated as a key contributor to the decline of water resources in the Preserve. Given the relatively small size of the shallow groundwater aquifer within the Preserve (see Figure 36), it is particularly vulnerable to the influence of groundwater pumping.

Ecological Significance of Declining Water Resources

The decline of surface water and groundwater resources on the Preserve is a cause for concern in its own right, but changes in those resources also have and will have cascading impact on the biota of the Preserve. This will be especially true of the aquatic animals and plants that are now spatially restricted during the June survey periods (Figures 22, 23; Appendix B). Chief among the species that might experience a decline are the fishes and lowland leopard frogs that currently inhabit the Preserve. The presence of the two of the three species of fishes now present at the Preserve (Gila topminnow and Gila chub) is a relatively recent occurrence (though records are incomplete prior to the 1980s); presumably these species were washed down from the upper reaches of Cienega Creek during floods, but have become established because there is suitable habitat at the preserve. Despite their relatively recent tenure in the Preserve, they almost certainly occurred there historically and their continued presence requires perennial water flow. The impact of the reduced flow and extent at the Preserve has not been studied but further declines of surface flow and extent will almost certainly impact the fish, particularly in the historically dry May and June period. The Arizona Game and Fish Department recently began annual fish monitoring at two sites within the Preserve (Marsh et. al. 2009, 2010; Clarkson et. al. 2011). Surveys in 2012 failed to find Gila chub in the creek, and though others have reported seeing it (Don Carter, *personal communication, December 2012*), it is a species that lives in relatively deep pools that form in the few areas of bedrock intrusion near the stream channel. These are also the areas downstream of the recent headcutting, an event that has washed considerable sediment into these deeper pools. The chub's habitat appears to have declined as a result. Lowland leopard frogs also require open water and though they have never been very abundant at the Preserve, their numbers also have appeared to decline in recent years (Dennis Caldwell, *unpublished data*).

Aquatic or semi-aquatic animals are not the only group that appears to have declined or may decline in the future. The decline in base flow also impairs hydrological function of the system by increasing depth to groundwater, which in turn, affects riparian vegetation that relies on groundwater (Figure 38). Evidence of this can be found in the mesquite bosque vegetation community that borders the mesic riparian vegetation along the creek margins. The extent and vigor of this species appears to be on the decline.

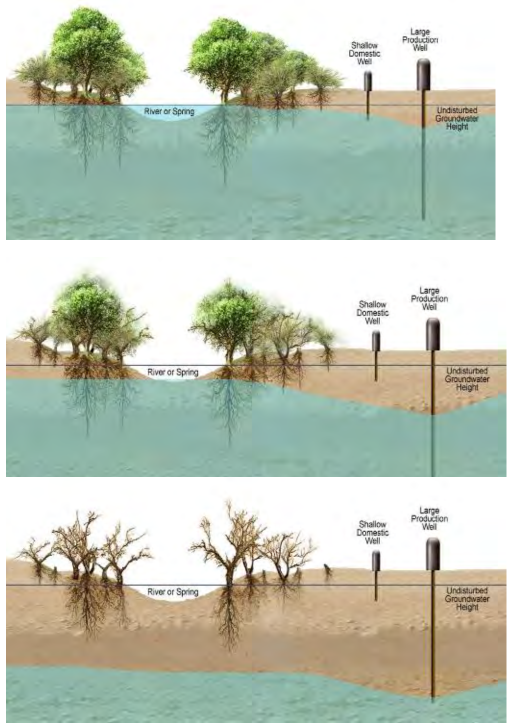


Figure 38. Effects of groundwater decline upon riparian vegetation, from climate change and/or groundwater pumping. The first effects include reduced canopy foliage and reduced herbaceous vegetation diversity and cover. Loss of base flows to stream is shown in second panel, followed by death of characteristic woody riparian trees as groundwater declines below the root zone. Illustration by Bill Singleton and Julia Fonseca originally appeared in Fonseca (2008).

Variability and Thresholds

The *variability* of surface water resources, particularly in the last few years of the monitoring effort (Figures 12, 13, 16, 19) also deserves attention. Recent research has shown that ecosystem dynamics become more variable prior to changing from one dominant state to another (also known as a regime shift; Oborny et. al. 2005; Carpenter and Brock 2006). Whether the variability of extent of streamflow, in particular, signals a future regime shift at the Preserve remains to be seen, but it is interesting to note that this variability began to occur around the time that the headcut began to progress upstream.

The concept of variability also relates to thresholds, which, when crossed, can change the system from one state to another. Of particular interest at the Preserve is the depth to shallow groundwater, which controls the type and extent of riparian vegetation (Figure 39). Fremont cottonwood and willow trees, for example, are very sensitive to declines in groundwater levels and when depth to water consistently exceeds approximately 5 m, these species begin to decline in vigor and may die out altogether (Figure 40).

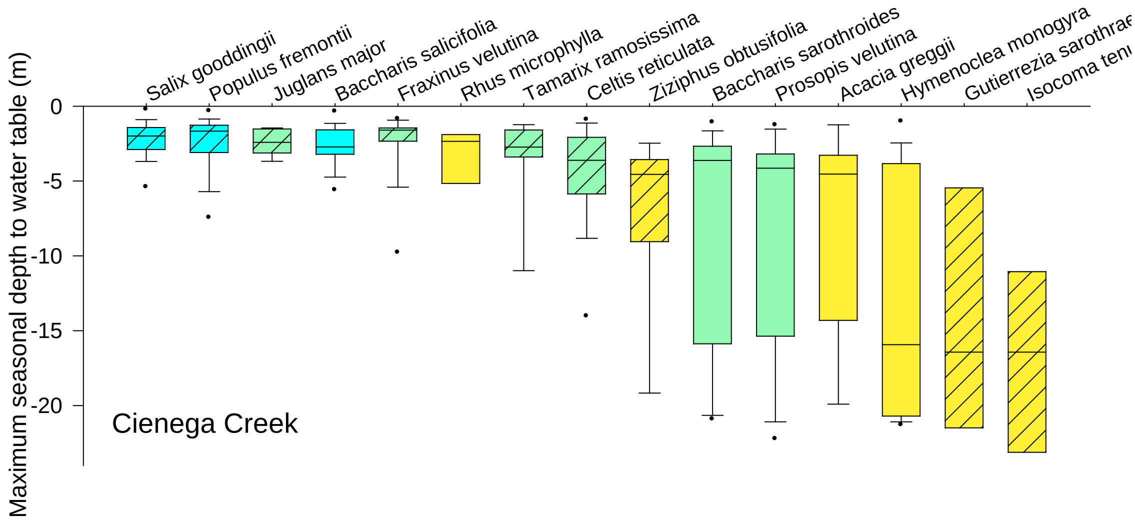


Figure 39. Depth-to-water thresholds for plant species at the Cienega Creek Natural Preserve. Cottonwood (*Populus fremontii*) and willow (*Salix goodingii*) have among the lowest thresholds for depth to water. If water levels drop much further than these minimums, stress or death can result. Note that velvet mesquite (*Prosopis velutina*) has a much greater tolerance, but it occurs away from the shallow groundwater aquifer of the Preserve, where well depths have declined (see Figure 26). Mesquite trees has similarly declined in a number of areas (see Figure 34).

Figure 40. Many cottonwood trees at the Cienega Creek Natural Preserve are showing signs of drought stress. Note the thin canopies of many of the trees. July 2013.

Tamarisk trees, an invasive, non-native species, may be an indicator of a regime shift and this species has increased in abundance in recent years. Though recent control efforts have been successful, the potential for this species to gain a greater foothold in the Preserve is significant and—as we see with the depth to groundwater data (Figure 26)—a highly fluctuating shallow groundwater table may be an important early warning sign of such change.

A Look to the Future

Land use within the watershed. The Preserve is one of the most ecologically important areas of southern Arizona, which results from the water resources that are highlighted in this report. The fact of the Preserve's close proximity to Tucson make it almost unique among areas of similar ecological importance, but development in close proximity to ecological sensitive areas has historically not fared well for the latter. The area in and around the Preserve has historically been the focus of development (particularly in the downstream area of Vail), which has increased significantly, especially in the late decade. Development pressures will only increase in the coming decades as more and more people continue to move to the Tucson region for the jobs and lifestyle. Many of these people will also seek a more exurban or rural place to live (Figure 41). Given the slower—but still steady—pace of development in the area around the Preserve, groundwater pumping will only increase the stress on the water resources of the Preserve (Figure 42). This, coupled with lower rainfall from climate change (see next section), will likely result in less water for natural systems like Cienega Creek.

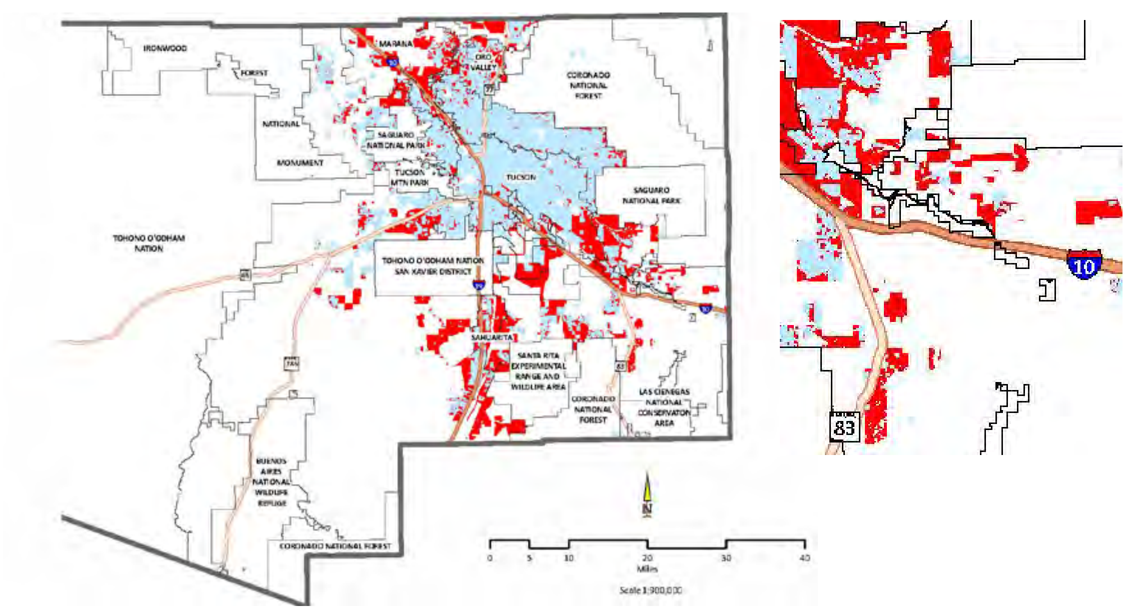


Figure 41. Projected development (red) and existing development (blue) in eastern Pima County over the next 30 years. Image at right is the area around the Preserve. Image from Pima County (2012b).

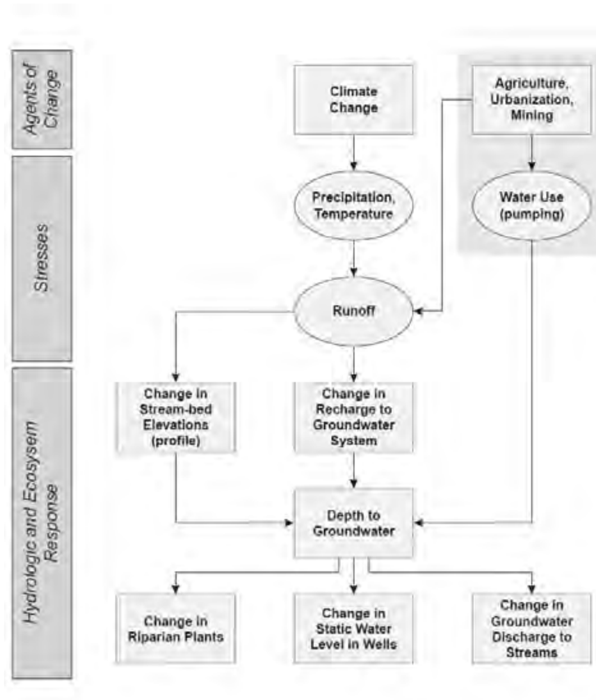


Figure 42. The increased scale and scope of human activities, along with climate change, will put greater and greater pressure on shallow groundwater ecosystems. Figure from Fonseca (2008).

Climate Change. Climate change deserves special attention because its impacts will—if it has not already—impact the water and related resources of the Preserve. During the 20th Century, temperatures on the surface of the earth increased by 0.5°F to 1.1°F, with a dramatic rise in temperatures in the last 50 years (PRISM Group 2007). Models of temperature increases in Arizona have exceeded average global temperature increases by 50% since the 1970s (PRISM Group 2007). Looking forward, worldwide temperatures are predicted to increase between 3.2°F to 7.2°F in the next 100 years (Meehl et. al. 2007). For the southwestern U.S., there is a prediction of a 10-20% reduction in precipitation in the Southwest region in the next 75 years (Christensen et. al. 2007), with most reductions in precipitation during the winter months when circulation patterns over the Pacific Ocean prevent moisture from entering the region through a movement of the storm track to the north. This will leave southern Arizona more arid. Drier conditions are expected to be particularly severe during years when La Niña patterns predominate (Seager et. al. 2007). By contrast, summer monsoons in Pima County result from warm, moist air from the Gulf of Mexico and eastern Pacific, resulting in high-intensity monsoon rains. The processes which bring monsoon rains to southeastern Arizona is not expected to be disrupted in the same way as those processes that affect winter precipitation, though there is considerable uncertainty in these models. Whether the shift in winter versus summer precipitation that occurred at and around the Preserve during the period of record for this study (Figure 43) is a result of climate change is unknown, but as was indicated earlier, the impact of both a reduction in winter precipitation and increase of steady summer precipitation has important

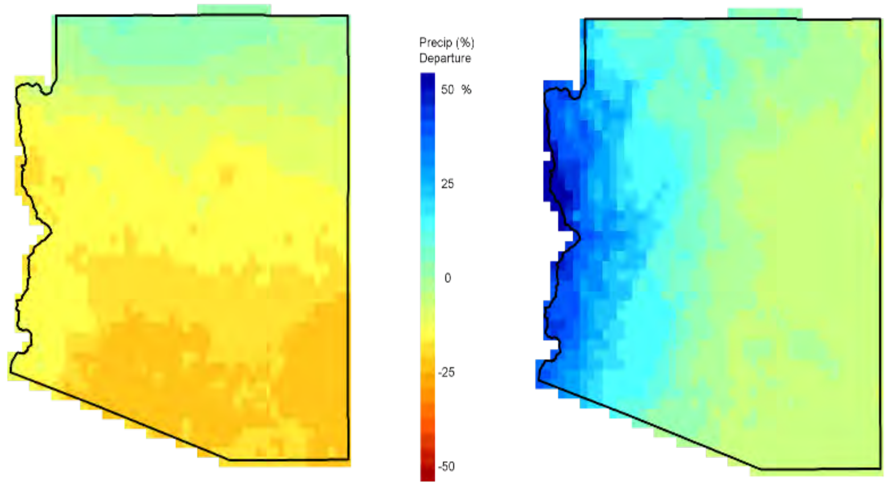


Figure 43. Projected change in precipitation for winter (left) and summer (right) by 2099 under the "business as usual" climate scenario. Projections downscaled by Maurer et al. (2007) for Arizona.

consequences for a host of resources and parameters including groundwater storgage and base flow volume and extent.

Beyond temperature and precipitation impacts will be disruptions to ecological function and structure. For example, much of the water that makes its way into the small aquifer at the Preserve starts further up in the watershed. Here, wildland fire is expected to increase and will hasten transitions to new plant communities, have cascading effects on sensitive plant and animal species (McKenzie et. al. 2004), and impair ecosystem functions. Though fire was once restricted to montane forests, woodlands, and semi-desert grasslands, there is now an increased fire risk in areas such as the Preserve because of the spread of buffelgrass and other invasive species such as brome (Franklin et. al. 2006). Recent efforts to control buffelgrass in the Preserve have been successful, but the rapid, region-wide spread of the species will pose a considerable challenge to managers in the longer term.

Climate change, in combination with other stressors, will also impair watershed function. Warmer and drier soils will generally store more water, thereby increasing the threshold for initiation of runoff, a situation whereby precipitation is in excess of the soil's capacity to store water. However, a combination of more intense summer storms with an increase in urbanization—which can impair the ability of many systems to absorb water (Kepner et. al. 2004)—can lead to cascading impacts, most importantly by changing the structure of stream beds, thereby affecting aquifer recharge. This impairs hydrological function of the system by increasing depth to groundwater, which in turn, affects riparian vegetation that relies on groundwater. All of these changes could have severe consequences for key conservation targets, such as aquatic species (e.g., Parker 2006).

The trees of the mesic riparian cottonwood/willow forests such as at Cienega Creek are susceptible to mortality in the late spring. With a possible reduction in average winter precipitation, dieoff of individuals or entire communities may occur. Acute drought stress on trees in this community was seen throughout the region in the last 10 years, for example along the Santa Cruz River in Santa Cruz County (Amy McCoy, *unpublished data*) Rincon Creek in eastern Pima County (Kirkpatrick et. al. 2007), and on mesquite and cottonwood trees within the Preserve (see Figure 40).

The Rosemont Mine. Another key stress on the water resources of the Preserve will be the Rosemont mine (Figure 44). If approved, the mine will have significant impacts to water quality and quantity in both the short and long-term (Myers 2010; U. S. Forest Service 2011; Pima County 2012a). Short-term impacts include the diversion and impoundment of stormwater, and possible contamination of that water. Long term, the abandoned open pit will act as a groundwater “sink” that will draw groundwater into the pit. Contamination of groundwater is also a likely outcome of the mining operation. Pima County has vigorously opposed the Rosemont operation, in part because of the impacts the mine will have on water resources, impacts that will be revealed far beyond the boundary of the project area. In the case of surface water, these impacts will be to the surface and groundwater inputs of the Preserve.

As part of the mitigation negotiations with the U.S. Army Corps of Engineers, Rosemont Copper has apparently purchased options for water rights that are currently owned by the Rancho del Lago Golf Course. The golf course diverts water from the creek at the del Lago dam (Figure 45) and Rosemont is may allow some of that water to remain the creek channel as mitigation measure for the proposed mine. Allowing these waters to stay within the natural system would clearly be better for the system than piping it to a golf course, but given the large-scale impacts of Rosemont’s operations on the water resources upstream of the Preserve, the Company’s proposed action may not be effective if Rosemont’s mining operation results in a decline in base flows (Pima County 2012a).

Management Options: Linking Data to Opportunity and Constraints

Key water resources at the Cienega Creek Preserve are on the decline. Whether these declines are temporary or will be reversed naturally, only time will tell. However, given the current trajectory of these resources; the ecological and hydrogeological history of the Preserve; and the coming threats of development, mining, and climate change, one could be forgiven if she/he were pessimistic about the future of water and associated resources at the Preserve. Among the many questions being asked about the future, perhaps the most important is: what can we do about the current situation to stop it from getting worse? Answers to that question might range from doing nothing to significant intervention. The most prudent and achievable answer probably lies somewhere in the middle.

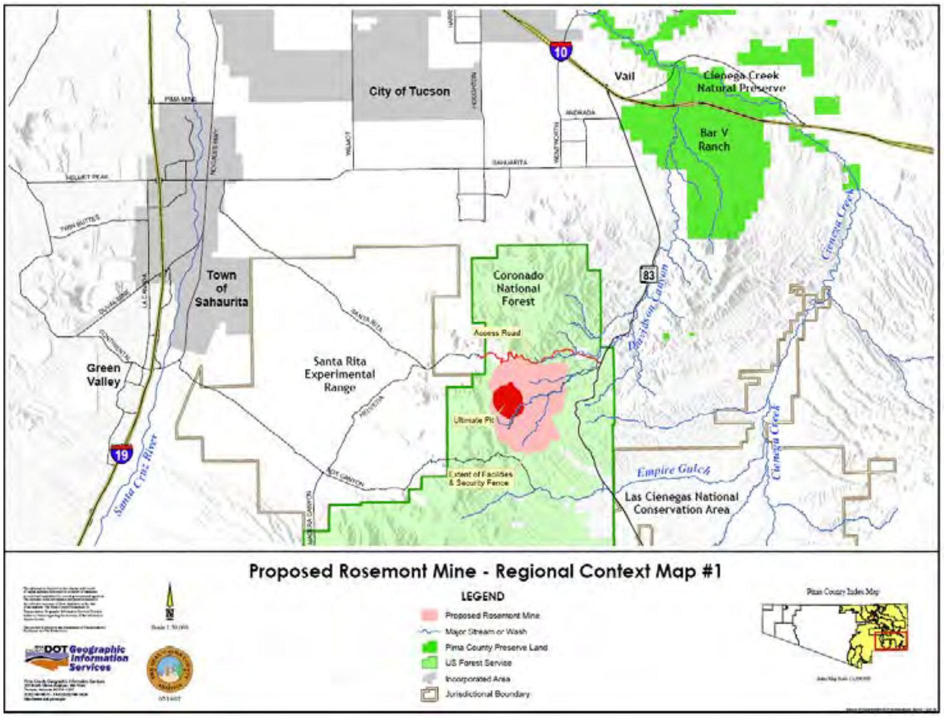


Figure 44. The proposed Rosemont Mine is directly upstream of the Preserve and, if built, will impact surface and groundwater resources of the Preserve.

Figure 45. Surface water from Cienega Creek is currently diverted into this culvert, which takes the water to the del Lago Golf Course. Leaving this water in the stream channel would be beneficial.

This "middle road" can best be described as adaptation, which refers to adjusting management actions in the face of changing conditions. The first line of defense in adaptation is to create *resistance* to change. This often involves efforts at reducing or mitigating impacts on resources that are likely to be impacted in the future. In the case of the Preserve, examples might include purchasing water rights and fencing of additional sensitive areas. Promoting resistance provides a reduction in a threat before it has a chance to test the capacity of a system to withstand change. The next, most widely discussed tenet of adaptation deals with promoting system *resilience* (Turner II et. al. 2003; Tompkins and Adger 2004; Millar et. al. 2007; Heller and Zavaleta 2009). Resilience is the capacity of a system to resist or regenerate from change before that system undergoes a fundament shift to a different state. Just as healthy humans are better able to deal with and recover from disease or illness, so too are healthy ecosystems able to deal with stresses and still return to a "healthy" state.

Fortunately, resilience is built into the dynamic nature of riparian systems such as Cienega Creek. Many riparian plants and systems are adapted to hydrologic and geomorphic disturbances and tolerate both seasonal and annual variation in environmental conditions (Naiman and Decamps 1997). Therefore, resilience strategies should focus on supporting this natural dynamic of riparian systems to return to their natural state following disturbance (Dale et. al. 2001).

Management actions that can foster resilience include reducing anthropogenic threats, reducing fragmentation and increasing connectivity among natural land-cover patches, maintaining adequate representation (e.g., communities and species), protecting key ecosystem features and processes, and focusing restoration efforts to those projects that restore and maintain ecosystem processes and functions (Heller and Zavaleta 2009). Restoration programs that reestablish appropriate hydrological processes, actively intervene with horticultural techniques to propagate and establish native vegetation where necessary, and manage for genetic diversity to facilitate evolutionary processes can build upon the natural resilience of riparian systems. A key action for the Preserve would be to restore diverted flows to Cienega Creek (Figure 45).

The Sonoran Desert Conservation Plan has a number of resilience elements built into a host of actions taken since the plan was enacted including:

- Acquisition of over 71,000 acres of fee-owned (ownership) lands, and over 120,000 acres of leased lands, with particular emphasis on lower elevation communities such as riparian corridors, which had poor representation in the montane-dominated reserve system prior to the initiation of the SDCP;

- Development of a regional reserve design (Maeveen Marie Behan Conservation Land System; see Pima County 2012b) that spans physical gradients such as topography, geology and soils;

- Preservation and repair of connectivity through designation of critical landscape connections and Priority Conservation Areas for specific taxa (see Pima County 2012b);

- Adoption of a new policy to minimize effects of new groundwater pumping on springs and streams;

- Investments in fencing for management of livestock on County-owned lands, and improved pasture management and restoration efforts on County ranches;

- Modifications of stock-watering systems to provide safer and more lasting access to water for wildlife;

- Buffelgrass management in reserves and along County roadways;

- Additional allocation of effluent for riparian projects ("Conservation Effluent Pool");

- Acquisition of groundwater rights;

- Implementation of the Pima County Drought Management Plan.

Continuing and Expanding Monitoring at the Preserve

This reporting summarizes a host of water resource data that has been collected at the Preserve since its inception in 1988. Without these data, we would not know that key resources are on the decline and in need of management and research attention. Going forward, the RFCD plans to continue funding PAG to conduct ongoing monitoring of the Preserve. The County will also commit additional monitoring resources as part of the County's forthcoming MSCP (Pima County 2012b). Known as the Ecological Monitoring Program, the County will conduct more in-depth monitoring of wildlife, vegetation, and other resources at the Preserve on other areas owned and managed by the County (Powell 2010).

This report summarizes data that can inform a conversation about gaining greater efficiencies in the water resource data that is already be collected and more work is need to determine if the monitoring program is sufficient to meeting the management objectives for the Preserve (McGann and Associate Inc. 1994; Pima County Regional Flood Control District 2009) and—if necessary—suggest changes to either the objectives or the monitoring program. For example, it may no longer be prudent to measure flow at the Tilted Beds site (Figure 11) and instead choose a different site to monitor. Such a detailed conversation should happen, but it is beyond the scope of this report to offer specific suggestions. For now, the recommendation is to continue the current monitoring effort, especially considering the declining trends that have been observed.

Future Analyses

This report represents an important first analysis of the water data the Preserve. Additional analysis and modeling can help clarify some of the uncertainties outlined in the discussion. Addition analysis and modeling could include:

1. Determining change in composition, condition, and extent of riparian vegetation since the Preserve was created. This work can lead to estimates of groundwater consumptive use by riparian vegetation.

2. More in-depth analysis of the geomorphologic changes that have occurred since the Preserve was created.

3. Evaluation of extent and timing of both incision and sediment deposition.

4. Isotopic research to determine the relative contribution of summer versus winter precipitation on the shallow groundwater aquifer.

5. Thorough examination of impact of groundwater pumping, with mapping and reporting on locations of non-exempt and exempt (domestic) wells; estimates of consumptive use from these wells; and groundwater modeling to simulate rate and timing of storage and release.

Acknowledgements

This report—and the insights it provides on the condition of the water resources within the Cienega Creek Preserve—would have been possible without the work of many people over the years who had the foresight and persistence to plan and collect the data that make this report meaningful. Many deserve recognition in this regard, but particular thanks go to Julia Fonseca, Claire Zucker, Mead Mier, Rachel Loubeau, David Scalero, and staff at the Arizona Department of Water Resources. Mike List produced Figures 4 and 5 and digitized and produced Appendices A-E. Erik Glenn produced Figure 2. Andy Wigg provide streamflow and precipitation data. Gita Bodner, Jeanmarie Haney, Julia Fonseca, Mead Mier, and Frank Postillion provided valuable reviews of an earlier draft of this report.

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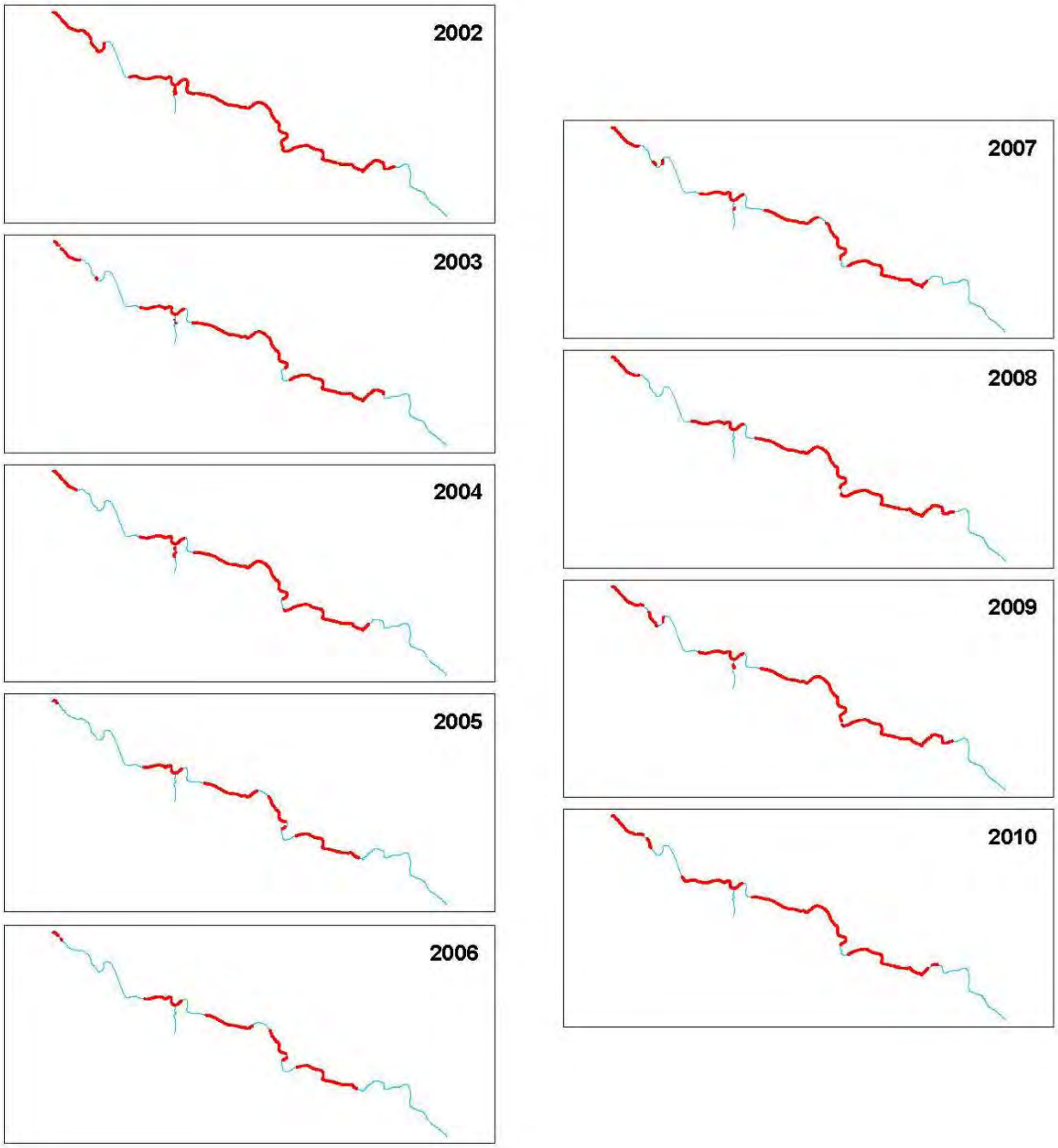
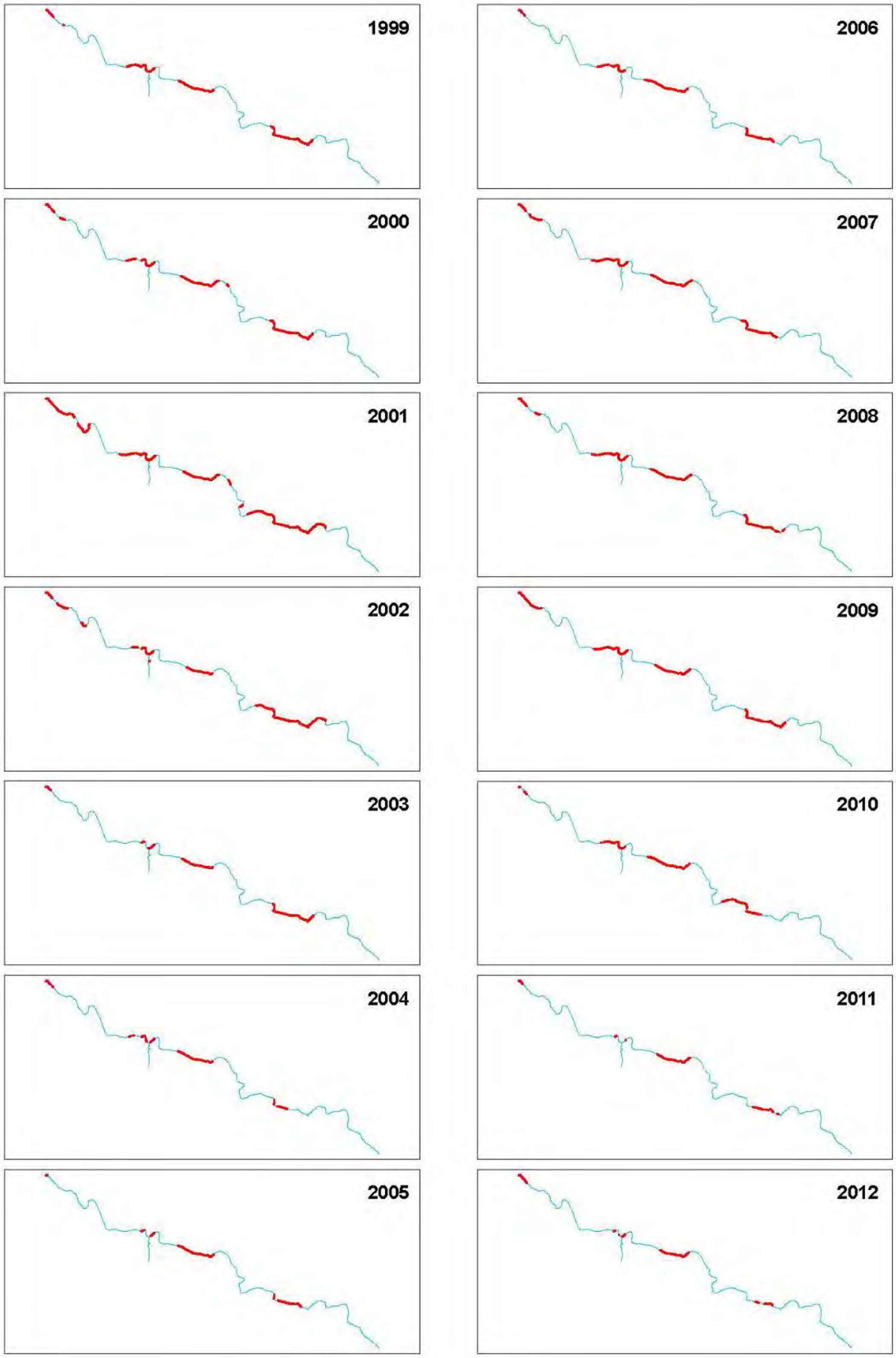
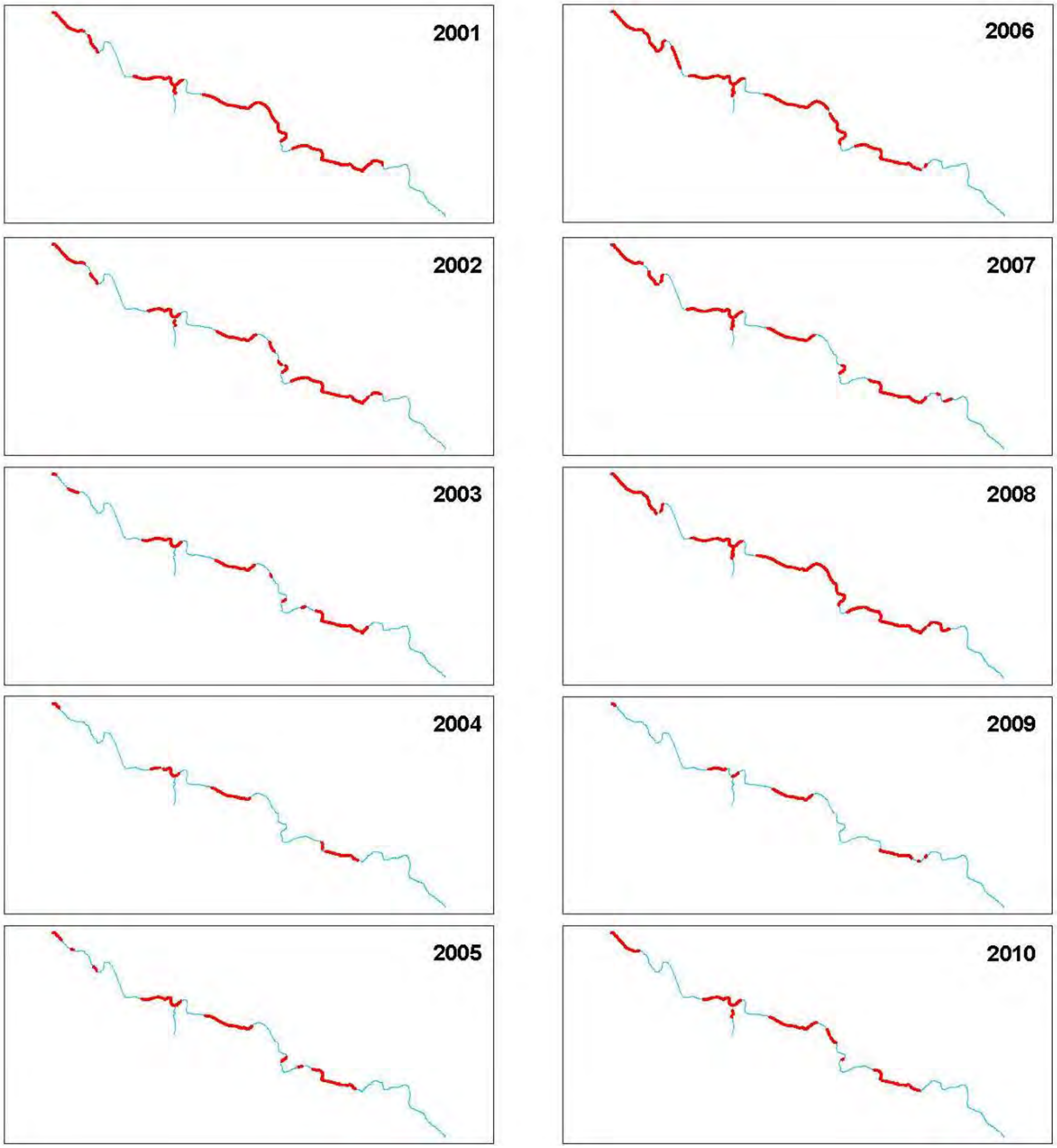


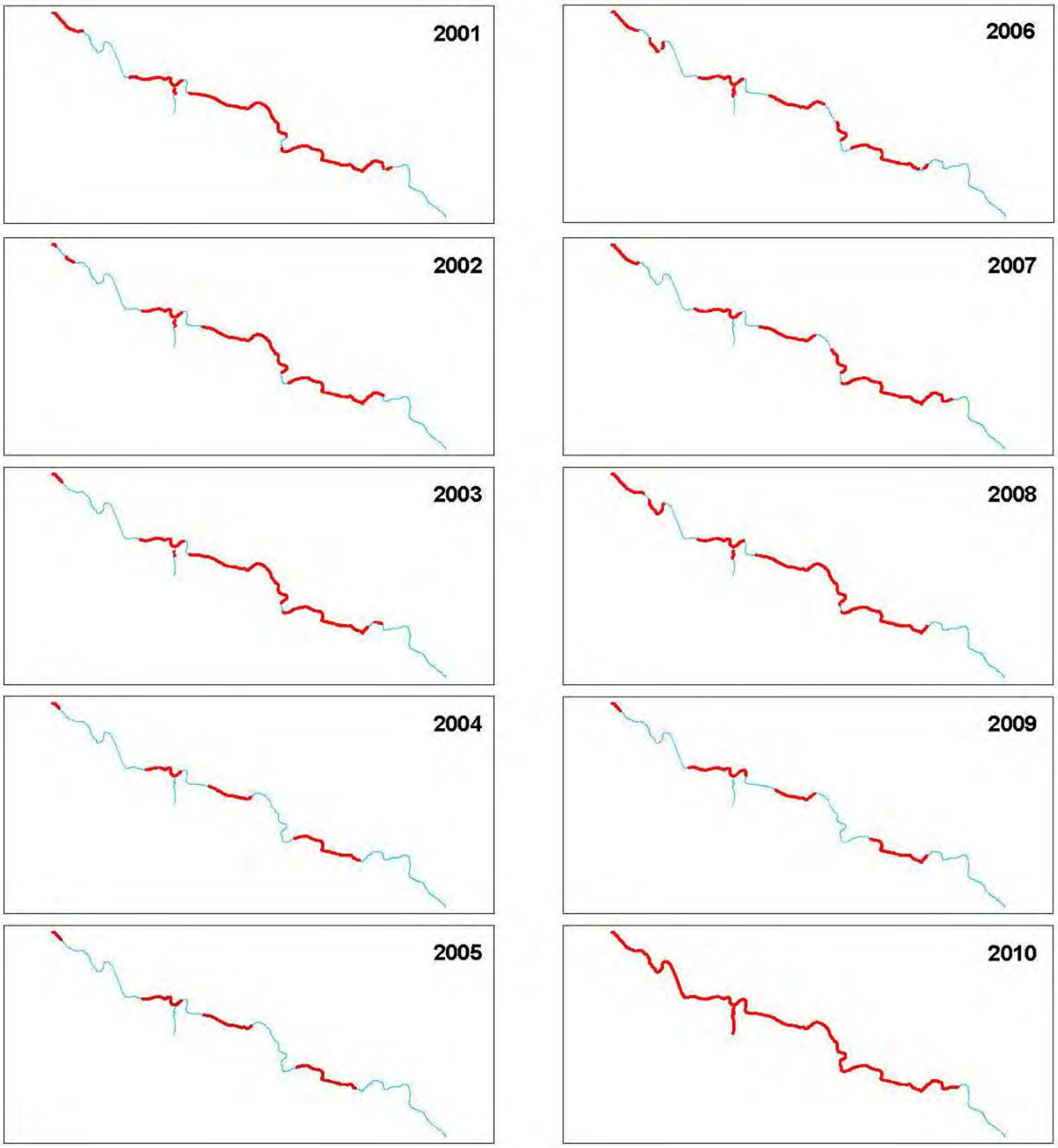
Appendix A. Length of streamflow at the Cienega Creek Preserve, March observations.



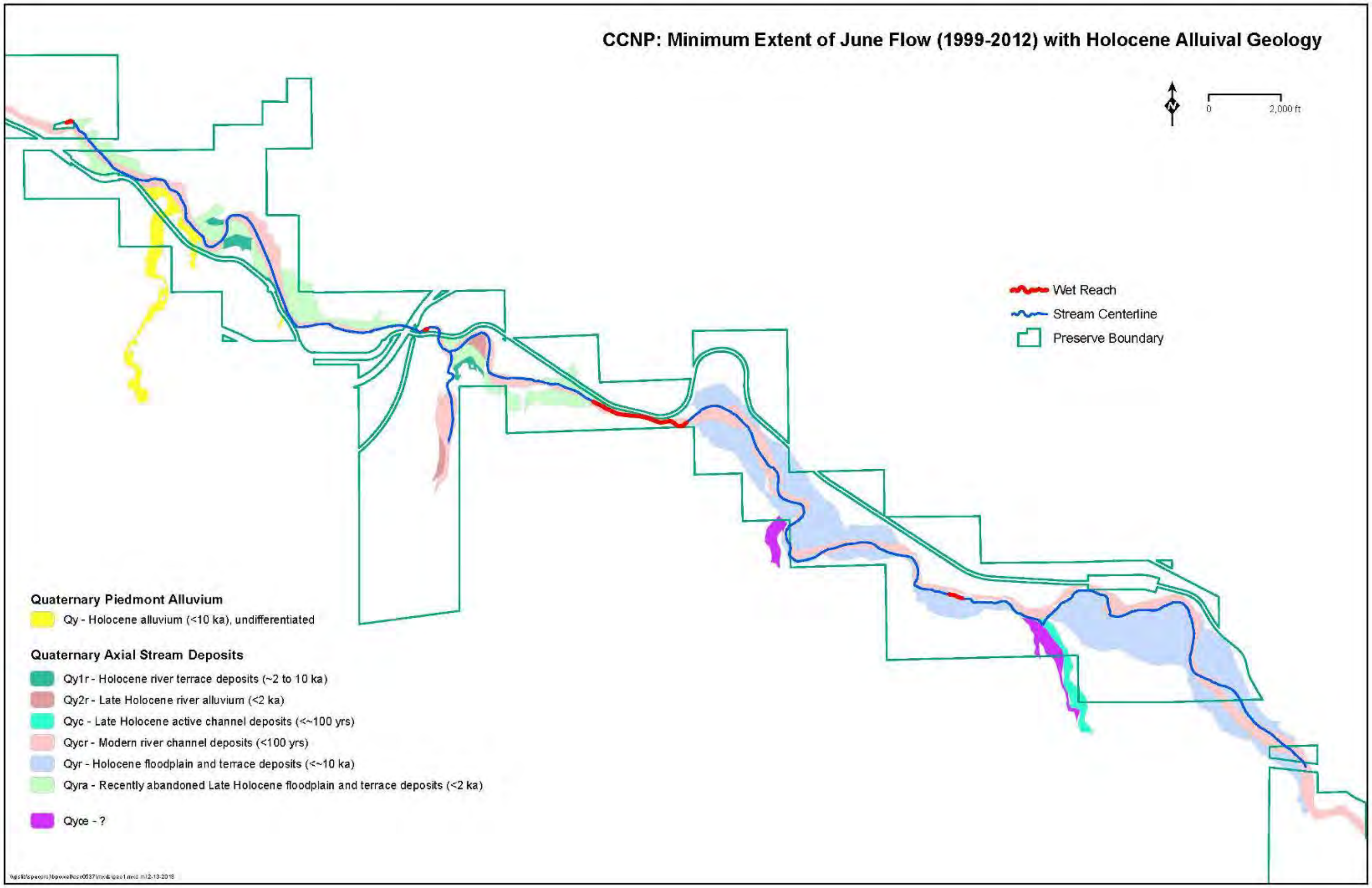
Appendix B. Length of streamflow at the Cienega Creek Preserve, June observations.



Appendix C. Length of streamflow at the Cienega Creek Preserve, September observations.



Appendix D. Length of streamflow at the Cienega Creek Preserve, December observations.



Appendix E. Intersection of June minimum flows with floodplain deposits.

ground water

Evaluating Climate Variability and Pumping Effects in Statistical Analyses

by Timothy D. Mayer[1], and Roger D. Congdon[2]

Abstract

As development of ground water resources reaches the limits of sustainability, it is likely that even small changes in inflow, outflow, or storage will have economic or environmental consequences. Anthropogenic impacts of concern may be on the scale of natural variability, making it difficult to distinguish between the two. Under these circumstances, we believe that it is important to account for effects from both ground water development and climate variability. We use several statistical methods, including trend analysis, cluster analysis, and time series analysis with seasonal decomposition, to identify climate and anthropogenic effects in regional ground water levels and spring discharge in southern Nevada. We discuss the parameterization of climate and suggest that the relative importance of various measures of climate provides information about the aquifer system response to climate. In our system, which may be characteristic of much of the arid southwestern United States, ground water levels are much more responsive to wet years than to dry years, based on the importance of selected climate parameters in the regression. Using cluster analysis and time series seasonal decomposition, we relate differences in amplitude and phase in the seasonal signal to two major forcings—climate and pumping—and distinguish between a regional recharge response to an extremely wet year and a seasonal pumping/evapotranspiration response that decays with distance from the pumping center. The observed spring discharge data support our hypothesis that regional spring discharge, particularly at higher elevation springs, is sensitive to relatively small ground water level changes.

Introduction

Ground water sustainability is defined as "development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences" (Alley et al. 1999). Increasingly, attention is being placed on how to manage ground water resources in a sustainable manner (Bredehoeft 2002, 1997; Sophocleous 1997; Alley and Leake 2004). Many areas of ground water development in the United States are approaching or exceeding their limits of sustainability. Under these conditions, it is likely that even small changes in inflow, outflow, or storage will affect water supply or biological resources. Anthropogenic impacts of concern may be on the scale of natural variability, a condition that confounds analyses and makes it difficult to distinguish between the two. Moreover, it is often the variability of flows and water level fluctuations that determines the extreme conditions limiting water availability and threatening biological resources.

Ground water systems tend to react more slowly than surface water systems to short-term climate variability. Because of this, many past studies on ground water flow have neglected climate variability and used long-term average climate conditions or recharge, particularly in temporal simulations of ground water flow (Hanson et al. 2004). At short time scales of interest or where there is extensive aquifer development, this approach has provided acceptable simulations and predictions of large-scale changes in ground water storage (Hanson et al. 2004). However, it is becoming apparent that climate variability and change need to be accounted for in the

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management and analyses of ground water resources (Winter et al. 1999; Alley et al. 1999; Gleick and Adams 2000; Hanson et al. 2004; Weber and Stewart 2004; Scanlon et al. 2005). We believe that this is especially true in systems where the effects of ground water development and climate variability are approximately equal in scale and where these effects have economic or environmental consequences.

When considering climate variability explicitly, one of the first and most important questions is how to represent climate. There are a number of measures available to parameterize climate, including raw precipitation data and several precipitation and drought indexes (Hayes 2006). The indexes differ in their statistical distribution and centering and how they measure deviations from historical norms. Our study examines issues regarding climate parameterization while investigating the effects of climate variability and ground water development on the Muddy River Springs area (MRSA), a regional spring system about 100 km north of Las Vegas, Nevada (Figures 1 and 2). We use statistical analyses to examine water levels and spring discharge for a period that includes a significant increase in ground water development and several years of drought and record precipitation. We begin by examining and characterizing temporal and spatial trends in ground water levels in the system. The long-term well records in the area integrate the combined effects of multiple factors such as climate, seismic activity, barometric pressure, earth tides, evapotranspiration (ET), confined or unconfined conditions, and pumping from different aquifers. The effect of each of these factors varies in frequency and magnitude, but our preliminary analyses indicated that the two main factors affecting the system at scales of concern appear to be climate and ground water pumping.

After identifying and evaluating trends in ground water levels, we examine the relationship between ground water levels in the carbonate rock aquifer and regional spring discharge in the MRSA. We show that in this system, spring discharge is affected by rather small changes in ground water levels resulting from climate and pumping effects. We hypothesize that changes in spring discharge will be proportional to those in hydraulic head at each spring. The higher the elevation of the spring, the smaller the initial hydraulic head and the more sensitive the spring is to water level changes. Our examination of changes in spring discharge in relation to spring elevation and ground water level changes validates our hypothesis. The methods and results we present here are useful in quantifying and assessing climate variability and pumping-related impacts to ground water levels and springs in other regional spring systems, especially where those impacts are at similar scales.

Study Site and Setting

Much of the eastern Great Basin is underlain by a thick sequence of limestone and dolomite rocks known as the carbonate rock province (Harrill and Prudic 1998). Beneath southern Nevada, these carbonate rocks are

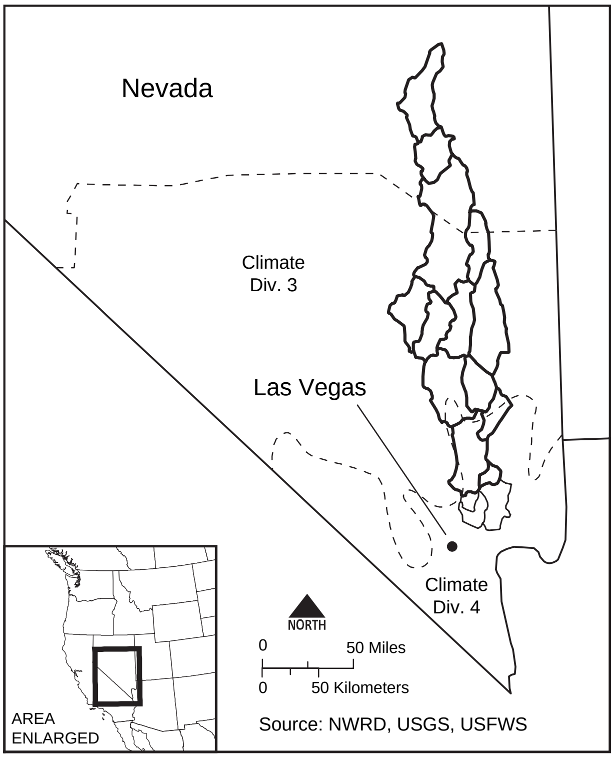

Figure 1. Map of southeastern Nevada showing Eakin's (1966) original White River ground water flow system (bold outline), adjacent southern basins (narrow outline), and the boundaries of Nevada Climate Divisions 3 and 4.

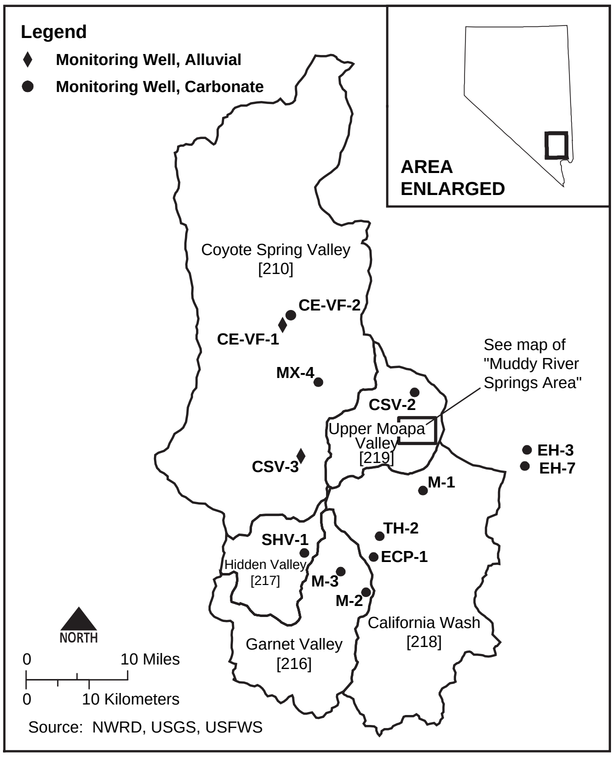

Figure 2. Map of five hydrographic basins within, or adjacent to, the southern portion of the White River ground water flow system, with carbonate and alluvial wells discussed in the text.

widely distributed and permeable enough to facilitate ground water flow at a regional scale. One such regional flow system is the White River ground water flow system, originally defined by Eakin (1966) to encompass 13 topographic basins, extend more than 400 km, and terminate at the MRSA (Figure 1). The flow system consists of numerous local basin fill aquifers underlain by a large regional carbonate rock aquifer that transmits ground water from basin to basin, beneath topographic divides. Much of the flow in the regional carbonate rock aquifer occurs where rocks have been fractured or where openings have been enlarged by dissolution (Prudic et al. 1993; Dettinger et al. 1995). Eakin (1966) identified the regional ground water flow system based on (1) the hydrologic properties of the rocks in the area; (2) the movement of ground water inferred from hydraulic gradients; (3) the relative distribution and quantities of estimated recharge and discharge in the system; (4) the relative uniformity of the discharge of the principal springs; and (5) the chemical composition and warm temperature of the discharge from the principal springs. Additional geologic, isotopic, and numerical studies have confirmed the existence of the regional flow system with minor differences (Harrill et al. 1988; Kirk and Campana 1990; Dettinger et al. 1995; Thomas et al. 1996; GeoTrans Inc. 2001, 2003; Johnson and Mifflin 2006).

Using a water budget approach, Eakin (1966) estimated that 78% of the recharge to the regional flow system occurs as precipitation in the higher elevation mountain ranges of the four northern basins in the flow system and 62% of the discharge from the regional flow system occurs from springs in the Pahranagat and Upper Moapa valleys in the southern part of the flow system. The MRSA in the Upper Moapa Valley (Figure 2) was reported to be the terminal discharge of the regional flow system (Eakin 1966; Harrill et al. 1988; Prudic et al. 1993), although other researchers hypothesize that additional subsurface flow continues beyond the springs to the southeast (Johnson and Mifflin 2006). The springs are located upgradient of a normal fault that juxtaposes low-permeability rock of the Muddy Creek Formation against the carbonate rock aquifer (Dettinger et al. 1995). Eakin (1966) estimated that approximately 1.4 m^3/s of discharge occurs here from about 20 springs. The springs are thermal, discharging at a nearly constant temperature of 32°C (Scoppettone et al. 1992). They occur within a 2-km radius and form the headwaters of the Muddy River. The occurrence of spring discharge at the terminus of regional ground water flow systems is characteristic of the carbonate rock province (Harrill and Prudic 1998).

The MRSA supports eight rare, endemic, aquatic species, including the Moapa dace (*Moapa coriacea*), a federally listed endangered fish since 1967 (U.S. Fish and Wildlife Service, 1996; Scoppettone et al. 1998). The Moapa dace is thermophilic and occurs typically in water temperatures ranging from 26°C to 32°C (Deacon and Bradley 1972). Because the Muddy River cools as it flows downstream, the fish are restricted to the thermal headwater springs (Cross 1976). Like many native fish of the southwestern United States, the Moapa dace have declined due to habitat alteration and introduction of nonnative fish (Deacon and Bradley 1972; Scoppettone et al. 1998). The Moapa Valley National Wildlife Refuge, a 47-ha area of springs and wetlands located in the MRSA, was established in 1979 for the protection of Moapa dace (Figure 3).

The transmissivity of the carbonate rock aquifer in the MRSA and surrounding area is quite variable but can be extremely high. Estimated transmissivities range from 200 m^2/d in several carbonate wells in Coyote Spring Valley to 20,000 m^2/d or higher in wells directly upgradient or adjacent to the springs in the MRSA (Bunch and

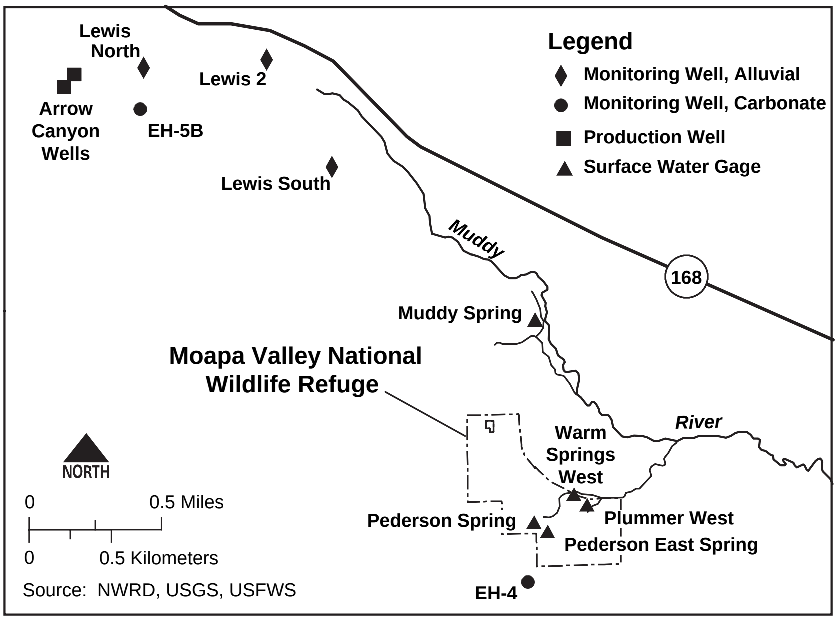

Figure 3. Close-up of MRSA showing Moapa Valley NWR boundaries, Muddy River and tributaries, carbonate production wells, carbonate monitoring wells, alluvial monitoring wells, and spring monitoring sites.

Harrill 1984; Buqo 1994; Dettinger et al. 1995). High-permeability zones such as this are commonly found up-gradient of areas of regional spring discharge. Dettinger et al. (1995) analyzed 39 well tests in southern Nevada and found that wells located up to 16 km upgradient of regional springs show transmissivities about 10 to 20 times greater, on average, than those located farther away. The high transmissivity of the carbonate rock aquifer has resulted in a fairly uniform potentiometric surface over an extensive area in and around the MRSA.

There are three primary hydrogeological units in the Upper Moapa Valley: the Quaternary alluvial fill, the Tertiary Muddy Creek Formation, and the Paleozoic carbonate system (Pohlmann 1994). The alluvial fill material provides a shallow, high-yield aquifer that is recharged from the underlying carbonate aquifer. The Muddy Creek Formation underlies the alluvial fill in much of the valley and is considered a semiconfining unit. The Paleozoic carbonates extend below and underlie the other units and are part of the regional carbonate rock aquifer of the White River flow system. Vertical hydraulic gradients in this area are upward from the carbonate rock aquifer to the alluvial fill aquifer.

Like many areas of the southwestern United States, southern Nevada is experiencing tremendous population growth. Municipalities and other water users are turning to the regional carbonate rock aquifer to meet future demand. Ground water in both the shallow alluvial aquifer and the deeper carbonate rock aquifer in the MRSA has been developed. Pumping in the alluvial aquifer for irrigation has been ongoing since World War II, with many of the irrigation water rights being acquired and changed to industrial purposes by power interests since the 1960s. Pumping in the carbonate rock aquifer for municipal supply purposes started in 1986 and increased significantly beginning in 1998. Most of the carbonate pumping now occurs at two adjacent wells: the Arrow Canyon wells 1 and 2, located about 3.5 km northwest of the wildlife refuge (Figure 3).

Theoretical Ground Water Level/Spring Discharge Relationships

Many public agencies and private organizations are concerned that ground water development of the carbonate rock aquifers may negatively impact regional spring systems like the MRSA and the biological resources associated with those systems. It is well established that spring discharge in the MRSA emanates from the regional carbonate aquifer (Eakin 1966; Prudic et al. 1993; Thomas et al. 1996). The potentiometric surface of the carbonate rock aquifer is greater than the land surface elevation of the springs. This hydraulic head differential causes ground water in the carbonate rock aquifer to rise to the land surface, through fissures and fractures, manifesting itself as spring discharge. We are assuming that the flow at a spring is governed by Darcy's law, or some similar proportionality, which states that flow through a porous medium is proportional to the hydraulic head differential or hydraulic gradient (Fetter 1994). The greater the hydraulic head differential between the elevation of the spring orifice and the hydraulic head of the aquifer, the greater the spring discharge, other factors being equal.

All ground water pumping leads to the development of a drawdown cone around the pumping center. As the drawdown cone extends to the springs, the hydraulic head differential at the springs will be reduced. Darcy's law states that a reduction in the hydraulic head differential will result in a proportional decrease in flow. The elevations of spring pool orifices in the MRSA vary by more than 20 m (Southern Nevada Water Authority 2003). The uniform potentiometric surface of the carbonate rock aquifer underlying the MRSA means that the head differential at the various springs decreases with increasing elevation of the spring orifice. We hypothesize that the springs in the system with the smallest head differential, the highest elevation springs, will be proportionately most sensitive to any decline in the potentiometric surface of the carbonate rock aquifer resulting either from ground water pumping or climate effects.

Methods

Climate Data

Each state in the nation has been divided into 1 to 10 climate divisions. These are areas of climate uniformity with water resource data aggregately assessed through principal component analysis, based on information from 10 to 50 individual stations (Guttman and Quayle 1996). Monthly divisional climate data and indexes, including monthly temperature and precipitation, Standard Precipitation Index (SPI), and various Palmer Drought Index (PDI), are compiled back to 1895 for each climate division in the country. We evaluated two climate parameterizations in the study: precipitation and SPI. Monthly precipitation data and SPI were obtained for two of Nevada's four climate divisions: Climate Divisions 3 (South Central) and 4 (Extreme Southern) (Western Regional Climate Center, 2006). Divisions 3 and 4 encompass the north-central and south portions, respectively, of the White River flow system (Figure 1). We calculated moving averages of the monthly precipitation, defined back from points in time, for various time scales for each division.

The SPI is a recently developed normalized index of drought (McKee et al. 1993), designed to explicitly express the fact that it is possible to simultaneously experience wet and dry conditions on multiple time scales. For SPI, historical precipitation data are used to compute the probability distribution of the monthly and seasonal observed precipitation totals (the past 2, 3, 6 months, etc., up to 72 months), and the probabilities are normalized to a cumulative normal distribution. The mean of SPI is then 0 for any particular location and time scale, and the units are normalized variates or standard deviations away from the mean. Positive SPI values indicate greater than average precipitation, while negative values indicate less than average precipitation. Values of 2.0 and −2.0 are defined as extremely wet and extremely dry conditions, respectively. Because SPI is a standardized measure of precipitation, SPI values from different climate divisions are comparable.

Ground Water and Surface Water Data

Water level data are available for a number of carbonate and alluvial monitoring wells for varying periods (Berger et al. 1988; Southern Nevada Water Authority 2006; USGS 2006). Figures 2 and 3 and Table 1 give the location, aquifer type (carbonate or alluvial), well level elevation, period of record, and frequency of measurements of all monitoring wells investigated in this study. Of particular interest are two carbonate monitoring wells, EH-5B and EH-4, located in the MRSA near the pumping center and the springs (Figure 3). Both wells have monthly measurements dating back to 1987, with continuous measurements beginning in 1997.

Monthly pumping data are available for the alluvial production wells from 1983 through 2005 and for the carbonate production wells from 1992 to 2005 (Las Vegas Valley Water District 2001; Moapa Valley Water District 2005; Nevada Power Co., unpublished data). Annual carbonate pumping from 1987 to 1992 was estimated by Las Vegas Valley Water District (2001). We grouped and averaged annual volumes for both carbonate and alluvial pumping for an 11-year period (1987 to 1997) and a 9-year period (1998 to 2005), based on the availability of pumping and monitoring data and the significant increase in pumping from the carbonate rock aquifer that began in 1998.

Four USGS surface water gauging stations in the MRSA are considered in this study: Pedersen Spring (site no. 09415910), Pedersen East Spring (site no. 09415908), Muddy Springs (site no. 09415900), and Warm Springs West (site no. 09415920) (Table 1; Figure 3). All four sites record spring discharge continuously. The gauges at Pedersen Spring and Pedersen East Spring are V-notch weirs that measure two small springs on the wildlife refuge. These are the highest elevation springs in the area. The weir at the Pedersen Spring gauge developed a leak in 2003, and we use flow data only from 1998 through water year 2002. The gauge at Pedersen East Spring was recently installed, in April 2002.

The gauges at Warm Springs West and Muddy Springs are Parshall flumes that were installed in 1985 and have operated since that year, except for a 21-month gap from October 1994 to June 1996. Warm Springs

Table 1

Monitoring Site Name, Basin, Aquifer, Period of Record, and Frequency of Measurements

Well Name	Hydrographic Basin	Aquifer	Water Level Elevation[1] (m)	Period of Record	Frequency of Measurements
EH-5B	Upper Moapa Valley	Carbonate	553.4	1987–2005	Periodic[2] to 1997, continuous from 1997
EH-4	Upper Moapa Valley	Carbonate	553.4	1987–2005	Periodic to 1997, continuous from 1997
CSV-2	Upper Moapa Valley	Carbonate	547.4	1985–2005	Periodic, continuous from 1991 to 1994 and 1999 to 2005
Lewis North	Upper Moapa Valley	Alluvial	552.3	1987–2005	Periodic
Lewis South	Upper Moapa Valley	Alluvial	546.8	1987–2005	Periodic
Lewis 2	Upper Moapa Valley	Alluvial	547.9	1988–2005	Periodic
EH-3	Lower Moapa Valley	Carbonate	Unknown	1987–2005	Periodic
EH-7	Lower Moapa Valley	Carbonate	Unknown	1987–2005	Periodic
MX-4	Coyote Spring Valley	Carbonate	555.2	1985–2005	Periodic, continuous from 1990 to 1996 and 1999 to 2005
CE-VF-2	Coyote Spring Valley	Carbonate	566.0	1987–2005	Periodic, continuous from 2004
CE-VF-1	Coyote Spring Valley	Alluvial	584.3	1988–2005	Periodic
CSV-3	Coyote Spring Valley	Alluvial	556.0	1987–2005	Periodic
SHV-1	Hidden Valley	Carbonate	554.2	1985–2005	Periodic, continuous from 2001
M-1	California Wash	Carbonate	553.5	2001–2005	Continuous
ECP-1	California Wash	Carbonate	553.5	2001–2005	Continuous
TH-2	California Wash	Carbonate	553.1	2001–2005	Continuous
M-2	Garnet Valley	Carbonate	552.5	2001–2005	Continuous
M-3	Garnet Valley	Carbonate	553.1	2001–2005	Continuous

Spring Name	Hydrographic Basin	Aquifer	Spring Orifice Elevation (m)	Period of Record	Frequency of Measurements
Pedersen Spring	Upper Moapa Valley	Carbonate	552	1998–2002	Continuous
Pedersen East Spring	Upper Moapa Valley	Carbonate	551	2002–2005	Continuous
Warm Springs West	Upper Moapa Valley	Carbonate	548 (average elevation)	1998–2005	Continuous
Muddy Springs	Upper Moapa Valley	Carbonate	535	1998–2005	Continuous
Plummer West	Upper Moapa Valley	Carbonate	536	1998–2004	Periodic

[1]Water level elevation as of January 2001.
[2]Periodic means one or two measurements a month.

West measures the collective discharge from five spring groups upstream on the refuge, including the Pedersen Spring and Pedersen East Spring groups. The Muddy Springs gauge measures the outflow from Muddy Springs, the largest and lowest elevation spring in the area.

Several factors affected the quality of records at these surface water stations prior to 1998, including an unmeasured irrigation diversion above one station, a fire that may have affected another station, a gap in the records because of lack of funding, and some unexplained variability or discontinuities in the flow records. For these reasons, we use data only from 1998 on for these sites. In addition to these four sites, the U.S. Fish and Wildlife Service made monthly measurements of spring discharge at the Plummer West spring (Table 1; Figure 3) from June 1998 to November 2004 using a 45° V-notch weir installed at the outflow of the spring pool. This spring is lower in elevation relative to other springs in the immediate area and does not contribute to the collective flow measured at the Warm Springs West site. A theoretical rating was used to convert stage to discharge at this site. The measurements stopped when the weir was removed because of habitat restoration at the spring.

Elevation Data

The Southern Nevada Water Authority completed a comprehensive elevation survey of numerous wells and stream gauges in the MRSA and surrounding basins, including several of the monitoring sites in this study (Southern Nevada Water Authority 2003, 2005). We referenced elevations from the survey and used a level to determine the elevations of spring monitoring sites not included in the survey (Table 1). The spring elevations were used in combination with the ground water elevations in carbonate monitoring wells to estimate the hydraulic head differential at each spring or spring group.

Statistical Analyses

We used a *t*-test to compare the average pumping volumes for two periods, pre- and post-1998, based on a fourfold increase in pumping from the carbonate rock aquifer that occurred beginning in 1998. Temporal trends in the two carbonate monitoring wells, EH-5B and EH-4, in the MRSA were analyzed pre- and post-1998 periods as well. We evaluated three main stressors: climate, alluvial pumping/ET, and carbonate pumping. We excluded seismic activity, barometric pressure, and earth tides on the grounds that effects from these factors are minor and short term, at least for our scales of interest (Pohlmann 1994; Fenelon and Moreo 2002; Waddell and Roemer 2006).

Explanatory variables for the multiple regressions used in the trend analysis were initially evaluated through automated stepwise procedures (Helsel and Hirsch 1992; Ott 1993) using the statistical software SPSS. We then used regression diagnostics, regression statistics, and residual plots to select variables, to test regression assumptions, and to evaluate multicollinearity among variables, which can cause the values of coefficients to be unstable or their signs to be unreasonable (Helsel and Hirsch 1992). These steps were done iteratively, using the data from the EH-5B and EH-4 carbonate monitoring wells, different explanatory variables, and different periods of record, until we developed a common subset of explanatory variables that applied to both wells. We relied on the variance inflation factor, standardized coefficients, PRESS statistic, and adjusted r^2 to help us evaluate variables and regressions. Candidate explanatory variables for the multiple regressions included a wide range of divisional climate statistics from Divisions 3 and 4, including monthly precipitation, 6- to 36-month moving averages of monthly precipitation, 4- to 72-month SPI, and higher order transforms of all moving averages and SPIs. We address some of the differences and implications of using various climate parameterizations in a later section.

We did not quantitatively model pumping or ET in the statistical analysis. The alluvial pumping/ET signal was assumed to be seasonal and was represented with the periodic functions, sine and cosine, with the time variable used to test the assumption that there were no long-term changes resulting from alluvial pumping/ET. We interpreted coefficients from the sine and cosine terms in the regressions to define the amplitude and phase of the seasonal periodicity (Helsel and Hirsch 1992). These authors suggest always adding both sine and cosine terms, even if one of the pair is not statistically significant, to allow the regression to determine the phase shift from the data rather than arbitrarily.

Carbonate pumping was represented with a binary variable, which was changed from zero to one during periods of increased carbonate pumping. This was done for two reasons. First, we did not have actual monthly pumping data for the entire record; only annual pumping data were available. Second, this approach permitted us to use analysis of covariance to quantify any statistically significant changes that occurred coincident with periods of increased pumping (Helsel and Hirsch 1992; Ott 1993). The key variables in the analysis of covariance approach are the interaction terms or the products of the binary variable with time, sine, and cosine. The regression coefficients and statistics associated with these terms indicate changes in time, amplitude, or phase during periods of increased carbonate pumping. Our approach implicitly assumes that a threshold level of carbonate pumping exists below which there are no measurable effects. Preliminary statistical analysis showed this assumption to be acceptable in our system for the period of interest, but such an approach would not be appropriate in all cases.

For the analysis of spatial trends in carbonate and alluvial monitoring wells throughout the system, we considered the period January 2001 to September 2005, a period encompassing extreme climate variability and increased carbonate pumping. Continuous data, when available, were averaged to monthly values. Several months of data were missing in 2004 for some of the carbonate wells in California Wash. We estimated these missing data based on regressions with TH-2, a carbonate well located in the same basin with a complete record for the period. Spatial trends in all wells in the southern portion of the flow system were compared through hierarchical cluster analysis, using average linkage and correlation coefficient distance, and through time series seasonal decomposition. We tested for statistically significant seasonality through regression analysis using the sine and cosine of time, as mentioned previously. In those wells with seasonality, we used a seasonal decomposition procedure in the time series analysis in SPSS to compute and compare the amplitude and phase of the seasonality at all wells for four complete years, January 2001 to December 2004. In the seasonal decomposition procedure, the time series is separated into seasonal, trend, and cycle components. The seasonal index is the average deviation of each month's water level from the level that was due to the other components that month, expressed in the original measurement units. The seasonal index provided an objective measure to compare the relative amplitude and phase of the seasonality for all wells. We also examined the recharge response to the extremely wet year in 2005 for all wells.

For the analysis of spring discharge/ground water relationships, we considered the period 1998 to 2005, when spring discharge data are most reliable. For each spring, we normalized flow to the initial flow value in the period of record and then plotted the normalized flow as a function of carbonate water levels at EH-5B. The slopes for linear regressions of normalized flow vs. ground water elevation were computed and compared, based on the elevations of the spring orifices and the assumed hydraulic head differential at each spring.

Results and Discussion

Climate Data

Figure 4a shows total winter precipitation in Climate Divisions 3 and 4 for the period 1985 to 2005. Winter precipitation and late spring snowmelt, rather than summer precipitation, have been shown to be the principal sources of recharge in the fractured carbonate rock of this area (Winnograd et al. 1998). Winter precipitation was quite variable during this period, particularly in Climate Division 4. The winter totals of 2005, 1993, and 1992 were the highest, second highest, and third highest October to March precipitation totals, respectively, in Climate Division 4 since recordkeeping began in 1895. The winter total of 2002 was the second lowest October to March total in Division 4 since 1895.

The 12-, 24-, and 60-month SPI for Nevada Climate Divisions 3 and 4 from 1980 through 2005 are shown in Figure 5. The SPI plots show that both wet and dry conditions have been experienced simultaneously in each division, depending on the time scale of interest. There is less variability in the SPI values at longer time scales.

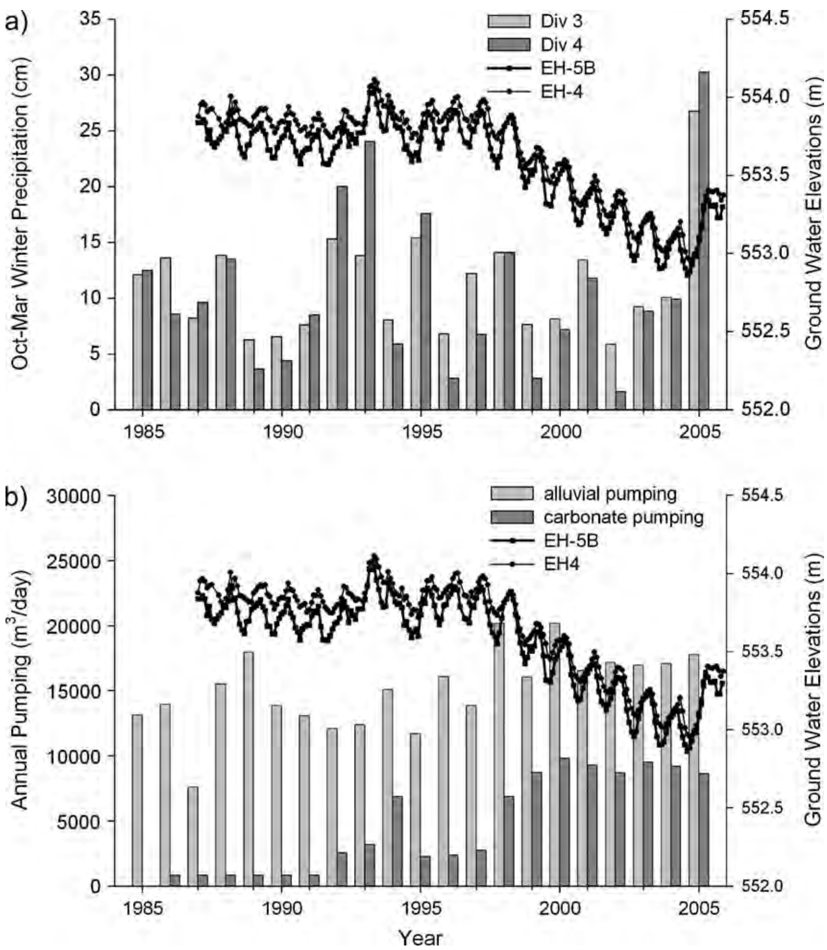

Figure 4. Water levels in carbonate monitoring wells EH-5B and EH-4 for the period 1985 to 2005 with October to March winter precipitation in Nevada Climate Divisions 3 and 4 (a, top plot) and annual alluvial and carbonate pumping (b, bottom plot).

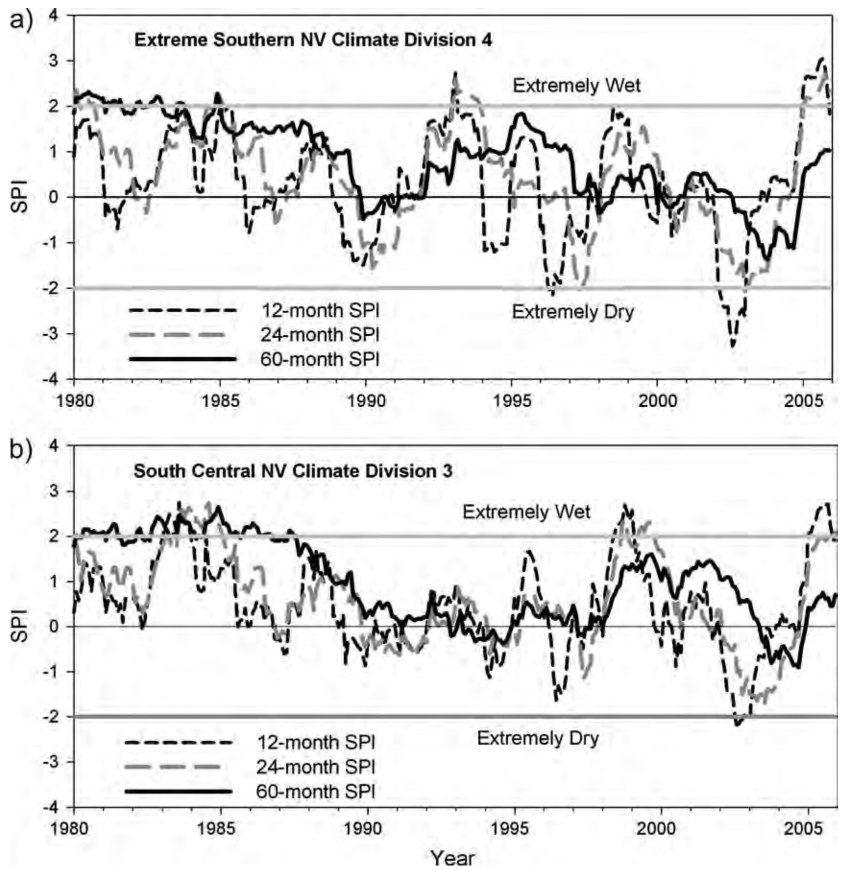

Figure 5. The 12-, 24-, and 60-month SPI for Nevada Climate Divisions 4 (a, top plot) and 3 (b, bottom plot) for 1980 to 2005. The definition of the terms *extremely wet* and *extremely dry* is discussed in the text.

Generally, conditions have been more variable for Division 4 (Extreme Southern Nevada) than Division 3 (South Central Nevada). Considering the 12- and 24-month SPI, Division 4 (Figure 5a) was extremely wet in 1992 and 1993 and extremely dry in 1996 and 1997. In contrast, Division 3 (Figure 5b) was normal or slightly above normal in 1992 and 1993 and not as dry in 1996 and 1997 but was extremely wet in 1998 and 1999. Both climate divisions experienced extremely dry conditions in 2002 and extremely wet conditions in 2005.

One purpose of this study was to discuss the implications of using various climate parameterizations in this type of statistical analysis. Specifically, we explore the difference in using raw precipitation data, in the form of moving average precipitation, vs. a drought index such as the SPI. Generally, the two parameters track similar trends. Moving averages become normally distributed and linearly related to SPI at longer time scales, as a consequence of the larger sample sizes and the Central Limit Theorem (Ott 1993). Guttman (1998) reported that the SPI spectral characteristics conform to what is expected for a moving average process.

A major difference between the two variables is with their units and frequency distributions. The units of SPI are normalized variates, and the frequency distribution is symmetric and centered about a mean of 0. The absolute value of SPI is 0 under average conditions and increases as conditions become either wet or dry. Any regression term containing SPI, or any of its higher order transforms, is the product of the regression coefficient and the value of SPI at that time step. Such a term will have the least amount of influence on the predicted water level under average conditions, when the product is close to zero, and will be larger and more influential, although opposite in sign, as the conditions become wetter or drier. We characterize the regression response to this parameterization as symmetric, in the sense that both wet and dry years will be influential in determining the simulated water level. The PDI (Palmer 1965) and other standardized precipitation or drought indexes centered on zero (see Hayes [2006] for a description of several common indexes) will have similar characteristics.

By contrast, the units of precipitation are nonstandardized values and are always positive, and the frequency distribution of moving average precipitation at shorter time scales is asymmetric and positively skewed (McKee et al. 1993). The square or cubic transform of this variable increases this skewness. Any product in the regression containing precipitation, or any of its higher order transforms, will have the least amount of influence on the predicted water level under dry conditions, or low values of precipitation, and will be more influential as conditions get wetter and precipitation values increase. We characterize the regression response to this parameterization as asymmetric, in the sense that wet years will be more influential in determining the simulated water level than dry years. We propose that the relative importance of these two parameters, moving average precipitation vs.

SPI, in a regression analysis, will have implications about whether the system responds asymmetrically to only wet or dry conditions or symmetrically to both wet and dry conditions.

We excluded two other common climate parameterizations in this study, the PDI and the cumulative rainfall departure from normal, on the basis of critical reviews of these parameterizations. The PDI is a widely used measure of meteorological drought severity (Palmer 1965). Alley (1984) criticized the PDI as being complex to calculate, using somewhat arbitrary rules to designate droughts or wet periods, and being limited in geographical extent. Guttman (1998) compared the PDI and the SPI and reported that the spectral characteristics of the PDI varied geographically, while those of the SPI did not. He concluded that the PDI is a complex structure with a long memory, while the SPI is an easily interpreted, moving average process.

The cumulative rainfall departure from normal measures the accumulated departure of precipitation from a mean defined for some time period. Weber and Stewart (2004) criticized the measure as being problematic for nonnormally distributed precipitation, a common condition in arid environments. Furthermore, they pointed out that the calculated departure is extremely variable depending on the starting and ending points and the length of the period for which the mean is defined.

Pumping and ET

The pumping from the carbonate rock aquifer increased slowly from 1987 to 1997 and then considerably after 1998 (Figure 4b). Carbonate pumping averaged 2200 m^3/d for the period 1987 to 1997 and 8870 m^3/d for the period 1998 to 2005, a statistically significant fourfold increase ($p = 0.000$). The higher values pumped in 1993 and 1994 compared with other years in the earlier period are partly due to a 121-d aquifer test conducted from December 1993 to April 1994 (Buqo 1994).

Annual alluvial pumping increased slightly over the same period from 13,500 m^3/d for the period 1987 to 1997 to 17,750 m^3/d for the period 1998 to 2005 ($p = 0.005$) (Figure 4b). By comparison, we estimated ground water discharge from the alluvial aquifer through phreatophyte ET in the MRSA to be about 5000 m^3/d, based on preliminary information from a USGS study of ET in the area (G.A. DeMeo, written communication, 2006). Based on these estimates, alluvial pumping seems to place a greater demand on the alluvial aquifer than ET. Ground water discharge through ET does not occur in the southern part of the flow system outside the MRSA because of the greater depths to alluvial ground water in other areas. Both alluvial and carbonate pumping are generally greatest during the months of May through September, when demand is highest. Minimum pumping occurs in January in both aquifers.

Temporal Trends in Two Carbonate Monitoring Wells

Ground water elevations in the carbonate rock aquifer in the MRSA, as measured in wells EH-5B and EH-4, show a strong seasonal trend, with minimum annual elevations usually observed in the fall (Figure 4). Two other trends are evident in the ground water level data: annual increases in 1992, 1993, and 2005 and a multiyear decrease beginning in 1998. The increases in 1992, 1993, and 2005 correspond to years of high winter precipitation, especially in Division 4 (Extreme Southern Nevada) (Figure 4a). The decrease beginning in 1998 coincides with the fourfold increase in pumping from the carbonate rock aquifer that occurred at the same time in the MRSA (Figure 4b). The initial water level elevations and the magnitude of increases and declines in both wells are similar, despite the distance separating the two wells and their varying proximities to the pumping center. This is indicative of the uniformity of the potentiometric surface in the carbonate rock aquifer in the MRSA, as a result of the high transmissivities.

We first examined data statistically from EH-5B and EH-4 data for the years 1987 to 1998, a period of minimal carbonate pumping. For both wells, the optimum explanatory variables determined through stepwise multiple regression analysis were sine, cosine, the cube of the Division 4 24-month moving average monthly precipitation, the Division 3 30-month SPI, the Division 4 60-month SPI, time, and carbonate pumping. These seven explanatory variables explained between 65% and 75% of the variance of the data for the period. The most influential terms in the regression, based on the standardized coefficients and the *t* values, were the sine/cosine, followed by the cubic transform of the Division 4 24-month moving average monthly precipitation. The regression coefficient for time for this period was positive but very small, meaning that there was no long-term decline associated with the alluvial and carbonate pumping that occurred prior to 1998. The effect of the 121-d aquifer test in 1994 in the carbonate rock aquifer, as measured with the carbonate binary pumping variable, was statistically significant but short-lived, appearing to extend about 2 months after the completion of the aquifer test.

The importance of the cubic transform of Division 4 24-month moving average precipitation in the regression is interesting for several reasons. First, the selection of this term, rather than lower order terms of the 24-month moving average, implies that the system is quite responsive to wet years since the cube leads to right skewness in the data and emphasizes wet years. We are using climate division data, which are primarily based on valley floor weather stations, as a surrogate measure of recharge in the system. But the proportion of recharge in mountainous areas during wet years may be much greater than is indicated by the precipitation data from valley floor weather stations. The importance of the cubic transform over lower order terms in the regression may be an indication of the greater proportion of recharge in wetter years.

Second, the fact that a higher order transform of precipitation was selected rather than higher order transforms of SPI means that the system response appears to be asymmetric and more sensitive to wet years than to dry years, as described previously. An example of this asymmetry can be observed in the response of water levels to the extremely wet period in 1992 to 1993 and the lack of a response to the extremely dry period in 1996 to 1997. This sensitivity to wet years, often associated with El Niño events, has been described for other ground water systems in the arid southwestern United States (Hanson et al. 2004; Scanlon et al. 2006).

Finally, the stepwise selection of a precipitation variable from Climate Division 4 ahead of Division 3 states that precipitation in the southern portion of the flow system is quite important. In the original conceptual flow model (Eakin 1966), most of the recharge was believed to occur in the north and recharge in the southern portion was believed to be minor. Our results may contradict this and support greater recharge in the southern portion of the flow system, as suggested by Johnson and Mifflin (2006). Higher precipitation rates, thin soils, and the exposure of high-permeability carbonates at the surface all likely contribute to greater recharge in the high-elevation areas of the southern portion of the flow system.

Next, we extended the regressions for both carbonate monitoring wells to December 2002. This period includes 5 years of increased carbonate pumping, 1998 to 2002, and the extreme drought of 2002. We used the same seven explanatory variables as in the previous regressions, along with three interaction terms of carbonate pumping with time, sine, and cosine. The interaction terms capture any change in the slope with time and the periodicity, corresponding to the period of increased carbonate pumping after 1998. The regressions explained between 95% and 96% of the variance in the two carbonate monitoring wells for the period 1987 to 2002 (Figure 6). The adjusted r^2 values improved considerably from regressions for the previous 1987 to 1998 period, in part because the long-term decline beginning in 1998 dominates the variance and this trend is simulated very well by the regression equations. The regression equations for the 1987 to 2002 period are shown subsequently:

$$\begin{aligned}\text{EH-5B monthly water level (m)} &= 1.78 \times 10^{-5}(t)\\ &+ 0.085\left[\sin(2\pi t)\right] + 0.048\left[\cos(2\pi t)\right]\\ &+ 1.61 \times 10^{-5}(\text{D4 24 m avg})^3 + 0.039(\text{D3 30 m SPI})\\ &+ 0.023(\text{D4 60 m SPI}) + 6.033(\$bc\$)\\ &- 1.77 \times 10^{-4}(\$bc\$ \times t) + 0.013\left[\$bc\$ \times \sin(2\pi t)\right]\\ &+ 0.027\left[\$bc\$ \times \cos(2\pi t)\right] + 553.09\end{aligned}$$

$$\begin{aligned}\text{EH-4 monthly water level (m)} &= 8.22\text{E} \times 10^{-6}(t)\\ &+ 0.066\left[\sin(2\pi t)\right] - 0.009\left[\cos(2\pi t)\right]\\ &+ 1.21 \times 10^{-5}(\text{D4 24 m avg})^3 + 0.042(\text{D3 30 m SPI})\\ &+ 0.012(\text{D4 60 m SPI}) + 6.320(\$bc\$)\\ &- 1.85 \times 10^{-4}(\$bc\$ \times t) + 0.026\left[\$bc\$ \times \sin(2\pi t)\right]\\ &+ 0.033\left[\$bc\$ \times \cos(2\pi t)\right] + 553.55\end{aligned}$$

where t = time (day of year); sin and cos = the sine and cosine terms for the periodicity; D4 24 m avg = the 24-month moving average precipitation (mm) for Climate Division 4; D3 30 m SPI = the 30-month SPI for Climate

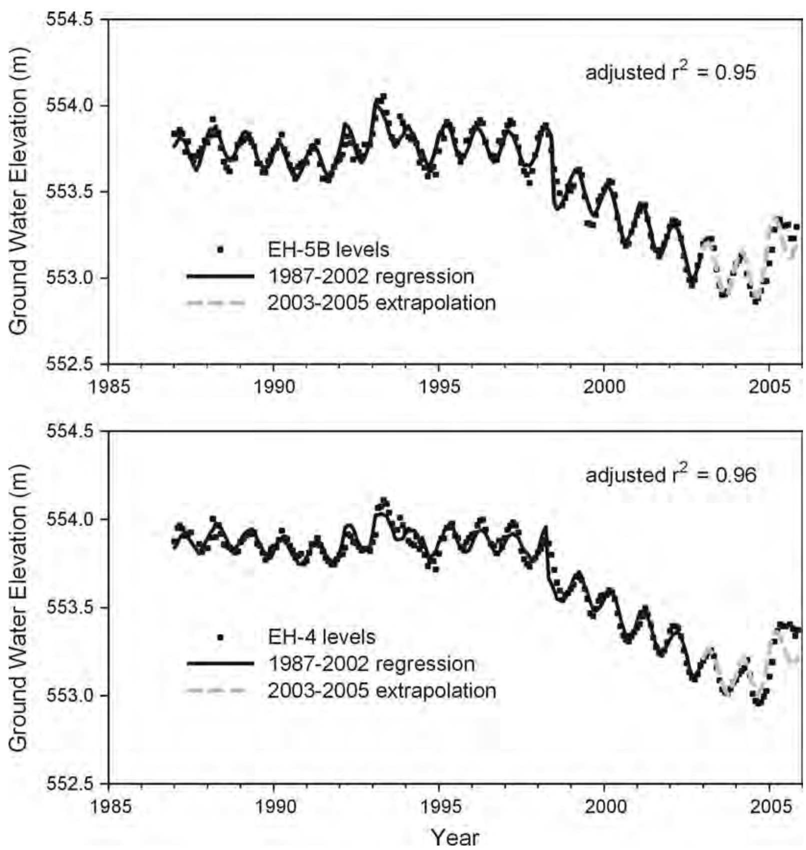

Figure 6. Water levels in carbonate monitoring wells EH-5B and EH-4 for 1987 to 2005 with multiple regressions for 1987 to 2002 and extrapolations of the regression for the period 2003 to 2005.

Division 3; D4 60 m SPI = the 60-month SPI for Climate Division 4; bc = the binary variable for the carbonate pumping; bc $\times t$ = the interaction term of the carbonate binary variable and time; and bc $\times \sin(2\pi t)$ and bc $\times \cos(2\pi t)$ = the interaction terms of the carbonate binary variable and the periodicity.

Coefficients and prediction values from the regressions for each well were basically equal for the two periods, 1987 to 1998 and 1987 to 2002, and the two regressions plot on top of each other during the overlapping years. Only the value of the regression coefficient for the carbonate binary variable changed between the two periods. The coefficient for the interaction term with time was negative and statistically significant, indicating that ground water levels began declining coincident with the increased carbonate pumping in 1998. The interaction terms with sine and cosine indicated that the amplitude of the seasonal pattern increased by 2.7 cm and the phase shifted 2 to 3 weeks earlier in both wells after 1998, although only the phase shift in EH-5B was statistically significant. Extrapolations of the 1987 to 1998 regressions beyond 1998 with climate terms alone were unable to simulate the long-term decline that began in 1998. To simulate this decline, we had to add the binary variable to account for increased carbonate pumping. We infer from these results that the long-term decline in carbonate levels beginning in 1998 is a result of the increased carbonate pumping that began at the same time.

The regressions for the period 1987 to 2002 were extrapolated for 3 years from 2003 to 2005, using the same explanatory variables, in an attempt to validate the statistical model (Figure 6). The regressions appear to simulate the ground water trends in these years for both wells, continuing to decline through 2004 and then increasing in 2005 in response to the extremely wet year. The wet year response in 2005, as predicted by the regressions, is based on the responses observed and fitted statistically in the 1987 to 2002 regressions. While the extremely wet years in 1992, 1993, and 2005 caused large increases in water levels, the extremely dry conditions of 2002 appear to have relatively little effect on water levels. This demonstrates what we interpret to be the sensitivity and asymmetry in the system response to wet years over dry years.

Spatial Trends in Carbonate and Alluvial Monitoring Wells

Most of the carbonate wells examined in this study show similar behavior, with a seasonal pattern imposed over a long-term declining trend from 1998 until 2004 and a large increase in response to the 2005 wet year (Figure 7). We assume that these wells are responding to the same climate and pumping signals as described for EH-5B and EH-4 previously. The multiyear declining trend through 2004 observed in most of the carbonate wells is most likely a result of the increased carbonate pumping in the MRSA. CE-VF-2 and SHV-1, the two more distant carbonate wells, do not appear to start declining until about 2000 rather than 1998.

Figure 8 presents the results from the cluster analysis of all wells examined in this study. Nine of the 11 carbonate wells are very similar to each other, with a similarity level more than 97. However, even within this group, there are subtle but important differences in the amplitude and phase, as indicated by the results from the time series seasonal decomposition (Figure 9). EH-5B has the greatest amplitude and the earliest phase in comparison to the other carbonate wells. It also has more of a characteristic pumping-induced asymmetry, as observed by Johnson and Mifflin (2006), in contrast to the other carbonate wells, which are more symmetric and sinusoidal. The seasonal amplitude, phase, and asymmetry may be related to the proximity of EH-5B to the Arrow Canyon production wells (Figure 3) and other alluvial production wells. MX-4 and M3 have slightly smaller amplitudes and later phases compared with the other carbonate wells. There is a north-south trending thrust fault separating these two wells from the MRSA and California Wash. The stratigraphic position of the carbonate rocks may be shifted across the fault, and this may be part of the reason for the smaller amplitude and later phase in the wells west of the fault. We observed no evidence of pumping-induced asymmetry in the hydrograph for MX-4, in contrast to Johnson and Mifflin (2006). CE-VF-2 and SHV-1, two other carbonate wells farther west of the thrust fault and the MRSA, partitioned quite differently from the main group of carbonate wells because of a lack of seasonality and, in the case of SHV-1, a much smaller decline and recharge response.

In general, carbonate wells located closer to the MRSA tend to have larger amplitudes and earlier phase shifts than those farther away, with the most distant wells in Hidden Valley and Coyote Spring Valley showing no seasonality and a delayed drawdown as well. Such a pattern could be suggestive of a muted or attenuated signal with distance from the source, although this is more clearly evident in the upgradient direction than in California Wash or Garnet Valley. Given the complex geology and the fractured nature of the flow system, responses may not be expected to be isotropic or solely a simple function of linear distance. Johnson and Mifflin (2006) postulated the presence of a hydraulic barrier between California Wash and the MRSA based on their modeling results, but we found no evidence here to support the existence of such a barrier.

The alluvial monitoring wells responded and partitioned quite differently from the carbonate wells and from each other (Figures 7 and 8). The three alluvial wells in the MRSA partitioned into two separate clusters, which are quite unique from the carbonate wells in the same basin. The amplitude is much greater and the phase is earlier than in the adjacent carbonate wells (Figure 9). These differences may be due to the different hydraulic properties of the unconfined alluvial aquifer and the fact that the seasonal signal is partly a result of alluvial pumping in the same aquifer. There is also more of a pumping-induced asymmetry observed in the seasonal pattern, particularly in Lewis North, the closest alluvial well to the Arrow Canyon production wells. Only one of these three wells, Lewis North, shows a long-term decline through 2004 (Figure 7). CSV-3, an alluvial well in Coyote Spring Valley, has poorly defined seasonality, a long-term

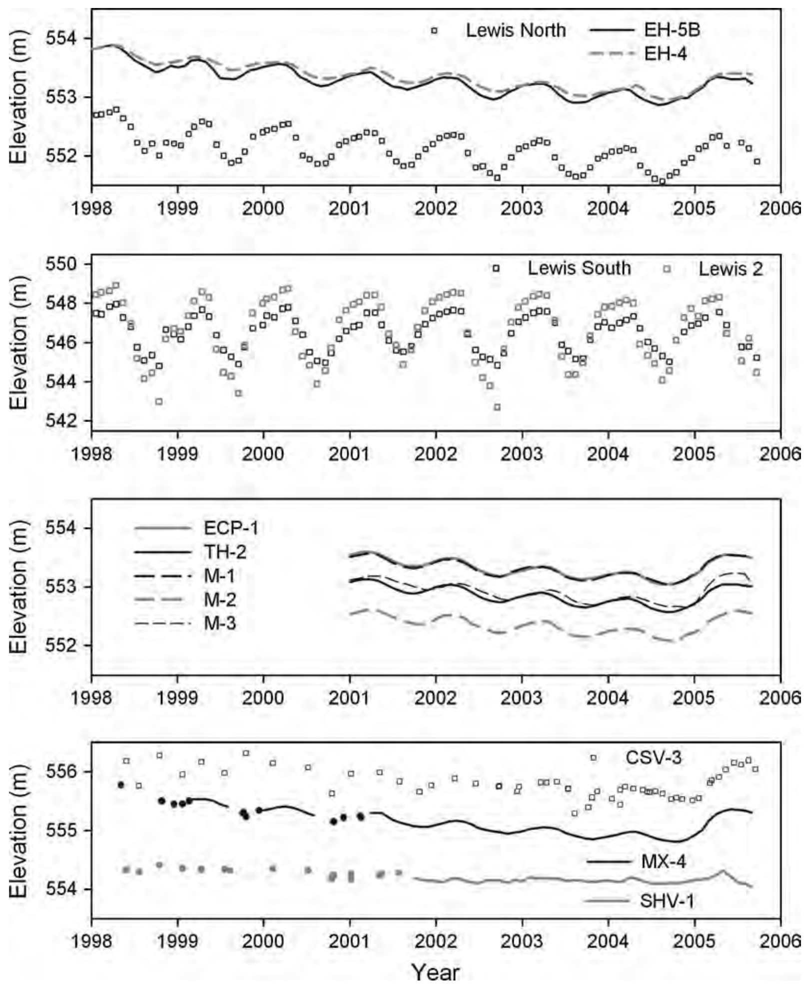

Figure 7. Hydrographs from representative carbonate and alluvial monitoring wells in the MRSA (top two plots), California Wash and Garnet Valley (third plot), and Coyote Spring Valley and Hidden Valley (bottom plot) for the period 1998 to 2005. Lines represent periods of continuous data in the carbonate wells. Symbols represent periodic measurements, open for alluvial wells and closed for carbonate wells. Note the different scales on the vertical axes. Three wells discussed in the text, CSV-2, CE-VF-1, and CE-VF-2, are not plotted.

decline beginning in 2000, and a response to the 2005 wet year. It was partitioned with CE-VF-2, a carbonate well in the same basin with a very similar hydrograph. CE-VF-1, a second alluvial well in northern Coyote Spring Valley, showed no seasonality or long-term decline or recharge response. It partitioned very differently from any of the other wells (Figure 8).

The response to the extremely wet year in 2005 varied by aquifer type. The timing and magnitude of the response are quite uniform in most of the carbonate wells, with the exception of SHV-1 (Figure 7). The 2005 wet year response is more dampened and short-lived in two alluvial wells, Lewis North and CSV-3, and not present at all in the other three alluvial monitoring wells (Figure 7). The widespread and rapid response to the 2005 wet year in the carbonate rock aquifer is surprising. We assumed that climate responses in the regional carbonate aquifer would be attenuated. We believe that the uniform, widespread wet year response, as well as the importance of Division 4 precipitation in the regression analysis, suggests that the carbonate rock aquifer is directly recharged from higher elevation areas in the southern portion of the flow system. The carbonate lithologies are exposed at the surface at higher elevations and are likely quite efficient in capturing recharge, as suggested by others (Winnograd and Thordarson 1975; Winnograd et al. 1998; Johnson and Mifflin 2006). Thomas et al. (1996) postulated that most of the recharge to the Sheep Mountains on the west side of Coyote Spring Valley must flow north and east into the basin and the MRSA because of noncarbonate barriers to westward, southward, and southeastward flow. The results from this study support these conclusions.

The trends described in this study appear to be unique to the southern portion of the White River flow system. They are completely lacking in the records for other wells outside the flow system including EH-7 and EH-3, two carbonate monitoring wells located east of the MRSA (Figure 2), and several other carbonate monitoring wells located to the west of Coyote Spring Valley and the Sheep Mountains. The relevance of these spatial relationships is that they indicate that both climate and pumping impacts are propagated at approximately the same scale throughout much of the southern portion of this system. The area is hydraulically connected through the carbonate rock aquifer. Climate and pumping effects are small but spatially extensive, in part because of the high

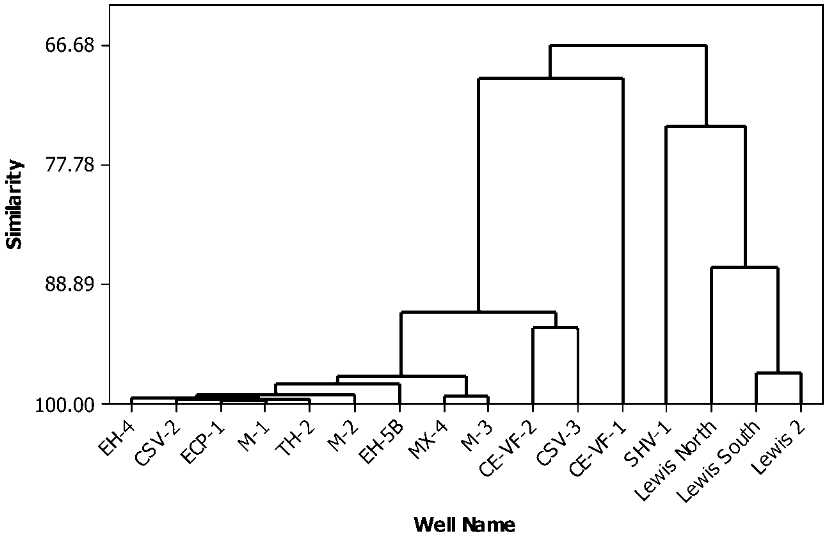

Figure 8. Cluster tree of 11 carbonate and 5 alluvial wells, using average linkage and correlation coefficient distances, with water levels from the period January 2001 to September 2005. The five alluvial wells are Lewis North, Lewis South, and Lewis 2 (all in the MRSA) and CSV-3 and CE-VF-1 (in Coyote Spring Valley).

transmissivity of the carbonate rock aquifer. Next, we examine what these effects mean for regional spring discharge.

Trends in Spring Discharge

Ultimately, much of the interest in ground water level trends relates to effects on spring discharge. Since 1998, we have observed a small but widespread pumping-induced decline in carbonate water levels in the MRSA and adjacent basins, followed by a sharp increase in water levels in response to the record precipitation in 2005. Trends in spring discharge are similar to carbonate water level trends, decreasing through 2004 and increasing after that. The springs essentially behave as artesian flowing wells. However, there are differences in the responses among individual springs, as discussed subsequently.

We hypothesized that because the drawdown is widespread and fairly uniform in the carbonate rock aquifer underlying the MRSA, the sensitivity of any one spring to declines in the water level should be related more to the elevation of the spring orifice and the initial hydraulic head rather than the proximity to pumping. Higher

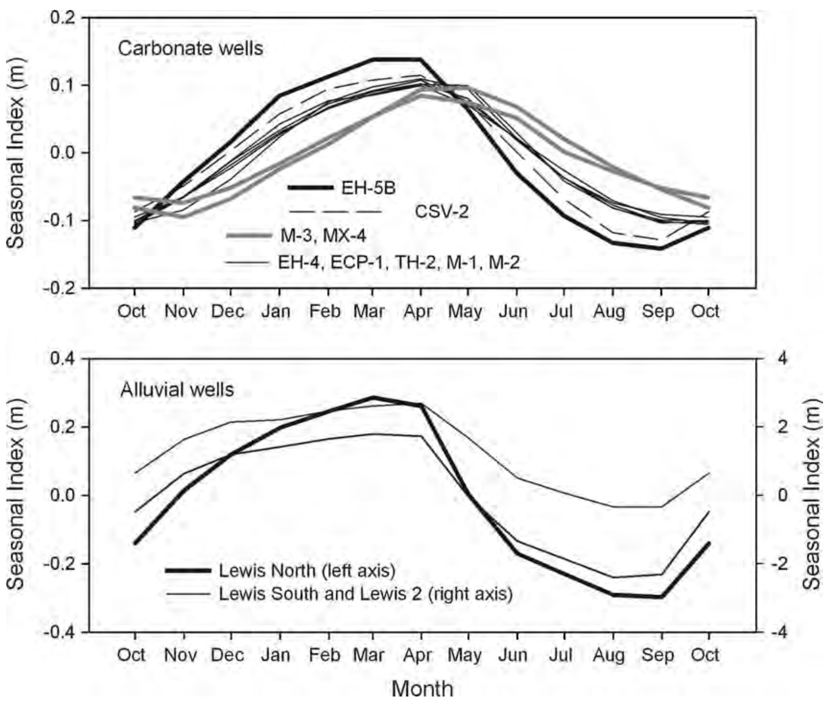

Figure 9. Seasonal indexes for carbonate and alluvial monitoring wells with statistically significant seasonality, based on time series seasonal decomposition of water level data for a 4-year period from January 2001 to December 2004. The seasonal index is the average deviation of each month's water level (in meters), from the level that was due to the other components that month.

elevation springs will be proportionately more sensitive to a uniform decline in ground water levels than lower elevations springs because of their smaller hydraulic head. The elevations of the spring orifices are presented in Table 1. Figure 10 presents normalized spring discharge for several springs of different elevations as a function of ground water elevation at EH-5B. Higher elevation springs have generally steeper regression slopes, meaning that they lose proportionately more flow for a given decline in head than the lower elevation springs. The fairly uniform water level declines or increases observed in the carbonate rock aquifer head result in much greater proportions of head loss or gain at higher elevation springs, with commensurate changes in flow. This indicates that the sensitivity of the various springs to ground water level declines is partly a function of their elevation and initial hydraulic head.

The higher elevation springs may represent some of the most important habitat for thermophilic, aquatic species in the Muddy River Springs ecosystem. Temperatures in the thermal water are warmer at the headwaters of the springs (Cross 1976), and there is generally less habitat disturbance and fewer introduced species in the headwater areas, especially at some of the smaller higher elevation springs. The position of these springs in the landscape means that they are very important in terms of habitat value and more susceptible to pumping-related impacts.

Conclusions

When ground water development approaches the limits of sustainability, even small changes in inflow, outflow, or storage can have economic or environmental consequences. In this study, we explore the premise that under such conditions, anthropogenic impacts of concern may be on the same scale as climate variability and both will need to be accounted for explicitly in any analysis. We use statistical methods to examine the response of water levels and spring discharge in a regional flow system in southern Nevada to climate and pumping. We consider the issue of climate parameterization and evaluate the use of several measures of climate variability, including raw precipitation data and several precipitation and drought indexes. Ultimately, the cubic transform of 24-month moving average precipitation was the most useful measure in our system because it captures the integrated water level response to precipitation over time and the asymmetric response of the system to wet conditions over dry conditions. This sensitivity to wet years, often

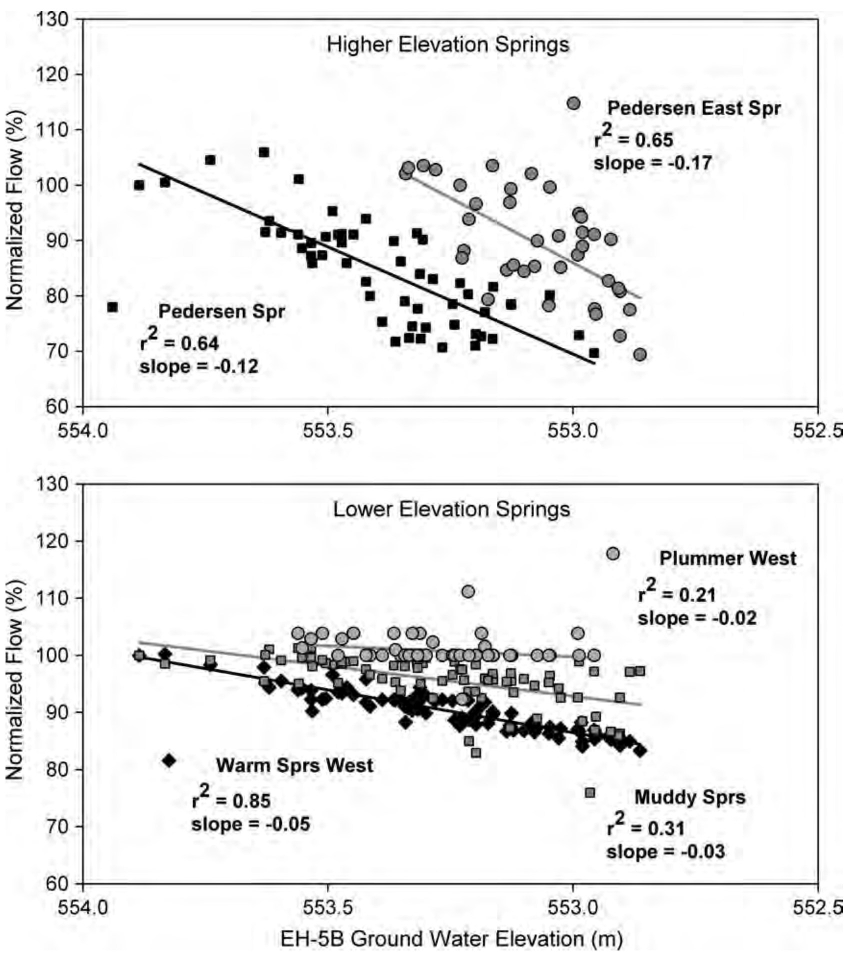

Figure 10. Normalized flow at various springs in the MRSA as a function of EH-5B levels. Values on the *x* axis are from high to low. Periods of record for each spring are given in the text.

associated with El Niño events, has been described for other ground water systems in the arid southwestern United States (Hanson et al. 2006; Scanlon et al. 2006).

Using cluster analysis and time series seasonal decomposition, we show that both climate and pumping impacts are propagated at approximately the same scale throughout much of the flow system. Relatively small changes in carbonate water levels are observed to cause corresponding changes in regional spring discharge. The sensitivity of any one spring to changes in water levels is, in part, related to the elevation and hydraulic head at the spring. The higher the elevation of the spring, the less hydraulic head at the spring initially and the more sensitive the spring is to ground water level changes. This is important since these springs represent some of the most important habitat for aquatic species in the Muddy River Springs ecosystem. Our statistical results give strong inference that the carbonate rock aquifer and the regional springs are well connected and responding to changes in climate and pumping and that the system is reaching the limits of sustainability.

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Prepared in cooperation with the National Park Service

Potential Effects of Groundwater Pumping on Water Levels, Phreatophytes, and Spring Discharges in Spring and Snake Valleys, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

Scientific Investigations Report 2011–5032

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft	1,233	cubic meter (m^3)
	Flow rate	
acre-foot/yr (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallons per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Leakance	
foot per day per foot [(ft/d)/ft]	1	meter per day per meter

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8.$$

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Potential Effects of Groundwater Pumping on Water Levels, Phreatophytes, and Spring Discharge in Spring and Snake Valleys, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

By Keith J. Halford and Russell W. Plume

Abstract

Assessing hydrologic effects of developing groundwater supplies in Snake Valley required numerical, groundwater-flow models to estimate the timing and magnitude of capture from streams, springs, wetlands, and phreatophytes. Estimating general water-table decline also required groundwater simulation. The hydraulic conductivity of basin fill and transmissivity of basement-rock distributions in Spring and Snake Valleys were refined by calibrating a steady state, three-dimensional, MODFLOW model of the carbonate-rock province to predevelopment conditions. Hydraulic properties and boundary conditions were defined primarily from the Regional Aquifer-System Analysis (RASA) model except in Spring and Snake Valleys. This locally refined model was referred to as the Great Basin National Park calibration (GBNP-C) model. Groundwater discharges from phreatophyte areas and springs in Spring and Snake Valleys were simulated as specified discharges in the GBNP-C model. These discharges equaled mapped rates and measured discharges, respectively.

Recharge, hydraulic conductivity, and transmissivity were distributed throughout Spring and Snake Valleys with pilot points and interpolated to model cells with kriging in geologically similar areas. Transmissivity of the basement rocks was estimated because thickness is correlated poorly with transmissivity. Transmissivity estimates were constrained by aquifer-test results in basin-fill and carbonate-rock aquifers.

Recharge, hydraulic conductivity, and transmissivity distributions of the GBNP-C model were estimated by minimizing a weighted composite, sum-of-squares objective function that included measurement and Tikhonov regularization observations. Tikhonov regularization observations were equations that defined preferred relations between the pilot points. Measured water levels, water levels that were simulated with RASA, depth-to-water beneath distributed groundwater and spring discharges, land-surface altitudes, spring discharge at Fish Springs, and changes in discharge on selected creek reaches were measurement observations.

The effects of uncertain distributed groundwater-discharge estimates in Spring and Snake Valleys on transmissivity estimates were bounded with alternative models. Annual distributed groundwater discharges from Spring and Snake Valleys in the alternative models totaled 151,000 and 227,000 acre-feet, respectively and represented 20 percent differences from the 187,000 acre-feet per year that discharges from the GBNP-C model. Transmissivity estimates in the basin fill between Baker and Big Springs changed less than 50 percent between the two alternative models.

Potential effects of pumping from Snake Valley were estimated with the Great Basin National Park predictive (GBNP-P) model, which is a transient groundwater-flow model. The hydraulic conductivity of basin fill and transmissivity of basement rock were the GBNP-C model distributions. Specific yields were defined from aquifer tests. Captures of distributed groundwater and spring discharges were simulated in the GBNP-P model using a combination of well and drain packages in MODFLOW. Simulated groundwater captures could not exceed measured groundwater-discharge rates.

Four groundwater-development scenarios were investigated where total annual withdrawals ranged from 10,000 to 50,000 acre-feet during a 200-year pumping period. Four additional scenarios also were simulated that added the effects of existing pumping in Snake Valley. Potential groundwater pumping locations were limited to nine proposed points of diversion. Results are presented as maps of groundwater capture and drawdown, time series of drawdowns and discharges from selected wells, and time series of discharge reductions from selected springs and control volumes.

Simulated drawdown propagation was attenuated where groundwater discharge could be captured. General patterns of groundwater capture and water-table declines were similar for all scenarios. Simulated drawdowns greater than 1 ft propagated outside of Spring and Snake Valleys after 200 years of pumping in all scenarios.

Introduction

Currently, southern Nevada relies on the Colorado River for most of its water supply. Supplementary water supplies are needed to offset a persistent drought in the Colorado River Basin. Groundwater resources from basin-fill and consolidated-rock aquifers in eastern Nevada are a potential source for this supplemental water supply. These aquifers provide water to springs, streams, wetlands, limestone caves, and other biologically sensitive areas on Federal lands in eastern Nevada, which provide habitat for numerous species of plants and animals, including one species of federally listed endangered fish. These water-dependent features also are visited and enjoyed by anglers, hunters, and tourists, including numerous visitors to Great Basin National Park.

Assessing hydrologic effects of developing groundwater supplies in the Western United States can be greatly improved through use of groundwater models. Hydrologic effects typically include the timing and magnitude of capture from streams, springs, wetlands, and phreatophytes—deep rooted plants that obtain their water from the water table or the layer of deposits just above it. Assessments of general water-table decline initially were limited to simple analytic models of water-table decline—drawdown with a Theis (1935) solution and capture of groundwater discharge with a Glover and Balmer (1954) solution. These analytical solutions approximated hydrologic changes that were caused by new pumping wells.

Solving directly for change is a good method because the hydrologic effects of groundwater development typically are defined by drawdown and capture of groundwater discharge. Analytical solutions, however, cannot easily simulate complex aquifer geometry, heterogeneous hydraulic properties, or a wide range of surface-water features. Modern numerical models, however, allow for the inclusion of many additional hydrologic features and can be quite complex (Leake and others, 2008). Additional model complexity also has made model results more uncertain, which needlessly encourages more controversy in a historically contentious process. The relative simplicity of analytical solutions can be applied correctly by solving directly for change with numerical models.

Purpose and Scope

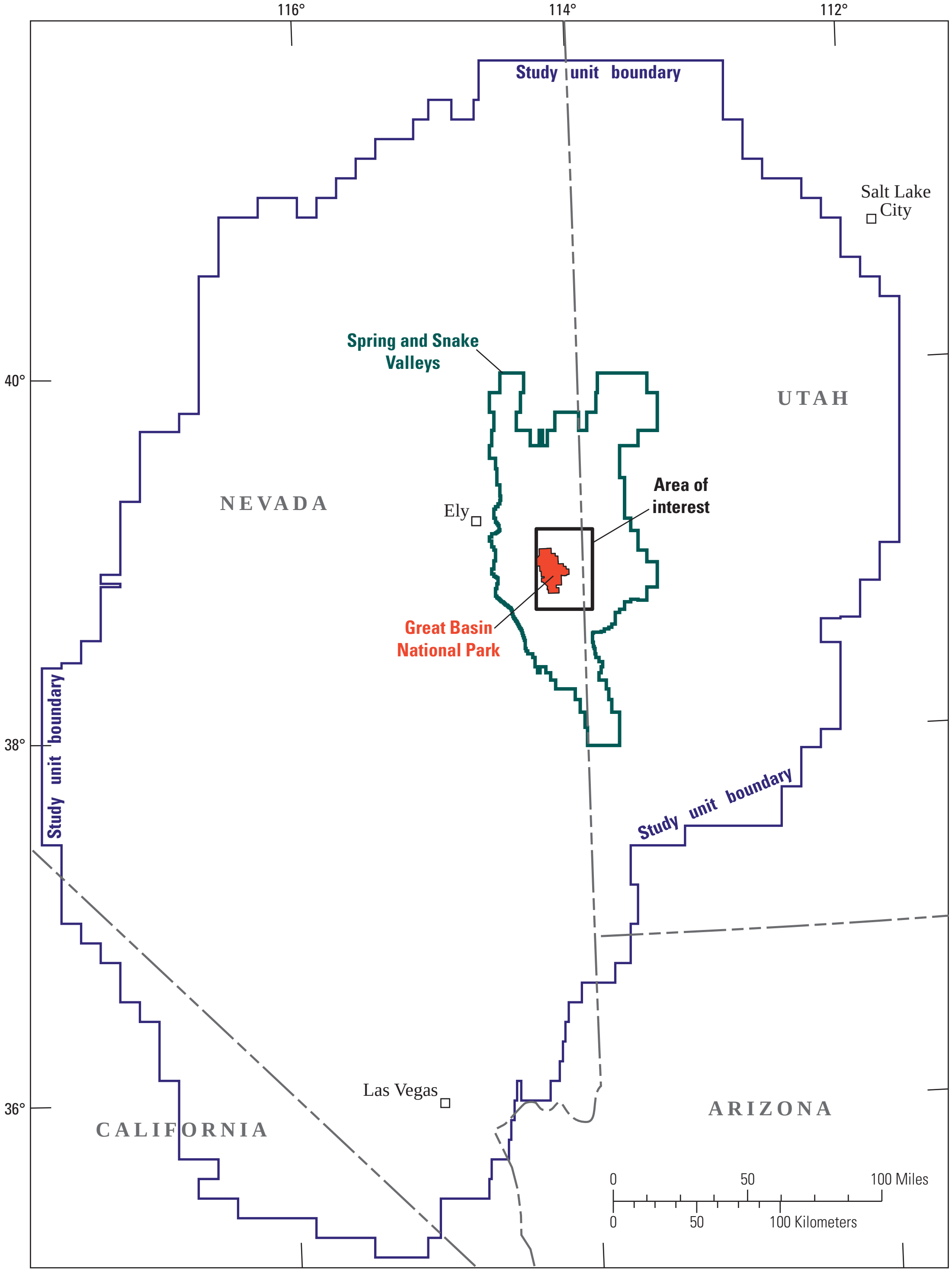
The purpose of this report is to estimate potential effects of water-supply development on water levels, phreatophytes, and spring discharges around the southern Snake Range in Spring and Snake Valleys. The effects of water-supply development were investigated with revised models of the carbonate-rock province as defined in the Great Basin Regional Aquifer-System Analysis (Prudic and others, 1995). Recharge, hydraulic conductivity, thickness of basin fill, and transmissivity were refined exclusively in Spring and Snake Valleys by calibrating a three-dimensional, groundwater-flow model. Geometries of the hydrogeologic units within the area of interest (fig. 1) were refined and principally reflected findings from Elliott and others (2006). Transmissivity and specific-yield estimates were constrained from specific capacity, aquifer-test results, and analysis of multiple-year water-level declines in response to groundwater pumping. Groundwater-discharge areas in Spring and Snake Valleys were defined with results from the Basin and Range Carbonate-Rock Aquifer System (BARCAS) study (Welch and others, 2007). Potential effects of water-supply development on water levels and spring discharges were simulated with a variant of the calibrated model. This predictive model simulated ground-water discharge with the direct-drawdown approach where groundwater discharge is limited to observed locations and estimated rates.

Approach

Potential effects of groundwater development were assessed with the direct-drawdown approach in this study. Application of the direct-drawdown approach requires a groundwater-flow model for calibration and a separate model for prediction. Transmissivity distributions are estimated with the calibration model that simulates all relevant processes, including recharge. The predictive model uses the transmissivity distribution that was estimated with the calibration model and observed groundwater discharges. This approach is superior to modifying the calibration model because simulated and observed groundwater discharge will differ in the calibration model.

Direct simulation of drawdown can reduce model complexity and uncertainty because fewer hydrologic features need to be simulated in the predictive model. Model input, other than the proposed pumpage, is limited to hydraulic-conductivity, storage-coefficient, and groundwater-discharge distributions. Drawdown models simulate changes so relatively unchanging quantities, such as recharge and existing pumpage distributions, are not simulated and do not need to be defined. The absence of these features simplifies presentation of model results and avoids the large uncertainty associated with recharge and historical pumping estimates.

The U.S. Department of the Interior, National Park Service needed estimates of the potential effects of groundwater pumping from Snake Valley on springs, streams, and water levels in caves in and adjacent to Great Basin National Park (fig. 1**)**. Understanding potential effects of groundwater pumping from Snake Valley is important because groundwater discharge to springs and streams in ecologically sensitive areas may be captured. This study estimates potential hydrologic effects of water-supply development in Spring and Snake Valleys by integrating hydrologic data from recent investigations (Elliott and others, 2006; Welch and others, 2007) in a broader regional framework (Prudic and others, 1995).



Modified from Prudic and others, 1995

Figure 1. Location of study area, Spring and Snake Valleys, area of interest, and Great Basin National Park, Nevada.

Description of Study Area

The study area for this report is the 100,000 mi^2 carbonate-rock province of the Great Basin (fig. 1) as defined by Harrill and Prudic (1998). The study area was selected because groundwater flow was simulated previously for the Regional Aquifer-System Analysis (RASA) Program of the Great Basin (Prudic and others, 1995), and because pumping effects can propagate across multiple basins in the carbonate-rock province (Schaefer and Harrill, 1995). Aquifers in the study area comprise permeable basin-fill deposits or carbonate rocks (Harrill and Prudic, 1998).

Most of this investigation centers on Spring and Snake Valleys and the area of interest (fig. 1). The area of interest is southern Spring and Snake Valleys including the Great Basin National Park. Hydrogeologic interpretation was refined throughout Spring and Snake Valleys because these are defined hydrographic areas that encompass the area of interest.

Precipitation is the source of all water, both surface discharge and groundwater, in Spring and Snake Valleys. Groundwater recharge originates as high-altitude precipitation, and a small percentage of this becomes recharge primarily as infiltration of spring-snowmelt runoff along mountain fronts. Annual precipitation in mountainous areas generally exceeds 16 in. and has been estimated to exceed 40 in. on some of the high mountain ranges (PRISM Group, 2006). However, the area over which this precipitation falls constitutes only a small part of Spring and Snake Valleys. As a result, the total volume of precipitation available as potential groundwater recharge is relatively small. Total annual precipitation in basin lowlands generally ranges from 6 to 10 in. (Western Regional Climate Center, 2009). The area over which this range of precipitation falls constitutes a large part of Spring and Snake Valleys. However, very little of this precipitation becomes groundwater recharge because the precipitation is mostly lost as evaporation or is transpired by plants.

The topography of Spring and Snake Valleys is typical of the Great Basin section of the Basin and Range physiographic province. Basins and adjacent mountains generally are oriented north-south. Land-surface altitude in basin lowlands ranges from 4,300 ft in northern Snake Valley to 6,500 ft in southern Snake (Hamlin) Valley. Land-surface altitude in mountainous areas exceeds 13,000 ft in the southern Snake Range.

Hydrogeology

Spring and Snake Valleys are deep structural basins composed of carbonate and siliciclastic-sedimentary rocks of Paleozoic age and igneous intrusive rocks of Jurassic to Tertiary age. Basin-fill deposits of Tertiary and Quaternary age and volcanic rocks of Tertiary age have accumulated in these structural basins, reaching thicknesses of 5,000–10,000 ft (Sweetkind and others, 2007, pl. 1). For purposes of the present study, these rocks and deposits are divided into six hydrogeologic units that are from oldest to youngest: (1) low–permeability, siliciclastic-sedimentary rocks of early Cambrian and older age, and granitic rocks of Jurassic and Tertiary age; (2) permeable carbonate rocks of middle Cambrian to Devonian age and Mississippian to Permian age, and intervening siliciclastic-sedimentary rocks of Mississippian age; (3) low-permeability volcanic rocks of Tertiary age; (4) older sedimentary rocks of Miocene age; (5) low-permeability, fine-grained basin-fill deposits of Tertiary and Quaternary age; and (6) permeable coarse-grained basin-fill deposits of Quaternary age. The distribution and occurrence of each of the units is shown in figure 2 and their lithologic and hydrologic characteristics are summarized in figure 3.

The siliciclastic-sedimentary rocks of Cambrian and older age, and the granitic rocks of Jurassic to Tertiary age are grouped together as a single hydrogeologic unit because both have low permeability. The former consists mostly of metamorphosed quartzite and shale and the latter consist of granite, granodiorite, and quartz monzonite (Hose and others, 1976, p. 3–6 and 22–25). Quartzites can be highly fractured and potentially have significant secondary permeability. However, shales can be squeezed into fractures partly sealing off any secondary permeability (Winograd and Thordarson, 1975, p. 39–40). A general indication of its low permeability is that perennial mountain streams are restricted mostly to watersheds underlain by this hydrogeologic unit. This unit mostly impedes the movement of groundwater.

The carbonate and siliciclastic-sedimentary rocks of Cambrian to Permian age comprise three sequences: (1) carbonate rocks and minor interbedded siliciclastic-sedimentary rocks (shale and sandstone) of Cambrian to Devonian age; (2) siliciclastic-sedimentary rocks and minor carbonate rocks of Mississippian age; and (3) carbonate rocks of Pennsylvanian and Permian age (fig. 3). The total stratigraphic thickness of this unit is about 29,000 ft in the Schell Creek Range and Confusion Range on the west and east sides, respectively, of the study area (Stratigraphic Committee of the Eastern Nevada Geological Society, 1973). An oil exploration well drilled in 1983 in southern Snake Valley (fig. 4) penetrated nearly 12,000 ft of this hydrogeologic unit. The hole penetrated Ely Limestone and Chainman Shale at depths of 1,250 and 2,450 ft, respectively. Abrupt increases in borehole diameter and sonic travel time both indicate the presence of several zones of high porosity in this sequence of carbonate rocks (fig. 4). The thick sequences of carbonate rocks can be very permeable as a result of fracturing and subsequent solution widening of fractures. These rocks frequently function as regional aquifers in the eastern Great Basin. Perennial streams are absent in drainage basins underlain by carbonate rocks because these rocks are sufficiently permeable for precipitation to infiltrate.

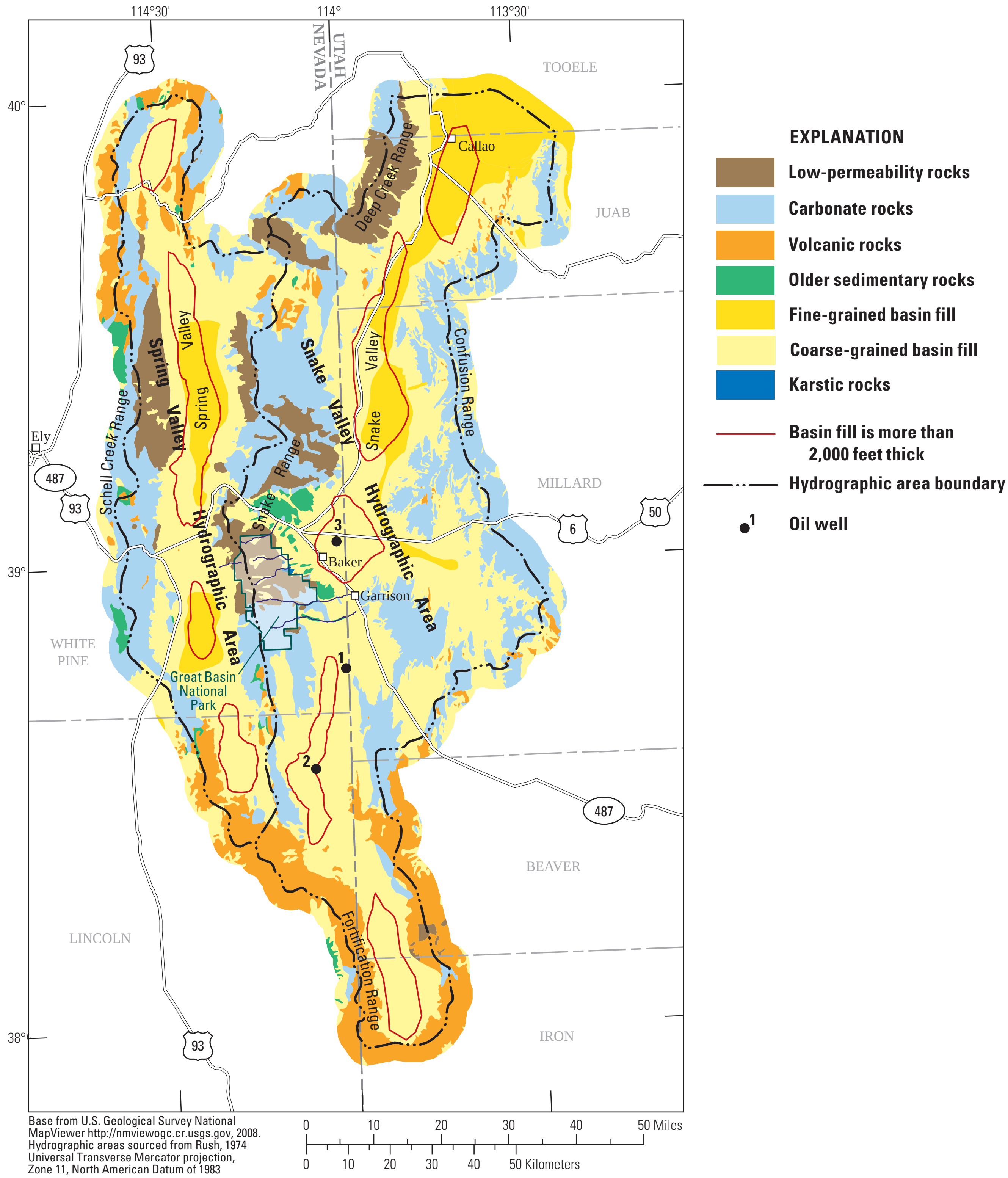


Figure 2. Surface geology and thickness of basin fill in Spring and Snake Valleys, Nevada and Utah.

Series	Hydrogeologic unit	Approximate thickness, in feet	Lithology	Simplified hydrogeologic units / Aquifers	Model layer
Quaternary to Tertiary	Younger basin-fill deposits	0 to less than 500 feet	Unconsolidated to poorly cobsolidated clay, silt, sand, gravel, and boulders of alluvial fans, basin lowlands, and stream flood plains.	Fine-grained basin fill Coarse-grained basin fill	1–3
Quaternary to Tertiary	Volcanic rocks	500 to 3,000 feet	Flows, shallow intrusives, ash-flow tuffs. Compositions range from basalt to rhyolite.	Volcanic rocks	1–4
Tertiary	Older basin-fill deposits	Less than 1,000 to more than 2,000 feet	Tuffaceous conglomerate, siltstone, mudstone, and limestone. Typically contains interbedded volcanic rocks.	Fine-grained basin fill Coarse-grained basin fill	3
Tertiary to Jurassic	Granitic rocks	More than 2,000 feet[1]	Granodiorite and quartz monzonite.		
Triassic to Cambrian	Siliceous sedimentary rocks	More than 2,000 feet[1]	Chert, siliceous shale, siltstone, sandstone, quartzite, and conglomerate.	Low permeability rocks	1–4
Permian to Cambrian	Clastic sedimentary rocks	More than 2,000 feet[1]	Conglomerate, sandstone, quartzite, and shale.		
Devonian to Cambrian	Carbonate rocks	More than 2,000 feet[1]	Limestone and dolomite with subordinate sandstone and shale.	Carbonate rocks Karstic rocks	1–4

[1] Total model thickness is 2,000 feet.

Figure 3. Hydrogeologic units, thickness, lithology, aquifer, and model layers of series in southern Spring and Snake Valleys, Nevada and Utah.

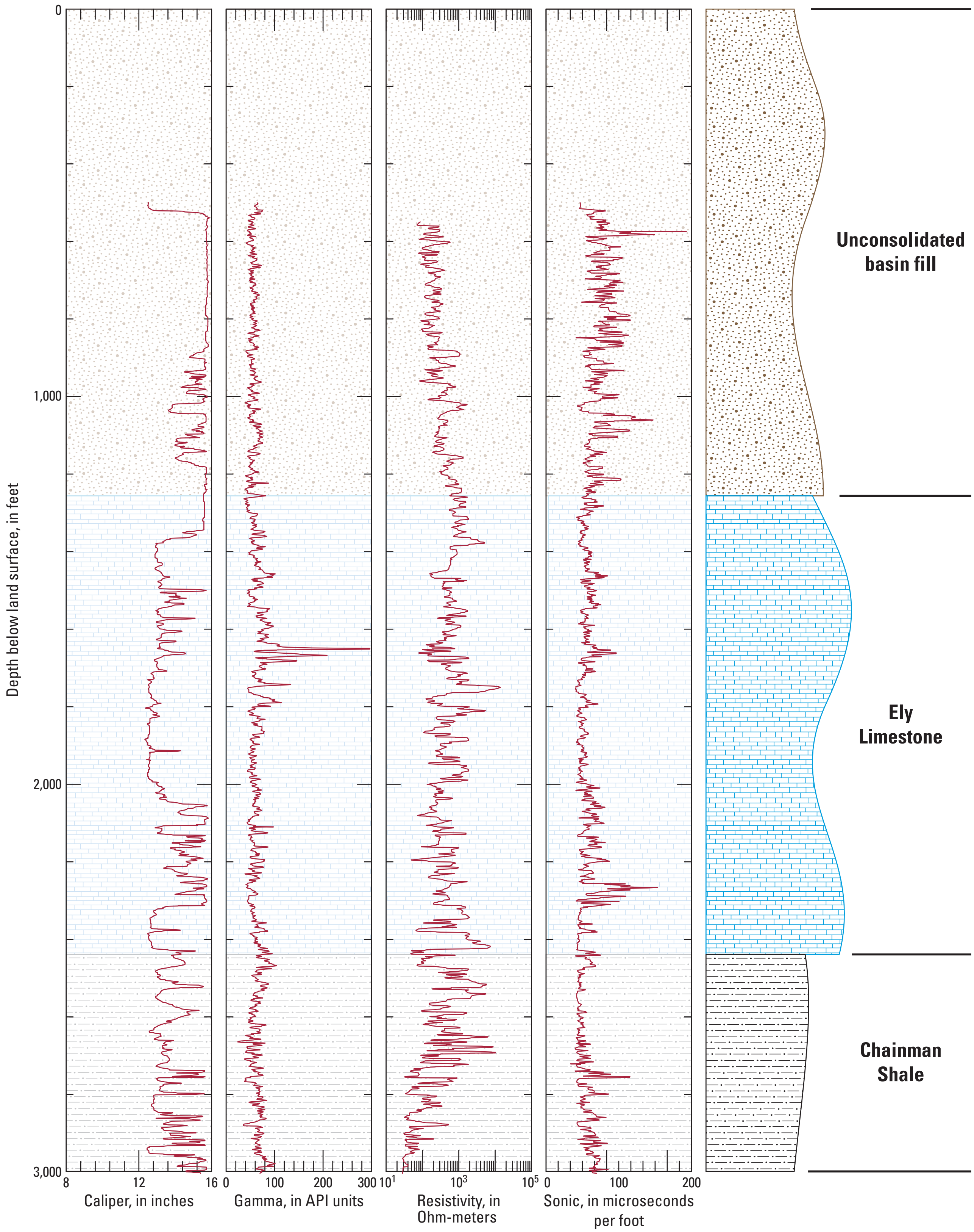


Figure 4. Lithologic and geophysical logs for oil exploration well number 1 (API 27-033-05245), Snake Valley, Nevada. (Location of oil exploration well is shown in figure 2.)

Karstic rocks occur near the eastern boundary of Great Basin National Park and host caves such as Lehman Cave (National Park Service, 2007). These karstic rocks locally affect surface-water and groundwater flow between Baker and Lehman Creeks. Baker Creek loses 2,900 acre-ft/yr (4 ft^3/s) and Lehman Creek gains 2,200 acre-ft/yr (3 ft^3/s) along the reaches that bound Lehman Caves and Rowland Spring (Elliott and others, 2006).

The volcanic rocks consist of ash-flow tuffs of rhyolite-to-andesite composition exposed in mountainous southern parts of the study area and basalt, andesite, and rhyolite lava flows in mountainous northern parts (Sweetkind and others, 2007, p. 30). Oil exploration well number 2 that was drilled in Southern Snake (Hamlin) Valley (figs. 2 and 5) penetrated tuff at depths of 3,470–4,100 ft. Oil exploration wells number 1 (fig. 4) and number 3 (fig. 6) that were drilled farther north in Snake Valley (fig. 2) penetrated basin-fill deposits and underlying rocks of Paleozoic age and did not penetrate any volcanic rocks. Oil exploration wells numbers 1, 2, and 3 (fig. 2) have Nevada Bureau of Mines and Geology (2008) API numbers: 27-033-05245, 27-017-05223, and 27-033-05288, respectively. Sweetkind and others (2007, p. 31) have inferred subsurface thicknesses of 500–8,000 ft of tuff in southern parts of the study area. Hydraulic conductivity of volcanic rocks can range over several orders of magnitude. High values probably represent fractured volcanic-rock aquifers, and low values represent volcanic rocks that function as confining units (Sweetkind and others, 2007, p. 32).

Older sedimentary rocks of Miocene age are exposed along the west margin of Snake Valley from the southern end of the northern Snake Range to the southern Snake Range several miles south of Baker, Nevada (fig. 2). Where exposed, these rocks comprise west dipping cemented fine-grained lacustrine deposits and coarse-grained sandstone and conglomerate (Sweetkind and others, 2007, p. 28). They are thought to be present at uncertain depth beneath younger basin-fill deposits. They include evaporite deposits of anhydrite and gypsum (figs. 5 and 6) and an uncertain thickness of overlying rock that underlies younger basin fill. These rocks probably function as a low permeability interval between younger basin-fill deposits (basin-fill aquifers) and Paleozoic carbonate rocks at depth.

Coarse-grained and fine-grained basin fill of Holocene to Pliocene age underlie alluvial fans and basin lowlands in Spring and Snake Valleys (fig. 2). The alluvial fans comprise poorly sorted mixtures of sand and gravel and, in close proximity to mountain fronts, increasing proportions of cobbles and boulders. Toward basin lowlands these deposits consist of sand and gravel. The basin-fill aquifers are found in these deposits.

The fine-grained basin fill comprises, silt, and clay of Holocene to Pliocene age that accumulated in a playa in Spring Valley and in Lake Bonneville in Snake Valley (Sweetkind and others, 2007, p. 30). These deposits underlie the lowest parts of basins and function as confining units between shallow water table and deeper confined aquifers that consist of coarse-grained basin-fill deposits. Fine-grained basin fill and coarse-grained basin fill probably complexly interfinger where they meet near the margins of basin lowlands.

Loose uncemented sand and gravel deposits are indicated by borehole washouts in all caliper and sonic logs where the lithologic log reported unconsolidated basin fill (figs. 4–6). This evidence includes abrupt increases in hole diameter and sonic travel time. Washouts are evident especially at 500–600 and 1,240–1,400 ft in oil well number 3 (fig. 6).

Geophysical and lithologic logs show low permeability material occurs at depths greater than 1,600 ft below land surface in oil well numbers 2 and 3. Borehole diameter increases gradually at depths below 2,150 ft and increases abruptly at a depth of 2,300 ft in oil well number 2 (fig. 5). This indicates that a more soluble evaporite underlies the 500-foot thick anhydrite sequence. Dissolution of an evaporite also would decrease resistivity and increase sonic travel time. The lithologic change from unconsolidated basin fill to clay at 1,400 ft below land surface in oil well number 3 is inconsistent with increasing resistivity and decreasing sonic travel time (fig. 6). The geophysical logs indicate shale was encountered rather than clay, but the permeability is low for either clay or shale.

Groundwater flow through basin fill occurs at depths less than 2,000 ft in Snake Valley south of U.S. Highway 50 (fig. 2). Basin fill that is thicker than 2,000 ft covers less than 30 percent of Snake Valley. Deeper sediments predominantly are low permeability rocks where the thickness of basin fill exceeds 2,000 ft.

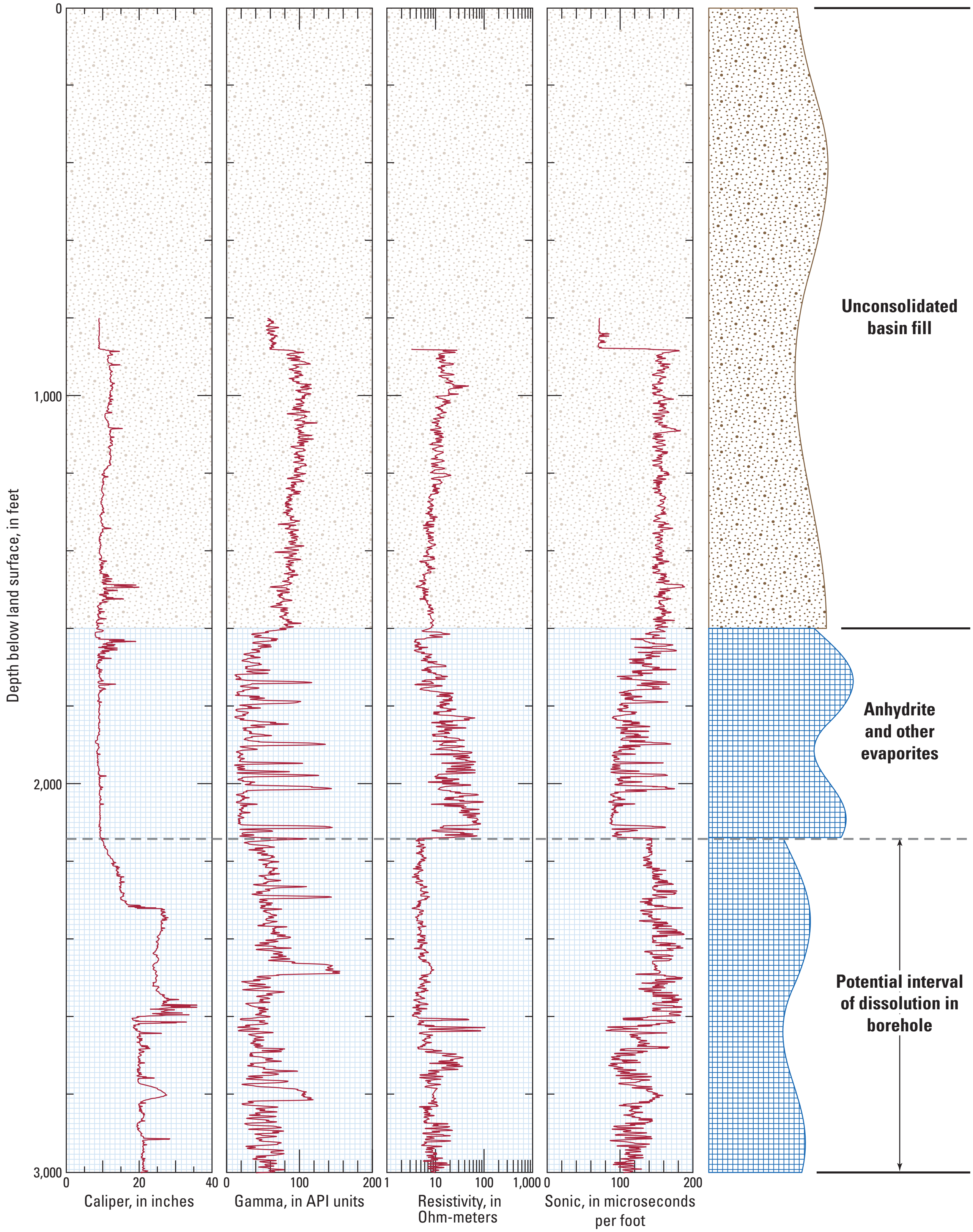


Figure 5. Lithologic and geophysical logs for oil exploration well number 2 (API 27-017-05223), Snake Valley, Nevada. (Location of oil exploration well is shown in figure 2.)

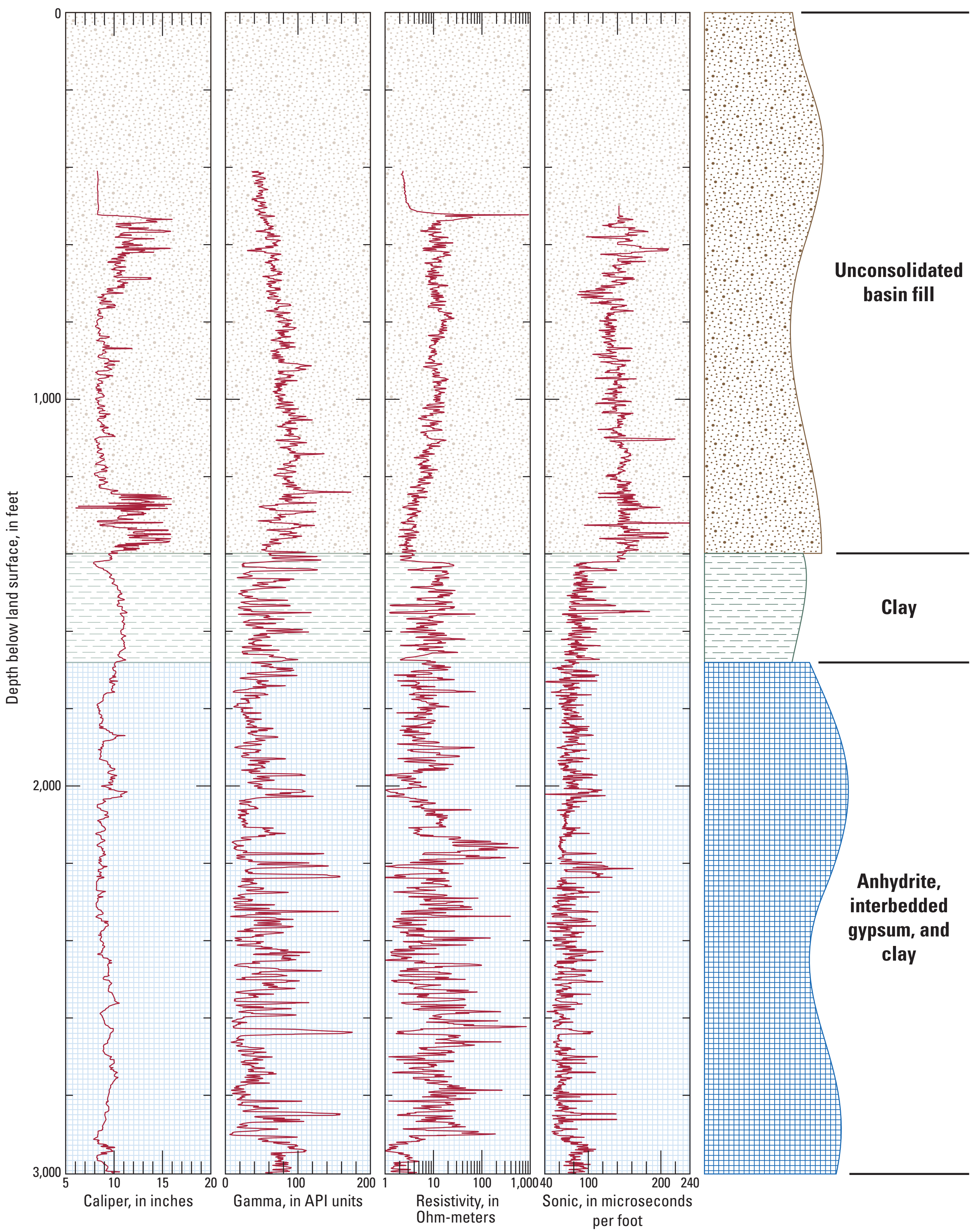


Figure 6. Lithologic and geophysical logs for oil exploration well number 3 (API 27-033-05288), Snake Valley, Nevada. (Location of oil exploration well is shown in figure 2.)

Hydraulic Properties

The hydraulic properties of basin fill, carbonate rock, and volcanic rocks were estimated from eight aquifer tests in Lake, Spring, and Snake Valleys (fig. 7). Transmissivity and specific yield were estimated for each aquifer test by fitting analytical or numerical groundwater-flow models to measured water-level responses. Water-level responses were analyzed for five conventional aquifer tests where a single well was pumped for less than 1 week. The maximum volume pumped during a conventional aquifer test did not exceed 40 acre-ft (table 1). Water-level responses to multiple years of irrigation pumping were analyzed for three "irrigation" aquifer tests. The volumes of pumped water were more uncertain, but minimum volumes ranged from 10,000 to 210,000 acre-ft (table 1). Transmissivities of basin fill have been estimated from other aquifer tests in the study area (Ertec Western, Inc., 1981; Leeds, Hill and Jewett, Inc., 1981, 1983; Bunch and Harrill, 1984).

Ranges of transmissivity and specific yield of basin fill and carbonate rock were estimated using irrigation aquifer test results by analyzing water-level changes in multiple observation wells that were caused by groundwater pumping for irrigation (table 1). Water-level declines during the 2000–03 irrigation seasons were analyzed in Snake Valley because crops had been inventoried (Welborn and Moreo, 2007) and drought conditions existed during this period. Hydraulic properties were estimated by minimizing a weighted sum-of-squares objective function that compared simulated and measured drawdowns (Halford, 2006). Seasonal drawdowns from spatially distributed groundwater pumping were simulated with a three-dimensional, MODFLOW model.

Ranges of transmissivity and specific yield were estimated with the irrigation aquifer tests because groundwater withdrawals were uncertain. Annual pumping estimates were computed as the product of irrigated acreage and annual consumptive use, which was annual application minus return flow. Irrigated acreage in Snake Valley was estimated from crop inventories and satellite imagery during 2000, 2002, and 2005 (Wellborn and Moreo, 2007). Irrigated acreage in Lincoln County from 1963 through 2008 was estimated from well logs, crop inventories, and satellite imagery (Southern Nevada Water Authority, 2009) using methods from Moreo and others (2003). Annual consumptive use was estimated to the nearest foot so annual consumption was either 2 or 3 ft (U.S. Geological Survey, 2010). An annual consumptive use of 2 ft was more likely where surface water was available.

Hydraulic-property estimates from aquifer tests represent an integrated average through an area and thickness of aquifer. The volume of aquifer investigated reasonably can be defined and compared by a drawdown threshold. This threshold is defined by the error associated with the drawdown estimates which were about 0.1 and 1 ft for conventional and irrigation aquifer tests, respectively. The drawdown threshold for conventional aquifer tests is smaller than for irrigation aquifer tests, because water levels were measured continuously and minimally affected by environmental noise. Areal extent and volume of investigated aquifer become nearly proportional as the volume of water pumped increases. This is because aquifer thickness becomes "small" relative to the affected area.

Hydraulic-property estimates from the conventional aquifer tests were more certain than from the irrigation aquifer tests but represented less than 500 acres. This is because the uncertainty of the volume pumped during conventional aquifer tests was less than 10 percent. The maximum volume pumped during conventional aquifer tests was 40 acre-ft (table 1).

Hydraulic-property estimates from the irrigation aquifer tests were less certain than from the conventional aquifer tests but represented areas of more than 50,000 acres. Hydraulic-property estimates were less certain because the uncertainty of the volume pumped during irrigation aquifer tests was about 40 percent. The volumes pumped during irrigation aquifer tests were 1,000 times more than volumes pumped during conventional aquifer tests (table 1). Differences in annual consumptive use affected transmissivity and specific-yield estimates, but the area where drawdowns exceeded 1 ft did not change.

Transmissivity of the basin fill ranged from 1,200 to 13,000 ft^2/d where basin fill thickness exceeded 1,000 ft (table 1). The average hydraulic conductivity of the coarse-grained, basin fill was 3 ft/d and the fine-grained, basin fill was 0.1 ft/d. Specific yield of the basin fill volumetrically averaged 15 percent and ranged from 12 to 18 percent from the irrigation aquifer tests. Vertical-to-horizontal anisotropy could not be estimated and was assumed to be 0.1.

Transmissivity of the carbonate rocks ranged from 7,000 to 55,000 ft^2/d (table 1). Specific yield of the carbonate rocks averaged 2 percent and ranged from less than 1 to 4 percent. Vertical-to-horizontal anisotropy of the carbonate rocks ranged from 0.2 to 1 at sites W101, W103, and W105.

Hydraulic conductivity of granitic, intrusive, volcanic, and other low-permeability rocks rarely exceeded 0.1 ft/d. These rocks typically restrict groundwater flow. Site W508M was the only well in low-permeability rocks that was tested in the area of interest and the transmissivity of the volcanic rocks was 70 ft^2/d (table 1; Southern Nevada Water Authority, 2009). Hydraulic conductivity averaged 0.06 ft/d across the well-screen interval at site W508M. Hydraulic conductivity averaged 0.01 ft/d in wells UE-19i and UE-20f at the Nevada Test Site (Blankennagel and Weir, 1973), which is about 100 mi northwest of Las Vegas (fig. 1). These wells penetrated more than 20,000 ft of partially welded tuff, rhyolytic lava, and bedded tuff. Hydraulic conductivity of granitic rocks in wells U-15k, ER-8-1, and U-12s at the Nevada Test Site are 0.0000001, 0.000002, and 0.006 ft/d, respectively.

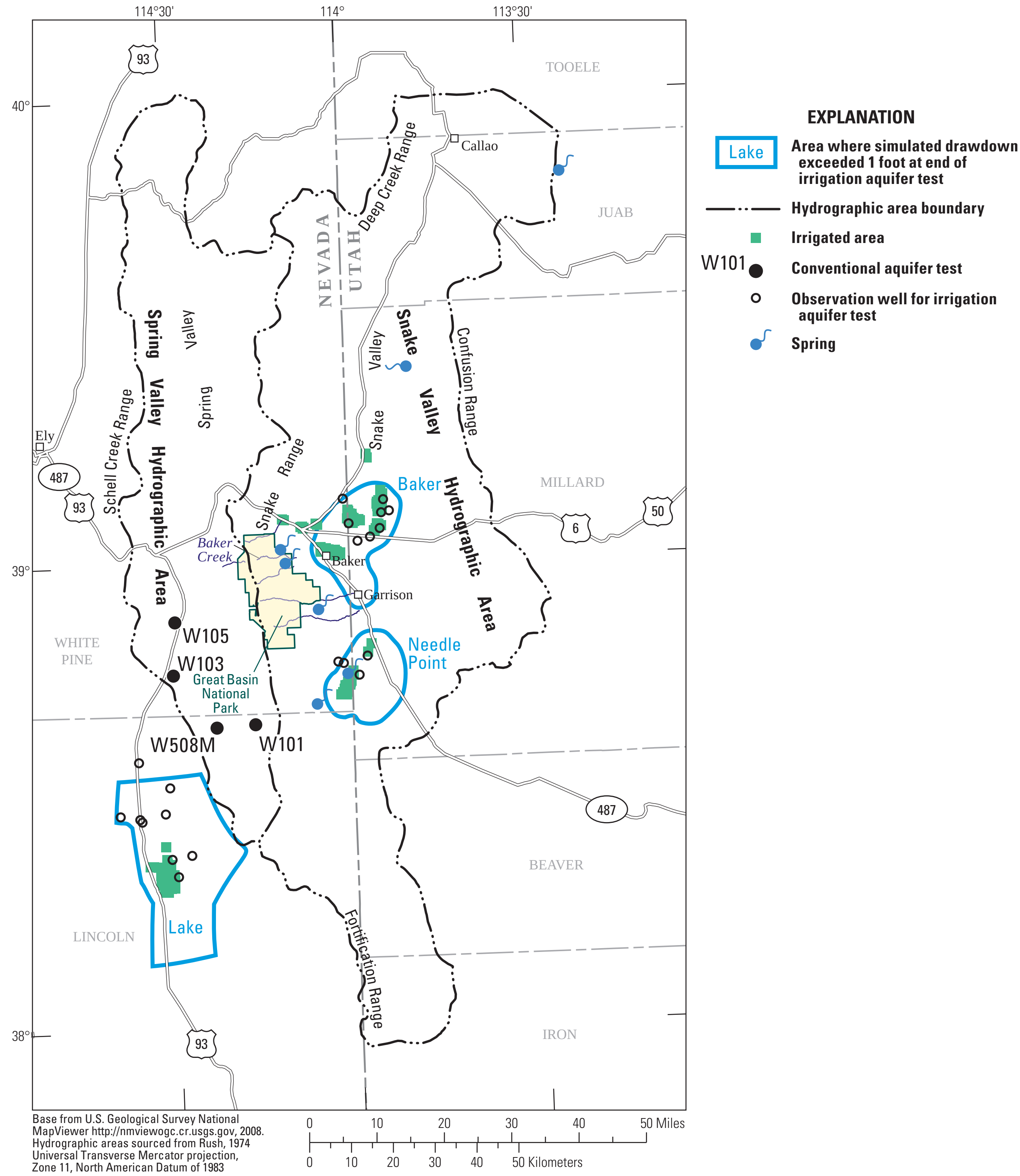


Figure 7. Aquifer test locations and investigated areas, Nevada and Utah.

Table 1. Hydraulic properties estimated from eight aquifer tests, Nevada and Utah.

[Data from U.S. Geological Survey (2010), accessed February 14, 2010, at http://nevada.usgs.gov/water/aquifertests/index.htm. Site locations are shown in figure 7. acre-ft, acre-foot; ft^2d, square foot per day. na, not applicable]

Site	Lithology	Observation wells	Volume pumped (acre-ft)		Transmissivity (ft^2/d)		Specific yield	
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Irrigation aquifer tests								
Lake	Basin fill	9	210,000	310,000	9,000	13,000	0.12	0.18
Baker	Basin fill	8	31,000	46,000	5,600	9,000	0.12	0.18
Needle Point	Basin fill	4	10,000	15,000	1,200	1,300	0.12	0.13
	Carbonate rock	4	10,000	15,000	7,000	16,000	0.001	0.006
Conventional aquifer tests								
Baker Creek	Basin fill	4	0.4		800		0.05	
W101	Carbonate rock	1	33		10,000		0.02	
W103	Carbonate rock	1	7		10,000		0.04	
W105	Carbonate rock	1	40		55,000		0.04	
W508M	Volcanic rock	0	0.1		70		na	

Estimation of Hydraulic Property Distributions with Numerical Models

The hydraulic conductivity of basin fill and transmissivity of basement rock distributions in Spring and Snake Valleys were refined by calibrating a steady state, three-dimensional, numerical groundwater-flow model of the carbonate-rock province to predevelopment conditions. Hydraulic properties and boundary conditions were defined primarily from the RASA model (Prudic and others, 1995) except in Spring and Snake Valleys. This locally refined model will be referred to as the Great Basin National Park calibration (GBNP-C) model. Groundwater flow through the study area was simulated with the modular finite-difference model MODFLOW (Harbaugh and others, 2000).

Refinement of RASA Model

The GBNP-C model was divided areally into 230 rows of 184 columns of variably spaced, rectangular cells (fig. 8). The smallest cells were 1,640 ft on a side, square cells that encompassed the Great Basin National Park. This 1.1 million acre area was divided into 152 rows of 122 columns. Cell lengths and widths were multiplied successively by 1.2 away from the area of uniform small cells. A maximum cell dimension of 39,000 ft was specified so the largest GBNP-C model cells would not contain more than one of the original RASA nodes. The model grid was oriented north-south in UTM, zone 11, NAD83 projection for convenience.

The GNBP-C model was divided vertically into four layers that extended below the average water table under predevelopment conditions. Layer 1 was 10 ft thick to better simulate groundwater/surface-water interaction. Layer 2 was 50 ft thick to better define extensive fine-grained deposits in Snake Valley (Reheis, 1999) that affected water-level responses to irrigation pumping near Baker, Nevada. Layers 1 and 2 were active only in Spring and Snake Valleys and were added primarily to simulate surface-water features with limited subsurface penetration. The water table occurred at the top of layer 3 outside of Spring and Snake Valleys. Layer 3 primarily simulated basin fill more than 60 ft thick in Spring and Snake Valleys (Watt and Ponce, 2007) and the full thickness of basin fill beyond Spring and Snake Valleys. Layer 4 simulated basement rocks through the entire study area. The thicknesses of layers 3 and 4 were variable and ranged from 1 to 2,000 ft.

Minimal groundwater flow was expected at depth so the thickness of basin fill in layer 3 was limited to 2,000 ft. Groundwater flow tends to diminish with depth in isotropic, homogeneous aquifers (Tóth, 1962) but could be significant at depth in an anisotropic, heterogeneous aquifer if the most transmissive units were at depth (Freeze and Witherspoon, 1967). The hydraulic conductivity of the heterogeneous basin fill in Spring and Snake Valleys generally decreases with depth because of increased cementation, induration, and occurrence of evaporative deposits (Welch and others, 2007). Unconsolidated coarse-grained younger sedimentary rocks occur in the upper 2,000 ft and become indurated with depth. These deposits generally are underlain by Miocene sediments that contain thick anhydrite in southern Snake Valley (fig. 5).

Nominal thicknesses were assigned to layer 4 primarily for drawing sections and were not used to define the transmissivity of the basement rocks. Thickness of the basement rocks in layer 4 was assigned so the thickness of layers 3 and 4 totaled about 2,000 ft. Thicknesses in layer 4 also were used to extrapolate hydraulic conductivity where basement rocks occurred at the water table.

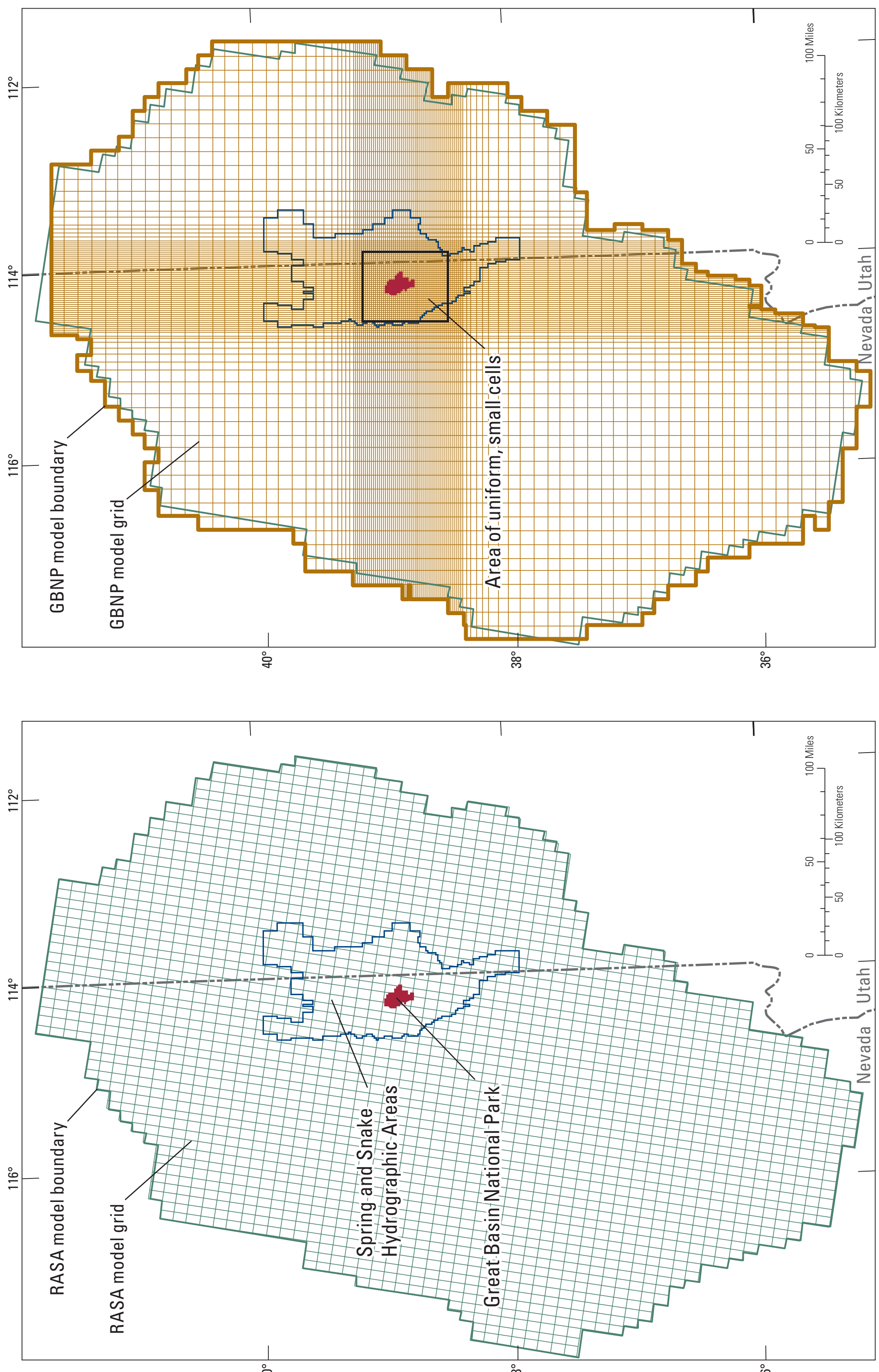


Figure 8. Finite-difference grid and lateral boundaries for the RASA and GBNP-C models, Spring and Snake Valleys, Nevada and Utah.

Hydraulic Properties

All hydraulic properties in the GBNP-C model were defined through the Block Centered Flow (BCF) package (McDonald and Harbaugh, 1988) to maintain continuity with the RASA model. Transmissivity of layers and vertical leakance between layers are specified directly in the BCF file so corresponding layer thicknesses were not developed for the RASA model. Transmissivity and vertical leakance of active layers outside of Spring and Snake Valleys were interpolated directly from the RASA model (Prudic and others, 1995) and were not changed during model calibration. All hydraulic properties were assumed laterally isotropic throughout the entire model.

Hydraulic conductivity and transmissivity were distributed throughout Spring and Snake Valleys with pilot points, which are mapped locations where hydraulic properties were assigned (RamaRao and others, 1995). A total of 416 pilot points were used with 104 mapped locations that were projected through all four model layers. Hydraulic properties were interpolated from pilot points to model cells with kriging (Doherty, 2008b). Interpolation occurred within the basin-fill, carbonate-rock, karst, and low-permeability hydrogeologic units. Pilot-point density was greatest around Great Basin National Park in Snake Valley (figs. 1 and 9). Pilot points were at aquifer-test sites so hydraulic-property estimates could be specified.

The spatial variability of hydraulic conductivity and transmissivity was defined with variograms of basin fill, basement rocks, and karst. All variograms were exponential, applied to log-transformed properties, and estimated the assigned value at each pilot point, nugget = 0 (Isaaks and Srivastava, 1989). The basin-fill and basement-rocks variograms had a 2:1 anisotropy where the major axes were aligned with the trough of Snake Valley for interpolation of properties north of U.S. Highway 50 and a range of 60 mi along the major axis. Karst was defined with a third variogram with a 4:1 anisotropy where the major axis paralleled the losing reach of Baker Creek and the gaining reach of Lehman Creek. The range of the karst variogram was 5 mi because the extent was limited to the area around Lehman Caves (fig. 9).

Hydraulic conductivity of the basin fill, layers 1, 2, and 3, was estimated during model calibration because transmissivity is affected strongly by changes in saturated thickness near the edge of unconsolidated sediments. Hydraulic conductivity was interpolated between coarse-grained and fine-grained units because a gradational change between units was conceptualized. Average hydraulic conductivities of the coarse-grained units in Snake Valley were 1–5 ft/d and about 20–30 times greater than the hydraulic conductivities of the fine-grained units (table 1).

Transmissivity of the basement rocks was estimated because hydraulic conductivity is highly variable and thickness is correlated poorly with transmissivity. This finding resulted from extensive testing of the lower carbonate aquifer around the Nevada Test Site (Winograd and Thordarson, 1975, p. C20). The observations of Winograd and Thordarson (1975) were,

> "None of the eight holes drill-stem tested showed a uniform pattern of increase or decrease in fracture transmissibility, and open fractures were present as much as 1,500 feet beneath the top of the aquifer and 4,200 feet below land surface. In some holes the transmissibility increased markedly with depth; in others the most permeable zones were near the top of the zone of saturation."

Hydraulic-property estimates were limited to a single value per hydrogeologic unit at the mapped location of each pilot point (fig. 10). Between 1 and 3 hydraulic properties were estimated at each mapped location. Coarse-grained basin-fill was assumed to have the same hydraulic conductivity at a mapped location regardless whether any intervening fine-grained basin-fill was present in layer 2. Hydraulic conductivity of basement rocks in layers 1–3 was calculated from transmissivity estimates in layer 4 so consistent hydraulic properties could be specified in the mountain blocks. A hydraulic conductivity that is specified from estimates in deeper layers will be discussed herein as "tied".

Hydraulic properties were specified and not estimated at 228 of the 416 pilot points in Spring and Snake Valleys (table 2). About 80 percent of these values were specified because the hydraulic conductivity was tied to hydraulic-property estimates in deeper layers. The remaining specified values were aquifer-test results (table 1). Assigned hydraulic-conductivity estimates in basin fill were transmissivity estimates from aquifer tests divided by the simulated thickness of basin fill in the GBNP-C model. Aquifer-test results were specified because transmissivity estimates are known within a factor of 2. This is a minor degree of variability relative to the uncertainty in transmissivity values that were estimated through regional model calibration. Potential variability in hydraulic conductivity of the basin fill was reduced artificially where results from the Baker irrigation analysis were assigned to two mapped locations in the basin fill.

Continuity with the remainder of the RASA model area was maintained with 188 additional pilot points that surrounded Spring and Snake Valleys (fig. 9). These pilot points occupied 94 mapped locations in layers 3 and 4. Transmissivity estimates were sampled from the RASA model (Prudic and others, 1995), assigned to these pilot points, and not changed during calibration of the GBNP-C model.

Vertical hydraulic conductivity in Spring and Snake Valleys was assumed 0.1 of lateral hydraulic conductivity. Vertical leakance values were computed from estimated hydraulic conductivity distributions for each layer and have units of feet per day per foot (d^{-1}).

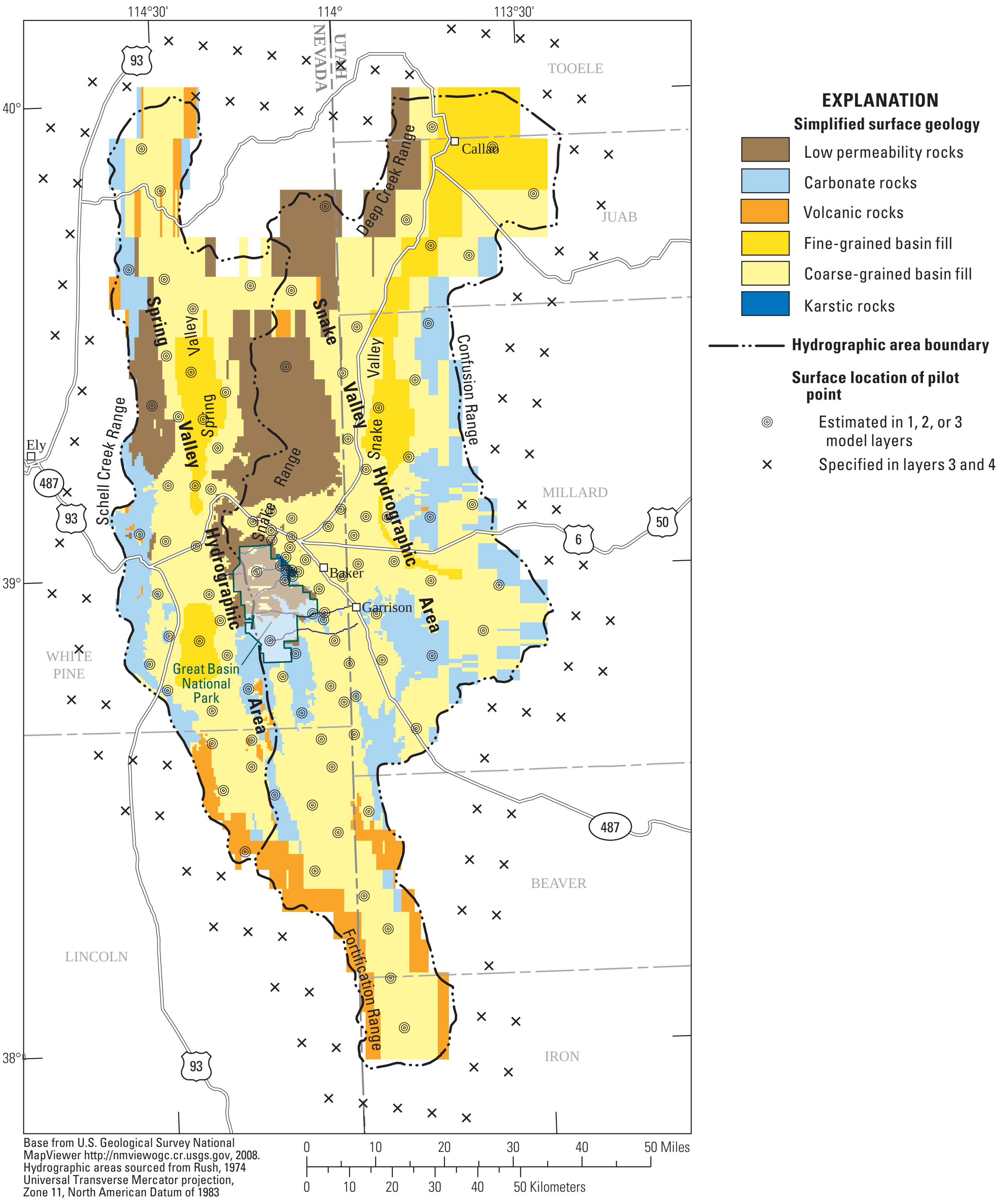


Figure 9. Simplified surface geology and mapped pilot points for interpolation of hydraulic conductivity or transmissivity, Spring and Snake Valleys, Nevada and Utah.

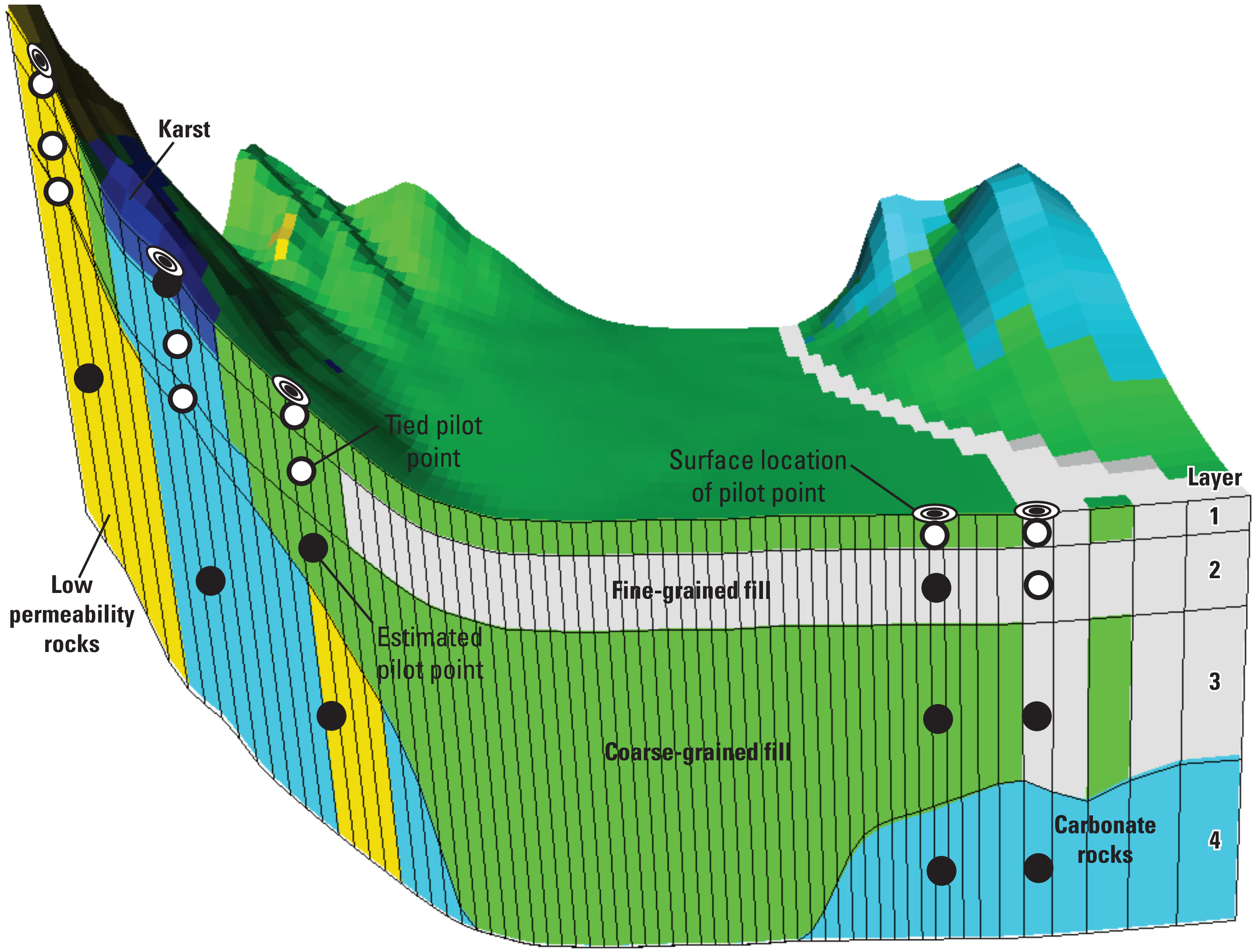


Figure 10. Example of distributing pilot points vertically and constraining hydraulic-property estimates to a single value per mapped location.

Table 2. Distribution of pilot points for estimating hydraulic conductivity and transmissivity by model layer and hydrogeologic unit, Spring and Snake Valleys, Nevada and Utah.

[–, no pilot points]

Simplified hydrogeologic unit	Hydraulic conductivity pilot points						Transmissivity pilot points	
	Layer 1		Layer 2		Layer 3		Layer 4	
	Estimated	Specified	Estimated	Specified	Estimated	Specified	Estimated	Specified
Low permeability rocks	–	4	–	5	–	9	25	6
Carbonate rocks	–	15	1	14	–	22	52	15
Volcanic rocks	–	1	–	1	–	1	3	3
Fine-grained basin fill	–	6	24	9	6	–	–	–
Coarse-grained basin fill	2	71	5	40	60	6	–	–
Karstic rocks	5	–	5	–	–	–	–	–

Recharge

Recharge mostly occurs through the alluvial fans and carbonate mountain blocks in Spring and Snake Valleys. Precipitation in excess of local evapotranspiration (ET) is available for infiltration and surface runoff on mountain blocks. Most of the mountain blocks are underlain by low-permeability bedrock that limits local infiltration and directs runoff to alluvial fans where it infiltrates. Recharge from runoff to the valley floors was assumed negligible and not simulated.

Recharge areas are herein classified as mountain block and mountain front where recharge, regardless of area, refers to water that has infiltrated deeper than the root zone and migrated through the unsaturated zone to the water table. Mountain-block recharge is precipitation that infiltrated bedrock in the mountains. Mountain-front recharge is surface runoff that is routed through streams and unmapped channels and infiltrates through basin fill.

Mountain-Block Recharge and Mountain-Front Recharge

Mountain-block recharge primarily occurs where permeable carbonate rocks are exposed and to a much lesser extent through granitic, intrusive, volcanic, and other undifferentiated low-permeability rocks. Recharge to permeable, carbonate rocks was simulated as spatially variable specified flow rates and assigned with the MODFLOW recharge package. Recharge in low-permeability rocks was simulated with specified heads because recharge rates vary widely across mountain blocks, but are all small quantities relative to other recharge terms. Heads were specified at the bottom of drainages where perennial streams occurred. Flow rates were constrained by average hydraulic conductivities of 0.0002 ft/d in the low-permeability rocks.

Mountain-front recharge represented net infiltration of surface runoff from mountain blocks onto alluvial fans that primarily occurred within a few miles of the contact between mountain block and basin fill. Mountain-front recharge does not differ conceptually from stream recharge. Subsurface flow between the mountain block and basin fill is not a component of mountain-front recharge and was simulated as a separate component of flow.

Recharge Distribution

A potential recharge distribution was estimated from available precipitation—where available precipitation is the annual precipitation minus 9.5 in. Annual precipitation was defined by the 1971–2000 PRISM distribution (Daly and others, 1994; PRISM Group, 2006). A minimum, annual precipitation threshold of 9.5 in. was specified because the volume of annual precipitation in excess of 9.5 in. totaled 240,000 acre-ft. This volume equals the annual groundwater discharge from Spring Valley, Snake Valley, and Fish Springs (Welch and others, 2007). A minimum, annual-precipitation threshold of 8 in. was specified previously by Maxey and Eakin (1949), but in relation to the Hardman (1936) precipitation distribution.

Accumulating the volume of precipitation above a precipitation threshold differs from accumulating volumes of precipitation for estimating recharge with Maxey and Eakin (1949). Maxey-Eakin recharge estimates sum the entire volume of precipitation between two contour intervals and reduce the volume with an efficiency coefficient. Precipitation-threshold recharge estimates sum the volume in excess of the threshold, but an efficiency coefficient is not applied. Maxey-Eakin style precipitation volumes before multiplying by efficiency coefficients are about triple precipitation-threshold volumes for a precipitation threshold of 9.5 in. in Spring and Snake Valleys.

Precipitation on the valley floor of Hamlin Valley in southern Snake Valley was excluded from available precipitation because annual PRISM estimates were deemed anomalous—greater than 20 in. These estimates of annual precipitation seemed excessive because vegetation in Hamlin Valley is similar to non-phreatophytic vegetation elsewhere in Snake Valley where annual precipitation is less than 8 in. Annual precipitation likely was overestimated by PRISM because most of the floor of Hamlin Valley occurs at altitudes greater than 6,000 ft above sea level.

Potential recharge rates were the volume of available precipitation accumulated in 1 of 63 recharge zones divided by the infiltrating area of a zone. The recharge zones resulted from dividing Spring and Snake Valleys into 18 rows from north to south and splitting each valley into eastern and western halves (fig. 11). The east-west subdivision of each valley was the thalweg as defined by the minimum land-surface elevation along each GBNP-C model row. Western zones in Snake Valley near U.S. Highway 50 were subdivided further (fig. 11). The infiltrating area of a zone extended from 300 ft above the thalweg to the mountain divide. Areas that were mapped as low-permeability rocks or without surface channels were excluded from the infiltrating area. Areas without surface channels were defined by model cells where the length of mapped channels in a cell divided by the square-root of cell area was less than 0.25.

Recharge was distributed throughout Spring and Snake Valleys with pilot points (RamaRao and others, 1995). A total of 209 pilot points were used in layer 1 (fig. 11). Recharge rates were interpolated from pilot points to model cells with kriging (Doherty, 2008b). Interpolation occurred independently within the basin-fill, carbonate-rock, and low-permeability hydrogeologic units (fig. 9). Pilot-point density was greatest around GBNP in Snake Valley (fig. 11).

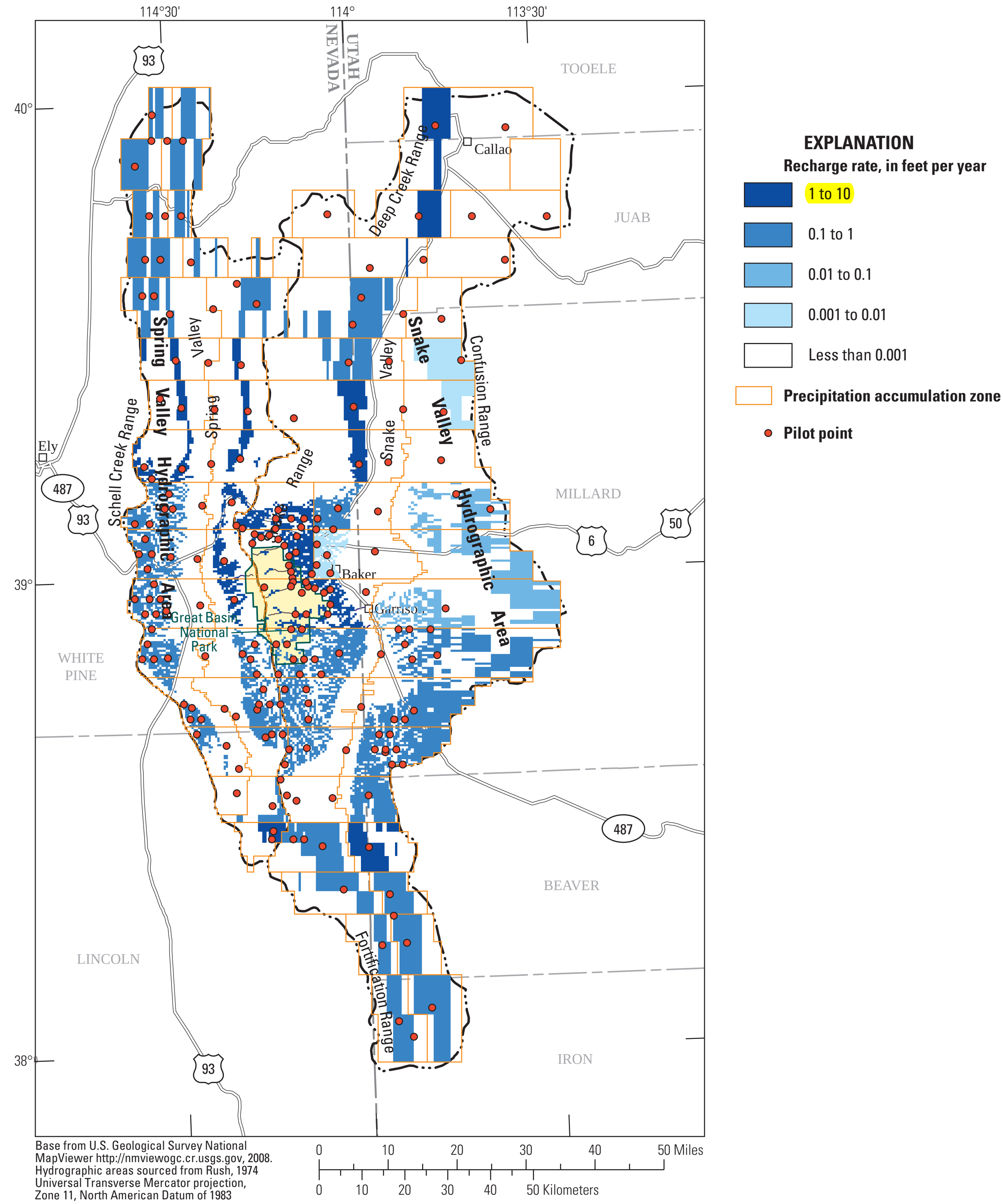


Figure 11. Potential recharge and mapped pilot points for distributing recharge rates in the GBNP-C model.

The spatial variability of recharge was defined with variograms of basin fill and basement rocks. All variograms were exponential, applied to log-transformed recharge rates, and would estimate the assigned value at each pilot point, nugget = 0 (Isaaks and Srivastava, 1989). The basin-fill variogram had a 2:1 anisotropy where the major axis was aligned with the axis of the valleys, a bearing of 10°, and a range of 40 mi along the major axis. The basement-rocks variogram was isotropic with a range of 30 mi and applied to the carbonate-rock and low-permeability hydrogeologic units.

Initial pilot-point values were sampled directly from the potential recharge distribution (fig. 11). An initial annual rate of 0.0001 ft was assigned to pilot points mapped over low-permeability hydrogeologic units. Fixed values of zero were assigned on the valley floors where steep recharge-rate gradients existed between mountain front and valley floor. Pilot-point values on the valley floor were assigned and not estimated.

Recharge to the remainder of the GBNP-C model outside of Spring and Snake Valleys was distributed as specified in the original RASA model (Prudic and others, 1995). Annual recharge outside of Spring and Snake Valleys totaled 1,342 and 1,341 thousand acre-ft in the GBNP-C and RASA models, respectively. Minor differences existed because of the differences in grid resolutions and rotation.

Groundwater Discharge

Groundwater discharged from the surfaces of Spring and Snake Valleys by evapotranspiration and spring discharge prior to development. Evapotranspiration (ET) is a process by which shallow groundwater is either evaporated from soils or transpired by plants. Spring discharge ultimately evapotranspires from the valleys so spring discharge is included in remote-sensing estimates of ET (Smith and others, 2007; Welch and others, 2007, p. 50).

The predevelopment distribution and annual rates of groundwater discharge from Spring and Snake Valleys have been mapped and quantified (fig. 12). Groundwater discharge generally occurred across valley floors where playa, phreatophytic vegetation, marsh, meadow, and open water were present (Smith and others, 2007). Groundwater-discharge areas were subdivided into areas of similar ET rates that are referred to as ET units. The groundwater-discharge rate from an ET unit (GW_{ET}) was the difference between annual ET and annual precipitation. Annual groundwater-discharge estimates totaled 208,000 acre-ft from Spring and Snake Valleys (Welch and others, 2007, app. A).

Big Springs, Big Springs run, and Twin Springs, which occur on the floor of Snake Valley, were simulated explicitly in the GBNP-C model. GW_{ET} rates were reduced to the average, 0.2 ft/yr, downgradient of each explicitly simulated spring or gaining reach because spring discharge was incorporated in the original estimates. Areas of reduced GW_{ET} extended downgradient until the cumulative GW_{ET} in excess of 0.2 ft/yr equaled spring discharge. For example, discharge from Big Springs and Big Springs run equaled the GW_{ET} in excess of 0.2 ft/yr from Big Springs to 2 mi north of Garrison (fig. 12). This approach was not applied to Cave, Home Farm, Kious, Rowland, and Spring Creek Springs and gaining reaches of Lehman and Strawberry Creeks because the discharges are small relative to the uncertainty of the GW_{ET} estimates (table 3).

Distributed GW_{ET} and spring discharge were simulated as specified discharges in the GBNP-C model that were simulated with the well package in MODFLOW (Harbaugh and others, 2000). Distributed GW_{ET} was sourced from model layer 1 and the specified discharge equaled cell area multiplied by the mapped GW_{ET} rate (fig. 12). Spring discharges were specified at measured rates and were sourced from layers 2, 3, or 4 (table 3).

Losses from Baker Creek and gains on Lehman Creek were simulated with specified heads in the GBNP-C model because creek stages are known better than the distribution of gains and losses. Baker Creek loses 2,900 acre-ft/yr (4 ft^3/s) and Lehman Creek gains 2,200 acre-ft/yr (3 ft^3/s) along the reaches that bound Lehman Caves and Rowland Spring (Elliott and others, 2006).

Groundwater discharge from the remainder of the GBNP-C model outside of Spring and Snake Valleys was simulated as specified in the original RASA model (Prudic and others, 1995). Distributed GW_{ET} was simulated with the evapotranspiration package (Harbaugh and others, 2000). Spring discharges were simulated as drains in layer 4 (table 3). The major surface-water features: Colorado River, Death Valley, Great Salt Lake, Humboldt River, Lake Mead, Sevier Lake, Sevier River, Virgin River, and Utah Lake were simulated as general-head boundaries that were specified in layer 3 (fig. 13).

Groundwater pumping is not simulated in the GBNP-C model because steady-state conditions prior to development were simulated. Groundwater currently is pumped from Spring and Snake Valleys for irrigation and totaled 50,000 acre-ft/yr during 2005 (Welch and others, 2007). Irrigation pumping was simulated in the transient, predictive model.

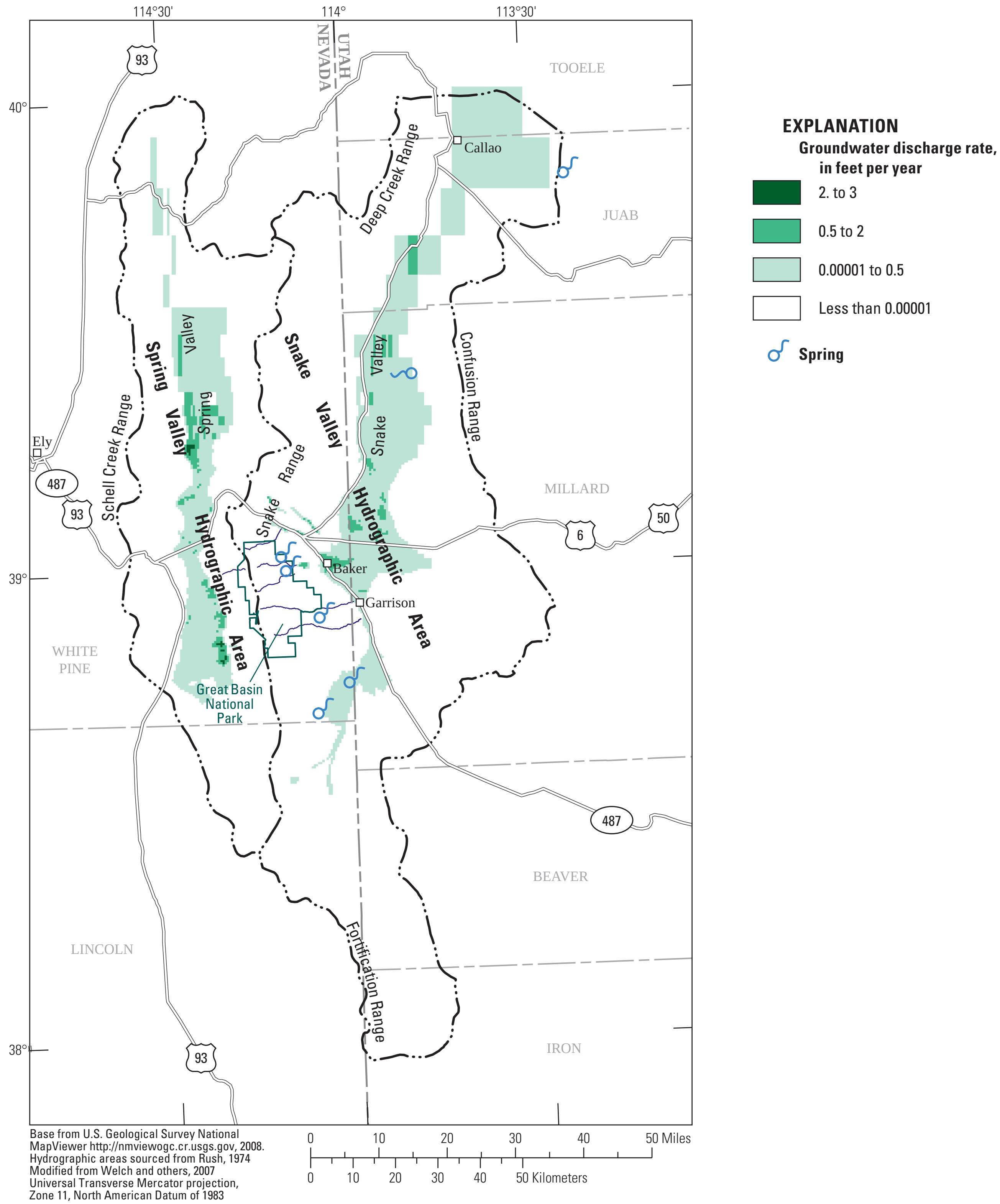
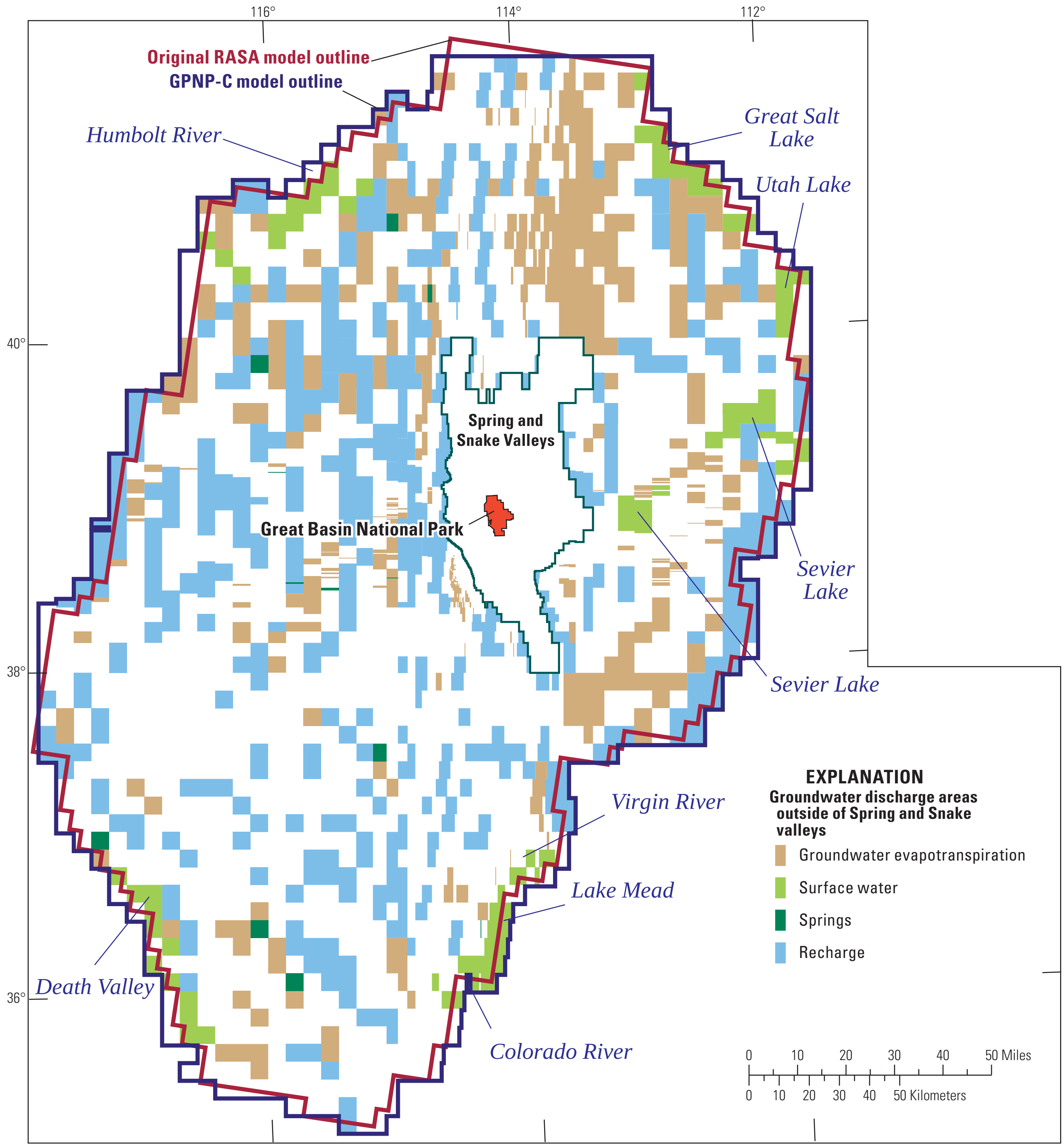


Figure 12. Groundwater discharge from phreatophytes and springs in the GBNP-C model, Spring and Snake Valley, Nevada and Utah.

Table 3. Stage and simulated discharges from springs in the GBNP-C and RASA models.

[Stage is the minimum pool elevation in feet above North American Vertical Datum of 1988 (NAVD 88). na, not applicable]

Spring or gaining reach	Layer in GBNP–C model	Stage	Simulated spring discharge, in acre-feet per year	
			GBNP–C model	RASA model
Inside Spring and Snake Valleys				
Big Springs	3	5,570	7,000	na
Big Springs run near NV-UT boundary	3	5,446	8,300	na
Cave Spring	2	7,200	100	na
Home Farm Springs	3	5,915	900	na
Kious Spring	3	6,006	400	na
Lehman Creek	1	6,080	2,200	na
Rowland Spring	2	6,580	700	na
Spring Creek Spring	4	6,120	1,400	na
Strawberry Creek	1	6,640	200	na
Twin Springs	4	4,810	4,000	4,000
Outside Spring and Snake Valleys				
Ash Spring	4	3,610	8,100	11,500
Ash Meadows	4	2,280	12,100	17,000
Blue Lake	4	4,260	17,600	20,100
Campbell Embay.	4	6,100	9,400	7,400
Duckwater	4	5,605	20,000	13,300
Fish Creek	4	6,040	100	2,800
Fish Springs	4	4,300	25,700	25,700
Grapevine Springs	4	2,780	500	700
Hiko and Crystal Springs	4	3,810	13,800	12,400
Hot Creek Springs	4	5,620	0	2,000
Manse Spring	4	2,770	3,000	3,900
Mormon Hot Springs	4	5,290	1,600	2,200
Muddy River	4	1,800	32,000	37,400
Nelson	4	5,900	1,400	1,800
Panaca	4	4,770	8,600	9,900
Railroad Valley	4	4,765	3,100	6,000
Rogers and Blue Point	4	1,580	1,000	1,200
Shipley Spring	4	5,800	3,100	4,400
Warm Springs	4	5,760	3,300	5,000
White River	4	5,220	23,200	23,100
TOTAL			212,800	211,800



Modified from Prudic and others, 1995

Figure 13. Groundwater evapotranspiration, surface-water features, and springs in the GBNP-C model that are outside of Spring and Snake Valleys, Nevada and Utah.

Boundary Conditions

The upper boundary of the model was the water table, but transmissivity was not simulated as a function of water-table altitude. Water-table altitudes were known adequately to define typical saturated thicknesses in the basin fill. Steady-state conditions prior to development were simulated so saturated thickness and transmissivity of the basin fill would not change during model calibration. Hydraulic-conductivity estimates compensated for any errors in saturated thickness. These compensating errors were minor given that the uncertainty of hydraulic conductivity is much greater than the uncertainty of the saturated thickness.

The lower model boundary was simulated as a no-flow boundary throughout the study area, which was interpreted as 2,060 ft below the water table in Spring and Snake Valleys. Assigned thicknesses minimally affected results because transmissivities were the primary hydraulic property that was estimated. Minimal groundwater movement was expected at all depths in most mountain blocks because of the occurrence of volcanic, intrusive, and other low-permeability rocks. Deep circulation within the basin fill was not expected because of stratification in the alluvial deposits and increasing cementation with depth. Transmissivity of the basement rocks (layer 4) was estimated directly so assigned thickness did not affect simulated groundwater flow.

Lateral boundaries were simulated as no-flow because model boundaries coincided with surface-water divides or were parallel to directions of groundwater flow (Prudic and others, 1995). These boundaries ranged from 50 to 200 mi from the periphery of Spring and Snake Valleys so the effects of simulated groundwater development in Spring and Snake Valleys likely would not propagate to these boundaries. Surface-water divides occur along ridges of low-permeability mountain blocks and were assumed to be coincident with groundwater divides. Lateral boundary conditions along the periphery of Spring and Snake Valleys were simulated by the supporting RASA model.

Calibration

Recharge, hydraulic-conductivity, and transmissivity distributions of the GBNP-C model were estimated by minimizing a weighted composite, sum-of-squares objective function. About 43 percent of the 813 pilot points that defined these distributions were adjusted with PEST (Doherty, 2008a). Differences between measured and simulated observations defined the goodness-of-fit or improvement of calibration. These differences, residuals, were weighted and summed in the objective function,

$$\Phi(x) = \sum_{i=1}^{nobs} [(\hat{o}_i - o_i) w_i]^2, \qquad (1)$$

where

x is the vector of parameters being estimated,

$nobs$ is the number of observations that are compared,

$(\hat{o}_i)$ is the ith simulated observation,

(o_i) is the ith measurement or regularization observation, and

w_i is the ith weight. Weights emphasized better measurements and allowed for multiple measurement types that had different units.

Although the sum-of-squares error serves as the objective function, root mean square (RMS) error was reported because RMS error was compared easily to measurements. Root mean square error is,

$$RMS = \sqrt{\Phi / \sum_{i=1}^{nobs} w_i^2}, \qquad (2)$$

Measurement and regularization observations controlled model calibration. Measured water levels, simulated water levels from original RASA model, depth-to-water beneath groundwater evapotranspiration area, spring discharges, land-surface altitudes, spring discharge at Fish Springs, and changes in discharge on selected creek reaches were measurement observations. Estimated values are guided by regularization observations to preferred conditions where parameters are insensitive to measurement observations. This approach is Tikhonov regularization (Doherty, 2008a).

Tikhonov regularization limited recharge, hydraulic conductivity, and transmissivity estimates at pilot points to reasonable values (Doherty, 2003). Sharp differences between nearby values in similar hydrogeologic units were penalized to ensure relatively continuous recharge, hydraulic conductivity, and transmissivity distributions. Unrealistic hydraulic property distributions were avoided by limiting the fit between measured and simulated observations (Fienen and others, 2009). This irreducible, weighted-measurement error combined measurement and numerical model errors.

Measurement Observations

Measured and simulated water levels were compared from 140 wells in Spring and Snake Valleys (fig. 14). More than 85 percent of the wells were screened in basin fill and the remaining 20 wells were completed in carbonate rock (appendix A). Simulated water levels were linearly interpolated laterally to points of measurement from the centers of surrounding cells but were not interpolated vertically (Doherty, 2008b). Measured water levels were weighted more than other observation types because these were the least ambiguous measurement observations.

Continuity with the remainder of the RASA model area was tested with 188 additional water levels that surrounded Spring and Snake Valleys. These water levels were simulated with the original RASA model (Prudic and others, 1995) at 94 mapped locations in layers 3 and 4 (fig. 14). The water levels sampled from the original RASA model became measurement observations for the GBNP-C model.

Depth-to-water beneath GW_{ET} and land-surface altitude observations were defined with a Digital-Elevation Model (DEM) that sampled 1:24,000-scale maps every 30 m and reported to the nearest whole meter (U. S. Geological Survey, 1999). At least 256 points from the DEM were in the smallest model cells. The range of DEM altitudes in the smallest cells typically was from less than 10 ft on the valley floors to more than 1,100 ft in the Snake Range. Observations of depth-to-water beneath GW_{ET} were land-surface altitude minus 5 ft and occurred at every GW_{ET} cell, which created 5,037 observations (fig. 14). Land-surface altitude observations were sampled at 7,601 locations. Each simulated water level that was below land surface was replaced with the land-surface altitude so the residual equaled zero and did not affect model calibration. For example, a simulated water table of 6,500 ft would be changed to 7,000 ft where land-surface altitude is 7,000 ft and the residual would be 0 ft. A simulated water table of 7,500 ft at the same location would not be changed and the residual would be 500 ft.

The supporting spring stage was an observation at most springs because spring discharges were specified (table 3). Supporting spring stage was the pool elevation plus 10 ft. Fish Springs was an exception because the spring was outside of Spring and Snake Valley. Fish Springs was simulated as a drain, as in the original RASA model (Prudic and others, 1995). Simulated discharge was compared to measured discharge from Fish Springs in the objective function.

Losses from Baker Creek and gains on Lehman Creek were simulated with specified heads in the GBNP-C model because creek stages were known better than the distribution of gains and losses. Baker Creek loses 2,900 acre-ft/yr (4 ft^3/s) and Lehman Creek gains 2,200 acre-ft/yr (3 ft^3/s) along the reaches that bound Lehman Caves and Rowland Spring (Elliott and others, 2006). Simulated losses and gains were compared to measured losses from Baker Creek and gains on Lehman Creek in the objective function.

Weights were adjusted iteratively so all observation types affected model calibration. Measured water levels, water levels that were simulated with the original RASA model, depth-to-water beneath GW_{ET}, land-surface altitude, and supporting spring-stage observations were assigned weights of 1, 0.1, 0.2, 0.3, and 1, respectively. Water levels that were simulated with the original RASA model were assigned the smallest weights because these observations exist where hydraulic properties are not changed by calibration. Discharge from Fish Springs, losses from Baker Creek, and gains on Lehman Creek were weighted differently because of unit differences between discharges and water levels.

Observation weights were not assigned to reflect measurement error because model-discretization error typically dominates measurement error (Belcher, 2004). Model-discretization errors have been assigned previously with a contrived equation (Faunt and others, 2004; eq. 2, p. 281). This approach seems like a fool's errand because the equation appears to have been created around the irreducible error of a calibrated model. Absolute values of weights did not affect calibration results because model fit was evaluated exclusively with unweighted residuals.

Regularization Observations

Regularization observations were equations that defined preferred relations between pilot points that defined recharge, hydraulic-conductivity, or transmissivity distributions. Regularization observations affected calibration most where the GBNP-C model was insensitive to measurement observations. Homogeneity was the primary relation that was enforced with Tikhonov regularization (Doherty and Johnston, 2003). Regularization observations that related pilot points within 20 mi of one another were weighted equally. Inverse-distance weighting was used where pilot points were separated by more than 20 mi.

Ratios of initial estimates of recharge rates were the preferred relation between pilot points for the recharge distribution. Initial recharge estimates were assigned to pilot points by precipitation accumulation zone (fig. 11). Preferred relations were defined between pilot points with the same simplified surface geology (fig. 9). For example, a regularization observation was created where two pilot points were in coarse-grained basin fill; but a regularization observation was not created where one point was in coarse-grained basin fill and the other point was in carbonate rock. More than 5,400 regularization observations constrained recharge estimates with these preferred relations.

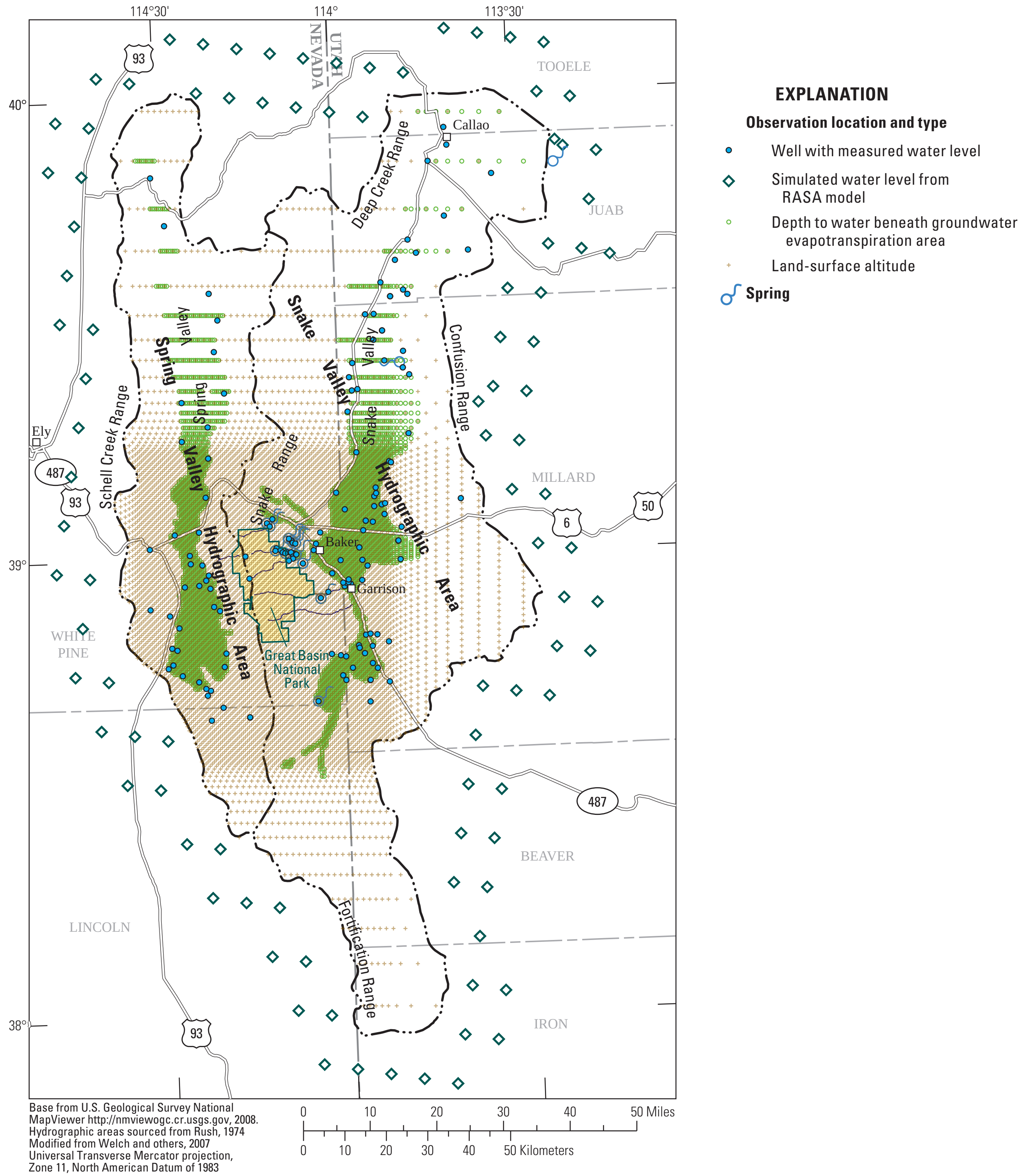


Figure 14. Locations of measured water levels, simulated water levels from original RASA model, groundwater evapotranspiration discharge areas, springs, and land-surface altitudes observations in the GBNP-C model.

Homogeneity within simplified geologic classes was the preferred relation between pilot points for the hydraulic conductivity and transmissivity distributions. Hydrogeologic classes were incorporated as observations, instead of as parameters, so hydraulic conductivity or transmissivity in a hydrogeologic class could differ where dictated by measurement observations. Volcanic, intrusive, and other low-permeability units were assumed to have uniformly low hydraulic conductivities, which were reflected in the regularization observations. A preferred heterogeneity was specified where coarse-grained basin fill was assumed to be 30 times more permeable than fine-grained basin fill. More than 5,800 regularization observations constrained hydraulic conductivity and transmissivity estimates with these preferred relations.

Goodness of Fit and GBNP-C Model Results

Simulation results and observations compared favorably in the vicinity of Spring and Snake Valleys where water levels and discharges were compared. Average and RMS water-level errors of 10 and 39 ft, respectively, were not great relative to the 5,400 ft range of measured water levels (fig. 15). Measured water levels ranged from 4,340 to 10,630 ft above NAVD 88 near Callao, Utah, and Baker Lake, Nevada, respectively. The range of measured water levels was similar to simulated water levels that ranged from 4,360 to 10,620 ft above NAVD 88. Minimum and maximum water-level errors ranged from -156 to 128 ft and occurred in northern Snake Valley where the GBNP-C model is discretized coarsely. About 85 percent of simulated water levels were within 50 ft of measured water levels.

An error of 775,000 ft² or an RMS error of about 40 ft was estimated to be the irreducible, weighted-measurement error. Model error could be estimated only from model calibration because numerical model errors typically exceed measurement errors (Belcher, 2004). Model error asymptotically approached the estimated error of 775,000 ft², which could have been any value between 750,000 and 800,000 ft².

Measured water levels, residuals, and simulated water-level contours are mapped for each layer in Spring and Snake Valleys and in the area of interest in appendix B. Measured water levels and residuals are posted on separate maps with simulated water-level contours for each layer. Simulated water levels from GBNP-C model, measured water levels, simulated water levels from original RASA model, depth-to-water beneath GW_{ET}, land-surface altitude, and spring-stage observations are reported in an interactive Microsoft© Excel workbook in appendix C.

Water-level residuals with absolute values greater than 50 ft were considered significant. About 80 percent of the simulated water levels and depth-to-water beneath GW_{ET} residuals are within 50 ft of measured targets because RMS errors are 39 and 41 ft, respectively. Water-level residuals of less than 50 ft also are small relative to the more than 2,000 ft range of water levels in the basin fill in Spring and Snake Valleys (fig. 16). Locations, simulated values, measured values, and residuals are reported for all observations in appendix C.

Water-level residuals exhibited little spatial pattern in the basin fill except surrounding Spring and Snake Valleys where hydraulic properties from the original RASA model were specified (fig. 16). Residuals were greatest where low-permeability intrusive and volcanic rocks were simulated more accurately in Spring and Snake Valleys. Areas west of Spring Valley and surrounding southern Snake Valley were affected by a strong transmissivity contrast. The transmissivity distribution from the original RASA model was more generalized, whereas the transmissivity distribution that was estimated with the GBNP-C model was more representative of the mapped hydrogeologic units (fig. 9).

The distribution of significant water-level residuals and altitudes in the basement rock (model layer 4) were similar to those in the basin fill (fig. 17). Significant residuals in the basement rock primarily occurred outside of Spring and Snake Valleys in the same areas where significant residuals occurred in the overlying basin fill. Simulated water-level differences between basin-fill and carbonate-rock aquifers typically were less than 10 ft in Spring and Snake Valleys.

Transmissive structures were estimated consistently even though hydraulic property estimates at pilot points were non-unique. Areas of transmissivity in excess of 10,000 ft²/d occurred along eastern Snake Valley (fig. 17) and south of the Snake Range in Spring and Snake Valleys (fig. 16). These relatively high-transmissivity structures persisted during all phases of model calibration. Simulated water levels were affected and flow was deflected from the east to the north by these structures.

Hydraulic-property distribution and pilot-point estimates are mapped for all layers in Spring and Snake Valleys and in the area of interest in appendix B. Distributions and pilot-point estimates of hydraulic conductivity are mapped for layers 1, 2, and 3. The distribution and pilot-point estimates of transmissivity are mapped for layer 4. The transmissivity of all four layers also is reported in appendix B. Pilot-point locations, interpreted geology, simulated thickness, and parameter estimates are reported in appendix D.

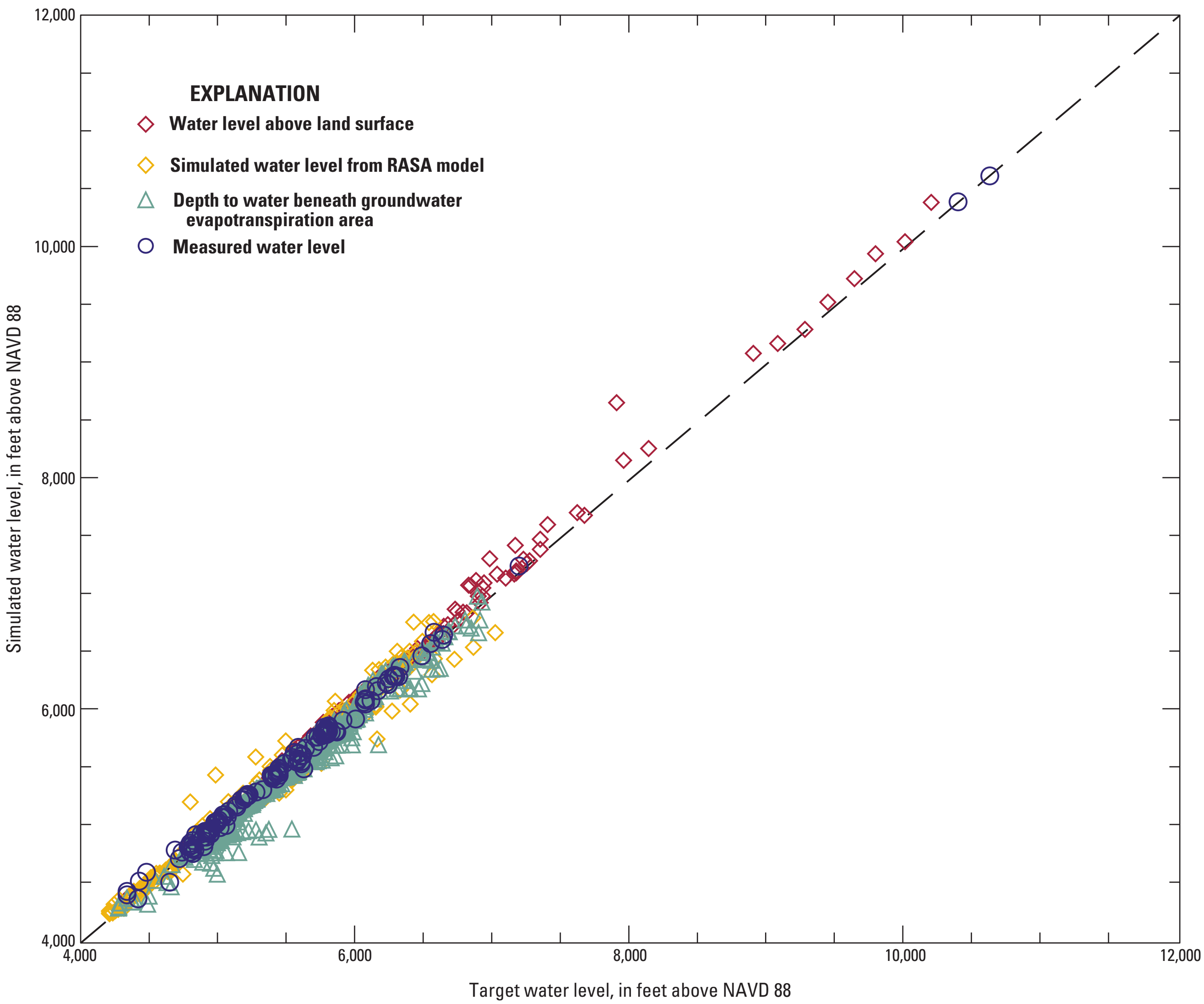


Figure 15. Simulated and target water levels for the calibrated GBNP-C model, Nevada and Utah.

Recharge was generated principally by the Snake Range and the Schell Creek Range to a lesser degree (fig. 18). The estimated distribution of recharge was similar to the potential recharge distribution (fig. 11). Maximum annual recharge rates were about 10 ft and occurred as mountain-front recharge just downgradient from the contact between basement rocks and basin fill. The annual volume of recharge to Spring and Snake Valleys consistently was estimated around 260,000 acre-ft. The simulated recharge distribution and pilot-point estimates are mapped in Spring and Snake Valleys and in the area of interest in appendix B. Pilot point locations, interpreted geology, and recharge rate estimates are reported in appendix D.

The GBNP-C model simulated more groundwater flow through Spring and Snake Valleys than the original RASA model (table 4). This largely occurred because annual simulated GW_{ET} and spring discharge from Spring and Snake Valleys in the GNBP-C model was 64,000 acre-ft greater than from the original RASA model. The GNBP-C model also simulated local flow in the mountain blocks that was not simulated by the original RASA model. Recharge to the GNBP-C model in Spring and Snake Valleys included the net, annual addition of 23,000 acre-ft from specified heads in the mountain blocks. Simulated water budgets in the study area outside of Spring and Snake Valleys were similar in both the GNBP-C and original RASA models (table 4).

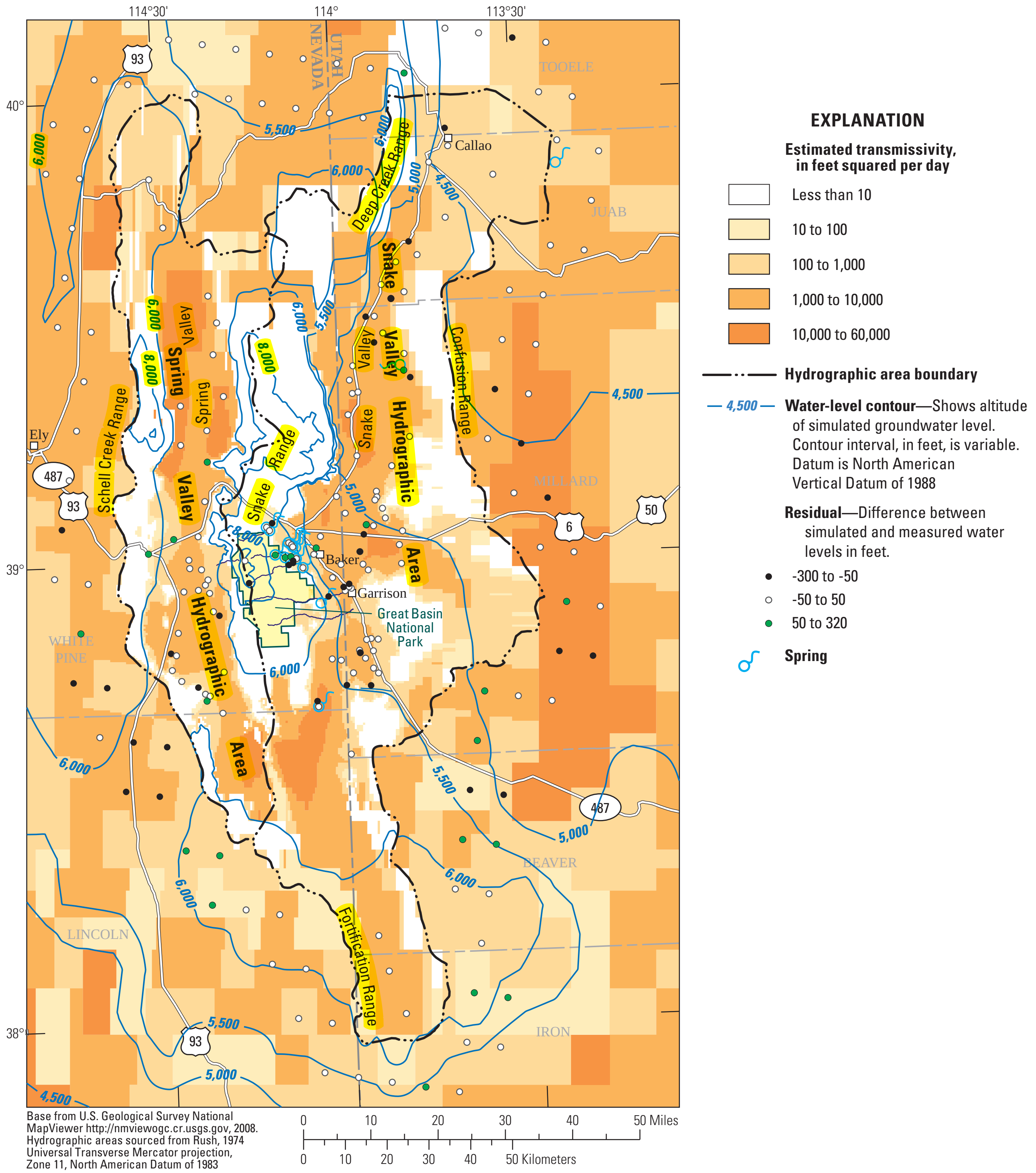


Figure 16. Estimated transmissivities, simulated water-level contours, and water-level residuals in the basin fill in model layer 3, Nevada and Utah.

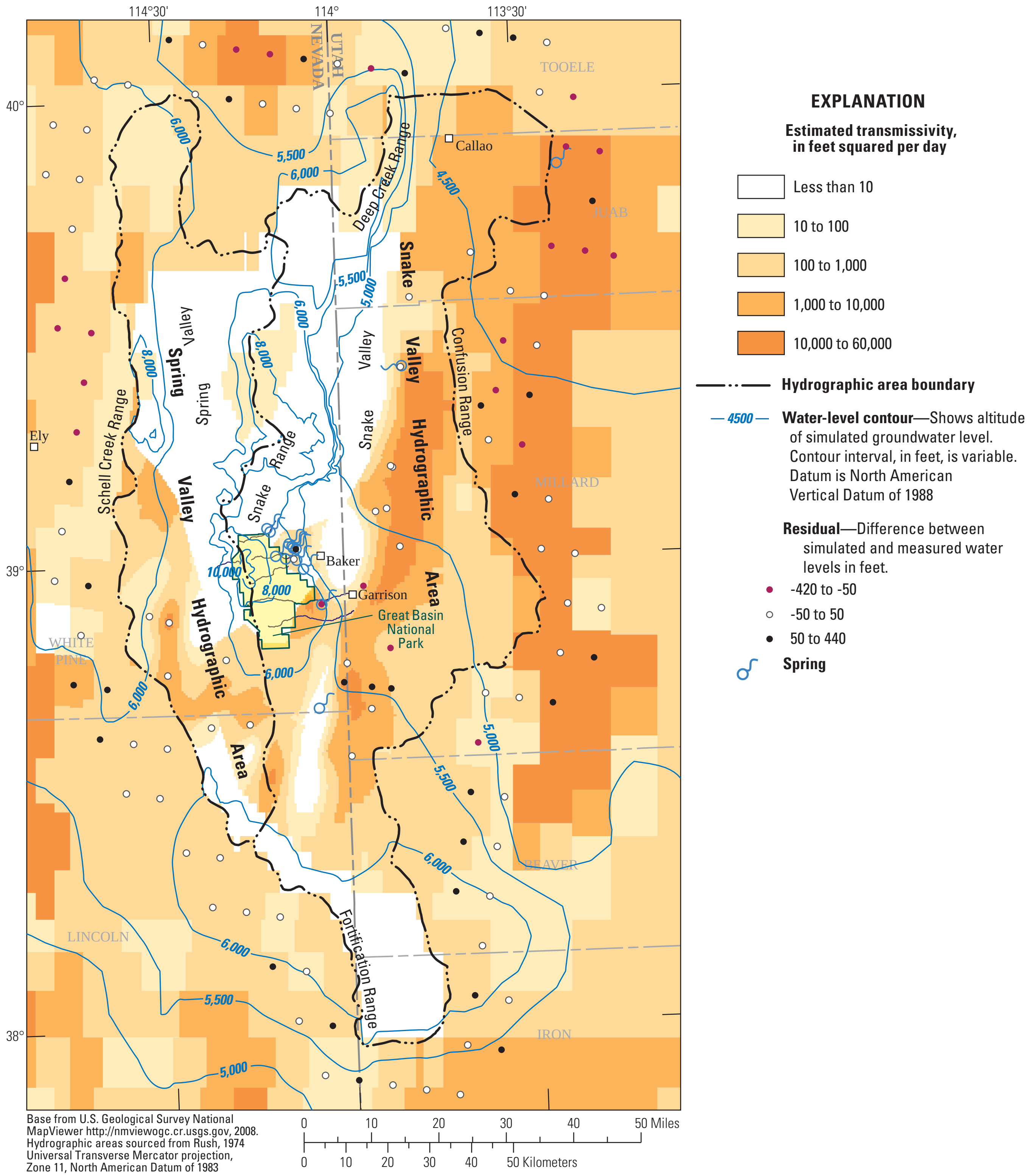


Figure 17. Estimated transmissivity, simulated water-level contours, and water-level residuals in the basement rocks in model layer 4, Spring and Snake Valleys, Nevada and Utah.

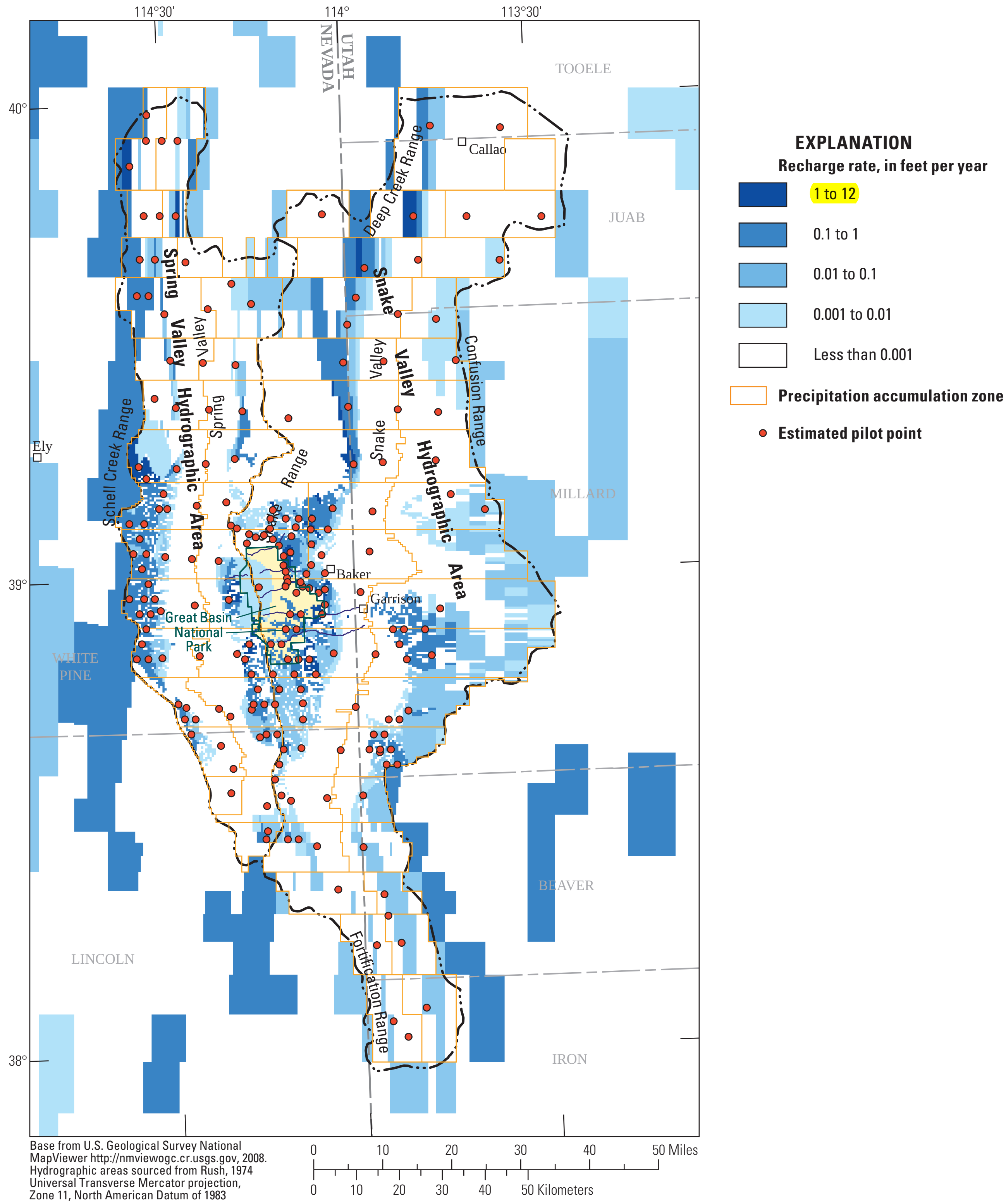


Figure 18. Calibrated recharge distribution and pilot points for GBNP-C model in Spring and Snake Valleys, Nevada and Utah.

Table 4. Water budgets simulated with the GBNP-C and original RASA models, Spring and Snake Valleys, Nevada and Utah.

[All values are in thousands of acre-feet per year. Values may not match presented values due to rounding. **GBNP-C** is the Great Basin National Park calibration model. **RASA** is the original Great Basin Regional Aquifer System Analysis model (Prudic and others, 1995)]

Budget component	Study area outside of Spring and Snake Valleys		Spring and Snake Valleys	
	GBNP-C	RASA	GBNP-C	RASA
INFLOW				
Recharge[1]	1,342	1,341	259	183
Spring and Snake Valleys	49	37	–	–
Total inflow	1,391	1,378	259	183
OUTFLOW				
GW_{ET}[2]	1,084	1,071	187	142
Spring discharge	188	208	23	4
Surface water	104	99	0	0
Spring and Snake Valleys	–	–	49	37
Total outflow	1,376	1,378	259	183

[1]Recharge is the sum of recharge and flow to specified heads in mountain blocks in Spring and Snake Valleys.

[2]GW_{ET} is groundwater discharge by evapotranspiration in excess of local precipitation.

Alternative Models

Transmissivity estimates were affected primarily by the magnitude and distribution of groundwater-discharge estimates. About 90 percent of the 210,000 acre-ft of annual discharge from Spring and Snake Valleys was simulated as distributed GW_{ET} in the GBNP-C model (table 4). These discharge rates are uncertain, but were assumed as known while calibrating the GBNP-C model.

A significant uncertainty is associated with the distributed GW_{ET} estimates from Spring and Snake Valleys because the average groundwater-discharge rate of 0.2 ft/yr is small relative to the measured quantities (Moreo and others, 2007). Groundwater-discharge rates were the differences between measured evapotranspiration and precipitation rates, which averaged 0.6 and 0.4 ft/yr, respectively. An uncertainty of ±0.05 ft/yr could be expected in the groundwater-discharge rates, which would cause annual distributed GW_{ET} from Spring and Snake Valleys to range from 151,000 to 227,000 acre-ft (table 5).

The uncertainty in distributed groundwater-discharge rate of ±0.05 ft/yr was a maximum tolerable value. Tolerance was defined by annual distributed GW_{ET} discharges of 122,000 and 151,000 acre-ft from Spring and Snake Valleys for decreases in distributed groundwater-discharge rates of 0.10 and 0.05 ft/yr, respectively. A 20 percent decrease in diffuse groundwater-discharge estimates was tolerable but a 40 percent decrease was not. This was because the mapped vegetation distribution and associated groundwater discharge would differ visibly in response to existing pumping for irrigation in Snake Valley.

The effects of uncertain distributed GW_{ET} estimates on transmissivity estimates were bounded with alternative models, GBNP-LowET and GBNP-HighET, that were calibrated to the lower and upper rates of distributed GW_{ET}, respectively. The alternative models were calibrated to the objective function that was defined for the GBNP-C model. Recharge, hydraulic conductivity, and transmissivity at the same pilot points defined in the GBNP-C model were estimated to calibrate the alternative models. Recharge, hydraulic-conductivity, and transmissivity estimates that calibrated the GBNP-C model became the initial parameter estimates for the alternative models. All three models equally fit the observations with weighted-measurement errors between 780,000 and 790,000 ft^2 or RMS errors of about 40 ft.

All recharge changed about 10 percent more than changes in distributed GW_{ET} in Spring and Snake Valleys (table 5). Recharge and induced flow from specified heads increased 45,000 acre-ft/yr in the GBNP-HighET model, while distributed GW_{ET} increased 40,000 acre-ft/yr. Proportionate reductions also occurred in the GBNP-LowET model. Disproportionate changes in recharge and discharge were balanced by changes in subsurface flow between Spring and Snake Valleys and the remainder of the study area.

About 75 percent of the annual recharge volume entered Spring and Snake Valleys at rates between 0.2 and 4 ft for the GBNP-C and alternative models (fig. 19). The annual recharge volume consistently totaled 30,000 acre-ft from areas with annual recharge rates less than 0.2 ft in all three models.

Transmissivity of all model layers differed by less than a factor of 2 between the GBNP-HighET and GBNP-LowET models through more than 96 percent of Spring and Snake Valleys (fig. 20). Transmissivity of the basin fill increased between the Snake Range and the groundwater-discharge areas and through the playas in northern Snake Valley. The transmissivity of the carbonate rock through the Confusion Range in eastern Snake Valley decreased as recharge increased.

Transmissivity estimates were minimally sensitive to groundwater-discharge estimates east of GBNP (fig. 20). Transmissivity estimates in the basin fill between Baker and Big Springs changed less than 50 percent between the two alternative models. This indicates that drawdown from proposed groundwater development in Snake Valley can be estimated with transmissivity distributions from the GBNP-HighET, GBNP-C, and GBNP-LowET models and the results will differ little.

Table 5. Water budgets simulated with GBNP-C, GBNP-LowET, and GBNP-HighET models in Spring and Snake Valleys, Nevada and Utah.

[All values are in thousands of acre-feet per year. Values may not match presented values due to rounding. **GBNP-C** is the Great Basin National Park calibration model. **GBNPLowET** is the alternative Great-Basin National Park model, where annual GW_{ET} has been reduced by 0.05 foot. **GBNP-HighET** is the alternative Great-Basin National Park model, where annual GW_{ET} has been increased by 0.05 foot]

Budget component	Spring and Snake Valleys		
	GBNP-C	GBNP-LowET	GBNP-HighET
INFLOW			
Recharge	234	199	276
Specified heads in mountain blocks	36	34	39
Spring and Snake Valleys	19	18	21
Total inflow	289	251	336
OUTFLOW			
GW_{ET}[1]	187	151	227
Specified heads in mountain blocks	12	11	12
Spring discharge	23	23	23
Spring and Snake Valleys	68	66	74
Total outflow	289	251	336

[1]GW_{ET} is groundwater discharge by evapotranspiration in excess of local precipitation.

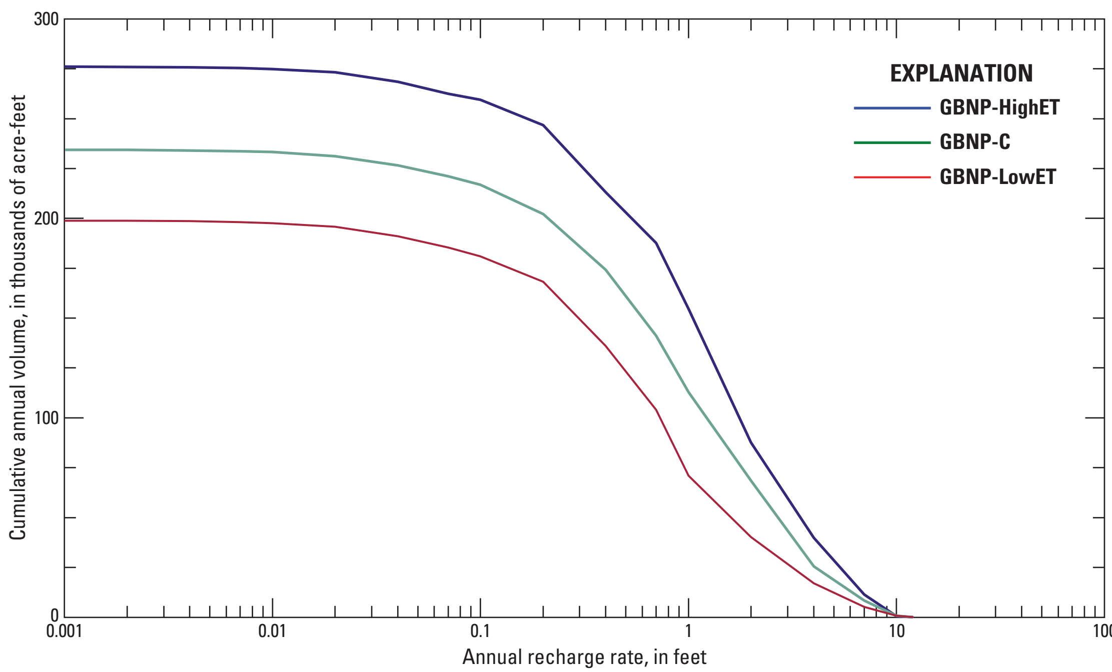


Figure 19. Cumulative recharge volumes for GBNP-HighET, GBNP-C, and GBNP-LowET models, Spring and Snake Valleys, Nevada and Utah.

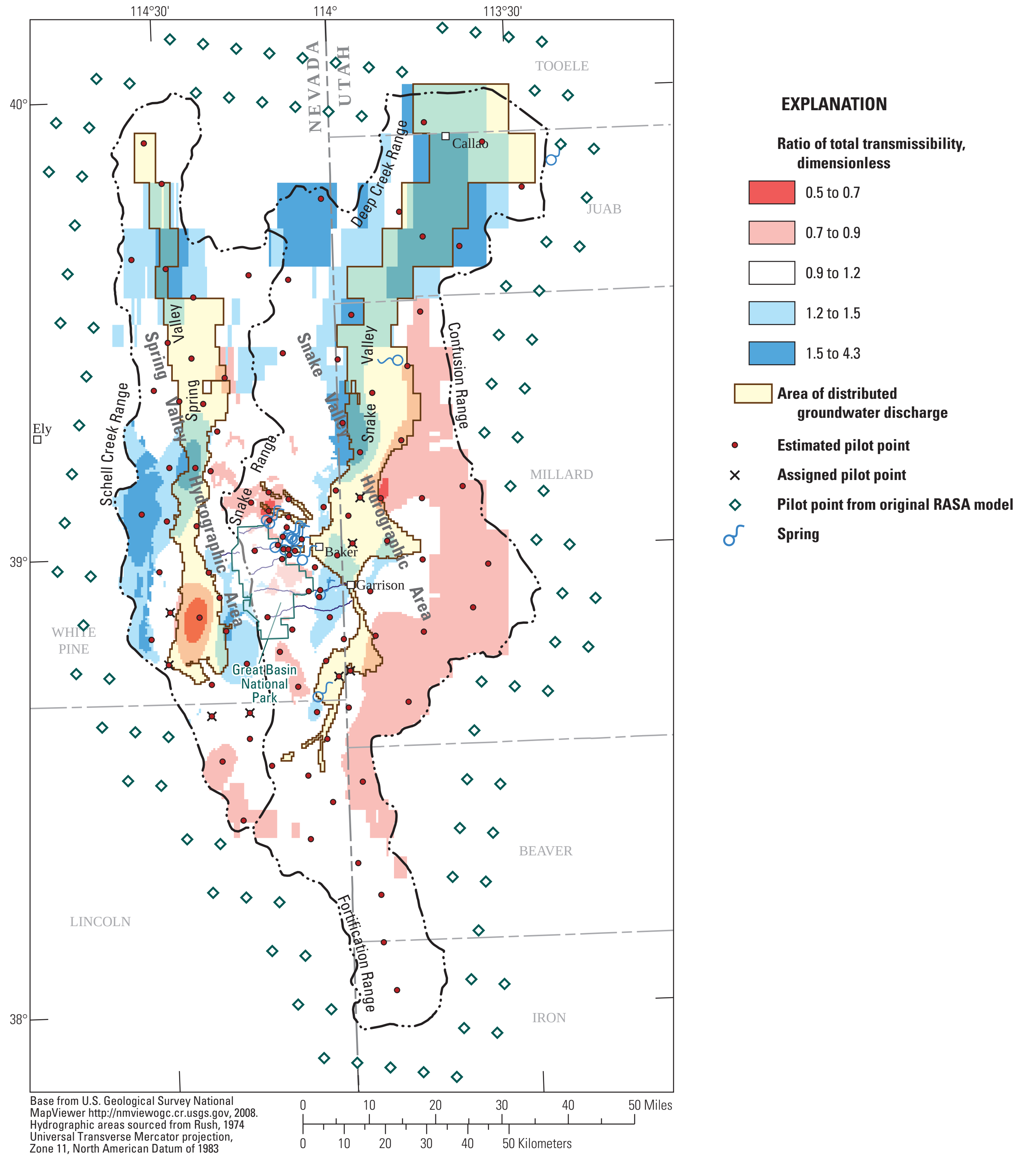


Figure 20. Ratio of GBNP-HighET transmissivity divided GBNP-LowET transmissivity (layers 1–4), Spring and Snake Valleys, Nevada and Utah.

Potential Effects of Groundwater Pumping from Snake Valley

The Great Basin National Park predictive (GBNP-P) model was developed to estimate the potential effects of pumping from Snake Valley on springs, streams, and water levels in caves in and adjacent to GBNP (fig. 1). Pumping from Snake Valley includes existing withdrawals for irrigation and proposed groundwater development. The GBNP-P model was a transient groundwater-flow model where changes in groundwater storage were simulated. The hydraulic conductivity of basin fill and transmissivity of basement rock were the same distributions that were estimated with the GBNP-C model. Specific yield was estimated from aquifer tests in Spring and Snake Valleys (table 1) and distributed with the surface geology (fig. 9).

Pumped groundwater comes from storage and reductions in discharge to streams, springs, wetlands, and phreatophytes. Groundwater storage, which is derived from the compressibility of the aquifer system under confined conditions and gravity drainage of pores under unconfined conditions (at the water table), is the initial source of water to new pumping wells (Bredehoeft and Durbin, 2009). Groundwater discharge to streams, springs, wetlands, and phreatophytes is the ultimate source of pumped groundwater after a new equilibrium (no change in storage) is reached. This source will be referred to as groundwater capture.

Hydraulic diffusivity largely controls the delay between the start of pumping and most water being supplied by groundwater capture. Hydraulic diffusivity is the ratio of transmissivity divided by storage coefficient. Characterizing pumping responses with hydraulic diffusivity implies that an aquifer system is two-dimensional and vertical differences in drawdown are minor. This simplification is reasonable when analyzing drawdowns and groundwater capture that occur during decades of groundwater development. Simplifying multiple, three-dimensional, hydraulic-property distributions to a single hydraulic-diffusivity distribution helps assess the sensitivity of GBNP-P model results to errors in hydraulic-property estimates.

Direct-Drawdown Approach

Direct simulation of drawdown reduced model complexity and uncertainty because fewer hydrologic features were simulated. Model input, other than the proposed pumpage, was limited to hydraulic-conductivity, transmissivity, storage-coefficient, and groundwater-discharge distributions (Leake and others, 2010). The drawdown models simulated changes so relatively unchanging quantities, such as recharge and existing pumpage distributions, do not need to be simulated explicitly. The absence of these features simplified presentation of model results and avoided the uncertainty associated with recharge and historic pumping estimates.

Simulation of groundwater capture will better conform to a mapped distribution with the direct-drawdown approach than with extrapolation of a calibrated model. Groundwater discharge that is simulated with a calibrated model will spatially deviate from the mapped groundwater discharge, even where total simulated and measured discharges are equal. The availability of groundwater discharge that can be captured is defined directly from mapped discharges with the direct-drawdown approach, so simulated capture cannot exceed measured discharge at each cell.

The availability of groundwater discharge that can be captured in Spring and Snake Valleys is limited. Simulated groundwater capture from springs cannot exceed measured discharges, which range between 100 and 8,300 acre-ft/yr in Snake Valley (table 3). Simulated groundwater capture from phreatophytes and wetlands, which is distributed areally, is limited to rates that average 0.2 ft/yr and do not exceed 3 ft/yr (Welch and others, 2007).

Groundwater capture that is limited by availability can be simulated accurately with wells and drains in MODFLOW (Harbaugh and others, 2000). Observed discharge rates are injected into the model with wells, Q_{WEL}, and removed with drains, Q_{DRN} (fig. 21). Drain elevations are the extinction depths below the existing water table. Drain conductances are the observed discharge rates divided by the extinction depths. Differences between injected and drained water, simulate the reduction in groundwater discharge that pumping captures. The direct-drawdown approach limits the amount of captured groundwater to measured discharges. Variations of this approach have been applied in finite-element models (Durbin and others, 2008). Combining existing packages to simulate a function not supported formally in MODFLOW has been applied previously with the river and drain packages (Zaadnoordijk, 2009).

Capture of distributed GW_{ET} and spring discharge were simulated in the GBNP-P model using a combination of well and drain packages in MODFLOW (Harbaugh and others, 2000). Distributed GW_{ET} was captured from layer 1 and could not exceed the mapped GW_{ET} rate (fig. 12). Spring discharges were captured from layers 2, 3, or 4 and could not exceed the measured rates (table 3). A uniform extinction depth of 15 ft was assumed for all distributed GW_{ET} and springs. Uniform extinction depths of 5 ft and 10 ft were tested and minimally changed predicted drawdowns and groundwater capture.

Capture of discharge to streams in low-permeability mountain blocks was simulated with specified heads set to zero. These heads were specified at the bottom of drainages where perennial streams occurred. Groundwater capture was not limited because groundwater/surface-water interaction was minimal and discharge to these streams was less than 5 percent of the volumetric budget in the GBNP-C model (table 5).

Hydraulic conductivity of basin fill and transmissivity of basement-rock distributions from the GBNP-C model were specified in the GBNP-P model (app. B). Transmissivity in the alternative models differed from the GBNP-C model by less than 20 percent in Snake Valley south of Baker (fig. 20).

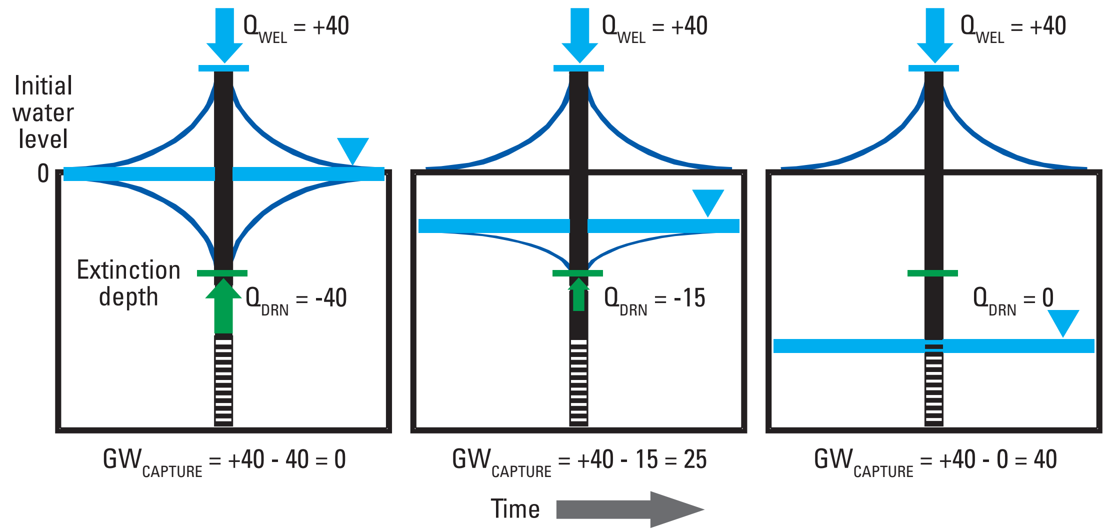


Figure 21. Example of limited groundwater capture in a cell as simulated in the GBNP-P model with the well and drain packages in MODFLOW where the water table is declining because of regional pumping, Spring and Snake Valleys, Nevada and Utah.

Hydraulic-property distributions from the alternative models were not considered because the range of pumping rates investigated was greater than transmissivity differences between the GBNP-C model and either alternative model (appendix D).

Specific yield was the significant component of storage coefficient in the GBNP-P model because drainage from the water table released 50–100 times more water than aquifer compressibility per foot of drawdown. Specific yields in the basin fill and carbonate rocks were estimated from aquifer tests in Spring and Snake Valleys. Specific yield ranged from 12 to 18 percent in the basin fill and from 1 to 4 percent in the carbonate rocks (table 1). Specific yields of 2 and 15 percent were specified for bedrock and basin fill, respectively, in the GBNP-P model (fig. 9). A uniform specific storage of 2×10^{-6} 1/ft was assigned to layers 2, 3, and 4 in Spring and Snake Valleys and to layer 4 through the remainder of the model.

Reasonable hydraulic-diffusivity estimates in Snake Valley south of U.S. Highway 50 could deviate from the assigned values in the GBNP-P model by as much as 50 percent. This constraint assumes that the average transmissivity could be as much as 20 percent greater than in the GBNP-P model and the specific yield of the basin fill is 12 percent instead of 15 percent. Increasing the hydraulic diffusivity by 50 percent would cause the simulated delay between the start of pumping and detection of drawdown at a site to be 33 percent less (earlier) than in the GBNP-P model. Decreasing the hydraulic diffusivity by 50 percent would cause the simulated delay between the start of pumping and detection of drawdown at a site to be 50 percent greater (later) than in the GBNP-P model.

Estimates of distributed GW_{ET} capture, spring declines, and regional-drawdown extent were affected minimally by not simulating transmissivity as a function of drawdown. This was because the simulated extinction depth for distributed GW_{ET} and spring discharge was 15 ft, which is a minor change relative to saturated thickness of the basin fill. The extent of regional drawdown typically is defined by the 10-foot contour, which also is a slight change relative to saturated thickness of the basin fill. Simulating transmissivity independently of drawdown likely affected model results near proposed points of diversion where simulated drawdowns exceeded 100 ft. Simulated drawdowns of 100 and 200 ft typically would be underestimated by 5 and 13 percent, respectively, in a 1,000-foot thick aquifer because transmissivity was not simulated as a function of drawdown.

Effects of Existing Irrigation

Groundwater withdrawals for irrigation have affected water levels and captured groundwater discharge in Snake Valley. Annual groundwater withdrawals for irrigation in Snake Valley averaged 13,000 acre-ft between 1945 and 2004 (Southern Nevada Water Authority, 2009) and averaged 19,000 acre-ft during 2000, 2002, and 2005 (Welborn and Moreo, 2007). This assumed annual consumptive use for irrigation averaged 2.5 ft. Water levels have declined between 0.3 and 0.7 ft/yr near Baker, Nevada in response to groundwater withdrawals for irrigation since 1990 (U. S. Geological Survey, 2010). The extent and volume of captured groundwater discharge in Snake Valley was estimated with the GBNP-P model.

Potential cumulative effects of irrigation in Snake Valley were simulated by pumping 19,000 acre-ft/yr during a 40-year period. Irrigation pumpage was distributed as observed during 2002 (fig. 22; Welborn and Moreo, 2007) and withdrawn from the basin fill (layer 3). A 40-year period was simulated so the total pumpage (760,000 acre-ft) equaled cumulative pumpage from 1945 to 2004 (Southern Nevada Water Authority, 2009).

Simulated drawdowns of more than 10 ft in the pumping interval (layer 3) extended little beyond the irrigated areas (fig. 22). Simulated drawdowns exceeded 3 ft over 200,000 acres at the end of the 40-year period. Detectable drawdowns occurred primarily in the basin fill except in southern Snake Valley where drawdown from irrigation propagated into the carbonate rocks.

Distributed GW_{ET} primarily was captured at rates of less than 1 ft/yr near the irrigated areas and at rates of less than 0.083 ft/yr more than 2 mi from the irrigated areas (fig. 23). Drawdown propagation at the water table (layer 1) was attenuated where groundwater discharged (fig. 23). Captured groundwater discharge supplied more than 80 percent of 19,000 acre-ft/yr pumped at the end of the 40-year period.

Simulated Drawdown and Groundwater Capture

Total annual potential groundwater withdrawal and the period of analysis were specified by the Nevada State Engineer in section VI of Interim Order no. 2 for the Snake Valley water-rights hearing (Nevada Division of Water Resources, 2008). The order states,

> "The Applicant is hereby ordered to provide a groundwater model that simulates pumping and potential impacts from pumping groundwater in the amount of 10,000 acre-feet annually, 25,000 acre-feet annually, and 50,000 acre-feet annually for the time frames of 10 years, 25 years, 50 years, 100 years, and 200 years."

Potential groundwater-withdrawal locations were limited to nine proposed points of diversion (fig. 24). Each proposed point of diversion was assumed to be a single well that could pump 1,200–3,400 gal/min (2,000–5,600 acre-ft/yr). Wells in more transmissive areas were selected for the 10,000 and 25,000 acre-ft/yr scenarios where only five wells were needed (table 6). All nine wells were pumped to simulate annual pumpage of 50,000 acre-ft/yr from Snake Valley.

Pumpage from the proposed points of diversion was simulated with the multi-node well package (Halford and Hanson, 2002). This approach simulated groundwater pumping from multiple layers, computed drawdown in pumped wells, and limited production rates that exceeded user-specified drawdowns. Screened intervals were assumed to extend from 60 to 2,060 ft below the water table (layers 3 and 4) because depths of withdrawal were unspecified. Diameters of production wells were assumed to be 24 in. A maximum drawdown of 1,000 ft was specified for all wells.

A fourth scenario was simulated where annual pumpage totaled 50,000 acre-ft and drawdown in the production wells was unlimited. This scenario was tested because annual production of 50,000 acre-ft could not be produced when drawdown could not exceed 1,000 ft. Annual production initially totaled 43,000 acre-ft and decreased to 40,000 acre-ft where total withdrawals of 50,000 acre-ft were specified and drawdown was limited. Unlimited production of 50,000 acre-ft/yr was an absurd simulation because drawdown in the well at proposed point of diversion PD-27 exceeded 400,000 ft.

Irrigation pumpage was simulated in addition to potential groundwater pumpage in four additional scenarios because existing irrigation pumping has decreased water levels and captured groundwater discharge. Simulation of potential groundwater pumping is identical to the approach reported for the four previous scenarios (table 6). These four additional scenarios differ because 40 years of pumping 19,000 acre-ft/yr were simulated prior to potential groundwater pumping commencing. Irrigation pumpage was distributed as observed during 2002 (fig. 22; Welborn and Moreo, 2007) and withdrawn from the basin fill (layer 3). Irrigation pumpage of 19,000 acre-ft/yr continued as distributed during the 200-year predictive period.

Results from the eight GBNP-P model scenarios are presented as maps of groundwater capture and drawdown (appendix E), as time series of drawdowns and discharges from selected wells (appendix F), and as time series of discharge reductions from selected springs and volumetric controls (appendix G). Groundwater capture and drawdown maps are presented at the scale of the area of interest and the scale of Spring and Snake Valleys for each layer after 10, 25, 50, 100, and 200 years of pumping for a total of 40 maps per scenario (appendix E). Drawdown and discharge time series from selected wells were simulated with the multi-node well package, including unpumped wells, that were completed in layers 2 and 3 in the mountain block and layers 3 and 4 in the basin fill (appendix F). Simulated discharge reduction is the sum of well and drain packages at selected springs (appendix G, table 3).

Distributed GW_{ET} was captured at a maximum rate of 3 ft/yr and drawdown propagation was attenuated where groundwater discharged at greater rates (fig. 24). Water-table declines propagated farther from pumping wells south of Great Basin National Park because less groundwater discharge was available for capture than near Baker, Nevada. The water table declined minimally north of U.S. Highway 50 because more groundwater discharge was available for capture. General patterns of groundwater capture and water-table declines were similar for all scenarios (appendix E). Simulated drawdowns greater than 1 ft propagate outside of Spring and Snake Valleys after 200 years of pumping (fig. 25). This occurs in all scenarios (appendix E).

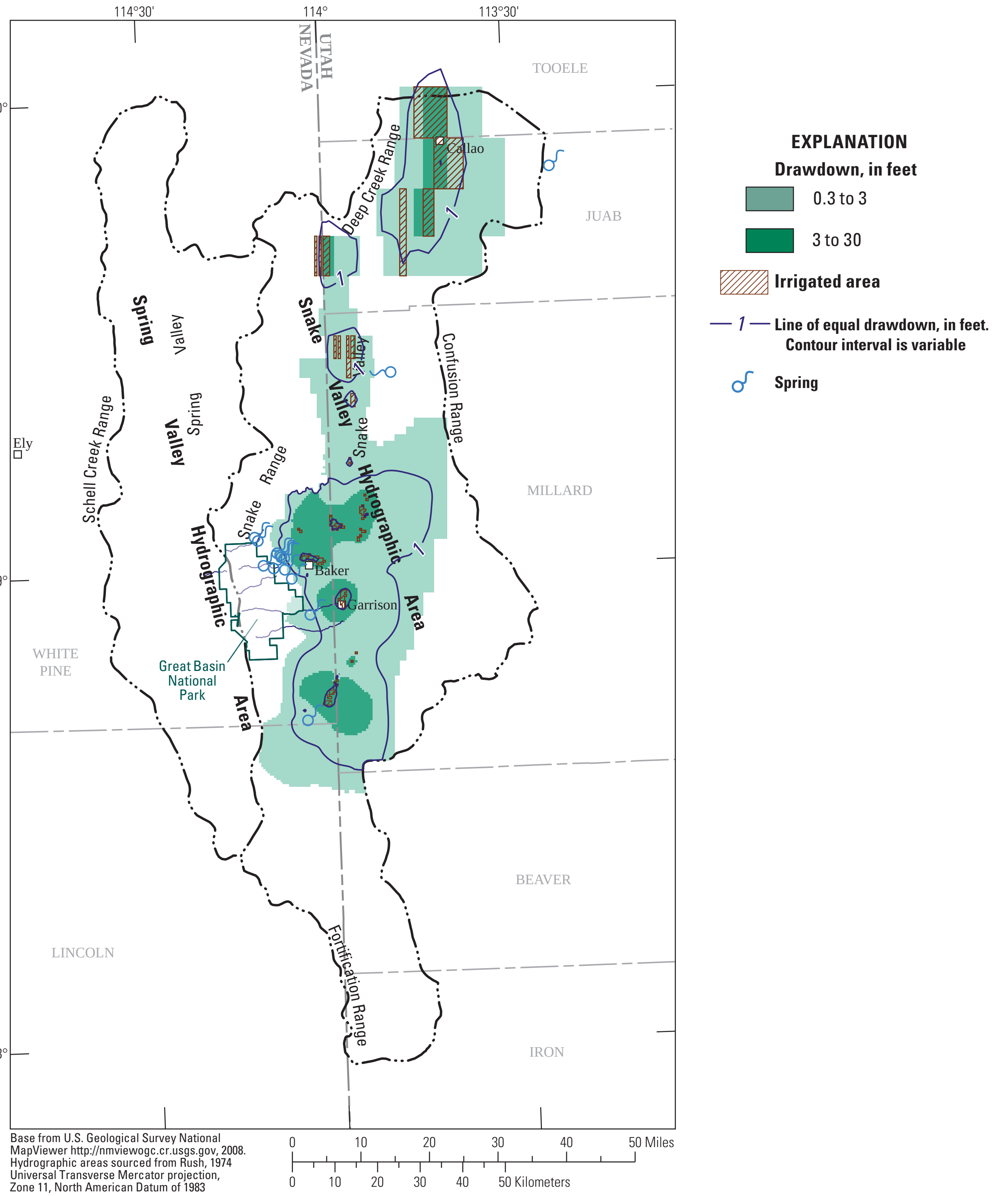


Figure 22. Irrigated acreage during 2002 and drawdowns in the basin fill (model layer 3) from 40 years of pumping 19,000 acre-ft/yr for irrigation, Snake Valley, Nevada and Utah.

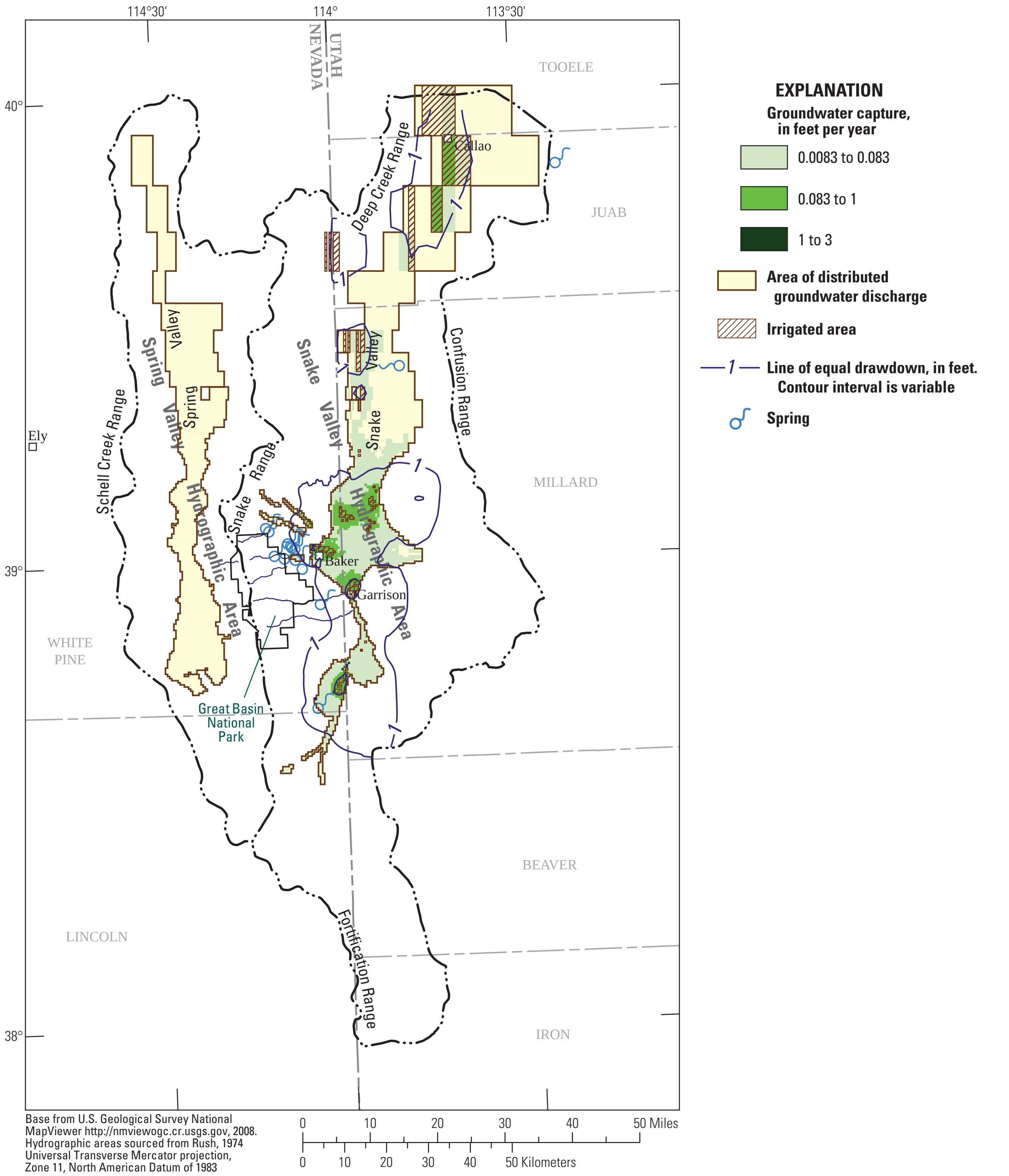


Figure 23. Simulated groundwater capture and drawdown of the water table (model layer 1) from 40 years of pumping 19,000 acre-ft/yr for irrigation, Spring and Snake Valleys, Nevada and Utah.

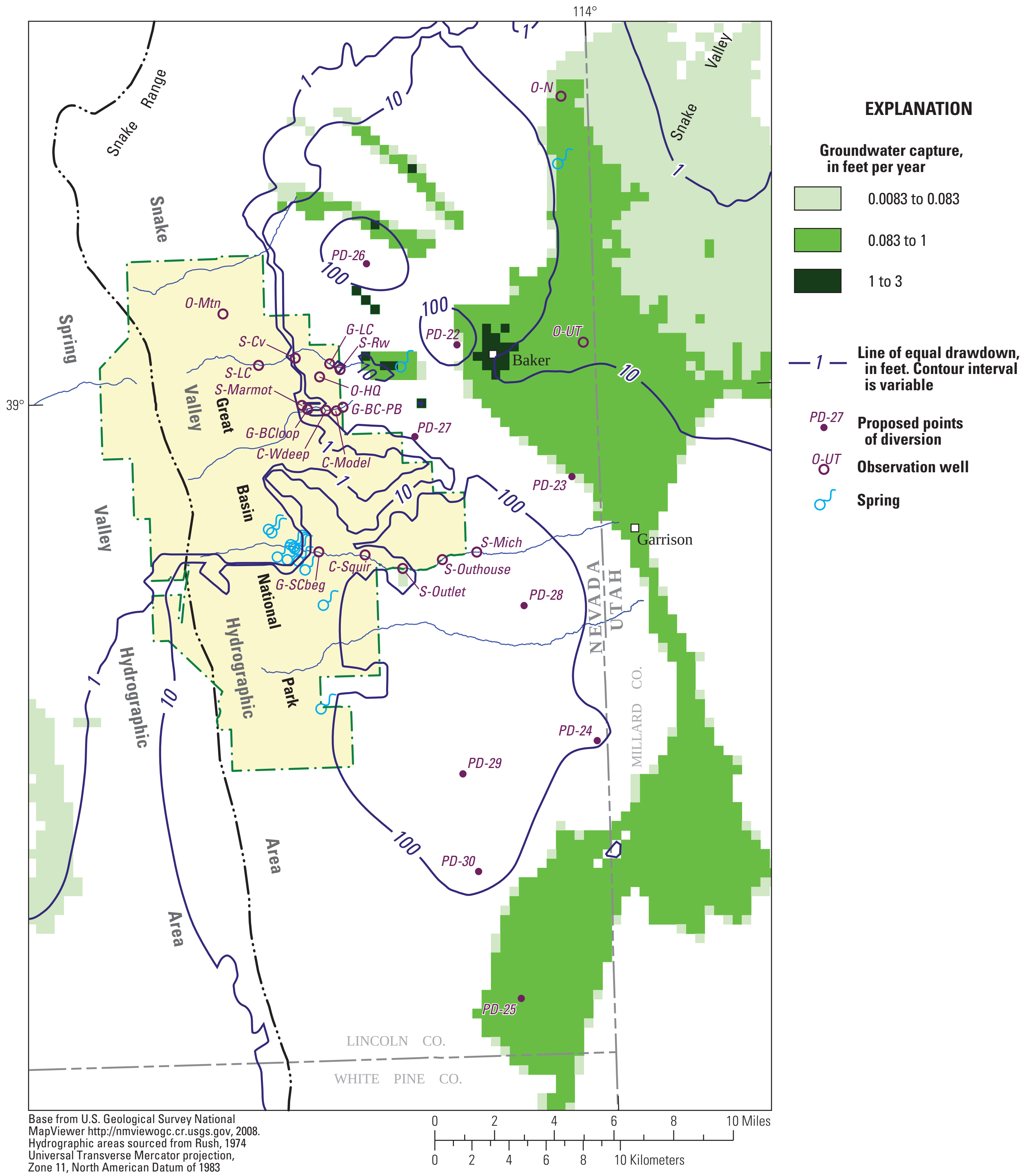


Figure 24. Simulated groundwater capture and drawdown in the area of interest, layer 1 after 200 years of pumping 40,000 acre-ft/yr from Snake Valley, Nevada and Utah.

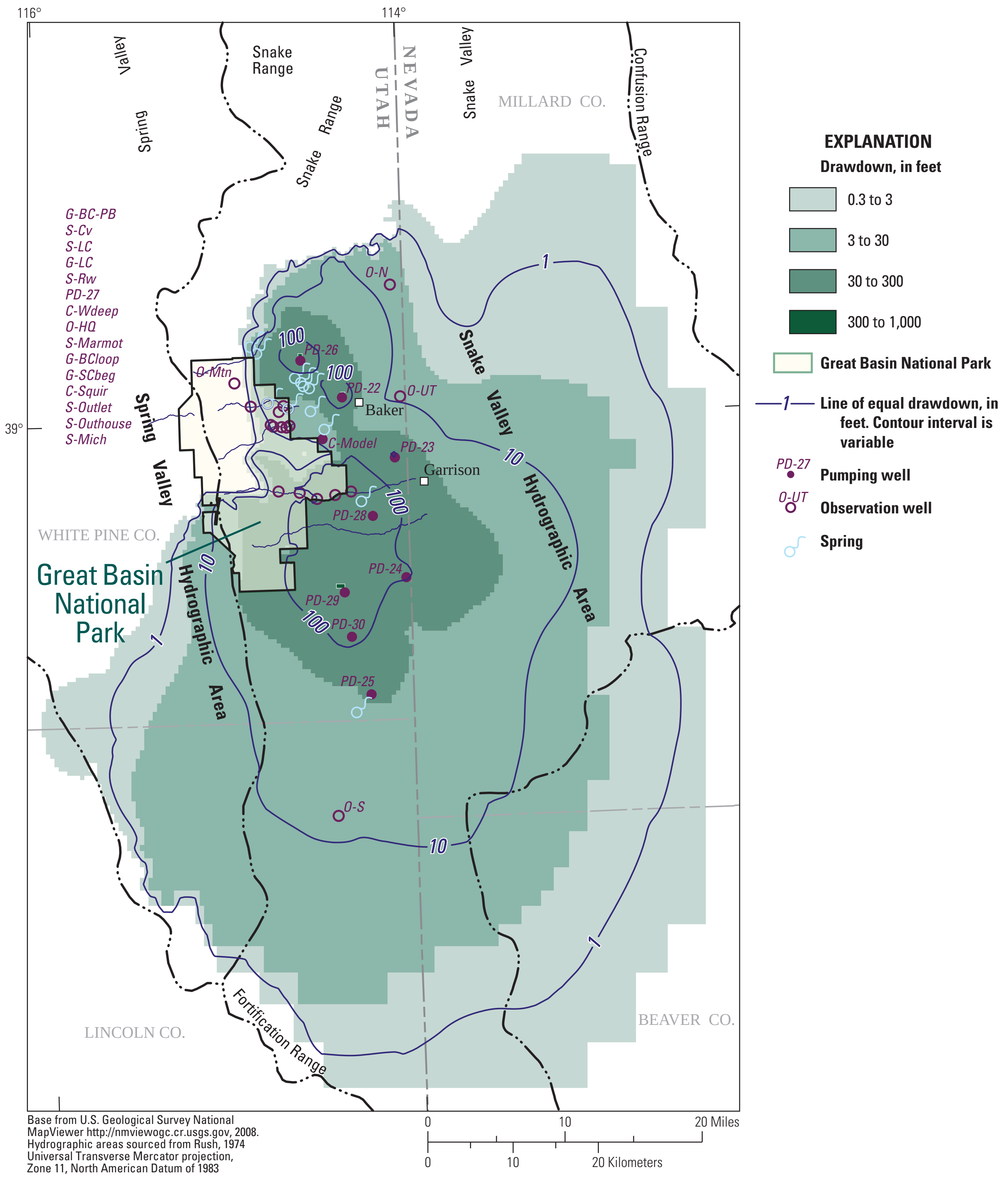


Figure 25. Simulated drawdown in Spring and Snake Valleys, model layer 4 after 200 years of pumping 40,000 acre-ft/yr from Snake Valley, Nevada and Utah.

Table 6. Proposed points of diversion and pumping rates for groundwater development scenarios in southern Snake Valley, Nevada and Utah.

[Easting and Northing are in Universal Transverse Mercator Projection, Zone 11, NAD 83. L suffix in scenario indicates drawdown limited in pumping wells. U suffix in scenario indicates drawdown unlimited in pumping wells. –, well not pumped]

Application Number, Nevada State Engineer	Proposed point of diversion	Easting, m	Northing, m	Groundwater development scenarios: Total annual pumpage specified, in acre-feet			
				10,000-L	25,000-L	50,000-L[1]	50,000-U
54022	PD-22	748,062	4,322,770	–	–	5,395	5,556
54023	PD-23	754,254	4,315,753	2,000	5,000	5,556	5,556
54024	PD-24	755,615	4,301,694	2,000	5,000	5,556	5,556
54025	PD-25	751,525	4,287,959	2,000	5,000	5,556	5,556
54026	PD-26	743,191	4,327,091	–	–	3,725	5,556
54027	PD-27	745,799	4,317,881	–	–	12	5,556
54028	PD-28	751,674	4,308,884	2,000	5,000	4,980	5,556
54029	PD-29	748,385	4,299,921	–	–	3,364	5,556
54030	PD-30	749,235	4,294,718	2,000	5,000	5,556	5,556
Total annual pumpage at end of scenario:				10,000	25,000	40,000	50,000

[1]Annual pumped volumes of less than 5,000 acre-feet were constrained by a maximum drawdown of 1,000 feet in the pumping well.

Drawdown and discharge time series from 4 of 16 wells can be displayed simultaneously for the 200-year simulation period of a scenario (fig. 26; appendix F). All user-defined options are cells in the spreadsheet shown in figure 26 that are shaded gray. Drawdown or discharge is selected in row 27 and wells are selected in row 28. Discharges can be reported in units of cubic feet per day (CFD), acre-feet per year (ACRE-FT/YR), cubic feet per second (CFS), or gallons per minute (GPM) by selecting units in cell C25. Pumping scenarios: 10,000 acre-ft/yr, Limited (10K-L); 25,000 acre-ft/yr, Limited (25K-L); 50,000 acre-ft/yr, Limited (50K-L); and 50,000 acre-ft/yr, Unlimited (50K-U) are selected in cell E25. The same scenarios where 19,000 acre-ft/yr of irrigation also is simulated are identified as 10K-L+IRR, 25K-L+IRR, 50K-L+IRR, and 50K-U+IRR, respectively.

Simulated discharge reduction from selected control volumes and springs is the sum of all external sources and sinks in a control volume (appendix G, table 3). Discharge reduction from springs is the sum of well and drain packages in a flow-model cell, which is a control volume. Discharge reduction from 4 of 44 springs or control volumes can be displayed simultaneously for the 200-year simulation period of a scenario (fig. 27; appendix G). All user-defined options are spreadsheet cells that are shaded gray. Springs or control volumes are selected in row 27 (fig. 27). Simulated discharge reductions can be reported in units of cubic feet per day (CFD), acre-feet per year (ACRE-FT/YR), cubic feet per second (CFS), or gallons per minute (GPM) by selecting units in cell C25. Pumping scenarios: 10,000 acre-ft/yr, Limited (10K-L); 25,000 acre-ft/yr, Limited (25K-L); 50,000 acre-ft/yr, Limited (50K-L); and 50,000 acre-ft/yr, Unlimited (50K-U) are selected in cell E25. The same scenarios where 19,000 acre-ft/yr of irrigation also is simulated are identified as 10K-L+IRR, 25K-L+IRR, 50K-L+IRR, and 50K-U+IRR, respectively.

Additional simulations can be tested by downloading the GBNP-C and GBNP-P models and selected supporting files (appendix H). All MODFLOW files and supporting utilities are in the zipped file, GBNP-USGS.zip. The supporting utilities are batch files, FORTRAN programs, and macros in Microsoft© Excel workbooks. The zip file contains subfolders for the geologic framework, FORTRAN programs, the calibration model (GBNP-C), the predictive model (GBNP-P) without existing irrigation, the predictive model (GBNP-P) with existing irrigation, and PostScript mapping instructions.

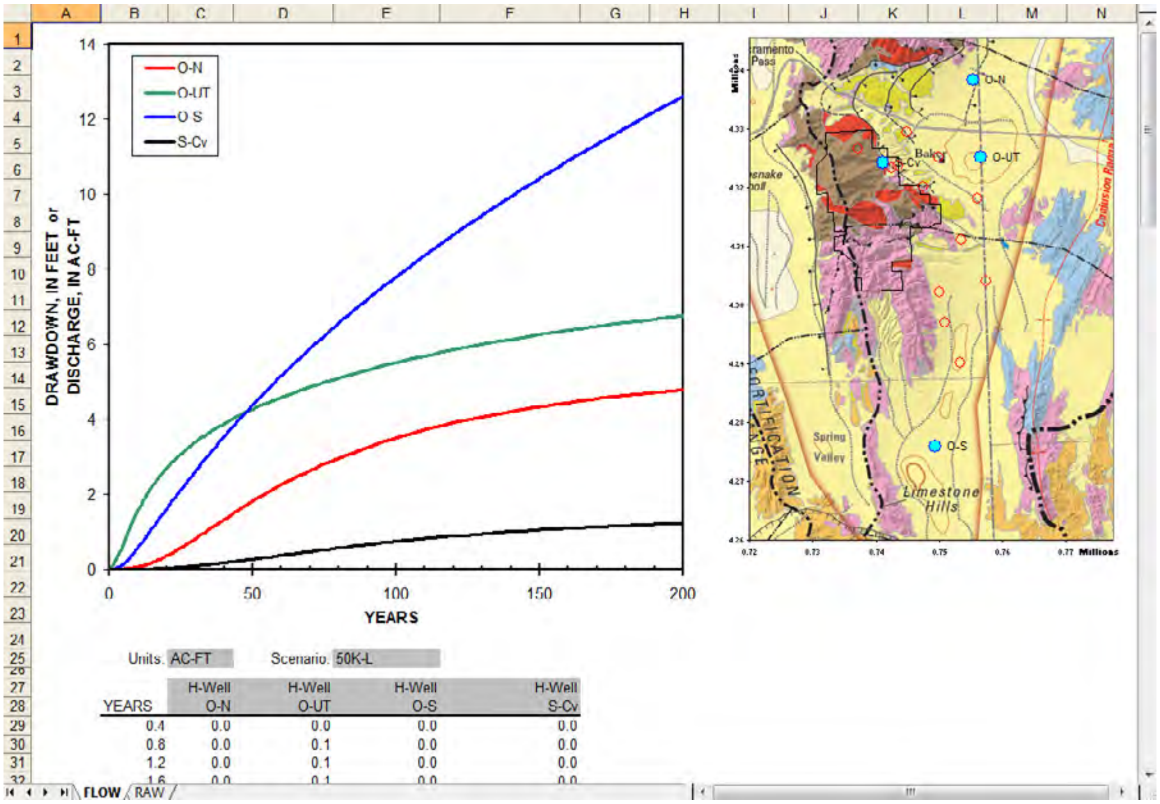


Figure 26. Example of drawdown and discharge time series from selected wells and observation points in Snake Valley east of Great Basin National Park.

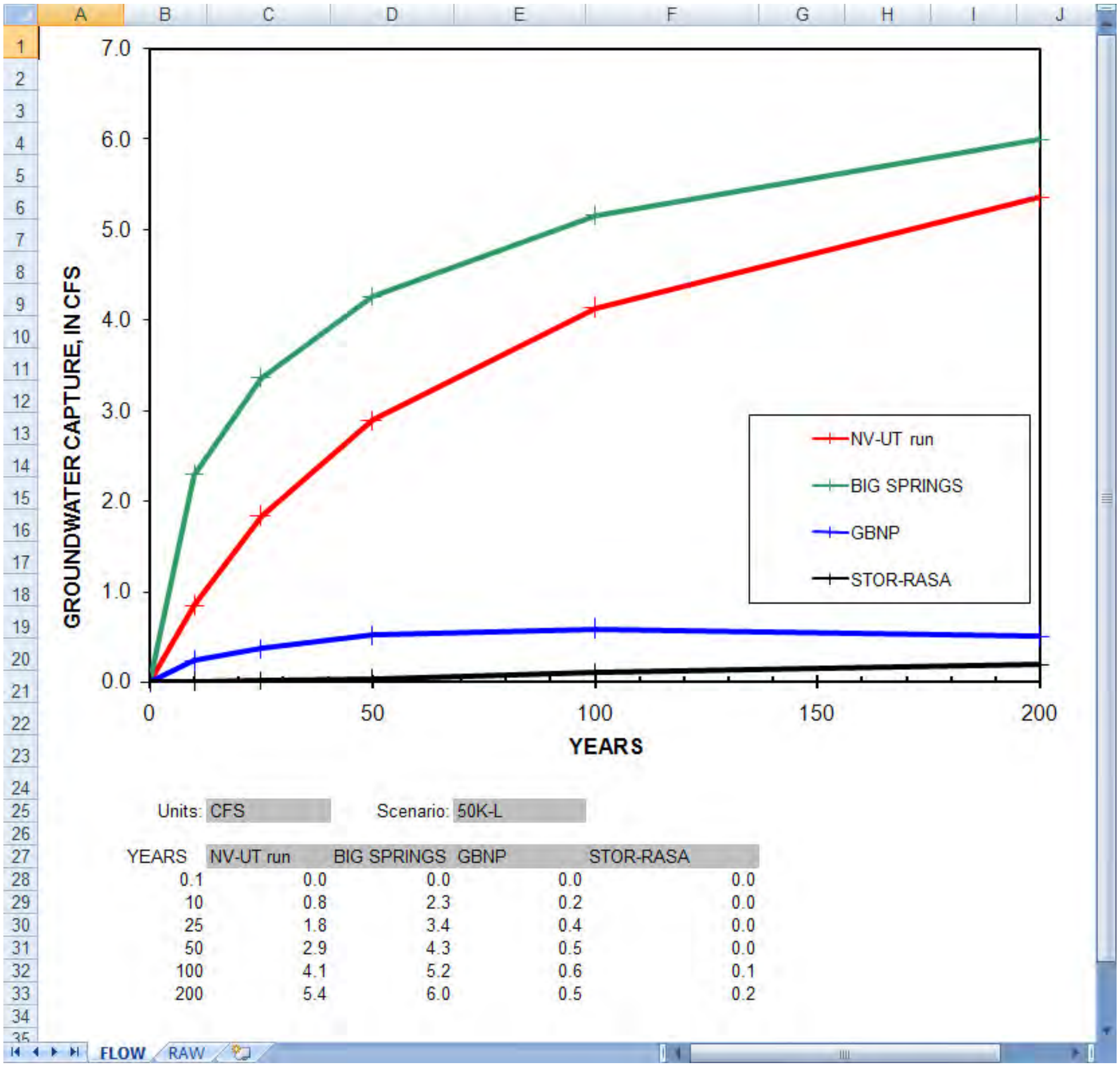


Figure 27. Example from appendix G of simulated reduction in spring discharges and capture from selected areas.

Model Limitations

The flow model addresses questions about regional groundwater flow and groundwater development in Spring and Snake Valleys, but cannot mimic exactly the actual system. This model, or any other model, is limited by simplification of the conceptual model, discretization effects, and difficulty in obtaining sufficient measurements to account for all spatial variation in hydraulic properties throughout the model area.

Measured groundwater levels and discharges were not matched perfectly by simulated observations, even after calibration, because errors cumulatively affect model results. These irreducible errors result from simplification of the conceptual model, grid scale, and insufficient measurements.

Lateral discretization of the study area into a rectangular grid of cells and vertical discretization into layers forced an averaging of hydraulic properties. Each cell represents a homogeneous block or some volumetric average of the aquifer medium. Discretization errors occurred in every model cell, which includes the smallest model cells. Bedding structures in the alluvium and fracture networks in the bedrock were averaged in these small cells that were 1,640 ft on a side and 10 ft thick. Flow paths are averaged over lengths of about 0.5 mi due to the averaging of the hydraulic properties.

The extent of drawdown predictions easily can be displaced 0.5 mi along the contact between basin fill and low permeability bedrock. These are areas where drawdown changes from less than 1 ft to more than 10 ft across distances of 0.5 mi or less (appendix E). A minimum uncertainty of 1,640 ft exists because of discretization errors. Projection of the mapped surface geology to the water table also contributed to uncertainty where the contact between basin fill and low permeability bedrock occurs in the saturated groundwater-flow system.

Errors in hydraulic diffusivity inversely affect the timing of groundwater capture. Hydraulic diffusivity is transmissivity divided by storage coefficient, which functionally is specific yield for unconfined aquifer conditions. Groundwater capture will occur sooner as hydraulic diffusivity increases and will be delayed as hydraulic diffusivity decreases. Errors in hydraulic-diffusivity estimates of 50 percent in the GBNP-P model are not unexpected so 50-percent errors in timing of groundwater-capture estimates can occur.

Drawdown and groundwater capture predictions will differ if recharge changes. Water levels will decline further than predicted if recharge decreases. For example, a 10 percent decrease in recharge would cause simulated water levels to decline 5 ft near Rowland Spring after 20 years. Water-level declines occur less quickly away from the recharge areas. Simulated water levels near Baker, Nevada, decline less than 5 ft, 200 years after decreasing recharge by 10 percent.

Transmissivity estimates likely are affected by compensating errors along the periphery of Spring and Snake Valleys. This is because these values contact the assigned hydraulic properties from the supporting RASA model outside of Spring and Snake Valleys. Compensating errors have a greater potential to affect results along the Confusion Range where transmissivity estimates exceed 10,000 ft^2/d east of Snake Valley.

Summary

The National Park Service needs estimates of the potential effects of pumping from Snake Valley on springs, streams, and water levels in caves in and adjacent to Great Basin National Park. Understanding potential effects of pumping groundwater from Snake Valley is important because groundwater discharge to springs or streams in ecologically sensitive areas may be captured. The hydrologic effects of developing groundwater supplies are assessed using numerical, groundwater-flow models to estimate the timing and magnitude of capture from streams, springs, wetlands, phreatophytic plants, and water-table decline.

The study area was the 100,000 mi^2 carbonate-rock province of the Great Basin that was simulated previously for the Regional Aquifer-System Analysis, RASA Program of the Great Basin. The study area was much greater than Spring and Snake Valleys because pumping effects can propagate across multiple basins in the carbonate-rock province. Aquifers in the study area are basin fill and carbonate rock.

Spring and Snake Valleys are deep structural basins comprising carbonate and siliciclastic sedimentary rocks of Paleozoic age and igneous intrusive rocks of Jurassic to Tertiary age. Basin-fill deposits of Tertiary and Quaternary age and volcanic rocks of Tertiary age have accumulated in these structural basins, reaching thicknesses of more than 1 mile. Siliciclastic sedimentary rocks of Cambrian and older age and granitic rocks of Jurassic to Tertiary age are grouped together as a single hydrogeologic unit because both have low permeability. The thick sequences of basin-fill deposits and carbonate rocks can be very permeable and function as regional aquifers. Groundwater flow through basin fill occurs at depths shallower than 2,000 ft in Snake Valley because deeper sediments predominantly are clay and evaporite deposits as encountered in oil-well logs.

Transmissivity and specific yield of basin-fill and carbonate-rock aquifers were estimated from aquifer tests in Lake, Spring, and Snake Valleys. Transmissivity of the basin fill ranged from 1,200 to 12,000 ft^2/d where basin-fill thickness exceeded 1,000 ft. Transmissivity of the carbonate rocks ranged from 10,000 to 55,000 ft^2/d. Specific yield of the carbonate-rock and basin-fill aquifers averaged 2 and 15 percent, respectively.

The hydraulic conductivity of basin fill and transmissivity of basement-rock distributions in Spring and Snake Valleys were refined by calibrating a steady-state, three-dimensional, numerical groundwater-flow model of the carbonate-rock province to predevelopment conditions. Hydraulic properties and boundary conditions were defined primarily from the RASA model except in Spring and Snake Valleys. This locally refined model was referred to as the Great Basin National Park calibration or GBNP-C model. Groundwater flow through the study area was simulated with a 4-layer, finite-difference, MODFLOW model that extended from the water table to 2,000 ft below the water table in the basin fill.

Hydraulic conductivity and transmissivity were distributed throughout Spring and Snake Valleys with pilot points, which were mapped locations where hydraulic properties were assigned. Values at pilot points were interpolated to model cells with kriging in basin fill, basement rocks, and karst. Hydraulic conductivity of the basin fill was estimated because transmissivity is affected strongly by changes in saturated thickness near the edge of unconsolidated sediments. Transmissivity of the basement rocks was estimated because hydraulic conductivity is highly variable and thickness is correlated poorly with transmissivity. Continuity with the remainder of the RASA model area was maintained with additional pilot points that surrounded Spring and Snake Valleys.

Mountain-block and mountain-front recharges were distributed throughout Spring and Snake Valleys with pilot points and interpolated to model cells with kriging. Initial pilot-point values were sampled directly from the potential recharge distribution defined as annual precipitation in excess of 9.5 in.

Groundwater discharge from phreatophyte areas and springs was simulated as specified discharges in the GBNP-C model. Distributed groundwater-discharge estimates in Spring and Snake Valleys were specified directly from previous investigations. Spring discharges were specified at measured rates and sourced from model layers 2, 3, or 4. Groundwater discharge from the remainder of the GBNP-C model outside of Spring and Snake Valleys was simulated as specified in the original RASA model.

Recharge, hydraulic-conductivity, and transmissivity distributions of the GBNP-C model were estimated by minimizing a weighted composite, sum-of-squares objective function that included measurement and Tikhonov regularization observations. Measured water levels, simulated water levels from original RASA model, depth-to-water beneath distributed groundwater discharge and spring discharges, land-surface altitudes, spring discharge at Fish Springs, and changes in discharge on selected stream reaches were measurement observations. Tikhonov regularization observations were equations that defined preferred relations between the pilot points that defined recharge, hydraulic-conductivity, or transmissivity distributions. Ratios of initial recharge rates and homogeneity within simplified geologic classes were the preferred relations between pilot points. Regularization observations affected calibration most where the GBNP-C model was insensitive to measurement observations.

Simulated water levels compared favorably with target water levels and discharges for the model as a whole where the root mean square error for water levels was 39 ft. This error is small relative to the 5,400 ft range of measured water levels. Water-level residuals with absolute values greater than 50 ft were considered significant. Residuals were greatest where low permeability intrusive and volcanic rocks were simulated more accurately in Spring and Snake Valleys. Areas west of Spring Valley and surrounding southern Snake Valley were affected by a strong transmissivity contrast.

Transmissive structures were estimated consistently even though hydraulic property estimates at pilot points were non-unique. Areas of transmissivity in excess of 10,000 ft^2/d occurred along eastern Snake Valley and south of the Snake Range and persisted during all phases of model calibration. Simulated water levels were affected and flow was deflected from the east to the north by these structures.

The GBNP-C model simulated more groundwater flow through Spring and Snake Valleys than the original RASA model. This largely occurred because groundwater discharge from Spring and Snake Valleys in the GNBP-C model was 64,000 acre-ft/yr greater than in the RASA model. The GNBP-C model also simulated local flow in the mountain blocks that were not simulated by the RASA model. Simulated water budgets in the study area outside of Spring and Snake Valleys were similar in both the GNBP-C and RASA models.

The effects of uncertain distributed groundwater-discharge estimates in Spring and Snake Valleys on transmissivity estimates were bounded with alternative models. Specified annual distributed groundwater discharges from Spring and Snake Valleys simulated in the alternative models totaled 151,000 and 227,000 acre-ft. These were differences of 20 percent from the 187,000 acre-ft/yr specified in the calibrated GBNP-C model. Recharge changed about 10 percent more than changes in distributed groundwater discharge in the alternative models. Transmissivity estimates were minimally sensitive to groundwater-discharge estimates east of Great Basin National Park. Transmissivity estimates in the basin fill between Baker, Nevada, and Big Springs changed less than 50 percent between the two alternative models.

Potential effects of pumping from Snake Valley on springs, streams, and water levels in caves in and adjacent to Great Basin National Park were estimated with the Great Basin National Park predictive (GBNP-P) model. The GBNP-P model was a transient groundwater-flow model that simulated changes in groundwater storage. The hydraulic conductivity of basin fill and transmissivity of basement rock were the same distributions that were estimated with the GBNP-C model. Specific yields of 2 and 15 percent estimated from aquifer tests were specified for bedrock and basin fill, respectively, in the GBNP-P model based on surface geology. Groundwater capture and drawdown were simulated with a direct-drawdown approach in the GBNP-P model to reduce model complexity and uncertainty. Model input, other than the proposed pumpage, was limited to hydraulic-conductivity, transmissivity, specific yield, storage-coefficient, and groundwater-discharge distributions.

Capture of distributed groundwater and spring discharge were simulated in the GBNP-P model using a combination well and drain packages in MODFLOW. Maximum simulated groundwater capture was constrained by the mapped or measured distributed groundwater or spring discharge rates. Capture of discharge to streams in low permeability mountain blocks was simulated with specified heads set to zero.

Hydraulic property distributions from the alternative models were not considered because the range of pumping rates investigated was greater than transmissivity differences between alternative models. Specific yield was the significant component of groundwater storage in the GBNP-P model. Reasonable hydraulic-diffusivity estimates in Snake Valley south of U.S. Highway 50 could deviate from the assigned values in the GBNP-P model by as much as 50 percent.

Four groundwater-development scenarios were investigated where total annual withdrawals ranged from 10,000 to 50,000 acre-ft during a 200-year pumping period. Four additional scenarios also were simulated that added the effects of existing pumpage in Snake Valley. Potential groundwater withdrawal locations were limited to nine proposed points of diversion. Pumpage from the proposed points of diversion was distributed between 60 ft and 2,060 ft below the water table and the maximum drawdown was limited to 1,000 ft in three of four scenarios. Results from the GBNP-P model scenarios are presented as maps of groundwater capture and drawdown, time series of drawdowns and discharges from selected wells, and time series of discharge reductions from selected springs and control volumes.

Simulated drawdown propagation was attenuated where groundwater discharge could be captured. General patterns of groundwater capture and water-table declines were similar for all scenarios. Simulated drawdowns greater than 1 ft propagated outside of Spring and Snake Valleys after 200 years of pumping in all scenarios.

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Appendix A. Water-Level Observations

Observation wells, easting, northing, measured water levels, site identifier, local names, and identifier for PEST (Doherty, 2008a) are tabulated in a Microsoft© Excel workbook and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/.

Appendix B. Results from GBNP-C Model

Maps of calibrated recharge, hydraulic conductivity, and transmissivity distributions with pilot points and estimated values posted. Maps of calibrated, predevelopment water levels with measured water levels and residuals posted. These maps are available in PDF format and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/.

Appendix C. Residuals from GBNP-C Model

Residuals from water levels, evapotranspiration, land-surface altitude, and springs representative of predevelopment groundwater conditions are tabulated and can be displayed interactively from a Microsoft© Excel workbook and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/. The workbook is designed to view residuals by threshold values, layer, and observation type.

Appendix D. Pilot-Point Values for all Models

Pilot point name for PEST (Doherty, 2008a), easting, northing, model layer, thickness of cell with pilot point, type, lithology of cell for the GBNP-C, GBNP-LowET, and GBNP-HighET models are tabulated in a Microsoft© Excel workbook and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/. Pilot points are grouped by recharge, hydraulic conductivity, and transmissivity.

Appendix E. Predicted Drawdown Maps

Maps of drawdown and captured groundwater discharge from the four proposed development scenarios of pumping 10,000; 25,000; 40,000; and 50,000 acre-ft/yr. Maps are presented by model layer at 10, 25, 50, 100, and 200 years after pumping began for the four proposed development scenarios. These maps are available in PDF format and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/.

Appendix F. Predicted Time Series from Wells

Time series of drawdowns and discharges from selected wells are tabulated and can be displayed interactively from a Microsoft© Excel workbook and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/. The workbook is designed to simultaneously view as many as four time series.

Appendix G. Predicted Time Series from Springs

Time series of discharge reductions from selected springs and control volumes are tabulated and can be displayed interactively from a Microsoft© Excel workbook and can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/. The workbook is designed to simultaneously view as many as four time series.

Appendix H. MODFLOW Files and Supporting Utilities

All MODFLOW files and supporting utilities are in the zipped file, sir20115032_appH.zip can be accessed and downloaded at http://pubs.usgs.gov/sir/2011/5032/. The supporting utilities are batch files, FORTRAN programs, and macros in Microsoft© Excel workbooks. The zip file contains subfolders for the geologic framework, FORTRAN programs, the calibration model (GBNP-C), the predictive model (GBNP-P) without existing irrigation, the predictive model (GBNP-P) with existing irrigation, and PostScript mapping instructions. Contents of all subdirectories and necessary software are reported in README file in the root directory of the unzipped GBNP-USGS.zip file.

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Halford and Plume— **Potential Effects of Groundwater Pumping on Water Levels, Phreatophytes, and Spring Discharge, Spring and Snake Valleys, Nevada and Utah**—Scientific Investigations Report 2011–5032

ground water

Issue Paper/

Ground Water Development—The Time to Full Capture Problem

by J. Bredehoeft[1] and T. Durbin[2]

Abstract

Ground water systems can be categorized with respect to quantity into two groups: (1) those that will ultimately reach a new equilibrium state where pumping can be continued indefinitely and (2) those in which the stress is so large that a new equilibrium is impossible; hence, the system has a finite life. Large ground water systems, where a new equilibrium can be reached and in which the pumping is a long distance from boundaries where capture can occur, take long times to reach a new equilibrium. Some systems are so large that the new equilibrium will take a millennium or more to reach a new steady-state condition. These large systems pose a challenge to the water manager, especially when the water manager is committed to attempting to reach a new equilibrium state in which water levels will stabilize and the system can be maintained indefinitely.

Introduction

This article is an issue paper, a philosophical paper that expresses our viewpoint. A discussion of our perspective will provide a road map for readers. We are concerned with the management of ground water development; we restrict ourselves to water quantity—water quality is always an issue, but it is not our concern here.

Undeveloped ground water systems are commonly found in a state of equilibrium, where, on average, equal amounts of water are recharged and discharged. Ground water systems tend to filter out higher frequency fluctuations in weather; the larger the system, the more filtering it tends to provide. The base flow of streams reflects the effects of the ground water system as a filter. In other words, the larger the ground water system, the more the equilibrium between inflow and outflow reflects long-term averaging of fluctuations in weather. Our analyses generally assume that climate is stationary; if the climate is changing, as recent evidence suggests, then the assumption of equilibrium should be questioned.

Ground water development perturbs the natural equilibrium. We are assuming that a principal objective in managing ground water development is to extend the life of the development as long as is feasible. It is possible for some ground water developments to reach a new equilibrium that includes pumping—we assume that this is desirable from a management perspective. In the new equilibrium state, pumping can be continued indefinitely. In reaching the new equilibrium, the natural state will be perturbed—there will be inevitable impacts on the natural system. Society may decide that the impacts imposed in reaching the new equilibrium are too detrimental, and they may in some way constrain the development. Our focus in this paper is the length of time that some ground water systems take to transition to a new equilibrium state that includes pumping.

Hydrogeologists predict the response time of ground water systems using models. Models provide good predictions in the near field at early times. For example, pumping test analyses give good predictions on how to size the infrastructure, well dimensions, pump size, and so forth. As predictions extend in both time and space, they become more uncertain. Much has been written about this uncertainty. We use model predictions from field situations to illustrate some of our ideas; we are aware of the many pitfalls in modeling and the resulting uncertainty associated

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with predictions (Konikow and Bredehoeft 1992; Bredehoeft 2003, 2005). Nowhere in these discussions of uncertainty did the authors argue that the predictions are not useful. Quite the contrary, we argued that predictions were worthwhile but should be used with a full awareness of the difficulties and resulting uncertainties.

We use Nevada as a prototype for our discussion. Nevada ground water law codifies some of the basic principles of ground water hydrology; for this reason, it is a nice example. Hence, we illustrate our ideas with two examples from Nevada. The most recent example is the proposal by the Southern Nevada Water Authority (SNWA) to develop a large ground water supply in eastern Nevada. The proposed SNWA development is ongoing and in the news. We present model predictions of the proposed SNWA development as an illustration of the major point of our paper. We also discuss how the water manager, in this instance the Nevada State Engineer, dealt with the model prediction that a long time would be required to reach a new equilibrium that includes the proposed pumping.

Nevada, with a few exceptions, treats each individual valley as a legally distinct ground water system. Some of the valleys are hydrologically self-contained; others are integrated by the underlying Carbonate Aquifer that underlies the region. SNWA is seeking water rights in a number of valleys. Each of these valleys requires a separate hearing and ruling by the State Engineer—granting or denying applications to pump ground water. So far there have been two hearings and ruling by the State Engineer who provided SNWA with rights to pump in Spring Valley and more recently in Cave, Dry Lake, and Delamar valleys.

The Water Budget

Meinzer (1931) elaborated on the idea of the water budget to estimate the "safe yield" of aquifers. Meinzer was not the first to express these ideas; he refers back to the earlier work of C.H. Lee from 1908 to 1911 in Owens Valley, California. According to Meinzer (1931), "Before any large ground-water developments are made, the average rate of discharge for any long period is obviously equal to the average rate of recharge." This was obvious to Meinzer and presumably his colleagues in the ground water community of the day—we have yet to find who first stated this idea. The principle establishes the reciprocal relationship between recharge and discharge in the undeveloped state and allows us to measure one as a surrogate of the other. Meinzer went on to urge the periodic inventory of the system in order to establish the elements of the budget through time.

A budget is a static accounting of the state of the system at a given time, often before the system is developed. Meinzer's idea was that the amount that could be developed depended upon the quantity of discharge from that system that could be salvaged. Nevada water law codified this idea in their definition of perennial yield:

> *Perennial yield* of a ground-water reservoir may be defined as the maximum amount of ground water that can be salvaged each year over the long term without depleting the ground water reservoir. Perennial yield is ultimately limited to the maximum amount of the natural discharge that can be salvaged for beneficial use . . . .

It follows that:

$$R_0 = D_0 \tag{1}$$

where R_0 is the undeveloped recharge and D_0 is the undeveloped discharge. We can introduce pumping into this expression:

$$R_0 - (D_0 - \Delta D_0) - P = \mathrm{d}V/\mathrm{d}t \tag{2}$$

where ΔD_0 is the change in the discharge created by the pumping (the salvage or capture), P is the rate of pumping, and $\mathrm{d}V/\mathrm{d}t$ is the rate of change of ground water in storage in the system.

Meinzer and others recognized that water must be removed from storage before a new equilibrium state could be reached. Again, Nevada water law codified this storage:

> *Transitional storage reserve* is the quantity of water in storage in a particular ground water reservoir that is extracted during the transition period between natural equilibrium and new equilibrium conditions under the perennial yield concept of ground water development. . . . the transitional storage reserve of such a reservoir means the amount of stored water which is available for withdrawal by pumping during the non-equilibrium period of development (i.e., the period of lowering of water levels).

At the new equilibrium state, the water budget is as follows:

$$\mathrm{d}V/\mathrm{d}t = 0 \quad \text{(by definition)} \tag{3}$$

$$P = \Delta D_0, \quad \text{where } \Delta D_0 \leq D_0 \tag{4}$$

and we constrain the pumping to be less than or equal to the discharge in order to allow a new equilibrium. If we allow for pumping to induce recharge, then at the new equilibrium:

$$P = \Delta R_0 + \Delta D_0 \tag{5}$$

where ΔR_0 is the change in undeveloped recharge produced by the pumping, ΔD_0 is the change in recharge produced by the pumping, and $\Delta R_0 + \Delta D_0$ is defined as the *capture*.

Capture

Theis (1940) introduced the principle of capture. Later, the USGS in Lohman (1972) published the following definition of capture:

> Water withdrawn artificially from an aquifer is derived from a decrease in storage in the aquifer, a reduction in the previous discharge from the aquifer, an increase in recharge, or a combination of these changes. The decrease in discharge plus the increase in recharge is termed capture.

Capture is an all-important concept in managing ground water; a ground water system can only be maintained indefinitely if the pumping is equaled by the capture—a combined *decrease* in the undeveloped discharge and *increase* in undeveloped recharge. If pumping continually exceeds capture, then water levels in the system can never stabilize, and the system will continue to be depleted. In other words, if pumping exceeds the potential capture in the system, a new equilibrium state that includes the pumping can never be reached. Again, let us remind the reader that our focus in this discussion is ground water systems that, when developed, can be maintained indefinitely.

The water budget applies to the system at a given time—a snapshot in time. The usual practice is to calculate a budget for the undeveloped state and then for the final state when the system reaches the new equilibrium. In discussing the budget, or inventory idea, Meinzer (1931) drew the analogy to a surface water reservoir. One can pump anywhere from a surface water body and have a similar impact; however, where one pumps in a ground water system becomes important, as we show subsequently. While the water budget describes the state of the system at a given time, it does not inform us about the time path the system will take to reach the new equilibrium state; the time path depends upon aquifer dynamics. It should be remembered that in 1931, when Meinzer wrote his paper, Theis' (1935) seminal paper that presented a general transient ground water flow equation had not yet been published.

In 1931, hydrogeologists did not have the ability to predict the time to reach a new equilibrium state. However, we argue that the expectation of Meinzer's work, and the work of others, was that once pumping was introduced, a new equilibrium would be reached in a reasonable period of time. However, it takes some ground water systems an inordinately long period to reach a new equilibrium. The time may be so long that the fact that a new equilibrium eventually is reached becomes meaningless. It is this problem we address subsequently.

Aquifer Dynamics

Theis (1935) introduced time into ground water theory. This allowed hydrogeologists to make temporal predictions. Historically, the profession went through several phases of prediction. In the 1940s, well hydraulics blossomed. Led by Theis and Jacob, ground water hydrologists solved the boundary value problem associated with various conceptual models of the aquifer and the associated confining layers. The predictive capability associated with the solutions allowed hydrogeologists to estimate relevant parameters of the ground water system—transmissivity, storage coefficient, leakance of a confining layer, and so forth. Armed with a theoretical conceptual model, one could predict response to pumping, which in turn allowed for well design, the sizing of pumps, and well spacing, among other facets of development.

Hydrologists of the day also sought to investigate ground water systems; however, they recognized the limitations imposed by the theoretical approach. Bob Bennett and Herb Skibitski, working at the USGS in the 1950s, developed the resistor/capacitor network, analog model of ground water systems. This allowed the creation of analog models of field systems in which realistic boundary conditions and internally variable parameter distributions could be simulated. The USGS created an analog model laboratory in Phoenix in approximately 1960, where models were constructed and predictions made for several tens of ground water systems. Walton and Prickett (1963) created a similar laboratory at the Illinois State Water Survey where they built analog models of Illinois ground water systems.

By the late 1960s, digital computers had advanced to the point that realistic ground water models could be constructed and analyzed using digital methods (Pinder and Bredehoeft 1968). The technology for solving the resulting massive matrix inversion problems had been pioneered by petroleum reservoir engineers and applied mathematicians working for petroleum companies. Reservoir engineers are involved with solving the same basic flow equation that we use for ground water, and the techniques were readily adapted to ground water problems. Digital computers have become increasingly more powerful; as the computer advanced, so did the ground water modeling technology. One can now create very realistic ground water models on a PC. Techniques are available to optimize the parameter distributions within the models (Hill and Tiedeman 2007). Advances in technology now make it feasible to make predictions of the behavior of complex ground water systems. Predictions, even in the best-calibrated model, have an associated uncertainty. Our predictive capability has grown steadily since Theis (1935) used the analogy between the flow of ground water and the flow of heat and Jacob (1940), starting from first principles, showed that the analogy was correct. Hydrogeologists now routinely predict ground water system behavior.

The Time to Reach a New Equilibrium

Given our ability to predict, it is of interest how long it takes for a ground water system to reach a new equilibrium, assuming that a new equilibrium state is possible. One can envision ground water systems in which the pumping greatly exceeds any potential capture. In such an instance, the system can never reach a new equilibrium, and water levels within the system will continue to decline until the system is depleted. We are concerned here with systems in which a new equilibrium state is feasible—that is, pumping can ultimately be balanced by capture.

Hypothetical Basin- and Range-Valley-Fill Aquifer

We first examine a hypothetical system that resembles some of the valleys in the Basin and Range (Figure 1). The two streams entering the basin on the left provide on

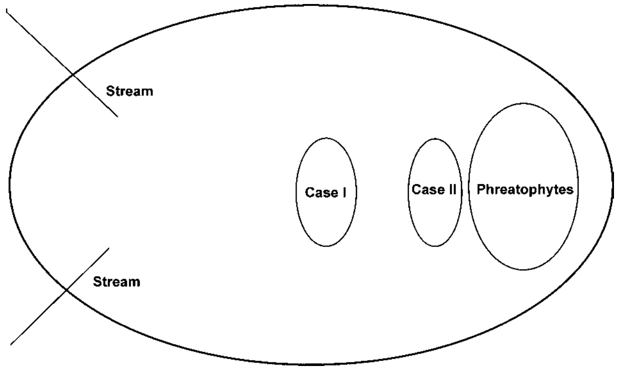

Figure 1. Plan view of a hypothetical valley-fill aquifer in the Basin and Range.

average 100 cubic feet per second (cfs) of recharge to the aquifer. The area of phreatophytes, to the right, discharges on average 100 cfs of ground water through evapotranspiration (ET) before ground water development. We consider two scenarios of ground water development located in the areas labeled case I and case II, respectively; each development pumps at a rate equal to the recharge—100 cfs.

We assume two-dimensional horizontal flow and the properties listed in Table 1. In our hypothetical system, we assume that ground water consumption by phreatophytes is diminished as pumping lowers the water table in the area containing phreatophytes. We deliberately created a ground water system in which capture of water that would otherwise be lost by ET can occur. As the water table drops between 1 and 5 feet, the consumption of ground water by ET is linearly reduced. The phreatophyte reduction function is applied to each cell in the model.

In order for this system to reach a new state of sustained yield, the phreatophyte consumption must be eliminated entirely. Using the model, we can examine the phreatophyte use as a function of time. Figure 2 is a plot of the phreatophyte use in our system vs. time since pumping was initiated. The location of the pumping makes a significant difference in the dynamic response of the system. In case II, where the pumping is close to the phreatophytes, the ET is reduced to 65 cfs in 10 years. In contrast, in case I, the ET is reduced to approximately 5 cfs in 10 years. Case I takes a long time to fully eliminate the ET; it is approximately 1000 years before the ET is totally eliminated. Even seasoned hydrologists are surprised at how long it can take an unconfined system to reach a new equilibrium state in which no more water is removed from storage.

We can also investigate the total amount of water removed from storage in our hypothetical valley-fill aquifer (Figure 3). It is important to notice that even though the two developments (case I and case II) are equal in size, the aquifer responds differently depending upon where the developments are sited. In case II, where the pumping is close to the phreatophytes, the amount of water removed from storage is approximately 50% less than that in case I. In case I, a large cone of depression must be created in order to impact the phreatophyte ET.

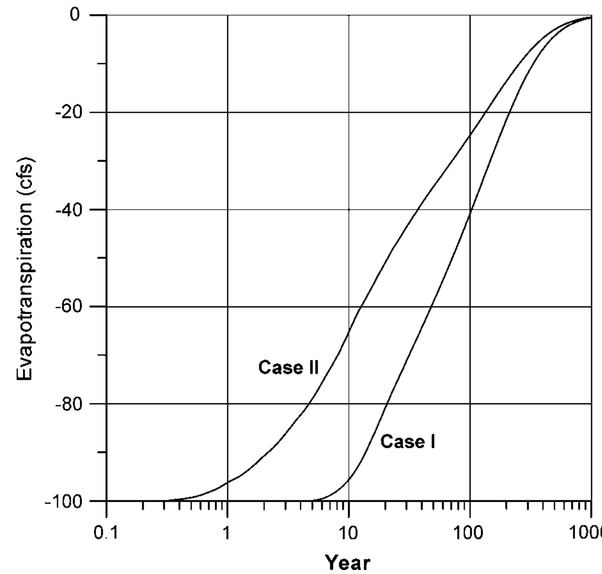

Figure 2. ET vs. time in our hypothetical valley-fill aquifer.

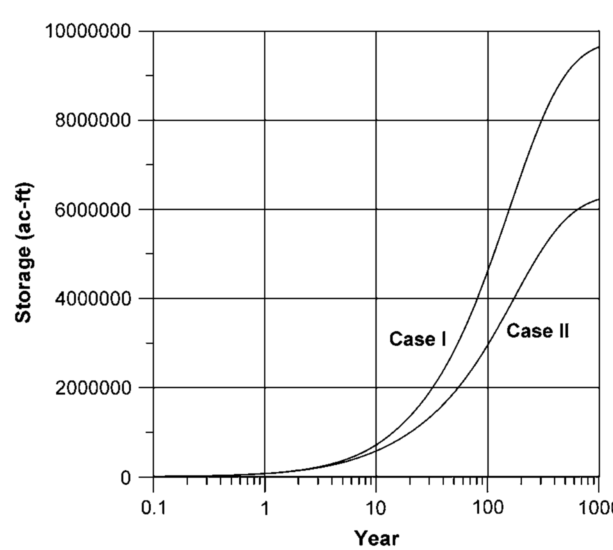

Figure 3. The volume of water removed from storage as a function of time in our hypothetical valley-fill aquifer with two developments—case I and case II (Figure 1).

Table 1
Aquifer Properties for Hypothetical Basin Shown in Figure 1

Basin size	50 × 25 miles
Model cell dimensions	1 × 1 mile
Hydraulic conductivity	0.00025 ft/s
Saturated thickness	2000 feet
Transmissivity	0.5 ft^2/s (~43,000 ft^2/d)
Storage coefficient	0.1%–10%
Phreatophyte consumption	100 cfs
Wellfield pumping	100 cfs
Recharge	100 cfs

This example of our rather simple Basin- and Range-valley-fill aquifer illustrates the importance of understanding the dynamics of aquifer systems. While this is a simple example, the principles illustrated apply to aquifers everywhere. In this case, it is the rate at which the phreatophyte consumption can be captured that determines how this system reaches sustainability; this is a dynamic process. Capture always involves the dynamics of the aquifer system. It makes a big difference in the response of the system where the wells are located. Thomas et al. (1989) describe the ground water hydrology of Smith Creek Valley, Nevada, where the USGS did a Regional Aquifer Systems Analysis (RASA) investigation; our simple example has many of the elements of Smith Creek Valley.

Paradise Valley

Alley and Leake (2003) explored the concept of "sustainability"; they used as their example a development in Paradise Valley in northern Nevada. The Humboldt River flows across the southern end of the valley. They used a model of ground water pumping near the southern end of the valley, not too far to the north of the Humboldt River, to examine the source of the ground water pumped vs. time (Figure 4). There are four sources of water that support the pumping: (1) water from storage; (2) capture of ET; (3) capture of surface water leaving the valley; and (4) induced recharge from the Humboldt River. Each of these sources varies with time.

The principal source of ground water in Paradise Valley during the early period is depletion of storage in the system. The storage declines to only 4% of the supply in year 300. The capture of water from ET grows from 20% in year 1 to approximately 75% of the total in year 300. The induced recharge from the Humboldt River grows from 0% in the early years to approximately 20% of the total in year 300. The capture of outflow from the valley grows to 3% in 300 years. The ground water system in Paradise Valley will take more than 300 years to reach a new equilibrium state. The time is about one-third as long as in case I in our hypothetical valley-fill aquifer explored earlier. Even after 300 years, 4% of the water pumped is still coming from storage.

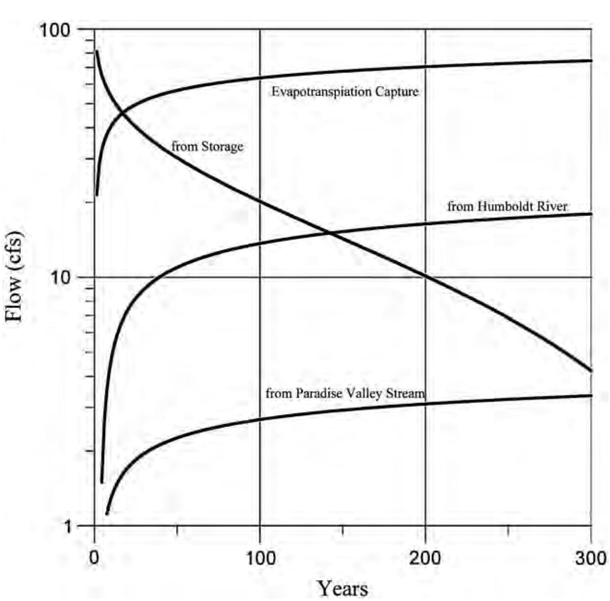

Figure 4. Computed sources of ground water to supply the pumping in Paradise Valley, Nevada (data from Alley and Leake 2003).

Both the induced recharge from the Humboldt River and the reduced outflow from the valley decrease the streamflow of the Humboldt River. This poses a potential future problem since the surface water in the Humboldt River, like most streams in the West, is overappropriated. Downstream surface water users will be hurt as this ground water development goes forward. An investigation of the undeveloped water budget for Paradise Valley would not have indicated induced recharge from the Humboldt River to be a significant source of water to the wells.

SNWA Development

The SNWA is proposing to pump 170,000 acre-feet/year of ground water just to the south of Ely, Nevada—approximately 200 miles north of Las Vegas. The water will be conveyed, via a pipeline, to Las Vegas. This will increase the water supply for Las Vegas by perhaps 40%; the fraction depends upon how much water is available in the future for Las Vegas from the Colorado River. The cost of the pipeline is currently estimated to be more than $3.5 billion.

The area under consideration for development is within the Carbonate Rock Province as defined by the USGS RASA investigation (Prudic et al. 1995), where there is a thick sequence of Paleozoic carbonate rocks. This sequence of rocks usually contains a Carbonate Aquifer that has the potential to integrate ground water flow between the valleys in the area (Eakin 1966). Analyzing ground water flow in this system entails investigating a much larger set of valleys than simply those that contain the pumping. The proposed SNWA pumping is situated mostly within the White River Regional Flow System (Figure 5).

There are several estimates of the recharge and/or discharge for portions of the ground water system pictured in Figure 5 (Eakin 1966; Las Vegas Valley Water District 2001; Welch and Bright 2007). A USGS RASA study of the system indicated that the pumping would reach a new steady state (Schaefer and Harrill 1995). The RASA, while calculating the impacts of a new equilibrium that included the pumping, did not estimate the time to reach the new state, other than to indicate that it was more than 200 years.

We realize that uncertainties associated with models and model predictions place confidence bounds around predicted values. However, we present single-valued graphs of predicted results to illustrate our points; we recognize that this oversimplifies the results. Figure 6 is a model prediction of the expected drawdown of the water table at the new equilibrium state that includes the

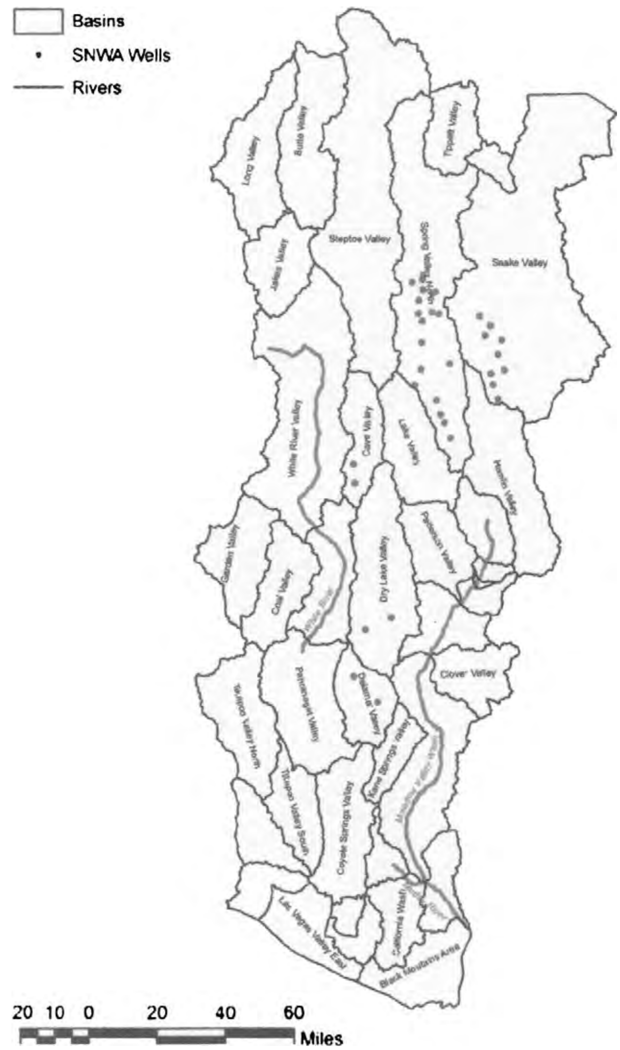

Figure 5. Map of the valleys in Nevada impacted by the proposed SNWA development. The proposed pumping wells are indicated.

proposed SNWA pumping. There is a very large area where the drawdown exceeds 700 feet. The deeper Carbonate Aquifer has similar drawdowns. Of particular interest is how long this system takes to reach the new equilibrium. Figure 7 is a plot of the change in storage in the system vs. time.

This figure is especially telling. The storage should level out and reach a stable level as the system reaches a new equilibrium (as in Figure 3), but this system is not close to reaching a new equilibrium state after 2000 years of projected pumping. A plot of the predicted ET vs. time (Figure 8) shows that the system has not reached a new equilibrium in 2000 years.

Combining Figures 7 and 8, we see that at 500 years, approximately 32% of the water pumped is coming from the depletion of storage and 65% from capture of ET. At 1000 years, 23% is coming from storage and 74% from capture of ET. At 2000 years, 14% is still coming from storage, while 82% is from capture of ET.

Nevada water law has only an implied reference to time; it only requires that the system reaches a new equilibrium state at some undetermined future time. The law was written before the tools were available to predict the future dynamics of ground water developments. The fact that the model predicts times more than 2000 years to reach a new equilibrium should change one's perspective on ground water management of this system.

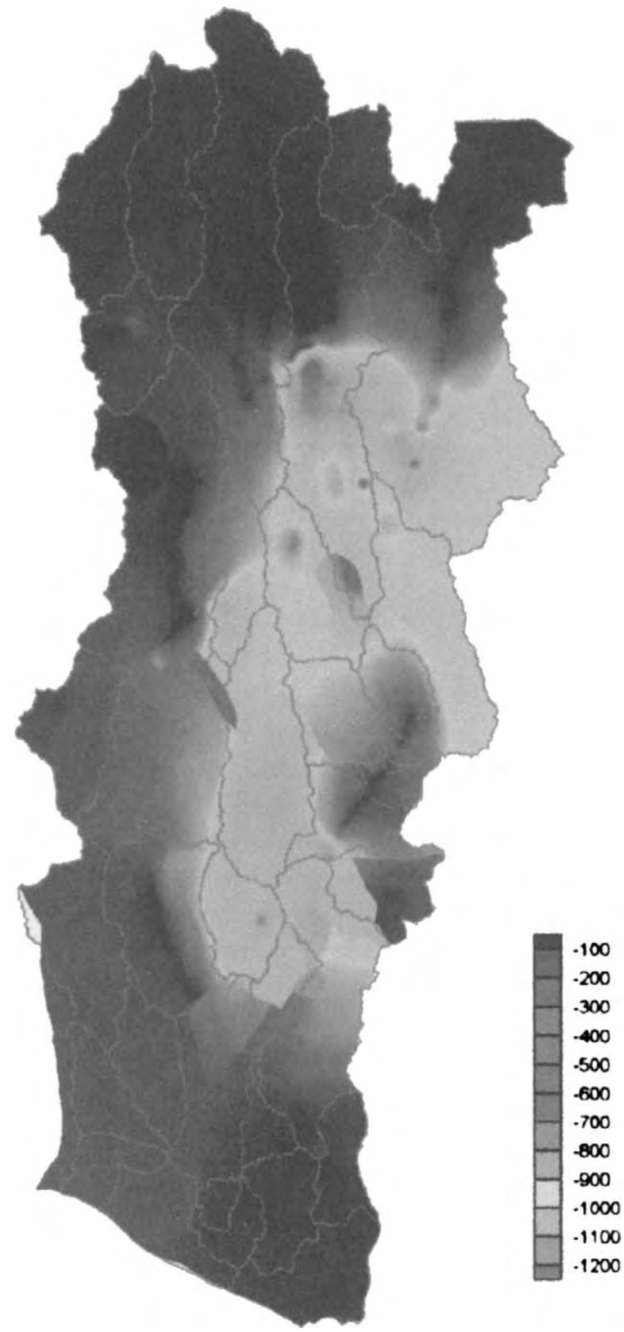

Figure 6. Computed expected drawdown in the water table at the new equilibrium state that includes the proposed SNWA pumping—predicted steady-state model.

Monitoring to Control Impacts

A strategy known as adaptive management relies on preventing impacts by monitoring the ground water

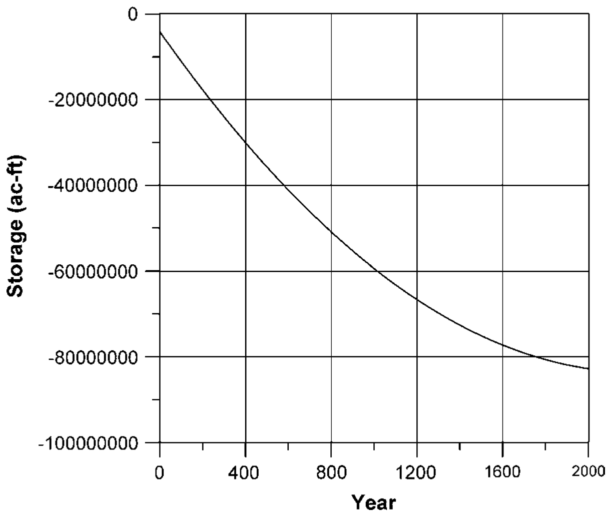

Figure 7. Predicted change in storage with proposed SNWA pumping.

system and changing the pumping stress when an undesirable impact is observed. The federal government entered into such agreements with SNWA before withdrawing their objections to the project. However, long-term monitoring also suffers from a prediction problem associated with the response time of the ground water system. We illustrate the monitoring problem with our hypothetical aquifer (Figure 1). We will examine a situation where we are attempting to maintain a spring at the lower end of our valley. Let us imagine that rather than having an area of phreatophytes discharging ground water, we have a single spring that discharges at 100 cfs before development. Our objective is to maintain the spring flow. We now start the case I ground water development that also pumps at 100 cfs.

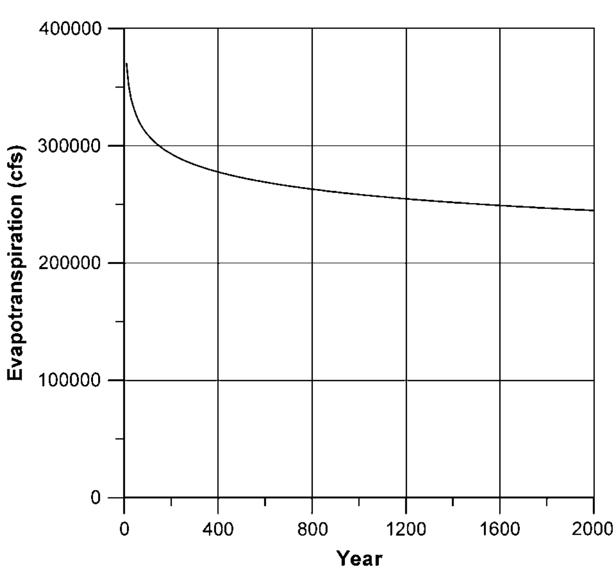

Figure 8. Computed plot of ET vs. time.

Let us further suppose we impose a monitoring and control strategy on the system. We monitor the spring with the intent that once the spring flow drops below 90 cfs (a 10% decline in flow), we will stop pumping ground water; in other words, our intent (as stated earlier) is to preserve the spring flow. We will use a 10% drop in flow as an observable signal that indicates that pumping is impacting the spring; smaller drops in flow could be ambiguous. (We are not arguing that this is a rational policy; rather we are illustrating a point.) Figure 9 shows the discharge of our spring vs. time; pumping stopped in area 1 in approximately 50 years when the spring discharge dropped to 90 cfs. The minimum spring flow occurs at approximately 75 years, 25 years after we stopped pumping. The reduction in flow is 13 cfs—larger than what it was when we stopped pumping. The maximum drawdown at the spring, created by the pumping, takes 25 years after pumping stops to work its way through the system.

We also see that the system does not recover readily to its predevelopment state even though the spring discharge equaled the recharge and was 100 cfs. Perhaps this is best understood if we look at the water removed from storage by the pumping and the rate at which it is replenished. During the period of pumping, the spring flow drops more or less linearly from 100 to 90 cfs. The amount of water removed from storage during this period averages approximately 95 cfs. The reduction in spring discharge averaged 5 cfs over the 50-year period—the capture of spring discharge averaged 5 cfs over the period. In other words, 95% of the ground water pumped during the 50 years of pumping came from storage. During the remaining 250 years since pumping stopped, the spring discharge averaged approximately 90 cfs. During that period, we are putting back in storage, on average, 10 cfs. This means that during the 250 years since the pumping ceased, we have restored just more than 50% of the water that was removed from the storage during the pumping period. You can easily see that this simple system will take approximately 500 years to return to its original state.

This hypothetical model illustrates the monitoring problem. If the monitoring point is some distance removed from the pumping, there will be (1) a time lag between the maximum impact and the stopping of pumping and (2) the maximum impact will be greater than what is observed when pumping is stopped (unless one has reached a new equilibrium state during the pumping period). The time for full recovery of the system will be long, even in the case where one has not reached the new equilibrium.

The real world is more complex. Those that advocate monitoring seldom envision totally stopping the pumping; rather, they imagine changes in the development that minimize damages. Stopping the pumping is a management action of last resort and we showed that it has problems. Less stringent management actions have a correspondingly lesser beneficial impact and even more problems.

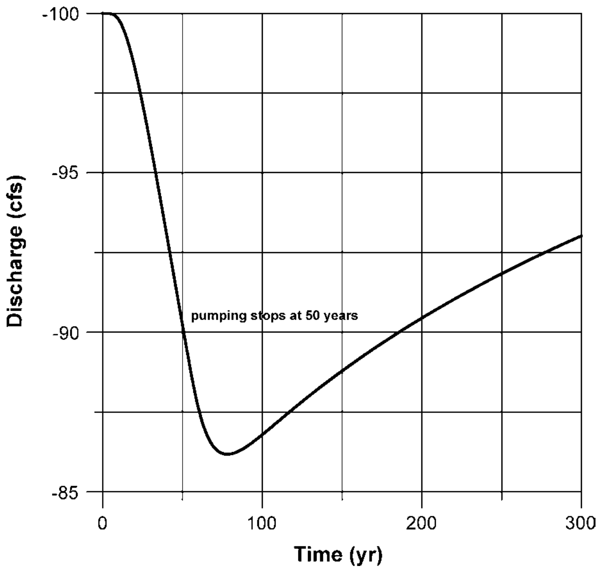

Figure 9. Predicted spring flow from a hypothetical aquifer (Figure 1 with phreatophytes in area 1 replaced by a spring). Pumping ceases after 50 years when the spring flow drops to 90 cfs.

Discussion

We do not think that the SNWA development in Nevada is all that unique nor do we think that this is typically only a western problem. Large aquifer systems exist throughout the country and the world. The response time problem is typical of large systems; there are other developments where the hydrologic boundaries where capture can take place are far from the pumping. Long times will be involved before the system can reach a new equilibrium—assuming that a new equilibrium is feasible. When the time to reach, or even approach, a new equilibrium exceeds a millennium or more, one has to ask—"Is the fact that the system will ultimately reach a new equilibrium meaningful?" It may be too distant in the future to have much meaning—too much can happen, civilizations change, the climate itself may change, and so forth. The bottom line is—it is important to predict the time trajectory of ground water systems, especially if one hopes to manage the system. Hydrogeologists have the tools to make these predictions.

The more vexing problem faces the water managers. For example, the SNWA development in Nevada can, given thousands of years, reach a new equilibrium. The question for the water manger, in this case the State Engineer, is how to deal with a system that takes so long to reach the new state—clearly, the law did not anticipate such long times.

Monitoring for control also has fundamental problems. The maximum impacts are larger than those observed at the time pumping stops, and they occur some time after the pumping stops. This is especially true if the monitoring is some distance away from the pumping. In addition, ground water systems will be very slow to recover to their predevelopment state once pumping is stopped.

In the case of SNWA's recent applications to pump in Cave, Dry Lake, and Delamar valleys, the Nevada State Engineer (2008) dealt with the problem as follows:

> The State Engineer finds that there is no dispute that the basins of the White River Flow System are hydrologically connected, but that does not mean that isolated ground-water resources should never be developed. The State Engineer finds he has considered the hydrologic connection and is fully aware that there will eventually be some impact to down-gradient springs where water discharges from the carbonate-rock aquifer system, but the time frame for significant effects to occur is in the hundreds of years.

> The State Engineer finds that a monitoring-well network and surface-water flow measurements will be part of a comprehensive monitoring and mitigation plan that will be required as a condition of approval and will provide an early warning for potential impacts to existing rights within the subject basins and the down-gradient basins of White River Flow System. The State Engineer finds that if unreasonable impacts to existing rights occur, curtailment in pumping will be ordered unless impacts can be reasonably and timely mitigated.

Conclusions

Some ground water systems in which a new equilibrium state that includes pumping can be achieved may take a long time to reach the new equilibrium. This is especially true where the discharge from the system that can potentially be captured by the pumping is a long distance away from the pumping center. Such a system may take more than a millennium, some more than two millennia, to reach the new equilibrium state.

This can pose a problem for the water manager, especially if the manager seeks to achieve a new equilibrium that will allow the pumping to persist for a prolonged period—essentially indefinitely.

One strategy, adopted by the State Engineer in Nevada, is to allow a large amount of pumping, more that can be sustained by a new equilibrium, while monitoring the system for adverse impacts. This strategy poses two problems: (1) a large ground water system creates a delayed response between the observation of an impact and its maximum effect and (2) there is a long time lag between changing the stress and observing an impact at a distant boundary.

If a water manager allows more pumping than the pumping can capture, then sooner or later the pumping must be curtailed or a new equilibrium can never be reached and the system will be depleted.

Acknowledgments

The authors wish to thank the editor and reviewers for their helpful suggestions.

Disclaimer

In fairness to the reader, we need to state that both authors of this paper acted as consultants on issues related to proposed ground water development in eastern Nevada. We consulted on opposing sides—Durbin for SNWA and Bredehoeft for the environmental coalition that opposes the development. Durbin's model of the proposed development for SNWA was documented, including its calibration, in a public document presented to the Nevada State Engineer at a hearing on SNWA's application for permits to pump ground water in Spring Valley, Nevada. Both authors presented the results of Durbin's model analysis in a public statement to the Nevada State Engineer at a hearing on SNWA's application to pump ground water in Cave, Dry Lake, and Delamar valleys, Nevada. The results are presented here as an example of model predictions; the predictions reflect all the caveats stated earlier.

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