As of: 11/20/15 1:58 PM
Received: November 18, 2015
Status: Pending_Post
Tracking No. 1jz-8mbz-8h8g
Comments Due: November 20, 2015
Submission Type: Web

PUBLIC SUBMISSION

Docket: NRC-2015-0051
Department of Energy; Yucca Mountain, Nye County, Nevada; Supplemental Environmental Impact Statement

Comment On: NRC-2015-0051-0004
Department of Energy; Yucca Mountain, Nye County, Nevada; Correction and Extension of Comment Period

Document: NRC-2015-0051-DRAFT-0053
Comment on FR Doc # 2015-23510

Submitter Information

8/21/2015
80 FR 50875
65

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General Comment

Inyo County Board of Supervisors' Comment Letter RE: U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain (Docket ID NRC-2015-0051)

Thank you for the opportunity to comment on the Supplement to the U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain. Please find the Inyo County Board of Supervisors' full comments attached, including the following documents:

1) Inyo County Board of Supervisors' Comment Letter re: U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain;

2) Attachment 1: Bredehoeft, John, NAE , and King, Michael, R.G., C.E.G., C.HG, Memorandum Research Program for Evaluation of Yucca Mountain Nuclear Waste Repository Site, October 10th, 2015; and,

3) Attachment 2: Andy Zdon and Associates, LLC, Technical Review Summary of the Draft Supplement To

SUNSI Review Complete
Template = ADM-013

E-RIDS= ADM-03
Add= C. Pineda (CCP4)

U.S. Department Of Energy's Environmental Impact Statement For The Proposed Nuclear Fuel And High-Level Radioactive Waste Repository At Yucca Mountain, Nevada, October 23, 2015 (including appendices A - E).

Attachments

InyoCountyBOSFinalSupplementalEISCommentLetter15

Attachment 1 Hydro Revised SEIS Memo_Final_w appendix

Attachment 2 Andy Zdon and Associates Yucca Mtn Technical Review Summary

Andy Zdon Inc Appendix A

Andy Zdon Inc Appendix B part 1

Andy Zdon Inc Appendix B part 2

Andy Zdon Inc Appendix C

Andy Zdon Inc Appendix D

Andy Zdon INc Appendix E

BOARD OF SUPERVISORS
COUNTY OF INYO

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November 17, 2015

Cindy Bladey
Office of Administration
Mail Stop: OWFN-12-H08
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

RE: U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain

Docket ID NRC-2015-0051

Dear Ms. Bladey:

On behalf of the Inyo County Board of Supervisors, I thank you for the opportunity to comment on the Supplement to the U.S. Department of Energy's (DOE) Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain (SEIS). As an Affected Unit of Local Government, only a few miles down watershed from the proposed Yucca Mountain repository, the long-term health, safety and welfare of Inyo County residents is our highest concern, particularly in relation to potential contamination of ground water resources as a result of the proposed repository. We thank the Nuclear Regulatory Commission (NRC) for addressing the County's concerns regarding the Draft SEIS and the County's concerns regarding potential groundwater contamination from the proposed Repository.

NRC's National Environmental Protection Act (NEPA) regulations (10 CFR § 51.109(c)(2)) provide that it will not be practicable to adopt any EIS prepared by DOE for a geologic repository if there is "significant and substantial new information or new considerations [that would] render such environmental impact statement inadequate." As identified in these comments, such new information exists and should be analyzed in the SEIS. In addition, we believe that the final SEIS should address mitigation, remediation and groundwater monitoring to ensure that any contaminants from the repository that enter the groundwater system are detected and that the impacts, should such contamination be detected, are mitigated.

The Adoption Determination Report prepared by the NRC for the DOE's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain (EIS) noted that the previous EISs did not provide a complete and adequate discussion of the impacts on soils and surface materials from a potential future discharge of contaminated groundwater, and specifically noted the following items should be addressed:

- NRC Item #1 - "A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods;
- NRC Item #2 - A description of the physical processes at the surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants; and,
- NRC Item #3 - Estimates of the amount of contaminants that could be deposited at or near the surface. This involves estimates of the amount of groundwater involved in discharge or near-surface evaporation, the amounts of radiological and non-radiological contaminants in that water, contaminant concentrations in the resulting deposits, and potential environmental impacts (e.g. effects on biota)."

Additionally, Inyo County raised the following concerns with regard to the previous EISs:

- Inyo Item #1 - The full extent of the lower carbonate aquifer, particularly those parts that could become contaminated and how water can leave the flow system should be described;
- Inyo Item #2 - The potential for a decrease or elimination of the upward vertical gradient beneath Yucca Mountain due to proposed future up-gradient groundwater pumping and export by the Southern Nevada Water Authority;
- Inyo Item #3 - Impacts to Endangered Species that are dependent on the springs in the region; and,
- Inyo Item #4 - Cleanup and remediation measures should be described.

Inyo County has reviewed the SEIS in collaboration with two hydrogeologist consultants, Hydrodynamics and Andy Zdon and Associates, Inc, both of whom have extensive expertise in the proposed Yucca Mountain Nuclear Repository environmental analysis completed to date, with particular emphasis on the Death Valley Regional Flow System Numerical Model (DVRFM) used to inform the EIS and SEIS. Attached hereto are the independent analyses of the SEIS prepared by each of the aforementioned consultants.

Hydrodynamics' general opinion is that both DOE and NRC have done a credible job of extending the analysis to the accessible environment as Hydrodynamics suggested in comments on the original environmental documents (see attached Memorandum). Their analysis incorporated Hydrodynamics published reports providing the results of the Lower Carbonate Aquifer (LCA) and Death Valley hydraulic studies submitted in prior comments. Hydrodynamics notes that the DOE and NRC analyses did not indicate additional problems that would make the repository more hazardous. The following key points can be made from Hydrodynamics' review.

- **Point 1**: DOE/NRC analysis suggested that pumping at Amargosa Farms would capture all of the potential contamination. When pumping was included, no contaminants made it to Death Valley. Continued pumping into the future is a reasonable assumption.

- **Point 2**: DOE/NRC analysis indicate that the upward hydraulic head gradient between the LCA and the overlying Tertiary aquifer is a barrier to radionuclide transport both in the area of the repository and in the Amargosa Farms area. Should pumping stop at the Amargosa Farms or the upward gradient be degraded and contaminants migrate to the Carbonate aquifer, radionuclide transport through the LCA into the Death Valley Furnace Creek springs will be relatively fast. The upward head gradient must be preserved into the future to protect the human and natural resources of Inyo County.

- **Point 3**: Hydrodynamics' estimate of discharge in the Furnace Creek area and the DOE's estimates do not match. However, DOE's evapotranspiration (ET) values used in the DVRFM were significantly larger then Hydrodynamics' values, and represent a worst case scenario for radionuclide transport.

- **Point 4**: DOE/NRC particle tracking and radionuclide dose models for the Death Valley Furnace Creek and lower section of Amargosa Valley areas are SMALL, and are well within EPA health standards.

- **Point 5**: DOE's FEIS does not provide a viable mitigation plan as required by the NEPA permitting process. A mitigation plan is completely absent from the NRC 2015 Supplement to DOE's EIS in a Draft Report for Comment.

Since 2010, Inyo County has worked in collaboration with the U.S. Bureau of Land Management, U.S. Geological Survey (USGS), Nye County, and other interested parties to conduct detailed and ongoing analysis of the DVRFM used to inform the EIS and SEIS. The results of these studies document substantive changes to the conceptual model presented in previous Yucca Mountain analyses by the U.S. Department of Energy and NRC. This important new work has not been considered and incorporated into the analysis presented in the SEIS. The new field work and analysis by the USGS and consultants in the Inyo County portion of the Amargosa Basin (Shoshone-Tecopa area specifically) affects the conceptual model for the Amargosa Desert – Ash Meadows area. The post-2010 field work and studies are discussed at length in the attached Andy Zdon and Associates study.

The SEIS states on page 2-6 that "[S]ome small portion of the groundwater flow from beneath Yucca Mountain may enter the Southern Death Valley Subregion to the south and east." The attached Andy Zdon and Associates report finds that by failing to consider existing conditions and post-2010 field work and analysis, the SEIS underestimates flow from the Amargosa Desert and Ash Meadows through the Amargosa River and the aquifer into Inyo County (particularly the Shoshone area). In addition, the report shows that the conceptual model as presented in the SEIS appears to have substantial uncertainties and inconsistencies. Further, the report finds that due to the absence of consideration of new data and analysis concerning the conceptual model of the Amargosa River basin that has been conducted since 2010, the SEIS is non-responsive to NRC items #1, 2, 3 and 4. Moreover, the SEIS is also non-responsive to Inyo County's concerns concerning the previous EISs that are identified above because of the lack of consideration of new data and analyses pertinent to the SEIS.

The Andy Zdon and Associates study also identifies deficiencies in the SEIS resulting from: (1) the DVRFM's failure to address potential changes associated with seismic activity in the region over the one-million year planning horizon; (2) potential changes in groundwater should water rights in the Amargosa Farms area be fully exercised or if the region's solar energy production potential is realized; (3) lack of analysis of increased groundwater pumping up gradient from Yucca Mountain that may result from groundwater pumping and water export proposed by the Southern Nevada Water Authority (SNWA) pursuant to applications to pump groundwater that were filed with the Nevada State Engineer in 1989; (4) a lack of analysis of potential impacts of the repository on endangered and threatened species, such as the Amargosa Vole, Least Bell's Vireo; and, (5) the continued absence of a remediation plan or analysis of potential environmental impacts should remediation be implemented. Items 1 through 3 are reasonable foreseeable events, which should be considered in the analysis according to NEPA and discussion of items 4 and 5 is also required by the Act.

With regard to the proposed groundwater pumping by SNWA, such pumping is reasonably foreseeable and should be analyzed in the SEIS to describe the impacts of such regional groundwater pumping on the hydrology under and in the vicinity of the proposed repository. It is clear that SNWA's groundwater pumping is reasonably foreseeable. The Final SEIS on page 8-46 (§8.4.2), incorporates Chapter 5 of the Rail Alignment EIS. On page 5-37(§5.2.2.6), the Rail Alignment EIS describes potential groundwater development projects—including a massive groundwater extraction and importation project by the SWNA that is located over and within the regional carbonate aquifer. The Rail Alignment EIS states that "...cumulative water use for the projects described above could total more than 430 million cubic meters (350,000 acre-feet) per year." Some of this groundwater may be withdrawn from the LCA or from areas recharging the LCA.

Moreover, with regard to the SWNA project, the SEIS does not mention a ruling of the Nevada State Engineer (Ruling 5465, January 4, 2005) (http://water.nv.gov/scans/rulings/5465r.pdf), which has already granted the SNWA the right to pump 8,905 acre-feet of groundwater from the Tikapoo and Three Lakes Valley hydrographic basins as part of its regional groundwater importation project. Significantly, in Ruling 5465, the State Engineer found that groundwater in Tikapoo and Three Lakes Valleys eventually discharges through the LCA at Ash Meadows and Death Valley. Despite the scope of the SNWA project, the only assessment of impacts of the proposed project assumes that such pumping will only be 10,600 acre-ft/yr as opposed to the 350,000 acre-ft/yr described in the Rail Alignment EIS (See SEIS, p. 2-18.)

In the vicinity of Yucca Mountain, there is an upward hydraulic gradient between the LCA and the overlying volcanic aquifers. The upward gradient is important to the performance of the repository because it restricts groundwater flow and radionuclide transport pathways to overlying volcanic and alluvial aquifers and it prevents radionuclides from entering the LCA. The SEIS should analyze the potential groundwater pumping under the SNWA project to determine whether such pumping would affect the upward hydraulic gradient beneath Yucca Mountain. As identified in the attached Andy Zdon and Associates Study (page 3-18 – 3-19), a new numerical model of the regional aquifer system released by the USGS in 2014 can be used to assist in the required analysis.

Not only does SNWA's project have the potential to affect the vital upward hydraulic gradient, but a continuation of existing groundwater pumping over the long-term could affect the gradient. The SEIS modeled the effects of maintaining 2003 pumping rates for 500 years and concluded that such pumping would not affect the hydraulic gradient (SEIS, p. 2-

28 to 2-29). In contrast, in a report done as part of the County of Inyo's assessment of the repository, Bredehoeft, J. and M. King., 2010, "Potential Contaminant Transport in the Regional Carbonate Aquifer Beneath Yucca Mountain, Nevada, USA." *Hydrogeology Journal.* Vol. 18, Issue 3. pp. 775–789, the authors found that when the Death Valley regional groundwater flow system hydrogeologic framework model (the DVRFM) developed by the U.S. Geological Survey *was run for 1000 years at 1995 groundwater pumping levels*, the model predicted drawdown of 10 meters in the lower carbonate aquifer in the vicinity of Yucca Mountain and more than 70 meters of additional drawdown in the Amargosa Valley in the next several hundred years. Given the importance of the upward hydraulic gradient, the SEIS should assess the potential impacts on the gradient of maintaining existing groundwater pumping over the long-term.

The DVRFM was used by DOE in the development of the site-scale hydrogeologic framework model (HFM2006), which in turn was used to develop the model used to simulate groundwater flow directions and flow rates of water from beneath the repository to the southern end of the controlled area boundary. The DOE's site scale model takes boundary conditions from the DVRFM. The DVRFM was calibrated to water levels observed in the mid-1990s. The model is capable of generating steady-state water levels that do not include the impacts of pumping on water levels. DOE used the steady-state water levels (that essentially excluded the impacts of a continuation of existing pumping) as the boundary condition for its hydrogeologic Site Model. Consequently, neither the predicted drawdown in the Amargosa Valley, nor the drawdown in the lower carbonate aquifer in the vicinity of Yucca Mountain that will result from a continuation of groundwater pumping at current levels in the vicinity of the repository, was considered in the SEIS's analyses of the potential impacts to upward gradient in the lower carbonate aquifer.

As noted NRC's Adoption Determination Report (Section 3.2.1.4.2), an incomplete and inadequate characterization of a potential impact constitutes a significant new consideration that renders the SEIS inadequate—irrespective of the magnitude of potential impacts.

Although the SEIS provides a discussion of potential cumulative impacts (SEIS Section 4.5.2), Inyo County believes that the SEIS fails to provide a sufficient analysis of cumulative impacts associated with the movement of contaminates through groundwater into the Amargosa desert and then into Inyo County from the proposed repository in combination with contaminants from Nevada National Security Site and/or the Beatty Low-Level Waste and Hazardous Waste Disposal Facilities (where a recent explosion caused a fire that may have released nuclear material into the atmosphere and the groundwater table). As defined in 40 CFR 1508.7, cumulative effects are those impacts that result from incremental impacts of a proposed action when added to other past, present and reasonably foreseeable future actions, regardless of whether a federal or nonfederal agency or person undertakes such actions. Cumulative effects can result from individually minor but collectively significant actions that can take place over time. Actions causing cumulatively significant impacts should be examined in an EIS (40 CFR 1508l25(a)(2)). The federal courts have required that an agency take a "hard look" at the cumulative effects of a project,
Oregon Natural Resources Council v. Marsh, 52 F. 3d 1485 (9th Cir. 1995).

The SEIS and DOE's previous EISs do not adequately address groundwater monitoring and mitigations for potential groundwater contamination affecting Inyo County communities, including Tecopa, Shoshone, and Furnace Creek. The SEIS and the previous environmental documents admit that there will be leakage of contaminants from the proposed repository. However, the SEIS and the previous EISs do not analyze mitigation and remediation measures that are necessary to protect the public health and safety and other environmental impacts from radionuclides and other contaminants leaving the repository site due to flooding or traveling through the saturated zone and surfacing within or outside of Inyo County. Rather, DOE defers mitigation and remediation planning to such time that "detection of any unusual conditions in groundwater." In addition, none of the environmental documents describe a monitoring plan that would be capable of detecting "unusual conditions in groundwater." The only commitment to monitoring is DOE statement that it will conduct monitoring activities, including monitoring groundwater quality, but no details are provided. (Final EIS, Chapter 9, p. 9-8 and 9-9.)

Procedures for monitoring existing baseline conditions and potential contamination escaping from the repository and groundwater quality through the Amargosa Basin need to be identified and analyzed in the SEIS. Monitoring procedures should also include protocols for informing affected residents of possible groundwater concerns should any contamination be detected. The SEIS should identify mitigations to prevent or minimize impacts to the health, safety and welfare of Inyo County residents, particularly to disadvantaged and Tribal communities.

The County also believes that the SEIS should provide a more robust analysis of environmental justice concerns and mitigations associated with the likelihood of disproportionate impacts to low-income communities and Native American tribes resulting from locating the repository in an area of predominantly disadvantaged communities than is provided in Section 3.4 of the SEIS. As described in the attached hydrogeological models, contaminants from the repository may impact groundwater in the communities of Furnace Creek, Shoshone and Tecopa. Groundwater contamination in and around Furnace Creek will directly impact the water in the historic home of the Timbisha-Shoshone Native American Tribe who continue to live in Death Valley. The community of Tecopa is a disadvantaged community with a 27% poverty rate. The SEIS should address environmental justice impacts for these communities which are most vulnerable to potential contamination and should address monitoring to ensure that these communities are protected.

In addition to health and safety concerns regarding potential impacts from the Yucca Mountain Repository, Inyo County is also concerned that potential groundwater contamination may also have widespread socioeconomic impacts affecting nearby residents, and Inyo County generally. Inyo County's base economic industries are agriculture and tourism, which largely supported by visitors to Death Valley National Park. As described in previously submitted comments, groundwater contamination from Yucca Mountain would irrecoverably devastate these industries and, if only a small amount of contaminates should escape from the repository, the resulting publicity would severely adversely affect tourism in Eastern Inyo County. Therefore, the SEIS inadequately analyzes socioeconomic impacts to Inyo County that would result from potential groundwater contamination.

In 2008, Inyo County contracted with economic consultants to determine the potential impacts of the Yucca Mountain Repository on the Inyo County economy[1]. Their research indicated that above and beyond the financial impacts the County would realize from actual contamination, the mere existence of the Repository could stigmatize nearby areas. The impacts of this stigmatization were then modeled, and their analysis indicated that upon announcement of the Repository's operation, visitation to Death Valley National Park and vicinity will drop between 17.3 and 26.3 percent. If the Repository operates for ten years with no incident, it is estimated that the drop in visitation will be between five and 14.7 percent. If there is a transportation incident, it is estimated that visitation will drop between 29 and 57 percent. The resulting total annual losses resulting from loss of visitation to Death Valley are predicted to range from about \$32,000,000 to \$184,000,000. Predicted revenue decreases to the County range between about \$350,000 and \$4,000,000. Additional losses could occur from the diseconomies of scale and investment disincentives. As noted above, potential groundwater contamination raises similar concerns about socioeconomic effects.

Thank you again for the opportunity to comment on the DOE's SEIS for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain. If you have any questions, please contact the County's Administrative Officer, Kevin Carunchio, at (760) 878-0292 or kcarunchio@inyocounty.us.

Sincerely,

Supervisor Matt Kingsley, Chairperson
Inyo County Board of Supervisors

Attachments:

1) Bredehoeft, John, NAE , and King, Michael, R.G., C.E.G., C.HG, Memorandum Research Program for Evaluation of Yucca Mountain Nuclear Waste Repository Site, October 10th, 2015
2) Andy Zdon and Associates, LLC, Technical Review Summary of the Draft Supplement To U.S. Department Of Energy's Environmental Impact Statement For The Proposed Nuclear Fuel And High-Level Radioactive Waste Repository At Yucca Mountain, Nevada, October 23, 2015

[1] Gruen Gruen + Associates, *A County at Risk: The Socio-economic Impacts of the Proposed Yucca Mountain High-level Nuclear Waste Repository,* 2008.

The HYDRodynamics Group, LLC

INYO COUNTY YUCCA MOUNTAIN REPOSITORY ASSESSMENT OFFICE

MEMORANDUM
RESEARCH PROGRAM FOR EVALUATION OF
YUCCA MOUNTIAN NUCLEAR WASTE REPOSITORY SITE
U.S. Nuclear Regulatory Commission (NRC) 2015 Supplement to the U.S. Department of Energy (DOE)
Environmental Impact Statement (EIS)
Draft Report for Comment Review

October 10, 2015

Michael King, R.G., C.E.G., C.HG, and Dr. John Bredehoeft, NAE:
The *Hydrodynamics* Group, LLC

The *Hydrodynamics* Group, LLC reviewed NRC's 2015 Supplement to DOE's EIS in a Draft Report for Comment for the Yucca Mountain Nuclear Repository site. DOE's Final Environmental Impact Statement (FEIS) and subsequent SEIS are part of the required National Environmental Protection Act (NEPA) project permitting process. The format and issues to be address in both the FEIS and SEIS are mandated by statute.

Background

Hydrodynamics reviewed the DOE's October Draft 2007 SEIS in December of 2007. It was our general conclusions that the DOE 2007 Draft SEIS:

1. Did not fully reference or utilize DOE sponsored Inyo County hydrogeology research on the Lower Carbonate Aquifer (LCA).
2. Did not fully or accurately characterize the LCA.
3. Did not adequately discuss the upward gradient in the LCA as a barrier to radionuclide transport or possible impacts on repository performance with a possible loss in the upward gradient due to regional groundwater usage.
4. Did not model radionuclide transport out to the point of the accessible environment in the biosphere.

DOE in writing its original EIS referred its safety analysis to a point of compliance that is 18 km to the south of the proposed repository. Their argument was that the point of compliance is the point of maximum contamination from the repository; if the repository proved to be safe at this point, it would be safe at points further downstream. We argued that the DOE analysis of safety should be carried to the point where contaminants were brought to the accessible environment. The NRC accepted this argument and in response

DOE's 2008 analysis extended contaminant transport from the point of compliance to the surface environment.

In the 2008 DOE analyses two critical issues were identified: 1) groundwater pumping at Amargosa Farms, and 2) discharge from the springs at Furnace Creek. Two climate scenarios were considered: 1) present day, and 2) a wetter and cooler climate.

The NRC published their 2015 Supplement to DOE's EIS Draft Report for Comment. As stated by the NRC, the scope of the Draft Report for Comment was:

> *This supplement describes the affected environment and assesses the potential environmental impacts with respect to potential contaminant releases from the repository that could be transported through the volcanic-alluvial aquifer in Fortymile Wash and the Amargosa Desert, and to the Furnace Creek/Middle Basin area of Death Valley. This supplement evaluates the potential radiological and nonradiological impacts—over a one million year period—on the aquifer environment, soils, ecology, and public health, as well as the potential for disproportionate impacts on minority or low-income populations. In addition, this supplement assesses the potential for cumulative impacts associated with other past, present, or reasonably foreseeable future actions. The NRC staff finds that all of the potential direct, indirect, and cumulative impacts on the resources evaluated in this supplement would be SMALL.*

Statement of the Problem

Inyo County concerns and issues are to ensure that repository siting and subsequent repository activities do not adversely impact the public health, safety, or welfare of County residents, including those in Death Valley National Park. Therefore, our review of the FEIS and SEIS is specific to the geology and hydrogeology related sections:

1. Affected Environment
2. Environmental Impacts of Postclosure Repository Performance
3. Cumulative Impacts

Key questions in determining the acceptance of DOE's FEIS and SEIS, and NRC's supplement to DOE's EIS are 1) does the document utilize the latest data and analysis to accurately characterize the current environment at the Yucca Mountain repository site; and 2) does it document the potential impacts of the repository on the environment, and/or the environment on the performance of the repository?

NRC Draft Report Review

Hydrodynamics reviewed the 2015 NRC Draft Comment on DOE's Supplement to its EIS relative to 1) review comments on DOE's 2008 FEIS, and 2) the current NCR updated analysis of DOE's 2008 FEIS. The results of NRC's FEIS supplemental report are discussed for specific issues concerning impacts in Inyo County.

DOE/NRC's approach to evaluating potential impacts of Yucca Mountain stored nuclear waste materials on the down-gradient hydrologic environmental is based on the results of the numerical and analytical models of:

1. Yucca Mountain Numerical Site Model
2. DOE's Death Valley Regional Numerical Model
3. DOE's Nuclear Particle Tracking Analysis
4. Analytical Model that extend the dose calculations to the Amargoasa Desert and to Death Valley.

Yucca Mountain Numerical Site Model: This model evaluated radionuclide/groundwater migration from the respostory through the unsaturated zone to the water table, and then down-gradient from the site. The Yucca Mountain site consist of an upper unsaturated zone, saturated Territary Aquifer, and an underlying Lower Carbonate Aquifer (LCA). A key assumption in this model is that the upward hydraulic head gradient between the LCA and the overlying Tertiary aquifer is an adequent barrier to downward radionuclide transport. Contaminant transportt was therefore confined to the upper Territary Aquifer. The reported pathway for groundwater movement from below the repository was down Forty-Mile Wash into the Amargosa Valley to the major groundwater pumping at Amargosa Farms. The model was specific to the 18 kilometer point of compliance. The DOE Death Valley Regional Model (DVRM) was utilized to evaluate groundwater movement beyond the point of compliance. The DVRM was developed by the U.S. Geological Survey (USGS).

Hydrodynamics' modeling of the Death Valley groundwater system showed that the LCA was the key to radionuclide transport into the Death Valley National Park Furnace Creek spring system. This analysis showed that if radionuclides enters into the LCA groundwater system, transport to the Furnace Creek springs could be as short as 500 years. The NRC referenced *Hydrodynamics'* report, but stated that the upward head gradient betwen the LCA and the Tertiary aquifer prevents transport through the LCA, and the fast track scenioro from happening.

DOEs Death Valley Regional Model (DVRM): DOE divided the discharge area of the Death Valley Regional flow System into: Central Death Valley sub-region, and the Southern Death Valley sub-region. *Hydrodynamics* focused its analysis on the major springs that discharge into the Furance Creek area in the Central Death Valley sub-region. The DVRM orginally modeled steady-state groundwater flow conditions. Transient groundwater flow was modeled to a limited extent. The model was also used to evaluate both current climate and potential wet conditions in the future.

Point 1

Hydrodynamics used a model based upon data that describes the LCA taken from the DVRM to simulate groundwater flow through the LCA from Yucca Mountain to the Furance Creek major springs in Death Valley National Park. This work suggested that the Furance Creek springs were points of discharge from the regional flow system. Chris Fredrick's (USGS geologist) geologic mapping supported *this* analysis. Dr. Fredrick's geological maps of the Southern Funeral Mountain Range were published by the USGS. *Hydrodynamics'* calculated an estimate of the current discharge of the springs in the ATTACHED Report.

DOE took a different approach in their DVRM analysis than *Hydrodynamics*. They established estimates of the Evapo-Transperation (ET) for the playa areas of the Central sub-region. These two approaches yield differing values for the Central sub-region discharge that are summarized in the following table:

	Hydrodynamics discharge ac-ft/yr	DOE discharge ac-ft/yr	DOE ET ac-ft/yr
FC Springs	3600	2300	
Cottonwood Basin			3030
FC Ranch			3410
Middle Basin			1960
Badwatter Basin			5950
West side vegetation			5390
Mormon Point			3950
TOTAL ET			23690

Hydrodynamics estimated discharge from the Furnace Creek springs to be 3,600 ac-ft/yr compared to 2,300 ac-ft/yr calcualted by DOE. DOE's value is approximately 38% lower then the *Hydrdynamics* discharge value. However, DOE used the total ET, 23,000 ac-ft/yr, to make its analysis of contaminant transport Implicit in the DOE ET estimate is that water transpired is discharge from the Middle Death Valley Regional Flow sub-region. The value used in the final DVRM was 3,410 ac-ft/yr for the Furnace Creek Ranch area. This value is much closer to the *Hydrodynamics* estimate of discharge in the Furnace Creek Ranch area. The DOE reported ET of 23,700 ac-ft/yr is a relative large value in comparison to *Hydrodynamics* calculated value. By using a larger value, DOE's DVRM represents a more conservative estimate of contaminant transport to the Dearth Valley National Park area. DOE shows that even using their higher ET values (shown in the table above) the repository meets the NRC safety test.

Point 2

The DVRM particle tracking analysis showed that radionuclides do not reach the LCA providing current pumping rates at the Amargosa Farm are maintained into the future. This pumping preserves the upwardhead gradient between the LCA and the Tertiary aquifer that, in theory, prevents radionuclides from migrating into the LCA. There is agreement that some level of pumping in at the Amargosa Farms will continue into the future. A significant reduction of pumping at the Amargosa Farms into the future could be problematic in terms of mixing LCA fluids with potential radionuclide in the shallower aquifer system. However, we have no evidence future pumping will be greatly reduced.

Point 3

Spring deposits in the lower section of Amargosa Valley. would be an area of discharge in a cooler, wetter climate. The DVRM accounted for this condition. DOE limited its detailed analysis of the lower section of the Amargosa Valley in the Franklyn Lake Playa region because it is the farthest down-gradient region in the DVRM with limited potential impacts on our understanding of groundwater flow from the repository. The current understanding of the of the the Franklyn Lake Playa area from the DVRM particle tracking analysis showed only 2 out of 8,000 particles reach the Franklyn Lake Playa area.

Andy Zdon & Associates, Inc. completed a detailed hydrogeology analysis of the lower section of Amargosa Valley in the last year for Inyo County. This analysis indicates that the primary source of groundwater discharge to this region is through the Ash Meadows spring area. This conclusion is consistent with DOE's analysis that shows limited impact on the lower section of Amargosa Valley from potential radionuclide discharge from the Yucca Mountain Repository. The results of the Andy Zdon & Associated analysis are now published.

DOE's Nuclear Particle Tracking Analysis & Dose Calculations: DOE conducted a radionuclide particle tracking analysis to determine the trajectory of contamination. DOE then used an analytical model to estimate radioctive doses at specific locations throughout the Death Valley region. The NRC reported the dose values for both the Death Valley area and the Furnace Creek area in the following tables:

Table 3-8. Amount of Radiological and Nonradiological Material (From the Repository) in the Aquifer Environment Between the Regulatory Compliance Location and Death Valley

	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (Ci)	1.5	1,320	1.5	1,320
Th isotopes (Ci)	0.18	791	0.18	791
Np-237 (Ci)	1.4	581	1.4	581
I-129 (Ci)	2.5	65	2.2	15
Tc-99 (Ci)	1,260	1,520	1,160	435
Se-79 (Ci)	5.8	204	5.8	204
Mo (kg)	1.4×10^6	4.6×10^5	1.4×10^6	3.0×10^5
V (kg)	2.2×10^3	4.2×10^5	2.2×10^3	4.2×10^5
Ni (kg)	1.7×10^7	1.3×10^8	1.7×10^7	1.3×10^8

U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, Ni = nickel,

Table 3-9. Average Concentrations of Radiological and Nonradiological Material From the Repository Discharging in Groundwater at Furnace Creek, Death Valley				
	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (pCi/L)	0	0	0	0
Th isotopes (pCi/L)	0	0	0	0
Np-237 (pCi/L)	0	0	0	0
I-129 (pCi/L)	0	0.65	0.02	0.17
Tc-99 (pCi/L)	0	13.5	9.3	3.8
Se-79 (pCi/L)	0	0	0	0
Mo (mg/L)*	0	0.001	0	3.7×10^{-4}
V (mg/L)	0	0	0	0
Ni (mg/L)	0	0	0	0

*calculated peak concentration of 0.04 mg/L for Mo occurs at 58,000 years after repository closure
U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, V = vanadium, Ni = nickel

(Taken from NRC's 2015 Supplement to DOE's EIS in a Draft Report for Comment Pages No. 3-22 and 3-23)

NCR found that impacts on the aquifer environment at Furnace Creek and Middle Basin to be SMALL. The *Hydrdynamics Group* agree with this conclusion.

Compliance with NEPA Requirements

As stated earlier, DOE's FEIS and subsequent SEIS are part the required National Environmental Protection Act (NEPA) project permitting process. The format and issues to be address in both the FEIS and SEIS are mandated by statute. *Hydrodynamics* review of NRC's 2015 Supplement to DOE's EIS in a Draft Report for Comment did not provide a mitigation plan for radionuclide releases from the Yucca Mountain Repository. The mitigation plan in the DOE FEIS was limited to a brief discussion on cooperation with multiple public and government agencies to develop an actual mitigation plan.

DOE and the NRC conclude in the FEIS and SEIS reports that radionuclides will be released from the Yucca Mountain repository. Although DOE concluded that doses of radionuclides at the accessible environmental are SMALL, this does not alleviate the requirement to provide a mitigation plan. This deficiency must be corrected for acceptance of the NRC 2015 Supplement to DOE's SEIS in their Draft Report for Comment.

SUMMARY OF REVIEW COMMENTS

It is *Hydrodynamics* general opinion that both DOE and NRC have done a credible job of extending the analysis to the accessible environment as we suggested. Their analysis incorporated *Hydrodynamics* published reports providing the results of LCA and Death Valley hydraulic studies submitted in prior comments. DOE and NRC analysis did not indicate additional problems that would make the repository more hazardous. The following key points can be made from this review.

Point 1: DOE/NRC analysis suggested that pumping at Amargosa Farms would capture all of the potential contamination. When pumping was included no contaminants made it to Death Valley. Continued pumping into the future is a reasonable assumption.

Point 2: DOE/NRC analysis indicate that the upward hydraulic head gradient betwen the LCA and the overlying Tertiary aquifer is a barrier to radionuclide transport both in the area of the repository and in the Amargosa Farms area. Should pumping stop at the Amargosa Farms or the upward gradient be degradated and contaminants migrate to the Carbonate aquifer, radionuclide transport through the LCA into the Death Valley Furnace Creek springs will be relatively fast. The upward head gradient must be preserved into the future to protect the human and natural resources of Inyo County.

Point 3: *Hydrodynamics* estimate of discharge in the Furnace Creek area and the DOE's estimates do not match. However, DOE's ET values used in the DVRM were significantly larger then *Hydrodynamics* values, and represent a worse case sceniro for radionuclide transport.

Point 4: DOE/NRC particle tracking and radionuclide dose models for the Death Valley Furnace Creek and lower section of Amargosa Valley areas are SMALL, and are well within EPA health standards.

Point 5: DOE's FEIS does not provide a viable mitigation plan as required by the NEPA permitting process. A mitigation plan is completely absent from the NRC 2015 Supplement to DOE's EIS in a Draft Report for Comment.

PROPOSED ACTION TO CORRECT DIFFENCES IN THE NRC 2015 SUPPLEMENTAL EIS DOCUMENT

The NRC 2015 Supplement to DOE's SEIS should be corrected to include 1) a plan to monitoring the potential release of radionuclides at the source in the Yucca Mountain Repository, and 2) incorporating mitigation plans to capture the radioactive materials before entering the unsaturated and saturate groundwater flow system. It is our opinion that it may be prohibitive to effectively prevent radionuclides from reaching the assessable environment, such as the Amargosa Farms area, once they move into the saturated zone aquifer system beneath the Yucca Mountain Repository.

It is important that DOE and the NRC address groundwater use conditions that may reduce the upward gradient in the LCA. Specifically, groundwater use permits have been approved and pending for pumping of large quantities of groundwater from the LCA on the northern and eastern boundaries of the DVRM boundaries. The potential for impact of increased Carbonate pumping on the upward head gradient between the LCA and the Tertiary aquifer at both the repository site and in the Amargosa valley area has not been analyzed. As part of the NEPA permitting process, potential impacts that could result from pumping under these permits should be determined.

ATTACHMENT
***Hydrodynamics'* Water Use in the Furnace Creek Ranch Area**
of
Death Valley Report

WATER USE IN THE FURNACE CREEK AREA OF DEATH VALLEY

Marvin Jensen, Consultant, Fort Collins, CO
John Bredehoeft, The Hydrodynamics Group, Sausalito, CA
Terry Fiske, U.S. National Park Service, Death Valley, CA

INTRODUCTION

As a part of an ongoing effort by Inyo County, California to investigate the potential ramifications of a nuclear repository at Yucca Mountain the Hydrodynamics Group is investigating the Paleozoic Carbonate Aquifer. This aquifer is known to underlie the repository site. The ultimate discharge from the aquifer is thought to be in the springs on the southwest flank of the Funeral Mountains in the Furnace Creek are of Death Valley. This discharge of groundwater in the Death Valley springs is one of the potential pathways by which radionuclides from the repository might migrate back to the biosphere.

It is of particular interest to estimate the discharge from the springs. This provides a quantitative estimate of the flow through the aquifer, which in turn allows us to estimate quantitatively the hydraulic properties of the Carbonate Aquifer.

The springs support local vegetation in the alluvial fan area of the Furnace Creek and particularly the Furnace Creek Ranch. The Ranch includes a golf course, motel facilities, and a small Indian village. Another facility, Furnace Creek Inn, is located near the mouth of the fan. It was our intent to estimate the water use from the vegetated area of the Inn and the Ranch. Our original thought was that the irrigated vegetation and the human consumption used most of the water from Travertine and Texas springs. As we will see below, the irrigation demand during the summer months is approximately equal to the discharge of the two springs.

SPRING DISCHARGE

The discharge of the springs is not as readily measured as one might imagine. The water from Texas and Travertine springs are collected in tunnels, sumps, and buried tiles in the alluvium of Furnace Creek Wash below the springs. It is difficult to separate the Texas and Travertine spring flows in the collection system. Measuring the springs is also complicated by the fact that there are often several orifices.

The U.S. Geological Survey (USGS) investigated the spring flow in the 1960s (Pistrang and Kunkel, 1964). There are more recent measurements by the National Park Service (NPS), data taken in 2001 and 2003. With the help of Chris Fredrick of the USGS, we tried to reconcile the earlier measurements. Table 1 is a summary of the spring data that includes our best estimate of the current spring discharge:

Table 1. Summary of Furnace Creek spring discharge—flow in cfs.

Spring	Pistrang & Kunkel	NPS 2001/2003	This report
Texas	0.50	0.45	1.0
Travertine	3.90	3.39	3.2
Navel			0.1
Nevares	0.60	0.32	0.5
Cow Creek	0.10	0.10	0.1
Salt Creek			0.1
Total (flow in cfs)			5.0

WATER USE

Our combined estimate for Texas and Travertine springs is 4.2 cfs. Much of this flow goes to support the facilities in the oasis at Furnace Creek wash. As suggested above, these facilities include Furnace Creek Inn and Furnace Creek Ranch. Both have extensive grounds that are irrigated, including a golf course and date plam grove at the ranch. Both have lodging, restaurants, and bars; they both have large swimming pools.

It was our initial estimate that most of the water from Travertine Spring in particular is consumed by the facilities, including the irrigation in the Furnace Creek area. With that thought in mind, we set out to estimate the water consumption in the area. Figure 1 is a commercial satellite image of the Furnace creek area of Death Valley.

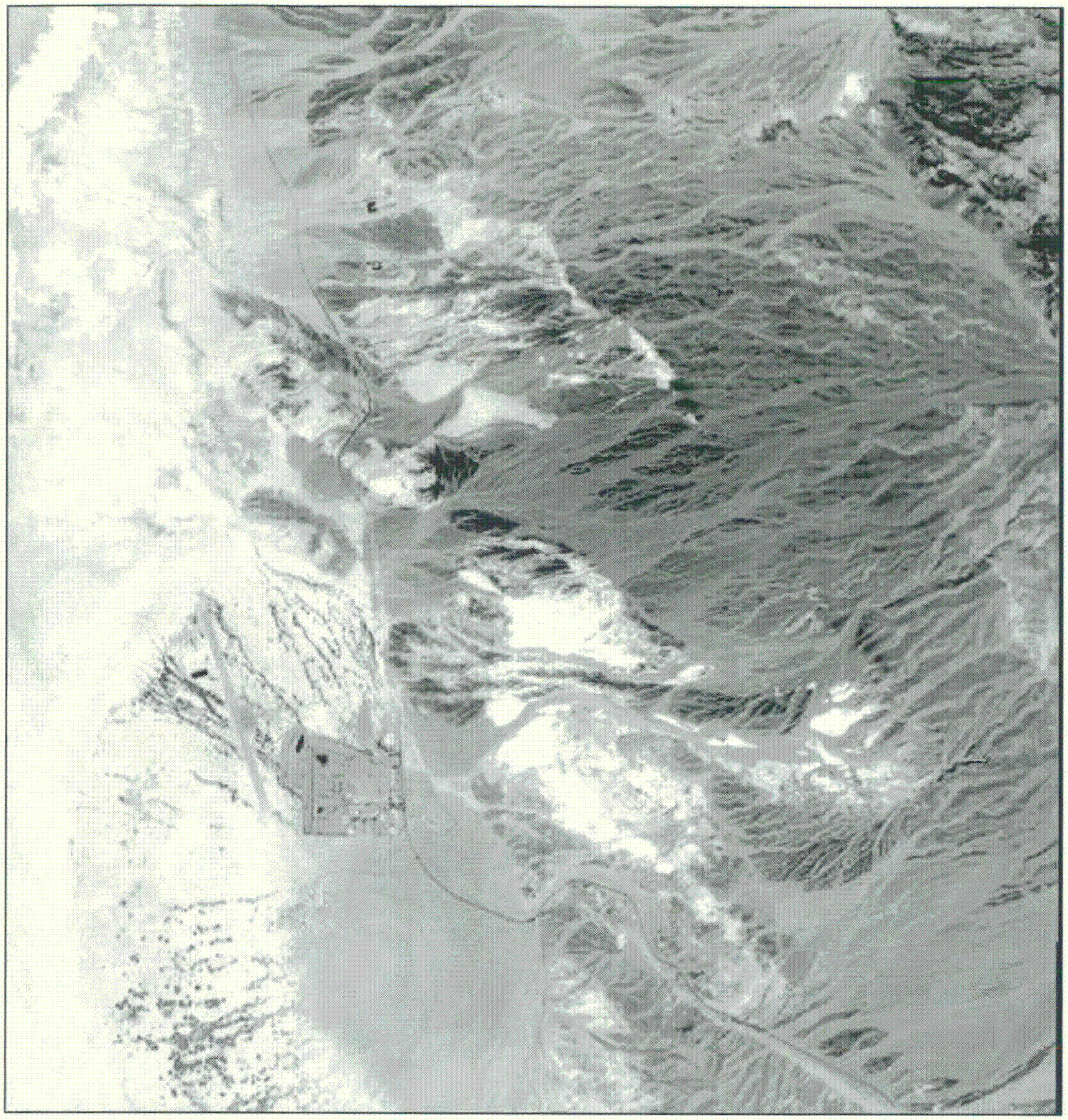

Figure 1. IKONOS satellite image of the Furnace Creek area of Death Valley.

On Figure 1, the image the Furnace Creek Ranch stands out, along with the airstrip. Figure 2 is a blow-up of the ranch area.

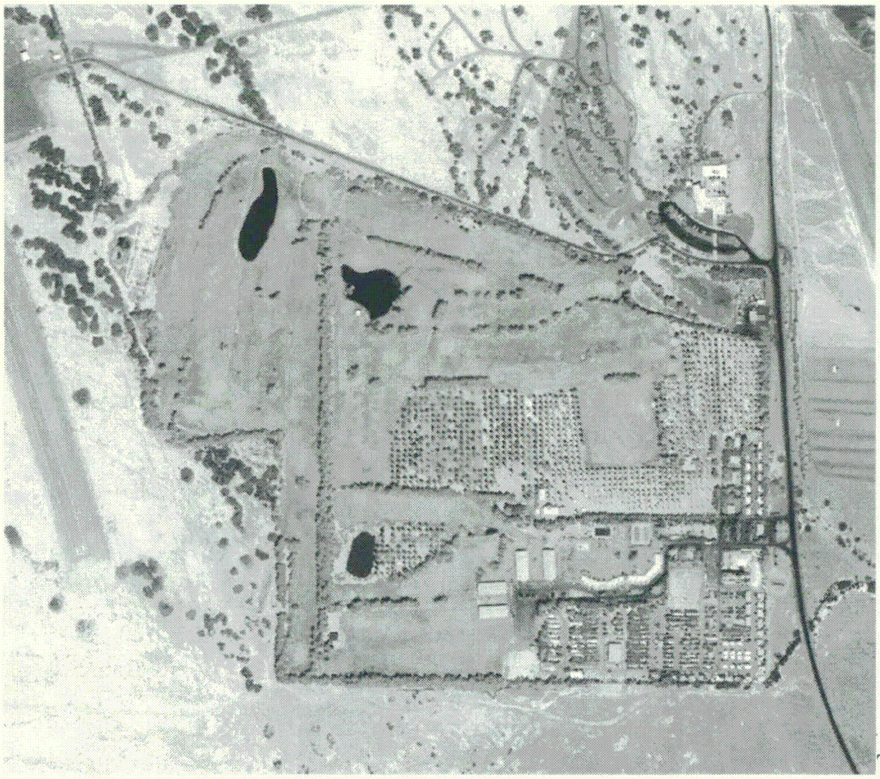

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Figure 2. IKONOS false-color infrared image of the Furnace Creek Ranch area.

These IKONAS images have a 1-meter resolution. They can be viewed as TIFF files in Photoshop where they can be blown up to show individual automobiles in the parking lots. The golf course, the date grove, the various buildings, and even the swimming pool show up on Figure 2. The vegetation is easily mapped on this image. By looking closely one can see shadows cast by the palm trees. Figure 3 is a blow up of the Furnace Creek Inn and its surroundings.

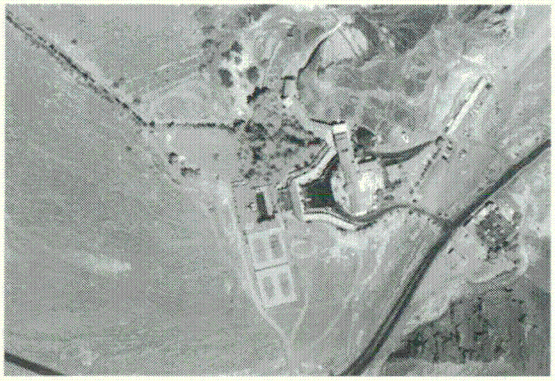

Figure 3. IKONOS false color infrared image of the Furnace Creek Inn and its surroundings.

One can see in the furnace Creek Inn image individual cars in the parking lot even on this picture. Things are much sharper working with the original satellite image. The image can be loaded and manipulated in Photoshop; this makes the interpretation possible on one's PC.

EVAPOTRANSPIRATION ESTIMATES FOR VEGETATED AREAS[1]

Our purpose was to estimate the annual net evapotranspiration (ET) from vegetated areas of Furnace Creek Ranch and Furnace Creek Inn. A preliminary estimate was made of net ET by salt cedar growing along dry creek beds, or drains, below Furnace Creek Ranch.

Climate

Calculated reference ET is the most commonly used index of evaporative climate evaporative demand. It is based mainly on net radiation, but also includes the effects of humidity and wind speed as measured over well-watered vegetation such as clipped grass or alfalfa. The first step in estimating ET from the vegetated areas of Furnace Creek Ranch and Furnace Creek Inn was to estimate reference ET for the area. A large part of the Furnace Creek Ranch is in grass because of the golf course, but there also is a large area of date palms. The color infrared satellite photographs indicate that some of the areas of date palm appear to have vegetative ground cover, and other areas appear to be essentially bare soil between date palms.

Because of the large area of short grass, grass reference ET similar to that used by the California Irrigation Management System (CIMIS) was used to characterize average evaporative demand. Daily reference ET was calculated for a three-year period (1999-2001) using daily CIMIS data primarily from Ripley, California. Although Ripley (Lat 33.53 °N, Long. 11.63 °W, Elev. 251 ft.) is further south than the study area (Lat 36.47 °N, Long. 116.87 °W, Elev. -194 ft.), its elevation is closer to that of the study area than other CIMIS stations at higher latitudes such as Barstow, CA (Lat. 34.88 °N, Elev. 2,040 ft), and Owens Lake, CA (Lat. 36.48 °N, Elev. 3,684 ft). CIMIS Blythe, CA (Lat. 33.56 °N, Elev. 275 ft.) is located near Ripley and has similar climate to that of Ripley. Imperial Valley is also below sea level, but is located further south at about 32.8 to 33.1 °N latitude. Long-term average, or normal temperature data from the National Weather Service Death Valley Station No. 2319 (NCDC, 1992) were also used with the Hargreaves equation (Hargreaves and Samani, 1985; Hargreaves et al., 1985) for grass reference ET because it requires only mean air temperature and extraterrestrial solar radiation.

Climate Variables and Calculations

Three years of daily climate data from the station at Ripley, CA were downloaded from CIMIS. CIMIS stations generally are located over irrigated grass or irrigated alfalfa so that air temperatures are modulated by ET from the underlying surface. The long-term or normal air temperature reported for Death Valley appears to be from the airport which

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would not be modulated by ET from the irrigated area. Therefore, the average air temperatures at Death Valley are generally several degrees C higher than that at Ripley (Figure 4). However, air temperature is not the major variable controlling reference ET. All calculations were done using SI metric units and summary values were converted to English units of feet and acre-feet (ac-ft).

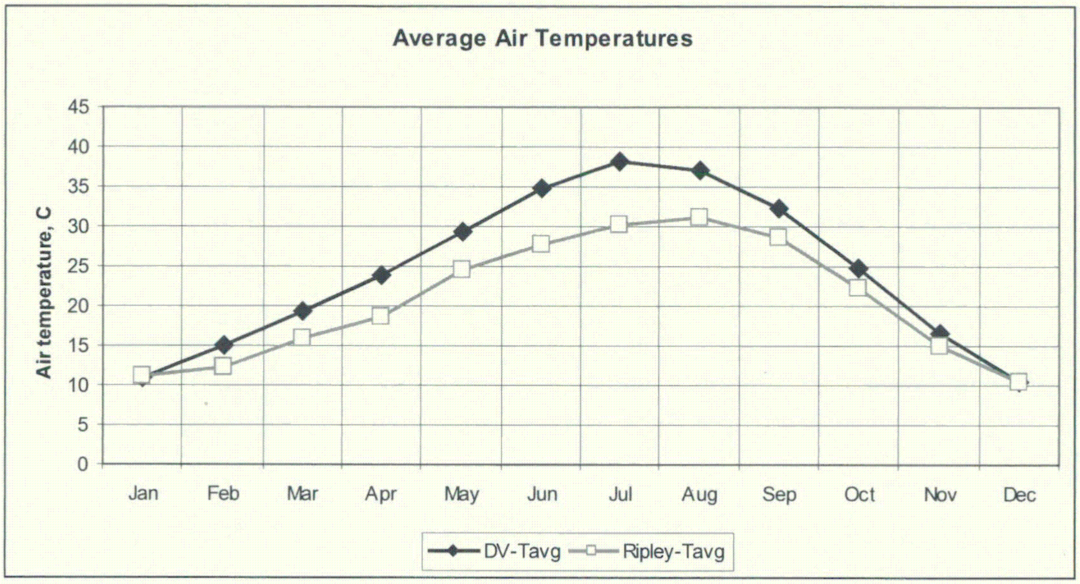

Figure 4. Average monthly air temperatures at Death Valley and Ripley, California.

Evaporative demand, or reference ET, is controled mainly by solar radiation. The estimated clear-day solar radiation at Death Valley compared to that at Ripley is shown in Figure 5. During the summer months, there is very little difference in estimated clear-day solar radiation at Death Valley compared with Ripley, California. Because solar radiation is the primary variable, the estimated ASCE grass reference ET for Ripley was very similar to that based on the Hargreaves equation at Death Valley as shown in Figure 6. Also shown in Figure 6 for comparative purposes is the average 99-01 CIMIS ET_o for Ripley and the weighted average ASCE ET_o for 89-02 Imperial irrigation District (IID). The results indicate that the mid-summer average ASCE ET_o for Ripley is a bit lower than the average ASCE ET_o for the IID, but higher than the 99-01 average CIMIS ET_o for Ripley. ASCE ET_o values typically are slightly higher than CIMIS ET_o calculated from hourly data. The average ASCE ET_o values for Ripley were considered to be a reasonable and conservative estimate for the area.

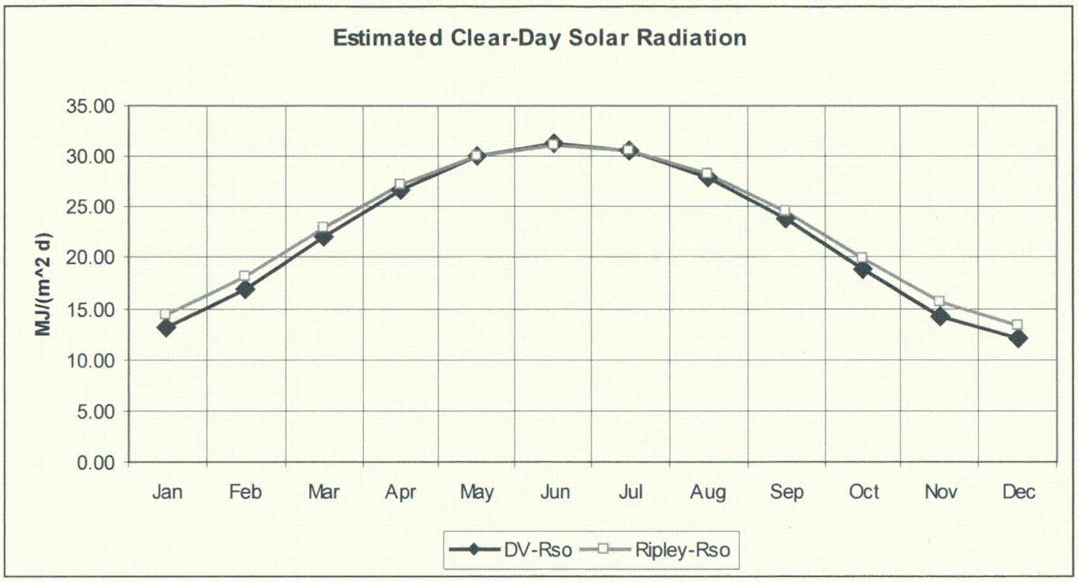

Figure 5. Estimated solar radiation on cloudless days at Death Valley and at Ripley, California.

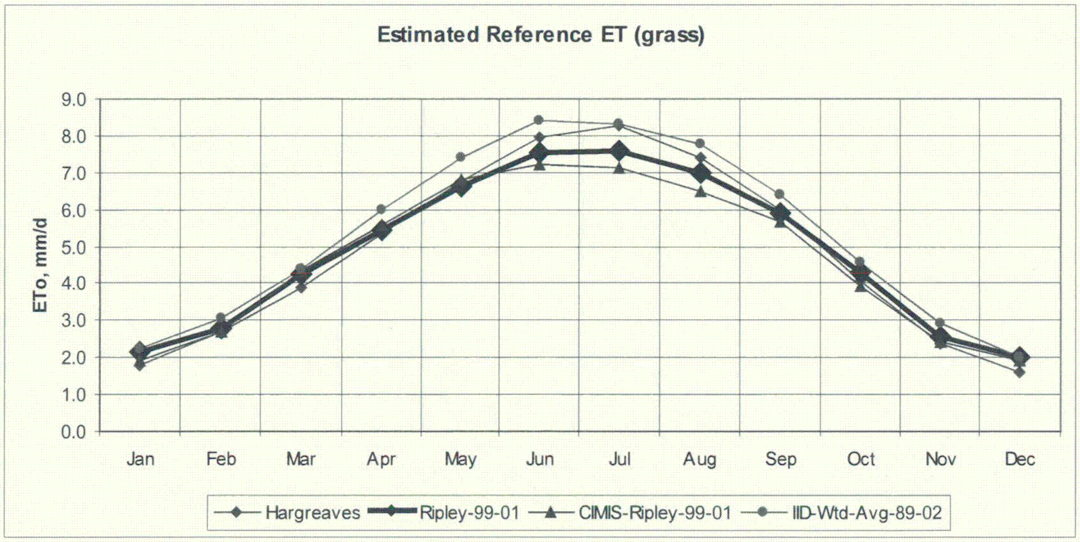

Figure 6. Estimated grass reference ET (ETo) at Death Valley using Hargreaves ET_o equation, ASCE ET_o and CIMIS ET_o for 99-01 Ripley, California, and weighted average ASCE ET_o for 1989-2002 Imperial Irrigation District.

ASCE Standardized Reference ET Equation

The daily ASCE reference crop ET was estimated using Equation 1.

$$ET_{os} = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

where ET_{os} = the standardized reference crop ET for a short vegetated surface under reference ET conditions in mm/d, R_n = net radiation at the reference surface in MJ/(m^2 d), G = soil heat flux density at the soil surface in MJ/(m^2 d), T = mean daily air temperature at 2-m height in °C, u_2 = mean daily wind speed at 2-m height, e_s = saturation water vapor pressure at the 2-m height calculated as the average vapor pressure at maximum and minimum air temperature in kPa, e_a = actual vapor pressure at the 2-m height in kPa, Δ = the slope of the vapor pressure-temperature curve in kPa/°C, and γ = the psychrometric constant in kPa/°C.

Crop (Vegetation) Coefficients

Today, the most common method used to estimate ET for crops and other vegetation is to first calculate reference ET and then apply a coefficient that varies with growth stage or time of year. Estimated ET is, therefore, the product of the coefficient (K_c) and reference ET.

$$ET = K_c\, ET_o \qquad (2)$$

Table 2. Coefficients for various vegetative groups and associated acreage.

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Golf course [a]	0.85	0.85	0.85	0.85	0.85	0.80	0.80	0.80	0.80	0.80	0.85	0.85
Ponds	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Date palms, with ground cover [b]	1.01	1.04	1.09	1.14	1.19	1.21	1.21	1.21	1.21	1.21	1.10	1.00
Date palms, clean cultivated [c]	0.81	0.84	0.89	0.94	0.99	1.01	1.01	1.01	1.01	1.01	0.90	0.80
Date palms, bare ground [d]	0.71	0.74	0.79	0.84	0.89	0.91	0.91	0.91	0.91	0.91	0.80	0.70
Grass, poor growth	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Vegetation by housing areas [e]	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Salt cedar (deciduous) by drains [f]	0.23	0.23	0.45	0.79	1.11	1.18	1.18	1.15	0.90	0.61	0.32	0.22

[a] Assumed to be fairway quality Bermuda grass in summer and overseeded with intermediate ryegrass in the winter (Brown et al., 2003) and adequately watered year round.

[b] For this area, 0.2 added to cleaned cultivated monthly date palm K_c.

[c] Coefficients for clean cultivated date palms based on early studies using soil sampling measurements reported by Jensen and Haise (1963) and adapted to grass reference ET for use along the Colorado River.

[d] For this area, 0.1 was subtracted from clean cultivated monthly date palm K_c because of essentially no vegetation between date palms.

[e] Vegetation by buildings assumed to be grass, shrubs and trees. The area of buildings, parking and roads was reduced by a factor of 0.3.

[f] Developed for use with grass reference ET and verified with measurements made in lysimeters in Arizona by van Hylckama (1974).

Coefficients typically are derived for use with either a grass reference ET (ET_o) or an alfalfa reference ET (ET_r). For this study, a grass reference ET was calculated and coefficients developed for the various groups of vegetation and associated acreage are summarized in Table 2.

Areas of Vegetation

Areas of different vegetation were outlined on a scanned copy of one of the satellite color photographs and the areas were then calculated using a CAD program. The scaling factor for the main vegetated area was based on the length of the airport runway. The scaling factor for the Furnace Creek Inn was based on an assumed length of the swimming pool of 80 ft. Alternatively, the tennis courts could have been used. A summary of the areas of various types of vegetation is presented in Table 2.

Average Annual Flow Rate

Average annual flow rate needed to sustain estimated net ET was calculated as the total annual ET in ac-ft divided by the area involved as summarized in Table 2. Net ET was calculated as estimated ET minus normal precipitation. Annual normal precipitation for Death Valley is only 2.28 inches.

Table 3. Areas of various vegetation types used in estimating average monthly and total annual ET depth and volume.

Vegetated area	Area, Acres	Estimated Net ET, ft	Estimated Net ET, ac-ft
Golf course	102.7	4.6	472
Ponds	3.1	5.6	18
Date palms w ground cover	7.7	6.6	51
Date palms, clean cultivated	3.5	5.4	19
Date palms, bare ground	13.4	4.9	65
Grass, poor growth	4.1	4.5	18
Vegetation, bldgs, parking, etc.	33.6	6.2	63 [a]
Furnace Creek Inn vegetation	10.4	6.2	65
Vegetation by NE buildings	1.3	6.2	8
Resort subtotal	180	4.3	779
Salt cedar by drains	140	4.8	672

[a] The area was reduced by a factor of 0.3 to account for buildings, parking lots and roadways.

RESULTS

The estimated average monthly and annual rate of flow from Furnace Creek springs needed to sustain the estimated rate of net ET on the vegetated areas is summarized in Figure 7. The average annual flow rate for both resort and salt cedar vegetation is about 2.0 cfs. The average annual flow rate for resort vegetation is 1.1 cfs and for salt cedar areas it is 0.9 cfs for a total of 2.0 cfs. However, the irrigation demand ranges from a low value of 0.50 cfs in the winter to a high of 3.75 cfs in the summer.

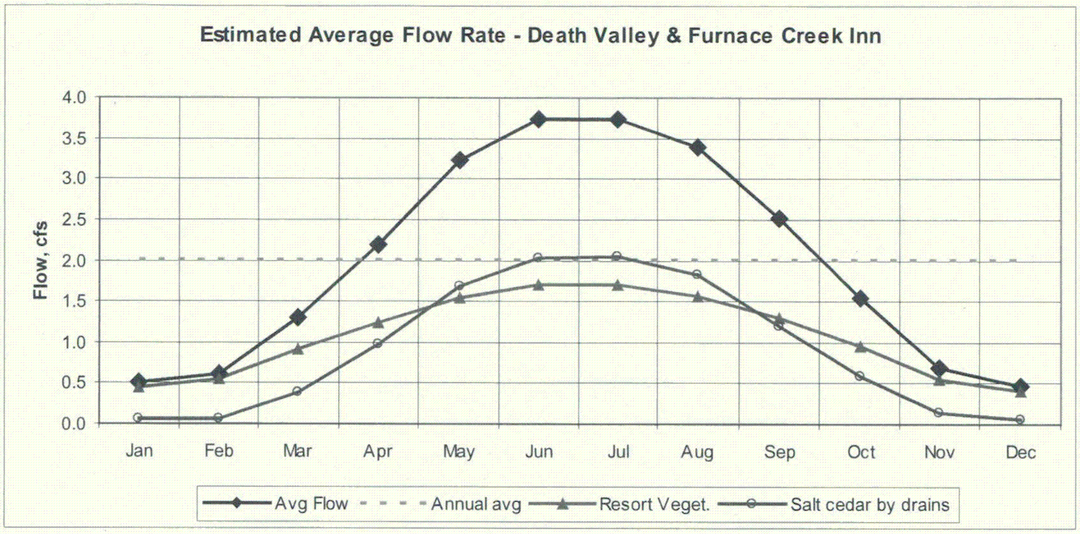

Figure 7. Estimated average flow rate needed to sustain net evapotranspiration of resort vegetation and salt cedar by drains.

DISSUSSION & CONCLUSIONS

The evapotranspiration by the various crops is high. It ranges a low of 4.4 ft/yr for grass to a high of 6.6 ft/yr for date palms with a grass undercover. The irrigated area is not large; the total is reduced for the buildings and paved area by 30%. The total annual consumptive use by the irrigation and the salt cedar is only 2.0 cfs. However, the demand is high in the summer months—3.75 cfs. The peak demand in the summer approaches the total low of both Texas and Travertine springs—our estimate 4.2 cfs. Given the uncertainty in the discharge of the springs, and perhaps some seasonal variation in flow, the irrigation demand is 90% of the combined discharge of the two springs—this is close to the estimated total flow of the two springs.

REFERENCES

Hargreaves, G.H. and Z.A. Samani. 1985. Reference crop evapotranspiration from temperature. *Applied Engrg. in Agr.,* Am. Soc. Agr. Engr, 1(2):96-99.

Hargreaves, G.L., G.H. Hargreaves, and J.P. Riley. 1985. Agricultural benefits for Senegal River Basin, *J. Irrig. and Drain. Engr., Am. Soc. Civ. Engr.*, 111(2):113-124.

Jensen, M.E., and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *J. Irrig. & Drain. Div., Am. Soc. Civ. Engr.*, 89:15-41.

National Climate Data Center. 1992. Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, California. *Climatography of the United States No. 81.*

Pistrang, M.A. and F. Kunkel. 1964. A brief geologic reconnaissance of the Furnace creek Wash area, Death Valley National Monument, California. *U.S. Geological Survey Water Supply paper 1779,* Y1-Y35.

van Hylckama, T.E.A. 1974. Water use by salt cedar as measured by the water budget method. *U.S. Geological Survey Prof. Paper 491-E*, 30 pp.

Walter, I. A., R.G. Allen, R. Elliott, M. E. Jensen, D. Itenfisu, B. Mecham, T. A. Howell, R. Snyder, P. Brown, S. Eching, T. Spofford, M. Hattendorf, R. H. Cuenca, J. L. Wright and D. Martin. 2000. "ASCE's Standardized Reference Evapotranspiration Equation." *Proc., 4th National Irrig. Symp.*, ASAE, Phoenix, AZ.

BRIEF RESUMES OF THE AUTHORS

M.E. JENSEN, Ph.D

Marvin E. Jensen retired from the Agricultural Research Service, USDA, in 1987, and from Colorado State University in 1993. Since 1993, he has been consulting on water consumption issues. He has 25 years of experience in measuring evapotranspiration in field experiments and over 40 years experience in estimating evapotranspiration. Jensen was the editor of the 1974 ASCE Report Consumptive Use of Water and Irrigation Water Requirements, and the senior editor of the 1990 ASCE Manuals and Reports on Engineering Practices No. 70 entitled Consumptive Use and Irrigation water Requirements.

As a specialist in irrigation water management and crop water requirements, he has over 125 publications. He was inducted into ARS-USDA Science Hall of Fame in 2000; Elected to National Academy of Engineering in 1988; awarded an Honorary Dr. of Science Degree from North Dakota State University in 1988; Elected Honorary Member of the American Society of Civil Engineers (ASCE) in 1988; received the ASCE Tipton Award in 1982 and the American Society of Agricultural Engineers (ASAE) John Deere Gold Medal Award in 1982; the ASAE Soil and Water Engineering Award in 1974; and the ASCE Huber Civil Engineering Research Prize in 1968.

JOHN BREDEHOEFT, Ph.D.

In 1995 John Bredehoeft established the consulting firm—The HydroDynamics Group. He devoted the previous 32 years to public service at the U.S. Geological Survey (USGS). His expertise is in water resources, especially groundwater; he has worked on many aspects of water related problems. During his years at the USGS, he held both scientific research and high-level management positions. In 1994, Bredehoeft retired as a senior research geologist from the Water Resources Division of the USGS.

In the tradition of the USGS, Bredehoeft held positions in both research and high-level management. For five years in the 1970s, he managed the USGS National Water Research Program. In the early 1980s, he was the Regional Hydrologist, Western Region, where he supervised the Survey's water activities in the eight western states—Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon, and Washington.

Bredehoeft taught one year as a visiting professor at the University of Illinois; and was a consulting professor at Stanford for 8 years, and at the University of California—Santa Cruz, and San Francisco State University for several years. He served on numerous national advisory committees for the National Research Council, the National Science Foundation, and the Department of Energy.

He received numerous awards: member of the U.S. National Academy of Engineering; Editor of the scientific journal, ***Ground Water*** (1991-95); received both the Horton Medal of the American Geophysical Union (the highest award given to a hydrologist), the Penrose Medal of the Geological Society of America (the highest award given to a geologist), and made a life-member of the National Ground Water Association (their highest award).

TERRY FISKE

Terry is a Ranger for the National Park Service assigned to Death Valley National Park. Terry is responsible for the water supply system at the park. The current water system is old and subject to contamination. Terry is currently reengineering the water system, modernizing it for use in the 21st Century.

WATER USE IN THE FURNACE CREEK AREA OF DEATH VALLEY

Marvin Jensen, Consultant, Fort Collins, CO
John Bredehoeft, The Hydrodynamics Group, Sausalito, CA
Terry Fiske, U.S. National Park Service, Death Valley, CA

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SPRING DISCHARGE

The discharge of the springs is not as readily measured as one might imagine. The water from Texas and Travertine springs are collected in tunnels, sumps, and buried tiles in the alluvium of Furnace Creek Wash below the springs. It is difficult to separate the Texas and Travertine spring flows in the collection system. Measuring the springs is also complicated by the fact that there are often several orifices.

The U.S. Geological Survey (USGS) investigated the spring flow in the 1960s (Pistrang and Kunkel, 1964). There are more recent measurements by the National Park Service (NPS), data taken in 2001 and 2003. With the help of Chris Fredrick of the USGS, we tried to reconcile the earlier measurements. Table 1 is a summary of the spring data that includes our best estimate of the current spring discharge:

Table 1. Summary of Furnace Creek spring discharge—flow in cfs.

Spring	Pistrang & Kunkel	NPS 2001/2003	This report
Texas	0.50	0.45	1.0
Travertine	3.90	3.39	3.2
Navel			0.1
Nevares	0.60	0.32	0.5
Cow Creek	0.10	0.10	0.1
Salt Creek			0.1
Total (flow in cfs)			5.0

WATER USE

Our combined estimate for Texas and Travertine springs is 4.2 cfs. Much of this flow goes to support the facilities in the oasis at Furnace Creek wash. As suggested above, these facilities include Furnace Creek Inn and Furnace Creek Ranch. Both have extensive grounds that are irrigated, including a golf course and date plam grove at the ranch. Both have lodging, restaurants, and bars; they both have large swimming pools.

It was our initial estimate that most of the water from Travertine Spring in particular is consumed by the facilities, including the irrigation in the Furnace Creek area. With that thought in mind, we set out to estimate the water consumption in the area. Figure 1 is a commercial satellite image of the Furnace creek area of Death Valley.

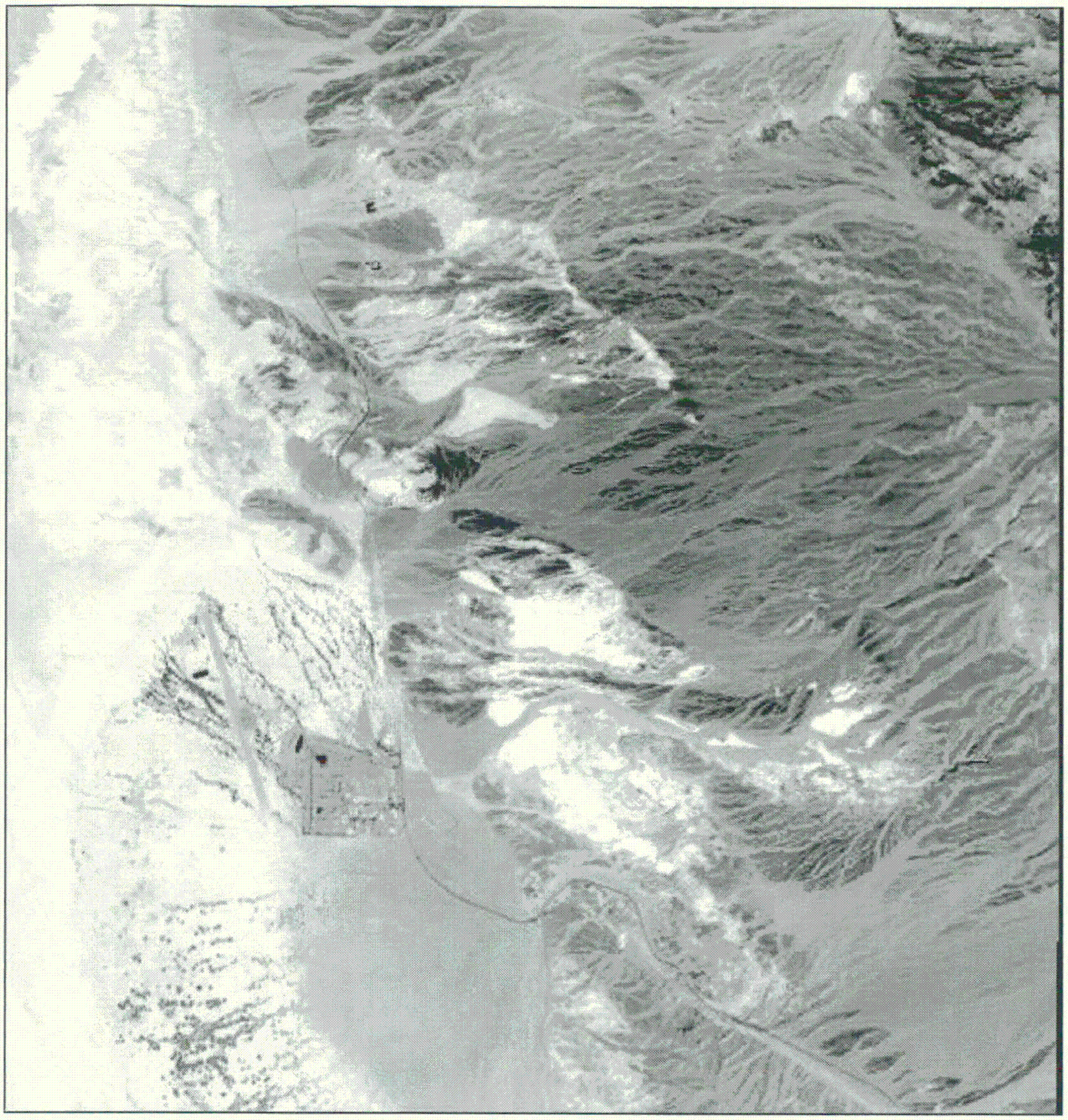

Figure 1. IKONOS satellite image of the Furnace Creek area of Death Valley.

On Figure 1, the image the Furnace Creek Ranch stands out, along with the airstrip. Figure 2 is a blow-up of the ranch area.

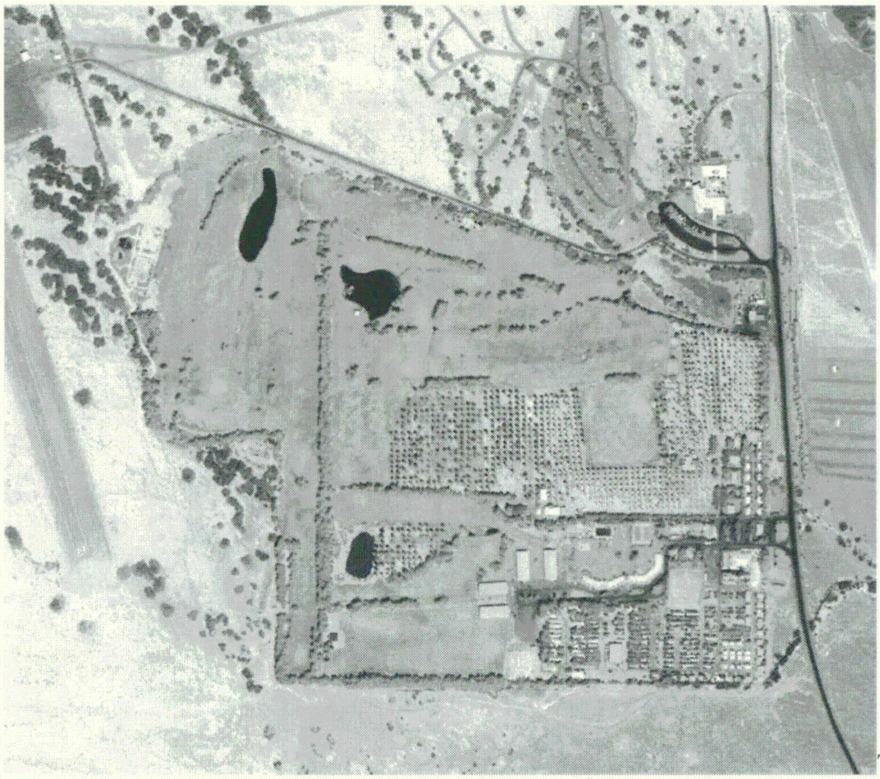
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Figure 2. IKONOS false-color infrared image of the Furnace Creek Ranch area.

These IKONAS images have a 1-meter resolution. They can be viewed as TIFF files in Photoshop where they can be blown up to show individual automobiles in the parking lots. The golf course, the date grove, the various buildings, and even the swimming pool show up on Figure 2. The vegetation is easily mapped on this image. By looking closely one can see shadows cast by the palm trees. Figure 3 is a blow up of the Furnace Creek Inn and its surroundings.

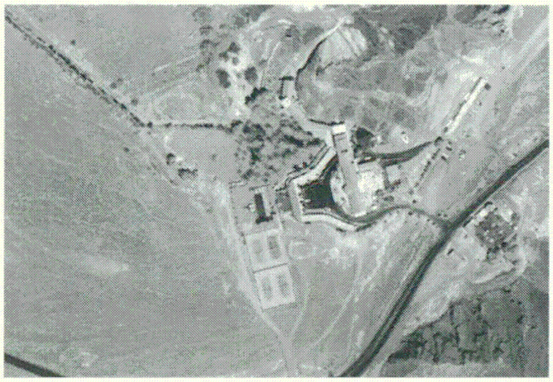

Figure 3. IKONOS false color infrared image of the Furnace Creek Inn and its surroundings.

One can see in the furnace Creek Inn image individual cars in the parking lot even on this picture. Things are much sharper working with the original satellite image. The image can be loaded and manipulated in Photoshop; this makes the interpretation possible on one's PC.

EVAPOTRANSPIRATION ESTIMATES FOR VEGETATED AREAS[1]

Our purpose was to estimate the annual net evapotranspiration (ET) from vegetated areas of Furnace Creek Ranch and Furnace Creek Inn. A preliminary estimate was made of net ET by salt cedar growing along dry creek beds, or drains, below Furnace Creek Ranch.

Climate

Calculated reference ET is the most commonly used index of evaporative climate evaporative demand. It is based mainly on net radiation, but also includes the effects of humidity and wind speed as measured over well-watered vegetation such as clipped grass or alfalfa. The first step in estimating ET from the vegetated areas of Furnace Creek Ranch and Furnace Creek Inn was to estimate reference ET for the area. A large part of the Furnace Creek Ranch is in grass because of the golf course, but there also is a large area of date palms. The color infrared satellite photographs indicate that some of the areas of date palm appear to have vegetative ground cover, and other areas appear to be essentially bare soil between date palms.

Because of the large area of short grass, grass reference ET similar to that used by the California Irrigation Management System (CIMIS) was used to characterize average evaporative demand. Daily reference ET was calculated for a three-year period (1999-2001) using daily CIMIS data primarily from Ripley, California. Although Ripley (Lat 33.53 °N, Long. 11.63 °W, Elev. 251 ft.) is further south than the study area (Lat 36.47 °N, Long. 116.87 °W, Elev. -194 ft.), its elevation is closer to that of the study area than other CIMIS stations at higher latitudes such as Barstow, CA (Lat. 34.88 °N, Elev. 2,040 ft), and Owens Lake, CA (Lat. 36.48 °N, Elev. 3,684 ft). CIMIS Blythe, CA (Lat. 33.56 °N, Elev. 275 ft.) is located near Ripley and has similar climate to that of Ripley. Imperial Valley is also below sea level, but is located further south at about 32.8 to 33.1 °N latitude. Long-term average, or normal temperature data from the National Weather Service Death Valley Station No. 2319 (NCDC, 1992) were also used with the Hargreaves equation (Hargreaves and Samani, 1985; Hargreaves et al., 1985) for grass reference ET because it requires only mean air temperature and extraterrestrial solar radiation.

Climate Variables and Calculations

Three years of daily climate data from the station at Ripley, CA were downloaded from CIMIS. CIMIS stations generally are located over irrigated grass or irrigated alfalfa so that air temperatures are modulated by ET from the underlying surface. The long-term or normal air temperature reported for Death Valley appears to be from the airport which would not be modulated by ET from the irrigated area. Therefore, the average air temperatures at Death Valley are generally several degrees C higher than that at Ripley (Figure 4). However, air temperature is not the major variable controlling reference ET. All calculations were done using SI metric units and summary values were converted to English units of feet and acre-feet (ac-ft).

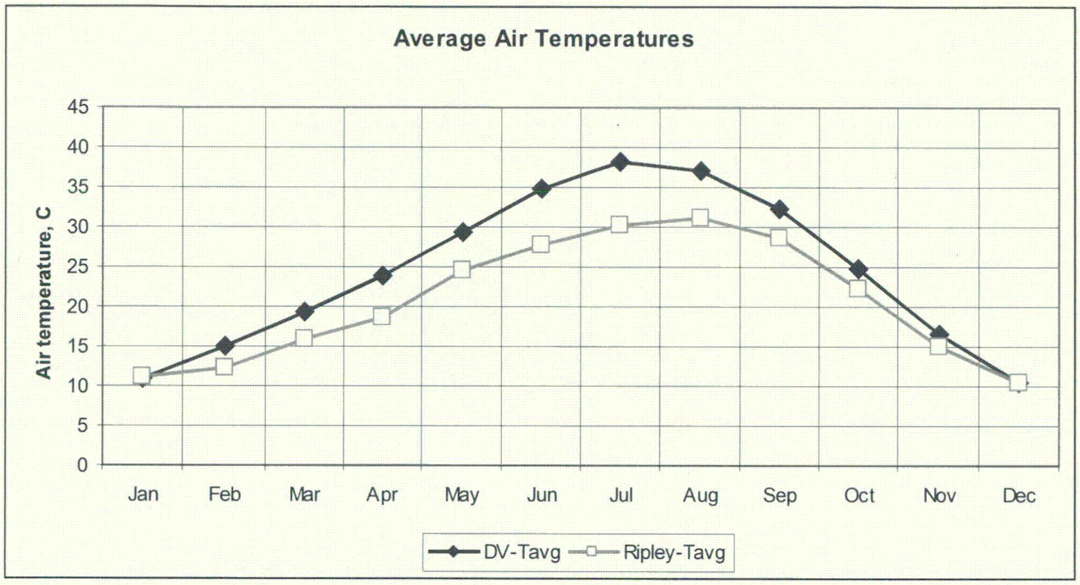

Figure 4. Average monthly air temperatures at Death Valley and Ripley, California.

Evaporative demand, or reference ET, is controled mainly by solar radiation. The estimated clear-day solar radiation at Death Valley compared to that at Ripley is shown in Figure 5. During the summer months, there is very little difference in estimated clear-day solar radiation at Death Valley compared with Ripley, California. Because solar radiation is the primary variable, the estimated ASCE grass reference ET for Ripley was very similar to that based on the Hargreaves equation at Death Valley as shown in Figure 6. Also shown in Figure 6 for comparative purposes is the average 99-01 CIMIS ET_o for Ripley and the weighted average ASCE ET_o for 89-02 Imperial irrigation District (IID). The results indicate that the mid-summer average ASCE ET_o for Ripley is a bit lower than the average ASCE ET_o for the IID, but higher than the 99-01 average CIMIS ET_o for Ripley. ASCE ET_o values typically are slightly higher than CIMIS ET_o calculated from hourly data. The average ASCE ET_o values for Ripley were considered to be a reasonable and conservative estimate for the area.

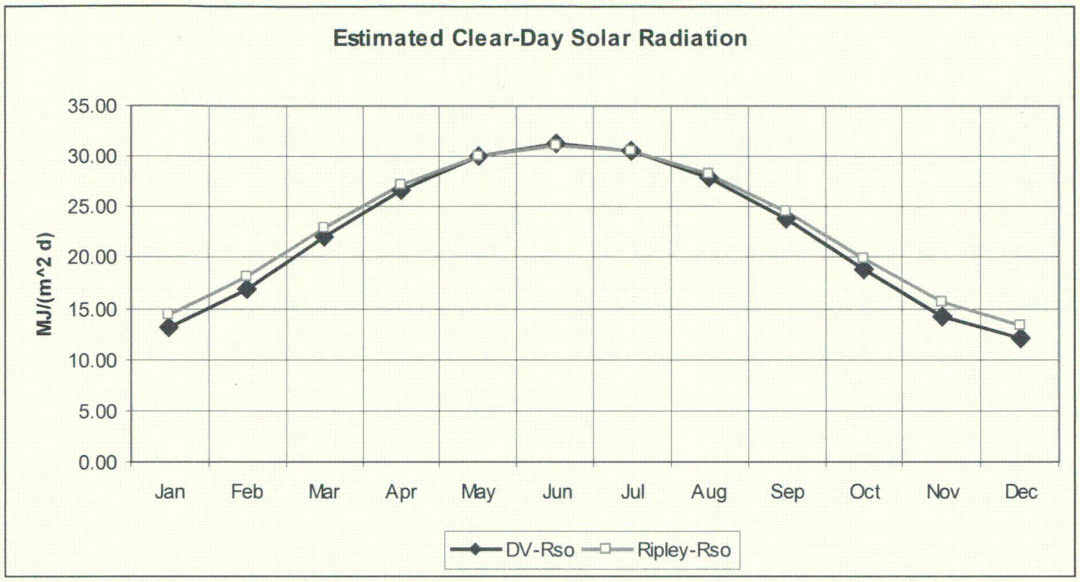

Figure 5. Estimated solar radiation on cloudless days at Death Valley and at Ripley, California.

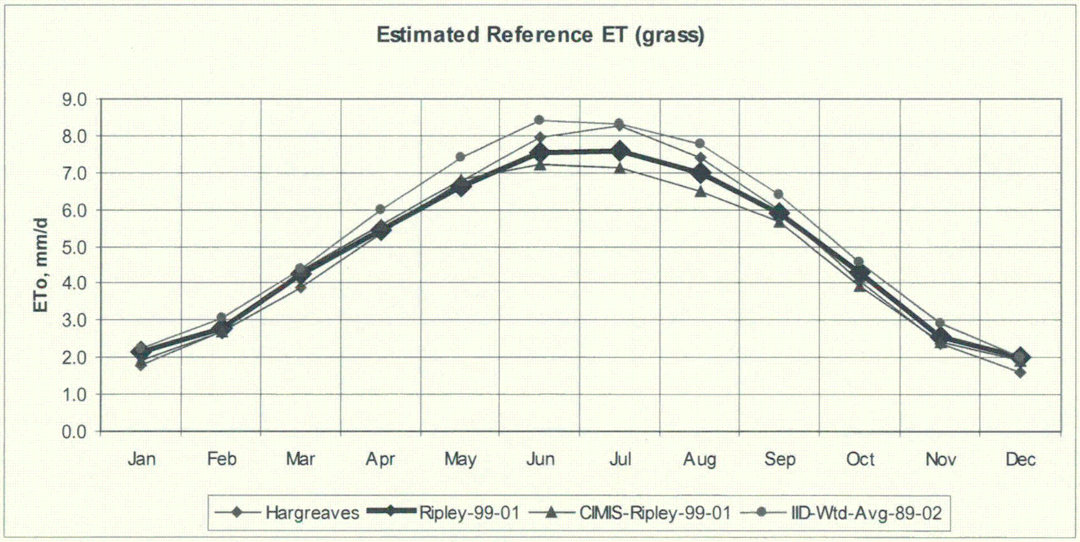

Figure 6. Estimated grass reference ET (ETo) at Death Valley using Hargreaves ET_o equation, ASCE ET_o and CIMIS ET_o for 99-01 Ripley, California, and weighted average ASCE ET_o for 1989-2002 Imperial Irrigation District.

ASCE Standardized Reference ET Equation

The daily ASCE reference crop ET was estimated using Equation 1.

$$ET_{os} = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

where ET_{os} = the standardized reference crop ET for a short vegetated surface under reference ET conditions in mm/d, R_n = net radiation at the reference surface in $MJ/(m^2\ d)$, G = soil heat flux density at the soil surface in $MJ/(m^2\ d)$, T = mean daily air temperature at 2-m height in °C, u_2 = mean daily wind speed at 2-m height, e_s = saturation water vapor pressure at the 2-m height calculated as the average vapor pressure at maximum and minimum air temperature in kPa, e_a = actual vapor pressure at the 2-m height in kPa, Δ = the slope of the vapor pressure-temperature curve in kPa/°C, and γ = the psychrometric constant in kPa/°C.

Crop (Vegetation) Coefficients

Today, the most common method used to estimate ET for crops and other vegetation is to first calculate reference ET and then apply a coefficient that varies with growth stage or time of year. Estimated ET is, therefore, the product of the coefficient (K_c) and reference ET.

$$ET = K_c\, ET_o \qquad (2)$$

Table 2. Coefficients for various vegetative groups and associated acreage.

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Golf course [a]	0.85	0.85	0.85	0.85	0.85	0.80	0.80	0.80	0.80	0.80	0.85	0.85
Ponds	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Date palms, with ground cover [b]	1.01	1.04	1.09	1.14	1.19	1.21	1.21	1.21	1.21	1.21	1.10	1.00
Date palms, clean cultivated [c]	0.81	0.84	0.89	0.94	0.99	1.01	1.01	1.01	1.01	1.01	0.90	0.80
Date palms, bare ground [d]	0.71	0.74	0.79	0.84	0.89	0.91	0.91	0.91	0.91	0.91	0.80	0.70
Grass, poor growth	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Vegetation by housing areas [e]	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Salt cedar (deciduous) by drains [f]	0.23	0.23	0.45	0.79	1.11	1.18	1.18	1.15	0.90	0.61	0.32	0.22

[a] Assumed to be fairway quality Bermuda grass in summer and overseeded with intermediate ryegrass in the winter (Brown et al., 2003) and adequately watered year round.

[b] For this area, 0.2 added to cleaned cultivated monthly date palm K_c.

[c] Coefficients for clean cultivated date palms based on early studies using soil sampling measurements reported by Jensen and Haise (1963) and adapted to grass reference ET for use along the Colorado River.

[d] For this area, 0.1 was subtracted from clean cultivated monthly date palm K_c because of essentially no vegetation between date palms.

[e] Vegetation by buildings assumed to be grass, shrubs and trees. The area of buildings, parking and roads was reduced by a factor of 0.3.

[f] Developed for use with grass reference ET and verified with measurements made in lysimeters in Arizona by van Hylckama (1974).

Coefficients typically are derived for use with either a grass reference ET (ET_o) or an alfalfa reference ET (ET_r). For this study, a grass reference ET was calculated and coefficients developed for the various groups of vegetation and associated acreage are summarized in Table 2.

Areas of Vegetation

Areas of different vegetation were outlined on a scanned copy of one of the satellite color photographs and the areas were then calculated using a CAD program. The scaling factor for the main vegetated area was based on the length of the airport runway. The scaling factor for the Furnace Creek Inn was based on an assumed length of the swimming pool of 80 ft. Alternatively, the tennis courts could have been used. A summary of the areas of various types of vegetation is presented in Table 2.

Average Annual Flow Rate

Average annual flow rate needed to sustain estimated net ET was calculated as the total annual ET in ac-ft divided by the area involved as summarized in Table 2. Net ET was calculated as estimated ET minus normal precipitation. Annual normal precipitation for Death Valley is only 2.28 inches.

Table 3. Areas of various vegetation types used in estimating average monthly and total annual ET depth and volume.

Vegetated area	Area, Acres	Estimated Net ET, ft	Estimated Net ET, ac-ft
Golf course	102.7	4.6	472
Ponds	3.1	5.6	18
Date palms w ground cover	7.7	6.6	51
Date palms, clean cultivated	3.5	5.4	19
Date palms, bare ground	13.4	4.9	65
Grass, poor growth	4.1	4.5	18
Vegetation, bldgs, parking, etc.	33.6	6.2	63 [a]
Furnace Creek Inn vegetation	10.4	6.2	65
Vegetation by NE buildings	1.3	6.2	8
Resort subtotal	180	4.3	779
Salt cedar by drains	140	4.8	672

[a] The area was reduced by a factor of 0.3 to account for buildings, parking lots and roadways.

RESULTS

The estimated average monthly and annual rate of flow from Furnace Creek springs needed to sustain the estimated rate of net ET on the vegetated areas is summarized in Figure 7. The average annual flow rate for both resort and salt cedar vegetation is about 2.0 cfs. The average annual flow rate for resort vegetation is 1.1 cfs and for salt cedar areas it is 0.9 cfs for a total of 2.0 cfs. However, the irrigation demand ranges from a low value of 0.50 cfs in the winter to a high of 3.75 cfs in the summer.

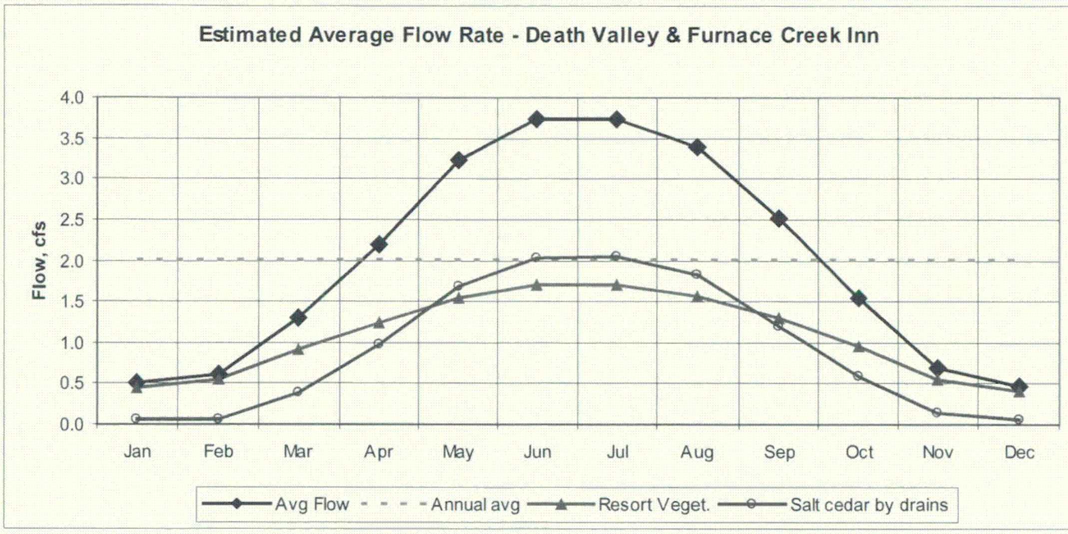

Figure 7. Estimated average flow rate needed to sustain net evapotranspiration of resort vegetation and salt cedar by drains.

DISSUSSION & CONCLUSIONS

The evapotranspiration by the various crops is high. It ranges a low of 4.4 ft/yr for grass to a high of 6.6 ft/yr for date palms with a grass undercover. The irrigated area is not large; the total is reduced for the buildings and paved area by 30%. The total annual consumptive use by the irrigation and the salt cedar is only 2.0 cfs. However, the demand is high in the summer months—3.75 cfs. The peak demand in the summer approaches the total low of both Texas and Travertine springs—our estimate 4.2 cfs. Given the uncertainty in the discharge of the springs, and perhaps some seasonal variation in flow, the irrigation demand is 90% of the combined discharge of the two springs—this is close to the estimated total flow of the two springs.

REFERENCES

Hargreaves, G.H. and Z.A. Samani. 1985. Reference crop evapotranspiration from temperature. *Applied Engrg. in Agr.,* Am. Soc. Agr. Engr, 1(2):96-99.

Hargreaves, G.L., G.H. Hargreaves, and J.P. Riley. 1985. Agricultural benefits for Senegal River Basin, *J. Irrig. and Drain. Engr., Am. Soc. Civ. Engr.*, 111(2):113-124.

Jensen, M.E., and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. *J. Irrig. & Drain. Div., Am. Soc. Civ. Engr.*, 89:15-41.

National Climate Data Center. 1992. Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, California. *Climatography of the United States No. 81.*

Pistrang, M.A. and F. Kunkel. 1964. A brief geologic reconnaissance of the Furnace creek Wash area, Death Valley National Monument, California. *U.S. Geological Survey Water Supply paper 1779,* Y1-Y35.

van Hylckama, T.E.A. 1974. Water use by salt cedar as measured by the water budget method. *U.S. Geological Survey Prof. Paper 491-E*, 30 pp.

Walter, I. A., R.G. Allen, R. Elliott, M. E. Jensen, D. Itenfisu, B. Mecham, T. A. Howell, R. Snyder, P. Brown, S. Eching, T. Spofford, M. Hattendorf, R. H. Cuenca, J. L. Wright and D. Martin. 2000. "ASCE's Standardized Reference Evapotranspiration Equation." *Proc., 4th National Irrig. Symp.*, ASAE, Phoenix, AZ.

BRIEF RESUMES OF THE AUTHORS

M.E. JENSEN, Ph.D

Marvin E. Jensen retired from the Agricultural Research Service, USDA, in 1987, and from Colorado State University in 1993. Since 1993, he has been consulting on water consumption issues. He has 25 years of experience in measuring evapotranspiration in field experiments and over 40 years experience in estimating evapotranspiration. Jensen was the editor of the 1974 ASCE Report Consumptive Use of Water and Irrigation Water Requirements, and the senior editor of the 1990 ASCE Manuals and Reports on Engineering Practices No. 70 entitled Consumptive Use and Irrigation water Requirements.

As a specialist in irrigation water management and crop water requirements, he has over 125 publications. He was inducted into ARS-USDA Science Hall of Fame in 2000; Elected to National Academy of Engineering in 1988; awarded an Honorary Dr. of Science Degree from North Dakota State University in 1988; Elected Honorary Member of the American Society of Civil Engineers (ASCE) in 1988; received the ASCE Tipton Award in 1982 and the American Society of Agricultural Engineers (ASAE) John Deere Gold Medal Award in 1982; the ASAE Soil and Water Engineering Award in 1974; and the ASCE Huber Civil Engineering Research Prize in 1968.

JOHN BREDEHOEFT, Ph.D.

In 1995 John Bredehoeft established the consulting firm—The HydroDynamics Group. He devoted the previous 32 years to public service at the U.S. Geological Survey (USGS). His expertise is in water resources, especially groundwater; he has worked on many aspects of water related problems. During his years at the USGS, he held both scientific research and high-level management positions. In 1994, Bredehoeft retired as a senior research geologist from the Water Resources Division of the USGS.

In the tradition of the USGS, Bredehoeft held positions in both research and high-level management. For five years in the 1970s, he managed the USGS National Water Research Program. In the early 1980s, he was the Regional Hydrologist, Western Region, where he supervised the Survey's water activities in the eight western states—Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon, and Washington.

Bredehoeft taught one year as a visiting professor at the University of Illinois; and was a consulting professor at Stanford for 8 years, and at the University of California—Santa Cruz, and San Francisco State University for several years. He served on numerous national advisory committees for the National Research Council, the National Science Foundation, and the Department of Energy.

He received numerous awards: member of the U.S. National Academy of Engineering; Editor of the scientific journal, ***Ground Water*** (1991-95); received both the Horton Medal of the American Geophysical Union (the highest award given to a hydrologist), the Penrose Medal of the Geological Society of America (the highest award given to a geologist), and made a life-member of the National Ground Water Association (their highest award).

TERRY FISKE

Terry is a Ranger for the National Park Service assigned to Death Valley National Park. Terry is responsible for the water supply system at the park. The current water system is old and subject to contamination. Terry is currently reengineering the water system, modernizing it for use in the 21st Century.

ANDY ZDON & ASSOCIATES, INC.

TECHNICAL REVIEW SUMMARY- DRAFT SUPPLEMENT TO U.S. DEPARTMENT OF ENERGY'S ENVIRONMENTAL IMPACT STATEMENT FOR THE PROPOSED NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY AT YUCCA MOUNTAIN, NEVADA

November 11, 2015

Prepared For:
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TECHNICAL REVIEW SUMMARY –SUPPLEMENT TO U.S. DEPARTMENT OF ENERGY'S ENVIRONMENTAL IMPACT STATEMENT FOR THE PROPOSED NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY AT YUCCA MOUNTAIN, NEVADA

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President, Principal Hydrogeologist

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EXECUTIVE SUMMARY

This technical review summary report (Review Summary Report) was prepared by Andy Zdon & Associates, Inc. (AZI) on behalf of the County of Inyo, Planning Department. The purpose of this report is to provide technical comments related to the *"Supplement to the U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada"* (Supplement to the EIS) prepared by the United States Regulatory Commission (NRC), and released August, 2015. This Supplement to the EIS was prepared in response to findings identified in the NRC's *"U.S. Nuclear Regulatory Commission Staff's Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain"*, herein referred to as the Adoption Determination (NRC, 2008).

The Adoption Determination noted that the EISs did not provide a complete and adequate discussion of the impacts on soils and surface materials from a potential future discharge of contaminated groundwater. More specifically, the Adoption Determination noted the following items that should be included (but not necessarily limited to) the following (as quoted from Adoption Determination):

- *NRC Item #1 - "A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods (for example, as discussed in DOE, 2008, Safety Analysis Report, Section 2.3.1.2);*
- *NRC Item #2 - A description of the physical processes at the surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants; and,*
- *NRC Item #3 - Estimates of the amount of contaminants that could be deposited at or near the surface. This involves estimates of the amount of groundwater involved in discharge or near-surface evaporation, the amounts of radiological and non-radiological contaminants in that water, contaminant concentrations in the resulting deposits, and potential environmental impacts (e.g. effects on biota)."*

In the County's comments (County of Inyo, 2008) with respect to the EIS (U.S. Department of Energy, 2008), the County raised the following points that needed to be addressed:

- Inyo Item #1 - The full extent of the lower carbonate aquifer, particularly those parts that could become contaminated and how water can leave the flow system should be described;
- Inyo Item #2 - The potential for a decrease or elimination of the upward vertical gradient beneath Yucca Mountain due to future upgradient water-gathering activities (e.g. by Southern Nevada Water Authority);
- Inyo Item #3 - Impacts to Endangered Species that utilize the springs in the region; and,
- Inyo Item #4 - Cleanup and remediation measures should be described.

Addressing all of these points are dependent on a complete description of the conceptual model of the basin. Consideration of work conducted in the Shoshone-Tecopa area since 2010 is absent from the Supplement to the EIS. This work affects the conceptual model employed in the Supplement to the SEIS. Therefore a summary of the conceptual model is provided to present key information for consideration, and to provide context to Section 3.0 summarizing AZI's modeling effort conducted as part of this review.

In summary, our review indicates that the Supplement to the EIS has been non-responsive to each of the items listed in the Adoption Determination and to each of the issues raised by Inyo County. Further, conducting a long-term impact analysis as presented will intrinsically have substantial uncertainties associated with both climate and environmental (including hydrogeologic) changes that can occur over one million years. Based on the lack of updated information presented in the Supplement to the EIS, and errors identified herein, there is a high degree of additional uncertainty attached to the conclusions presented. Although conservative assumptions are presented in the Supplement to the EIS, a full description of the uncertainties attached to such an analysis (and sensitivity analysis) is lacking.

Recommendations are made for future work including a reevaluation of the conceptual model and associated numerical flow and particle tracking modeling. This includes additional data collection including initiating a monitoring program protective of water resources within Inyo County (both in Death Valley and the Shoshone-Tecopa area), and for the development of a groundwater remedial action plan based upon the results of the reevaluation described above.

1.0 INTRODUCTION

This technical review summary report (Review Summary Report) was prepared by Andy Zdon & Associates, Inc. (AZI) on behalf of the County of Inyo, Planning Department. The purpose of this report is to provide technical comments related to the "*Supplement to the U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*" (Supplement to the EIS) prepared by the United States Regulatory Commission (NRC), and released August, 2015. The Supplement to the EIS was prepared in response to findings identified in the NRC's "*U.S. Nuclear Regulatory Commission Staff's Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain*", herein referred to as the Adoption Determination (NRC, 2008).

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The importance of these items is highlighted by the acknowledgement in the EISs of the likelihood of future discharges of contaminated groundwater to the surface (NRC, 2008). With respect to the Item #1 above, the Adoption Report noted that the following information was needed:

- *"A description of the full extent of the volcanic-alluvial aquifer, particularly those parts that could become contaminated, and how water (and potential contaminants) can leave the flow system"*;
- *"An analysis of the cumulative amount of radiological and non-radiological contaminants that can be reasonably expected to enter the aquifer from the repository, and the amount that could reasonably remain over time"*; and,
- *"Estimates of contamination in the groundwater, given potential accumulation of radiological and non-radiological contaminants. One way to analyze the overall impacts on groundwater may be a mass-balance approach that*

accounts for mass released, the part of the groundwater flow system affected to potential releases, and the expected processes that could affect released contaminants."

With respect to Items #2 and 3 above, the Adoption Report noted that the following information was needed:

- *"A description of the locations of the potential discharge of contaminated groundwater for present and expected future wetter periods:*
- *A description of the physical processes at the surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants; and,*
- *Estimates of the amount of contaminants that could be deposited at or near the surface."*

In the County's comments (County of Inyo, 2008) with respect to the EIS (U.S. Department of Energy, 2008), the County raised the following points that needed to be addressed:

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- Inyo Item #3 - Impacts to Endangered Species that utilize the springs in the region; and,
- Inyo Item #4 - Cleanup and remediation measures should be described.

As will be discussed in the following sections, substantial hydrogeologic investigative work has been conducted in the Lower Amargosa River (also known as Middle Amargosa Basin) area since 2010 by the U.S. Geological Survey and consultants. This new work which has been funded by the U.S. Bureau of Land Management, Inyo County, Amargosa Conservancy and The Nature Conservancy between 2010 and 2014, has resulted in multiple lines of investigation that have generally converged to a common conceptual model indicating the need for substantive changes to the conceptual model presented in the Yucca Mountain analyses by the U.S. Department of Energy and NRC. This work has not been considered and not incorporated into the analysis presented in the Supplement to the EIS. Much of that new work is summarized in the State of the Basin Report, Amargosa River Basin (Andy Zdon & Associates, Inc., 2014). Upon completion, the State of the Basin Report was widely disseminated to federal, state and local agencies, among others. This work is being published in *Environmental Forensics* (an official journal of the International Society of Environmental Forensics), a peer-reviewed journal (Zdon, Davisson and Love, 2015). A draft proof copy of that article is provided in Appendix A. The final article will be released December 11, 2015 at www.tandfonline/toc/uenf20/current. Additionally, the new conceptual model was presented in May, 2015 at the Devil's Hole Conference at Ash Meadows National Wildlife Refuge, Nye County, Nevada (Belcher, et. al., 2015).

The new work extended the foundational work demonstrating movement of groundwater from the Nevada portion of the Amargosa Basin feeds the springs in the Death Valley area (King and Bredehoeft, 1999). That this connection had substantial implications regarding radionuclide transport toward those Death Valley springs was subsequently demonstrated (Bredehoeft and King, 2010). More will be discussed regarding these implications in the following sections.

This report addresses each of the issues which have been highlighted in the Adoption Determination and by the County of Inyo by incorporating comments in the context of a conceptual model discussion, as well as in the results of independent modeling using a U.S. Geological Survey-developed numerical model. Section 4.0 summarizes the results of our review of each of the areas where further information is needed.

1.1 Background– Lower Amargosa River

The Amargosa River Basin covers an area of 3,124 square miles in east-central California and west-central Nevada (Figure 1-1). In 2009, the Amargosa River between Shoshone and the terminus of the Amargosa Canyon received Wild and Scenic status through an act of Congress. The Wild & Scenic Amargosa River (Amargosa WSR) is a groundwater dependent river, fed by surfacing groundwater along the river channel and from feeder springs that are tributary to the Amargosa WSR and its approximately 26 miles of perennial flow. Of note is that the Supplement to the EIS does not address potential impacts to this federally-designated WSR. Appendix B provides summaries of portions of the Amargosa WSR and associated springs in the area where all or part of the flows are derived from the Amargosa Desert area in Nevada. The determination that such flows are derived all or in part from the Amargosa Desert is based on geochemistry of the water present. Figures 1-2 through 1-4 show the locations of these and other springs in the area.

The Amargosa River Basin can be subdivided into three basin areas:

- Northern Amargosa Groundwater Basin (Nevada portion of the Basin also referred to as the Amargosa Desert Hydrographic Basin #230 by the Nevada Department of Water Resources);
- Middle Amargosa Valley Groundwater Basin (California); and
- Death Valley Groundwater Basin (California –Nevada).

The Northern Amargosa Valley Groundwater Basin is comprised of the Amargosa River Valley from the river's headwaters northwest of Beatty, Nevada, to the California-Nevada state line. Elevations in this portion of the Amargosa River Basin range from 6,317 feet above mean sea level (ft msl) at Bare Mountain south of Beatty and east of the Amargosa River, to about 2,300 ft msl at the California-Nevada state line near Death Valley Junction, California. The basin is bounded by consolidated rocks of the Yucca Mountain/Pahute Mesa area to the northeast, Bare Mountain on the east, and the Funeral Range to the west. The Northern Amargosa River Basin as defined covers 896 square miles. This is the region of focus in the Supplement to the EIS.

Of note is that the Supplement to the EIS states that the Ash Meadows is in a neighboring basin east of Amargosa Farms, and as such is not a discharge location for groundwater flowing from Yucca Mountain. It should be noted that both Amargosa Farms and Ash Meadows are with the Amargosa Desert Hydrographic Basin (#230) as delineated by the Nevada Division of Water Resources.

The Middle Amargosa Valley Groundwater Basin (also referred to as the Lower Amargosa River Basin in some publications and presentations, Groundwater Basin #6-20 as designated by the California Department of Water Resources) is comprised of the Amargosa River Valley along with Chicago Valley and parts of Greenwater Valley within Inyo and San Bernardino Counties, California. The California-Nevada state line is considered the northern boundary of the Middle Amargosa Valley Groundwater Basin. The elevation of the valley floor generally ranges from about 400 ft msl near Salt Creek in the southern portion of the valley to about 2,300 ft msl at the California-Nevada state line near Death Valley Junction. The basin is bounded by consolidated rocks of the Resting Springs and Nopah Ranges on the east, the Dumont Hills on the south, and the Greenwater Range and Ibex, Black, and Funeral Mountains (collectively known as the Amargosa Range) on the west. The surrounding mountains range in elevation up to 7,335 ft msl at Kingston Peak (within San Bernardino County along the southeast edge of the Basin) and up to 6,725 ft msl at Pyramid Peak, the high point of the Funeral Range to the west. The Middle Amargosa River Basin covers an area of 609 square miles.

The Death Valley Groundwater Basin (Groundwater Basin #6-18 as designated by the California Department of Water Resources) is comprised of the Amargosa River Valley from the Salt Creek area to the sink at Badwater in Death Valley, and northward to the northern physical terminus of Death Valley in Nevada (Oriental Wash Area of the Death Valley Basin as designated by the Nevada State Engineer). Elevations in this portion of the Amargosa River Basin range from -282 ft msl at Badwater, to 11,049 ft msl at Telescope Peak, the highpoint of the Panamint Range along the west side of Death Valley. The combined area of the California and Nevada portions of this lower part of the Amargosa River basin is 1,622 square miles. The springs described in the Supplement to the EIS in Death Valley National Park lie within the Death Valley Basin.

1.2 Land Use

The principal land uses (not including open space and wild lands) in the area are agricultural, recreational, wildlife, livestock and domestic/municipal uses. With increasing solar development, industrial use may increase in the future. Agricultural and domestic water is generally supplied with groundwater from private wells. Water for the town of Shoshone, California is entirely supplied by Shoshone Spring. As will be shown later in this report, spring flow at Shoshone Spring and other springs in the area result in whole or part from groundwater movement southward through the alluvial aquifer from the Amargosa Desert area of Nevada. The town of Beatty, Nevada derives its water from groundwater wells. However, some residents obtain their water solely from spring water. Sewage is generally treated by individual septic systems with the exception of at the communities of Beatty, Nevada, and Shoshone and Tecopa (both in

California) where sewage systems are presently serving some areas. Agricultural land use is primarily crops such as alfalfa (Nevada) and to a much lesser extent dates (California). Recreational uses include the use of spring water at the hot springs in Tecopa, California, and the hot springs northeast of Beatty, Nevada along U.S. Highway 95.

1.3 Hydrologic Activities (2010-2014) – Amargosa River Hydrologic Survey

Prior to 2010, hydrogeologic data collection and analysis were largely absent in the portion of the Amargosa River Basin south of the Nevada-California state line. Assumptions were made regarding groundwater flow into this portion of the Amargosa Basin absent much needed physical data. Most of the assumptions upon which the conceptual model for this portion of the basin was based were the result of residuals or assumed subsurface outflows from investigations of other portions of the flow system, and would therefore be prone to significant error and were speculative at that time.

Beginning in 2010, a considerable amount of hydrologic work has been conducted starting with the initial baseline hydrologic investigations (SGI, 2011 and 2012) that were sponsored by the Amargosa Conservancy. This work has been the result of a cooperative effort funded by the U.S. Bureau of Land Management, Nye County, Nevada, Amargosa Conservancy and The Nature Conservancy. Based on our review of the Supplement to the EIS as described earlier, this work has not been considered, and/or incorporated into the analysis. Such consideration and/or incorporation is necessary. That work over the past five years has included the following:

- Geochemical analysis (anions, cations, and metals) along with stable and unstable (uranium and strontium) isotope, noble gas, and radiocarbon analyses on springs, wells, and the Amargosa River;
- Periodic river gaging at several locations along the Amargosa River;
- Periodic spring flow and groundwater level measurements at springs and wells throughout the Middle Amargosa River Basin;
- Installation of four shallow monitoring wells 1) north of Shoshone along the Amargosa River, 2) along Willow Creek, 3) at Twelvemile Spring, and 4) at "Married Man's Camp" between Willow Creek and California Valley. This work included sampling and analyzing waters from those wells and outfitting those wells with transducer/data logger installations and periodic groundwater level data downloading (JWI, 2012 and JWI, 2013a);
- Refined geologic mapping being conducted by the USGS;
- Geophysical surveys by the USGS at selected locations throughout the Middle Amargosa Basin area;
- An in depth synoptic canvassing of the flow in the Amargosa River by the USGS to evaluate gaining and losing character of the River (conducted in February, 2014);

- Initiation of evapotranspiration studies along the Amargosa River in the Shoshone – Tecopa area (USGS – in progress); and,
- Development of a new, steady-state numerical groundwater flow model that simulates the Amargosa River region in the context of modeling flow throughout the carbonate rock aquifer system throughout the Great Basin (completed and published in 2014).

In addition, additional sampling and analysis was conducted to evaluate a source of water for potable water and fire suppression for the Tecopa – Tecopa Hot Springs community (JWI, 2013c). The extent of this data collection is an indication of the degree to which data were lacking in the area prior to 2010. The new work has highlighted an increased southward flow component from the Amargosa Desert than was previously estimated. For example, if it is assumed that flows from Shoshone Spring and Borax Spring west of the Amargosa River are between 500 and 1,000 gallons per minute of discharge (not including other discharges in the area) this discharge data, when considered in combination with new geochemical data that show that the discharge is largely derived from the groundwater underflow from the north, substantially increases the estimate of underflow into the Shoshone-Tecopa subregion above previous estimates. Therefore, substantially more flow must enter the subregion from the north to balance these groundwater discharges.

1.3.1 Results - Geochemistry

Of the work described above, geochemical analyses have been among the most informative. Although described in Section 2.0 (conceptual model), a summary of the geochemical results is presented here as well. A detailed description of the investigative results are provided in the report prepared by M.L. Davisson & Associates, Inc., and provided in Appendix C.

Stable isotope and other geochemical data indicate that Middle Amargosa River area groundwater appears to be a mixture of Ash Meadows (primarily from alluvium that is a mixture of waters derived from flow and/or recharge in the carbonate rock aquifer, volcanic rocks of the upper Amargosa River Basin, and the alluvial basin fill of the Amargosa Desert area), Spring Mountains and Kingston Range sources (Figures 1-5 and 1-6). The pathways (Figure 1-7) for that groundwater moving from the Pahrump Valley area to reach the area probably consist of one or a combination of:

- Water that moves through carbonate rocks from the Spring Mountains to the Ash Meadows and Amagosa Desert area, then southward toward the Shoshone-Tecopa area;
- Water that moves through carbonate rocks beneath the northern portion of the Nopah Range into Chicago Valley, then toward the Amargosa River;
- Water that moves from Pahrump Valley through the low, faulted divide into California Valley then towards the River; and,

Most of the spring/groundwater samples have characteristics indicative of having been influenced by Spring Mountain recharge by some route with western springs such as Shoshone and Borax being the least influenced by sources to the east (including the Spring Mountains) and most influenced by a source to the north. Most of the mixing is probably occurring via fractured rock at depth, and less so in the alluvium. Water quality in the springs in the Shoshone-Tecopa area likely evolves from a mixture of regional carbonate and Tertiary volcanic rock influences, but acquires increased chloride and sulfate possibly from the Tecopa lake bed deposits. Additionally, regional subsurface heat flow increases groundwater temperature and contributes to increased dissolved silica, decreased bicarbonate, and possibly increased pH, with the latter resulting in the high arsenic concentrations. The source of the arsenic could be from multiple sources, but as pH increases the solubility increases to significantly high levels as presented on Figure 1-8.

Noble gas concentrations of the water in the Shoshone-Tecopa area are strongly similar to those measured in the Ash Meadows area (Amargosa Desert of southern Nevada) groundwater noted by Thomas, et.al. (2003b). Their conclusions were that dissolved gas loss occurred during subsurface transport across faulted boundaries and compromised recharge temperature/elevation calculations. The noble gas recharge temperatures/elevation calculations for Amargosa River Valley groundwater mostly support the conclusions of Thomas, et.al. (2003b).

The $^3He/^4He$ ratios for the four measured springs (Thom, Wild Bath, Tecopa and Borehole) were unusually low, indicating old groundwater ages. The values were 5 to 10 times lower than measured groundwater under the Nevada Test Site. These low ratios could be due to high influx of ^4He from the Earth's crust caused by deep faults. Otherwise, if the low ratio is due to steady-state accumulation from local deposits, then groundwater ages greater than 100,000 years would be required. Additionally, the helium ratios did not suggest the presence of a shallow magmatic heat source for the Tecopa Hot Springs area, and indicate that the heat source is via deep circulation, probably along the faults that run through the area. The elevated temperature of the Tecopa Hot Spring water is not unusual since similar temperatures are seen at depth under the Nevada Test Site. However, at Tecopa, the warm water is driven to the surface probably by some structural control.

2.0 GROUNDWATER SYSTEM – CONCEPTUAL MODEL

The conceptual model of a groundwater system is the foundation of any analysis of a groundwater basin. The conceptual model describes groundwater occurrence, groundwater movement, hydraulic properties of aquifer materials, and groundwater inflow and outflow components. As new data have been gathered in the Middle Amargosa Basin since 2010, the conceptual model for the area has been updated as appropriate to reflect those data. This section provides an updated overview of the conceptual model reflecting the results of new geochemical data, groundwater level data, and river gauging results in the context of responding to the Supplement to the EIS.

As described earlier, the Adoption Determination noted the following items that should be included (but not necessarily limited to) the following (as quoted from Adoption Determination):

- *"A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods (for example, as discussed in DOE, 2008, Safety Analysis Report, Section 2.3.1.2);*
- *A description of the physical processes at the surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants; and,*
- *Estimates of the amount of contaminants that could be deposited at or near the surface. This involves estimates of the amount of groundwater involved in discharge or near-surface evaporation, the amounts of radiological and non-radiological contaminants in that water, contaminant concentrations in the resulting deposits, and potential environmental impacts (e.g. effects on biota)."*

Addressing all of these points is dependent on a complete description of the conceptual model of the basin. As described earlier, the work conducted in the Shoshone-Tecopa area since 2010 is generally absent from the Supplement to the EIS. Therefore a summary of the conceptual model is provided to present key information for consideration, and to provide context to Section 3.0 summarizing AZI's modeling effort conducted as part of this review.

The description of the hydrogeology of the Amargosa Basin south of Alkali Flat in the Supplement to the EIS is incorrect and fails to recognize the "small, intermittent" springs present as being the perennial, substantial springs that they are (see summaries in Appendix B). In that conceptual model, there is no mention of the springs of note, the extent of surface flow in the Amargosa River (which is incorrectly characterized as five miles in the Supplement to the EIS) or reference to work conducted since 2010 in that part of the basin, or even work conducted previously (e.g. Rose and Davisson, 1996), and that work's implications to the basin conceptual model.

2.1 Regional Setting and Geologic Conditions

The Amargosa River Basin is located in Inyo and San Bernardino Counties, California, and Nye County, Nevada within the Basin and Range geomorphic province. The Basin and Range region is characterized by basins of internal drainage with considerable topographic relief, alternating between narrow faulted mountain chains and flat arid valleys or basins. The ranges generally trend north-northwest parallel to the regional structural regime. The geology of the Amargosa Basin is very diverse containing Precambrian, Paleozoic and Mesozoic metamorphic and sedimentary rocks, Mesozoic-aged igneous rocks, Tertiary and Quaternary-aged volcanic rocks, and playa, fluvial and alluvial deposits (Planert and Williams, 1995). A regional geologic map is provided on Figure 2-1.

The valley areas are covered by coalescing alluvial fans forming broad slopes between the surrounding mountains and the valley floors. The regional gradient of the Northern Amargosa River Basin is generally to the south-southeast with gradients that typically range from five to 15 feet per mile. The basin fill deposits are interpreted to be underlain primarily by Paleozoic sediments although in the central portion of the basin floors, the basin fill sediments have not been fully penetrated by drilling. Generally, the Middle Amargosa Basin is marked by several unique features including the badland-type topography of the Tecopa lakebed deposits and the Amargosa River Canyon. Between Shoshone and Tecopa the slope of the valley floor flattens among the lakebed deposits, and then steepens as the river flows through the Amargosa River Canyon. Downstream of the canyon, the topography reverts to an area of broad, coalescing alluvial fans, eventually reaching the flat playa in Death Valley.

2.2 Hydrogeologic Units

In the Amargosa River Basin, the principal hydrogeologic units consist of unconsolidated basin fill materials, volcanic rocks (primarily in Nevada), and the carbonate rock aquifer. The following provides a summary of these three hydrogeologic units.

2.2.1 Basin Fill

Tertiary and Quaternary-aged basin fill deposits are present throughout the basin as alluvial, fluvial and lacustrine (lakebed) deposits. Coarse-grained deposits (primarily sand and gravel) within the basin fill are responsible for transmitting the greatest quantities of groundwater and are most relied upon for groundwater production in the region. The basin fill is generally unconsolidated, moderately to well-sorted sand, gravel, silt and clay, and wells completed in the basin fill can yield several hundred gallons per minute (Walker and Eakin, 1963). As the axes of the valleys are reached, the sorting of the sediments will increase which can serve to significantly increase the permeability of the sediments. With increasing depth, groundwater production can be expected to decrease in these deposits as increasing lithostatic pressure and infilling of pores coincident with their greater age may occur reducing permeability.

Within the basin fill, the fine-grained (clay and silt) deposits that largely comprise the lakebed deposits (for example in the Shoshone – Tecopa area) serve as aquitards. Aquitards are low permeability geologic units that inhibit groundwater flow and can serve as confining units. Wells and boreholes that are completed in aquifer materials underlying these aquitards may exhibit artesian conditions such as those observed from flowing wells and borings such as at Borehole Spring and Borax Spring in the Shoshone-Tecopa area.

2.2.2 Volcanic Rocks

For this review, the volcanic rocks are of key importance as the proposed repository at Yucca Mountain would store the nuclear fuel and high-level radioactive waste within these rocks. Groundwater movement from these rocks into the alluvial aquifer is of key importance, particularly since many of the springs and a portion of the Amargosa WSR flow is derived from the volcanic-alluvial aquifer system in the northern part of the Amargosa Basin.

Tertiary and Quaternary-aged volcanic rocks are present within the Amargosa River Basin particularly in the area of the headwaters of the Amargosa River in the Yucca Mountain and Beatty areas of Nevada, and in the Greenwater Mountains immediately west of Shoshone, California. In the California portion of the basin, the volcanic rocks are generally of lesser importance to the overall groundwater system as opposed to the northern portion of the basin in Nevada. However, locally, volcanic rocks can be of importance, for example, at the Shoshone Spring area where a basalt flow crossing the Amargosa River course appears to be driving water to the surface in the river bed resulting in the spring. This will be discussed further in Section 2.2.5.

2.2.3 Bedrock Units

Bedrock units underlying the alluvial valleys and generally comprising ranges such as the Nopah and Resting Spring Ranges, and portions of the Amargosa Range, consist of Precambrian to Mesozoic-aged metamorphic and sedimentary rocks. These geologic units consist of Paleozoic-age carbonate rocks (the "carbonate rock aquifer"); quartzite, and shale which have been folded and faulted (Figure 2-1). Generally, bedrock units such as these produce little water except where they are fractured and faulted, providing pathways for groundwater movement. Other bedrock units consist of the Mesozoic-aged granitic rocks as found in the Kingston Range. Within the granitic rocks, groundwater flow can be assumed to be negligible except where fracturing is present yielding modest quantities of groundwater.

Where carbonate rocks are present, greater movement of groundwater can occur due to the unique depositional and erosional characteristics of those rocks. Fractures and secondary solution openings along bedding planes can transmit considerable quantities of groundwater. Groundwater that discharges from the springs at Ash Meadows largely involves groundwater moving through these secondary openings in the carbonate rocks. Within the basin, significant groundwater flow through the carbonate rock aquifer occurs within the lower to middle Paleozoic-age carbonate rocks that comprise a package of rocks approximately 26,000 feet thick (Sweetkind, Belcher, et.al., 2004).

Groundwater flow in carbonate rocks can be very complex. Carbonate rocks with extensive solution channels or fractures primarily developed in one direction will have permeabilities that are highly oriented in specific directions. Therefore, the groundwater flow may not be predictable simply by drawing flow lines perpendicular to regional groundwater surface contours representative of the regional carbonate aquifer (Davis & DeWiest, 1966). Although the carbonate rock aquifer likely transmits large volumes of groundwater in the region, permeability is limited to areas of fracturing which proportionally makes up a small portion of the carbonate rock volume. Therefore, despite the potential for wells to obtain large yields from the carbonate rocks, that success is dependent on intersecting those fractured zones.

2.2.4 Geologic Structure

The rocks in the Amargosa River Basin have been extensively deformed by a variety of fault types that have occurred in the distant past as well as the present. These fault types include:

- Normal faulting typical to the Basin and Range with vertical displacement being dominant;
- Strike-slip faulting (lateral displacement dominant) typical of larger-scale regional fault systems such as the Furnace Creek – Fish Lake Valley Fault and Las Vegas Valley Shear Zones; and
- Thrust faults (low angle faults) that during the Paleozoic and Mesozoic resulted in displacing rock units in a manner that can affect groundwater movement in the present.

Springs may issue from the locations of faults due to either the lower fracture permeability of the fault in rock, or the displacement of permeable basin fill or rock adjacent to relatively impermeable materials. For example, Tecopa Hot Springs rise along a fault (Waring, 1915) that runs north-northwest through the basin (Figure 2-2). This fault is a part of the Furnace Creek Fault Zone (CDMG, 1994). Shoshone Spring also rises along the northward extension of the same fault that passes through Tecopa, part of the Furnace Creek Fault Zone (California Division of Mines, 1954). The Death Valley – Furnace Creek Fault System (inclusive of the Furnace Creek Fault Zone) is part of a large, currently active, northwest directed pull-apart zone. Movement along the Furnace Creek Fault Zone is primarily strike-slip (Brogan, Kellog, Slemmons and Terhune, 1991). The Death Valley – Furnace Creek Fault System is the second longest fault system in California (the San Andreas Fault System being the longest).

Thrust faults are present throughout the region, however given their age, in many areas their presence is concealed by overlying volcanic or basin fill deposits. Fracture permeabilities along thrust faults are insignificant due to the age of the structures and fracture filling and the low angle nature of the faulting not supporting fractures with significant apertures. However, in areas where impermeable rocks are thrust against more permeable rock in the subsurface (e.g., quartzite thrust against carbonate rocks), those faults may also serve as a barrier to groundwater flow. This can be seen along the base of the Nopah and Resting Spring Ranges where the carbonate rock sequence outcrops in the upper portions of the ranges and underlying Lower Cambrian and Precambrian clastic rocks outcrop along the base of each of these ranges. A notable exception is north of the Nopah Thrust in the northern portion of the Nopah Range. North of this fault, the carbonate-rock sequence is down-dropped relative to the carbonate rocks south of the thrust fault resulting in a potential pathway for an undetermined amount of water to seep from Pahrump Valley into Chicago Valley. Of note is the presence of Twelvemile Spring situated approximately west of this thrust fault, and an absence of springs along the west base of the Nopah Range further south.

2.2.5 Implications of Geologic Structure and Impact Analysis Time-Frame

A key aspect of the analysis presented in the Supplement to the EIS is the one-million-year timeframe used for the impact analysis. Although anticipated climate change scenarios for the impact analysis time-frame are provided in great detail, there appears to be little attention to physical changes to the hydrogeologic system over that time-frame.

As described earlier, the extensional geologic environment that has led to the current basin and range (block-faulted) topography began approximately 10 to 13 million years ago. Therefore, the impact analysis time frame accounts for a future timeframe that is significant in relation to overall age of the basin and range topography we see today. This is a seismically active region with significant slip rates on faults. For example, the Death Valley – Fish Lake Valley Fault Zone has a slip rate of 4-5 millimeters per year depending on the segment (Peterson, Bryant, et.al., 1996) which extrapolated over one million years results in offset of approximately four kilometers for that fault alone over a one million year period. Considering the numerous faults throughout the area of the flow system, over the one-million year time frame, significant horizontal and vertical displacements are likely to affect flow paths to some extent. The uncertainty that this ongoing deformation adds to the resulting analysis presented in the Supplement to the EIS should be noted.

2.3 Surface Water

The Amargosa River rises as spring flow from the southwest side of Pahute Mesa in Nevada. From here, the river flows generally southwest toward Beatty, Nevada, and after passing through the Amargosa Narrows where water is forced to the surface, enters the Amargosa Desert. After crossing the border into California, the river generally runs southward along a valley that follows the trend of the Furnace Creek Fault Zone, adjacent to California State Highway 127 near Death Valley Junction. Here, the river meets with Carson Slough (which drains Ash Meadows and is the chief tributary to the Amargosa River in Nevada), and continues its southward route passing to the east of the community of Shoshone and on to Tecopa. South of Tecopa, the river enters the Amargosa Canyon, being augmented by spring flow on its course. South of the Amargosa Canyon, the river flows by Dumont Dunes, and then heads west and then northward, rounding the Amargosa Range on the south and flowing into Death Valley.

The Supplement to EIS incompletely, and incorrectly characterizes Amargosa River flow along the portion of the Amargosa River in Inyo County that has been designated by Congress as Wild and Scenic (e.g., see Page 2-22, lines 22 through 24 in the Supplement). The characterization is incorrect in that:

- It incorrectly characterizes the Amargosa River as having only five miles of surface flow (instead of approximately 26 miles);

- It fails to recognize the designation of the river as Wild and Scenic;
- It fails to describe the river flow as observed (both in surface water flow and evapotranspiration discharges) in the Shoshone area; and,
- It fails to describe the feeder springs that supplement river flow.

As described in the State of the Basin Report (Andy Zdon & Associates, 2014), the principal surface water body in the region is the Amargosa River, an intermittent river with headwaters issuing from springs northeast of Beatty, Nevada inclusive of the Yucca Mountain area, and extending approximately 180 miles to the river's terminus at the playa in Death Valley. Except for portions of the river south of Shoshone, California, and near Beatty, Nevada, the Amargosa River typically flows on the surface only after periodic storms. In those areas where the river is usually dry, the flow of water is in the subsurface as observed in the Shoshone area when surface flow is commonly not present but where substantial phreatophytic vegetation is supported by the subsurface flow. The perennial reach of the Amargosa River between Shoshone and Dumont Dunes was designated as a National Wild and Scenic River in 2009. Except during runoff events from rainstorms, the perennial flow in the Wild and Scenic section of the river is completely supplied by groundwater.

A series of conceptual cross-sections following the course of the Amargosa River from near Oasis Mountain northeast of Beatty, Nevada, to Sperry below the Amargosa River Canyon in California are provided in Appendix D. As can be seen, areas with continual flow are typically where rock units create constrictions to flow, and that flow is driven to the surface. Beyond the constrictions, the flows typically percolate into the subsurface some distance downgradient. This occurs at the narrows southeast of Oasis Mountain, at the Amargosa Narrows south of Beatty, Nevada, at the Shoshone Spring area, and at the Amargosa River Canyon. Between Shoshone and Tecopa, the river can also rise to the surface, most likely the result of permeable zones intersecting clayey, Tecopa lake bed deposits causing flow to surface. As can also be seen in the cross-sections (Appendix D), the groundwater surface tends to flatten upgradient of these constrictions, then steepens once past them, as would be anticipated.

With respect to the contributions of flow from the Amargosa Desert, these cross-sections also illustrate how groundwater in the alluvial aquifer (inclusive of flows from both volcanic and carbonate sources) flows southward from the Amargosa Desert in Nevada toward Shoshone and Tecopa in Inyo County. The cross-section representing flow from the Eagle Mountain area, toward monitoring ARHS-01 toward Shoshone Spring also is included in (Belcher, et. al., 2015).

This condition also emphasizes the sensitivity of the relatively constant, or perennial reaches of the Amargosa River to changes in groundwater level and possible water quality impacts resulting from releases in either the carbonate or volcanic-alluvial aquifer systems. Additionally, given this condition, it appears that a considerable portion of the underflow moving through the Middle Amargosa system can be accounted for by the flow observed at the surface (for example in the Amargosa River canyon) plus spring discharge and any pumping. This does not result in a substantial amount of underflow, and further highlights the sensitive nature of the river system.

The USGS monitors the flow of the Amargosa River (USGS, 2013) at a gage 0.2 miles west (Gauge no. 10251300) of Tecopa. The USGS has monitored Amargosa River flow intermittently at other locations along the river over the past 50 years, but given the spotty nature of those records, they are of limited utility. The average flow of the river at this station based on 39 full years of data between 1962 and 2013 (some years missing) is 3.44 cubic feet per second (cfs), though is skewed high as a result of flood flows. The maximum mean annual flow recorded there was 14.9 cfs in 1983 when the record peak flow of 10,600 cfs was recorded on August 16, 1983. At times the river has been dry at this station. Mean annual flows at the Tecopa station along with the other stations mentioned are summarized on Table 2-1.

Other surface water bodies in the area consist of spring-fed ponds in the Ash Meadows area (Nevada), spring-fed Grimshaw Lake in the Tecopa area, and streams that issue from springs only to end where either that flow is utilized by vegetation, or it percolates back into the subsurface. One exception to this is Willow Creek, a significant spring-fed stream that rises northeast of China Ranch (south of Tecopa), and flows into the Amargosa River within the Amargosa River Canyon.

Finally, surface flows emanating from springs may flow towards, and discharge directly to the Amargosa River (for example multiple springs in the Amargosa Canyon) or may contribute to river flow after those waters have percolated back into the subsurface. Elsewhere spring flows can either evaporate or be transpired by vegetation. Given the scope of the comments in this review and work completed since 2010, a more detailed description of spring flow at Shoshone Spring is provided in the following section.

2.4 Regional Groundwater System

The regional groundwater flow system is considerably more extensive than the Amargosa River Basin watershed. The reason for this is the extensive area beyond the watershed boundary underlain by the carbonate rock aquifer that drains toward Death Valley (Bredehoeft and King, 2010, Belcher, 2004). In this large flow system, groundwater recharge results from precipitation in the form of snowmelt and rainfall that falls within the mountains of southern and central Nevada, and reaches the Amargosa River Basin where it is discharged (Planert and Williams, 1995).

The Northern Amargosa River Basin in Nevada appears to receive much of its carbonate-rock aquifer underflow from central Nevada. As shown on Figure 2-3, groundwater moves southward through Lincoln County, Nevada and beyond where it splits with a portion of that flow heading southwest toward the Amargosa Desert and Ash Meadows. The remainder of the flow moves southeast toward Muddy Spring and the Colorado River area.

Within the Middle Amargosa River Basin (between the California-Nevada state line and Salt Creek – also referred to as the Lower Amargosa River in Belcher, et.al., 2015), the river has long been postulated that groundwater moves directly through the carbonate aquifer southwest from the Spring Mountains and beneath Pahrump Valley toward the Tecopa – Shoshone – Chicago Valley – California Valley areas (Faunt, D'Agnese and O'Brien, 2004). However, based on the results of the current geochemical analyses and more recent detailed mapping by the USGS (Workman, et.al., 2002), it appears that the mechanism by which groundwater moves from the Spring Mountains/Pahrump Valley area toward the Shoshone-Tecopa area may be more complicated. Figures 2-4, 2-4a and 2-4b present a portion of the 2002 geologic map indicating that Precambrian to Cambrian bedrock units underlying the carbonate rock units outcrop along the western base of the Resting Spring Range and the portion of the Nopah Range south of the Nopah Peak Thrust. This would indicate that the saturated rocks beneath these ranges are primarily comprised of quartzite, shale, siltstone and dolomite of lesser permeability than would be expected of the Paleozoic-age carbonate rocks. Alternative flow paths likely include one or more of the following:

- Spring Mountain recharge moving toward Ash Meadows through carbonate rocks and basin fill, then southward toward the Shoshone-Tecopa area;
- Via carbonate rocks at the north end of the Nopah Range into Chicago Valley then toward the Amargosa Valley;
- From Pahrump Valley via the shallow divide into California Valley then toward the Amargosa River; and,
- Groundwater that moves from Pahrump Valley toward Ash Meadows and the Amargosa Desert, discharges to alluvium, and moves southward toward the Shoshone-Tecopa area.

The deeper flowpaths are most likely influential on the spring flows and discharge to the alluvium. The deeper flowpath beneath the northern Nopah Range was previously discussed (JWI, 2013a) as a potential source for Twelvemile Spring. These flowpaths are consistent with that previously proposed by others (Figure 2-5). Beyond the Middle Amargosa River Basin, groundwater moves west in the Death Valley Basin, then north augmented by underflow from the Owlshead Mountains area, to the Death Valley Playa.

The regional groundwater flow system covers an area of nearly 40,000 square miles. The following sections describe the occurrence and movement of groundwater, the aquifer characteristics of the basin fill and carbonate rock aquifers, and groundwater basin inflow and outflow components.

2.4.1 Groundwater Occurrence and Movement

Within the Amargosa River Basin, groundwater occurs primarily within the basin fill deposits (inclusive of the volcanic rocks) and carbonate rock aquifer. In the Northern Amargosa River Basin, groundwater is generally found within the basin fill from which most of the groundwater pumping in the Amargosa River Basin is concentrated. In the Ash Meadows area, the primary aquifer is the carbonate rock aquifer system. Groundwater within the carbonate rocks flows laterally across basins as interbasinal flow as described earlier. Further north (from Beatty, Nevada north) volcanic rocks are prominent and can provide significant flow where fractured.

The Supplement to the SEIS relies upon a hydraulic gradient west of Ash Meadows as a basis for stating on Page 2-11 that the "*...steep hydraulic gradient across the north-south trending fault indicates that little mixing of carbonate waters to the east* (at Ash Meadows) *with alluvial waters to the west in the present day climate.*" There appears to be uncertainty as to the effectiveness of this barrier to flow however, as the ruling by the Nevada State Engineer concerning Devil's Hole (which recognizes the hydraulic connectivity between these two areas) is designed to protect Devil's Hole (in the Ash Meadows area) from the effects of existing and future pumping in the Amargosa Desert.

The direction of groundwater movement usually parallels the slope of the ground surface, from points of recharge in the higher elevations to points of discharge such as springs or the Amargosa River in the valley. Within the basin fill aquifer, groundwater movement is from north to south from the northern portion of the basin in Nevada toward Shoshone and Tecopa. A potentiometric surface map of the shallow basin fill aquifer based on the groundwater levels collected by the USGS, AZI, AC, Nye County and Inyo County (by TEAM Engineering & Management, Inc.) during the 4th Quarter of 2010 is provided on Figure 2-6. This is the same map that was provided in the 2011 State of the Basin Report (Source Group, 2011). Based on the continued monitoring of groundwater levels in the area since that time, and the little change observed south of Death Valley Junction, this map is likely still consistent with existing conditions.

Precipitation and snowmelt runoff from the mountains surrounding the Middle Amargosa River Basin collect in the thick packages of alluvium that fill the valleys. The water percolates through the alluvium under the force of gravity, flowing downhill towards the lowest point in the Basin, the Amargosa River. Figure 2-7 shows the conceptualized flow paths of groundwater flowing in the alluvial valleys within the Middle Amargosa River Basin. North of Shoshone, groundwater flows south around Eagle Mountain in the alluvium that forms the floor of the valley through which runs the Amargosa River.

The valley and the Amargosa River are additionally fed from runoff from the east slope of the Amargosa Range and the west slope of the Resting Spring Range. Water from the east slope of the Resting Spring Range and the west slope of the Nopah Range flow into Chicago Valley, following the slope of the valley floor to the south. At the south end of the Resting Spring Range, the alluvial valley turns southwest towards Tecopa and the Amargosa River. Right at this bend is Resting Spring, which likely exists as a result of the change in valley direction and the constriction in the width of the alluvium in the valley between the Resting Spring Range and the Nopah Range, forcing groundwater to the surface at the spring location. Water from the southeastern slope of the Nopah Range and the western slope of the Kingston Range flows into California Valley and west around the southern tip of the Nopah Range. Some of this water likely flows down China Ranch Wash, which in turn is the source of the water from Willow Spring and Willow Creek.

Runoff from the eastern Ibex Hills flows into Greenwater Valley toward the Amargosa River. South of the Sperry Hills, runoff from the north facing slope of the Avawatz Mountains, along with the Salt Spring

Hills, Saddle Peak Hills and the Ibex Hills flows into the basin fill of Southern Death Valley, down the middle of which runs the Amargosa River.

Based on the results of AZI's spring reconnaissance, it is clear that a number of distinct spring sources are represented in this concentrated part of the Amargosa River Basin. Based on the current isotopic work, the elevated temperatures of the hot springs around Tecopa indicate that the spring water has most likely been at great depth. This is similar to warm springs in the Furnace Creek area of Death Valley National Park (Pistrang and Kunkel, 1964). The Furnace Creek area warm springs are also present along the Furnace Creek Fault Zone where deep circulation is postulated. This indicates that absent shallow heated igneous rocks, those waters moved at considerable depth (in the range of thousands of feet below ground surface) only to move upward along fractures or faults to the surface where it is discharged. In other springs, field water quality parameters are suggestive of groundwater flow of a more local nature such as at Crystal Spring (Kingston Range source) or Sheep Creek Spring (Avawatz Mountains source).

2.4.1.1 Groundwater Movement toward Shoshone Spring

The Supplement to the SEIS provides seemingly contradictory assumptions as described before concerning flow paths from the Amargosa Desert and Ash Meadows as described above in Section 2.4. As an example of groundwater movement from the Amargosa Desert –Ash Meadows area toward the Shoshone-Tecopa area, a description of Shoshone Spring, and its sourcing is provided below. Shoshone Spring is a key spring within the Inyo County portion of the Amargosa Basin and is the sole source of water for the town of Shoshone.

As shown in the conceptual cross-sections provided in Appendix D, Amargosa River reaches with continual surface flow are typically where rock or other low permeability soil units create restrictions to flow, and that flow is driven to the surface. Beyond the constrictions, the flows typically percolate into the subsurface some distance downgradient. With respect to the contributions of subsurface flow from the Amargosa Desert, these cross-sections also illustrate how groundwater in the alluvial aquifer (inclusive of flows from both volcanic and carbonate sources) flows southward from the Amargosa Desert in Nevada toward Shoshone and Tecopa in Inyo County. Of note is the attached cross-section inclusive of data from monitoring well ARHS-01 and Shoshone Spring. This southward groundwater movement in alluvium is also presented in the potentiometric surface map prepared in 2011 (Source Group, 2011). Additional contributions of groundwater from Pahrump Valley (sourced in the Spring Mountains to the east) contributes flow. That flow path may be from Pahrump Valley, northwestward toward the Ash Meadows/Amargosa Desert area, then south toward Shoshone. Further work would be required to refine that flow path.

It had long been thought that groundwater between Death Valley Junction and Shoshone ran shallow beneath the often dry Amargosa River channel. In order to test this concept, Monitoring Well ARHS-01 was installed during May 2012 approximately 4.5 miles north of Shoshone, California (Johnson Wright, 2012). During drilling, dry to moist soils consisting of approximately 40 feet of coarse-grained fluvial deposits and nearly 100 feet of fine-grained lakebed deposits were identified prior to encountering a zone of saturated sandy gravel at approximately 138 feet below ground surface. Within the well casing, groundwater rose to a depth of approximately 111 feet below ground surface after well construction was complete. Additionally, water from that well was found to be approximately 35 degrees Celsius (similar to Shoshone Spring), suggesting that the fault that runs along the axis of the Amargosa River (through Tecopa and Shoshone, and then north towards Eagle Mountain) may provide a connection to, and distribution system for, a deeper source of water.

Water quality analyses that included general chemistry, metals, stable isotope, and noble gas analysis indicated that these waters not only were similar in character to those waters that issue from Shoshone Spring (and Borax Spring to the south), but that their recharge areas were likely similar as well. The recharge area includes groundwater derived from both carbonate and volcanic sources that discharge to alluvium in the Amargosa Desert – Ash Meadows area of Nevada. From this recharge area, groundwater moves southward in the alluvium toward Shoshone (Andy Zdon & Associates, 2014).

As shown in the attached cross-section, the groundwater encountered in the saturated river gravels at ARHS-01 likely daylight near Shoshone Spring in an area where an existing basalt flow crosses the river channel from west to east. Free-flowing spring(s) are present at Shoshone Spring along with adjacent areas of discharge as evapotranspiration from phreatophytic vegetation elsewhere in the absence of surface water flow. Downgradient (south) of the basalt flow, additional free flowing spring flow occurs where faulting has provided a conduit for that flow to surface.

South of the town of Shoshone, phreatophytic vegetation consisting of mesquite, willow and other vegetation begin to diminish until that surface water infiltrates back into the river bed, moving southward toward Tecopa.

2.4.2 Aquifer Characteristics

Groundwater within the basin is held within the sand, gravel, silt and clay that make up the valley fill aquifer. Within the Northern Amargosa River Basin, hydraulic conductivity (the ability for a geologic material to transmit water) in the basin fill can range from 0.02 feet per day (f/d) in the low permeability clayey deposits, to 140 f/d in the coarse-grained sands and gravels (Belcher, 2004). AZI is unaware of any aquifer testing that has occurred within the basin fill in the Middle Amargosa River Basin or the Death Valley Basin, but it is likely that hydraulic conductivities generally fall within the same range as those described above.

The aquifer characteristics of the carbonate rock aquifer can be highly variable. Where fractures and solution openings exist, these rocks can be the most permeable materials in the basin. Absent fracturing, hydraulic conductivities can be extremely low. Carbonate rock hydraulic conductivities can range from 30 f/d or greater to much less than 0.001 f/d (Spitz & Moreno, 1996). The implications of orders-of-magnitude scale changes in hydraulic conductivity in very short geographic distances is discussed further in Section 3.0.

2.4.3 Groundwater Basin Inflow Components

Groundwater inflow components within the Amargosa River Basin include recharge from precipitation that falls within the drainage basin and groundwater underflow into the basin, primarily through the carbonate rock aquifer. In this area, large uncertainties exist regarding recharge rates, and currently, groundwater pathways for underflow into the basin. Therefore, best estimates of recharge are probably most available by evaluating groundwater discharge and changes in storage/changing groundwater levels in the area.

2.4.3.1 Recharge

Walker & Eakin (1963) estimated recharge to the Northern Amargosa River Basin from precipitation within the basin plus recharge from precipitation on the northern and western slopes of the Spring Mountains to be approximately 5,000 acre-feet per year (AFY). Within the California portion of the basin, the Middle Amargosa Basin and Death Valley Basin do not have specific recharge estimates associated with them (California Department of Water Resources, 2003).

As part of the water-supply feasibility study for a potable water source for Tecopa, JWI (2013c) estimated a recharge of approximately 700 afy from the Kingston Range using the Maxey-Eakin Method.

2.4.3.2 Groundwater Underflow

Walker & Eakin (1963) estimated that of the 17,000 AFY discharged from the springs at Ash Meadows on an annual basis; approximately 13,000 AFY might be the result of groundwater underflow through the carbonate rocks from the Spring Mountains to the east. The remaining 4,000 AFY being supplied by underflow from areas to the northeast in central Nevada. South of Death Valley Junction, the general absence of previous hydrogeologic investigations in the Shoshone – Tecopa region results in more generalized assumptions regarding underflow. Although a flowpath from Nevada towards the Death Valley area has been demonstrated by Bredehoeft and King, and others, as shown in Figure 2-7, regional groundwater flow in the basin fill enters the California portion of the basin from Ash Meadows, Oasis Valley, Jackass Flats and from recharge in the Spring Mountains via various potential routes. Additional underflow from the south from the Silurian Valley area enters the system between the Amargosa River Canyon and Saratoga Springs (Faunt, D'Agnese and O'Brien, 2004).

With respect to the Middle Amargosa River Basin, the existing Death Valley Regional Flow System model could be used to evaluate the groundwater budgets for specific zones in this part of the groundwater system, therefore extracting underflow estimates for each of these areas. However, there would be significant uncertainty associated with them, as the model was developed without the benefit of the data collection effort that has been ongoing for the last three years. With the existing data and proposed data collection and analysis, refinement to that groundwater model, or a new groundwater flow model focused on the Middle Amargosa River Basin, will be an essential management tool and will likely provide additional insight into the dynamics of regional flow in the area.

2.4.4 Groundwater Basin Outflow Components

2.4.4.1 Spring Flow & Evapotranspiration

Spring flow and evapotranspiration have been combined as a basin outflow component in this basin as in this area as they are unavoidably linked. In the Supplement to the EIS, evapotranspiration along the Amargosa River is provided based on that estimated in Nevada only (Page 2-9). Groundwater-dependent vegetation (phreatophytes) are present along the Amargosa River and in spring areas. Springs discharge water from the groundwater system, but in nearly all cases within the basin, that flow either evaporates, is used by plants, or percolates back to the groundwater system within a relatively short distance. One of the few exceptions to this is Willow Creek south of Tecopa which rises from spring flow within China Ranch, and generally maintains surface flow to its confluence with the Amargosa River. In the Nevada portion of the basin, the discharge from spring flow and evapotranspiration has been estimated at 23,500 AFY (Walker & Eakin, 1963).

In the Shoshone - Tecopa - Chicago Valley - California Valley area, the combined spring flow and evapotranspiration has been estimated at approximately 8,900 AFY. In the Death Valley Basin, combined spring flow and evapotranspiration has been estimated at approximately 35,000 AFY (San Juan, Belcher, et.al, 2004).

Based on the field reconnaissance activities, it is clear that the springs in the California portion of the basin emanate from a variety of sources. These sources appear to range from those with deep circulation paths (such as Tecopa Hot Springs), and those with shallow and potentially more local circulation paths (such as at Willow Creek).

2.4.4.2 Pumpage

Within the Amargosa River Basin, pumpage is primarily within the Northern Amargosa River Basin. This water is largely used for irrigation. Table 2-2 summarizes groundwater pumping from the Northern Amargosa River Basin since 1983 (NDWR, 2012a). This represents the most up to date pumping data available from the Nevada Division of Water Resources at the time of this report. Total pumping over time is also represented on Figure 2-8. Average annual pumping since 1983 has been 12,153 AFY. In 2012, a total of 17,622 AFY was pumped from the basin. As can be seen, over the 27 years of pumping records, the Northern Amargosa River Basin has seen a steady increase in pumping. For comparison purposes, the annual duty for the Northern Amargosa River Basin is 27,336.86 AFY (includes certificate, permit, and ready for action) as of February 21, 2012 compared to the estimated annual perennial yield of the basin of 24,000 AFY (Walker and Eakin, 1963). This updated annual duty is a reduction of approximately 1,700 AFY since first reported in the 2011 State of the Basin (Source Group, 2011).

Of note is that the Supplement to the EIS, states that the Yucca Mountain SEIS pumping rates in the Amargosa Desert differ from those estimated by the USGS in developing the Death Valley Regional Flow System Model (2010 version). The SEIS used Nevada Division of Water Resources pumping data in that it was believed that the greater pumping estimates (greater by 20 to 30 percent) were too high and would be problematic for evaluating pre-development conditions (Page 2-28, Lines 26 through 30). It should be noted that NDWR pumping estimates do not include non-permitted domestic pumping and well tend to underestimate pumping. First, the Supplement to the EIS continues to use 2003 pumping in the Amargosa Desert as typical of anticipated long-term pumping. As can be seen in Figure 2-8, *pumping at 2003 rates have been exceeded every year since 2004*. Secondly, much of the analysis presented in the Supplement to the EIS is based on modeling input which the Supplement to the EIS deems inaccurate on a key model component simply because the pumping exceeds that estimated by the Nevada Division of Water Resources in their pumpage inventory.

In the Middle Amargosa River Basin and Death Valley Basin, water supplies are more reliant on spring flow, and groundwater pumping is relatively insignificant in comparison to the Nevada portion of the basin. Groundwater pumpage for domestic or public use is probably on the order of less than 100 AFY (San Juan, Belcher, et.al. in Belcher, 2004). Water used for irrigation of date palms is supplied by spring water. It is unlikely that water use in the Shoshone-Tecopa area has changed significantly since the last State of the Basin Report (Andy Zdon & Associates, 2014). Furthermore, any additional water usage resulting from the proposed new potable water supply for Tecopa will be insignificant to the overall water budget of the area.

2.5 Future Groundwater Use and Discussion of Groundwater Availability

As shown in Table 2-2 and Figure 2-8, there has been an increased use of groundwater in the Nevada portion of the Amargosa Basin over the past 25 years. The potential for future development will be limited by both quantity and quality of water. However, as can be seen by the active duty for the Northern Amargosa River Basin, there is significant potential for pumping to increase considerably should water rights holders fully exercise their water rights. Given the over-allocated nature of the Northern Amargosa River Basin, significant impacts to the groundwater resource could result if that condition occurred. These uses are anticipated to increase due to future population growth, and the likely future addition of groundwater usage for solar energy development. Although wet cooling solar projects are not anticipated, groundwater usage for processes such as mirror washing will still be needed.

The incremental increase of solar projects within the region could result in a significant steepening of the increased trend in groundwater usage. The competing demands for renewable energy and protection of the Amargosa River point to the need for increased knowledge and baseline hydrologic data in the Middle Amargosa River Basin. Recommendations for future investigations are provided in Section 4.0 of this report.

3.0 NUMERICAL GROUNDWATER FLOW MODELING

The Supplemental Analysis relies on the Death Valley Regional Flow System Numerical Model (DVRFS Model) developed by the USGS (Belcher, et. al., 2010) for the contaminant transport modeling conducted in the analysis. This influential work has provided substantial insight into the hydrogeology of the Amargosa River Basin. However, for the purposes of the review, and in order to respond to questions posed by the County of Inyo regarding potential impacts to groundwater resulting from the proposed project, that model has limitations resulting from the extent of the model domain, boundary conditions, and intent of use for the numerical model. Although a number of modeling efforts have been conducted that cover the Nevada Test Site area and beyond, the DVRFS Model is the model generally relied upon in the Supplement to the EIS to evaluate both the flow regime and as a basis for particle transport predictions.

The Analysis of Postclosure Groundwater Impacts (DOE, 2014) is based on the version of the a modified version of the DVRFS model which has the limitations for use in this analysis as described above and the following sections. Further, the modeling failed to consider realistic future pumping scenarios in the region (e.g. potential Southern Nevada Water Authority (SNWA) pumping in basins with hydraulic connectivity to the project area based on actual, existing applications and permits), and in the Amargosa Desert specifically where pumping has already exceed those used in the SEIS and the Supplement to the EIS. It should be noted that simply applying new pumping rates into the DVRFS model, or modeling derived from it, would continue to be problematic as based on the new information that has been developed since 2010, further model refinement (to account for conceptual changes and for evaluation of model construction for use in transport analyses specifically) and recalibration would be needed prior to use for predictive simulations for impact analysis.

One key limitation results from the extent of the model grid and associated boundary conditions. The DVRFS Model has a northern extent that roughly coincides with that of the Nevada Test Site. Of note, the geochemical work in the region (e.g. Rose and Davisson, 1999) suggest a greater influence of basins to the north of the DVRFS Model grid than modeled. Railroad and Pahranagat Valleys in-turn receive groundwater underflow from basins further hydrologically upgradient to the north. In order to accommodate these underflows from Railroad and Pahranagat Valleys into the DVRFS Model, specified-head boundaries are included in portions of the northern and northeastern model boundaries. While this arrangement provided a reasonable approach for the original purposes of the model, it is problematic when considering potential impacts within the flow system from pumping stresses further to the north. Reductions in underflow cannot be represented simply by reducing the flow (e.g. if a specified flux boundary had been used), and changing head boundaries may lead to other problems associated with predictive capability in that hydraulic parameters were calibrated based on those head boundaries being set at their existing heads and conductances.

Other limitations arise from a series of uncertainties regarding the model (both the conceptual and numerical models) that were described previously (King and Bredehoeft, 1998). These limitations included:

- Uncertainty associated with evapotranspiration values;
- Uncertainties associated with sources of spring waters;
- Lack of sufficient groundwater level data;
- Lack of sufficient hydraulic parameter data; and,
- Uncertainties associated with boundary conditions.

Although a substantial amount of work was conducted to reduce those uncertainties, technical efforts focused on that part of the basin in Nevada and the flow path toward Death Valley, and uncertainties in conceptualization continue (Bushman, et.al. 2010).

Additionally, calibration of the DVRFS model did not have the benefit of data developed since 2010 that are now available within the Inyo County portion of the basin and that could be incorporated into future model calibration, nor the insight that the last five years of investigative work has provided (both in the California and Nevada portions of the model area). The Lower Amargosa River Valley (also referred to as Middle Amargosa Basin by California Department of Water Resources) in Inyo County accounts for a substantial portion of the modeled area within the DVRFS Model. It has not been until the hydrogeologic work conducted between 2010 and 2014 that significant efforts were made to reduce the uncertainties listed. That work has yet to be incorporated into the numerical modeling and so those uncertainties continue to follow in the analysis presented within the Supplement to the EIS. Changes in the numerical modeling incorporating the data collected between 2010 and 2014 could substantially alter flowpaths and relative amounts of flow into different portions of the Amargosa River Basin. This in turn could alter the results of particle tracking analyses.

When choosing a model, or conducting a numerical modeling exercise, the model will be specifically designed to answer specific questions or to provide insight into how a groundwater system works. In considering the limitations described above, it is important to recognize the original purposes of the development of the DVRFS flow model:

- To provide boundary conditions for site scale models at the Yucca Mountain and Underground Test Area Corrective Action Units on the Nevada Test Site;
- Evaluate impacts of changes in groundwater flux within the model area;
- Provide a decision-making tool with respect to groundwater for defense and economic development on the Nevada Test Site;
- Evaluate potential effects to the Nevada Test Site due to off-site groundwater development (and within the model area);

- Provide a framework for identifying an effective groundwater quality monitoring network; and,
- Facilitate the development of a cooperative, regional Death Valley groundwater management district.

As can be seen, contaminant transport analysis was not within the original concept for the development of the model. With respect to using the DVRFS Model for contaminant transport scenarios, the model report (Belcher, et.al, 2004) stated, "*The model also can be used to provide insight about contaminant transport. Flow direction and magnitude are appropriately represented using particle tracking methods as long as the particle paths are interpreted to represent regional, not local conditions.*" This is a key statement in that using the model for predicting contaminant transport to specific local receptors does not appear to be appropriate.

In 2014, the USGS released a numerical model for assessing regional-scale groundwater flow through alluvial and carbonate rock aquifer systems across Nevada as well as parts of California and Utah (Brooks et al., 2014). The study area encompassed by the model is shown on Figure 3-1. This model, herein referred to as the "Great Basin MODFLOW model," is based upon the USGS's MODFLOW-2005 groundwater flow simulator (Harbaugh et al., 2005). The Great Basin MODFLOW model is calibrated to steady-state conditions that existed before extensive groundwater development. This has the benefit of using the DVRFS Model as a partial basis for its development. According to the USGS, the model generally represents hydrologic conditions up through the 1960s over the majority of the study area, prior to the onsite of significant localized groundwater pumping. Current-day conditions are represented only in areas with limited groundwater resource development (although recent surface-water development and irrigation activities are included).

Key attributes of the Great Basin MODFLOW model include:

- The study area is delineated using an approximately 1.6-million node grid, representing 110,000 square miles, distributed over eight vertical layers; horizontal grid resolution corresponds to a uniform 1-mile by 1-mile grid.
- The equivalent porous medium concept is assumed to be valid, where flow-controlling features such as minor faults and fractures through consolidated rocks are comparatively small and densely distributed at the scale of the model.
- Representation of distinct hydrogeologic units (the Upper Basin-Fill Aquifer Unit, the Lower Basin-fill Aquifer Unit, the Volcanics Unit, the Thrusted Lower Carbonate Aquifer Unit, the Thrusted Non-Carbonate Confining Unit, the Upper Carbonate Aquifer Unit, the Upper Siliciclastic Confining Unit, the Lower Carbonate Aquifer Unit, and the Non-Carbonate Confining Unit) is achieved using the Hydrogeologic Unit Flow (HUF2) package for MODFLOW.

- A confined groundwater flow condition is assumed for all layers, implemented to assure numerical stability of the model.
- Only steady-state flow conditions represented.
- Model hydraulic properties are calibrated to groundwater elevation and spring data.

Additional MODFLOW packages employed in the model include the general head boundary (GHB) package for streams and rivers, the Drain package for springs and evapotranspiration, and the Well package for representing subsurface inflows and outflow at model boundaries.

According to the USGS, examples of potential applications of the Great Basin MODFLOW model include assessing the effects of different recharge regimes, the impacts of major faults or fault zones on groundwater flow, or different conceptual models of the spatial variation of hydraulic properties. The model is also deemed suitable for use in examining the ultimate effects of groundwater withdrawals on a regional scale, to provide boundary conditions for local-scale models, and to guide data collection. In the context of regional-scale groundwater withdrawals, the suitability of the model for assessing possible hydraulic responses of the aquifer system at Yucca Mountain and vicinity (e.g., the Armargosa Valley) to future groundwater pumping regimes in central and southern Nevada was assessed by AZI. This assessment entailed simulating the regional drawdowns associated with groundwater pumping at various locations included in the Southern Nevada Water Authority's (SNWA) applications and permits for extraction. Although the Great Basin MODFLOW model does not include the impacts of recent groundwater development, the confined character of the flow model implies that insights into the distal impacts of additional pumping can be quantified using groundwater head drawdowns as the primary metric.

3.1 Aquifer Properties

The regional distribution of hydrogeologic units and other features (e.g., faults) across the model domain is geometrically complex and is presented in detail by Brooks et al. (2014). The hydrogeologic units are delineated into localized zones characterized by representative hydraulic conductivities (Brooks et al., 2014: Tables A4-1 through A4-3). Un-weighted geometric mean values for the nine hydrogeologic units are summarized in Table 3-1; the spatial distributions (and unit thicknesses) of the most permeable materials, relative to the SNWA permit locations, are shown on Figures 3-2 through 3-8. In general, with the exception of relatively isolated portions of the alluvial materials, hydraulic conductivities are low, typically characterized by values on the order of 0.1 ft/day or less. For example, the geometric mean of the carbonate aquifer zones (unweighted; not accounting for spatial extent) is 0.12 to 0.14 ft/day. These low values are important for understanding the large simulated drawdowns associated with pumping, as described below.

3.2 Pumping Scenarios and Assumptions

The SNWA's extraction application and permits pertain to locations throughout central and southern Nevada, including Cave Valley (2 applications/permits), Delamar Valley (2 applications/permits), Dry Lake Valley (2 applications/permits), Railroad Valley (18 applications/permits), Spring Valley (77 applications/permits), Three Lakes Valley (9 applications/permits), and Tikapoo Valley (3 applications/permits). The total extraction rate implied by these applications and permits for these locations is approximately 310,000 acre·ft/year. This potential pumping was added to the Great Basin MODFLOW model using the MODFLOW Well package, as implemented through the U.S. Geological Survey's ModelMuse pre- and post-processor for MODFLOW (Winston, 2009).

Four separate extraction scenarios were addressed in the current assessment:

1. Extraction from Railroad Valley locations, exclusively;
2. Extraction from Cave Valley, Delamar Valley, Dry Lake Valley, and Spring Valley;
3. Extraction from Cave Valley, Delamar Valley, Dry Lake Valley, Spring Valley, Three Lakes Valley, and Tikapoo Valley;
4. Extraction from Cave Valley, Delamar Valley, Dry Lake Valley, Railroad Valley, Spring Valley, Three Lakes Valley, and Tikapoo Valley.

Individual extraction applications and permits include an approximate location and pumping rate, although a screened interval is generally not specified. To assign screened interval locations, the following set of rules were followed, with the underlying assumption that the vertical positions of the hydrogeologic unit contacts are accurately represented in the model structure on a local scale:

- Extraction occurs through a single well in the Upper or Lower Carbonate Aquifer if at least one unit is characterized by a local thickness equaling or exceeding 1,000 feet and the depth to at least one unit is less than 2,000 feet.
- Extraction occurs through a single well in the alluvium (defined as the combined thickness the Upper Basin-Fill and Lower Basin-Fill Aquifer Units) when the local unit thickness equals or exceeds 2,500 feet.
- Extraction occurs in the alluvium, by default, when both of the above conditions are true.
- If neither of the first two conditions is met, extraction is assumed to occur from a single well screened across the entire hydrostratigraphic section at the permit location, with MODFLOW's Well package used to distribute extraction rates from individual layers in proportion to the local transmissivity.

As discussed below, simulation of full permitted extraction rates under steady-state conditions results in exceedingly large predicted drawdowns. Therefore, an alternative, limited pumping case entailing Scenarios 1-4 was also simulated. In contrast to the full-pumping case, the limited pumping case does not consider extraction from locations where the carbonate and alluvial aquifers are both inconsistent with the first two assumptions listed above. In addition, extraction rates for those permits which are posited under the limited-pumping case are set to only 40 percent of the permitted value.

Finally, the steady-state assumption characterizing the Great Basin MODFLOW model limits its utility for evaluating permitted extraction rates over comparatively near-term time frames (i.e., decades). However, given the long-time frame for being analyzed in the Supplement to the EIS (e.g. one million years) this is of less consequence. Generally, questions concerning the sustainability of pumping rates across the spatial scale of the model are difficult to address. Consequently, a demonstration transient simulation based on Extraction Scenario 4 under full-pumping conditions was conducted using a single assumed specific storage value applied across the entire model domain.

3.3 Model Results

3.3.1 Limited-Pumping Scenarios

Simulated steady-state drawdowns associated with Scenarios 1-4 under the limited-pumping case are depicted on figures in Appendix E for the top layer of the Great Basin MODFLOW model. In addition to the uniform reduction of pumping to 40 percent of the permitted value, excluding consideration of permit locations that do not satisfy either screened-interval assumption for the carbonate and alluvial aquifers reduces the total pumping in the model by an additional 40 percent. The associated model results imply drawdowns ranging up to 2,000-3,000 feet. While these maximum drawdown values may be unrealistic in a practical sense (particularly since local unconfined conditions around the extraction locations are not modeled), they are comparable to the thicknesses of the basin-fill alluvium in many instances. As a result, the model results may provide some insight into the regional extent of drawdown associated with pumping from various locations over very long time periods.

Among the four scenarios, only Scenario 2 (groundwater extraction from only Cave Valley, Delamar Valley, Dry Lake Valley, and Spring Valley) results in a simulated drawdown in the first model layer of less than one foot in the vicinity of Yucca Mountain. Similar distributions of drawdown were generated for the other model layers (not depicted). In contrast, Scenarios 1, 3, and 4 yield maximum drawdowns near Yucca Mountain in the first model layer ranging up to 130 feet, 40 feet, and 180 feet, respectively. These results suggest that the modeled groundwater development in Railroad Valley would be of the highest significance in impacting hydrology in the Yucca Mountain area, compared to the other permitted locations.

Simulated impacts to the vertical movement of groundwater (using Layers 5 and 8 as surrogates for the Volcanics Unit and the Lower Carbonate Aquifer Unit, respectively) for Scenario 4 are shown on a figure in Appendix E. Specifically, the figure depicts the drawdown in model Layer 5 minus the drawdown in model layer 8, so that negative values (i.e., the unshaded contour lines on the figure) indicate where the previous upward-directed flow of groundwater would be reduced. The implied impacts to vertical water movement are complex; in some areas the net impact to upward flow is positive, while in some areas it is negative. In the vicinity of Yucca Mountain, the upward vertical head difference between the carbonates would be reduced in this particular model scenario, but only on the order of some 5 feet. Additional pumping from Railroad Valley would magnify this change, but the augmented pumping may not be hydrologically sustainable over very long time periods (as discussed below).

Changes in vertical head differences are also sensitive to which individual permit location extract from particular hydrogeological units. For example, for limited pumping under Extraction Scenario 4, 10 of the permit locations tap the alluvium and only 3 tap the carbonate aquifer(s), according to Rules 1 and 2 as listed in Section 3. Changing the screened intervals at these extraction locations, as well as those in some for the other valleys, could also alter the magnitude of the vertical head difference.

3.3.2 Full-Pumping Scenarios

Simulated drawdowns associated under presumed full-pumping (i.e. all permit locations operating at permit-specified extraction rates) for Scenarios 1 through 4 are shown on figures in Appendix E. The substantially larger overall pumping rates in comparison to those of the limited pumping case yield correspondingly excessive modeled drawdowns, extending to tens of thousands of feet in some areas. These results encompass the majority of the saturated thickness in some locations. The large steady-state drawdowns are a reflection of (1) the non-uniform distribution of natural recharge, with the majority occurring in the northeastern portion of the model domain, well away from the modeled permitted extraction areas, and (2) low overall hydraulic conductivity when averaged across the very large spatial scales of the model (Table 3-1). The sizes of the drawdowns would appear to preclude these simulation results from informing hydrologic impact assessments in the Yucca Mountain area, either as a result of unsustainable pumping rates or an ill-defined impact time-frame.

3.3.3 Transient Scenario

Because the steady-state character of the Great Basin MODFLOW model excludes its application in forecasting groundwater head declines in response to pumping as a function of time, a modified version of the model was implemented to help constrain the time scales associated with the drawdowns associated with extraction. The modification consisted of assigning a uniform specific storage parameter of 1.4×10^{-7} ft^{-1}, corresponding to the compressibility of water, across the entire (confined) model domain. This assumption is conservative with respect to the transient release of water from storage in response to pumping, since unconsolidated alluvial basin-fill would likely be characterized by higher specific storage values (i.e., greater than that implied by water compressibility exclusively), with unconfined conditions providing much higher values still (as specific yield), albeit limited in spatial extent.

The distribution of simulated drawdown in the first model layer after 365 years for Extraction Scenario 4 (full-pumping case) is shown in Appendix E. In comparison to the steady-state model, the time-dependent drawdowns after more than three centuries of extraction are substantially smaller (on the order of only a few hundred feet in the vicinity of the application and permit locations). This result implies that transient effects must be taken into account when computing pumping-induced drawdowns over time-frames important for water-supply planning purposes.

3.4 Modeling Discussion

The Great Basin MODFLOW model represents a calibrated, large-scale regional groundwater flow model that could be expected to offer predictive insights into potential hydrological impacts of future groundwater development in central and southern Nevada upon the Yucca Mountain area. Potential advantages of the model include (1) calibrated distributed hydraulic conductivity values and, (2) the vast spatial extent of the model, reducing the impacts of boundary condition assumptions on the Yucca Mountain-area hydrology imparted by smaller-scale models. However, the model is characterized by certain key limitations, including its overall calibration to pre-groundwater development data and its assumption of uniform confined groundwater flow conditions. These and other limitations such as steady-state only flow) contribute to excessive modeled drawdowns when the SNWA permits for the Cave, Delamar, Dry Lakes, Railroad, Spring, Three Lakes, and Tikapoo Valleys are included.

The key issue associated with the development of very large simulated drawdowns stemming from pumping is the associated time scale. Reduced extraction scenarios indicate that moderate hydrologic effects in the Yucca Mountain area are possible when groundwater head drawdowns extend across a major portion of the alluvial thickness in valleys to the north and east. The specific impacts on vertical gradients between hydrogeologic units near Yucca Mountain and elsewhere in the model domain will be dependent upon which units are tapped for development. Moreover, given the imprecise locations of both the permit locations, the depths to contacts between the hydrogeologic units, and local-scale variability in hydraulic properties (i.e., the validity of the equivalent porous medium assumption at the small scale), the magnitude and direction vertical groundwater flow will be uncertain. This also has a substantial effect on transport estimates. As presented in numerical flow/transport modeling conducted by Bredehoeft and King (2010), the predicted travel time of a particle from Yucca Mountain to Death Valley through the Carbonate Aquifer could be as short as 100 years or as long as 2,000 years, depending on porosity (itself a parameter that will have considerable uncertainty associated with it). This suggest a more time critical component to potential impacts to water resources in Inyo County than presented in the Supplement to the EIS.

Including even conservative storage assumptions in the model demonstrates that a long period of time will be required for large drawdowns to manifest. Consequently, sustainability of pumping rates may be constrained differently in the context of water supply planning verses the million-year assessment time frame associated with existence of the waste repository at Yucca Mountain. An additional detail, which was not considered in the current assessment, is the outward rate of propagation of pumping-induced cones of depression toward the Yucca Mountain area. Such an analysis would require a more developed and calibrated transient model, including location-specific storage parameters.

Based on the all of the information provided within Section 3.0, a reliable modeling tool that addresses the County of Inyo's concern regarding the effects of potential groundwater development within the region (particularly to the north of the DVRFS Model area (e.g. Railroad, Paharangat and connected valleys) is not currently available. Without such a reliable modeling tool, the Supplement to EIS cannot realistically analyze the potential impacts of the planned groundwater pumping by the Southern Nevada Water Authority on the upward hydrologic gradient under the proposed repository site.

4.0 SUMMARY COMMENTS TO SUPPLEMENT TO THE EIS

The review of the Supplement to the EIS and associated technical information provided herein has been largely to evaluate the responsiveness of the Supplement to the EIS to the Adoption Determination and Inyo County's previous comments. Primarily because it does not consider new information that has become available since 2010, the Supplement to the EIS is non-responsive to both the Adoption Determination and Inyo County's comments and concerns. The following summarizes these issues on an item-by-item basis with reference to the information provided herein.

On Page 1-2 of the Supplement to the EIS (Section 1.2.1, Lines 27 through 29), it states "*Since the ADR was prepared (in 2008), the NRC staff has not identified new information that would change the NRC's staff's position described in detail in the ADR.*" A review of the referenced section of the Supplement to the EIS indicates that analysis of post-2010 field work and analysis by the USGS and consultants in the Inyo County portion of the Amargosa Basin (Shoshone-Tecopa area specifically) that affects the conceptual model for Amargosa Desert – Ash Meadows area was not been reviewed by NRC staff.

As described in earlier in this review summary, that work consisted of:

- Geochemical analysis (anions, cations, and metals) along with stable and unstable (uranium and strontium) isotope, noble gas, and radiocarbon analyses on springs, wells, and the Amargosa River;
- Periodic river gaging at several locations along the Amargosa River;
- Periodic spring flow and groundwater level measurements at springs and wells throughout the Middle Amargosa River Basin;
- Installation of four shallow monitoring wells 1) north of Shoshone along the Amargosa River, 2) along Willow Creek, 3) at Twelvemile Spring, and 4) at "Married Man's Camp" between Willow Creek and California Valley. This work included sampling and analyzing waters from those wells and outfitting those wells with transducer/data logger installations and periodic groundwater level data downloading (JWI, 2012 and JWI, 2013a);
- Refined geologic mapping being conducted by the USGS;
- Geophysical surveys by the USGS at selected locations throughout the Middle Amargosa Basin area;
- An in depth synoptic canvassing of the flow in the Amargosa River by the USGS to evaluate gaining and losing character of the River (conducted in February, 2014);
- Initiation of evapotranspiration studies along the Amargosa River in the Shoshone – Tecopa area (USGS – in progress); and,

- Development of a new, steady-state numerical groundwater flow model that simulates the Amargosa River region in the context of modeling flow throughout the carbonate rock aquifer system throughout the Great Basin (completed and published in 2014).

It should also be recognized that although it appears that new work by DOE was conducted (for example the reference to the Analysis of Postclosure Impacts, DOE, 2014), that work was based on pre-2010 data collection and analysis, and not reflective of the new work conducted in the Amargosa Basin previously described above. Further that pumping in the Amargosa Desert has been substantially greater for more than 10 years than that presented as a basis for the analysis in the Supplement to the EIS, while it has also been recognized that there is a significantly greater component of groundwater movement southward to the Shoshone-Tecopa area than considered in the Supplement to the EIS, indicates that the conceptual model as presented in the Supplement to the EIS appears to have substantial uncertainties and/or inconsistencies.

Conducting an analysis with the long-term impact analysis presented will intrinsically be prone to substantial uncertainties associated with both climate and environmental (including hydrogeologic) changes that can occur over one million years. Additionally, based on the lack of updated information presented in the Supplement to the EIS, and errors presented herein, there is a high degree of additional uncertainty attached to the conclusions presented in the Supplement to the EIS.

4.1 Responsiveness to NRC Item #1

The Supplement to the EIS is non-responsive to NRC Item #1 (*"A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods"*) due to the absence of consideration of new data and analysis concerning the conceptual model of the Amargosa River basin that has been conducted since 2010. The Supplement to the EIS does not consider a more significant southward flow component that has been indicated by investigations during 2010 through 2014, and associated potential natural discharge locations in the Shoshone-Tecopa area inclusive of the Amargosa WSR.

As a result, the adequacy or appropriateness of the existing compliance point in the upper Amargosa Basin becomes unclear. Further, as described in Section 2.1 of the Supplement to the EIS, the compliance point is based on a calculated dose with respect to postclosure individual protection, human ingestion and groundwater protection standards. However, with the more significant southward component of groundwater flow in the alluvial deposits, toward the Amargosa WSR (with its resident threatened and endangered, water-dependent species), the use of this compliance point may no longer be appropriate. Further, in Section 2.1, the Supplement to the EIS states, *"Groundwater flow and potential releases traveling beyond the regulatory compliance location if uninterrupted, would discharge to Death Valley."* In light of our new understanding of the conceptual model of the basin, that statement can no longer be made definitively as a significant portion of groundwater from the Amargosa Desert – Ash Meadows area is now understood to move southward toward the Shoshone-Tecopa area and the Amargosa WSR.

One illustration of the changing conceptual model is Figure 2-3 in the Supplement. The flow paths illustrated in Figure 2-3 have now changed based on the new information developed since 2010. These new flow paths have been described previously in Section 2.0 of this Review Summary and elsewhere (Andy Zdon & Associates, 2014, Belcher, et. al., 2015). Further, there has been a lowering of the groundwater surface in the southern Amargosa Desert northwest of Death Valley Junction (in California) that is likely the effect of pumping in the Amargosa Farms area (the principal pumping center in the Amargosa Desert). This decrease in groundwater elevation is illustrated by the hydrograph of USGS shallow Monitoring Well NA9 (along the Amargosa River in Inyo County northwest of Death Valley Junction – shown in Figure 4-1). Here groundwater levels have dropped more than 20 feet in the past 25 years. Groundwater pumping in the area of the compliance point causing drawdown in the alluvial aquifer from which a southward flow component of groundwater flow toward the Shoshone-Tecopa area and the Amargosa Wild and Scenic River occurs illustrates the importance of recognizing the greater significance in that southward flow path.

4.2 Responsiveness to NRC Item #2

The Supplement to the EIS is non-responsive to NRC Item #2 (*"A description of the physical processes at the surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants")* due to the absence of consideration of new data and analysis concerning the conceptual model of the Amargosa River basin that has been conducted since 2010. The Supplement to the EIS does not consider a more significant southward flow component that has been indicated by investigations during 2010 through 2014, and associated potential natural discharge locations in the Shoshone-Tecopa area inclusive of the Amargosa WSR. Since those potential natural discharge locations were not considered, their physical process were also not considered.

4.3 Responsiveness to NRC Item #3

The Supplement to the EIS is non-responsive to NRC Item #3 (*"Estimates of the amount of contaminants that could be deposited at or near the surface. This involves estimates of the amount of groundwater involved in discharge or near-surface evaporation, the amounts of radiological and non-radiological contaminants in that water, contaminant concentrations in the resulting deposits, and potential environmental impacts (e.g. effects on biota")* due to the absence of consideration of new data and analysis concerning the conceptual model of the Amargosa River basin that has been conducted since 2010.

The Supplement to the EIS does not consider a more significant southward flow component that has been indicated by investigations during 2010 through 2014, and associated potential natural discharge locations in the Shoshone-Tecopa area inclusive of the Amargosa WSR. Section 2.3 does not recognize potential discharge locations other than an incorrectly characterized Amargosa WSR.

The analysis that was used to evaluate the estimates of the amount of contaminants that could be deposited at or near the surface were based on the use of models and associated analyses developed before the newer, refined understanding of the conceptual model had been developed resulting from hydrogeologic work conducted between 2010 and 2014. This is illustrated by the minimal particle tracks that were identified moving south from the Amargosa Desert toward Franklin Playa. Based on our new understanding of greater influence on the Shoshone-Tecopa area and the Amargosa WSR from alluvial groundwater movement from Amargosa Desert, a greater particle density moving south beyond Franklin Playa could be expected.

With respect to the effects on biota, the Supplement to the EIS is lacking in that area in that threatened and endangered species found in the Shoshone-Tecopa area downgradient from the potentially impacted alluvial aquifer are not provided. The Supplement to the EIS neither provides a listing of endangered species and their locations, nor an analysis of the potential impacts that the proposed project would have on those species. Species such as the Amargosa Vole, Least Bell's Vireo, and others are not mentioned in Section 2.3.1 (Ecology at Surface Discharge Sites). This omission is largely because that section only describes those plant and animal species that are commonly found, or are typical for the region.

Finally, in the Environmental Impacts section (Section 3.0) of the Supplement to the EIS, impacts to aquifer are based on public health exposure, but there is little discussion regarding impacts to biota other than the effects are considered to be small. The most detailed description of the biota of concern are simply listed plant and animals. There is no reference to threatened or endangered species present in the area.

4.4 Responsiveness to Inyo Item #1

The Supplement to the EIS is non-responsive to Inyo Item #1 (*"The full extent of the lower carbonate aquifer, particularly those parts that could become contaminated and how water can leave the flow system should be described"*) due to the absence of consideration of new data and analysis concerning the conceptual model of the Amargosa River basin that has been conducted since 2010. Since the Supplement to the EIS does not consider a more significant southward flow component that has been indicated by investigations during 2010 through 2014, and given the reliance on a transport-related conceptual model that is focused on more northerly areas, the influence of the lower carbonate rock aquifer, and how discharge from that to the alluvium and eventual southward migration of contaminants is not developed. Additionally, since the Supplement to the EIS fails to analyze the effects of potential pumping in connected areas to the DVRFS (e.g. Railroad Valley, Pahranagat Valley and their interconnected upgradient valleys) the full extent of carbonate aquifer system of interest is not provided.

4.5 Responsiveness to Inyo Item #2

The Supplement to the EIS is non-responsive to Inyo Item #2 (*"The potential for a decrease or elimination of the upward vertical gradient beneath Yucca Mountain due to future upgradient water-gathering activities."*) due to the absence of an analysis of the effects of pumping based on those discharge amounts (e.g. by applications by Southern Nevada Water Authority) that are under consideration by the Nevada State Engineer. Both

Railroad Valley and Pahranagat Valley are recognized as being areas of underflow into the DVRFS. As indicated by the modeling presented in Section 3.0, it is likely that the relative contributions of groundwater to the DVRFS are underestimated due to the low modeled hydraulic conductivities. Further, both Railroad and Pahranagat Valleys are interconnected with other valleys to the north in Nevada where SNWA has applied for substantial quantities of groundwater for export to southern Nevada. As shown in Section 3.0, it appears that existing models may not be reliable to answer these questions, and the analysis for the potential for a decrease or elimination of the upward vertical gradient beneath Yucca Mountain remains unanswered in the Supplement to the EIS.

The Supplement to the EIS references modeling of future SNWA pumping based on applications in wells to the east (without referencing what basins or even if those basins are in the regional flow system). That modeling was of 10,600 acre-feet per year of pumping by SNWA from an unnamed location, and is significantly less than the amount of pumping sought in the SNWA applications to the Nevada State Engineer. Absent from that analysis in the Supplement to EIS are the effects of pumping from valleys inclusive of, and in hydraulic connection with Railroad and Pahranagat Valleys.

4.6 Responsiveness to Inyo Item #3

As described earlier, the Supplement to the EIS is non-responsive to Inyo Item #3 (*"Impacts to Endangered Species that utilize the springs in the region"*). The Supplement to the EIS neither provides a listing of endangered species and their locations, nor an analysis of the potential impacts that the proposed project would have on those species. Species such as the Amargosa Vole, Least Bell's Vireo, and others are not mentioned in Section 2.3.1 (Ecology at Surface Discharge Sites). This largely because that section only describes those plant and animal species that are commonly found, or are typical for the region.

4.7 Responsiveness to Inyo Item #4

The Supplement to the EIS is non-responsive to Inyo Item #4 (*"Cleanup and remediation measures should be described"*). The Supplement to the EIS does not describe current cleanup and remedial technologies that could be deployed should a release occur. It is not clear what, if any, actions would be taken should a release occur at the site. Given the substantial uncertainties associated with conceptual model of the area with respect to particle transport, the Supplement to the EIS would substantially benefit with a detailed description of the uncertainties in the analysis, and how those uncertainties could be addressed through further investigation, or through a defined remedial action/mitigation plan presented in the document in the event of the what is noted in the Supplement to the EIS as a likely release of contaminants from the site.

4.8 Recommendations

Given all of the inherent uncertainties and unknowns presented in this review, and that many of the issues raised by the NRC staff and Inyo County have not been fully responded to, it is clear that a reevaluation and recalibration of the DVRFS Model be conducted along with a subsequent reevaluation of potential radionuclide transport in the aquifer systems of the Amargosa Basin. In order to support this effort, an intensive monitoring program, particularly in the Inyo County portion of the basin (in both the Lower Amargosa River area of Shoshone and Tecopa, and within the Death Valley area) should be initiated as soon as possible in order to begin developing a long-term record of groundwater level, flow and quality. Further, it is recommended that further work on the existing more regional model, or development of a new modeling tool, be used to reliably predict potential effects of the realistic potential Southern Nevada Water Authority groundwater withdrawals on the flow system beneath Yucca Mountain

Although the Supplement to the EIS relies on a series of assumed conditions to be maintained as barriers to radionuclide transport when a release occurs, the document provides scant information concerning remediation alternatives that could be used (if they exist) to address such a release and/or any other associated mitigation measures that might be contemplated. Such alternatives should be developed based on the results of the reevaluation recommended above. Given all of the uncertainties associated with the flow regime and analysis as presented in the Supplement to the EIS, a detailed remedial action plan should be developed that describes a course of action that would occur in order to remediate a release of radionuclides (within either the volcanic-alluvial or carbonate-rock aquifers) in a manner that would prevent impacts to springs and other water resources in Inyo County. It is likely that such an effort would highlight other critical data collection needs that could be addressed ahead of time, rather than waiting for a release to occur and that critical data collection effort reducing the ability to respond to a release in a timely manner.

5.0 CONDITIONS AND LIMITATIONS

This report has been prepared according to generally accepted standards of hydrogeologic practice in California at the time this report was prepared. Findings, conclusions, and recommendations contained in this report represent our professional opinion and are based, in part, on information developed by other individuals, corporations, and government agencies. The opinions presented herein are based on currently available information and developed according to the accepted standards of hydrogeologic practice in California. Other than this, no warranty is implied or intended.

6.0 REFERENCES

Andy Zdon & Associates, Inc., 2014. *2014 State of the Basin Report, Amargosa River Basin, Inyo and San Bernardino Counties, California and Nye County, Nevada.* June 28.

Bedinger, M.S., and J.R. Harrill, 2004. *Regional Potential for Interbasin Flow of Ground Water.* Appendix 1 of (Belcher, 2004).

Belcher, Wayne, D. Sweetkind, C. Hopkins, M. Poff, A. Zdon, M.L. Davisson, 2015. Evaluating Groundwater Flow Paths in Lower Amargosa River Valley, Nye County, Nevada and Inyo County, California – Conceptual Model. *Presentation at Devil's Hole Workshop, May 7, 2015.*

Belcher, Wayne, ed., 2004. *Death Valley Regional Ground-Water Flow System, Nevada and California – Hydrogeologic Framework and Transient Ground-Water Flow Model.* U.S. Geological Survey Scientific Investigations Report 2004-5205.

Bredehoeft, John D., and M. King, 2010. Potential Contaminant Transport in the Regional Carbonate Aquifer Beneath Yucca Mountain, Nevada, USA., in Hydrogeology Journal. Volume 18, Issue 3. Pp. 775-789.

Brogan, George E., Karl S. Kellogg, D. Burton Slemmons, and Christina L. Terhune, 1991. *Late Quaternary Faulting Along the Death Valley – Furnace Creek Fault System, California and Nevada.* U.S. Geological Survey Bulletin 1991.

Brooks, L.E., Masbruch, M.D., Sweetkind, D.S., and Buto, S.G., 2014. *Steady-state numerical groundwater flow model of the Great Basin carbonate and alluvial aquifer system,* U.S. Geological Survey Scientific Investigations Report 2014-5213, 124 p.

Buqo, Thomas S., (2004); *Nye County Water Resources Plan.*

Bushman, Michelle, Stephen T. Nelson, David Tingey and Dennis Eggett, 2010. Regional Groundwater Flow in Structurally Complex Extended Terranes: An Evaluation of the Sources of Discharge at Ash Meadows, Nevada. Journal of Hydrology 386 (2010). Pp. 118-129.

California Department of Water Resources, 2003 – California's Groundwater – Update. Department of Water Resources Bulletin No. 118.

California Department of Water Resources, Division of Water Rights, 2014. Water rights abstract for Middle Amargosa Basin and Death Valley Basin, California.

California Division of Mines, 1954. *Geology of Southern California.* California Division of Mines Bulletin 170.

California Geologic Survey, 2002. California Geomorphic Provinces. California Geologic Survey Note 36. 4 pp.

Carroll, D., 1962. *Rainwater as a Chemical Agent of Geologic Processes – A Review.* U.S. Geological Survey Water-Supply Paper 520-F.

Classen, H.C., 1986. Late Wisconsin paleohydrology of the west-central Amargosa Valley, Nevada, USA. Chem. Geol., 58, p. 311-323.

Davisson, M.L., Smith, D.K., Keneally, J., Rose, T.P., 1999. Isotope hydrology of southern Nevada groundwater: stable isotopes and radiocarbon. *Water Resources Research* 35, p. 279-294.

DOE, 2014. *Analysis of Postclosure Groundwater Impacts for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.* RWEV-REP-001-Update. October.

EPG, Inc., 2010. *Draft Environmental Impact Statement for the Amargosa Farm Road Solar Energy Project (NVN-084359).* March 19.

Faunt, Claudia C., Frank D'Agnese, and Grady M. O'Brien, 2004. *Hydrology.* Chapter D of (Belcher, 2004).

Faunt, Claudia C., Joan B. Blainey, Mary C. Hill, Frank D'Agnese, and Grady M. O'Brien, 2004. *Transient Numerical Model.* Chapter F of (Belcher, 2004).

Garside, Larry J., and John H. Schilling, 1979. *Thermal Waters of Nevada.* Nevada Bureau of Mines and Geology Bulletin 91.

Harbaugh, A.W., 2005. *MODFLOW-2005, the U.S. Geological Survey modular ground-water model—the ground-water flow process*, U.S. Geological Survey Techniques and Methods 6-A16, variously paged.

Hurst, R.W., 2012. A Multiple Isotopic Investigation of the Amargosa River: Inyo-San Bernardino Counties, CA and Nye County, NV. 25 pp.

Johnson Wright, Inc., 2012. Additional Hydrologic Investigations and Data Collection Results for Amargosa River Hydrologic Study. June 22.

Johnson Wright, Inc., 2013a. Additional Hydrologic Investigations and Data Collection Results for Amargosa River Hydrologic Study. June 22.

Johnson Wright, Inc., 2013b. Periodic Data Collection Results for Amargosa River Hydrologic Study. October 28.

Johnson Wright, Inc., 2013c. Tecopa Safe Drinking Water and Fire Water Supply Feasibility Study. November 12.

Larsen, D., Swihart, G.H., Xiao, Y., 2001. Hydrochemistry and isotope composition of springs in the Tecopa basin, southeastern California, USA. Chem. Geol., 179, p. 17-35.

King, Michael J., and J.D. Bredehoeft, 1999. Death Valley Springs Geochemical Investigation, Yucca Mountain Nuclear Repository, Inyo County Oversight – 1998. Report prepared for Inyo County Planning Department: Yucca Mountain Repository Oversight Program. March.

Malmberg, G.T., 1967. *Hydrology of the Valley-Fill and Carbonate Rock Reservoirs, Pahrump Valley, Nevada-California.* U.S. Geological Survey Water-Supply Paper 1832.

Mendenhall, W.C., 1909. *Some Desert Watering Places in Southeastern California and Southwestern Nevada.* U.S. Geological Survey Water-Supply Paper 22.

Nevada Department of Water Resources, 2011a. Website, summaries of pumpage, Amargosa Desert.

Nevada Department of Water Resources, 2011b. Website, summaries of pumpage, Pahrump Valley.

Nevada Department of Water Resources, 2014. Water rights Abstract, Basin 162 – Pahrump Valley.

Nevada Department of Water Resources, 2014. Water rights Abstract, Basin 230 – Amargosa Desert.

Nye County Water District, 2011. Website; Hydrologic data including well construction, and groundwater level data.

Pistrang, M.A. and Fred Kunkel, 1964. *A Brief Geologic and Hydrologic Reconnaissance of the Furnace Creek Wash Area, Death Valley National Monument, California.* U.S. Geological Survey Water-Supply Paper 1779-Y.

Planert, Michael and John S. Williams, 1995. *Ground Water Atlas of the United States, Segment 1, California Nevada.* U.S. Geological Survey Hydrologic Investigations Atlas 730-B.

Rose, T.P., M.L. Davisson, R.E. Criss, D.K. Smith, 1999. Isotopic Investigation of Recharge to a Regional Groundwater Flow System, Great Basin, Nevada, USA. International Atomic Energy Agency Symposium on Isotope Hydrology in Water Resources Management, May 1999. Vienna.

Rose, T.P., Kenneally, J.M., Smith, D.K., Davisson, M.L., Hudson, G.B. and Rego, J.H., 1998. Chemical and Isotopic Data for Groundwater in Southern Nevada. Lawrence Livermore National Laboratory, UCRL-ID-128000. 38 pp.

San Juan, Carma A., Wayne R. Belcher, Randell J. Laczniak and Heather M. Putnam, 2004. *Hydrologic Components for Model.* Chapter C of (Belcher, 2004).

Serpico, Phil, 2013. *Tonopah & Tidewater Railroad: The Nevada Short Line.* Omni Publications, Palmdale, Ca. 296 pp.

Spitz, Karlheinz and Joanna Moreno, 1996. *A Practical Guide to Groundwater and Solute Transport Modeling.* Wiley, New York. 461 p.

SGI, 2011. 2011 State of the Basin Report; Amargosa River Basin – Inyo and San Bernardino Counties, California & Nye County, Nevada. April 29.

Sweetkind, Donald S., Wayne R. Belcher, Claudia C. Faunt and Christopher J. Potter, 2004. *Geology and Hydrogeology: Chapter B of (Belcher, 2004).*

Thomas, J.M., Welch, A.H., Dettinger, M.D., 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin region, Nevada, Utah and adjacent states. U.S. Geological Survey Professional Paper 1409-C, 100 pp.

Thomas, J.M., Benedict Jr., F.C., Rose, T.P., Hershey, R.L., Paces, J.B., Peterman, Z.E., Farnham, I.M., Johannsen, K.H., Singh, A.K., Stetzenbach, K.J., Hudson, G.B., Kenneally, J.M., Eaton, G.F., and Smith, D.K., 2003a. Geochemical and Isotopic Interpretations of Groundwater Flow in Oasis Valley Flow System, Southern Nevada. Department of Energy, Nevada operations office, DOE/NV/11508-56. Publ. No. 45190, 113 pp.

Thomas, J.M., Hudson, G.B., Stute, M., Clark, J.F., 2003b. Noble gas loss may indicate groundwater flow across flow barriers in southern Nevada. Environ. Geol., 43, p. 568-579.

Thompson, David G., 1921. *Routes to Desert Watering Places in the Mohave Desert Region, California.* U.S. Geological Survey Water-Supply Paper 490-B.

Thompson, David G., 1929. *The Mohave Desert Region, California: A Geographic, Geological, and Hydrologic Reconnaissance.* U.S. Geological Survey Water-Supply Paper 578. 759 pp.

U.S. Department of Energy, 2009. *Analysis of Postclosure Groundwater Impacts for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-level Radioactive Waste at Yucca Mountain, Nye County, Nevada.* RWEV-REP-001. July.

U.S. Geological Survey, 2011. USGS National Water Information System Database. Streamflow records for Amargosa River near Beatty, Nevada; Amagosa River at Highway 95 below Beatty, Nevada; Amargosa River at Highway 127 near Nevada State Line, Inyo County, California; Amargosa River at Tecopa, California; Amargosa River at Dumont Dunes, San Bernardino County, California.

U.S. Nuclear Regulatory Commission, 2008. *U.S. Nuclear Regulatory Commission Staff's Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain.* September 5.

U.S. Nuclear Regulatory Commission, 2015. *Supplement to the U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.* Draft Report for Comment NUREG-2184. August.

Walker, George E., and Eakin, Thomas E., 1963. *Geology and Ground Water of Amargosa Desert, Nevada-California.* State of Nevada Department of Conservation and Natural Resources Ground-water Reconnaissance Series Report 14. March.

Waring, Gerald A., 1915. *Springs of California.* U.S. Geological Survey Water-Supply Paper 338.

Western Regional Climate Center, 2014. Precipitation and Temperature Record, Shoshone Station.

Winograd, I.J., Thordarson, 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California with special reference to the Nevada Test Site. U.S. Geological Survey Professional Paper 712-C, 126 pp.

Winston, R.B., 2009. *ModelMuse—A graphical user interface for MODFLOW–2005 and PHAST*, U.S. Geological Survey Techniques and Methods 6–A29, 52 p.,

Workman, Jeremiah B., Christopher M. Menges, William R. Page, Emily M. Taylor, E. Bartlett Ekren, Peter D. Rowley, Gary L. Dixon, Ren A. Thompson, and Lauren A. Wright, 2002. *Geologic Map of the Death Valley ground-water model area, Nevada and California.* U.S. Geological Survey Miscellaneous Field Studies MF-2381.

Zdon, Andy, M.L. Davisson, A.H. Love, 2015. *Testing the Established Hydrogeologic Model of Source Water to the Amargosa River Basin, Inyo and San Bernardino Counties, California.* Journal of Environmental Forensics 0:1-12, 2015. (To be available December 11)