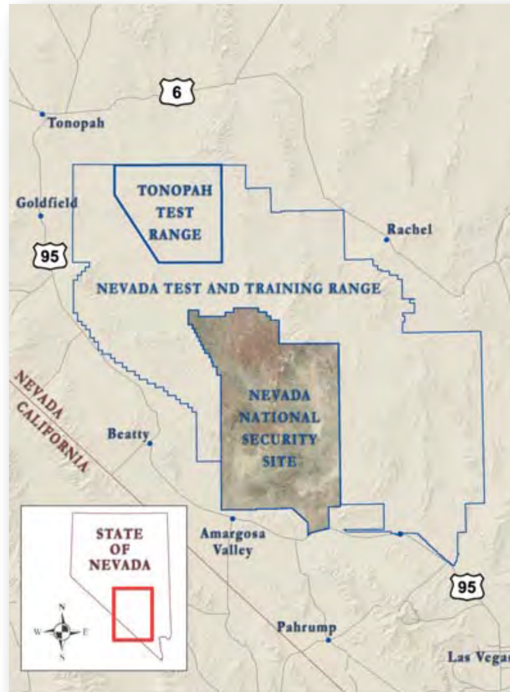
Nevada National Security Site (NNSS)

A large, geographically diverse outdoor laboratory, the NNSS is a preferred testing ground for National Nuclear Security Administration (NNSA) defense programs as well as many other research and development efforts.

- Big - 1,360 square miles
- Secure - Access to the site is controlled
- Remote - Surrounded by federally owned land



NNSS Programs

Defense Experimentation and Stockpile Stewardship

A primary mission of the NNSS is to help ensure that the nation's nuclear weapons remain safe, secure, and reliable. The Stockpile Stewardship program conducts a wide range of experiments using advanced diagnostic technologies, many of which were developed at the NNSS.

- Device Assembly Facility
- Nuclear Criticality Experiments Research Center
- U1a Complex
- Joint Actinide Shock Physics Experimental Research
- Big Explosives Experimental Facility
- Dense Plasma Focus

For further NNSS information contact:
Office of Public Affairs
NNSA Nevada Site Office
(702) 295-3521
nevada@nv.doe.gov
www.nv.energy.gov

Log No. 2012-193

Nevada National Security Site (NNSS)

National Nuclear Security Administration

NNSS Programs

Homeland Security and Defense Applications

Aerial Radiation Measurement

Homeland Security and Defense Applications personnel are the nation's experts trained in detecting and locating "dirty bombs," "loose nukes," and radiological sources. They train and enable our nation's first responders who would be among the first to confront a radiological or nuclear emergency.

- Remote Sensing Laboratory
- Federal Radiological Monitoring and Assessment Center
- T-1 Training Area
- Nonproliferation Test and Evaluation Complex
- Radiological/Nuclear Countermeasures Test and Evaluation Complex

Plume Mapping

First Responder Training

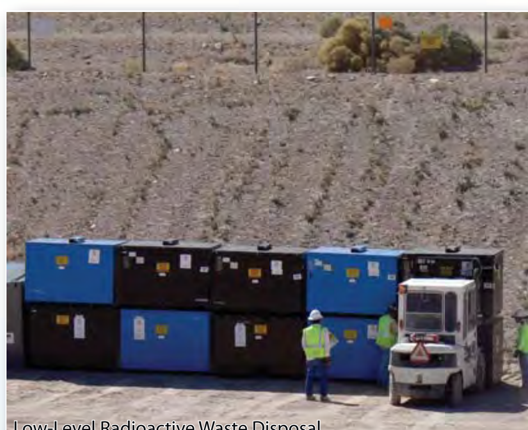
National Center for Nuclear Security

As the United States embarks on a new era of arms control, the tools for treaty verification must be more accurate and reliable and must work at stand-off distances. The National Center for Nuclear Security is poised to become the proving grounds for these technologies.

Environmental Management

The Environmental Management Program addresses the environmental legacy from historic nuclear weapons-related activities, while ensuring the health and safety of workers, the public, and the environment.

- Environmental Restoration
- Waste Management



Low-Level Radioactive Waste Disposal

For further NNSS information contact:
Office of Public Affairs
NNSA Nevada Site Office
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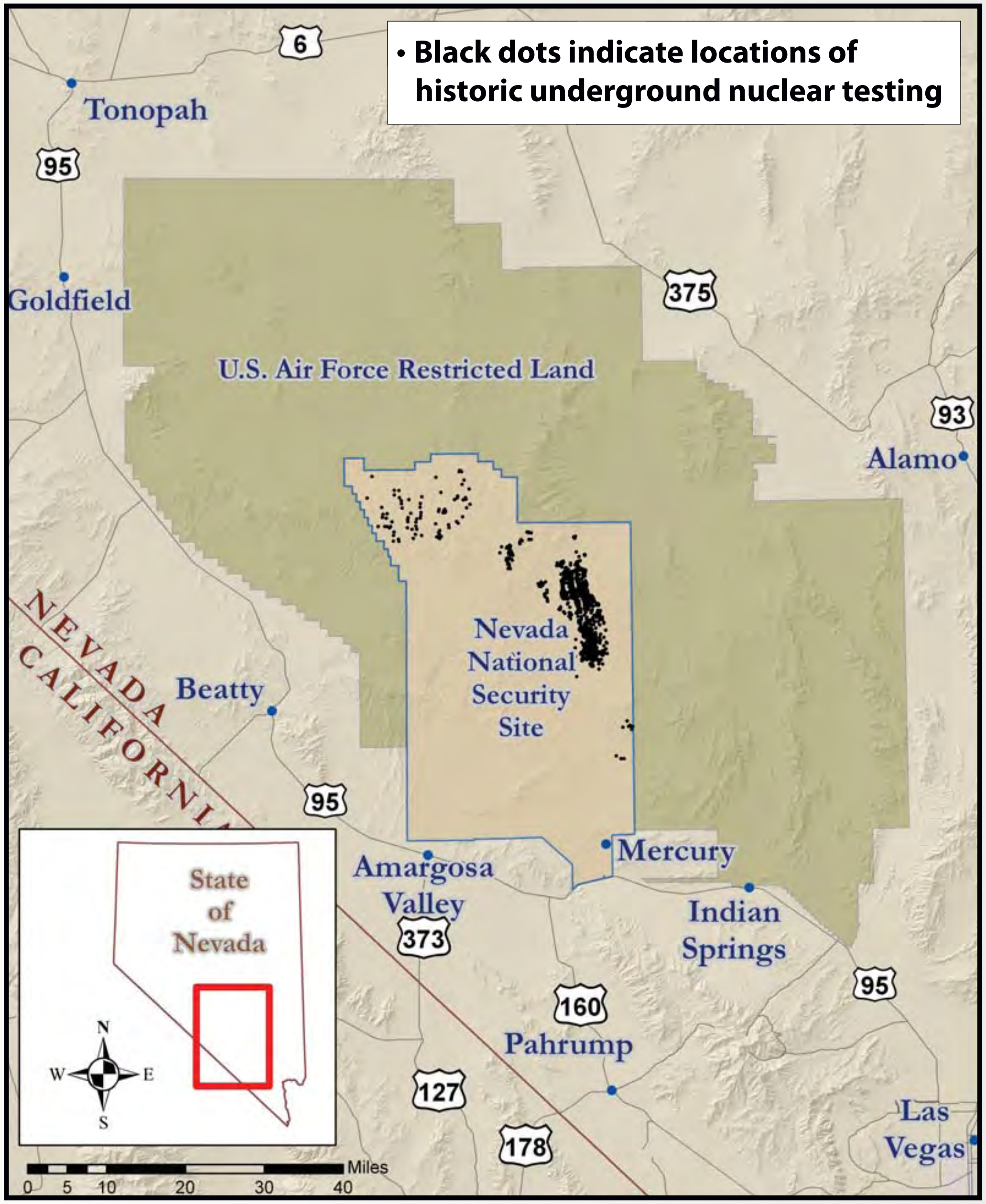
Nevada National Security Site

Log No. 2012-193

Why is there a Groundwater Program at the Nevada National Security Site?



The NNSS is a large (1,360 square miles), secure, remote, and geographically diverse outdoor laboratory surrounded by federally-owned land

Nevada National Security Site (NNSS) Background

- Historically used for nuclear research, development and testing
- Currently used for national security programs and other research and development efforts

Historic Nuclear Testing Impacts on the Groundwater

- 828 underground nuclear tests conducted from 1951 to 1992 at NNSS
- Underground tests conducted at depths ranging from approximately 90 to 4,800 feet below the ground surface
- One-third of these tests occurred near, below, or in the water table
- Some radioactive contamination detected in groundwater on the NNSS

NNSS Groundwater Program

NNSS complex geology and hydrology presents unusual challenges for identifying predominant flow paths and forecasting extent of long-term contaminant transport. Groundwater program objectives:

- Tackle challenges using investigative methods, such as drilling wells to investigate the hydrology and geology
- Sample wells, analyze samples, and build computer models from gathered data
- Implement controls to prevent access to contaminated groundwater
- Ongoing monitoring of wells on and off the NNSS
- Establish a comprehensive long-term monitoring network to ensure public protection

Nevada National Security Site

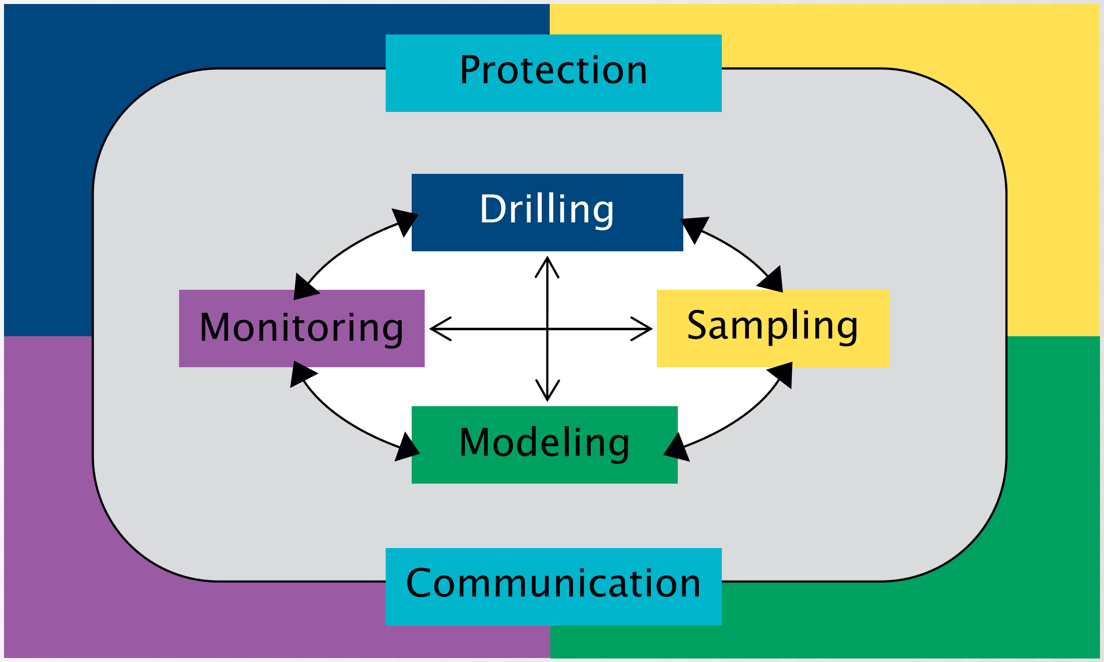
Understanding Groundwater... an Integrated Approach

Protection

The Nevada Site Office groundwater program works in accordance with regulations that protect public health, water resources and the environment.

Drilling

- Wells drilled to access groundwater and the surrounding geology
- To date, 60 wells drilled by Groundwater Program



Sampling

- Identifies constituents in groundwater and provides data for computer models
- Approximately 100 wells, springs, and surface waters sampled each year

Monitoring

- Part of a continuous early detection system
- Results reported annually in the Environmental Report

Modeling

- Computerized tool for visualizing the subsurface environment
- Initial computer models (groundwater flow and radionuclide transport) generated for historic underground test areas

Communications

Stakeholders stay informed and involved through the following:

- Ongoing and timely documents, news releases, outreach events, online publications and social media
- Public Meetings
- Nevada Site Specific Advisory Board

Log No. 2012-190

Nevada National Security Site
Federal Facility Agreement and Consent Order*
Groundwater Strategy

NDEP *- State of Nevada Division of Environmental Protection*

NNSA/NSO *- U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office*

CAU *- Corrective Action Unit: group of sites under investigation. There are five CAUs within Underground Test Area (UGTA) activities*

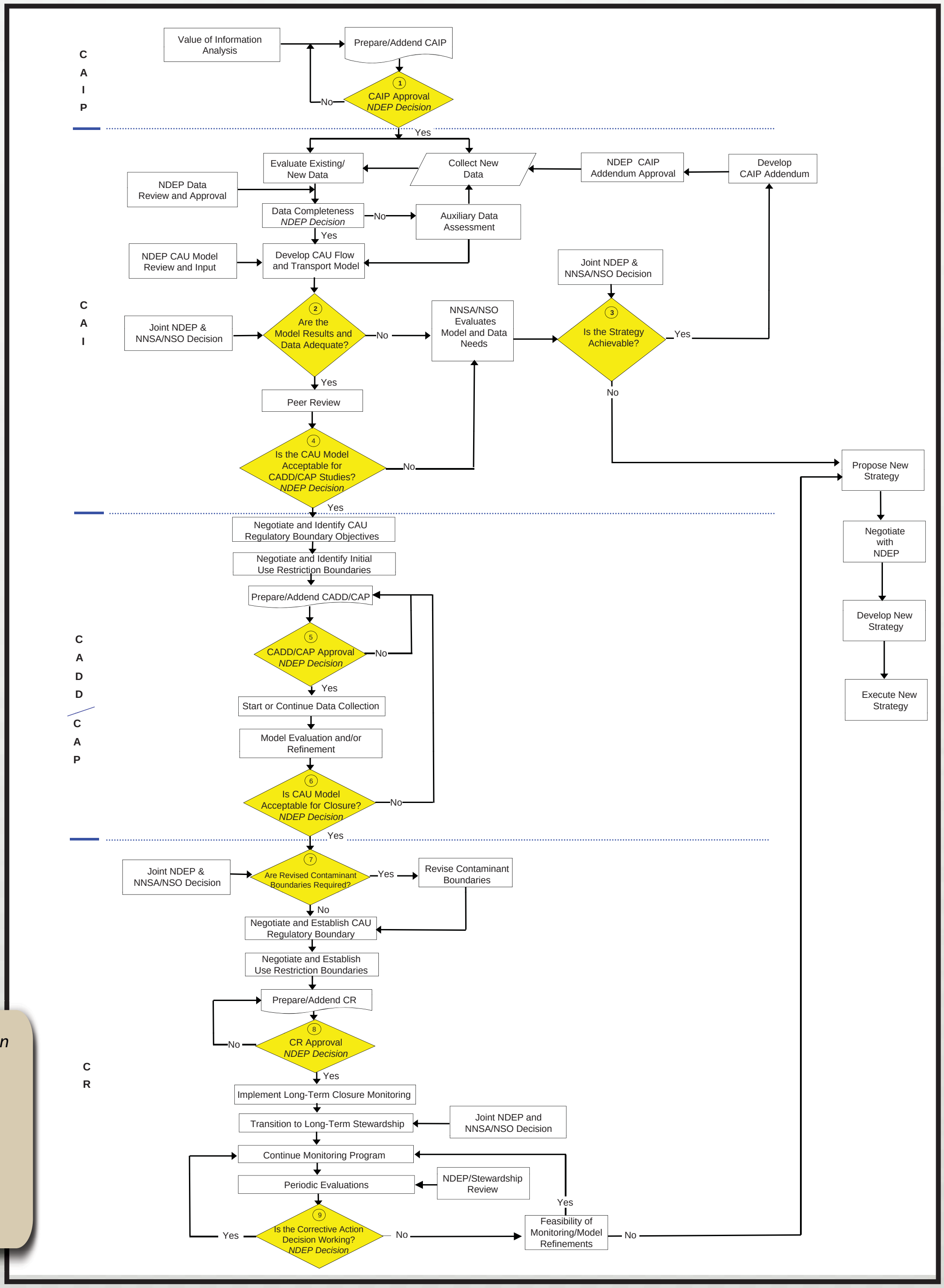
CAIP *- Corrective Action Investigation Plan: looks at existing information from the weapons testing program, the regional flow model, and one-dimensional transport simulations to determine the best options for site characterization and prioritization*

CAI *- Corrective Action Investigation: uses the information from the CAIP stage to develop CAU-specific models of flow and transport, taking the uncertainty of each specific hydrogeologic setting into account--these models are then used to forecast contaminant boundaries for 1,000 years*

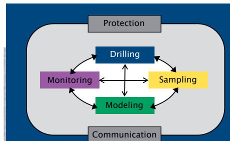
CADD/CAP *- Corrective Action Decision Document/Corrective Action Plan: includes developing and negotiating an initial compliance boundary, developing monitoring programs for model testing and closure, and identifying institutional controls*

CR *- Closure Report: involves negotiating the final compliance boundary for CAU closure; developing a closure report, which must be approved by NDEP; and developing and initiating a long-term closure monitoring program*

**Legally-binding agreement between the State of Nevada; U.S. Department of Energy, Environmental Management; U.S. Department of Defense; and U.S. Department of Energy, Legacy Management.*

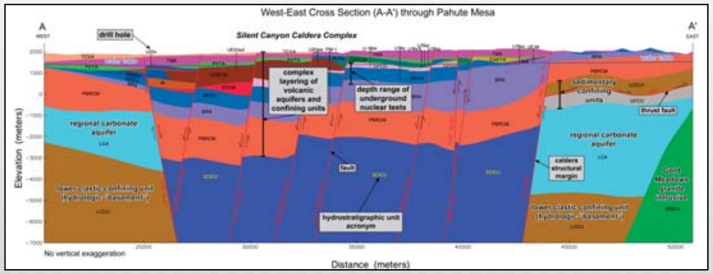


Decision point

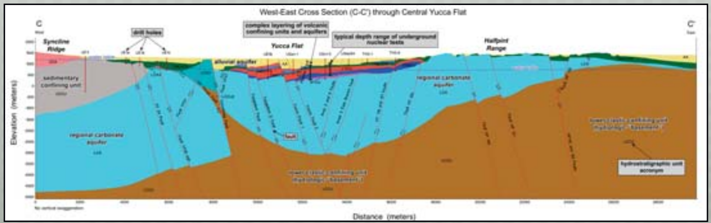


Wells & Drilling

Aquifers vs. Confining Units



- Aquifer - Unit through which water moves.
- Confining unit (also referred to as an "aquitard") - Unit that generally is impermeable to water movement.
- The rocks of the Nevada National Security Site are categorized according to their hydrologic properties (e.g., aquifer or confining unit).
- These units are then grouped into larger hydrostratigraphic units (colored layers on the cross sections). These hydrostratigraphic units together with faults, form the three-dimensional Hydrostratigraphic Framework Models.



- Cross Sections - Vertical slices through the Hydrostratigraphic Framework Models showing arrangement of hydrostratigraphic units below ground level and inside the models.
- In addition to recent groundwater studies, the Underground Test Area team is tapping into, and expanding upon, approximately 50 years of groundwater research

Why Do We Drill?

- Drilling and developing/testing wells provides access to the complex subsurface for sampling
- Gives access to groundwater and surrounding geology
- Provides multiple/ongoing opportunities to sample and monitor

Nevada National Security Site

The complex geologic features of the Nevada National Security Site include:

- More than 300 different geologic units representing more than 500 million years of geologic history
- At least seven Tertiary*-age calderas (i.e., large volcanic depressions)
- Mesozoic*-age thrust faults and folds (relatively "old") - due to compression
- Basin-and-range normal faults (relatively "young") - due to extension
- Granite rising through highly deformed sedimentary rocks
- Several deep (up to a mile) alluvial-filled basins

* **Tertiary Period** (dates from 65 to 1.8 years ago). Virtually all major existing mountain ranges were formed during this period.

* **Mesozoic Era** (date from around 250 to 65 million years ago). this era marks the beginning of land animals and plants.

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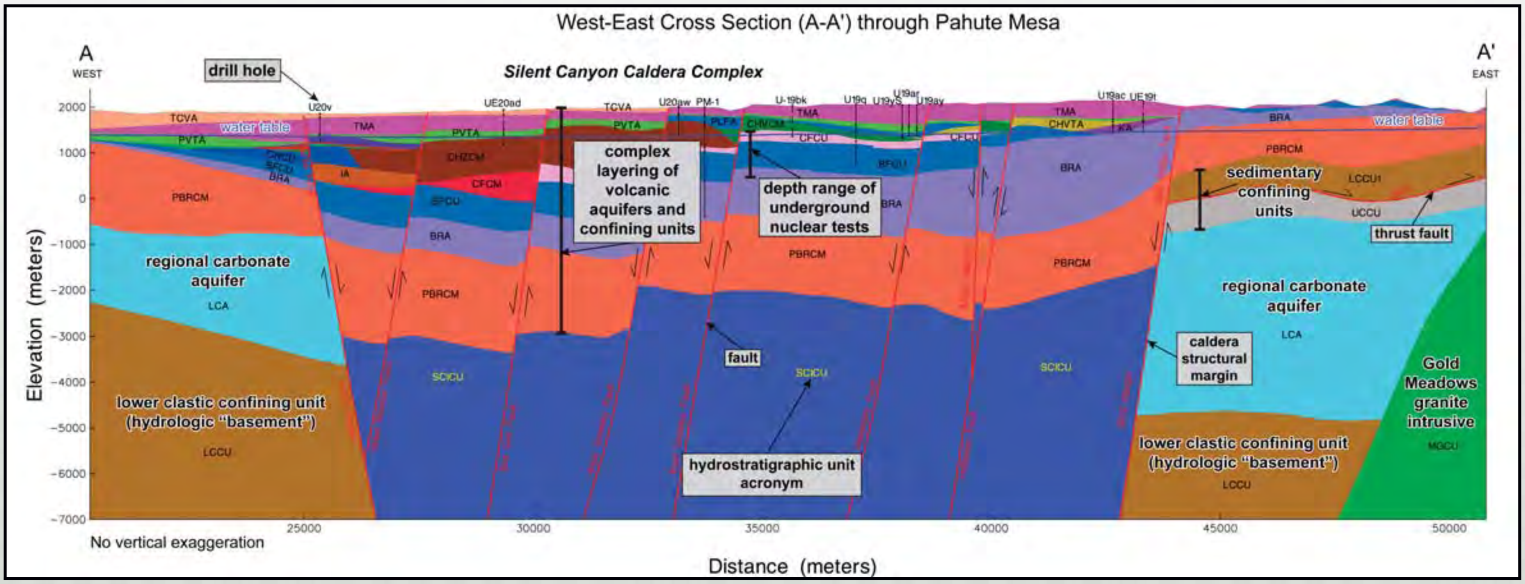
Nevada National Security Site

Aquifers vs. Confining Units



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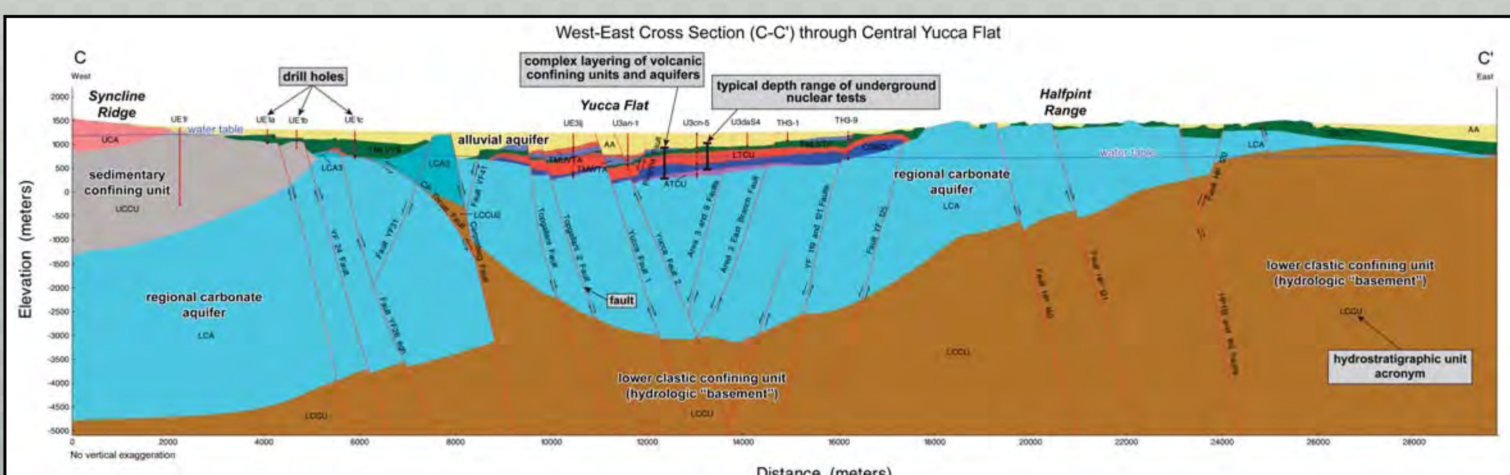

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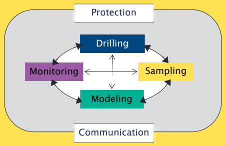

Sampling & Analysis

Obtaining Information from Well Sampling

- Water and rock cuttings/core collected
  - Aquifer specific samples
  - Depth discrete samples (various zones within an aquifer)
- Samples used and analyzed by several organizations, such as the Desert Research Institute and the U.S. Geological Survey
- Analysis of samples includes identifying the presence of dissolved metals, tritium, carbon-14, strontium-90, technetium, iodine-129, and plutonium
- Analysis results used as input for groundwater flow and transport modeling

Log No. 2012-196

Why Do We Sample?

- Identify the natural conditions of groundwater and geology in the subsurface, and constituents introduced by nuclear testing
- Acquire data used as building blocks for computer models
- Obtain laboratory results for regulatory compliance, stakeholder communications, and additional subsurface investigations

Nevada National Security Site

Log No. 2012-196

Sampling for Regulatory Compliance

- Samples collected from springs/surface waters and groundwater wells
  - More than 60 locations on and off the Nevada National Security Site
  - Frequency ranges from every three months to every three years
  - Frequency partially dictated by proximity to a contaminated aquifer
- Samples analyzed for tritium, gross alpha and beta activity, gamma-emitting radionuclides, plutonium, carbon-14, strontium-90, and technetium
- Analysis results used to monitor radionuclide concentrations for comparison to those set by state and federal regulations, and U.S. Department of Energy directives
  - *Safe Drinking Water Act*
  - *Clean Water Act*
  - *Radiation Protection of the Public and the Environment*
  - *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*

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NNSA
Nevada National Security Site

Log No. 2012-196

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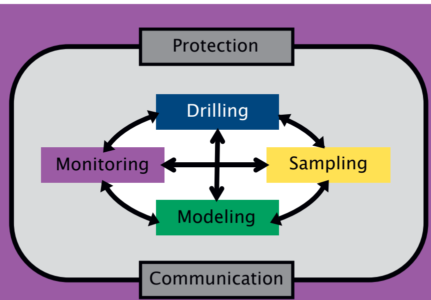
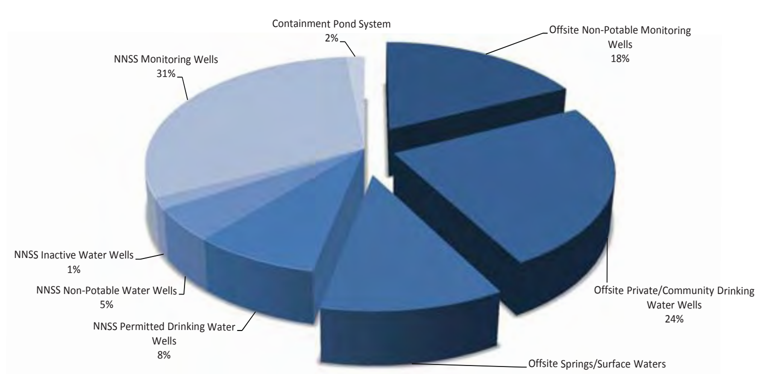


Monitoring

More than 60 wells, springs, and surface water locations are regularly monitored on and off the Nevada National Security Site. Results at these **Routine Radiological Environmental Monitoring Program** (RREMP) locations are used to identify trends and verify compliance with verify compliance with regulatory standards.

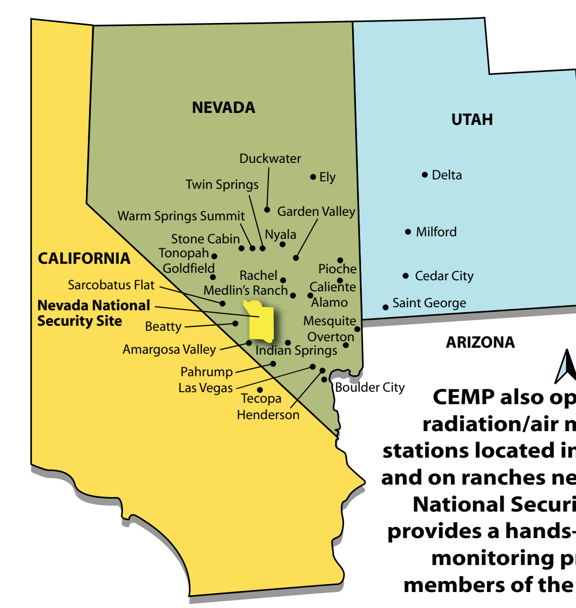
Break-out percentages of monitoring locations used in RREMP Program (locations monitored at different intervals).



Why Do We Monitor?

- Helps protect the public by providing a system of continuous detection
- Provides baseline to establish existing conditions

In addition to Nevada Site Office monitoring efforts, the **Community Environmental Monitoring Program** (CEMP) performs independent, annual monitoring at 29 springs and water supplies in communities surrounding the Nevada National Security Site.



CEMP also operates 29 radiation/air monitoring stations located in communities and on ranches near the Nevada National Security Site, and provides a hands-on role in the monitoring process for members of the community.

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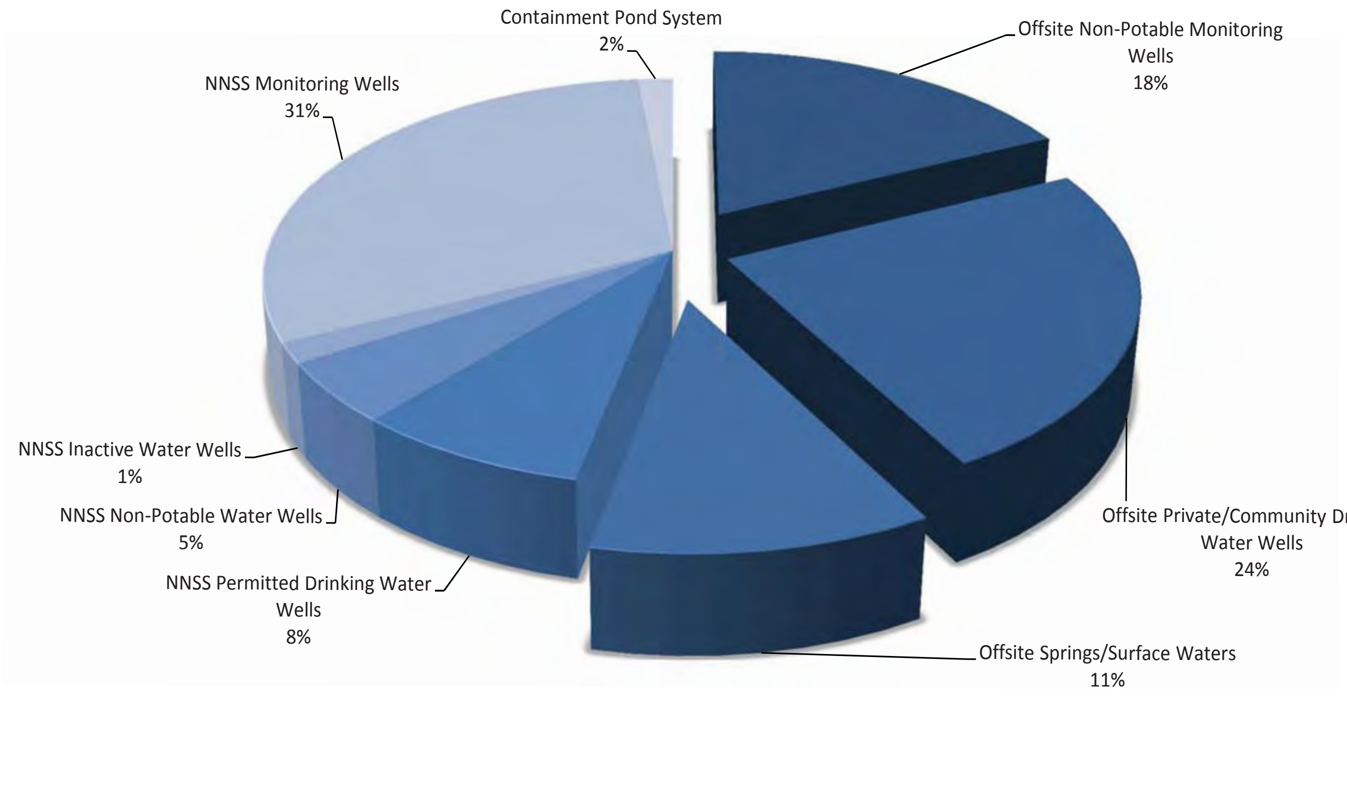

Why Do We Monitor?

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Nevada National Security Site

Log No. 2012-184

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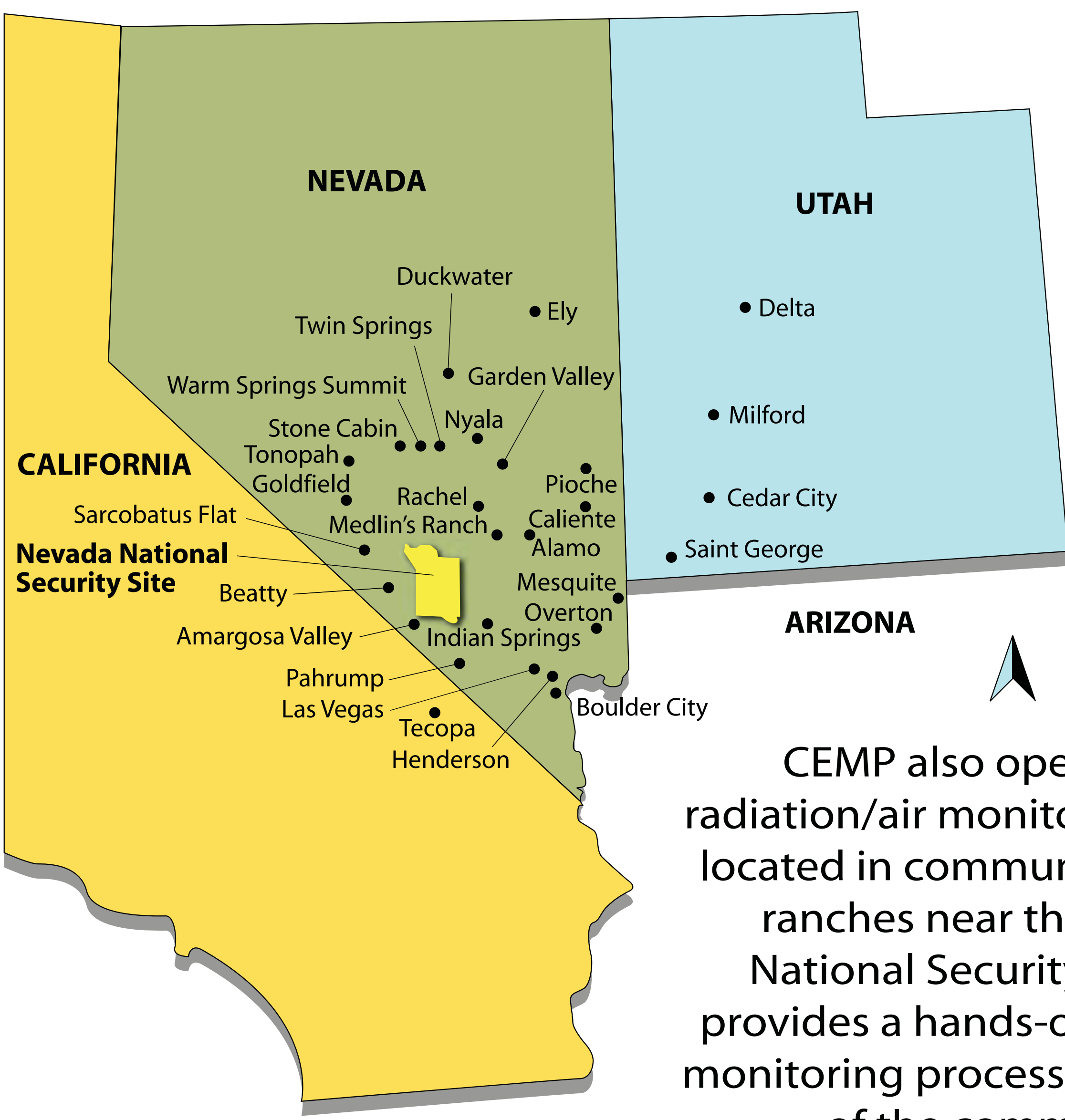

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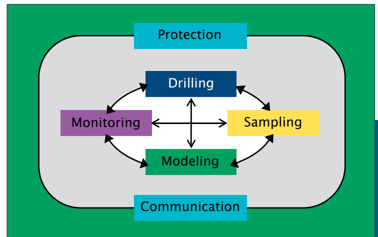
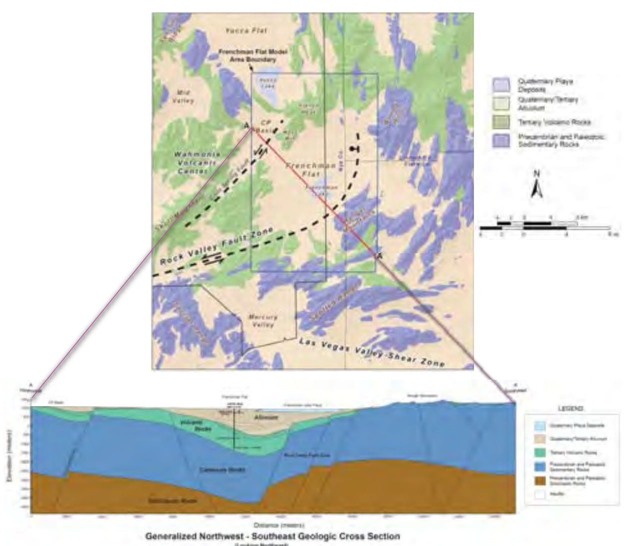
Log No. 2012-184



Modeling

Hydrostratigraphic Model of Frenchman Flat



Sampling data helps modelers develop subsurface maps, which provide important details on geologic features affecting groundwater flowpaths.

Log No. 2012-198

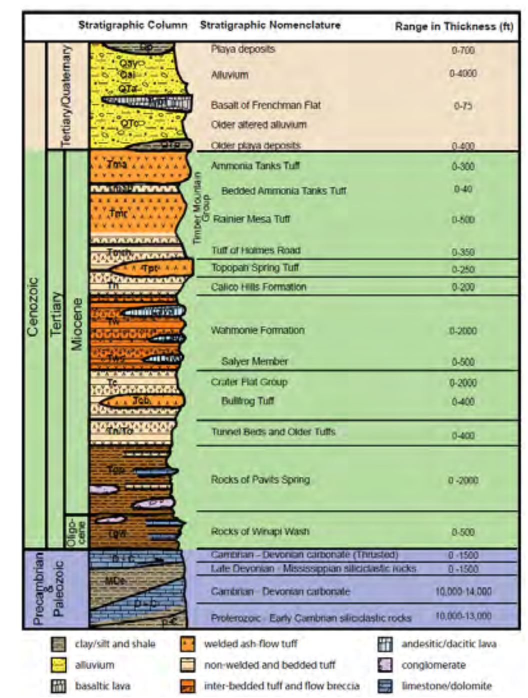
Why Do We Model?

- Creates 3-dimensional visual representations of otherwise inaccessible subsurface
- Tool that helps forecast where contamination is moving and how fast
- Provides flexibility for incorporating evolving data

Nevada National Security Site

Log No. 2012-198

Geologic setting of Frenchman Flat

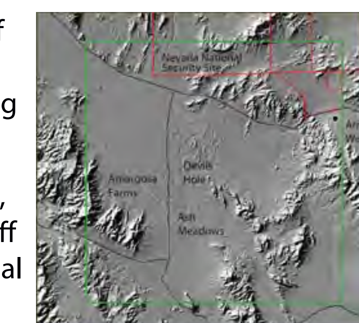


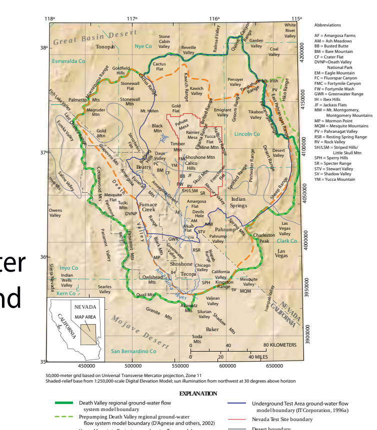
Log No. 2012-198

Resource Allocation

Death Valley Regional Groundwater Flow System (DVRFS) Model

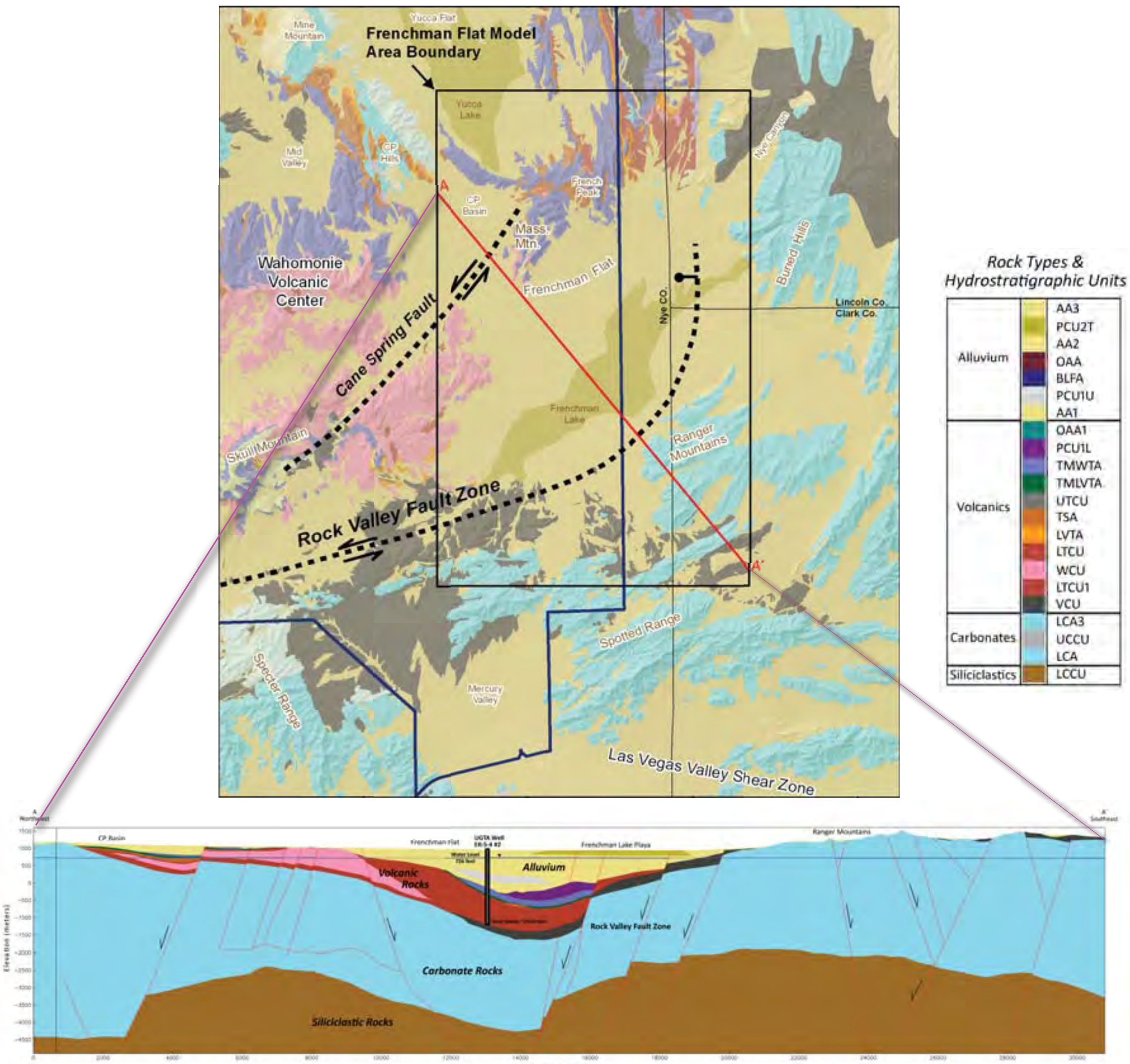
- U.S. Department of Energy (DOE) contributes funding
- DOE provides data, collected on and off the Nevada National Security Site, to be inserted into the U.S. Geological Survey's DVRFS model
- Water allocation for future resource demands considers effects of groundwater pumping activities and proposals





Log No. 2012-198

Hydrostratigraphic Model of Frenchman Flat



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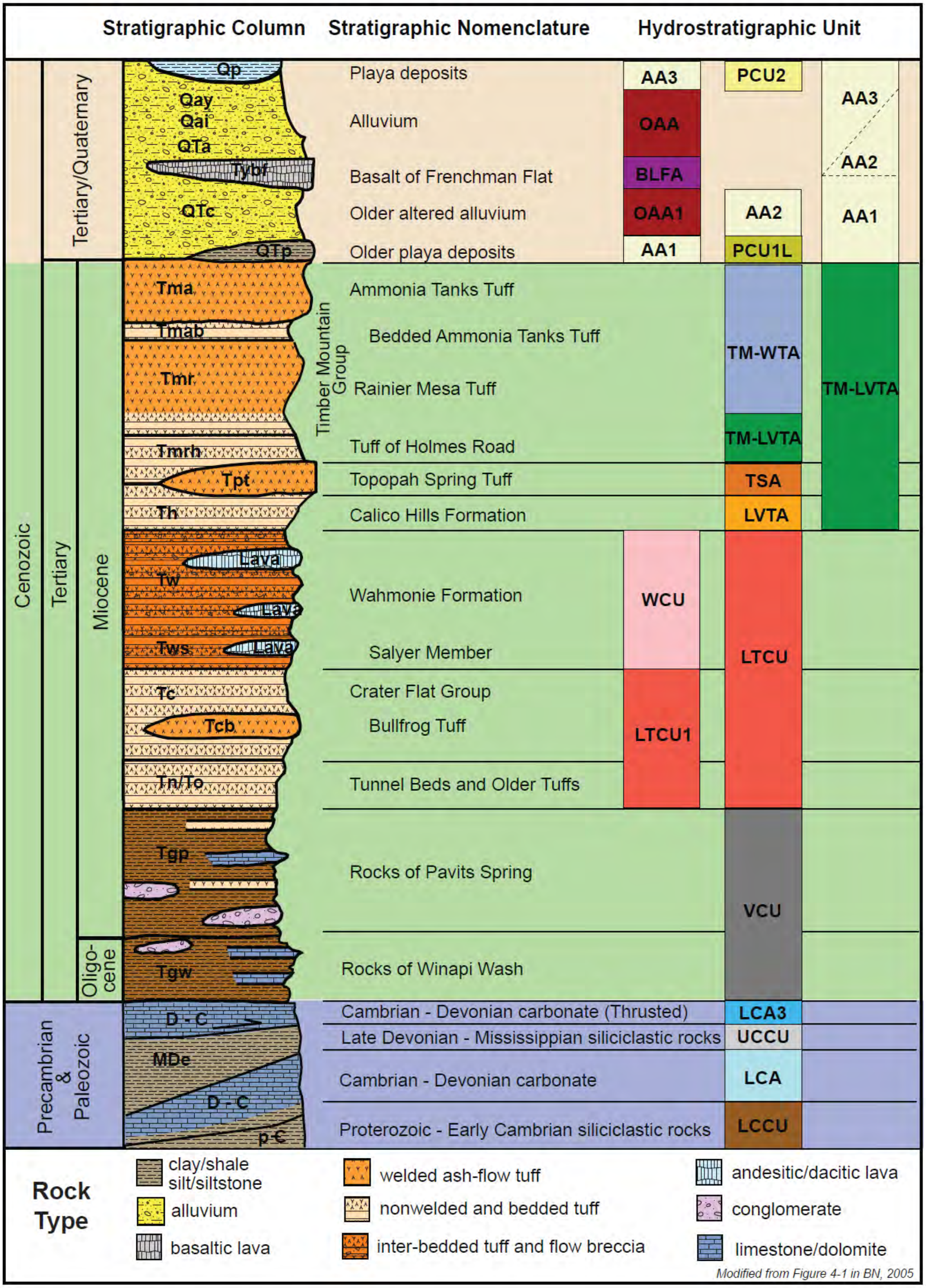
Why Do We Model?

- Creates 3-dimensional representations of otherwise inaccessible subsurface
- Tool that helps forecast where contamination is moving and how fast
- Provides flexibility for integrating available data
- Provides basis for regulatory compliance and risk decisions

NNSA
Nevada National Security Site

Log No. 2012-198

Geologic setting of Frenchman Flat



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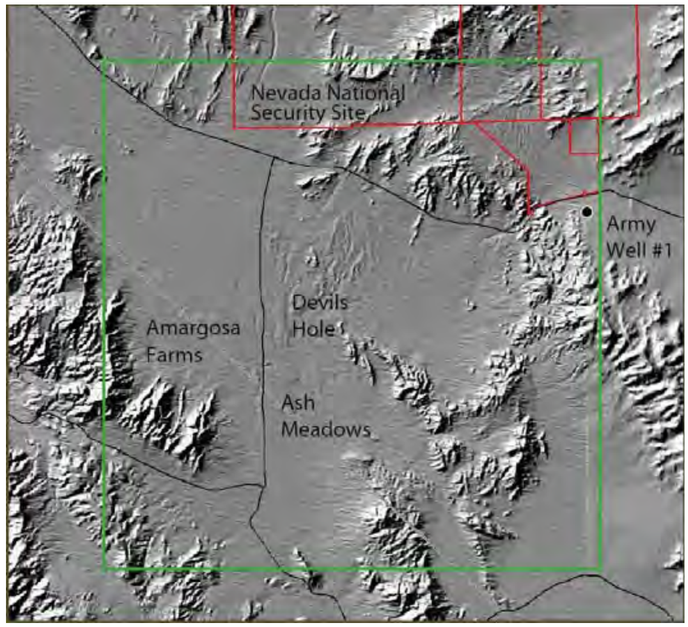

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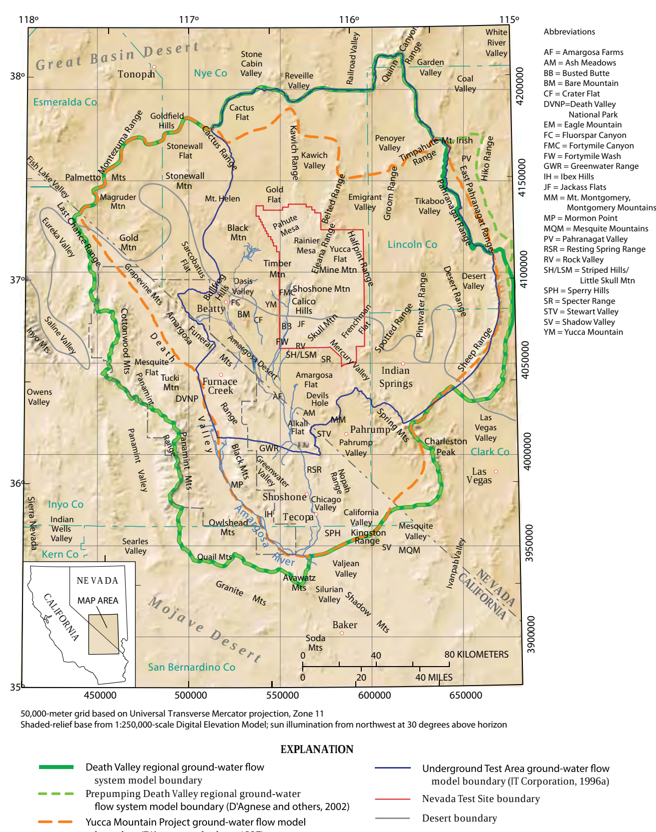


Log No. 2012-198

What We Know Today

- Groundwater affected by historic Nevada National Security Site activities has not reached public water sources

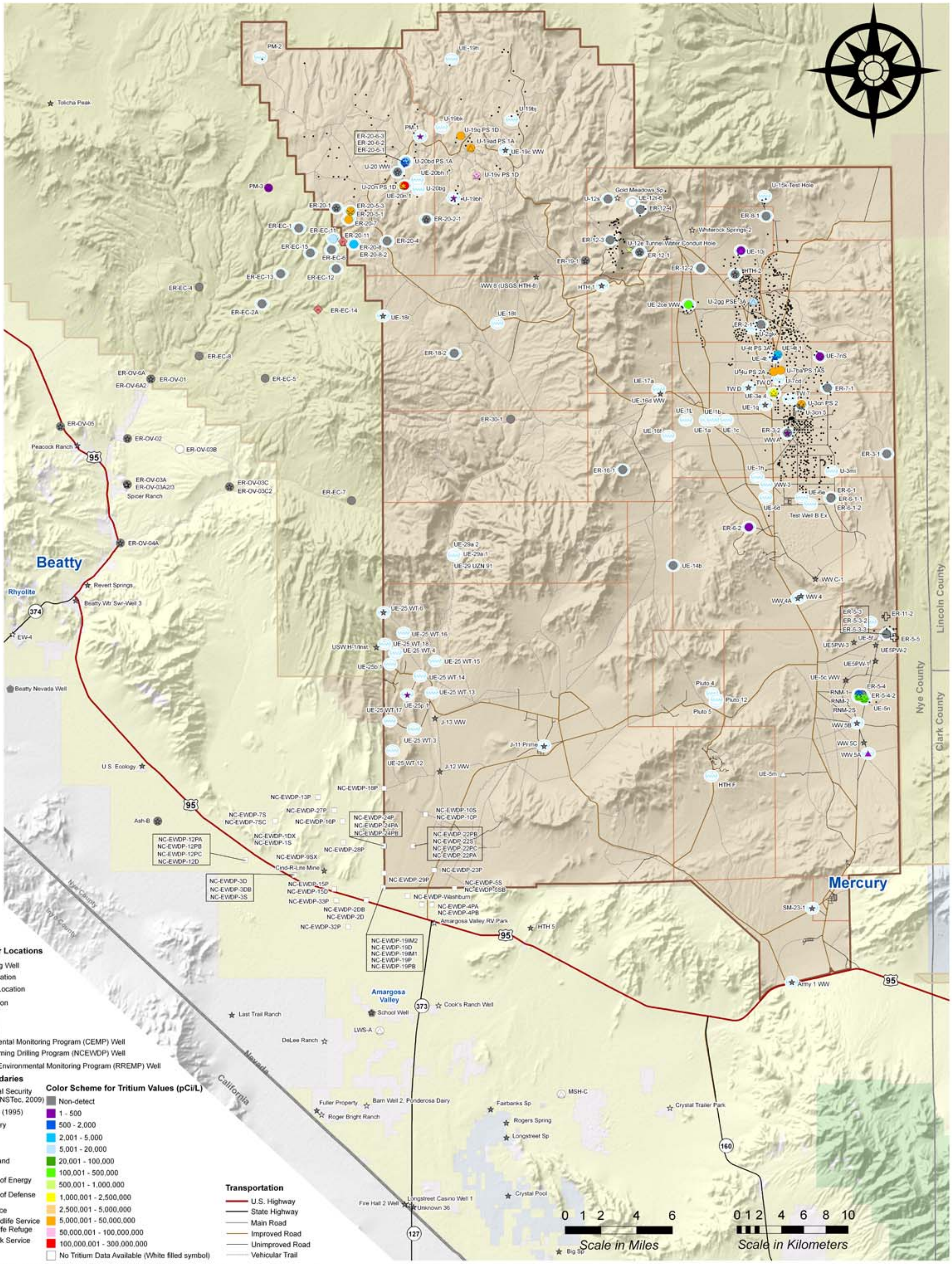
- Groundwater models are providing output that is key to enhancing current, and developing future monitoring strategies

- No forecasted threat to public

Nevada National Security Site

Log No. 2012-188

Tritium Values from Monitoring & Hydrogeologic Investigation Wells in the Vicinity of the Nevada National Security Site (NNSS)



All data shown on this map are considered preliminary, unless otherwise noted. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty or representation, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use constitutes or implies its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof.

Monitoring and Other Locations

- Water Level Monitoring Well
- Underground Test Location
- Other Well/Sampling Location
- Well Under Construction
- Recently Drilled Well
- Characterization Well
- Community Environmental Monitoring Program (CEMP) Well
- Nye County Early Warning Drilling Program (NCEWDP) Well
- Routine Radiological Environmental Monitoring Program (RREMP) Well

Administrative Boundaries

- Nevada National Security Site Boundary (NSTec, 2009)
- State Boundary (1995)
- County Boundary (ESRI, 2009)

Color Scheme for Tritium Values (pCi/L)

- Non-detect
- 1 - 500
- 500 - 2,000
- 2,001 - 5,000
- 5,001 - 20,000
- 20,001 - 100,000
- 100,001 - 500,000
- 500,001 - 1,000,000
- 1,000,001 - 2,500,000
- 2,500,001 - 5,000,000
- 5,000,001 - 50,000,000
- 50,000,001 - 100,000,000
- 100,000,001 - 300,000,000
- No Tritium Data Available (White filled symbol)

Land Management

- US Bureau of Land Management
- US Department of Energy
- US Department of Defense
- US Forest Service
- US Fish and Wildlife Service - National Wildlife Refuge
- US National Park Service
- Private Land

Transportation

- U.S. Highway
- State Highway
- Main Road
- Improved Road
- Unimproved Road
- Vehicular Trail

Source: NJ GIS, 2012; NSTec, 2010; Land Management data based on 2010 data from US Bureau of Land Management

The Latest from the Field

Well Development & Testing

In 2012, *well development and testing** activities completed at wells ER-EC-12 (upper and lower zone) and ER-EC-13 (upper zone)

Above: Characterization well in Pahute Mesa (2009). Left: Model evaluation well in Frenchman Flat (2012).

Groundwater Characterization Wells

In September 2012, two new *groundwater characterization wells*** under construction in Pahute Mesa

Model Evaluation Wells

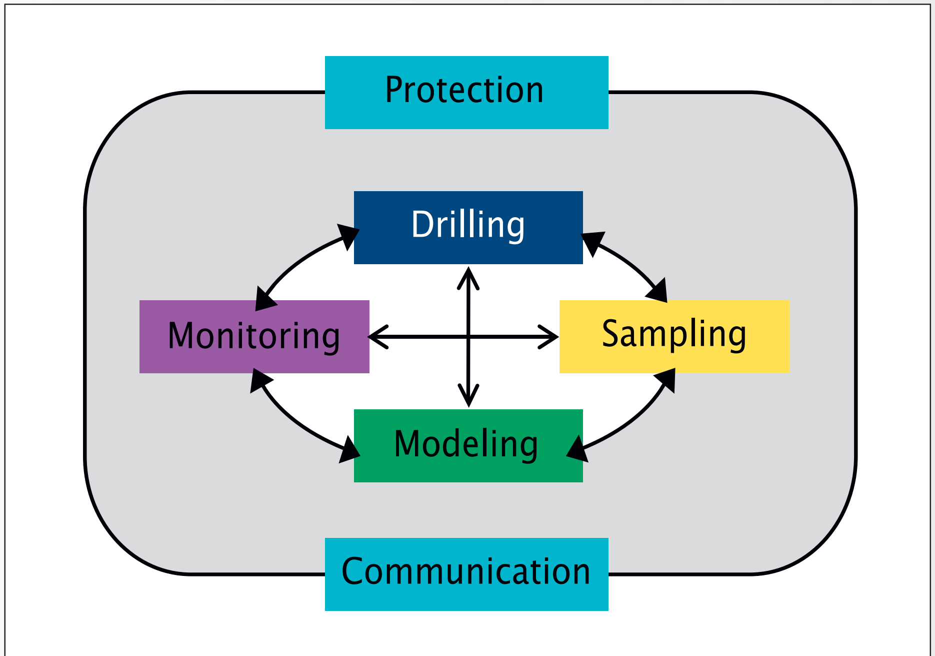
In August 2012, two *model evaluation wells*† (ER-5-5 and ER-11-2) drilled in Frenchman Flat

* ***well development and testing*** *- the extensive preparation of a well prior to sampling*
** ***groundwater characterization wells*** *-provide samples that identify water chemistry, pressure levels, and temperature, as well as gauge the surrounding geology*
† ***model evaluation wells*** *- used to test the soundness of computer model forecasts*

Nevada National Security Site

Log No. 2012-187

Communications

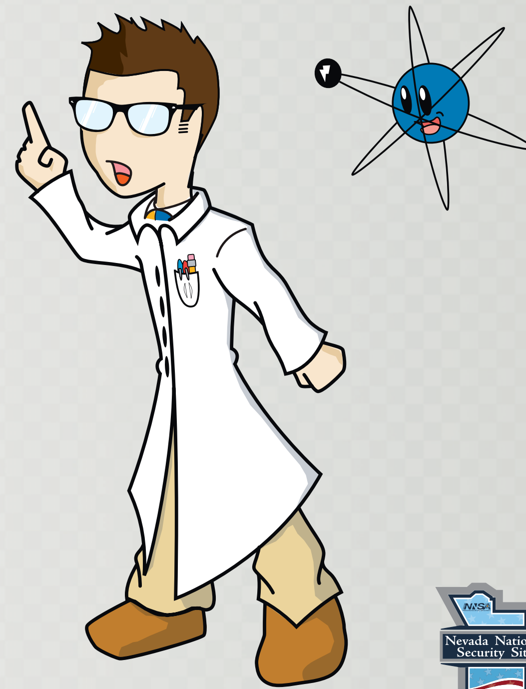


Stakeholders stay informed and involved through:

- Ongoing and timely documents, news releases, outreach events, online publications and social media
- The Nevada Site Specific Advisory Board, a volunteer citizens advisory group

Outreach

- Nevada Site Specific Advisory Board
- Operation Clean Desert
- Publications
  (Fact sheets, EM News Flash, Websites)
- Public Meetings
- Social Media
  (Facebook, Twitter, Flickr, YouTube)



Nevada National Security Site

Nevada Site Specific Advisory Board

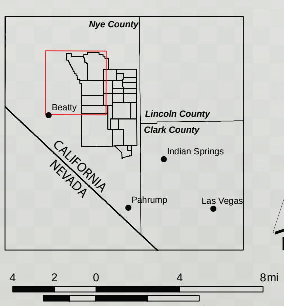
The Nevada Site Specific Advisory Board (NSSAB) is made up of southern Nevada residents and is federally chartered to provide recommendations to the Environmental Management Program at the Nevada National Security Site.

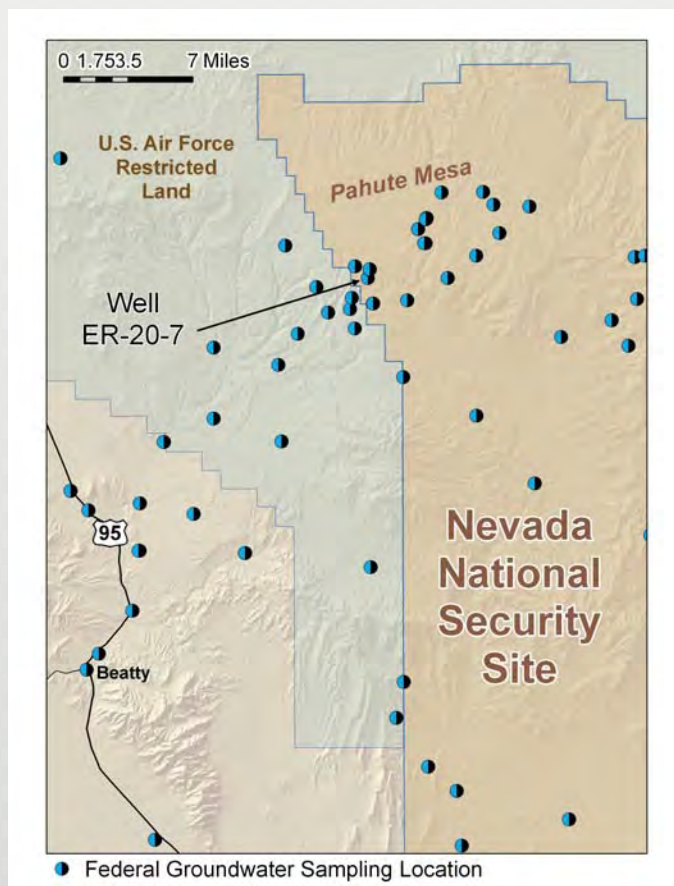
In 2002, the U.S. Department of Energy asked the NSSAB to site the location of a groundwater well that could be used to gain data for the groundwater characterization activities. In 2006, after four years of extensive research, the NSSAB recommended three groundwater wells on and near Pahute Mesa. In 2009, the U.S. Department of Energy drilled well ER-20-7, which was one of the NSSAB's recommended sites.

Current and past NSSAB members reside in Beatty, Amargosa Valley, Pahrump, and Las Vegas.

Nevada Site Specific Advisory Board members tour the drill site they recommended. Well ER-20-7 is located on Pahute Mesa at the Nevada National Security Site.

A Nevada Site Specific Advisory Board meeting held in Las Vegas, Nevada

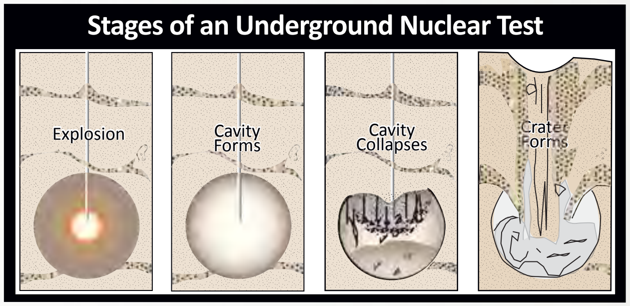




Log No. 2012-183

Understanding Radioactive Impacts to the Groundwater at the Nevada National Security Site (NNSS)

How it Happened...

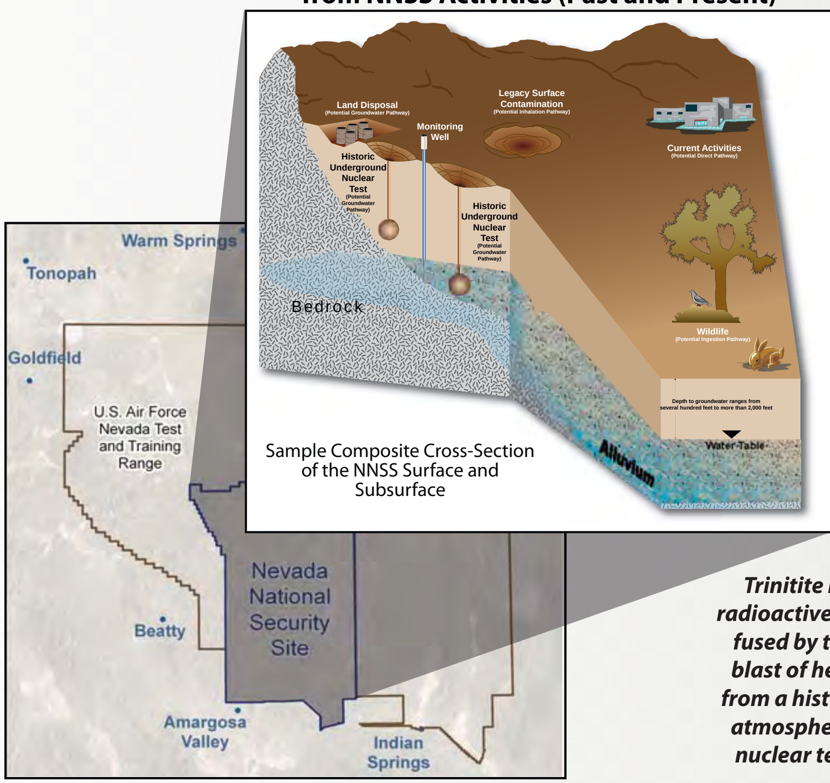


First there is an underground explosion, and then the surrounding rock is vaporized; next, as the rock cools and settles to the bottom of the cavity, the roof collapses into the cavity forming a depression on the surface, or a subsidence crater.

Groundwater Contamination Questions

- What are the contaminants of concern at the Nevada National Security Site?
- Am I affected by these contaminants?
- How is man-made radiation different from naturally-occurring radiation?

Potential Primary Exposure Pathways from NNSS Activities (Past and Present)



Sample Composite Cross-Section of the NNSS Surface and Subsurface

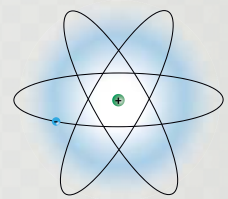
Answering the Questions...

- 43 radionuclides produced during nuclear tests considered a potential risk, of which tritium, carbon, iodine, chlorine, technetium, plutonium, cesium and strontium are dominant
- Radionuclides reside in melt glass, underground rubble and in rocks surrounding the cavity produced by the detonation of an underground nuclear device; when detonation occurred near or within groundwater, some radionuclides were released into and can be transported with the groundwater
- Tritium is incorporated directly into the water molecule and can easily move in groundwater, making it a primary indicator of contaminant transport; many of the longer-lived radionuclides, such as plutonium have limited solubility in groundwater and adsorb onto rock surfaces
- There is no public access to contaminated groundwater detected in wells on the NNSS and the surrounding federally-controlled land; these wells, and those down-gradient, are closely monitored to identify potential radionuclide migration to prevent public exposure

Tritium and What it Means to You

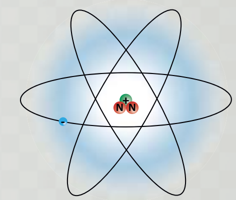
Hydrogen Atom

One proton
No neutrons
One electron



Tritium Atom

One proton
Two neutrons
One electron



- Tritium is a radioactive form (isotope) of hydrogen with a half-life of 12.3 years
- Like hydrogen, tritium can bond with oxygen to form tritiated water which is chemically identical to normal water
- Tritium primarily enters the body when people eat or drink water containing tritium
- Tritium emits a weak form of radiation (low-energy beta particle) that cannot penetrate deeply into tissue or travel far in air
- Half of tritium is eliminated from the body about 10 days after exposure
- Tritium occurs in surface waters (such as Lake Mead) at 10 to 30 picocuries per liter (U.S. Environmental Protection Agency standard for safe drinking water is 20,000 picocuries per liter)

Trinitite is radioactive soil fused by the blast of heat from a historic atmospheric nuclear test

Nevada National Security Site

Radiation Exposure and You

- Average person receives approximately 320 mrem* of radiation per year from exposure to various naturally-occuring and man-made sources
- Medical procedures (such dental or chest x-rays) expose the average person to another 298 mrem (not illustrated below)
- Health effects (primarily cancer) have been demonstrated in humans at doses exceeding 5,000-10,000 mrem delivered at high dose rates; below this dose, estimation of adverse health effects is speculative

The Average Annual Dose of Radiation

Radon - 230 mrem

- Gas produced by natural breakdown of uranium in soil, rock and water
- Migrates through porous areas like the ground and the foundation of your house

The Human Body - 31 mrem

- Large portion of our radiation exposure comes from within our own bodies and the bodies of others near us
- Potassium-40 and other radioactive isotopes found in the air, water and soil are incorporated into the food we eat, then into body tissue
- Carbon-14, the same isotope used for carbon-dating in archaeology, is naturally-occurring in our bodies

Cosmic - 30 mrem

- High-energy gamma radiation that originates in outer space and filters through the Earth's atmosphere in the form of rays such as sunlight
- Cosmic radiation increases with altitude

Terrestrial - 19 mrem

- Soil, rock, and clay are examples of material deposits in the Earth that contain naturally radioactive materials like uranium and thorium
- Naturally radioactive materials are also present in construction materials

Consumer Products - 12 mrem

- Small amounts emitted from such household items as smoke detectors and televisions

Tritium - 4 mrem

- Drinking two liters of water each day for a year that contains 20,000 picocuries of tritium per liter (allowable limit under the Safe Drinking Water Act)
- Equivalent to drinking 193 gallons ($3^{1}/_{2}$ 55-gallon drums) of water contaminated with 20,000 picocuries per liter of tritium

NNSA Nevada National Security Site

*mrem (millirem) is one one-thousandth of a rem which measures biological impact, or "dose" of radiation

Log No. 2012-186

NEVADA DIVISION OF WATER RESOURCES

(aka NEVADA STATE ENGINEER'S OFFICE)

WHAT WE DO

WATER RIGHTS (SURFACE AND GROUNDWATER)

- •APPROPRIATIONS
- •REALLOCATION
- •MONITORING

WATER AVAILABILITY (PERENNIAL YIELD)

ADJUDICATIONS

DAM SAFETY

FLOODPLAIN MANAGEMENT

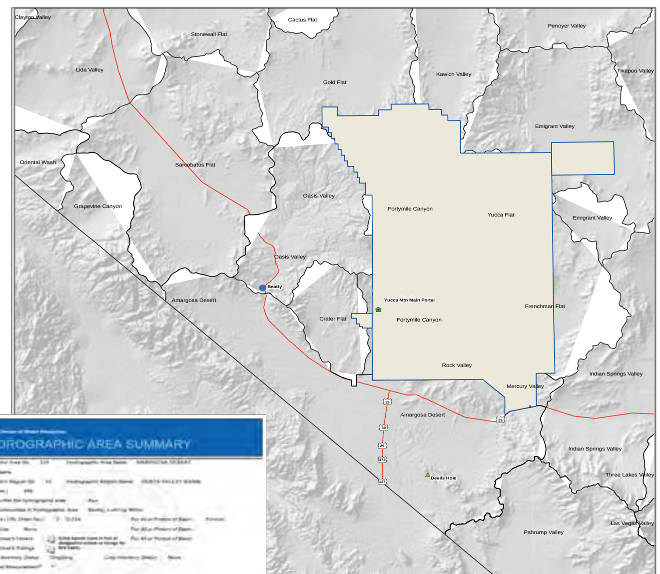
WELL DRILLING REGULATIONS

Nevada water law is based on two fundamental concepts: prior appropriation and beneficial use. Prior appropriation (also known as "first in time, first in right") allows for the orderly use of the state's water resources by granting priority to senior water rights. This concept ensures the senior uses are protected, even as new uses for water are allocated.

All water may be appropriated for beneficial use as provided in Chapters 533 and 534 of the Nevada Revised Statutes. Irrigation, mining, recreation, commercial/industrial and municipal uses are examples of beneficial uses, among others.

Department of Conservation and Natural Resources
Office of the State Engineer
Division of Water Resources
901 S. Stewart St.
Carson City, NV 89701

Jason King, P.E.
State Engineer



WATER RIGHTS ALLOCATIONS IN THE BEATTY AREA BASINS

HYDROGRAPHIC BASIN	PERENNIAL YIELD (acre-feet)	EXISTING APPROPRIATIONS (acre-feet)
Mercury Valley	24,000 (These Basins have a combined perennial yield)	0
Rock Valley		0
Fortymile Canyon - Jackass Flats		58
Fortymile Canyon - Buckboard Mesa		0
Oasis Valley		1,296
Crater Flat		681
Amargosa Desert		25,416
Grapevine Canyon	400	12
Oriental Wash	150	237
Lida Valley	350	76
Sarcobatus Flat	3,000	3,535
Stonewall Flat	100	12
Gold Flat	1,900	414
Kawich Valley	2,200	0
Emigrant Valley - Groom Lake Valley	2,800	12
Emigrant Valley - Papoose Lake Valley	10	0
Yucca Flat	350	0
Frenchman Flat	100	0
Indian Springs Valley	500	1,392
Pahrump Valley	12,000	62,433

http://water.nv.gov/

Nye County Water Level Measurement Program – Trends in Water Levels from 2004 to 2011

John Klenke and Levi Kryder – Nye County Nuclear Waste Repository Project Office

Introduction

Nye County's Water Level Measurement Program (WLMP), started in 1999, has collected over 6,000 water level measurements in domestic, agricultural, and other monitoring wells. The WLMP has also collected over 3,000 measurements from the Early Warning Drilling Program (EWDP) wells, down gradient from Yucca Mountain. With over 10 years worth of data, we now utilize new geostatistical tools available in ArcGIS in an effort to evaluate changes in water table elevation for the shallow aquifer over several time periods. Methodology, data, and maps are presented below.

Analysis Process

One of the challenges in the WLMP is keeping a consistent set of wells for measurement. Wells sometimes become plugged, are capped or abandoned, or access is prevented for some other reason. To evaluate changes in water table elevation in a consistent manner, it was first necessary to create a subset of data using the same wells at the same time of year. The WLMP contains water level data on 83 wells in the Amargosa Valley, 176 wells in the Pahrump area, and 38 wells from the Nye County EWDP. The set of wells was reduced by removing data from the deeper aquifer and only using wells with a continuous record over the time periods of interest, resulting in a subset of 20 wells in the Amargosa Valley, 57 wells in the Pahrump area, and 23 wells from the EWDP. Additional data from 35 wells in the US Geological Survey National Water Information System, and 6 wells from the Nevada Division of Water Resources Water Level Database were incorporated.

In an effort to minimize the effect of seasonal fluctuations caused by comparing water level measurements taken on different dates during different years in areas where the rate of water level changes were significant over short time periods, all water level were interpolated to September 15th for each year. In a few cases, in order to keep the dataset consistent, it was necessary to extrapolate single point well data by projecting the established water level trends for an individual well. Automated linear interpolation/extrapolation was used where possible; in other cases manual interpolation was required. The resulting data sets were subtracted (earlier year minus later year) to create difference data for each well. Barometric corrections were not applied to this dataset.

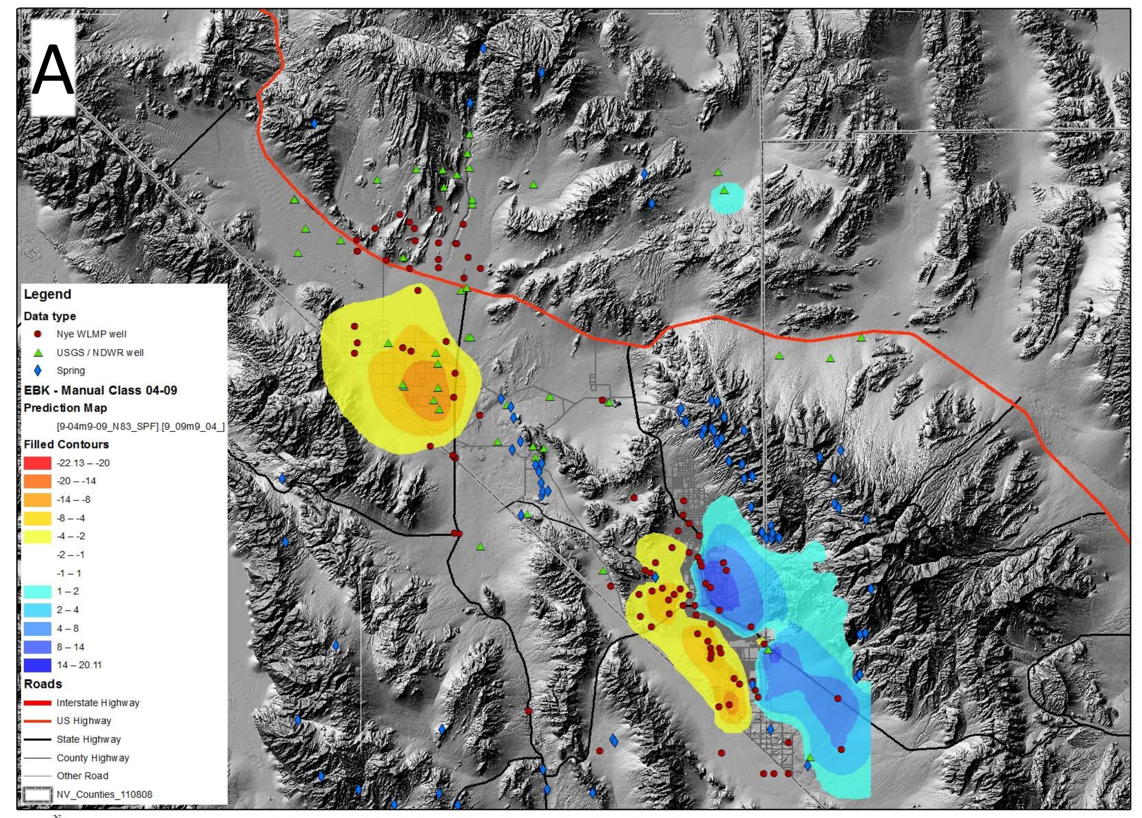
Contouring

Difference data were imported into ArcGIS and contoured using the new Empirical Bayesian Kriging (EBK) tool available in the Geostatistical Analyst extension. EBK is a geostatistical interpolation method that automates the parameter adjustment process to build a valid kriging model. The method also accounts for the error introduced in the predicted data by estimating the underlying semivariogram for the predicted data, rather than estimating the semivariogram for only the known data locations. Another advantage of EBK is its implementation in a "wizard" interface, allowing interactive parameter adjustments prior to outputting a data set. Parameters used for contouring the water level difference data are summarized in Table 1. Predicted data and their associated standard error surfaces are shown in the inset panels.

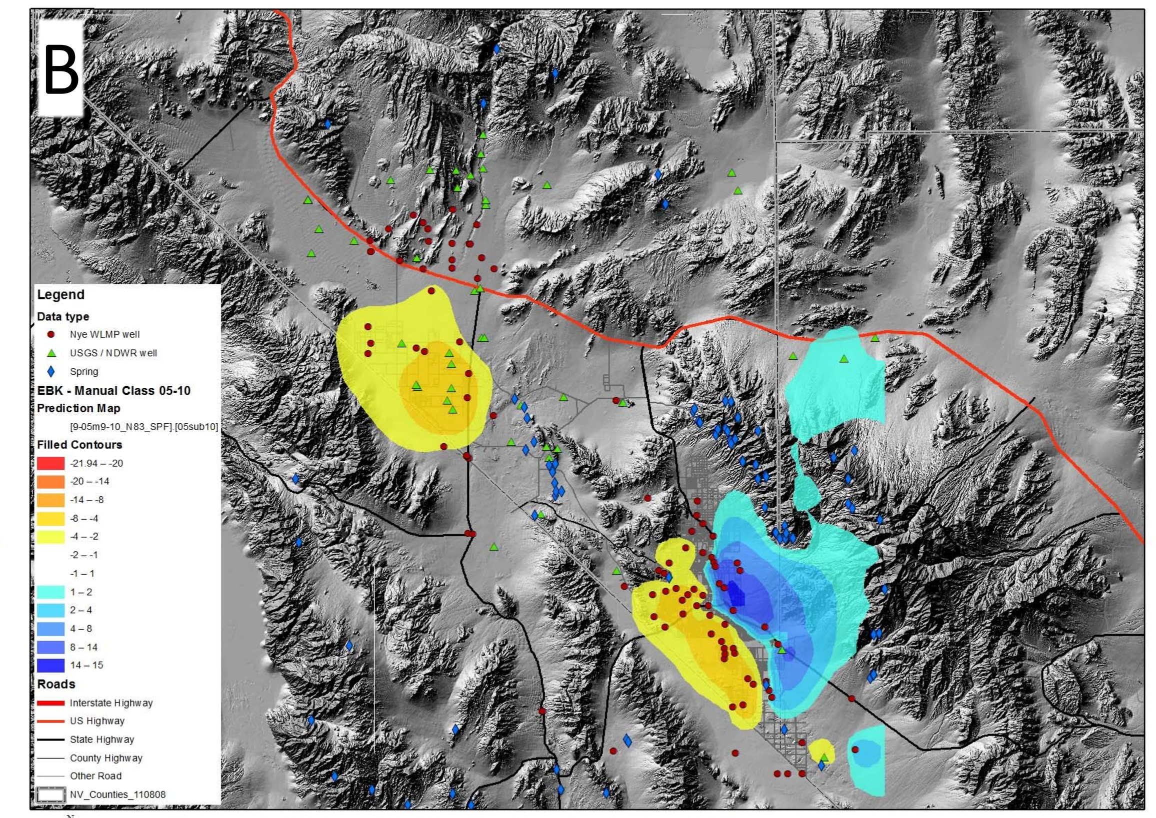
Maps

The top three maps (panels A, B, and C) show a long-term set of overlapping 5-year averages for the water level changes across the Pahrump and Amargosa Valleys (2004 to 2009, 2005 to 2010, and 2006 to 2011). Below each map is the Error of Prediction surface (panels D, E, and F), which represents the standard error for the model prediction data. EBK accounts for the error introduced by estimating the underlying semivariogram, and is therefore potentially more accurate than other kriging methods. In general, errors appear to be smallest where data are denser and the rate of change is minimal, and higher where data are more sparse or where the rate of change is higher. The 5-year difference maps are better for "averaging" changes over large areas, and for capturing water level changes in localized areas where changes are occurring slowly.

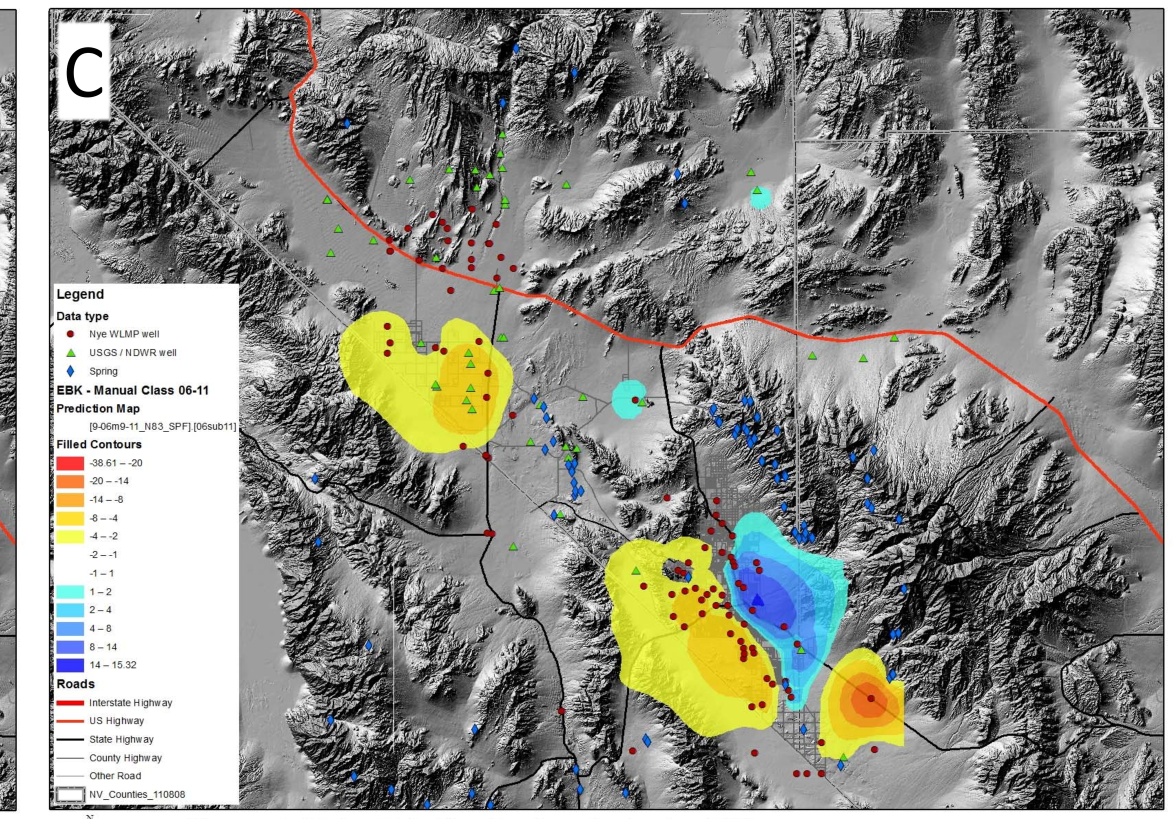
The bottom three maps (panels I, G, and H) show a short-term set of water level changes across the Pahrump and Amargosa Valleys, but over shorter, non-overlapping 2-year periods (2005 to 2007, 2007-2009, and 2009 to 2011). Short-term change maps are better for displaying the complexity of water level changes on a localized scale, illustrate the variability of water level changes over short time periods, and remove the "averaging" effect introduced in the long-term overlapping change maps.



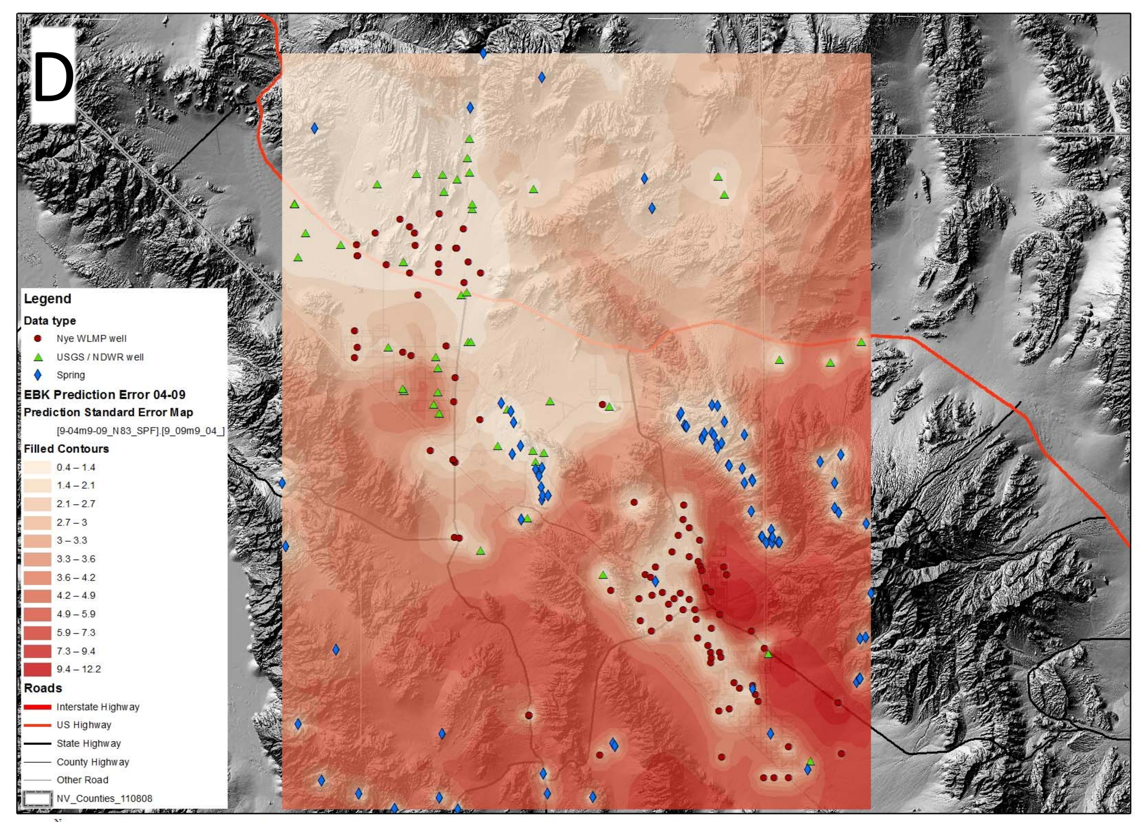
Changes in Water Table Elevation from September 2004 to September 2009, Southern Nye County, Nevada



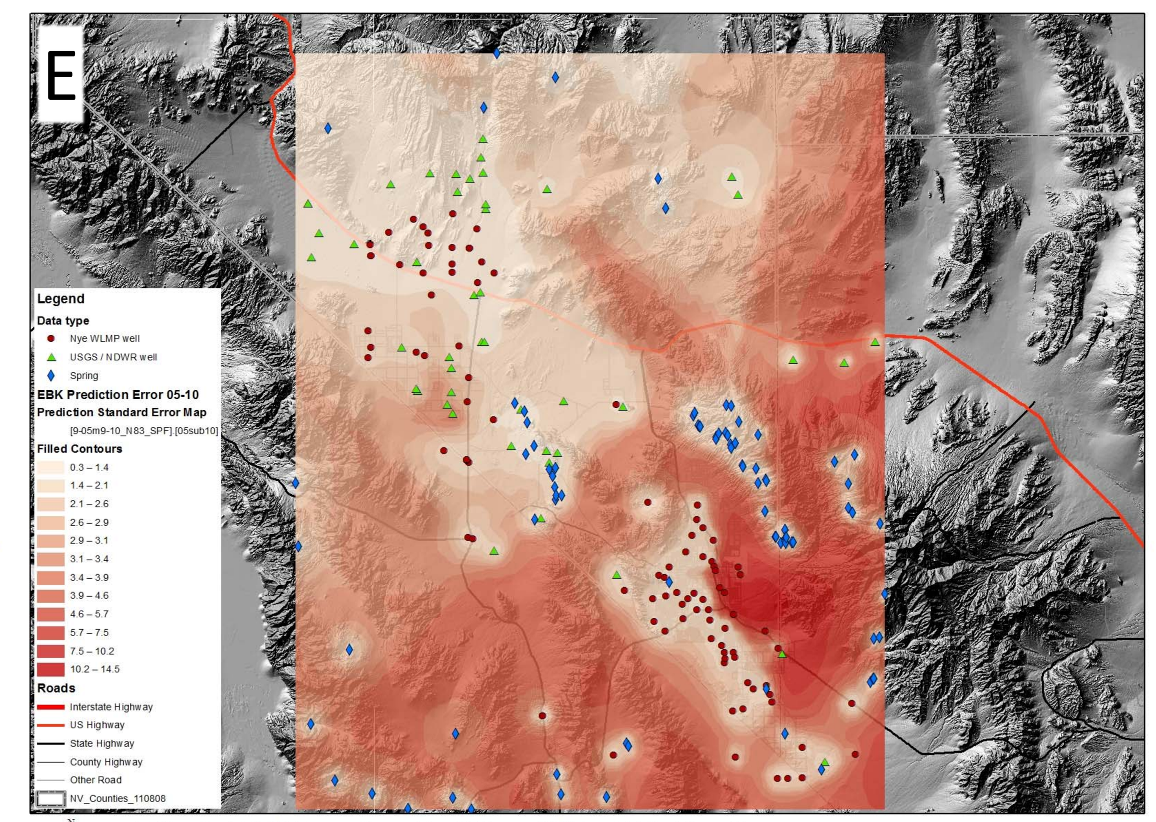
Changes in Water Table Elevation from September 2005 to September 2010, Southern Nye County, Nevada



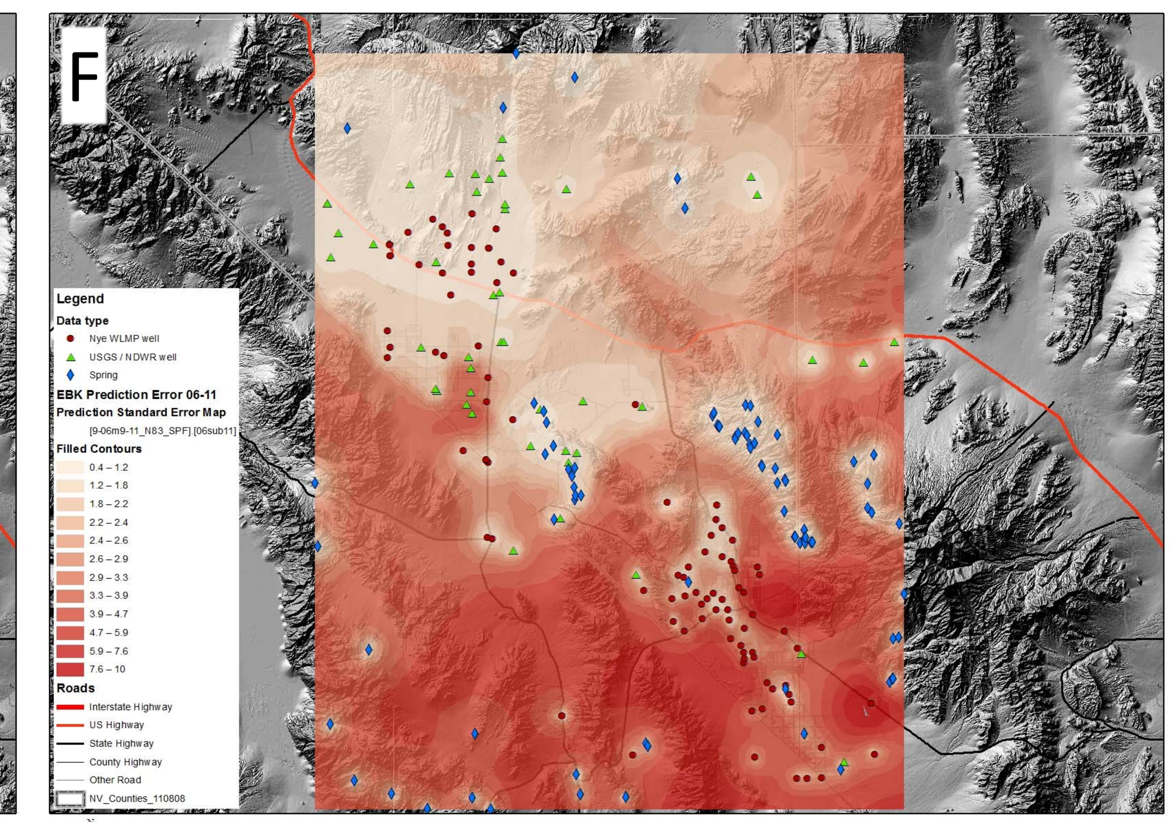
Changes in Water Table Elevation from September 2006 to September 2011, Southern Nye County, Nevada



Estimated EBK Errors from Prediction of Water Table Elevation Differences - September 2004 to September 2009



Estimated EBK Errors from Prediction of Water Table Elevation Differences - September 2005 to September 2010



Estimated EBK Errors from Prediction of Water Table Elevation Differences - September 2006 to September 2011

Pahrump Valley

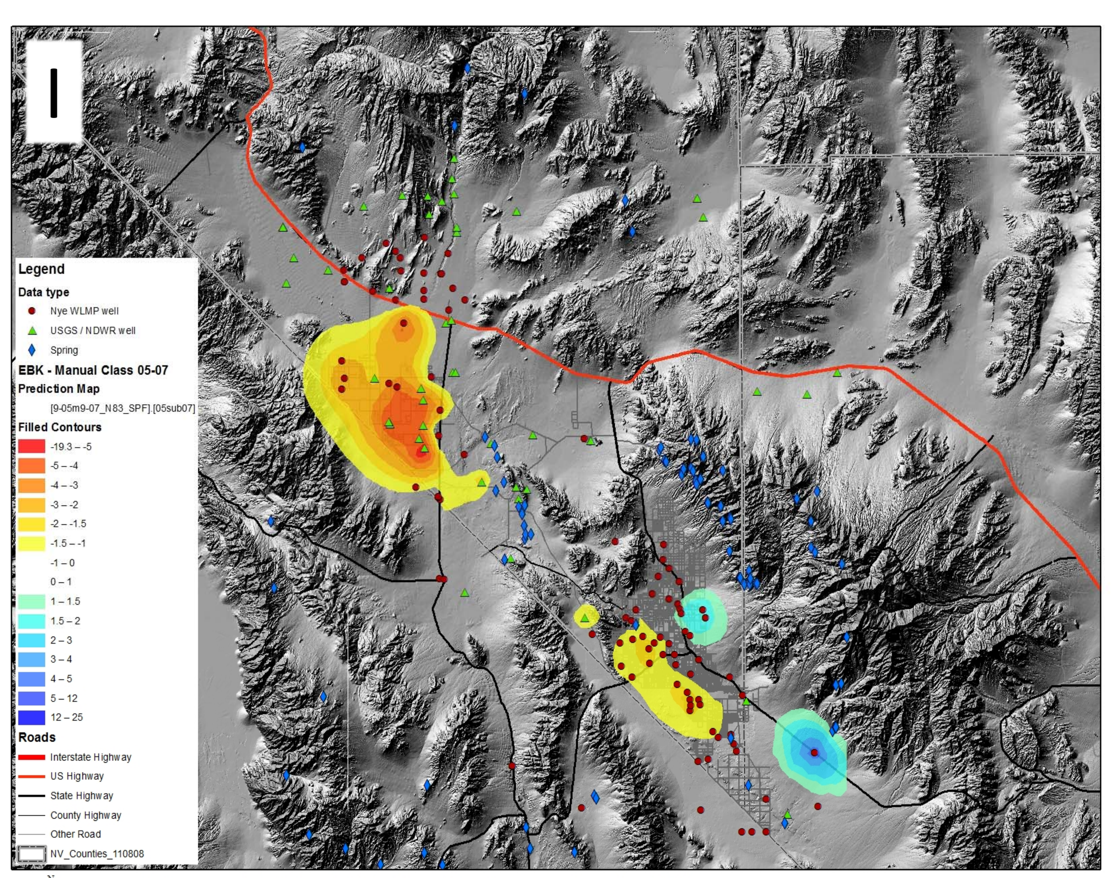
Both map sets clearly show the mounding of water on the east side of the Pahrump Valley (blue), which is believed to be due primarily to a large precipitation event in 2005, and decreased pumping from the alluvial fan located on the west side of the Spring Mountains. The short-term change maps better display the intricacies of the mound decay (blues turning to yellows-reds on maps covering later periods). Both long- and short-term maps also show the declines in the aquifer occurring across the center and the western part of the Pahrump Valley, with the long-term maps tending to spread the declines farther to the west, and the short-term maps showing the declines lessening with time (on later maps). The higher resolution short-term maps show the development of the interfingering of declines (yellows-reds) with the mounding to the east.

Amargosa Valley

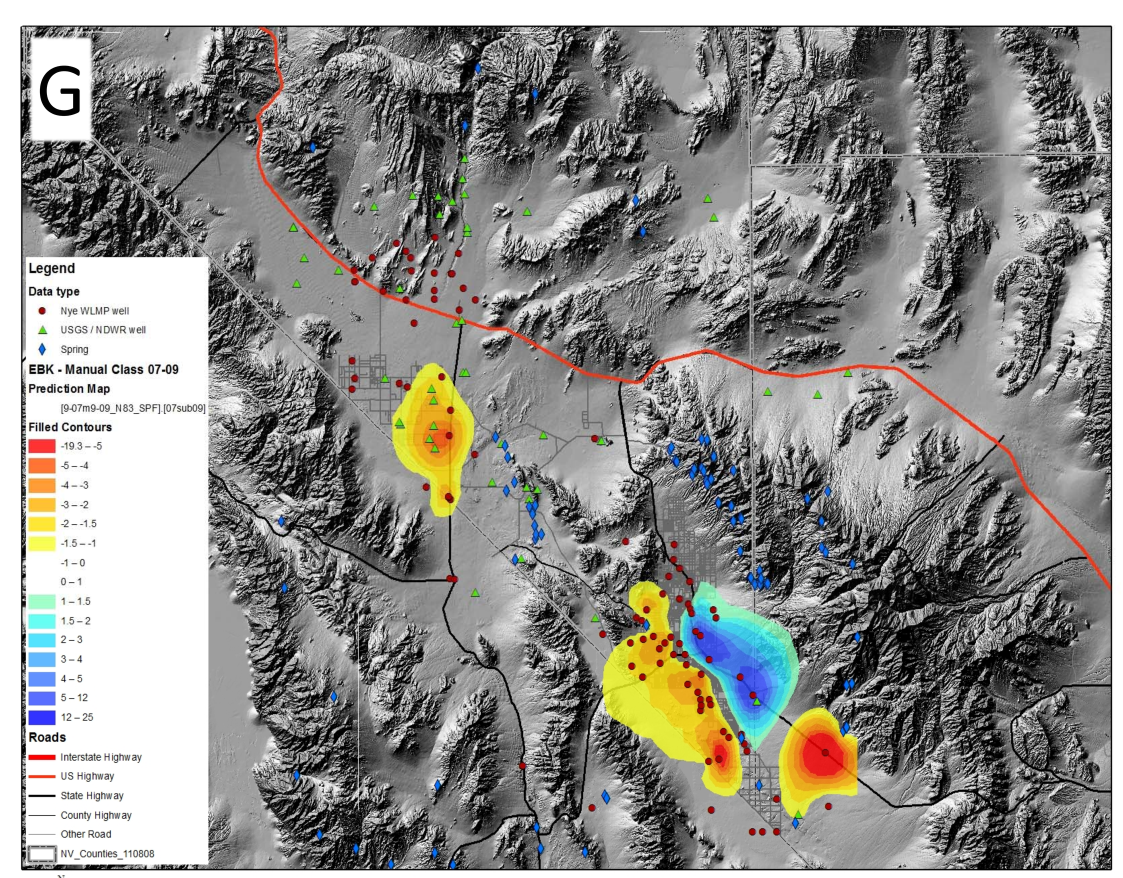
Similar to the Pahrump Valley, both long- and short-term difference maps show the water level declines with time over the Amargosa Valley, with the long-term maps tending to spread the declines farther to the west, and the short-term maps better depicting the reduced declines, particularly to the north, with time. Both sets of maps preserve the drawdown which is occurring on and around the Amargosa Dairy. The short-term maps show both drawdown (2007 to 2009 map), and the later water level rise (2009 to 2011 map) occurring in the southern part of the valley, south of the dairy. This may be a localized effect due to pumping, and then later recovery, in the wells on the Longstreet Casino property, and may not have an aerial extent as large as that predicted by the geostatistical model.

Table 1 – EBK Parameters

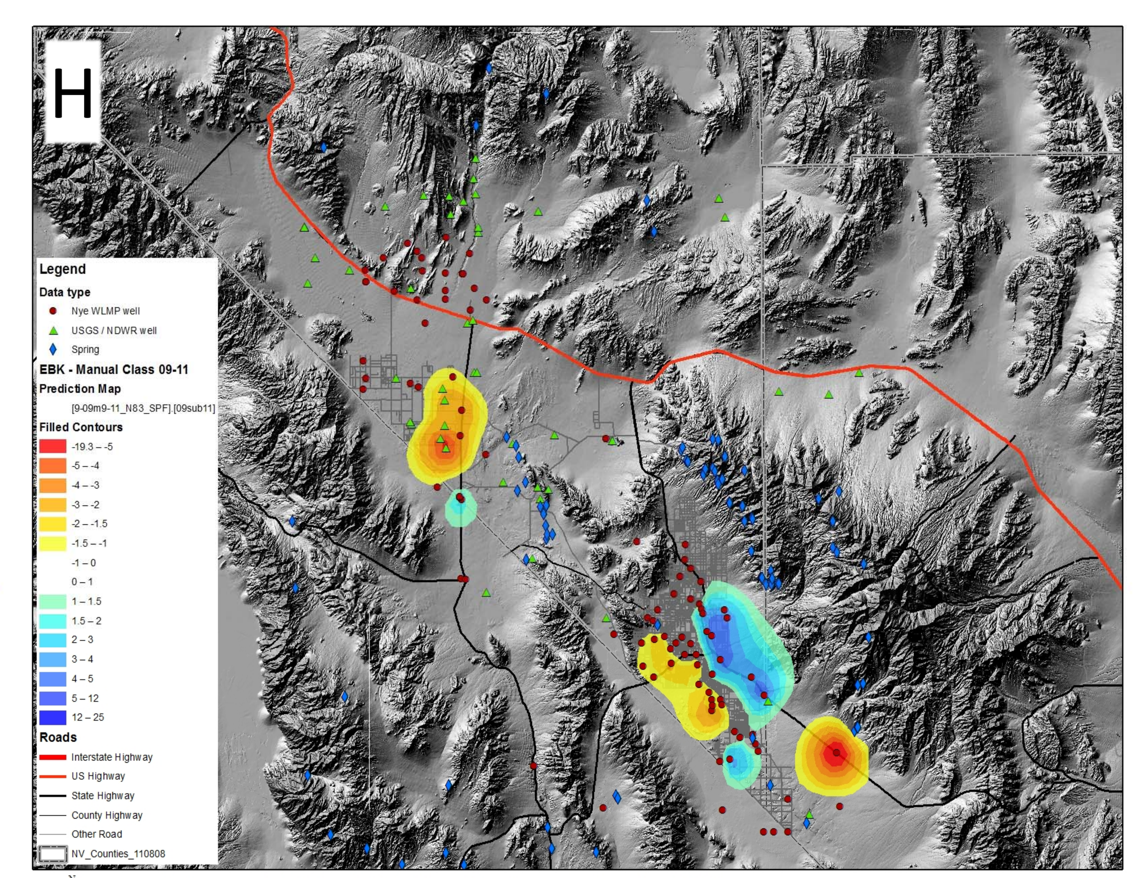
Parameter	Setting
Subset size	100
Overlap factor	1
Number of simulations	100
Transformation	Empirical
Neighborhood type	Standard circular
Maximum neighbors	15
Minimum neighbors	10
Sector type	4 sectors with 45° offset
Angle	0
Radius	24,305 feet



Changes in Water Table Elevation from September 2005 to September 2007, Southern Nye County, Nevada



Changes in Water Table Elevation from September 2007 to September 2009, Southern Nye County, Nevada



Changes in Water Table Elevation from September 2009 to September 2011, Southern Nye County, Nevada

Conclusions

Water level measurements, taken in wells over a large aerial extent, and over multi-year periods, provide the information necessary to develop maps of water level changes. Together with geostatistical processing techniques which minimize error, these maps can be used as tools to understand the complexities of water level changes across large areas such as the Pahrump and Amargosa Valleys. Sets of water level change maps constructed over differing time frames can offer different perspectives and aid in the understanding of complex water level changes occurring in the shallow aquifer. Collection of data under the WLMP continues today, and additional data will allow better assessments of groundwater resources in the future.

At first evaluation, EBK appears to be a valid method for contouring groundwater data, in most cases producing results that are similar to other methods (minimum curvature, etc.) while minimizing the artifacts sometimes associated with the other methods. The method will be further evaluated in the future.