Nevada National Security Site Environmental Remediation

Large-Scale Multi-Well Aquifer Tests Used to Define Flow Systems

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ABSTRACT

Over the past 5 years, 10 new groundwater wells have been drilled and hydraulically tested on Pahute Mesa Corrective Action Unit (CAU) under the Underground Test Area (UGTA) Activity at the Nevada National Security Site (NNSS). The new wells were drilled as part of a Phase II Corrective Action Investigation to gain a better understanding of the geology and hydrology of the system and to support development of a groundwater flow and transport model used for forecasting contaminant boundaries.

Multi-well aquifer testing provides the most integrated assessment of hydraulic properties and connectivity within complex geologic systems. By providing hydraulic connectivity, these tests can be used to generate insight on potential contaminant flow paths and provide constraint on overall groundwater flow pathways. Drawdown in observation wells provides direct evidence of a hydraulic connection. During well drilling and testing activities, a total of 20 aquifer tests were conducted with as many as 36 individual completion zones. A signal-processing method developed by the U.S. Geological Survey was used to improve pumping drawdown detection. Using this approach, drawdown as far away as 3-4 kilometers has been detected. In addition to the typical analysis for hydraulic property values, the observed hydraulic connectivity are qualitatively and quantitatively used to inform the hydrogeologic framework model which is updated using other permissible geologic interpretations, when necessary, to incorporate the aquifer-testing results. These results will be used for developing and building confidence in the conceptual and numerical models for the Pahute Mesa CAU.

INTRODUCTION

Underground nuclear testing was conducted at the NNSS from 1951 to 1992. Residual radiation from this testing has resulted in groundwater contamination at locations over the NNSS. The Underground Test Area activity was established to characterize the extent of contamination and its potential migration in groundwater. Operational Areas 19 and 20 - geographically known as Pahute Mesa – pose a special challenge because of the geologic complexity. Groundwater flows from Pahute Mesa to Oasis Valley, where it discharges in the form of springs and wetlands [2]. As part of developing the understanding necessary to protect the public, wells have been drilled and sampled in Western Pahute Mesa (Figure 1) to determine the extent of groundwater contamination. Additionally, constant-rate aquifer tests have been performed to evaluate hydraulic connections in three dimensions and support estimating the large-scale aquifer system properties that control groundwater flow velocity, and ultimately potential contaminant migration. The typical approach to these tests is to pump individual wells at the maximum achievable rate for 4 to 240 hours and observe water level declines in nearby wells. Given the scale and complexity of Pahute Mesa, a large network of monitoring wells were established early in a drilling campaign and continuously measured during drilling, cleaning, and testing in an effort to increase the distances that the pumping signal could be detected thereby reducing the overall cost associated with the characterization program while increasing the information obtained.

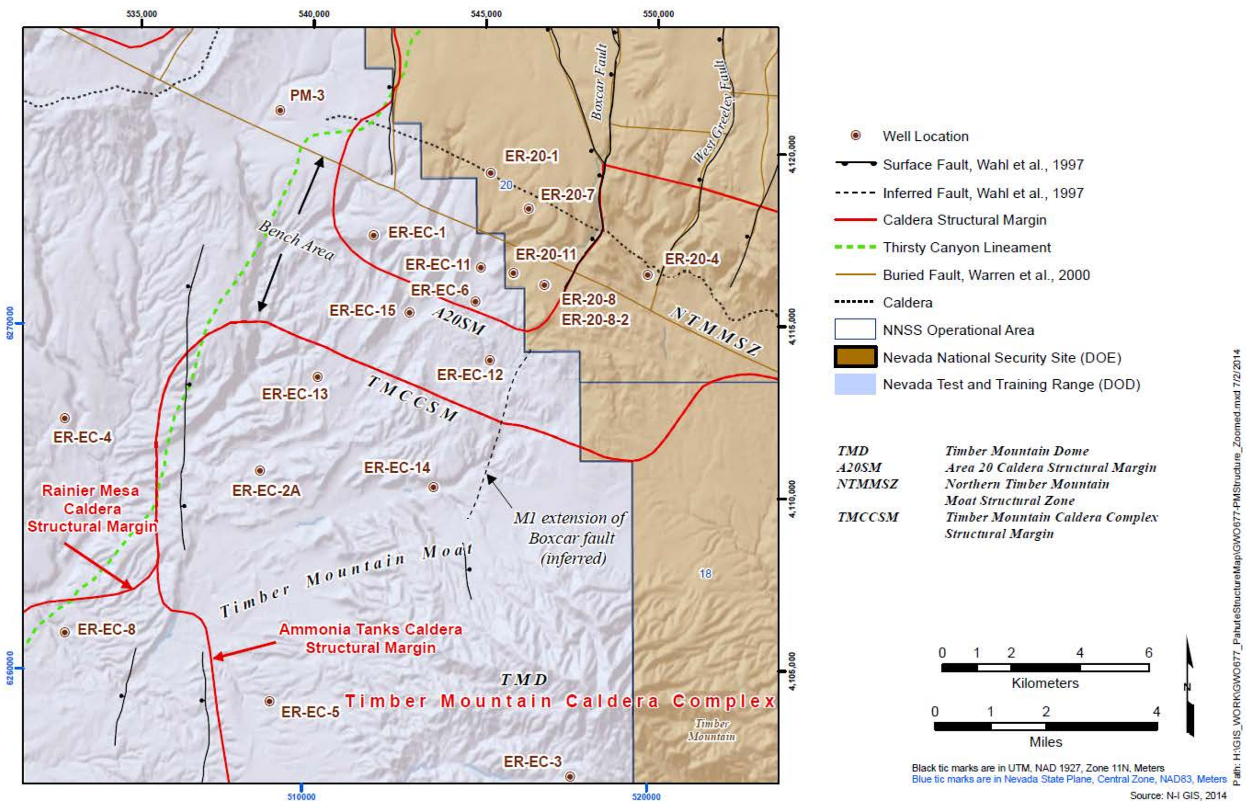

Figure 1 Western Pahute Mesa Well Location Map

DESCRIPTION

Observation of drawdown at wells distal from the pumping well provides a direct, integrated assessment of aquifer system connectivity and bulk hydraulic properties which control groundwater flow [3]. However, when wells are located kilometers apart, as in Western Pahute Mesa, inference of pumping effects can be difficult because natural groundwater level fluctuation overwhelms the pumping signal. Because the Western Pahute Mesa wells access lava and welded-tuff confined aquifer systems they show marked responses to earth tides and barometric pressure changes that make it difficult to identify potential effects of pumping. Since the magnitude of these natural groundwater level fluctuations is often comparable, uniquely identifying each component is accomplished by considering one or more background wells that shows similar fluctuations but is unaffected by pumping [3]. Halford et al. [3] developed a signal-processing approach to this problem that combines barometric pressure, earth tides, and water-level measurements to identify the source of observed water-level fluctuations, which when combined with extensive (31 discrete well zones) automated data collection throughout the well network at Pahute Mesa provides a tool to assess the impact of pumping. Examples of the benefits of this approach follow.

Assessing Local-Scale Connection Across the West Greely Fault

One of the striking geologic characteristics of Pahute Mesa is the extensive Basin-and-Range faulting. Flow path connections and continuity across faults can be difficult to infer from static head data alone. At the scale of Pahute Mesa, the complex fault conceptualizations [4] are difficult to evaluate. Well U-20 WW was intermittently used for pumping, and Wells ER-20-6 #3, UE-20bh 1, and U-20bg were monitored [5] (Figure 2). The pumping well and Well ER-20-6 #3 are separated from the other observation wells by the West Greeley fault (Figure 2). Using the approach described in [3] observation well water-levels were analyzed for drawdown from U-20 WW pumping. A maximum water-level drawdown of nearly 0.12 m in well UE-20bh 1, which is more than 1.6 km from the pumping well, was detected across the West Greeley fault [5]. Transmissive lavas were inferred to be juxtaposed providing connection across the fault. Conversely, drawdown estimates in the observation well nearest to (ER-20-6 #3, less than 1.6 km) and within the same structural block as the pumping well were less than detection (<0.03 m). Minimal drawdown within the same structural block indicates that lava units are likely separated by bedded tuff confining units. Numerical modeling of the aquifer test also showed that the fault properties cannot be greatly different from the host rocks, which suggests that the fault itself is not likely to be a preferential flow path – a valuable conceptual insight.

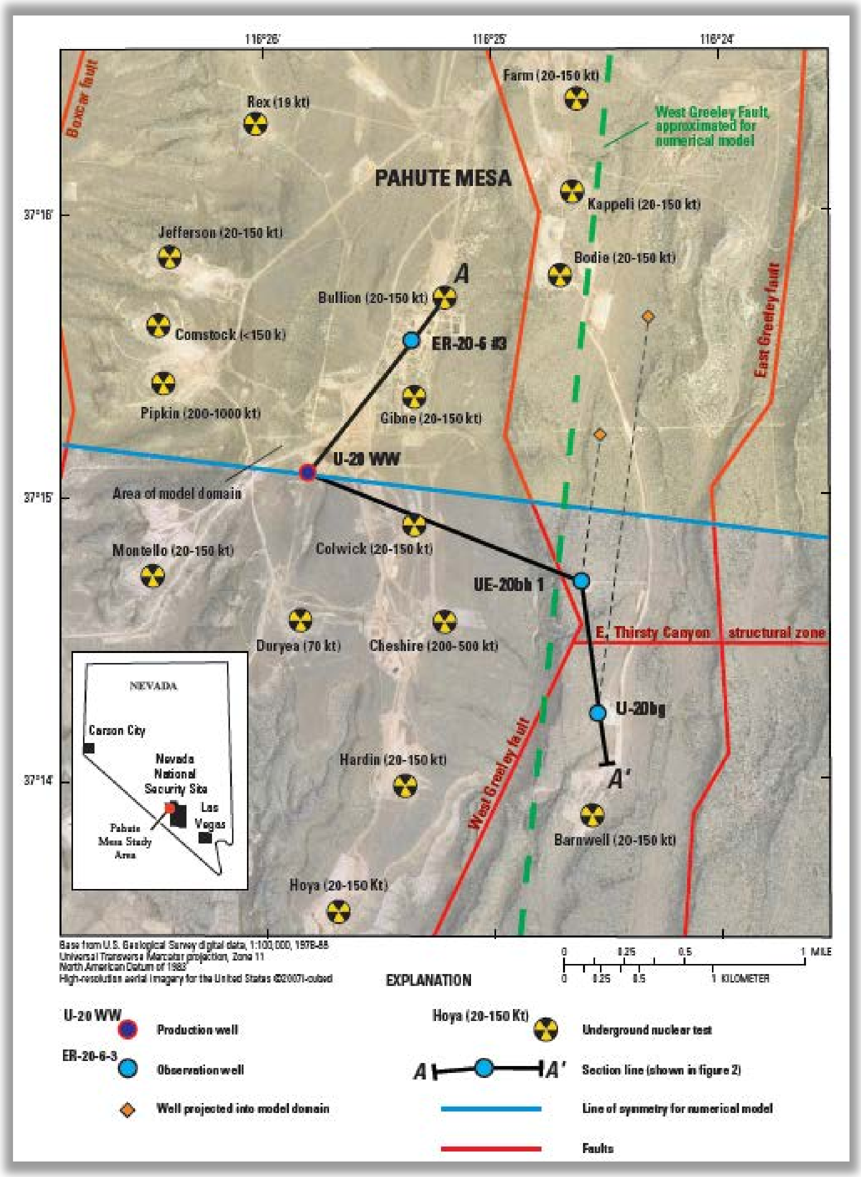

Figure 2 Location of U-20 WW and West Greeley Fault (from Garcia et al.)

Conceptual Evaluation of Large-Scale Connection Between Calderas

Developing and testing hydrogeologic conceptual models in the complex geologic setting at the NNSS is challenging. An illustration of this challenge is the area near well ER-EC-13. In the cutaway view of the geologic model (Figure 3) only the potential aquifers are shown; the complex juxtaposition resulting from faulting and caldera boundaries can be seen clearly. Hydraulic connection can be quickly assessed using a composite plot; drawdown plotted versus elapsed pumping time divided by the distance between the pumping and observation wells squared (t/r^2). Paths that have a higher transmissivity to storage ratio (higher hydraulic diffusivity) can be indicative of preferential transport paths [5].

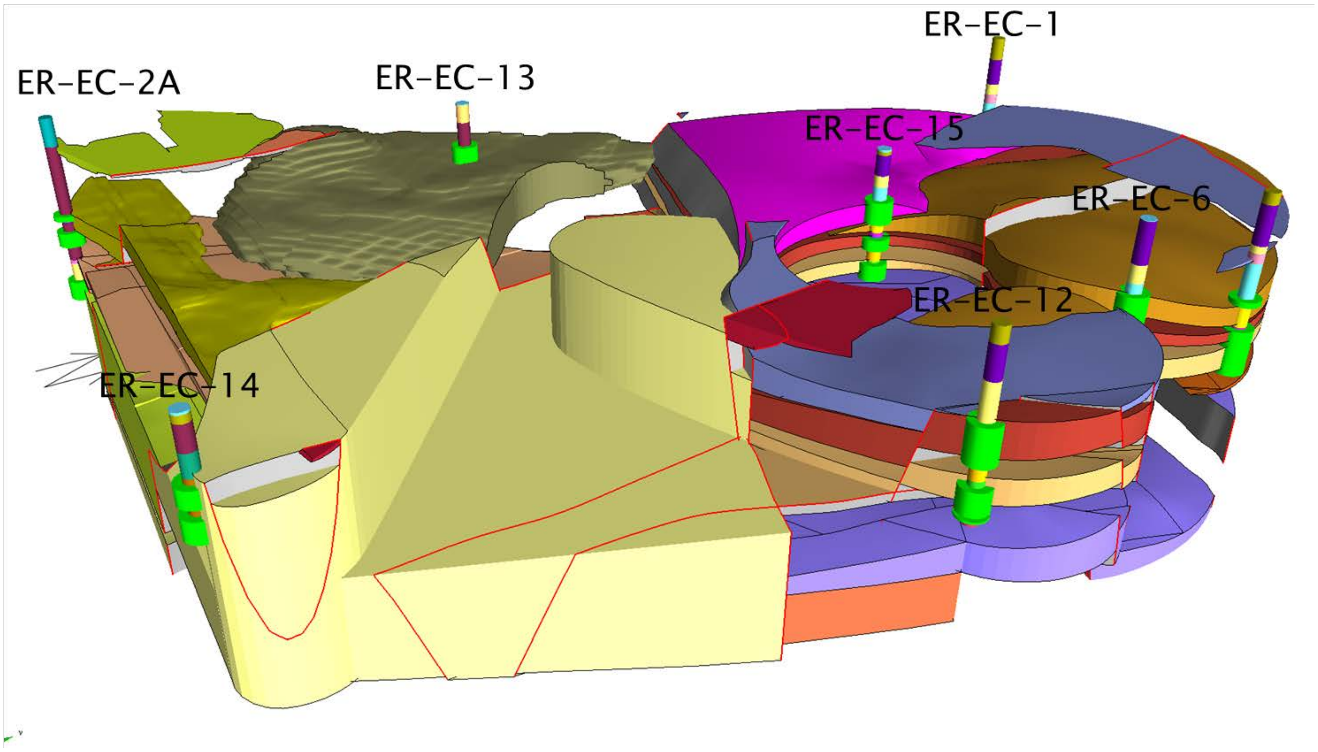

Figure 3 Cutaway View of the Geologic Model Near ER-EC-13 (north is at the right)

Well ER-EC-13 was pumped and surrounding wells monitored (Figure 3), and the water-levels analyzed using the approach of [2]. The composite plot is shown in Figure 4. It is notable that well ER-EC-1 had significant drawdown across a major structural feature and into different aquifer system geometry. Wells ER-EC-14S and -14D responded nearly identically, despite being completed in two different aquifers separated by a confining unit. This is conceptually important because it implies either a large-scale lack of confining unit continuity or leaky behavior from faults. The drawdown at well ER-EC-15S is significant because it is the only response noted at a well cluster with two other completions, and is in a shallower, fractured-rock aquifer conceptualized as a potential pathway for radionuclide migration.

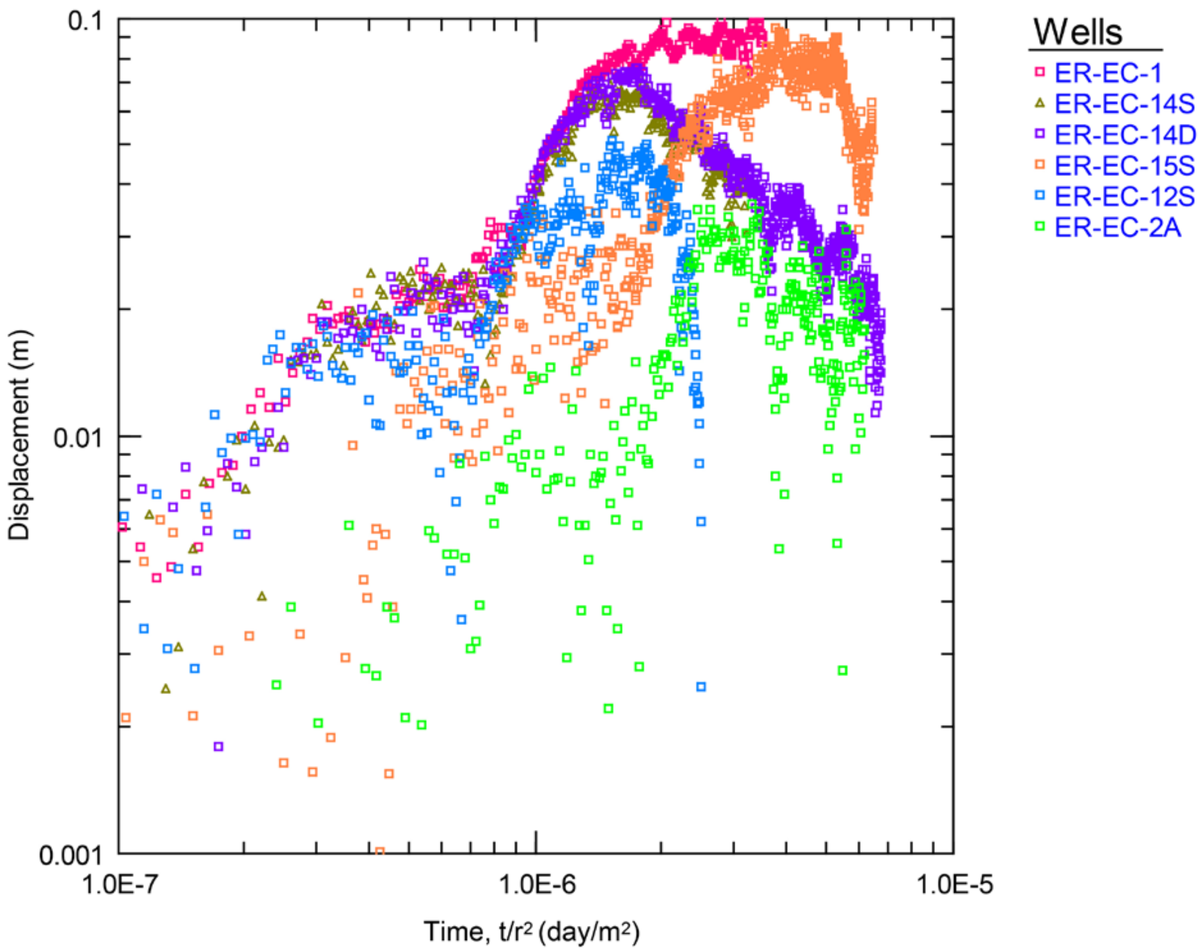

Figure 4 Composite Plot of response from ER-EC-13 Pumping

CONCLUSIONS

An extensive water-level monitoring system composed of over 31 discrete completion intervals with readings collected every 15 minutes from 2010 through 2014 has been combined with a signal-processing analysis approach to increase conceptual understanding and support more reliable large-scale aquifer system property estimates in the complex geologic setting at the NNSS. Even the pumped well with the fewest responses provided hydraulic connectivity and property data at distances up to 3 km. By establishing the monitoring network early in the drilling and testing campaign and using an automated monitoring system, significant improvements were made in the characterization by incrementally collecting overlapping datasets that could be evaluated as work progressed to develop site understanding. The regulator has accepted these data as a suitable replacement for a single planned MWAT using only one well described in the Corrective Action Investigation Plan, thereby reducing site-characterization costs and maximizing key information.

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