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LLNL-TR-693125

A Few Thoughts on the E-Tunnel Discharge at Rainier Mesa, Nevada National Security Site

A. Tompson

May 27, 2016

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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A. Tompson, Lawrence Livermore National Laboratory

[0] In reviewing the Quarterly Monitoring Reports assembled by Navarro for the Rainier Mesa E-Tunnel discharge for the past year (the “Navarro” data), Greg Raab of the Nevada Department of Environmental Proctection (NDEP) noticed a decreasing trend in the pH and was curious as to what was causing it. He noticed an upswing in the March 2016 data and speculated as to whether the trend would go up.

[1] Irene Farnham (Navarro) sent along the Navarro chemical and flow data from E-Tunnel, going back for some of the variables to 1997. Previously I was curious as to whether there was a trend in the discharge flow rates from E-Tunnel that corresponded to Greg Raab’s observations and comments about the decreasing trend in pH observed between 2015 and 2016. So, I plotted the two time series from the Navarro data (Figure 1) over roughly the same time period that Greg looked at, which are shown in Figure 1. There does not appear to be much of a correlation. (NB: The value of 7.1 for January 2016 in Figure 1 differs from the value of ~6.55 in Greg’s data).

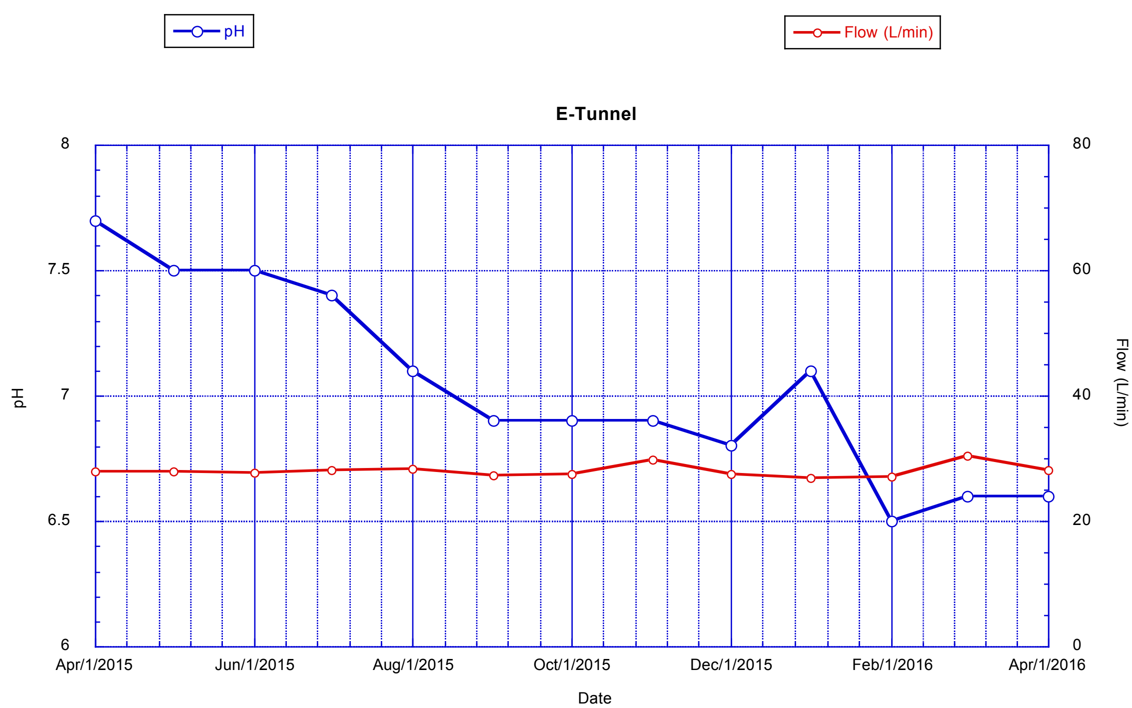
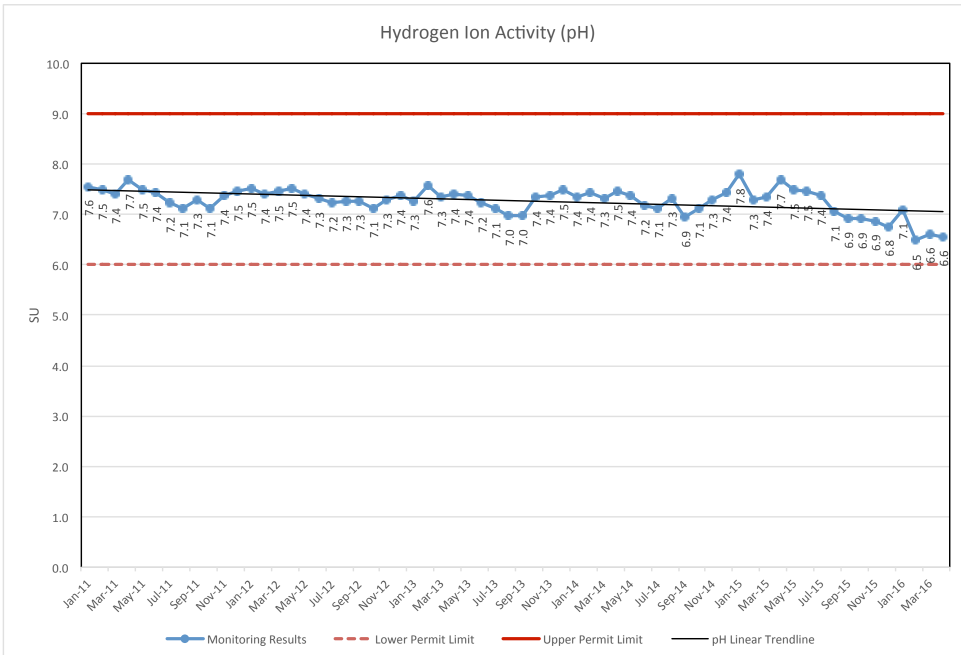


Figure 1: Time series of measured pH and flow rate at E-Tunnel between April 2015 and April, 2016

[2] The Navarro data spreadsheet itself included plots of pH and flow rate over a longer period (back to 2011), which *seemed* to suggest a declining trend in pH and flow rate over the period of the plots, along with what appear to be monthly variations within each year. These are shown in Figure 2.



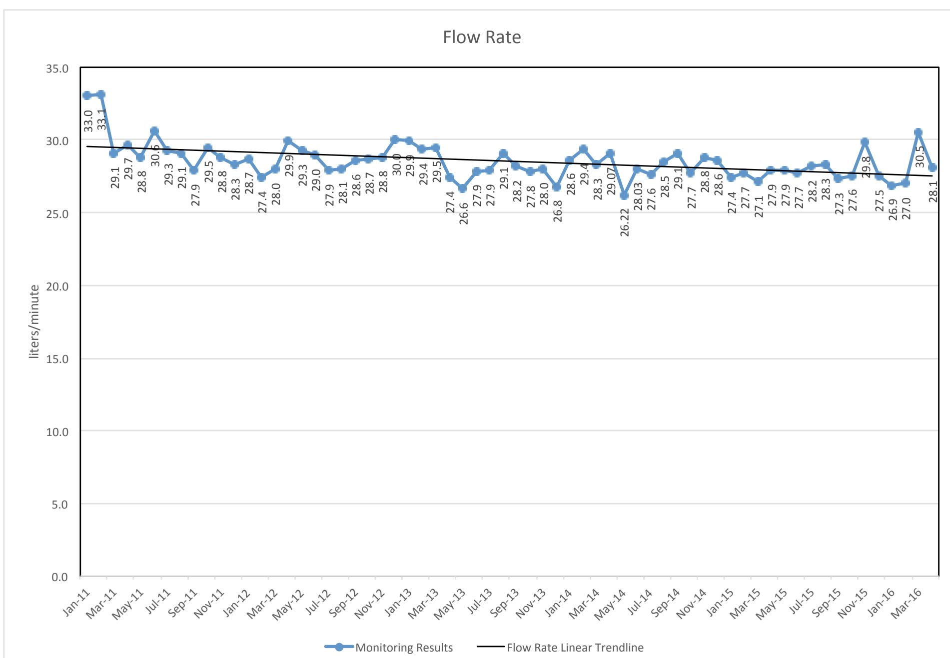


Figure 2: Time series of measured pH (top) and flow rate (bottom) at E-Tunnel between January 2011 and March 2016 (copied from Navarro spreadsheet).

[3] Interestingly, if the Navarro pH data are plotted back to 1997, a more complex picture emerges (Figure 3). On one hand, there are fairly regular variations in pH within each year that would seem to represent seasonal effects, most likely related to precipitation or recharge variations. But over the almost 2 decade length of the record, we also see a more irregular pattern of pH, going up to values higher that 8 at some times, and multi-year periods of both rising and declining trends. (Note the time bars at the bottom that correspond to the time intervals in previous plots.) *That said, a feature of the data that Greg examined that still remains notable is the appearance of pH values lower than 7.0.* For me, I see (at most) three phases in this time series. In the first, prior to 2003, there is a noisy plot centered at about 7.3. Then, between 2003 and 2009, I see a more variable set of data, centered closer to a pH of 8, rising to a peak near 8.5 in 2008. Then, after 2008, I see a year long decrease back to a less variable pattern centered at about 7.2. In the past year, I see a slight rise and then a steady decline to the relatively new low (<7.0) we have now. (This jump and decline looks similar to the behavior between 2008 and 2009.)

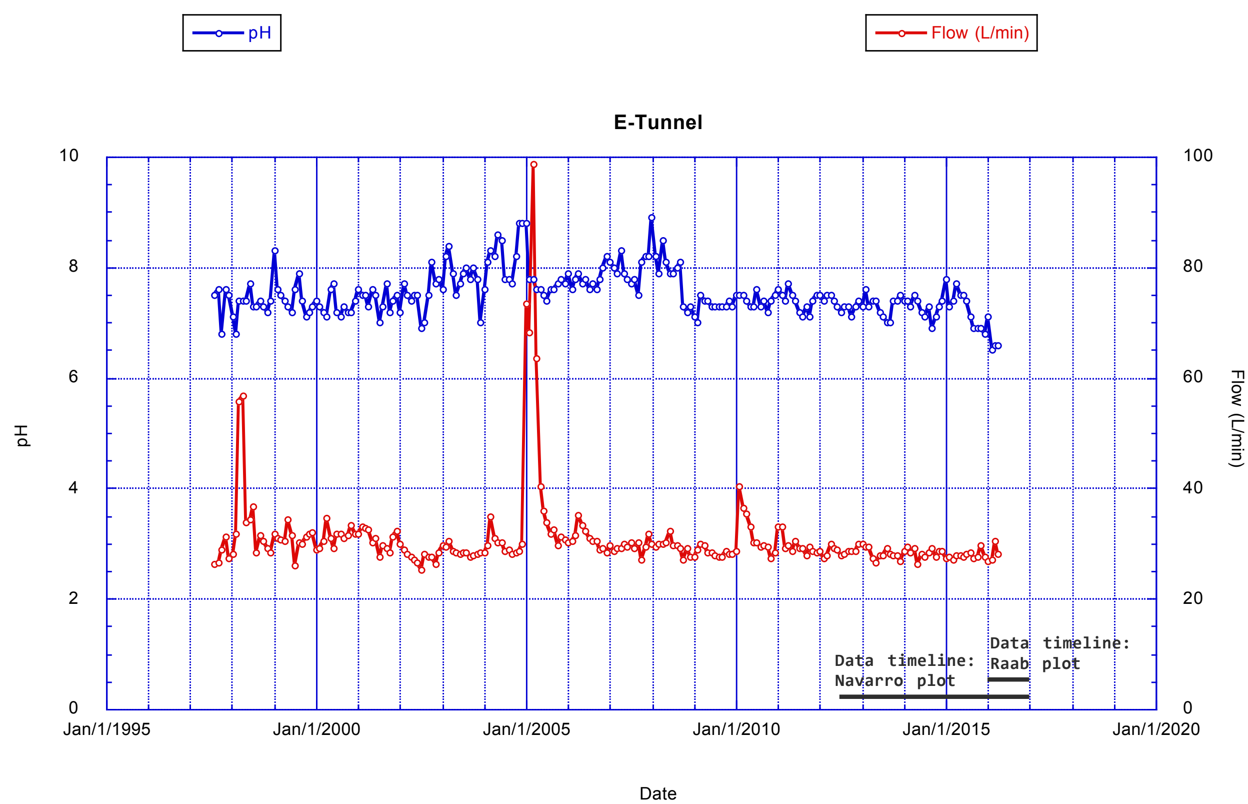


Figure 3: Time series of measured pH and flow rate at E-Tunnel between mid 1997 and April 2016. Time increments for data portrayed in Figures 1 and 2 are shown on lower right.

[4] When the discharge flow data are also plotted back to 1997 (Figure 3), a much more irregular pattern is revealed from that shown in Figure 2. There is clearly a series of small fluctuations occurring within each year that are fairly regular and most likely attributable to precipitation or other variable percolation effects in the tunnel complex. Yet there are also a few more prominent, transient spikes in discharge that are irregularly spaced in time. These have been related to specific, high precipitation events (as in Figure 4) that likely add water to tunnel segments closest to the portal (see discussion in the RMSM Conceptual Model Chapter, Fenelon, et al., 2014).

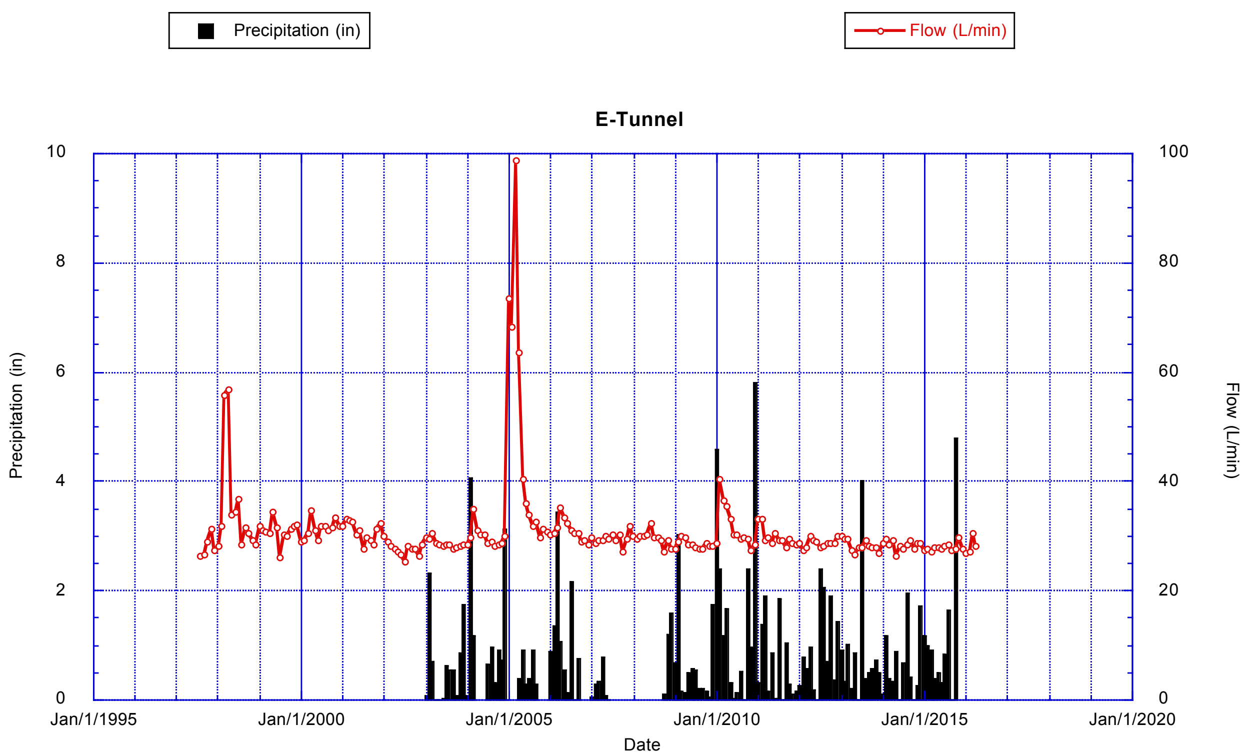


Figure 4: Time series of flow rate at E-Tunnel between mid 1997 and April 2016, along with measured precipitation at Rainier Mesa. Precipitation data is incomplete over the time interval shown.

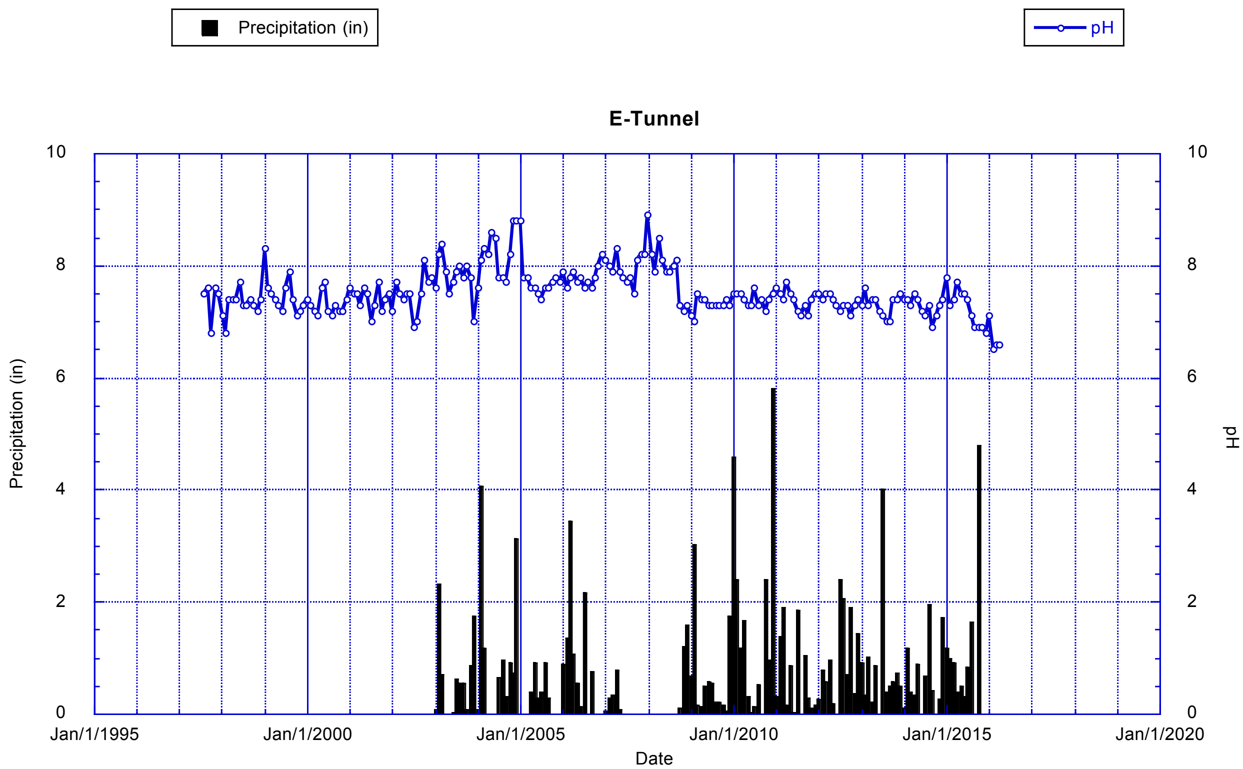


Figure 5: Time series of pH at E-Tunnel between mid 1997 and April 2016, along with measured precipitation at Rainier Mesa. Precipitation data is incomplete over the time interval shown.

[5] It is less clear whether or how pH variability relates to flow variability (Figure 3) or to precipitation (Figure 5), other than the annual fluctuations mentioned earlier. Altogether, what may be causing transient fluctuations in the pH? What comes to mind is that the pH and broader chemical composition of the tunnel discharge at the portal reflect, in effect, an intermixing of the waters draining from the various tunnel drifts that contribute to it. Chemically distinct waters in these streams may result from

- Passage of different water streams through different types of rock (between the perched system and various tunnel drifts),
- Contact of water with non-native materials in all or some subset of tunnels (e.g., grout, support structures, test apparatuses), or
- Exposure of water to test-altered rock in all or some subset of tunnels.

Transient changes in portal discharge chemistry may reflect transients in the tunnel inputs, water storage volumes, or water residence times in various tunnel drifts. For example, they may be produced by

- Variable levels of percolation into the drifts,
- Differing recharge levels at the mesa surface, or
- As a longer term result of the tunnel network as a whole accessing perched groundwater from more distant parts of the formation (see [8] below).

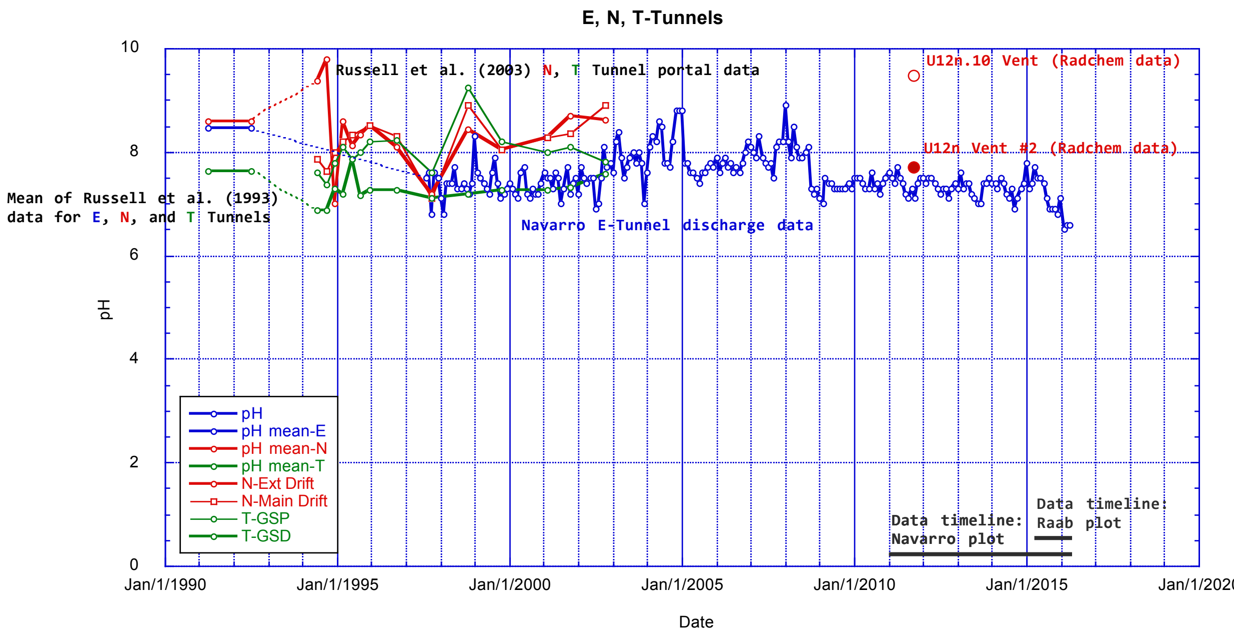


Figure 6: Mixed time series of pH from various sources at E-, N-, and T-Tunnels between 1992 and April 2016.

[6] I made an attempt to compare the Navarro E-Tunnel data for pH to other pH data available for E, N, and T tunnels. In Figure 6, I have plotted (1) mean pH data for the tunnels from the compilations in the Russell et al. (1993) report (Table 8); (2) N- and T-tunnel portal data from the Russell et al. (2003) report (Table 2.8), (3) two (of several) N-Tunnel vent hold values from the radchem database, and (4) the Navarro data as before. Again, there is a lot of variability and differences, although some interpretive leeway must be allowed for measurement complexities (e.g., CO2 bubbling out of collected samples, isolated conditions in U12n.10 Vent, etc.). Certainly, the early 1992-

1993 E-Tunnel pH values (albeit averaged values) appear higher than the values measured between 1998 and 2003. Over the whole extent of the data sets, it is possible to infer a long-term shift, on average, to lower pH values.

[7] Also, for kicks, I plotted the E-Tunnel ^{3}H time series from the Navarro dataset along with the discharge rates and precipitation data (below). Of course, the general trend is down, but how much of this is due to decay and how much to "emptying" of the available or accessible inventory? So, I also plotted a decay-corrected curve (corrected to 10/1/1997, the date of the first data point). Although there are same fluctuations, there is a notable steadiness to this discharge concentration, with perhaps only a hint of decrease (e.g., if the tritium did not decay, we're seeing a constant or near-constant concentration discharge over a 15+ year period. It also seems that higher flow rates may correlate, approximately, with diluted discharge (1998, 2006, 2010?), but its not so perfect.

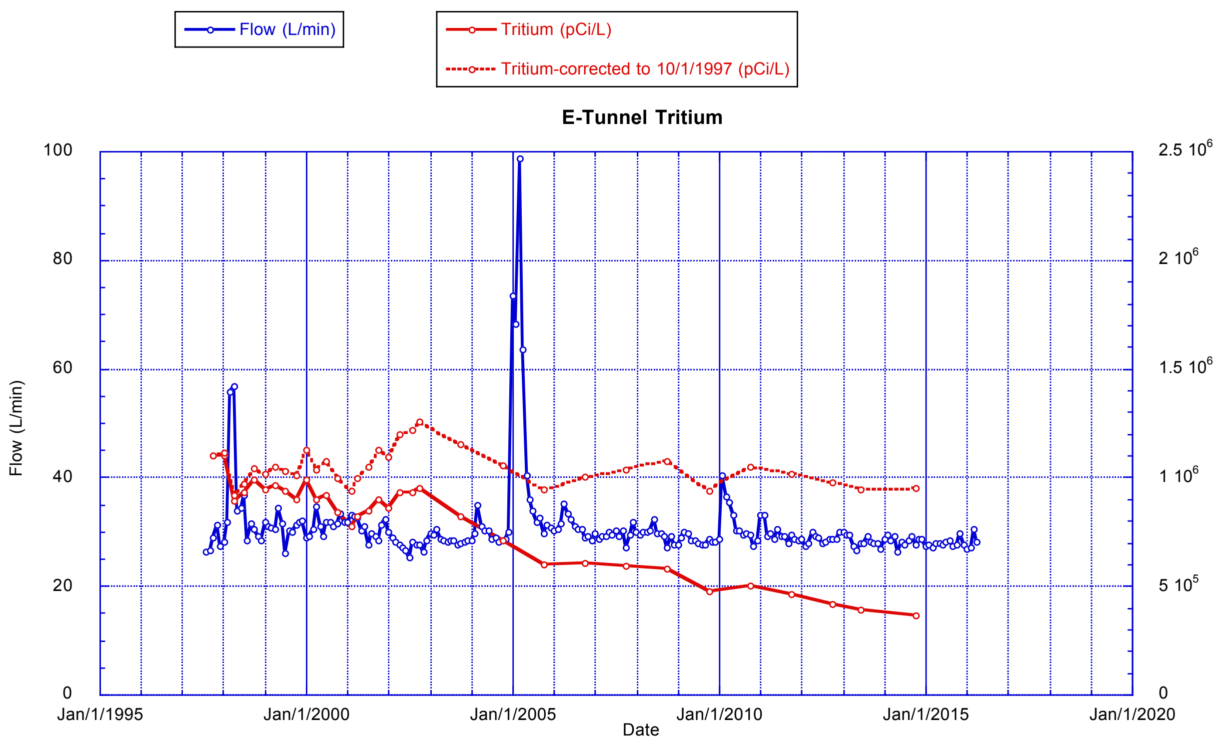


Figure 7: Time series of flow rate and tritium concentration (actual observed and corrected to 1997) in the E-Tunnel discharge between 1997 and April 2016.

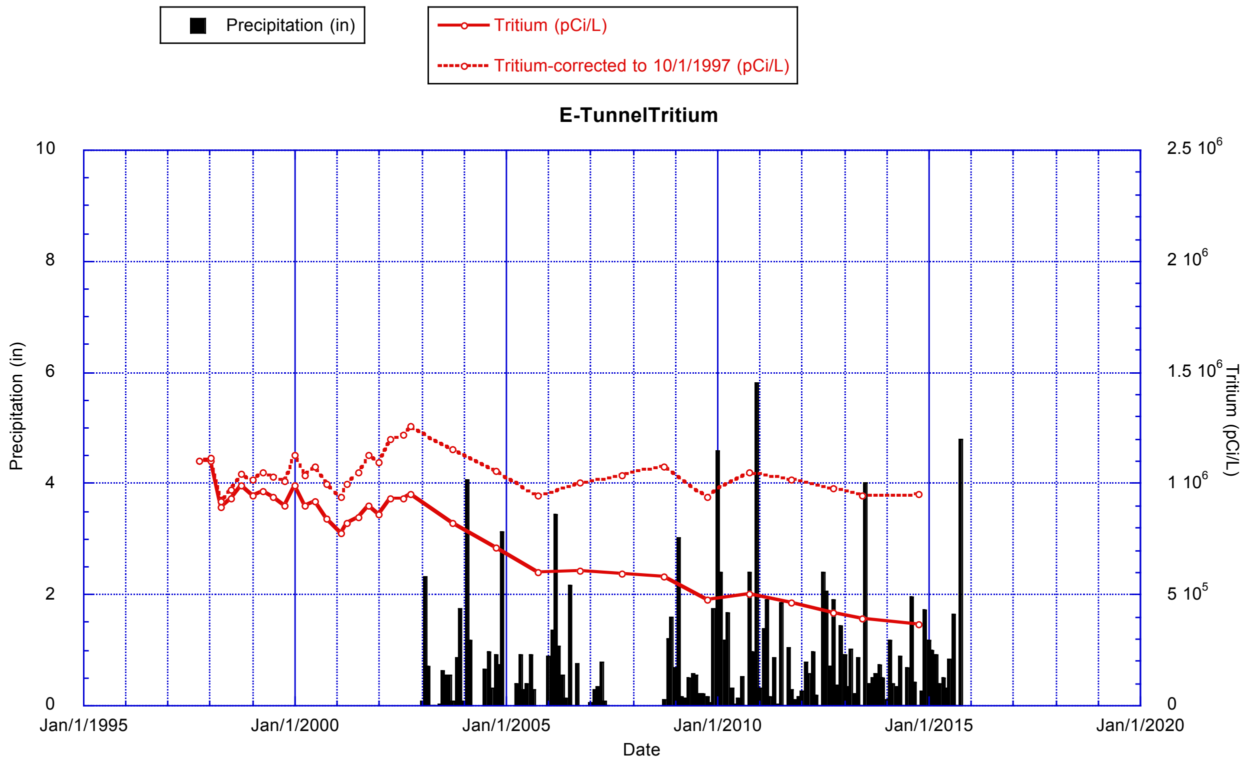


Figure 8: Time series of measured precipitation at Rainier Mesa and tritium concentration (actual observed and corrected to 1997) in the E-Tunnel discharge between 1997 and April 2016. Precipitation data is incomplete over the time interval shown.

A few additional observations or considerations:

[8] It is plausible that the drainage from the E-Tunnel drifts (Figure 9, in a simplified form) can be thought of as a long-term drainage network connected to a perched water system (Figures 10 and 11), but one subject to transient, short-term influences of recent precipitation. In this sense, different waters may be captured in the drain effluent over time, either from more immediate transient precipitation inputs or from an expanding hydraulic capture zone deeper in the Mesa (Figure 11). The tunnel network will tend to aggregate water percolating into many different drifts and through many different testing centers into the observed portal drainage. Variations in recharge rate, recharge geochemistry, or tritium elution along any of these drifts may influence observations at the portal.

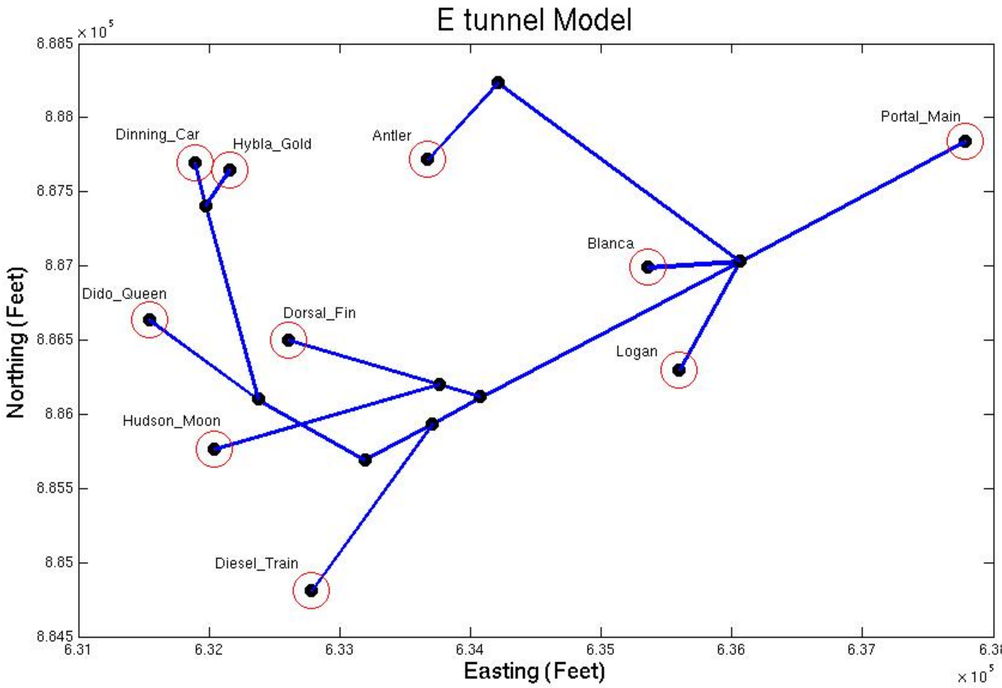


Figure 9: Simple network diagram of E-Tunnel showing locations of principal drifts and tests. Red circles denote nodal locations the main portal and tests as used in a model of tunnel drainage (Tompson et al., 2013); they do not represent cavities or cavity dimensions.

[9] As noted in [3] above, it is possible to infer a slight, long-term trend toward lower pH values over the period of observation. It's a little harder to see this in the corrected ^3H data, but the drainage spikes (upward) may correlate with diluted anti-spikes (downward) in concentration. There may be some similar correlations with precipitation. In this sense, it is as though the "normal" drainage may be coming from an aggregate well-mixed contaminated source, while periodic spikes represent injections of uncontaminated (or less contaminated) water.

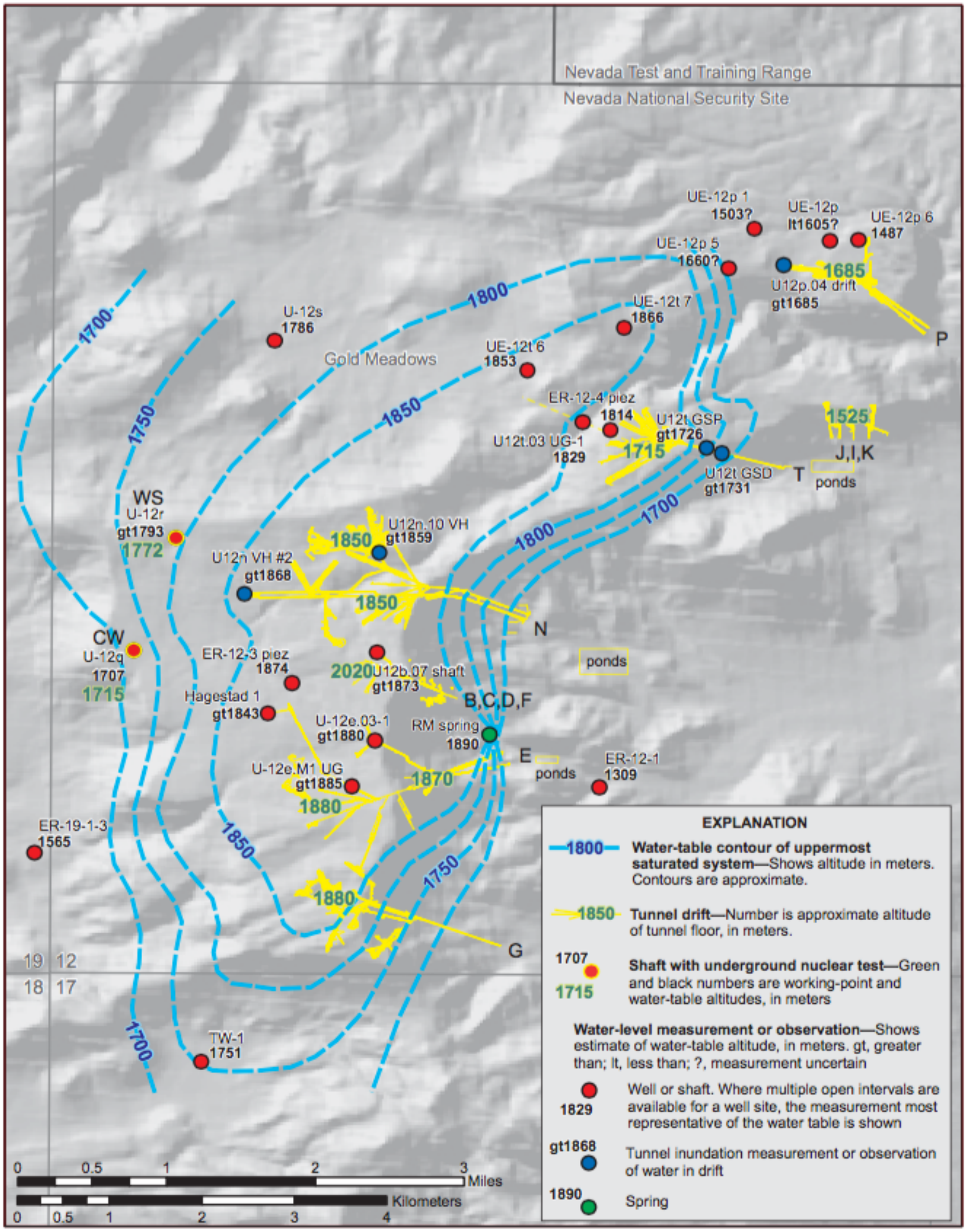


Figure 10: Water table contours showing the groundwater mound in the uppermost saturated system on RM (from figure 10 of the RMSM Conceptual Model Chapter, Fenelon et al., 2014). E-Tunnel is intercepting the uppermost portions of the mound.

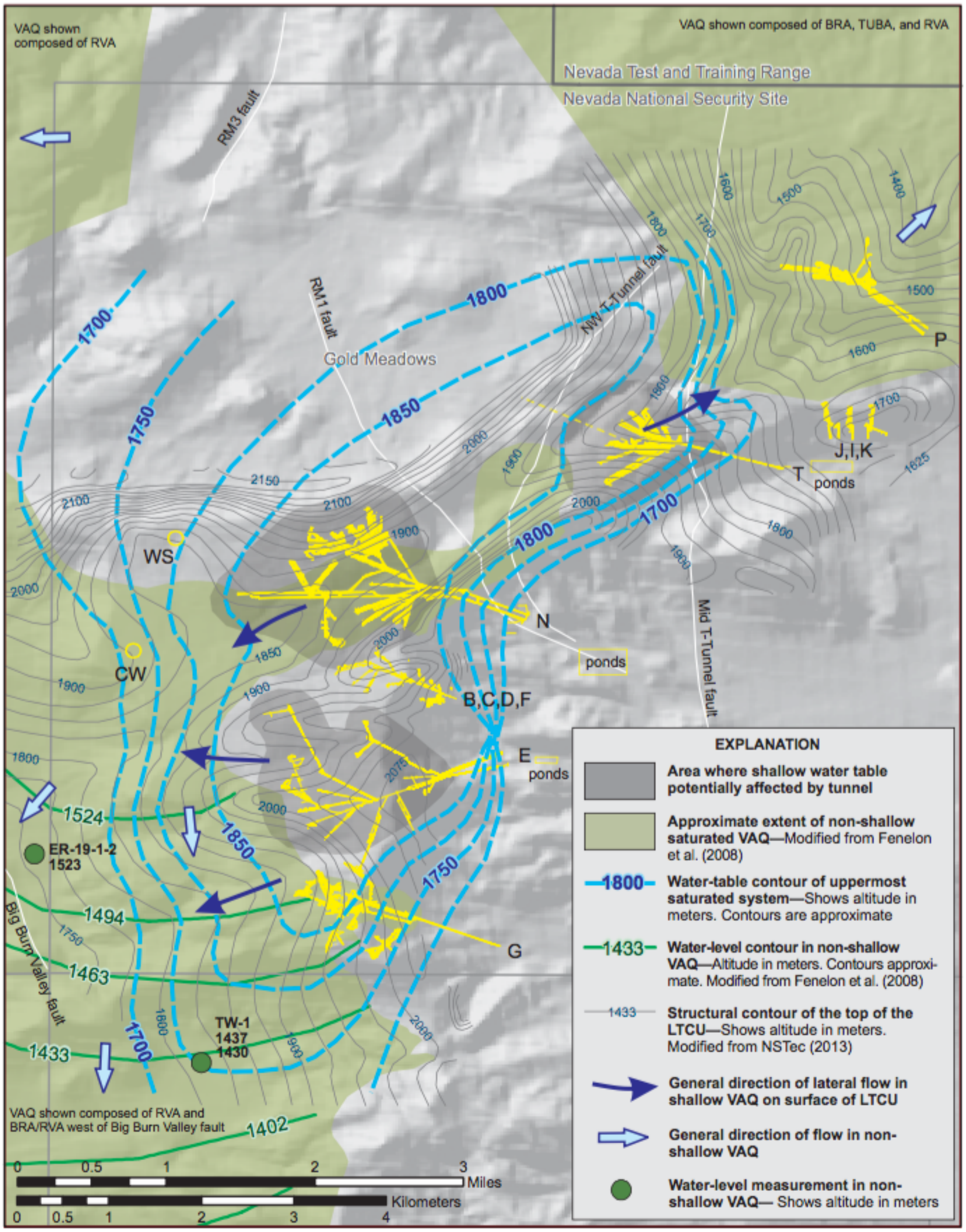


Figure 11: Water table contours showing the shallow groundwater mound (blue contours) in the uppermost saturated system on RM (from figure 18 of the RMSM Conceptual Model Chapter, Fenelon et al., 2014). E-Tunnel is intercepting the uppermost portions of the mound. The dark shaded area over E-Tunnel indicates the approximate area where the shallow water table is affected by tunnel drainage.

[10] As noted in [7] above, the corrected ^{3}H concentrations in the E-Tunnel discharge have not been changing much between 1997 and 2016 (Figures 7, 8). An approximate *average discharge concentration, <C>,* over this period (corrected to 10/1/97) is

$$\langle C \rangle \sim 1.056\text{E}{+}06 \text{ pCi/L} \tag{1}$$

Similarly, apart from short-term (precipitation-based) fluctuations, the discharge rates from E-Tunnel have also been approximately constant between 1997 and 2016 (Figures 4 and 7). An approximate *average discharge flow rate, <Q>,* over this period is

$$\langle Q \rangle \sim 30.72 \text{ L/min} \tag{2}$$

Thus, an apparent (constant) *^{3}H discharge flux, <J>,* (corrected to 10/1/97) can be estimated over this period as the product of <C> and <Q>:

$$\langle J \rangle \sim \langle C \rangle \langle Q \rangle = 3.21\text{E}{+}07 \text{ pCi/min} \tag{3}$$

This suggests *a total ^{3}H discharge amount, $M_{1997\text{-}2016}$*, (corrected to 10/1/97) over this period (specifically between 10/1/97 and 4/1/16, or T = 6,818 days) can be estimated from:

$$M_{1997\text{-}2016} \sim \langle J \rangle T = 3.15\text{E}{+}14 \text{ pCi} = 315 \text{ Ci.} \tag{4}$$

When corrected further back to the date of the Bowen et al. (2001) inventory, the *total ^{3}H discharge* (corrected to 9/23/92) between 1997 and 2016 becomes

$$M_{1997\text{-}2016} \sim 415 \text{ Ci.} \tag{5}$$

Based upon the Bowen et al. (2001) radionuclide inventory for the Rainier Mesa/Shoshone Mountain Principle Geographic Test Center, an estimate of the ^{3}H inventory allocated to the 9 tests in E-Tunnel, M_E, was developed by Tompson et al. (2013, Table C.1) using a yield weighting approach, where the test yields were based upon the announced yields or maximum of announced yield ranges from DOE/NV-209 rev15 (2000). This value, corrected to 9/23/92, is

$$M_E = 4.91\text{E}{+}04 \text{ Ci.} \tag{6}$$

Thus, the *total ^3H discharge observed in the E-Tunnel drainage between 1997 and 2016 represents a fraction,*

$F_1 = M_{1997\text{-}2016}/M_E = 0.0085,$ (7)

or 0.85%, of the total original ^3H inventory in E-Tunnel.

[11] An approximate and simplified model of the E-Tunnel discharge and tritium flux between the beginning of testing and the year 2020 was developed in the RMSM HST Document (Tompson et al., 2013). This model was calibrated to observed flow rates and tritium concentrations in the effluent that were available over this period. Figure 12 shows the predicted E-Tunnel tritium flux (green, uncorrected) between 1958 and 2000 from this model. *The predicted tritium flux in 1997 is highlighted (crossed dotted lines) and compares well with the observed value for 1997* of <J> ~ 4.63E-02 Ci/day, as based upon Equation (3).

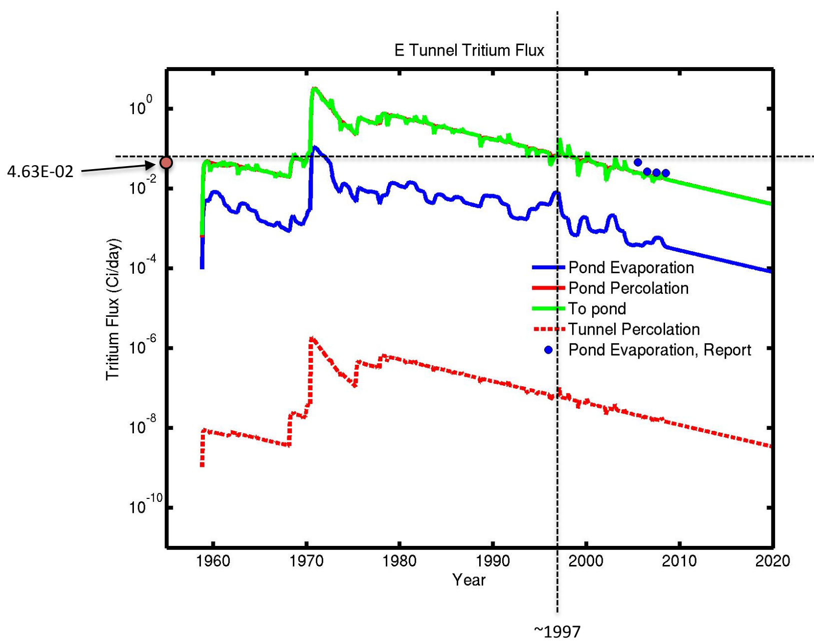


Figure 12: Predicted E-Tunnel tritium flux (green, uncorrected) between 1958 and 2000 from the E-Tunnel model in the RMSM HST Document (Tompson, et al., 2013).

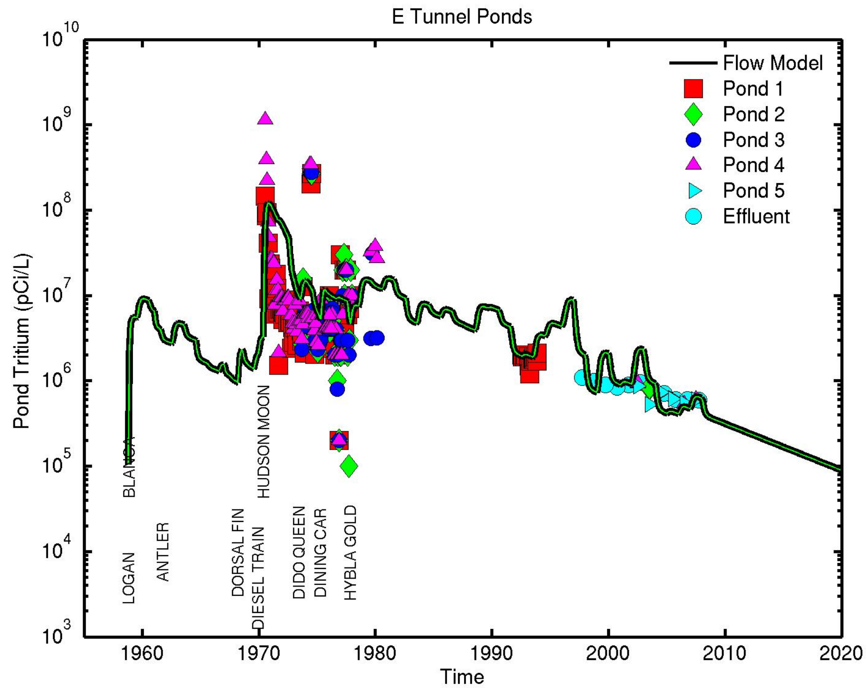


Figure 13: Predicted tritium concentrations in E-Tunnel ponds between 1958 and 2000 from the E-Tunnel model in the RMSM HST Document (Tompson et al., 2013) compared with various pond concentration observations.

[12] Figure 13 compares *predicted tritium concentrations in the E-Tunnel ponds* between 1958 and 2000 from the E-Tunnel model in the RMSM HST Document (Tompson et al., 2013) with various pond concentration observations. The predicted discharge concentration curve between 1997 and 2016 compares well with the observed data in this period, which are equivalent to the (uncorrected) observations in Figures 7 and 8. Notably, the model has released a total of

$$M_{released} = 2.77E{+}03 \text{ Ci} \tag{8}$$

of tritium over the lifetime of the simulation (corrected to 9/23/92). *This represents a fraction,*

$$F_2 = M_{released} / M_E = 5.64E{-}02, \tag{9}$$

or 5.6%, of the E-Tunnel inventory (Equation 6) assigned from Bowen et al (2001). Also, the total measured ^3H discharge (corrected to 9/23/92) between 1997 and 2016 (equation 5) *represents a fraction*

$$F_3 = M_{released} / M_{1997\text{-}2016} = 1.50E\text{-}01, \qquad (10)$$

or 15%, of the total tritium released into E-Tunnel in the model.

Synopsis

[13] To summarize:

- Water flowing out of the E-Tunnel complex is derived from (1) slow and fairly continuous drainage of perched groundwater into the entire tunnel network and (2) occasional transient spikes of water attributable to particularly high precipitation events that likely add water to parts of the tunnel closest to the portal.
- The pH and broader chemical composition of the tunnel water discharge at the portal reflect, in effect, an intermixing of the waters draining from the individual tunnel drifts that contribute to it. Chemically distinct waters in these streams may result from (1) passage of different streams through different types of rock (between the perched system and various tunnel drifts), (2) contact with non-native materials in all or some subset of tunnels (e.g., grout, support structures, test apparatuses) or (3) exposure to test-altered rock in all or some subset of tunnels. Specific attribution of any particular change observed at the portal (chemistry, flow rate) could potentially require additional observations in the tunnel network itself (difficult).
- Transient changes in portal discharge chemistry may reflect transients in the tunnel inputs, water storage volumes, or water residence times in various tunnel drifts. For example, discharge changes may be produced by (1) variable levels of percolation into the drifts, (2) differing recharge levels at the mesa surface, or (3) as a longer term result of the tunnel network as a whole accessing perched groundwater from more distant parts of the formation.
- Transient changes in portal pH values seem to show, on one hand, an annual kind of variability, likely related to precipitation patterns, and on the other, several multiyear trends associated with both rising and declining values.

Observations over the past year (April 2015 to April 2016) seem consistent with the potential onset of another period of decline (hard to tell) but do reveal one of the lowest pH values in the overall record.

- Tritium observations in the portal discharge between 1997 and 2016 show a consistent decline in activity that is attributable primarily to the effects of radioactive decay. In other words, when decay-corrected to the beginning point of the record (1997), the tritium activities appear roughly constant between 1997 and 2016 and do not seem to reflect any dilution or elimination of the aggregate tritium source originally emplaced (or available for discharge) in the tunnel system.
- The mass of tritium observed in the discharge between 1997 and 2016 represents 0.85% of the tritium assigned to the E-Tunnel tests from the Bowen (2001) inventory (Equation 7);
- The mass of tritium released into the modeled tunnel system (Tompson et al., 2013) over the lifetime of the model represents 5.6% of the tritium assigned to the E-Tunnel tests from the Bowen (2001) inventory (Equation 9); and
- The mass of tritium observed in the discharge between 1997 and 2016 represents 15% of the tritium released into the modeled tunnel system (Tompson et al., 2013) over the lifetime of the model (Equation 10).

References

Bowen, S. M., D. L. Finnegan, J. L. Thompson, C. M. Miller, P. L. Baca, L. F. Olivas, C. G. Geoffrion, D. K. Smith, W. Goishi, B. K. Esser, J. W. Meadows, N. Namboodiri, and J. F. Wild (2001), Nevada Test Site Radionuclide Inventory, 1951-1992, LA-13959-MS. Los Alamos, NM: Los Alamos National Laboratory.

Fenelon, J., K. Halford, and S. F. Carle (2014), Written communication, Subject: FLOW AND TRANSPORT CONCEPTUALIZATION, Draft chapter for Rainier Mesa/Shoshone Mountain CAU Flow and Transport Model, Nevada National Security Site, Nye County, Nevada. Las Vegas, NV: U. S. Geological Survey, November 6, 2014

Russell, C. E., L. Gillespie, and D. Gillespie, (1993), Geochemical and Hydrologic Characterization of the Effluent Draining From U12E, U12N and U12T Tunnels, Area 12, Nevada Test Site, US Department of Energy, Las Vegas, NV, DOE/NV/10845-21, UC-703

Russell C. E., R. H. French, R. A. Nicholson, J. S. Miller, and S. Benner, (2003), Evaluation of Monitoring Data from Impounded Water within U12n and U12t Tunnel – Rainier and Aqueduct Mesas, Nevada Test Site, Letter Report, Desert Research Institute, Division of Hydrologic Sciences, University and Community College System of Nevada, June.

Tompson, A. F. B., M. Zavarin, W. W. McNab, S. F. Carle, D. E. Shumaker, C. Lu, Y. Sun, G. A. Pawloski, Q. Hu, and S.K. Roberts (2013), Written communication, Subject: Hydrologic Source Term Processes and Models for Underground Nuclear Tests at Rainier Mesa and Shoshone Mountain, Nevada National Security Site. LLNL-TR-483852-DRAFT. Livermore, CA: Lawrence Livermore National Laboratory.

U.S. Department of Energy, Nevada Operations Office (2000), United States Nuclear Tests, July 1945 through September 1992, DOE/NV--209-REV 15. Las Vegas, NV.