Installing Deep Groundwater Monitoring Wells in a Volcanic Dominated Rift Basin: Los Alamos National Laboratory, New Mexico – 17594

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ABSTRACT

Los Alamos National Laboratory (LANL, or the Laboratory) is located in northern New Mexico near the west margin of the Española Basin. LANL is underlain by a complex basin-fill sequence of alluvial fan deposits, volcanic tuff, basaltic and dacitic lavas, and riverine deposits. On-going environmental remediation and characterization activities have evolved to improve the performance of groundwater monitoring wells, ensuring they yield representative groundwater and core samples. Groundwater occurs as canyon-fill alluvial water, perched intermediate-depth water associated with the basalts and other local-scale perching horizons, and as a regional-scale aquifer that is the main water supply for the area. Anthropogenic contaminants are found in all three groundwater zones. The regional aquifer below LANL is nominally 1000-1400 feet below ground surface (bgs). Monitoring wells at the Laboratory, are therefore, among the deepest routinely installed in the US. Logistical challenges at LANL include steep terrain, widespread cultural sites, and threatened and endangered species habitat restrictions. Additionally, the cost of installing monitoring wells is high because of groundwater depths and the variable drilling techniques that are required to characterize and install wells in a complex geologic environment.

A major challenge to the characterization approach at LANL has been to meet sample quality requirements while minimizing drilling costs. In the late 1990s threaded drill-casing was advanced by rotary drilling methods using compressed air as the only circulation fluid. This resulted in relatively low impacts to the geochemical integrity of rock and groundwater samples, but led to frequent episodes of stuck casing. Additional fluids were introduced to the air-rotary program, improving penetration rates, but also resulting in non-representative groundwater samples due to long-term impacts to the aquifer in the vicinity of the well screen. Mud-rotary drilling was incorporated into the program, but it also had significant long-term impacts on groundwater quality, and often inhibited identification of perched groundwater zones and accurate identification of the water table in the regional aquifer. Current drilling practice makes limited use of fluid additives (e.g. foam) to supplement air circulation methods in order to advance drill casing through the vadose zone. Starting about 100 feet above the water table, drill casing is advanced to the target horizon in the regional aquifer using only air and municipal water (when needed) for circulation. Additionally, the threaded drill casing couplings have been replaced with welded connections, significantly reducing the occurrence of stuck casing. Careful observations of water production and water levels during drilling, coupled with the ability to retract casing for video and geophysical logs, now allows for robust characterization of perched groundwater systems and accurate definition of the top of regional saturation. Recent advances in the drilling program include combined dual-rotary/sonic drilling to depths up to

1150 feet and dual-rotary casing advance at angles up to 25° from vertical. The former allows for core collection with minimal fluid addition, thereby preserving pore water chemistry. The latter method allows for well installation into portions of the aquifer otherwise inaccessible due to constraints at the surface (e.g., cultural sites or topography).

Similar to the development of drilling techniques, both well design and groundwater sampling system design have evolved throughout the program. Current well design emphasizes a minimal annulus of filter pack, maximum screen slot size based on formation sieve analyses, and thorough well development to mitigate formation damage due to drilling. To sample groundwater at multiple levels in the same well, earlier sampling systems included Westbay® multi-zone systems and dual-screen single-pump and dual-screen dual-pump systems designed in collaboration with Baski, Inc. These multi-zone sampling systems proved difficult to develop and maintain given the depth to groundwater, and most current well installations are configured with a single screen and a submersible pump. The ability to purge from a well-developed single-screen well has substantially improved the collection of representative groundwater samples. A carefully crafted groundwater characterization program in target aquifers at depths ranging from 1,000 to 1,400 feet bgs within a complex geologic setting, while also retaining the ability to collect representative core and groundwater samples, may have application at a number of sites throughout the environmental industry. Optimizing each well to meet program objectives while reducing total project costs benefits all environmental investigations. (LA-UR-16-27766)

INTRODUCTION

Los Alamos National Laboratory (LANL, or the Laboratory) covers 40 mi^2 in northern New Mexico. During its 70+ year history, LANL has focused on national security. Work associated with development of the first atomic bomb and subsequent programs to assure the nation's nuclear deterrence took place at facilities distributed across 47 technical areas (TA). At a few of these sites, contaminants released to the surface environment have migrated vertically over 1,000 ft, locally impacting perched groundwater and the regional aquifer. Contaminants, when present, are limited to the upper 30-100 ft of the regional aquifer. Because of the depth to water, the complex geology, and the desire to collect representative samples from the top of the regional aquifer, considerable time and effort has been devoted on optimizing the drilling and well design methods utilized in the hydrogeologic characterization, monitoring well network installation, and remedial action phases of the program. This paper summarizes key lessons learned while drilling, completing, developing, and sampling a deep, multi-zoned groundwater monitoring well program.

HYDROGEOLOGIC SETTING

The Laboratory is located on the Pajarito Plateau along the western margin of the Rio Grande rift in northern New Mexico (Fig. 1). The plateau sits above the deepest part of the west-tilted, sediment filled Española Basin (Broxton and Vaniman, 2005). The region is arid to semi-arid and groundwater recharge is dominated by precipitation in the adjacent highlands of the Jemez volcanic field. Hydrogeologic units consist of Miocene and Pliocene basin-fill deposits and interfingering volcanic rocks from the Jemez and Cerros del Rio volcanic fields. Miocene and Pliocene sedimentary and volcanic rocks are covered by Pleistocene ash-flow tuffs making up the Pajarito Plateau.

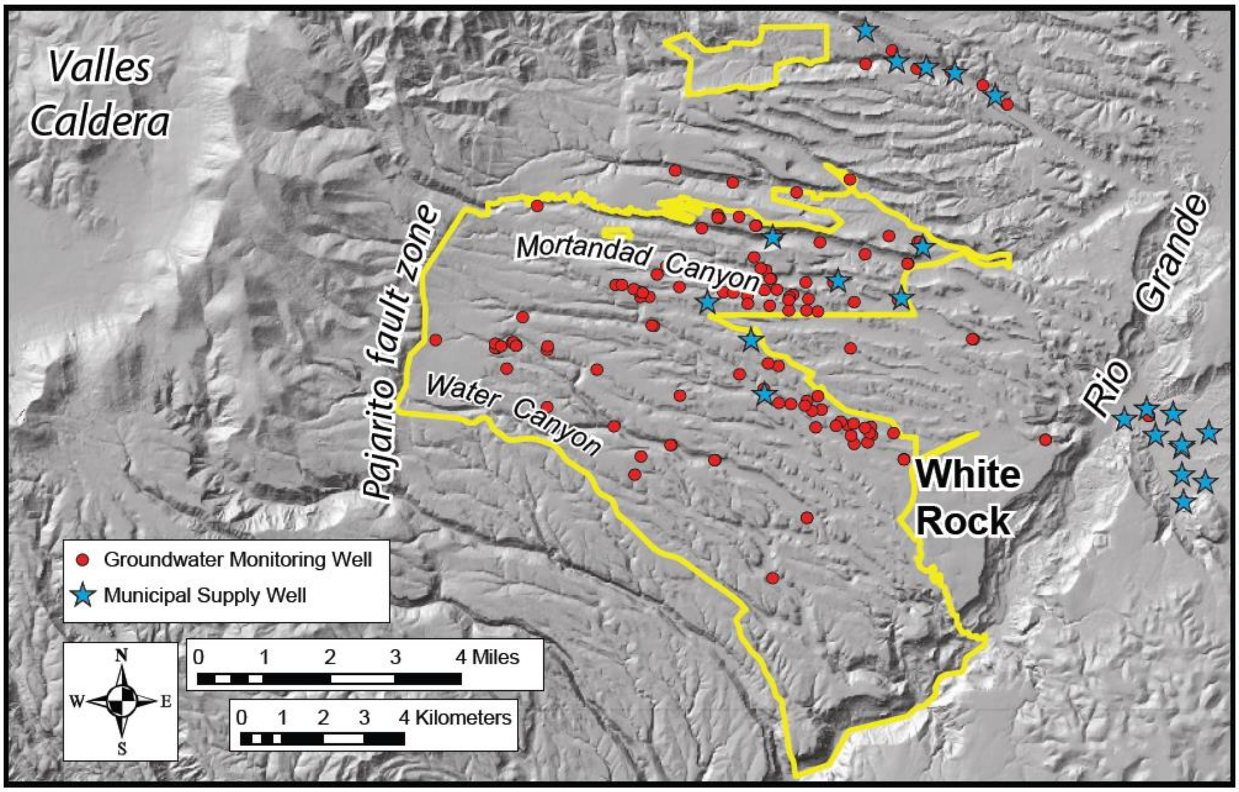


Fig. 1. Location of Wells at Los Alamos National Laboratory (yellow outline) in Northern New Mexico.

Groundwater at LANL occurs as shallow groundwater in canyon-fill alluvium, as a moderately deep perched groundwater system in the vadose zone, and as deep groundwater associated with the regional saturated zone. The vadose zone is between 600 and 1,200 ft thick beneath mesas of the plateau. The vadose zone is dominated by thick deposits of Pleistocene Bandelier Tuff that overlie the Pliocene Cerros del Rio basalt and fanglomerate of the Puye Formation (Fig. 2).

The regional aquifer consists of the Miocene Tesuque Formation, older fanglomerates, and pumice-rich volcaniclastic sedimentary rocks, Mio-Pliocene river deposits, and the Pliocene Puye Formation. These deposits form a westward-thickening wedge of relatively coarse grained sediments that represent the most productive part of the aquifer below LANL.

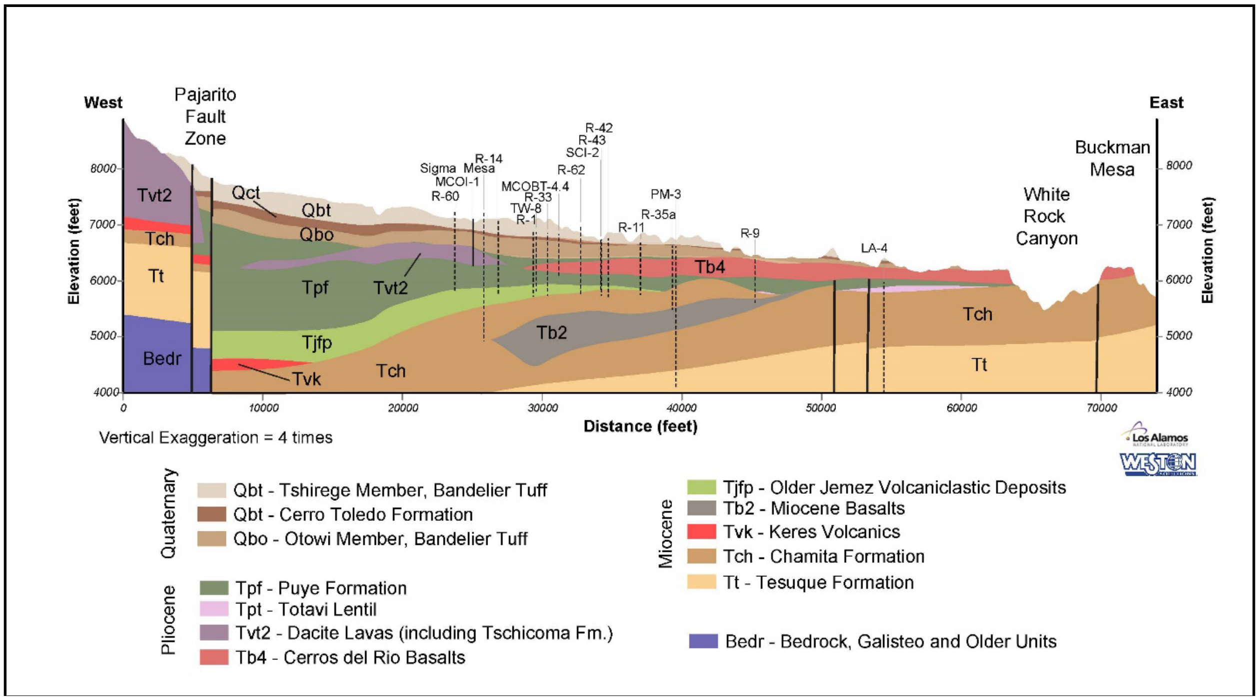


Fig. 2. West to East Cross Section Through LANL.

DRILLING CHALLENGES

Drilling methodology must take into account the highly variable lithologies encountered at LANL. The surface and near-surface is dominated by variably welded tuff ranging from soft unconsolidated tuff to hard densely welded tuffs that require rotary drilling methods. The Cerros del Rio basalt is a complex sequence of alternating dense lavas and variably consolidated sediments, cinder deposits, and breccias. The Puye Formation is a heterogeneous deposit made up of cobbles and boulders of dense dacite embedded in poorly to moderately consolidated sandy matrix. Locally, dacitic lavas, older fanglomerates, and riverine deposits are present deeper in the vadose zone and regional aquifer. When encountered, the riverine deposits are a particularly difficult drilling challenge because they often contain fine-grain flowing sands.

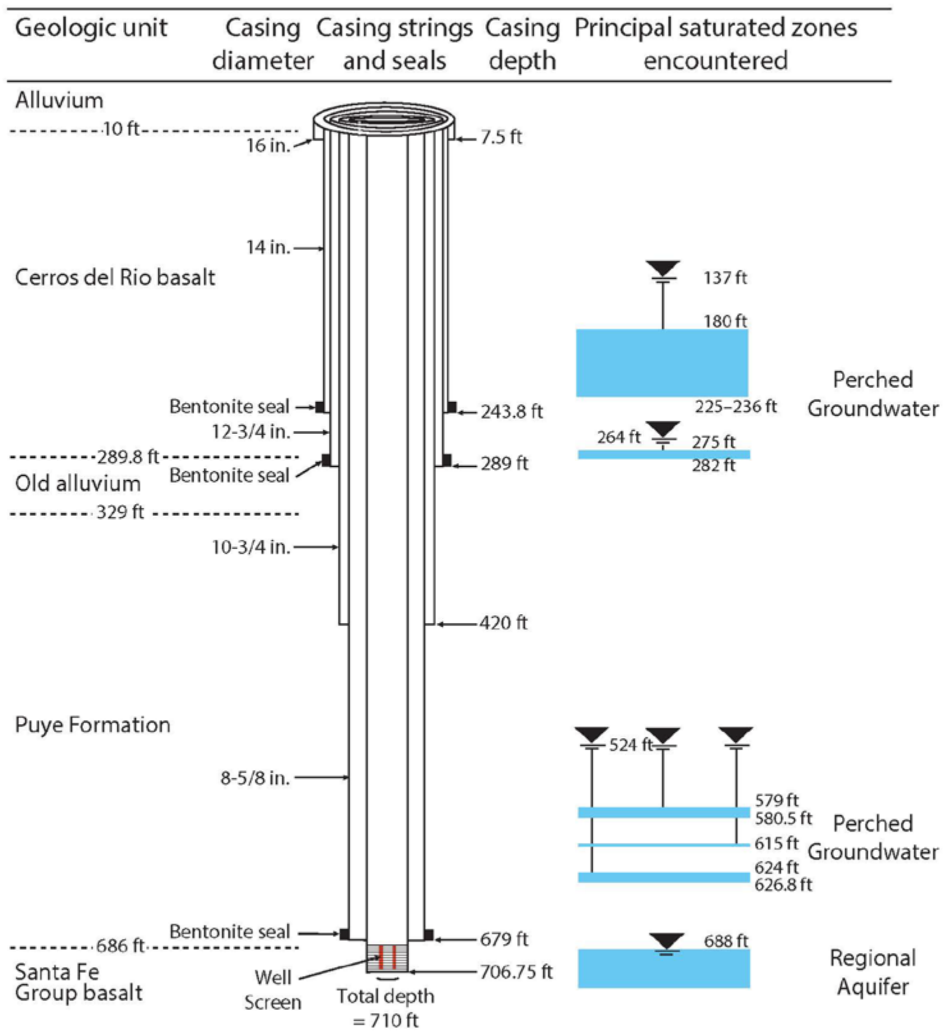
Methods used to accommodate the drilling variability include open-hole air-rotary, mud-rotary, and casing advance (air-rotary casing hammer and dual-rotary). Each method has relative advantages and drawbacks. Open-hole drilling can be the fastest penetration method but requires drilling fluid additives that may affect water quality and may not be successful in unstable strata. The extensive basalts and dacites at the site limit the use of the air-rotary casing hammer. In spite of its relatively high cost, dual-rotary casing advance is currently the preferred method of drilling. The drill casing addresses borehole stability problems and allows for potentially contaminated perched water to be sealed off before penetrating deeper aquifers. Limitations to the casing advance method include the inability to identify low-producing perched intervals and the possibility of getting the casing stuck.

Challenges encountered while drilling at LANL include lost circulation (air-rotary and mud-rotary), collapsed borehole, heaving sands and gravels, stuck drill casing, and broken tooling. Both the tuff and the lavas (basaltic and dacitic) can be highly fractured, leading to high fluid losses and cuttings not being fully evacuated from boreholes. The inability to properly clear drill cuttings from the borehole has led to stuck, damaged, and lost tooling.

WELL COMPLETION

Borehole Diameter

Final (total depth) borehole diameters have evolved over the course of the drilling program. Given the significant depth to water, all regional aquifer well boreholes are drilled with telescoped carbon steel drill casing. Typically, boreholes are initiated with an 18 to 24-inch surface conductor and the boreholes step-down along the way to total depth (Fig. 3). Drill casing strings are removed from the borehole during well construction, although some casing has been left behind when stuck. Leaving drill casing strings in the boreholes is acceptable if they are sealed per New Mexico Office of the State Engineer standards. Some sections of boreholes encounter dense basalt and dacite and are drilled in an open-hole fashion. A common approach is to finish boreholes with 12-inch drill casing because it offers plenty of working room for well construction and the ability to run 10-inch casing as a drilling contingency. Currently, the prescribed final borehole diameter is nominally 10-inches with the intent of constructing a nominal 2-inch annular filter pack around the 5.5-inch well screen. The 10-inch final diameter and nominal 2-inch filter pack thickness minimizes the filter pack thickness and enhances well development. This design produces wells that deliver the most representative groundwater samples as soon as possible after completion.



Telescoped drill casings to seal off multiple perched groundwater zones at well R-9

Fig. 3 Telescoped Drill Casing Through Multiple Perched Groundwater Zones.

Construction Materials

Monitoring wells are constructed from 5-inch inside diameter (I.D.)/ 5 9/16-inch outside diameter schedule 40 304 stainless steel casing. Well screens are 5-inch I.D. 304 stainless steel 0.040-inch slot, rod-based, wire-wrapped screens. Five-inch tubulars are necessitated by 4-inch pumps and motors, which are the smallest pumps capable of lifting water from the depths encountered at the LANL site.

Casing and screen ends are beveled for welded joints. Older wells are mostly constructed of threaded and coupled (T&C) casing and screen joints. Since moving to 10-inch final borehole diameters, flush welded casing has become necessary because the well casing couplings are too large to fit a sufficient tremie pipe alongside the T&C well casing. Typical well screens are 10 and 20 feet long and have 5 feet of primary filter pack above and below the screen slots, with 2 feet of transition sand above the primary filter pack. Seals are constructed with 3/8-inch bentonite chips and primary filter packs are 10/20 silica sand. Transition sand collars are installed above the primary filter packs and are finer 20/40 silica sand. All annular backfill materials are delivered downhole via tremie pipe and are flushed in place with potable water. High yielding bentonite slurries and grouts are not used for annular seals because of their tendency to become lost to the formations, particularly in fractured basalt. The wells are finished in the top 60 to 100 feet with a neat cement annular seal extending to ground surface.

Single vs Multiscreen Completions

Well completions at LANL include single-screen or multiscreen completions. In the current phase of LANL's groundwater investigation, multiscreen completion means two well screens whereas in earlier phases, three or more well screens were constructed. Active purge sampling systems are difficult, if not impossible, to design and install in wells with more than two screens. There are several reasons dual-screen well completions continue to be built at LANL. One significant reason is cost. Uncertainties about the depth of potential contamination exist in some areas of the site and drilling costs are substantial. Often one well with two screens can delineate groundwater contamination at a fraction of the cost of installing two separate wells. Similarly, a perched-intermediate aquifer may be encountered and a dual-screen well may be constructed in order to monitor two entirely different aquifers.

Well Development

Well development is one of the most important consideration for any groundwater well. Generally, the requirements for development at LANL include tracking and ensuring water volumes introduced during drilling and construction have been recovered and that water quality parameters have stabilized. Monitored and recorded water-quality parameters include pH, specific conductance, temperature, turbidity, oxidation-reduction potential, and total organic carbon. All water-quality field measurements are collected using a multi-parameter instrument with a flow-through cell. The target water-quality parameters for completion of well development are turbidity of less than 5 nephelometric turbidity units, total organic carbon less than 2 ppm, and stability in the other parameters. Purge volume requirements for well development specify the removal of 200% of water introduced below the water table during drilling and well construction.

Sampling Systems

Several different types of active-purge sampling systems are deployed in the LANL monitoring network based on the number of screens in the well. Single-screen wells have submersible systems consisting of environmentally retrofitted 4-inch Grundfos® submersible pumps, mostly from the 5S and 10S series. The pumps are installed on schedule 80, threaded and coupled, 1-inch stainless-steel drop pipe. These systems have either one or two polyvinyl chloride (PVC) gauge tubes for water-level measurement, and electrical service cable bound to the drop pipe. Dual-screen wells have dual access port valve (APV) systems that use pneumatically operated valves to purge water from the desired screened interval (Fig. 4). These systems share a single submersible pump for both screen intervals, contain at least one isolation packer, multiple 0.25-inch pneumatic control lines (nylon and/or stainless steel), two 1-in. schedule 80 PVC gauge tubes for water-level measurements, and electrical service cable bound to the drop pipe. These systems were designed and manufactured by Baski, Inc. Some dual screen wells have dual-pump systems that use a single pump in each screened interval. Pump operation and discharge are independent of one another. The most common two-pump systems include a submersible pump for the lower-screened interval and a pneumatic piston-type pump for the upper-screened interval. The lower submersible pump is installed on schedule 80, threaded and coupled 1-inch stainless-steel drop pipe. These systems have at least one isolation packer, either one or two PVC gauge tubes for water-level measurement, electrical service cable, and the upper pneumatic pump and tubing bundle bound to the drop pipe.

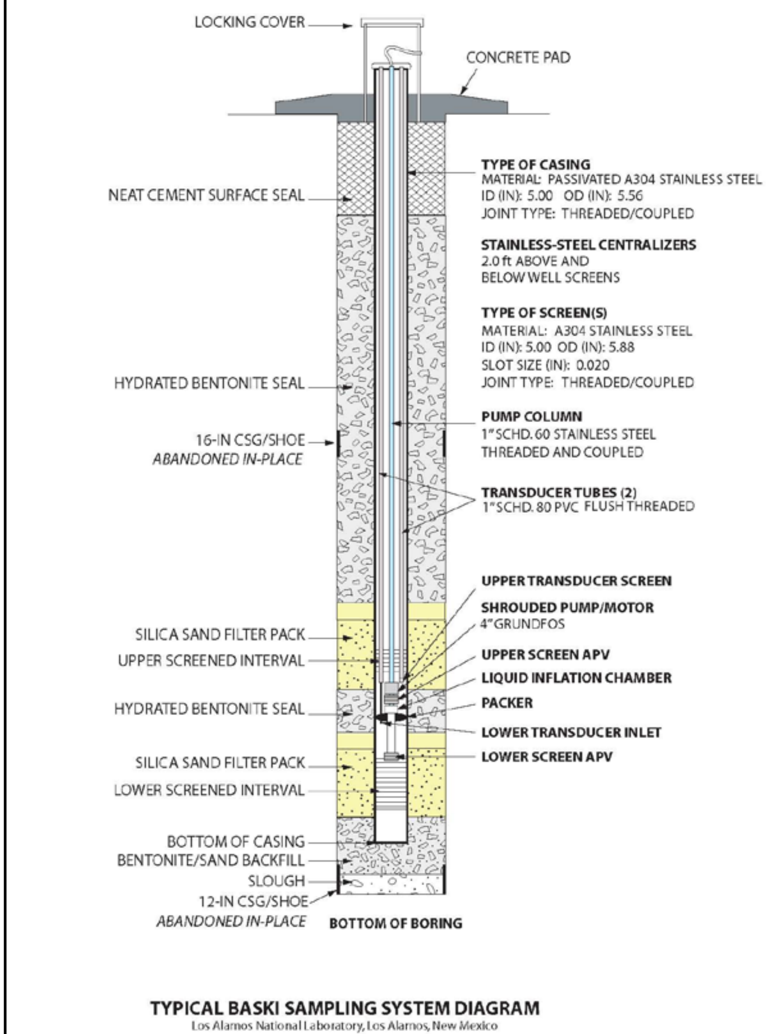


Figure 4. Typical Two-Screen Well Completion

CONCLUSIONS

Drilling is about tradeoffs, and understanding these tradeoffs is critical when designing a program focused on collecting representative groundwater samples from 1,000 feet depth in a hydrogeologically complex environment. Telescoped drill casing is essential when sealing off potentially contaminated perched zones, but its use may interfere with characterization of the hydrogeologic setting by precluding the use of some borehole geophysical logs and prevent identification of minor perched zones. Planning for large-diameter drill casing within the regional aquifer allows for the use of smaller diameter casing to reach total depth if unstable borehole conditions are encountered; however, a smaller final borehole diameter around the well screen promotes more effective well development. Stopping the introduction of drilling additives before entering the target aquifer reduces the likelihood of geochemical impacts to groundwater samples, but requires the use of additional volumes and pressures of compressed air to ensure cuttings returns. However, the added air can lead to long-lived effervescent conditions which can also adversely impact development and geochemical conditions around the well screen. Given the high costs of drilling monitoring wells to 1,000 ft, full characterization of the subsurface is often a desirable additional objective. However, trying to drill open-hole to allow for geophysical logging and downhole video to look for perched groundwater potentially reduces the chances of successfully completing wells within the regional aquifer.

FUTURE OF DRILLING AT LANL

As the LANL Environmental Management program matures and focus shifts from primarily subsurface characterization and groundwater monitoring to remedy selection, the drilling purpose and well design will evolve too. Monitoring wells will be supplemented with larger diameter extraction and injection wells. Angled and potentially horizontal completions will be added to the network as well. Lessoned learned from 18 years of monitoring well installation will need to be built upon to realize success in the upcoming phases of remediation hydrology and engineering.

REFERENCES

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