Updated Summary of Los Alamos National Laboratory Actions to Recommendations by the 2007 National Academy of Sciences Report "Plans and Practices for Groundwater Protection at the Los Alamos National Laboratory"

EXECUTIVE SUMMARY

From 2006 to 2007, the National Academy of Sciences (NAS) conducted an 18-mo review of plans and practices for groundwater protection at Los Alamos National Laboratory (LANL or the Laboratory). The review was requested by the Los Alamos Site Office (LASO) of the U.S. Department of Energy (DOE) to ascertain the effectiveness of the Laboratory's groundwater monitoring program. The NAS review panel was given a statement of task that included such topics as the control of sources of groundwater contamination, issues of groundwater data quality, and the effectiveness of the Laboratory's groundwater-monitoring approach in identifying contaminants that may migrate to public receptor locations. The specific wording of the panel's charter can be found in its final report (NRC 2007, 201416).

The NAS panel noted in its final report (NRC 2007, 201416) that the program was at the juncture between the Hydrogeologic Workplan characterization, which was terminated with the signing of the 2005 Compliance Order on Consent (the Consent Order), and the initial development of a sitewide monitoring plan. The panel considered the groundwater protection program to be a work in progress and the panel's findings to be a snapshot in time. The Laboratory believed the panel's recommendations would provide a basis for a stronger scientific foundation for decisions that would be made under the Consent Order.

The Laboratory discussed the 17 recommendations contained within the final report (NRC 2007, 201416) with the NAS panel in June 2007. Although the panel had concluded its work and disbanded, the Laboratory and DOE-LASO decided to respond formally to the recommendations. The Laboratory's 2007 responses (LANL 2007, 201401) were intended to be used for internal planning and reporting purposes and for communication with stakeholders and the interested public. Of the Laboratory's 2007 responses to the review panel's 17 recommendations, 13 responses clarified work that had been completed by 2007 or described approaches to work that was ongoing at the time. Four responses described work that was planned and approved in the baseline for consideration during the annual work plan prioritization process.

The 17 recommendations can be aggregated into five areas, which are consistent with an environmental cleanup program approach:

- Characterization
  - ❖ Finish characterization, conduct enhanced mass balance and geochemistry
- Contaminant fate and transport
  - ❖ Quantify contaminant pathways, capture uncertainty, improve models
- Containment
  - ❖ Confirm integrity of disposal sites, reduce liquid discharges and solid wastes
- Monitoring
  - ❖ Improve and expand on monitoring at both sitewide and local scales
- Quality program application
  - ❖ Address drilling fluid impacts, procedure consistency, data reduction and reporting
  - ❖ Improve confidence through peer-reviewed publications

In 2010, DOE-LASO requested the Laboratory provide an updated response to the review panel's recommendations (DOE 2010, 110744). The Laboratory's updated response is provided in this document. The text below provides the verbatim wording of the 17 NAS recommendations as stated in chapter 6 of the panel's final report (NRC 2007, 201416) (with emphasis added in bold to highlight the main ideas). Following each recommendation is the Laboratory's and DOE-LASO's coordinated response presented in 2007 (edited for clarity). The updated response of 2011 follows the 2007 response to indicate changes and progress over the last few years.

NAS Recommendation:

1. *LANL should* ***complete the characterization of major contaminant disposal sites and their inventories****, i.e., complete the investigation of historical information about these disposal sites with emphasis on radionuclides and chemicals likely to impact human health and the environment. Selected sites should be characterized by field analysis when historical information is insufficient to determine quantities of major contaminants disposed and to confirm the degree of transport that has occurred. LANL should devote greater effort to characterizing sources with significant inventories of contaminants (especially plutonium) that usually are strongly sorbing but still have the long-term potential to migrate in the presence of water.*

2007 LANL Response:

1. The complete characterization of the major contaminant disposal sites is included in the program's life-cycle baseline and is proceeding in accordance with a schedule established between the Laboratory and the New Mexico Environment Department (NMED). The approach is to characterize those sites with more substantial inventories early and move to sites with lesser inventories later in the program. Currently, the inventory at Material Disposal Areas (MDAs) H and AB are well known and are fairly well known at MDAs G and L. Limited records were kept for MDA C, so it is unlikely that the inventory at MDA C can be determined, but it may be possible to calculate volatile releases from MDA C without knowing the inventory explicitly.

   Inventory records for some of the solid waste management units (SWMUs) do not exist; for this reason, it can be difficult to determine the source term. However, with respect to the SWMUs, the Laboratory has a good estimate of the amount of strontium-90 released in Bayo Canyon and of radionuclides released in Los Alamos and Pueblo canyons. Additional information about soil contamination in Bayo Canyon was collected in the summer of 2007. In general, however, most of the SWMUs either will be cleaned up or will require no action.

2011 LANL Response:

1. Where feasible, the Laboratory is trying to determine waste-contaminant inventories for major disposal areas and has enhanced characterization of these areas to support corrective measures evaluations (CMEs). MDAs G, H, and L are in the CME stage and data necessary to support optimized remedy selection are being incorporated into CME reports. MDA B is currently being excavated. MDA C is still under investigation, and the mass of vapor-phase contamination will be estimated and included in upcoming reports. New wells drilled since 2007 have added considerably to understanding the hydrogeologic characteristics of the major contaminant disposal sites. For example, monitoring wells R-37, R-38, R-39, R-40i, R-40, R-41, R-49, R-52, R-53, R-54, R-55, and R-57 were added around the three MDAs at TA-54; these wells have provided characterization and monitoring data for the CME reports for MDAs G (LANL 2010, 111362); H (LANL 2010, 111506); and L (LANL 2010, 110852).

The updated performance assessment for MDA G includes a revised inventory (French et al. 2008, 106890). A mass balance was performed for the chromium investigation, and estimates of the distribution of the chromium inventory were included in the Sandia Canyon investigation report (LANL 2009, 107453). In addition, work to establish the waste contaminant inventory at MDA T is in progress and will support the CME for this site. At MDA T, an early inventory was calculated in plutonium equivalents; the updated inventory uses the results of the early inventory, supplemented by information determined from additional environmental inventory records. The updated inventory will examine specific radionuclides and will try to reconstruct the Resource Conservation and Recovery Act (RCRA) constituent inventory for nonradioactive constituents.

NAS Recommendation:

2. *For the major disposal sites, LANL should* ***develop mass balance estimates*** *of the quantities of disposed chemicals and radionuclides remaining in the surface soil and/or residing in the shallow alluvium, the vadose zone, and the regional aquifer.*

   Sitewide, LANL should perform a mass balance for hazardous and radioactive substances by assessing the types, quantities, and volumes of individual hazardous materials that have entered the site over the years.

2007 LANL Response:

2. The Laboratory employs mass balance calculations as one of its tools to assess waste disposal sites and determine appropriate remedies and cleanup goals. The Laboratory will not be able to perform a sitewide mass balance of the hazardous materials that have entered the site over the years because a mass balance requires knowledge of inventories of the materials disposed of, and records were not kept of inventories during the Laboratory's early years. However, a sitewide mass balance is not as relevant as mass balance studies that are planned or that have been conducted at certain areas. As a foundation for these and other studies, Birdsell et al. (2006, 094399) compiled an extensive amount of historical information on Laboratory sources and inventories that was presented to the NAS panel during its August 2006 workshop. This information will be valuable in assessments of contaminant transport for the individual areas within the site.

   It is most relevant to conduct a mass balance where releases are known to have occurred so the mass retained can be compared with the initial mass to estimate the mass released. This analysis was done in the draft performance assessment for MDA G and is being considered for Area AB. The Laboratory expects to perform a release scenario for every corrective action area through investigation reports. A mass balance performed for perchlorate provided important information for the Mortandad Canyon assessment (LANL 2007, 099128).

2011 LANL Response:

2. The Laboratory continues to employ mass balance calculations as a tool to assess waste disposal sites and determine appropriate remedies and cleanup goals. A mass balance was calculated for the chromium investigation in all media (LANL 2009, 107453, Appendix D, section D.2). This comprehensive mass balance analysis included an estimate of the total quantity of chromium released to Sandia Canyon over a period from the 1950s to 1970s and its current distribution in soil, alluvium, the vadose zone, and the regional aquifer. The MDA C Phase III investigation report is in progress and will be submitted to NMED in June 2011; for this investigation report, a volatile organic compound (VOC) mass balance and VOC distribution in the vadose zone are being calculated based

on vapor data. The CMEs for MDAs G, H, and L have been submitted (LANL 2010, 111506; LANL 2010, 111362; LANL 2010, 110852). They also included similar VOC mass balances and vadose zone distribution calculations based on vapor data. The VOC estimates account for mass distributed in both the vapor and liquid phases. MDA B is in the process of excavation and MDA A will also be excavated. Corrective measures have been completed at MDA V and are in progress at MDAs T and AB.

NAS Recommendation:

3. *LANL needs to* ***quantify the inventories of contaminants released in the canyons*** *in order to understand their potential threat to groundwater. The sitewide mass balance of inventories of hazardous and radioactive substances should include the surface water transport pathway.*

   LANL should continue to develop surface water and sediment monitoring programs. LANL should continue, and improve, its control of contaminants moving down the canyons to prevent further surface transport and redistribution offsite of both mobile and sorbing contaminants. Measures to control surface transport down canyons, including further reduction of aqueous discharges, removal of contaminated media, and appropriate use of barriers, etc., are needed.

2007 LANL Response:

3. Where possible, the Laboratory has quantified, or will quantify as part of its work scope, the inventory of contaminants released into canyons. This analysis has been completed for Mortandad Canyon (LANL 2007, 099128), and is currently being performed for Sandia Canyon. An attempt is currently underway for the South Canyons (Water, Ancho, and Cañon de Valle) related to Technical Area 16 (TA-16). The inventory cannot be determined for Los Alamos and Pueblo canyons because of limited records kept during the early years of the Laboratory. These are the main canyon areas that have contamination. The response to Recommendation 2 discusses the determination of a sitewide mass balance.

   With regard to surface water and sediment monitoring programs, the Laboratory is moving from the Federal Facility Compliance Act to an individual stormwater permit. As the next phase of improved stormwater monitoring program, the total daily maximum load (TDML) is being developed as part of the permit to further address sediment and contamination flux.

   Measures to control surface transport downcanyon are part of the stormwater program. A weir was constructed to contain sediments with contaminants that were released from upper parts of the Los Alamos watershed after the Cerro Grande fire. Other barriers are being considered as part of remediation required by the Consent Order. For example, permeable reactive barriers have been proposed as part of the remedy for control of high explosives in the TA-16 area. Corrective actions will be implemented as they are approved by NMED.

2011 LANL Response:

3. Since the 2007 response, a number of canyons investigation reports have been completed (LANL 2006, 094161; LANL 2009, 106939; LANL 2009, 107416; LANL 2009, 107497; LANL 2010, 111507; LANL 2011, 111811). The mass of chromium released has been estimated for Sandia Canyon, and a mass balance was calculated for all media (LANL 2009, 107453, Appendix D, section D.2). As stated previously, in Mortandad Canyon the inventory in the original source and the environmental distribution were determined for perchlorate, nitrate, and tritium (LANL 2007, 099128).

With regard to surface water and sediment monitoring programs, the Laboratory now has an individual stormwater permit (IP). The IP focuses on stormwater quality at solid waste management units and employs an iterative process for upgrading best management practices to control runoff and sediment transport.

In addition, the Laboratory has a robust site-scale stormwater monitoring program in the canyons that includes gage and sampling stations at key locations. A watershed-scale program is also in place in the Los Alamos and Pueblo watershed stations to mitigate contaminated stormwater transport. In addition to the low-head weir described in the Laboratory's 2007 response, other structures have been installed to control contaminants moving downcanyon in stormwater, including dense willow planting and wetland stabilization using grade-control structures. A pilot permeable reactive barrier has been installed as part of the remedy for control of high explosives in the TA-16 area (LANL 2010, 108534). A sediment monitoring plan describes the frequency, locations, and methods of monitoring sediment around the Laboratory.

NAS Recommendation:

4. *LANL needs to* ***better integrate geochemistry into its conceptual modeling****. Laboratory experiments and field tests, in addition to literature data, are necessary to substantiate LANL's general observations and assumptions about the geochemical behavior of contaminants.*

2007 LANL Response:

4. Geochemistry is an important aspect of conceptual modeling. Several efforts have been ongoing since completion of work under the Hydrogeologic Workplan (LANL 1998, 059599) to improve the integration of geochemistry into both conceptual and numerical models of flow and transport.

   Flow and transport modelers and geochemists at the Laboratory have specifically discussed integration, including (1) geochemical evidence that would distinguish conceptual models of contaminant transport along the top of the water table versus transport of contaminants at greater depths within the regional aquifer, (2) geochemical evidence for the Pajarito fault zone as a barrier to mountain block recharge, and (3) geochemical evidence relevant to understanding sources of recharge (both spatially and temporally).

   As work is prioritized in fiscal year (FY) 2009 and later years, the Laboratory will consider enhancements to conceptual and numerical models using geochemistry data. For example, geochemistry data that the Laboratory has collected, including carbon-14 dates, helium-tritium isotope data, oxygen and deuterium isotopes, and contaminant concentration trends, could be incorporated into the Laboratory's Regional Aquifer Flow and Transport Model to improve identification of aquifer structure, parameters to use, and boundary conditions. In addition, modeling efforts include upscaling of reactive transport parameters determined from column experiments (preexisting data and results from activities described in response to Recommendation 10) to define the reactive transport parameters. These parameters include dispersivity, matrix diffusion coefficients, sorption constants, and forward (and inverse) kinetic rate constants of the sorbed chemical species.

2011 LANL Response:

4. The Laboratory continues to incorporate geochemistry into characterization of sites and for development of conceptual models of the fate and transport of contaminants. For example, several geochemical investigations were made to obtain a quantitative assessment of site-specific processes

that affect retardation, release, and migration of chromium at the Laboratory. These investigations included collecting core from six boreholes drilled to the top of Cerros del Rio lavas (SCC-1 to SCC-6) for deionized (DI) water and U.S. Environmental Protection Agency (EPA) Method 3050 acid leach analysis of chromium and other analytes; collecting core through the Cerros del Rio lavas (SCI-2) and into underlying Puye Formation and Miocene sediments for DI and EPA Method 3050 leach analysis; analyzing potential background sources of natural chromium in groundwater; assessing the impact of wetland drying on chromium migration; and directing laboratory studies to define chromium attenuation mechanisms in site-specific lithologies. The laboratory studies included optical, X-ray diffraction (XRD), and scanning electron microscope (SEM) analysis of samples selected from core and cuttings; batch and column sorption experiments using these samples; and synchrotron X-ray absorption near-edge spectroscopy (XANES) to determine the speciation of trivalent chromium [Cr(III)] versus hexavalent chromium [Cr(VI)] on sample surfaces. The investigation results provided a substantial contribution to conceptual models of fate and transport and are discussed in detail in the Sandia Canyon investigation report (LANL 2009, 107453, Appendixes H, I, and J).

Geochemical trends in groundwater have been evaluated in all of the groundwater monitoring well network evaluations (see, for example, LANL 2007, 099128; LANL 2007, 098548; LANL 2008, 101330; LANL 2010, 109947), Temporal and spatial trends of constituents aid not only in evaluating the representativeness of data from given groundwater locations but also in evaluating groundwater age, flow, and transport.

Geochemical studies mentioned in the 2007 response, including the use of helium-tritium isotope data and carbon-14 groundwater ages, supplemented geochemical data used in the Groundwater Background Investigation Report, Revision 4 (LANL 2010, 110535), which identified zonal chemistry within the regional aquifer. This information can be used to supplement knowledge of flow pathways and to identify areas of local groundwater background.

Another example of the use of geochemistry in conceptual models is at MDA L. Here relative vapor diffusion rates were used to determine whether sporadic detections of VOCs in groundwater could have been derived from the vapor plume located in the vadose zone at MDA L (LANL 2010, 110852).

The above-mentioned examples are a few of the ways geochemistry is being used to contribute to conceptual models of flow and transport. The Laboratory may consider additional means to incorporate geochemistry into revisions of conceptual models in the future. This effort would involve planned enhancement to numerical models and the incorporation of existing data for improved calibration.

NAS Recommendation:

5. *LANL should continue to **review all operations and reduce discharges and releases to the greatest extent practical**. This includes efforts to minimize the disposal of solid wastes on mesa tops because waste disposal in those areas can pose a long-term threat to the regional groundwater.*

2007 LANL Response:

5. The Laboratory continues to review all operations to reduce liquid discharges and to minimize generation of low-level waste. The Laboratory must reduce discharges from its wastewater treatment facilities to ensure compliance with the Laboratory's National Pollutant Discharge Elimination System (NPDES) permit, to reduce potable water demand, and to provide for long-term sustainable operations. Since 1993, the Laboratory has reduced the total number of outfalls discharging to the

environment from 141 to 15. Over the same period, total liquid discharges have been reduced from 1300 to approximately 200 million gal./yr.

In 2007, the Laboratory established an institutional objective to "Achieve Zero Liquid Discharge by 2012." This objective was made to meet new permit conditions, to provide for water conservation, and to limit the flow of water available to remobilize contaminants in canyons and below the surface. The Laboratory has initiated a feasibility study to meet this objective. The study is evaluating options to reduce sources of wastewater, to reuse treated effluent, and to eliminate each of the remaining 15 outfalls. This feasibility study is a cooperative effort by the Laboratory's Environment, Safety, Health, & Quality Directorate and Environmental Programs Directorate in coordination with all outfall owners. It is scheduled to be completed by December 2007. In addition, the Laboratory has developed the Zero Liquid Discharge (ZLD) Project to eliminate the discharge of treated effluent from the TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF) into Mortandad Canyon. The ZLD project is scheduled to be designed and constructed in 2008.

The Laboratory has reduced the volume of low-level waste generated annually and will close the current low-level waste disposal site known as MDA G by the end of 2015. A new solid waste disposal area known as Zone 4 of Area G has been proposed to accommodate anticipated future work at the Laboratory. The proposed Zone 4 disposal area incorporates improvements that minimize the chance of transport to the regional aquifer. Approval of this site is under consideration by DOE.

2011 LANL Response:

5. As in 2007, the Laboratory continues to review all operations to reduce liquid discharges where feasible. The cleanup program has redirected much of its waste streams for off-site disposition.

   With respect to the ZLD initiative, progress has been made since completion of the feasibility study. An environmental assessment (EA) of the Sanitary Effluent Recycling Facility (SERF) was completed that included an assessment of the impacts of the facility on the Sandia wetland. The impacts must be mitigated to meet the requirements of the new permit by 2012. The project will reduce liquid effluent discharges to Sandia Canyon by recycling the Laboratory's sanitary wastewater for use in the cooling towers associated with the steam plant, the Strategic Computing Complex, and/or the Laboratory Data Communications Center. SERF is awaiting information on how much water is needed to maintain the Sandia wetland. A grade-control structure has been planned at the head of wetland, and negotiations are underway to determine how to reduce the discharge and meet SERF goals.

NAS Recommendation:

6. *LANL should* ***add a sitewide perspective to its future groundwater monitoring plans****. This perspective would include the following:*

   - *Design additional characterization, modeling, and geochemical investigations to better understand potential fast pathways between watersheds.*
   - *Increase the area of the regional aquifer that is monitored by sampling intercanyon areas from mesas or using directional wells from canyon bottoms.*
   - *Provide additional monitoring locations in the southern area of the site and on Pueblo de San Ildefonso lands.*

- *Develop more applications of geophysical techniques to supplement information provided by well drilling and sampling, especially for understanding vadose zone pathways.*
- *As LANL's site characterization and monitoring programs mature, well locations should be derived from a quantitative spatial analysis of monitoring well locations to identify areas with the greatest uncertainty in plume concentrations, using geostatistics or other methods, possibly coupled with flow and transport modeling.*

2007 LANL Response:

6. With respect to adding a sitewide perspective to future groundwater monitoring plans, the Laboratory response follows:

   - The Laboratory will consider additional characterization, geochemistry, and modeling where warranted by monitoring network evaluations or other assessments that indicate gaps where understanding is lacking. Fast pathways between watersheds are currently being examined in the chromium investigation, for example.
   - The NAS panel has recommended increasing the area of the regional aquifer that is monitored by sampling intercanyon areas from mesas or using directional wells from canyon bottoms. The Laboratory is reluctant to follow this recommendation for two reasons. First, the mesa intercanyon areas are much narrower than the canyon areas themselves, and the infiltration areas they contribute to the regional aquifer are small. At regional aquifer depths of hundreds to thousands of feet, the relative contribution of contaminants derived from mesa tops compared with intercanyon areas cannot be distinguished easily. Second, available information does not indicate that existing mesa monitoring locations are insufficient for monitoring contaminants in those areas.
   - The NAS panel has recommended additional monitoring locations in the southern area of the site and on Pueblo de San Ildefonso lands. With respect to the southern areas, the Laboratory has scheduled in its baseline the installation of two additional regional aquifer wells and two intermediate-depth groundwater wells in the South Canyons areas in Water and Ancho canyons. The Laboratory's water-supply wells and the site boundary are considered primary points of groundwater protection; if evaluations of monitoring network efficiency identify gaps in monitoring with respect to off-site migration, the Laboratory will include recommendations for wells in those locations, such as on San Ildefonso lands.
   - The NAS panel has recommended more applications of geophysical techniques be developed to supplement information provided by well drilling and sampling, especially for understanding vadose zone pathways. The Laboratory's environmental programs have conducted numerous geophysical investigations to assist in characterization, both sitewide and at the watershed scale, of which the panel may not be aware. These investigations are as follows, along with possibilities for extending them in the future to aid in understanding flow and transport.

     (1) Geophysical borehole field logs are available for every monitoring and characterization well. These logs were used in correlating geologic units and aided in construction of the geologic framework model for the Pajarito Plateau. The processed logs can be used to ascertain hydrologic properties of different stratigraphic units in the sitewide flow model.

     (2) A time-domain airborne electromagnetic (AEM) survey of a large part of the Pajarito Plateau was conducted to determine the depths and lateral extent of perched aquifers in

the vadose zone and the depths and pathways of infiltration to the regional aquifer (Baldridge et al. 2006, 094048). Further mining of this data set could yield additional insights.

(3) Aeromagnetic survey data collected by the Laboratory for the western Española Basin area was provided to the U.S. Geological Survey for its use in compiling a regional map showing buried geologic structures and contacts.

(4) Biehler et al. (1991, 201608) constructed a geophysical model of the Española Basin that estimated the thickness of the Santa Fe Group sediments. Ferguson et al. (1995, 056018) conducted a regional gravity study that detected a prominent, northeast-trending gravity low beneath the Pajarito Plateau. Based on these data, the gravity low detected by Ferguson et al. (1995, 056018) was interpreted as a sediment-filled graben within the western part of the Española Basin. This interpretation has been incorporated into the Laboratory's geologic framework model. Ferguson et al.'s work could be used to determine the penetration of faults at depth, and this information could then be used in flow models.

(5) A two-dimensional geophysical survey was conducted across Mortandad Canyon as part of investigations in that watershed (LANL 2006, 094161). The Laboratory may propose to extend this study to a three-dimensional survey across Mortandad Canyon to Sandia Canyon to investigate infiltration between the two canyons. The previously mentioned AEM survey results could guide the location of such a future study.

(6) GEOPHEX conducted high-resolution direct current resistivity surveys in portions of Mortandad, DP, Pueblo, Los Alamos, Sandia, Twomile, and Pajarito canyons that were presented in the Hydrogeologic Site Atlas (LANL 2006, 093196).

Future work could include a broad geophysical survey to detect the extent of perched water at TA-54 after the planned wells are drilled. This survey would be especially useful if perched water is encountered during drilling. In addition, an electrical resistivity method in the Sandia wetlands could determine whether the fault detected in that area is a conduit for flow and transport. The geologic framework model would be able to incorporate the fault at a 50-ft grid scale, and the resulting geology could then be imported into the sitewide flow and transport model.

- The NAS panel has recommended that new well locations should be derived from a quantitative spatial analysis of monitoring well locations to identify areas with the greatest uncertainty in plume concentrations using geostatistics or other methods, possibly coupled with flow and transport modeling. In fact, the Laboratory is using a comprehensive, integrated, decision-centered approach to recommend monitoring sites for current and future groundwater monitoring plans, as presented at the NAS briefing in Santa Fe in August 2006 (Echohawk et al. 2006, 201606). This approach is being implemented through monitoring network evaluations that are ongoing.

  The monitoring network design process is now directly tied to the remedy selection process using a probabilistic approach to conceptual model development and subsequent modeling. This probabilistic approach translates uncertainties in the conceptual model, including concerns about fast paths, via geostatistics into the numerical flow and transport modeling and ultimately into the remedy selection process. If there is insufficient understanding of the system to support remedy selection, the additional characterization that would be necessary (i.e., the gap) is identified by this approach. The characterization can then be performed and the conceptual and numeric modeling repeated.

The overall programmatic approach is to assess the existing Laboratory groundwater network and then add to or modify this network as remediation sites that require monitoring to support their selected remedies emerge during the CME phase. Ultimately, the result will be a long-term stewardship groundwater monitoring network that incorporates both overall monitoring and remedy performance monitoring requirements. This network will monitor for off-site migration of contaminants and impacts to regional drinking water wells.

2011 LANL Response:

6. The essence of this NAS recommendation is that the Laboratory should add a sitewide perspective to its future monitoring plans. The Laboratory has maintained a sitewide perspective over time throughout the program, while simultaneously focusing on essential smaller scale (watershed- or disposal area–specific) investigations. Bulleted specifics in the recommendation are repeated below in bold italics, followed by the updated response.

   - **Design additional characterization, modeling, and geochemical investigations to better understand potential fast pathways between watersheds.** Additional wells have been installed since 2007, especially in the areas of TA-54, TA-16, and in support of further characterization of the chromium contamination beneath Sandia and Mortandad canyons to improve our understanding of flow in the vadose zone and regional aquifer, especially the potential for fast pathways. The chromium investigation (LANL 2009, 107453) paid particular attention to fast pathways and potential lateral pathways.
   - **Increase the area of the regional aquifer that is monitored by sampling inter-canyon areas from mesas or using directional wells from canyon bottoms.** Since 2007, the chromium investigation (LANL 2009, 107453) and the Los Alamos and Pueblo canyons network assessment (LANL 2008, 101330) predicted potential lateral flow between canyon areas. Recent mesa-top wells that investigate intercanyon flow of perched and/or regional groundwater in areas were installed at TA-54 (R-37, R-41, R-52, R-56, and R-57); TA-16 (CdV-16-4ip, R-47i, R-63); TA-50 (R-60); and the chromium investigation area near Sandia and Mortandad canyons (TA-53i and R-50). Additional mesa-top wells are currently being installed at TA-21 (R-64 and R-65) and in the chromium investigation area (R-61, R-62, and SCI-4). Data substantiate the conceptual model that intercanyon lateral flow does occur.
   - **Provide additional monitoring locations in the southern area of the site and on Pueblo de San Ildefonso lands.** With respect to the southern areas, the Laboratory has installed the two scheduled additional regional aquifer wells referred to in the 2007 response (R-29 and R-30), a regional aquifer monitoring well at TA-16 (R-63), and two intermediate-depth groundwater wells (CdV-37-1i and R-27i) in the in Water and Ancho canyons. In addition, a perched-intermediate well (CdV-16-4ip) was installed at TA-16 to assess the feasibility of the pump-and-treat alternative during the remedy selection process in the revised CME for Consolidated Unit 16-021(c)-99; this well will be used to monitor perched groundwater at TA-16 after hydraulic testing is completed. Several regional monitoring wells have been added since 2007 near the Laboratory's border with San Ildefonso in Mortandad Canyon (R-36, R-44, R-45, R-50) and in Cañada del Buey (R-37, R-38, R-52, R-53, R-55, R-55i). Also, a well to monitor perched-intermediate groundwater (R-10i) will be installed on Pueblo de San Ildefonso land before December 2011. The Laboratory will also perform a network evaluation for TA-16 and Upper Water Canyon and will submit the report to NMED

by December 2011. If evaluations of monitoring network efficiency identify gaps in monitoring with respect to off-site migration, the Laboratory will include recommendations for wells in those locations, including San Ildefonso land.

- **Develop more applications of geophysical techniques to supplement information provided by well drilling and sampling, especially for understanding vadose zone pathways.** Electrical resistance tomography is planned for the Sandia Canyon wetland in the summer of 2011 to determine areas of saturation and potential infiltration zones in the vadose zone.
- **As LANL's site characterization and monitoring programs mature, well locations should be derived from a quantitative spatial analysis of monitoring well locations to identify areas with the greatest uncertainty in plume concentrations, using geostatistics or other methods, possibly coupled with flow and transport modeling.** Locations for wells have been determined through watershed network assessments that have been approved by NMED. The approach in these assessments is a quantitative one that uses changes in water levels and hydraulic head responses to determine flow directions in the regional aquifer, coupled with geostatistics and numerical modeling. Uncertainty analysis is built into this approach. The numerical models use probability analysis to calculate the monitoring efficiency of the network (i.e., 95% confidence of the monitoring network not missing a plume).

As the monitoring program evolves, the Laboratory will continue to maintain both a sitewide perspective and perspectives at smaller scales that address the particular issues of interest at a specific area to complete corrective measures. The monitoring program is reassessed annually with these scales in mind during updates to the Interim Facility-Wide Groundwater Monitoring Plan (IFGMP).

NAS Recommendation:

7. *LANL should increase its efforts to develop and use quantitative methods to describe contaminant pathways through the vadose zone and into the regional aquifer, as follows:*

    - *Mathematical models that incorporate the uncertainties from alternative conceptual models should underpin plans for design and operation of the sitewide monitoring system. Characterization of the vadose zone begun under the Hydrogeologic Workplan should continue with emphasis on new results from characterization and monitoring being used to test and improve the mathematical models.*
    - *To support an evaluation of the effectiveness of the monitoring system to provide early warning of potential impacts on the regional aquifer, LANL should quantify, to the extent possible, the inventory and current location of the contaminants disposed of in the major waste sites.*

2007 LANL Response:

7. A quantitative understanding of contaminant pathways between the vadose zone and the regional aquifer is important. One of the recently initiated activities at MDA G involves using tritium data collected from two intermediate (vadose zone) wells to construct a three-dimensional numerical representation of the existing vapor-phase plume. The next step will be to project the model to the aqueous phase and extend it to well R-22 to predict transport from the vadose zone to the regional aquifer at this downgradient well.

The mathematical models employed in the area assessments incorporate uncertainties from alternative conceptual models. As area assessments are conducted, the Laboratory will continue to evolve its conceptual models of wet versus dry settings with the idea that wet canyons and wet mesas should have similar infiltration characteristics and that these would differ from dry canyons and dry mesas. As with the work initiated at MDA G, the other area assessments will evaluate the transport of vapor-phase constituents and both mobile and sorbing constituents in the aqueous phase. A starting point for the area assessments necessitates knowing the inventory and current location of the contaminants disposed of in the major waste sites. The results of modeling through the various area assessments can then be joined conceptually at a larger scale to design an overall monitoring system. Outcomes of the area assessments may require new characterization and/or monitoring wells. Data collected from the new locations can then be incorporated into updated models. The integration of knowledge from the different area assessments will provide greater confidence in the overall monitoring network. (Currently, a sitewide three-dimensional model that captures the vadose zone and the regional aquifer is restricted by grid size and the time needed for computation.)

As the area assessments are conducted, the assumptions, conceptualizations, input parameters, data (including inventories and location of disposed contaminants), modeling processes, and other information will be formally documented through a modeling procedure (in draft). In addition, the Laboratory expects to publish the results of the modeling in peer-reviewed literature.

2011 LANL Response:

7. The Laboratory continues to develop and use quantitative methods to describe contaminant pathways through the vadose zone and into the regional aquifer. Numerous examples of quantification of vadose zone transport are provided in watershed network assessments and in the implementation of approved canyons work plans. A few examples follow.

    - Flow and transport calculations were updated for the MDA G performance assessment; the calculations considered uncertainty in parameters such as infiltration rates, release locations, and radionuclide adsorption coefficients (French et al. 2008, 106890). More recently a model of transient infiltration from pits was constructed using moisture data from the site to test assumptions made in the site-scale flow and transport simulations. At MDA G, the Laboratory also modeled the response to a subsurface vapor extraction test (LANL 2010, 109657). This model may be used to support design of proposed vapor extraction systems at MDAs L and G.
    - Currently a vadose zone model of radionuclide transport at MDA T is being calibrated to data from that area.
    - A model of vapor transport with comparisons to VOC data was developed for MDA L (LANL 2010, 110852).
    - A three-dimensional model of chromium migration in the vadose zone (mentioned in the 2007 response) now supports the concept of lateral flow in the vadose zone from Sandia Canyon toward Mortandad Canyon. In addition, the model was calibrated to estimate infiltration rates along the floor of Sandia Canyon.

    These are just a few examples of how vadose zone data are being used to quantify models and to understand, in some cases, connections between the vadose zone and the regional aquifer. Vadose zone models will continue to evolve through calibration to additional site data and be used to inform decisions related to corrective measures.

Recent advances in the field of computational hardware (with faster and larger multi-processor clusters) and software (with advanced high-performance computational methods—for example, those developed under the Advanced Simulation Capability for Environmental Management project [ASCEM] http://ascemdoe.org) will allow for development of a sitewide three-dimensional physical process model in the coming years that represents both the vadose zone and the regional aquifer.

The second part of this recommendation, regarding identifying the location and inventory of contaminants at major disposal sites, is addressed in the response to Recommendation 1.

NAS Recommendation:

8. *LANL should **confirm the integrity** (lack of surface disturbances or conditions leading to increased infiltration) **of the major disposal sites** in the dry canyons and mesas.*

   *LANL should **schedule regular subsurface surveillance beneath disposed wastes** on dry mesas and in dry canyons.*

2007 LANL Response:

8. The Laboratory conducts monthly surveillances at all nuclear environmental sites to confirm their integrity. MDAs have regularly scheduled surveillances as well. If the integrity of any site is at risk of being compromised such that its disturbance could create fast transport pathways, steps are taken to restore its integrity. Some examples are repairs to drainage, restoration of damage done by prairie dogs, and removal of storm-driven debris.

   The subsurface disposal sites are in trenches excavated in volcanic tuff and not in unconsolidated materials. Therefore, surveillance is of a different nature than in the surface disposal sites. Subsurface surveillance beneath disposed wastes has been, and continues to be, through pore-gas sampling and long-term vadose zone monitoring.

2011 LANL Response:

8. The 2007 response still applies in full. Subsurface surveillance beneath disposed wastes continues to be through pore-gas monitoring in the vadose zone. At MDA T, the monitoring network assessment recommended vadose zone moisture monitoring in addition to monitoring the regional aquifer. A work plan is being written for this additional monitoring. The results of tritium and VOC monitoring beneath waste disposal sites are reported in periodic monitoring reports (PMRs) of pore-gas sampling.

NAS Recommendation:

9. *LANL should **continue efforts begun under the Hydrogeologic Workplan to characterize the regional aquifer.** More large-scale pumping tests and improved analyses of the drawdown data are needed to establish a scientifically defensible conceptual model of the aquifer, i.e., leaky-confined, unconfined, or layered.*

2007 LANL Response:

9. The Laboratory plans to continue efforts to characterize the regional aquifer. Typically, hydraulic properties of the regional aquifer are estimated using specially designed field (pumping) tests. A series of single-hole and cross-hole pumping tests have been conducted at water-supply and

monitoring wells near the Laboratory that provided important information about the properties of the regional aquifer (McLin 2005, 090073; McLin 2006, 092218). However, instead of conducting additional tests, the Laboratory has proposed using the long-term data collected during naturally occurring variability in the water-supply pumping and the respective responses at the various observation points. The analyses of these data will produce a cost-effective and time-efficient estimate of the regional aquifer properties and will encompass responses over a wider area. An additional advantage of this approach compared with pumping tests is that the longer temporal record in water-level data reduces uncertainty and potential ambiguity in the observed drawdown at the monitoring wells from pumping. In addition, the heavier stresses placed on the aquifer during regular water-supply pumping produce cones of depression that are larger than those produced during pumping tests. The pumping regime can also be adjusted through communication with Los Alamos County authorities managing the water-supply wells to enhance the collected data; for example, different wells can be selected to be the major water producers during different stress periods. The objective is to perform a simultaneous interpretation using an inverse numerical model of the long-term record of the water-supply pumping and water-level data to obtain a large hydraulic tomography of the regional aquifer properties. A similar type of analysis has been successfully performed and published by Vesselinov et al. (2002, 201607). Currently, most of the boreholes and wells near the Laboratory are equipped with pressure transducers yielding data that can be used for this purpose. Preliminary analyses demonstrate the high-information content of the collected data; water-supply pumping responses are observed at most of the monitoring wells. The results of this study will yield a refined, more complete set of regional aquifer properties. This work will be considered the prioritization of work plans for FY2009.

2011 LANL Response:

9. The Laboratory has continued to increase its understanding of hydrologic properties of the regional aquifer and flowpaths within the aquifer. New regional aquifer wells installed since 2007 provide much of this additional information, including regional water-level elevations, hydrostratigraphy, and hydraulic properties. These data are applied to better understand the structure of groundwater flow in the aquifer. In addition, a number of pumping tests were conducted: one was conducted in 2009 to investigate communication in the regional aquifer between Test Well (TW) 8 and well R-1; a single-well pumping test was conducted at R-28 (described in LANL 2009, 107453); and two large-scale, 10-d pumping tests in the intermediate zone at well CdV-16-4ip are currently underway to understand the hydrologic properties of the deep perched-intermediate zone and the potential for using pump-and-treat methods as a corrective measure in this part of TA-16 (LANL 2010, 108534). In addition, cross-well drawdown responses have been observed during well development at wells R-44, R-45, R-50, R-57, and R-63.

   The tomography approach described in 2007 continues to be used to obtain a large hydraulic tomography of the regional aquifer properties. In this approach, the long-term data collected during naturally occurring variability in the water-supply pumping and the respective responses at various observation points are used to perform a simultaneous interpretation with an inverse numerical model. This approach has been used for the chromium area (LANL 2008, 102996); at TA-54 (LANL 2007, 098548); and at TA-21 (LANL 2010, 109947). Potential expansion of this methodology to other portions of the Laboratory may be considered; annual updates to the General Facility Information report (e.g., LANL 2010, 109084, Appendix C) provide an integrated interpretation of flow in the regional aquifer based on this methodology.

NAS Recommendation:

10. *LANL should* ***increase its attention to geochemistry within the context of its site characterization*** *work. LANL scientists should conduct more field and laboratory studies to measure basic geochemical parameters such as sorption coefficients with the goal of testing and verifying their conceptualizations of subsurface hydrogeochemical processes.*

2007 LANL Response:

10. Geochemistry is an important aspect of site characterization, which is linked closely to conceptual models of flow and transport (see response to Recommendation 4). Geochemistry has been an integral aspect of all well reports (e.g., Longmire 2005, 088510, among many other reports by Longmire et al.). Geochemistry has also been integral in the interpretation of results of the aquifer test at R-28. In addition, isotope geochemistry has provided important insights into flow pathways and the ages of groundwaters (Longmire et al. 2007, 096660).

    As mentioned in the response to recommendation 5, planned modeling efforts will include upscaling of reactive transport parameters determined from column experiments (preexisting data and results from activities described below) to define the reactive transport parameters, including dispersivity, the matrix diffusion coefficient, sorption constant and forward (and inverse) kinetic rate constant of the sorbed chemical species.

    Batch sorption experiments were conducted for americium, neptunium, plutonium, technetium, and uranium transport through the Bandelier Tuff at Los Alamos (Longmire et al. 1996, 056030) to generate input to the draft performance assessment for MDA G. Traditionally, however, the Laboratory has used sorption coefficients from analog sites (e.g., Yucca Mountain tuffs) in most of its modeling efforts. In addition to expanding the analog literature base from other DOE sites, a limited suite of sorption experiments for key contaminants and aquifer materials is planned to verify the applicability of these analog sites. The need for additional geochemistry studies will also be evaluated. For example, if monitoring data suggest that actinides have been transported farther than expected based on modeling studies, the Laboratory will consider experiments designed to examine colloid-facilitated transport of actinides. These experiments would supplement the limited number of experimental and modeling studies conducted to date related to colloid transport of contaminants at the site.

    The program has plans to continue a proof-of-concept activity to determine the applicability of isotopic measurements of contaminants to distinguish amongst background and anthropogenic sources of contaminants (including non-Laboratory anthropogenic sources) and to identify signatures of monitored natural attenuation processes. This information can be used to validate the Laboratory's assumptions about contaminant sources and behavior. Preliminary isotopic studies of perchlorate and chromium contamination have already begun.

    The findings from integrated modeling studies and from laboratory studies will be examined to assess the need for field-scale geochemistry tests.

2011 LANL Response:

10. Geochemistry continues to be a key line of evidence for understanding groundwater conditions along with potential flow and transport pathways at a site. For example, geochemistry continues to be an integral component of all well completion reports, well rehabilitation reports, groundwater background chemistry analyses, watershed network assessments, and assessments of reliability of groundwater

data. Furthermore, in the chromium studies, geochemistry was a contributing factor to understanding the potential for hexavalent chromium [Cr(VI)] to be attenuated in the vadose zone and the regional aquifer. This was accomplished through material characterization and chemical analysis, conventional batch tests and column experiments, and XANES spectroscopy. Chromium isotopes provided an additional line of evidence for reduction of [Cr(VI)] to [Cr(III)] in the subsurface (LANL 2009, 107453).

In addition, isotope geochemistry has provided important insights into flow pathways and the ages of groundwaters (Longmire et al. 2007, 096660). The program has collected preliminary isotopic data for perchlorate, chromium, sulfate, and boron, along with tritium data. This information can contribute to the understanding of contaminant sources and behavior.

The planned sorption experiments to verify the applicability of analog data for key contaminants and aquifer materials have not been conducted but will be revisited if necessary.

NAS Recommendation:

11. *LANL should* ***demonstrate better use of its current understanding of contaminant transport pathways in the design of its groundwater monitoring program****. Tables in the monitoring plan that give the rationale for locating monitoring wells should at least provide a general linkage between the proposed locations and the site's hydrology, or a section discussing the relation between well locations and pathway conceptualizations should be added.*

    LANL should take a sitewide approach to monitoring the intermediate and regional aquifers. Furthermore, the interim plan should summarize (e.g., in Section 1.6) the ways in which the information from related studies will be used for updating the plan. The current description of the conceptual models (in Appendix A of the plan) is useful, but it should be improved. First and foremost would be a description of potential pathways, both surface and subsurface, that connect the sources (listed in Appendix A) with the groundwater that is being monitored.

    LANL should examine the potential for approaches that both optimize the monitoring network and incorporate uncertainty into its design (Minsker, 2000; EPA, 2006).

2007 LANL Response:

11. The Laboratory will apply its understanding of contaminant transport pathways in designing its monitoring network. Ongoing canyons reports and network evaluations being done under NMED's direction will optimize monitoring locations; these reports will discuss the site's hydrology and the link between proposed monitoring locations and pathway conceptualizations. The canyons reports and network evaluations will then be referenced in the 2008 IFGMP. Data from the 2007 PMRs will also help to update the analytical suites and frequencies collected at each monitoring location.

    The Laboratory takes a sitewide approach to monitoring. The Consent Order drives monitoring on a watershed basis, but the sitewide approach is used for deeper zones in the intermediate and regional aquifers because the regional aquifer underlies the entire site and intermediate zones are not restricted to a single watershed. The sitewide perspective is incorporated in monitoring network evaluations by including objectives to protect drinking-water supplies and detect off-site transport.

    The conceptual model in the IFGMP (Appendix A of that plan) will be updated using information from the 2007 PMRs. As additional monitoring events are conducted and data provide insights into surface and subsurface pathways that connect contaminant sources to monitoring locations, this information will be captured in the PMRs and then used to update the IFGMP.

The Laboratory has examined the potential for approaches that optimize the monitoring network (see response to Recommendation 6); the ensuing network evaluations or area assessments incorporate uncertainty through a probabilistic modeling approach to ensure the monitoring network achieves its protection objectives at a 95% confidence level.

2011 LANL Response:

11. With the evolution of the groundwater monitoring program since 2007, the Laboratory has been applying its understanding of contaminant transport pathways in designing the monitoring network. The canyons reports and network evaluations for each major watershed (many of them listed in the references to this attachment) have optimized monitoring locations agreed upon by NMED; these reports discuss the site's hydrology and the link between proposed monitoring locations and pathway conceptualizations. The canyons reports and network evaluations are referenced in IFGMPs and are used to plan monitoring suites and frequencies for the coming monitoring year. Data from PMRs are also used to select the analytical suites and frequencies collected at each monitoring location. Tables 1.11-1 and 2.4-1 through 8.4-1 of the IFGMP provide the rationale for selection of locations for wells included in the plan.

    Until 2011, the Consent Order has driven groundwater monitoring on a watershed basis. Beginning in 2011, monitoring groups will be more aligned with areas of interest defined by extent of contamination or specific MDAs. The sitewide perspective has further been included in monitoring network evaluations by including objectives to protect drinking water supplies and to detect off-site transport.

    Conceptual models of various project areas are evaluated in the annually updated IFGMP to support the proposed monitoring. Since 2007 the PMRs have been issued quarterly or semiannually (depending on schedule) such that data from as many as 16 sampling rounds have been collected from many of the watersheds. Numerous additional wells also have been drilled in the past 4 yr, and water-quality data from the newer wells contribute substantially to the understanding of potential subsurface contaminant pathways. As additional monitoring events are conducted and data provide insights into surface and subsurface pathways that connect contaminant sources to monitoring locations, this information will be captured in the PMRs and then used to update the IFGMP.

    As a final point, the Laboratory has examined the potential for approaches that optimize the monitoring network. The overall programmatic approach is to assess the existing Laboratory groundwater-monitoring network and then add to or modify this network as remediation sites emerge from the CME phase and require more focused performance monitoring to support their selected remedies. The monitoring network design process is linked to the remedy selection process by a probabilistic approach to conceptual model development and subsequent modeling. This probabilistic approach translates uncertainties in the conceptual model via geostatistics into the numerical flow and transport modeling and ultimately into the remedy selection process. If our understanding of the system is not sufficient to support remedy selection, the additional characterization that would be necessary (i.e., the gap) is identified by this approach. The characterization can then be performed and the conceptual and numeric modeling repeated.

NAS Recommendation:

12. *LANL should plan and carry out* ***geochemical research to ascertain the interactive behavior of contaminants, materials introduced in drilling and well completion, and the geologic media****. As a part of LANL's future plans for sitewide monitoring, this work would include:*

    - *Determining the nature of interactions among materials proposed for use in constructing monitoring wells and the types of geological media that LANL intends to monitor,*
    - *Quantitative measurement of sorption of contaminants onto the natural, added, and possibly altered constituents that constitute the sampling environment of a monitoring well, and*
    - *Publication of results in peer-reviewed literature.*

2007 LANL Response:

12. The Laboratory has planned bench-scale experiments that will examine the nature of interactions among materials used in the past for drilling and constructing monitoring wells, contaminants, and the geologic media. The experiments will use core and cuttings from previously constructed wells and the knowledge gained from sorption measurements on tuff materials (see response to Recommendation 10). The Laboratory is also exploring the possibility of conducting a nondestructive field experiment at a well screen that is impacted by drilling fluids. Rock samples would be collected from various distances, extending laterally away from the well bore into nonimpacted aquifer material. The samples would be analyzed to identify secondary minerals, the extent and degree of drilling fluid impacts, and the sorption of materials onto both primary and secondary minerals.

    The results of the planned experiments will enhance the Laboratory's understanding of drilling fluid impacts, as described in the Well Screen Analysis Report, Revision 2 (LANL 2007, 096330). The natural site groundwater chemistry, aquifer-groundwater interactions, and interactions with drilling fluids will be synthesized in a report that will be submitted to a peer-reviewed journal.

2011 LANL Response:

12. The Laboratory recognizes the importance of understanding the chemical interactions of constituents in groundwater with geologic materials and with materials placed downhole. Some tests described in the 2007 response have been conducted. In place of other tests, the Laboratory has focused on a number of specific geochemical issues. The Laboratory is currently testing materials placed downhole during drilling or sampling to gain a better understanding of the cause of spurious detections of organic chemicals in some monitoring wells; the results of this analysis will be available at the end of FY2011. The Laboratory will continue to develop plans and testing programs to answer specific geochemical questions as the program evolves.

NAS Recommendation:

13. *LANL should plan and* ***conduct future characterization drilling and monitoring well drilling as separate tasks****. For monitoring locations where characterization data are unavailable, LANL should consider drilling simple test holes to obtain this data before attempting to drill the monitoring well(s).*

2007 LANL Response:

13. It should first be noted that the Laboratory's overall site characterization program, the Hydrogeologic Workplan (LANL 1998, 059599), has been completed and documented in a hydrogeologic synthesis report (Collins et al. 2005, 092028). Objectives for wells drilled during the Hydrogeologic Workplan included their use for both characterization and monitoring purposes. Since completion of the Hydrogeologic Workplan, the Laboratory has assessed the existing Laboratory groundwater monitoring network by area and has added to or modified this network as remediation sites with monitoring requirements are identified from the CME phase of an investigation. During the CME phase, additional specific characterization may be required. In this case, the Laboratory will first drill test holes to obtain data before a monitoring well is drilled. The precedent for this step-wise approach was established during first phase of the chromium investigation, in which several test boreholes were drilled before the locations of monitoring wells R-35a and R-35b were selected.

2011 LANL Response:

13. The Laboratory continues to separate characterization activities from monitoring when wells are drilled. As stated in the 2007 response, characterization boreholes were emplaced as a separate activity before drilling monitoring wells at R-35a and R-35b. A more recent example was reported in the Sandia Canyon investigation report (LANL 2009, 107453). Five core holes were drilled in 2002 to characterize the geotechnical properties of alluvium and tuff units beneath the middle part of Sandia Canyon, and six core holes were drilled in lower Sandia Canyon in 2006 to collect core from surface to the top of the Cerros del Rio lavas to determine the nature and extent of chromium in the upper vadose zone and to collect data to calculate chromium inventories. Later, the SCI-1 well was installed in the core hole SCC-1 after perched intermediate water was detected in the Puye Formation above Cerros del Rio basalt. The SCI-2 core hole was drilled to collect core samples to investigate the stratigraphy and geochemistry of hydrostratigraphic units beneath Sandia Canyon. Later, two wells were installed at the site: an intermediate well in the core hole (SCI-2) and a regional aquifer monitoring well (R-43). This and other similar examples demonstrate that characterization activities in wells are frequently carried out separately and before monitoring wells are drilled.

NAS Recommendation:

14. *LANL should **design and install new monitoring wells with the following attributes**:*

    - *A borehole drilled through the monitoring zone without the introduction of drilling muds or additives (i.e., use air or water),*
    - *One screened interval that targets a single saturated zone, and*
    - *A carefully planned design (length and depth of the well screen), which is confirmed with information collected in the drilling process.*

2007 LANL Response:

14. The Laboratory implemented this recommendation with the installation of well R-35 (LANL 2007, 098129).

    Because of ongoing concerns raised both internally and by stakeholders regarding the use of additives during drilling, the Laboratory will continue to attempt to advance boreholes through target monitoring intervals using only water and air. The first wells (R-35a and R-35b) attempted with this method were advanced using a combination of casing advance and open-hole drilling with foam/air-rotary to approximately 100 ft above the regional aquifer (the target monitoring interval). From 100 ft above the regional aquifer to total depths up to 350 ft into the regional aquifer, use of drilling additives (foam) was suspended, and drill casing was advanced with air-rotary using minimal amounts of municipal water to cool the drill bit as needed.

As indicated above, well R-35 consisted of a pair of boreholes (R-35a and R-35b) targeting different intervals within the regional aquifer. To reduce the potential for cross-communication between the zones of interest at each well and to ease the well development (well screen and filter pack cleaning), the Laboratory decided to drill two separate boreholes rather than complete a single well with two isolated screen intervals. The added effort and expense this decision entailed appear to have been worthwhile. The wells are providing distinguishably different chemical signatures, they respond to nearby municipal well pumping differently and show low turbidity and stable field parameters.

Decisions on both screen length and placement within the aquifer were based on careful review of data collected during drilling, including observations of groundwater production rate, open borehole groundwater chemistry, drill cuttings, and borehole geophysics. It should be noted that the usefulness of the geophysical logging suite was reduced by the presence of drill casing in the borehole. Specifically, a combinable magnetic resonance log, which provides valuable information on aquifer pore size and amount of "movable water," cannot be run through steel casing. The processes used in the successful design and installation of R-35a and R-35b will serve as a prototype for installing future wells.

2011 LANL Response:

14. As indicated in the 2007 response, wells R-35a and R-35b set a precedent for drilling without fluids other than air and potable water in the targeted zone. All subsequent monitoring wells were drilled using methods similar to those used at R-35a and R-35b that limit the use of fluids during drilling and well construction so they will not affect the water quality of the screened zones. The Laboratory continues to collect data that supports well design including screen length and placement; these data are summarized in a well design document that is submitted to NMED for approval before the well is constructed. Where appropriate, wells are drilled that target a single screened interval. Since 2007, 40 wells have been drilled that successfully demonstrate the ability to drill using minimal amounts of fluid and to reduce or eliminate their use within the targeted zone. Of these, 12 are perched intermediate wells, 13 are single-screen regional wells, and 15 are dual-screen regional wells. The dual-screen wells are completed using a purgeable Baski sampling system that allows for purging.

NAS Recommendation:

15. *LANL should* ***ensure that there is consistency and clarity of all related sampling and analytical procedures with documented follow-through and appropriate action****. This especially relates to:*

- *Having clear data quality objectives;*
- *Documenting how samples are to be collected;*
- *Documenting how data are handled, statistically compiled, and reported;*
- *Clear documentation of the quality of the data; and*
- *Identification of all suspect data.*

2007 LANL Response:

15. The Laboratory strives for continuous improvement in providing consistency and clarity in the quality assurance (QA) associated with the groundwater monitoring program. The Quality Assurance Project Plan (QAPP) for the Groundwater and Persistent Surface Water Monitoring Project follows a flow-down of requirements in the Consent Order for defining data-quality objectives. The QAPP requires data-quality objectives to be clearly stated in work plans approved by NMED. Similarly, the QAPP requires that documentation of sample collection methods is contained in sampling procedures and described in work plans.

    Several procedures address analytical laboratory measurements, handling of electronic and paper analytical records and field measurement records, secondary validation of analytical data, and management of electronic data. Compilation of data occurs partly in the reporting and data assessment processes; the latter is covered in QAPP and the Consent Order. Data-reporting requirements are covered in the QAPP; DOE Orders 231.1, 450.1, and 5400.5; the Consent Order; and work plans.

    Data quality is documented through analytical laboratory contracts that specify standards and certifications laboratories must meet and procedures they must follow. Verification that procedures are being followed is accomplished through audits and performance assessments of the analytical laboratories and through documentation and validation of the analytical results.

    Some data are determined as suspect on the basis of analytical laboratory or independent secondary validation evaluation. This identification occurs and is documented along with data results according to contracts and procedures. Other data are identified by the data user as suspect based on comparison with other analytical results or review of records. Where this comparison identifies analytical issues, they are documented in the water-quality database, along with data results, according to analytical laboratory contracts and procedures and through secondary validation. Where suspect data are identified through the user but the potential problem cannot be documented as resulting from field collection or analytical errors, the data issues are documented in written reports.

    One special category of suspect data involves data that are unreliable because of drilling fluid impacts. These data have been evaluated by the methodology described in the Well Screen Analysis Report, Revision 2 (LANL 2007, 096330), and the affected analytes will be documented in the Water Quality Database (WQDB).

2011 LANL Response:

15. The Laboratory presents clearly defined data-quality objectives for the groundwater monitoring program in the IFGMP, which is updated and submitted to NMED annually. Monitoring objectives are updated each year in the IFGMP; the objectives evolve as the monitoring program evolves and identifies monitoring needs of area-specific monitoring groups, as defined in the 2010 IFGMP (LANL 2010, 109830).

    The Laboratory has well-defined procedures documenting how samples are to be collected from monitoring wells, base-flow stations, and springs. Procedures also cover other relevant activities such as water-level monitoring, creating and maintaining chains of custody for sampling, field quality control (QC) samples, and sample containers and preservation. The procedures related to groundwater monitoring are updated regularly to ensure their consistency with updated regulatory guidance. The Laboratory is in the process of updating the other related procedures and plans to continue procedural updates on a minimum 3- to 5-yr frequency.

After samples are analyzed, the data are second-party validated, and the resulting qualifiers are carried with the data into the WQDB. This process has not changed since 2000. Some types of suspect data are captured through this process but to address the issue of water quality data suspected of being nonrepresentative as a result of the presence of drilling fluids near the screen, all groundwater quality data from 2000 to 2008 underwent a tertiary validation, at DOE's direction, in 2008. The results of this analysis are found in a WQDB lookup table. The perspectives on data reliability evolve as conditions around the well screen change, and updated perspectives are provided in appropriate decision documents. Audits and surveillances are conducted periodically and issues, when identified, are corrected through official processes.

NAS Recommendation:

16. *LANL should* ***ensure that measurements at or near background levels or near analytical detection limits (i.e., MDLs and PQLs levels) are scientifically and statistically sound and are reported appropriately****. The LANL site office of DOE should take steps to ensure that LANL and site regulators agree on how all such data are to be handled, compiled, and reported. LANL should make more effort to ensure that data uncertainties are made clear to public stakeholders.*

2007 LANL Response:

16. The Laboratory, DOE, and NMED are in mutual agreement on how groundwater data are handled and reported. The Laboratory's analytical measurements are obtained by methods that are scientifically and statistically sound, and the data are reported appropriately. Analytical laboratory measurements are obtained according to the National Nuclear Security Administration Service Center's Analytical Management Program's Model Statement of Work and QA requirements specified in DOE orders. Analytical results are reported by the Laboratory according to requirements specified in DOE orders. Analyses are conducted using analytical methods approved in work plans by the NMED.

    Environmental monitoring data are handled, compiled, and reported according to requirements in DOE orders, the Consent Order, and NMED-approved work plans. Where available (that is, for data collected since 2000), analytical laboratory qualifiers and qualifiers resulting from secondary validation are provided with the analytical data.

2011 LANL Response:

16. The 2007 response is still applicable. In short, analytical results are reported by the Laboratory according to requirements specified in DOE orders and per the Consent Order. Analyses are conducted using analytical methods approved in work plans by the NMED, and analytical laboratory qualifiers and qualifiers resulting from secondary validation are provided with the analytical data.

NAS Recommendation:

17. *LANL* ***should continue to track regional groundwater monitoring wells and water supply wells routinely to improve the statistical basis for reporting any increases above background****.*

    LANL's Quality Assurance Program Plan should enforce the documentation of any and all instances where it is believed that chemicals or radionuclides detected in groundwater are not the result of LANL operations, e.g., naturally occurring or anthropogenic contaminants or the result of sampling artifacts.

2007 LANL Response:

17. The Laboratory presently monitors the quality of regional groundwater in seven watersheds either quarterly or semiannually in accordance with the NMED-approved 2007 IFGMP (LANL 2007, 096665) and the Consent Order. Monitoring includes sample collection at surface base-flow stations, regional wells, natural springs, Los Alamos County, and City of Santa Fe water-supply wells. The data collected are reviewed weekly and are reported in scheduled PMRs. It is in part because of monitoring data collected in 2006 that the number of background locations and the statistical basis for reporting background exceedances, known as the upper tolerance limit, were enhanced in the 2007 Groundwater Background Investigation Report, Revision 3 (LANL 2007, 095817). The Laboratory plans to screen all analytical monitoring data to accepted background values.

    The Laboratory's groundwater data assessment team routinely compares analytical data results with QA/QC samples such as field blanks, trip blanks, duplicate samples, laboratory blanks, and other QC samples. Analytical results from primary monitoring samples are typically scrutinized alongside analytical laboratory QA/QC sample results to determine if false positives may be present because of improper handling of samples in the field, contamination during sample transport, or cross-contamination in the analytical laboratory.

    Documentation of occurrence of chemicals or radionuclides in groundwater that are not the result of Laboratory operations (naturally occurring or anthropogenic contaminants or the result of sampling artifacts) takes place in the annual report Environmental Surveillance at Los Alamos, in investigation reports, and other corrective actions reports.

2011 LANL Response:

17. The Laboratory continues to evaluate groundwater quality data through weekly data assessments and reports monthly to NMED those constituents that meet Consent Order reporting criteria (e.g., constituents for the first time above a standard) in accordance with the revised Consent Order of 2008. Groundwater quality data are also reported in PMRs, the annual update of General Facility Information, the annual update of the IFGMP, the annual Environmental Surveillance Report, CME reports, and special studies such as the ongoing evaluation of spurious detections of organic constituents in some wells. In addition, the Laboratory updated the Groundwater Background Investigation Report to Revision 4 in 2010 (LANL 2010, 110535). The revised report improved the statistical basis of constituent background concentrations by adding locations, including data from additional sampling rounds, and using a statistical approach recommended by the EPA. Collectively, enhancements made in the revision improved confidence in the statistical basis for reporting any increases above background.

SUMMARY

In summary, the NAS review was a constructive assessment that provided important feedback on the groundwater monitoring program's progress and future direction at a crucial turning point. The program continues to evolve as cleanup and assessment responsibilities are implemented. As the program evolves, focused characterization takes place at specific areas to obtain a better understanding of contaminant fate and transport. Numerical modeling, statistical tools, and geochemistry continue to be applied to data assessments for confidence-building in conceptual models of flow and transport.

At a glance, Table 1 compares the Laboratory's responses in 2007 and in 2011 with the NAS panel's recommendations. The NAS made 17 recommendations; of these, the 2007 responses to 13 of the recommendations described work that had been completed or described approaches to ongoing work, and 4 responses described work that was planned in the baseline as of 2007 and would be conducted, contingent upon funding. A number of responses also described work that may be proposed if warranted by new information. In 2011, only one response from 2007 remained the same and was not updated. For all other recommendations, work was either ongoing (in some cases, completed for one MDA but ongoing in another) or the focus had changed (for example, some of the proposed geochemistry work has been substituted by other geochemistry aimed at specific issues).

Substantial progress has been made since 2007 in confirming sources of contaminants at major disposal areas, determining their inventories, and taking steps to eliminate them as a normal part of the life cycle of a cleanup program. The additional new wells that have been installed in accordance with the NAS-recommended drilling methods and approved by NMED continue to improve the data set of groundwater background and representative groundwater quality, while further refining our understanding of fate and transport mechanisms and pathways, and hence cleanup needs. Ongoing QA proves to ensure the defensibility of groundwater data used in cleanup decisions. The Laboratory intends to continue evaluating and incorporating the NAS recommendations over the life cycle of its environmental cleanup program.

Table 1
Responses to National Academy of Sciences Recommendations

Rec. #	Summary	Status in 2007	Status in 2011
1	Complete the characterization of major disposal sites	Currently, these activities are included in the life-cycle baseline.	Inventories have been completed for Sandia Canyon and revised for MDA G; updated inventory calculations are in progress for MDA T; characterization is ongoing for major disposal sites.
2	Develop mass balance estimates	Estimates have been completed for some areas and are built into the life-cycle baseline where feasible.	Mass balance estimate have been completed at MDAs H and L and are underway at MDA C; environmental mass balance estimates have been completed for the chromium area in Sandia and Mortandad canyons.
3	Quantify inventories of contaminants released in canyons; continue to develop surface water and sediment monitoring programs	These activities are ongoing and will continue in life-cycle baseline.	Inventories have been completed for many watersheds; additional sediment controls have been installed; monitoring of stormwater, surface water, and sediment is ongoing.
4	Better integrate geochemistry into conceptual modeling	Additional work has been proposed in the life-cycle baseline but is contingent upon funding.	Geochemistry continues to be a line of evidence used to constrain conceptual models of flow and transport.
5	Review all operations; reduce discharges and releases to the extent possible	The feasibility study is expected to be completed in December 2007; other plans are included in the life-cycle baseline.	The Laboratory's goal to reduce effluent is ongoing.
6	Add a sitewide perspective to future groundwater monitoring plans	Ongoing network evaluations inform a sitewide perspective, and supplemental geophysics is in review.	Network evaluations and additional wells enhance the sitewide perspective.
7	Increase efforts to develop and use quantitative methods to describe contaminant pathways	Network evaluations in current program continue to develop and use quantitative methods; this approach will continue through the life cycle.	Efforts continue with quantitative modeling in the vadose zone and its connection to the regional aquifer.
8	Confirm the integrity of the major disposal sites; schedule regular subsurface surveillance	This analysis is ongoing in the current program and will continue through life cycle.	Surveillance is ongoing in the current program and will continue through life cycle; the 2007 response still applies.
9	Continue efforts to characterize regional aquifer	Proposed additional work is included in the life-cycle baseline but is contingent upon funding.	New wells, pumping tests, and hydraulic tomography add to the characterization of regional aquifer.
10	Increase attention to geochemistry within site characterization context	Proposed additional work is included in the life-cycle baseline but is contingent upon funding.	Geochemistry is integral to monitoring and remedy selection. The proposed work was not conducted, but other issue-directed geochemistry investigations are ongoing.

Table 1 (continued)

Rec. #	Summary	Status in 2007	Status in 2011
11	Demonstrate better use of understanding of contaminant pathways in design of monitoring program	Understanding of pathways is ongoing in the current program and will continue through the life cycle.	Understanding of pathways is ongoing in the evolution of monitoring program through network assessments, additional wells, evolution of IFGMP and will continue through program life cycle.
12	Conduct geochemical research on interaction of contaminants, drilling fluids, and geologic media	Additional work is proposed in the life-cycle baseline but is contingent upon funding.	Proposed work remains in the baseline. Chemical tests are directed at specific issues.
13	Conduct future characterization drilling and monitoring as separate tasks	Separation of the two tasks is built into the current strategy; precedent has already been set with the chromium investigation.	Examples demonstrate the continued separation of characterization and monitoring.
14	New monitoring wells: single-screen, drill without fluids, careful design for length and depth of well screen	The precedent has been successfully set with R-35a and R-35b; the Laboratory plans to continue this approach where feasible.	The approach has continued. Since 2007, 40 wells were drilled with minimal use of fluids: 12 in perched-intermediate zone, 13 single-screen regional wells, and 15 dual-screen regional wells.
15	Ensure consistency and clarity of related sampling and analytical procedures	Ensuring the consistency and clarity of related sampling and analytical procedures is ongoing in the current program and will continue through the life cycle.	Ensuring the consistency and clarity of related sampling and analytical procedures is ongoing and evolving.
16	Ensure measurements near detection limits are sound and are reported appropriately	The Laboratory, DOE, and NMED are in mutual agreement on reporting in DOE orders, Consent Order, and NMED-approved work plans.	The response from 2007 still applies; no changes have been made to the 2007 response.
17	Continue to track wells to improve statistical basis for reporting increases above background	Tracking of wells is ongoing in the current program and will continue through the life cycle.	Tracking of wells is ongoing in the current program and will continue through the life cycle. More data evaluations and reporting have been added.

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