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U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO RECOMMENDATIONS IN THE NATIONAL RESEARCH COUNCIL'S REPORT, "GROUND WATER AT YUCCA MOUNTAIN, HOW HIGH CAN IT RISE?"

On April 17, 1992, DOE was pleased to receive the final report from the National Research Council's Panel on Coupled Hydrologic/Tectonic/Hydrothermal Systems at Yucca Mountain, Nevada. The panel's report summarized a large body of published work, the results of recently collected data from the Yucca Mountain site, and well over 1,000 hours of field examination by panel members. DOE greatly appreciates all of the hard work by panel members since they began work on the review in the summer of 1990.

I would especially like to note that all of the panel's recommendations basically advocate changes in emphasis, levels of priority, or sequencing for site characterization studies already in place, or that are to be developed as part of our Site Characterization Plan (SCP). The panel has not, however, identified any technical area of emphasis relevant to assessing the groundwater upwelling hypothesis that was missing from the SCP for Yucca Mountain. This comes as good news to the program as well as to over 200 scientists who wrote and revised the SCP between 1986 and 1988. This gives DOE great confidence in the technical excellence and robustness of our site characterization program.

The DOE has identified 31 recommendations made by the panel in their final report. My staff arranged for U.S. Geological Survey (USGS) and Los Alamos National Laboratory (LANL) principal investigators, who are responsible for these study programs, to address the recommendations. The enclosure contains the panel's recommendations, followed by a response. Bolded text are the recommendations, which are supplemented by additional supporting text from the report, as appropriate.

Please receive these responses on behalf of the Office of Geologic Disposal/Office of Civilian Radioactive Waste Management. If you have questions or wish to discuss these responses further with me, Yucca Mountain Site Characterization Project Office technical staff, or the principal investigators at USGS or LANL, please contact me at (702) 794-7920.

for Maxwell Blanchard
Carl P. Gertz
Project Manager

RSED:TWB-378

Enclosure:
DOE Responses to NAS
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U.S. DEPARTMENT OF ENERGY RESPONSES TO RECOMMENDATIONS FROM
NATIONAL ACADEMY OF SCIENCES/NATIONAL RESEARCH COUNCIL
PANEL ON COUPLED HYDROLOGIC/TECTONIC/HYDROTHERMAL SYSTEMS AT YUCCA MOUNTAIN

NAS Recommendation 1:

"Further efforts should refocus away from the descending/ascending water controversy. Studies should concentrate on improving the knowledge of the ground water history of the Yucca Mountain area, to ascertain the validity of the widely held view that the isotopic composition of ground water of an area does not change much with time and that, therefore, differences in isotopic composition of present day ground water and carbonates at the surface are not the result of differences in the isotopic compositions of present and past ground waters.

1. Characterization of isotopic age and composition of calcites above and below the water table from cores should be supplemented with information on grain size, chemical variation (especially Ca-Mg-Mn-Sr) and D content of fluid inclusions.

2. Trenching and drilling of the Site 199 tufa mound should be carried out to describe and document the geology, hydrology, and geochemistry of this spring deposit in order to determine if it is the result of a perched water table and if carbonate is present in veins below the surface.

   [On pages 41-42 of the report, the Panel previously noted the presence of saltgrass, indicating the modern presence of near-surface water. It is suggested that the alternate conjecture as to the origin of the "tufa" by ascension of water 100 m up from the water table could be simply and conclusively tested by drilling and tests in a hole of about 100 m depth.]

3. Mineralogical, chemical, and isotopic analyses of windblown dust should be conducted in order to determine the magnitude of the contribution of such dust to carbonate deposits." [pp. 41-42, 56-57, 134-135]

DOE Response:

Because of the nature of our interactions, the Panel may have been misled as to the degree of emphasis of our geochemical/isotopic program on the "descending/ascending water controversy". Despite the visibility of that controversy, our studies are, and have been, dominantly weighted toward defining pathways for flow, the geochemical characteristics of those pathways relative to retardation, and the evolution of the hydrogeologic system under past climates and tectonic environments. Therefore, the essence of this recommendation is consistent with our long-standing scientific goals which are laid out in the current baselined site characterization program. All of the ongoing work and results shared with the Panel have been carried out under the aegis of existing site characterization study plans. None of this work is ad hoc or specifically in response to the upwelling hypothesis.

1.1 As this recommendation indicates, DOE has already shared early results of the work on calcite from recovered drill core with the NAS panel, and DOE does have extensive plans, described in Study Plan 8.3.1.3.2.1 (Mineralogy of

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Transport Pathways) and in Study Plan 8.3.1.5.2.1 (Quaternary Regional Hydrology), for continuing these studies on existing and new samples. A program is underway to determine ages of calcite by both U-series dating (by mass spectrometry), and, where young enough, by ^{14}C accelerator mass spectrometry. The history of deposition for these calcites may be complex and cover a wide range of ages. Textural examination includes grain size by microscopy, depositional sequence, and also zoning of growth bands of veins by fluorescence and of crystals by ion microprobe. Fluid inclusions that may occur in the calcites will receive thorough examination (as presently planned, by contract with Ed Roedder) and δD analyses as recommended by the Panel. An extensive suite of Sr, C, and O isotopic analyses on existing drill-core calcites has been completed, and future samples will receive these and other isotopic analyses. Although chemical analyses of the veins will include the recommended elements, recently completed work on calcretes and near-surface veins (Vaniman and others, 1992) indicates that the most diagnostic chemistry may include lanthanide elements and Fe-Sc ratios and abundances. Enrichment of both Fe and Sc in the soil by weathering of the tuffs is reflected also in their abundances in the near-surface veins, suggesting that these analyses may help to differentiate between calcites formed below the water table and those formed from downward-percolating water within the unsaturated zone. Finally, other minerals besides calcite help in reconstructing the hydrologic history. Under Study Plan 8.3.1.3.2.2 (Mineralogic and Geochemical Alteration of Yucca Mountain), K/Ar studies of zeolites, clays, and other K-bearing secondary minerals have revealed distinctive patterns of K/Ar values above and below the water table that reflect continuing interactions between minerals and ground water (Wolde Gabriel and others, 1992).

1.2 DOE's extensive plans for investigating site 199, including detailed mapping, possibly geophysics, drilling, trenching, and extensive geochemistry have been discussed with the Panel, and we understand this recommendation to be an endorsement of those plans. Limited but very careful dating of the deposit, some Sr isotope work, and preliminary micropaleontologic examination of a few samples have been completed, and the detailed mapping is underway. Current plans do provide for the activities discussed with the Panel to be carried out at Site 199, but they have yet to be funded. If mapping, and isotopic, mineralogic and paleontologic work does not provide adequate confidence to answer questions as to the origin of the calcareous deposits at this site, then some of the other more invasive methods may be needed (i.e., drilling, trenching). The conclusions reached about Site 199 are more likely to be controlled by the effects of past climates than to tectonic events.

1.3 Analyses of the major-element and mineralogic composition of wind-blown dust have been completed under Study Plan 8.3.1.5.1.4 (Paleoenvironmental History of Yucca Mountain), but additional sampling and analyses (under studies discussed in 1.1 above) are anticipated to characterize minor and trace elements and the Pb and Sr isotopic composition of dry fall. These data are expected to identify the source of the dry fall and its contribution to soil-zone materials, as well as to help in tracing the chemical and isotopic signatures of soil constituents into subsurface materials.

NAS Recommendation 2:

"The panel recommends that further efforts in the study of secondary calcites be refocused. In the panel's opinion, it is well established that surface calcite deposits at Yucca Mountain, such as those at Trench 14 and Busted Butte, did not precipitate from ground waters sampled in deep wells.

It is recommended that analyses of calcite veins intersected in drill cores be carried out for $\delta^{18}O_{VSMOW}$ and $\delta^{13}C_{PDB}$, as well as of fluid inclusions. Age dating with U and Th isotopes would be an essential part of this study to reconstruct the ground-water history of the Yucca Mountain area." [p. 56]

DOE Response:

See response to Recommendation 1.1 for discussion of the recommended analyses. Evidence for the isotopic concentrations of ancient ground waters is incomplete. The preliminary study of Sr, C, and O isotopes in existing drill-core calcites do indicate that the deeper deposits precipitated from ground water beneath the water table, possibly early in the history of saturation of the newly deposited volcanic rocks. Dating of these calcites has only recently begun; it is not yet determined whether the methods can be extended beyond a few hundred-thousand years into the past. It may not be possible to reconstruct much of the early Quaternary (and earlier) ground-water history of the area.

NAS Recommendation 3:

"A search should be made for suitable fluid inclusions in vein materials found in core to extract for hydrogen isotope analyses." [p. 57]

DOE Response: See response to Recommendation 1.1.

NAS Recommendation 4:

"Because of the importance of understanding the steep hydrologic gradient, the panel recommends that a series of wells be drilled in the region of the gradient north of Yucca Mountain. These wells should be drilled both within and outside of the gradient, and should be deep enough to penetrate the pre-Tertiary carbonates underlying the tuffs. Hydraulic head and permeability measurements from both pumping and interference tests in these holes should lead to at least a qualitative improvement in understanding the hydrological regime in this important area, as well as the cause of the steep gradient...The wells should be designed in close coordination with those responsible for geochemical studies (including isotopic studies)..." [p. 86-87]

DOE Response:

DOE agrees with the importance of understanding the large hydraulic gradient for the purpose of realistically portraying its causes in models used to simulate the present flow regime in the saturated zone at Yucca Mountain, as well as to predict the effects of climatic and tectonic changes. As has been discussed between the Panel and YMPO geoscientists, several alternative causes for the large gradient have been proposed, only one of which (Fridrich and others, 1991) assigns an important role to the pre-Tertiary carbonates beneath the site. The extensive drilling program recommended by the Panel would provide the lateral and vertical distribution of hydraulic head, permeability, and hydrochemical characteristics which, when considered in the context of geophysical data and geologic interpretations, would lead to an understanding of the conditions controlling flow paths and the water-table configuration.

The existing study plans, as expressed in the Site Characterization Plan and Study Plans 8.3.1.2.1.3 (Regional Flow System) and 8.3.1.2.3.1.1-6 (Site Saturated Zone), predate Fridrich and others' (1991) conceptual model that focuses on the probable importance of the carbonates, and these plans therefore do not explicitly call for investigation of the deep carbonate rock units. However, exploration of the lower carbonate aquifer has received increasing support both from within the project and from oversight groups, now including the NAS Panel. Tentative plans have been drawn up by the USGS but have not been formally submitted to the DOE. These plans include penetrating the pre-Tertiary rocks for USW G-5 (Yucca Wash), for USW G-7 (southwest of Busted Butte), and possibly for USW G-6 (Windy Wash). Substantial thicknesses of clastic rocks of the Eleana Formation at the two more northerly sites (G-5 and G-6) have much lower hydraulic conductivities than the underlying carbonates and may significantly impede groundwater movement into the carbonates. USW WT-23 and -24, which were originally designed only for potentiometric and hydrochemical characterization of the uppermost saturated zone, could be made large enough to allow later deepening into the deeper tuffs and Paleozoic rocks (see also our response to Recommendation 29). Together with geophysical studies, which should be completed in a similar time frame, the geologic and hydraulic information from the early holes discussed above will allow the most effective siting of holes having the primary objective of identifying the hydrogeologic cause of the steep gradient.

The latest drilling schedule reflects the Panel's view of the importance of early investigation of the large hydraulic gradient, but, in this context, "early" means three to five years. Drill hole USW G-5 is early on the drilling

schedule, and USW WT-23 will be the first water-table hole to be drilled. USW WT-24 is planned to follow about a year later as the second water-table hole in the area of the steep-gradient gradient. This time interval should allow modification of plans for USW WT-24 if unanticipated results are obtained from USW WT-23.

The Panel's drilling recommendation does not specify the number of deep holes, but the wording, "series of wells...both within and outside of the gradient", suggests several drill holes — perhaps in the range of 6 to 10 — into the pre-Tertiary carbonates. Although DOE agrees with the spirit of the recommendation for timely and substantial investigation of the steep hydraulic gradient, it is unlikely that the project will be funded to the level needed to complete the number of holes the Panel seems to imply are needed. A carefully phased approach appears to be the most prudent management option. When the prospects for reducing uncertainty begin to diminish significantly, then the need for additional drilling is greatly lessened.

NAS Recommendation 5:

"There is a need for better characterization of the long-term variability of the hydrologic regime in the Yucca Mountain area [particularly as it relates to variations of climate and recharge]. Additional chronological data are needed from isotopic analyses of ground waters, as well as of spring deposits and dry lake sediments. The panel recommends that samples of water at various depths in the Alkali Flat/Franklin Lake subbasin be dated and further analyzed for the isotopic concentrations." [p. 87]

DOE Response:

The Panel's recommendations are consistent with the work activities under Study Plan 8.3.1.2.3.2, Saturated-Zone Hydrochemistry, and Study Plan 8.3.1.5.2.1, Quaternary Regional Hydrology. A very complete suite of chemical and isotopic analyses of ground-water samples is specified in Study Plan 8.3.1.2.3.2, along with a discussion of plans for sampling from discrete intervals, wherever possible, to minimize the ambiguities that result from composite sampling over large depth intervals. Analyses of radioisotope and stable-isotope data from sediments, spring deposits, and ground water are among the principal techniques of investigation in the Study Plan 8.3.1.5.2.1, for purposes of dating and tracing ground-water flow as well as studying the variability of past climates. Modest efforts are in progress with a few Sr analyses of water from Franklin Lake playa taken in July 1992. More intensive studies, including other isotopes and sampling as a function of depth, are planned in FY 1994 or later.

NAS Recommendation 6:

"Existing well data (drilling, stratigraphy, repeat temperature surveys, pumping tests) should be re-examined to determine if the major permeable horizons are associated with specific formations and/or formation interfaces." [p. 87]

DOE Response:

Chapter 3, pages 3-179 through 3-192, of the Site Characterization Plan (DOE, 1988) provides a rather complete summary of the YMPO's earlier observations on this topic, as well as those of other workers in nearby areas such as Rainier Mesa (Claassen and White, 1979) and Pahute Mesa (Blankennagel and Weir, 1973). The Panel's discussion leading to this recommendation does not indicate an awareness of these earlier analyses, nor does it provide a basis for determining that the work was inadequate. Comparisons of drilling, logging, stratigraphic, in-situ hydraulic-test, and core-test data have shown that the dense, brittle rocks (e.g., rhyolites and welded tuffs) tend to be more fractured and, therefore, more permeable than partially welded and non-welded tuffs. Depth also appears to be a major factor, probably because of fracture filling as well as fracture closure by lithostatic stress, but structural setting (proximity to faults or fracture zones and/or orientation of fractures relative to principal stresses) is also very important and may override other factors locally. Within the depths penetrated (about 3000 feet) by three closely spaced holes at the UE-25c site, Geldon (1992) found the occurrence of water-bearing fractures to be independent of lithology and depth; he is currently conducting a multifaceted study, consistent with the Panel's recommendation, of the relationships among hydrology, hydrogeology, and fractures over a larger area of Yucca Mountain.

With the exception of temperature logs run during pumping tests, the Panel is correct that there has been no systematic comparison of temperature logs with stratigraphic and structural data for the purpose of testing stratigraphic control of permeability. Because of its unique shape, the log for UE-25p#1 has been subjected to greater analysis than those for other holes. There is a good correlation of mapped faults with the most prominent thermal features in this hole. This log, interpreted together with the quite thorough hydraulic-test data, provides compelling reasons to be cautious in applying empirical, one-dimensional analyses of temperature logs in this area, as might be inferred to be recommended from the discussion on pages 175 and 177 of the Panel's report. However, a systematic documentation of the stratigraphic and/or structural features corresponding with temperature inflections and excursions in boreholes would be an appropriate undertaking in the planned interpretations of existing and future temperature logs.

NAS Recommendation 7:

"Permeability studies of the "slug test" variety in some Yucca Mountain area wells produced an anomalous fall-off response in the graphic representation of fluid behavior. This has been interpreted to indicate the minimum horizontal stress in the crust (Szymanski, 1989). The panel recommends that the anomalous response in the slug tests be reanalyzed to determine the cause of the observed behavior." [p. 87]

DOE Response:

The report does not indicate by reference or discussion that the panel was aware of the YMPO's review (Dudley and others, 1989) of Szymanski's earlier (November, 1987) draft of his 1989 report. Pages 99-107 of the YMPO review contain a detailed discussion of Szymanski's analysis, particularly with respect to the slug tests in borehole USW H-3. Five of the six tests in that hole showed the anomalous stepped recovery, leading Thordarson and others (1985) to perform analyses beyond those typically applied to the Yucca Mountain tests. In addition, hole H-3 was sited where the water table is very deep, so that the initial heads applied were on the order of 750 meters, and it was drilled close to USW G-3, where in-situ stress was measured by the hydrofrac technique at about the same depth as the hydraulic tests in H-3. Stock and others (1985) reported the least principal total stress at a depth of 1074 m to be about 6.8 MPa, which is indeed substantially greater than the fracture closure pressures, 2.8-3.5 Mpa, postulated by the earlier YMPO reviewers (see discussion on p. 177 of the Panel's report). However, reduction of the total stress to an effective stress by removing the hydrostatic pressure results in a value of 3.5 MPa, which compares favorably with the estimated closure pressures. The alternative cause (multiple feedzones) suggested in page 177 of the Panel's report does not appear to be feasible in the context of the H-3 data — i.e., that each of the five stacked test intervals contained multiple feedzones causing very similar effects.

The permeability structure of the site area is certainly of great interest. However, the slug-test technique was introduced (Cooper and others, 1967) for testing materials of rather low permeability. The flow paths of greatest interest in characterizing Yucca Mountain are too permeable for tests of this type, which in fact were first applied when Yucca Mountain was being evaluated as a potential saturated-zone site. The YMPO does not consider reanalysis of the slug-test data to be of high priority. However, if slug tests are performed in the future, they are likely to be conducted with smaller applied heads so as not to induce mechanical responses or would be conducted at various applied heads to test the fracture-dilation hypothesis more rigorously (Dudley and others, 1989, p. 29).

NAS Recommendation 8:

"The panel considers it worthwhile to attempt to remeasure hydraulic potential in isolated sections of existing boreholes." [p. 88]

DOE Response:

DOE agrees that knowledge of the three-dimensional distribution of hydraulic head is essential to an understanding of flow in the vicinity of Yucca Mountain, and careful measurements of head as functions of depth and geology are planned for future test wells. Also, re-entry of hole USW G-2 (from which an obstruction has recently been removed) to investigate head variation with depth is a very likely first step in the exploration of the steep-gradient zone, although opinions differ as to the likely success of the attempted re-entry and as to the value of information to be gained after more than a decade of head equilibration. Some existing holes have been completed with quasi-permanent instrumentation or are known to have obstructions; those that are the best candidates for successful re-entry are also among those for which the most reliable data on vertical head distribution are available. The Panel's report does not reference nor evaluate original sources for the existing data that are pertinent to this concern, referring instead in Appendix B (p. 178) to tables of data as selected and presented by Szymanski (1989). With consideration of the more complete information that is available, the recommended activity is not feasible or cost-effective for most of the existing boreholes.

NAS Recommendation 9:

"One of the major sources of uncertainty in the present understanding of the hydrologic regime is the recharge in the Fortymile Canyon area, and the rate of evapotranspiration in the Franklin Lake Playa area. The panel therefore recommends that efforts be made to characterize more fully the recharge and discharge rates for the ground-water system in the vicinity of Yucca Mountain." [p. 88]

DOE Response:

This recommendation coincides very well with the YMPO's plans for investigation of the regional hydrologic system, as described in the Site Characterization Plan (DOE, 1988, pp. 8.3.1.2-125 - 8.3.1.2-137) and in Study Plan 8.3.1.2.1.3 (Regional Ground-Water Flow System). The third and fourth activities in this study address Fortymile Canyon recharge and Franklin Lake evapotranspiration, respectively.

NAS Recommendation 10:

"Independent determination of permeability is necessary to constrain and guide computer modeling studies. Since much of the permeability is believed to be fracture controlled, laboratory measurements of permeability on small rock samples may not be representative of flow conditions in situ. Well tests in this case are invaluable. The panel recommends, therefore, a carefully designed set of pressure interference tests between wells to delineate the permeability structure in the Yucca Mountain area." [p. 88]

DOE Response:

We also consider fractures to provide the dominant component of bulk permeability and have not, as this recommendation implies, relied on laboratory measurements on small samples to provide these data. However, pumping-test data do indicate dual-porosity behavior, and knowledge of interstitial hydraulic characteristics is relevant for some considerations, e.g., transient responses to climate change. Pressure-interference testing is included prominently in Study Plan 8.3.1.2.3.1 (Characterization of the Site Saturated Zone Groundwater Flow System) specifically at Solitario Canyon, at the UE-25c test-well complex, and at a possible successor to the UE-25c site. These are the only testing locations where the test wells have been sited with interference testing in mind. Where pumping tests are to be performed at other locations, observation wells throughout the vicinity will be monitored. However, in existing plans, holes that might serve as observation wells will normally have been drilled for hydrogeologic, potentiometric, and hydrochemical information; consequently, they generally will not be optimally sited for pressure-interference testing.

In its report, the Panel has given greater emphasis to the steep-gradient zone and the deep carbonate rocks than is currently reflected in YMPO plans. As is noted in our response to Recommendation 4, very extensive evaluations would have to precede a commitment to extensive deep drilling and testing in these targets. An additional requirement to site a large number of drillholes for a "carefully designed set of interference tests" is presently judged quite likely to escalate costs beyond reason in comparison with potential benefits. Estimating the permeability structure principally by parameter-estimation techniques based on reasonably robust hydrogeologic, potentiometric, and hydrochemical data, in conjunction with results of previous and planned aquifer testing, seems at this time to be the most cost-effective approach. Obtaining sufficient interference-test data for modeling constraints and guidance is certainly a worthwhile objective, but a testing program that considerably exceeds the scope of current plans could be justified only if the saturated zone were assigned a much greater role as a waste-isolation barrier.

NAS Recommendation 11:

"The hydrologic models of the Yucca Mountain area have been restricted to the Tertiary tuff aquifer, which may be an oversimplification of the ground-water system. The panel recommends that a multi-layered model be constructed which includes both the shallow Tertiary aquifer and the Paleozoic carbonate rocks with currently available data. The data should also be used in a sensitivity analysis to test the coupling between the tuff aquifer and the Paleozoic carbonates. Current hydrologic information from the single hole penetrating the carbonate aquifer in the Yucca Mountain area is insufficient to characterize such a model. Additional drill hole data and tests in the carbonate aquifer are critically needed. Such a model should also be useful in assessing the "drain" concept as an explanation for the steep hydraulic gradient north of Yucca Mountain. Moreover, the panel recommends that geochemical data, as well as hydraulic data, be used to assess the validity of the modeling. The panel strongly urges that the use of geochemical interpretations become an integral part of the hydrogeological modeling at Yucca Mountain." [p. 88]

DOE Response:

DOE agrees that the existing single-layer models of the Yucca Mountain region need to be replaced by more realistic models based on site data. The Site Characterization Plan (DOE, 1988, p. 8.3.1.2-145) specifies the development of a regional-scale quasi-three-dimensional flow model, consisting of upper and lower layers and an intervening "leakance" or coupling layer. Tentative and very general plans exist also in Study Plan 8.3.1.2.3.3 (Saturated Zone Hydrologic System Synthesis and Modeling) for developing a fully three-dimensional flow model at the site scale, covering tens of kilometers. We anticipate that the hydrogeologic, potentiometric, and hydrochemical information obtained during exploration of the steep-gradient zone will dictate whether a multi-layer or fully 3-D model is more appropriate. The existing thermal data indicate the need to simulate interlayer connectivity along certain faults at least.

Although directed principally at transport processes, three-dimensional modeling that is being done under Study Plan 8.3.1.3.7.1, Retardation Sensitivity Analysis), includes flow-field simulations that are complementary to strictly hydrologic modeling. The three-dimensional finite-element mesh presently extends from the land surface to the base of the Tertiary section, but it could be extended to include the Paleozoic aquifer. The mesh was developed for use with the code FEHM (finite element heat and mass transport) in a wide variety of problems including, but not limited to, vapor transport, dissolved-species transport, dual porosity-dual permeability calculations, hydrothermal effects of magmatic intrusions, and coupled flow-heat-stress modeling.

DOE also agrees strongly with the Panel's recommendations with respect to integration of geochemical and hydrogeologic interpretations, and with respect to the need for additional data from the carbonate aquifer. Although conceptual models of the flow system differ somewhat among individual YMPO geoscientists, most of these concepts emphasize structural control of permeable pathways. Hydrochemistry (including isotopes) is a powerful tool for identifying preferential flowpaths and for providing clues to the geology of the upgradient direction. Hydrochemistry is expected to be a very important, even diagnostic, indicator for determining the hydrogeologic causes of the steep hydraulic gradient and in investigating whether or not coupling occurs between the

carbonate and tuff aquifers.

As was discussed in DOE's responses to the Panel's recommendations 4 and 10, DOE anticipates a phased approach to exploring the Paleozoic carbonate aquifer because of the large costs associated with drilling. The incremental value of additional information will be evaluated in part by sensitivity analyses using models developed concurrently with data development. Such analyses, of course, be influenced by the waste-isolation role assigned to the saturated zone at Yucca Mountain. If only the future water-table elevation is of concern with respect to the saturated zone, the thoroughness with which the carbonate aquifer must be hydrologically characterized will be less than if the saturated zone is also relied upon as a principal retardation barrier to waste migration.

NAS Recommendation 12:

"The panel recommends that, as sufficient data become available, more definite three-dimensional modeling studies be carried out for both the transient and steady states. A transient three-dimensional model can provide new insights into the evolution of the ground-water system over the past 10-20 ka." [p. 88]

DOE Response:

The hydrologic models that are currently in use by the YMPO or planned for future development include the capability (i.e., storage coefficients) for transient-flow applications. As was discussed in our response to recommendation 11, we anticipate analyses using site-scale, three-dimensional ground-water flow models early enough to investigate, during and as a guide to exploration, the sensitivity of the hydrologic system to uncertainties in the hydraulic characteristics of the rocks. System response time is an important output parameter for consideration during sensitivity studies. Concurrently, the credibility of model output will be evaluated in iterative comparisons with the ground-water paleosystem, as estimated from paleoclimatic and paleohydrologic studies. DOE agrees that insights into the evolution of the system, as well as into the hydrogeology of the system, should result from the integration of modeling and exploration.

NAS Recommendation 13:

"...an understanding of the relationship between recharge and precipitation is still evolving. It is essential to consider methods to reduce uncertainty in estimates of ground water recharge under different climatic conditions. In particular, the panel recommends undertaking an assessment of the reliability of empirical methods and newly developing considerations in estimating recharge under present arid, as well as much wetter and cooler, conditions to evaluate the potential effects of climate change on the water table." [p. 89]

DOE Response: In the Site Characterization Plan, the assessment recommended by the Panel would be performed under Study Plan 8.3.1.5.2.2 (Characterization of the Future Regional Hydrology Due to Climate Changes), under which limited work is now being done. As the Panel's discussion suggests, a thorough and predictive understanding of the influence of climatic factors on recharge is beyond the present capability of hydrologic science and is likely to remain so for decades at least. The YMPO experimentation that is underway or planned will provide guidance for evaluating the reliability of empirical methods for estimating present and future recharge. In Activity 8.3.1.5.2.1.4, (Analog Recharge Studies) sites in the Toiyabe and Kawich Ranges have been intensively studied to provide estimates of recharge at locations that are climatologically, geologically and botanically analogous to Yucca Mountain during the late Pleistocene. The Fortymile Wash recharge study (Activity 8.3.1.2.1.3.3) and the artificial and natural infiltration experiments and monitoring under Study Plan 8.3.1.2.2.1 (Unsaturated-Zone Infiltration), will contribute to an understanding of recharge processes under present conditions, which is needed before extrapolating to wetter conditions. Comparison of the results of modeling with those of paleohydrology field studies (including fracture-filling characterization) will also contribute to this understanding. Responsiveness to the Panel's recommendation will occur in the form of a sustained long-term effort as data and insights are developed in the field.

NAS Recommendation 14:

"The panel recommends that the assumptions and results of Czarnecki's (1991) model of increased rainfall and recharge be critically reviewed considering paleoclimate reconstructions, the potential for increased precipitation, and methods of calculating recharge in arid regions. To reduce the present uncertainty level, it will be necessary to obtain additional hydrologic, paleoecologic, and recharge data to provide constraints on future modeling efforts." [p. 89]

DOE Response:

DOE agrees with the Panel that Czarnecki's model, and all other models that are in use or are being developed for predictive purposes, should be frequently reviewed with consideration for the available pertinent information. Czarnecki (1991) is not included in the references for the Panel's report, but the discussion in Appendix B indicates that the Panel is aware that the basic model under discussion is that of Czarnecki and Waddell (1984), as modified slightly and applied by Czarnecki (1985) in evaluating the potentiometric effects of doubling the precipitation. Significant parts of both the Yucca Mountain Environmental Assessment (DOE, 1986) and the Site Characterization Plan (DOE, 1988) were based on and referenced these two reports, resulting in their review by a large and dominantly adversarial audience. In general the comments mirrored the observations of the investigators evaluating their own work (Czarnecki and Waddell, 1984; Czarnecki, 1985): (1) use of a single-layer model to simulate a three-dimensional system limits the potential uses of the model; (2) steady state is assumed, whereas recharge may be less than or greater than the present discharge; (3) the applied distribution of present recharge may be a poor approximation to the actual; and (4) use of the Maxey-Eakin empirical relationship among altitude, precipitation, and recharge is not supported by a rigorous demonstration of its applicability. These are similar to the comments of this Panel, and the responses to recommendations 11-13 are applicable. Additionally, in its discussion on page 135 of the report, the Panel notes that the assumed 100-percent increase over modern precipitation (from which a 15-fold increase of recharge was estimated) probably is greater than reasonable conservatism requires. A principal objective of the climate program is to improve upon that assumption to avoid the need for overly conservative bounding calculations. As for the Maxey-Eakin technique, the method is easily criticized and can even be shown to be considerably in error in specific locales. Nonetheless, for purposes of estimating average recharge rates over large areas, experience has shown the method to have considerable utility, and none of the criticisms of which we are aware are accompanied by feasible alternatives for regionalizing local data that appear to be more rigorously derived. Therefore, although it is DOE's intent to improve YMPO models on a regular basis and to continue field experiments in recharge, we expect that estimating regional recharge is likely to require continued use of a Maxey-Eakin type of approach, though modified by geologic and ecologic associations.

NAS Recommendation 15:

"To resolve the apparent contradiction between what appears to be increased discharge (as a consequence of increased high-elevation recharge at Fortymile Wash) and evidence in the Yucca Mountain area for increased aridity in existing fossil records, the panel recommends a continued search for evidence of perennially moist conditions in currently dry water courses in the area, and for high-elevation (>2000 m) fossil records contemporaneous with a possible latest Wisconsin-early Holocene pluvial episode. The panel also recommends establishment of a data base relating species' ranges to measured climatic parameters, and its application to the macrofossil record." [p. 89]

DOE Response:

All of the suggested work on paleoclimates (as well as the evaluation of fossils in perennially wet and high-elevation areas) is, in general terms, within one of three study plans that have already been approved by DOE: 8.3.1.5.1.2 (Paleoclimate Study — Lake, Playa, and Marsh Deposits); 8.3.1.5.1.3 (Climatic Implications of Terrestrial Paleoecology); and 8.3.1.5.1.4 (Analysis of the Paleoenvironmental History of the Yucca Mountain Region). Mineralogical comparisons of various hydrogeologic settings under Study Plan 8.3.1.3.2.2, (Mineralogic and Geochemical Alteration), are an important component of this set of studies. The suggestion to pay particular attention to areas that might be expected to have experienced discharge based on model results is highly constructive in emphasizing the need to integrate ongoing modeling with field investigations. The relation of modern vegetation to climate as an aid in interpreting the macrofossil record is specifically the topic of Activity 8.3.1.5.1.3.3 (Determination of Vegetable-Climate Relationships).

NAS Recommendation 16:

"The three percent lower velocity anomaly identified [by Evans and Smith, 1992] under Crater Flat is considerably smaller in magnitude than velocity anomalies associated with known large-scale high silica magma chambers, such as Long Valley, where velocity increases of six to eight percent are typically found (Iyer, 1988). The possibility that molten rock is present beneath Crater Flat deserves further study." [p. 98]

DOE Response: See response to Recommendation 18.

NAS Recommendation 17:

"The study plan [8.3.1.8.5.1] for the characterization of volcanic features calls for drilling core holes to investigate aeromagnetic anomalies that may represent either buried volcanic centers or intrusive rocks (probably basaltic in composition). No mention is made of studying the core to determine the extent, if any, of hydrothermal activity (temperature variations in adjacent rocks, fluid inclusion studies, hydrothermal alteration products) that may have been induced by intrusion or extrusion of a body of volcanic rock. The panel recommends this type of investigation be added to the work plan." [p. 101]

DOE Response:

The recommended studies are indeed appropriate but, under the SCP structure, they are associated with geochemical investigations of broader scope conducted under Study Plan 8.3.1.3.2.2 (History of Geochemical and Mineralogic Alteration at Yucca Mountain). The work most directly relevant to this issue is a study of illite/smectite ordering in samples from three deep drill holes at Yucca Mountain (Bish, 1989). Illite/smectite geothermometry, coupled with K/Ar dating of K-rich clays, suggests that no significant hydrothermal alteration has occurred around Yucca Mountain in the last 11 million years. Unpublished illite/smectite data for drill hole USW VH-2 in Crater Flat, west of Yucca Mountain, indicate that basaltic dikes did not introduce sufficient heat into the intruded tuff to cause any increased ordering of the clay structure. This type of information is planned in the SCP to be developed (if necessary) or compiled under Activity 8.3.1.8.5.2.2 (Chemical and Physical Changes Around Dikes), within the study for characterization of igneous intrusive features. G. Valentine (LANL) has modeled the extent of thermal alteration in relation to the dimensions and initial temperature of tabular intrusives, and is field-checking the predicted limited extent of alteration at erosionally exposed dikes and sills in the Halfpint Range.

NAS Recommendation 18:

"Further teleseismic studies for better definition of the low velocity zone beneath Crater Flat should be carried out. A combination of P- and S-wave velocity and attenuation studies should constrain both the nature and source (e.g., possible fraction of melt if present) of this velocity anomaly. Although the panel does not consider it likely that either a larger volume or a different style of igneous intrusion will be found that is consistent with the recent geologic record, it would be prudent to follow up with an evaluation of this anomaly to ascertain its significance." [p. 101]

DOE Response:

NAS recommendations 16 and 18 are closely related. They have been combined and covered under this response. The plan for examining the possible presence of subsurface magma in the Yucca Mountain region is described in Activity 8.3.1.8.1.1.3 (Presence of Magma Bodies in the Vicinity of the Site), within Study Plan 8.3.1.8.1.1 (Probability of Magmatic Disruption of the Repository).

DOE agrees that the anomaly observed from teleseismic tomography studies by Evans and Smith (1992) could be attributed to magma at deep crustal and mantle depths. Additionally, the seismic gap of the Crater Flat/Yucca Mountain area could be controlled by strain release associated with recent magmatic processes. Magma, if present in the subsurface, could affect the basis for volcanic risk assessment for the Yucca Mountain site based on the presently known geologic record. We agree with your recommendations and have plans for further investigations of the possibility of the presence of magma.

Before implementing these studies, however, we plan to have an external review of the geophysical data for the Yucca Mountain area. Based on the results of the review, a decision will be made by the Yucca Mountain Project Office whether the evidence of subsurface magma is sufficient to require additional geophysical studies focused on the potential anomaly. If the answer is affirmative, we intend to develop a plan for the investigations, which would be focused on geophysical exploration. One option we will also implement, as noted in the Study Plan activity, is an assessment of the $^3He/^4He$ ratios in ground water (in conjunction with Study Plan 8.3.1.2.3.2 (Saturated Zone Hydrochemistry) above and down gradient of the potential anomaly.

While DOE agrees there are indications of the possible presence of magma, there are also inconsistencies with the data, not all of which were considered by Evans and Smith (1992). The center of the anomaly is south of the Nevada Test Site region. This location coincides with the magmatic gap of the southern Great Basin, an anomalous area that exhibited no Cenozoic volcanism during intense episodes of extension. The proposed anomaly overlaps a major step in the regional gravity field, the trend of which partly parallels the low velocity anomaly. Further this area was probably positioned above a zone of incoherent slab or a slab gap during the period of extension and silicic volcanism to the north (Severinghaus and Atwater, 1990). Both the effect of the steep gradient in the gravity field and the anomalous subduction history need to be considered in the development of a range of alternative interpretations of the low velocity anomaly. The presence of a magma body is certainly one interpretation, but only limited consideration has been given to alternative interpretations.

Continuing, the shape of the teleseismic anomaly and its extension to the east and northeast do not appear obvious from the data of Evans and Smith (1992; their fig. 3). The low velocity zone appears to extend more definitively into adjoining areas of Death Valley and southern Nevada than northeastward into eastern Nevada and Utah. Time-volume and petrologic studies of the basalt cycles of Crater Flat support a history of waning volcanism. This appears inconsistent with the presence of a large body of partial melt in the lower crust and upper mantle. Yet, there is no recognized surface expression of a partial melt zone in either the topography or structure of rocks of southern Nevada. The body, if present, could have formed recently and not yet modified the shallow crust. Alternatively, if there is a magma body, it may have had only a limited effect on the geologic record of the region, perhaps because of waning extension and the presence of preserved lithospheric mantle in the southern Great Basin. Finally, the seismic gap of Crater Flat, though possibly related to recent magmatic activity, may simply be an area of low shear strain accumulation (Gomberg, 1991).

It is essential not to dismiss the teleseismic evidence. The key information needed is an evaluation of whether the anomaly is produced by partial melt or other processes. Using geophysical methods that might test the existence of partial melt or discriminate other possible processes should clearly be a high priority. But the first step is to conduct a complete examination of the teleseismic data, the strengths and weakness of the method, and the results from other geophysical surveys already used in the area, particularly the seismic-reflection line across the Amargosa Valley. DOE plans to engage that process as soon as possible.

NAS Recommendation 19:

"Another means of measuring changes in crustal dimensions is the Global Positioning System (GPS)...Although the impact of this information on increased understanding of the hydrologic conditions around Yucca Mountain is uncertain, knowledge of the rate of crustal strain is clearly important to nearly any seismic risk assessment related to the proposed repository site. In the panel's view, this information used as an accessory to, or confirmatory of, more standard information on rates of crustal deformation, can provide additional confidence in the prediction of future tectonic behavior and the probabilities of seismic events in the area.

"The panel recommends that a combined GPS and leveling program be carried out across the Yucca Mountain region. ... Leveling surveys and local GPS surveys across Quaternary faults have been initiated by the USGS (G. Perasso, pers. commun., 1991), but longer baseline studies should also be included." [p. 107]

DOE Response:

As noted by the panel, the DOE is already conducting geodetic leveling surveys and trilateration surveys across faults near Yucca Mountain. The periodic leveling survey was initiated in 1982 and extends from U.S. Highway 95 about 15 miles west of Amargosa Valley across Crater Flat and Yucca Mountain to the vicinity of Mercury. More detailed surveys across selected faults were established by standard surveying techniques during the following year. The first GPS measurements of these fault quadrilaterals were completed last year, but the costs to extend GPS coverage to the long level line was prohibitive. Possibly expanding the regional aspects of crustal strain monitoring by GPS reoccupation of long-established base stations over a much larger area is anticipated in Study Plan 8.3.1.17.4.10 (Geodetic Leveling). Currently being examined is a joint effort (with the USGS/DOE NTS Weapons Program studies) to reoccupy a Nevada Test Site network which, in part, intersects the Yucca Mountain area of interest.

NAS Recommendation 20:

"The panel recommends that DOE conduct a detailed literature search to determine the hydrologic effects of other historic earthquakes, local and worldwide, to evaluate the potential for significantly large water table rises by the coupling of the seismic and hydrologic systems. Such information as earthquake magnitudes, type of faulting, rupture length of the fault, depth to the pre-earthquake water table, and details of the hydrologic system and its response should be obtained for comparisons and analysis of possible natural analogs to Yucca Mountain." [p. 111]

DOE Response:

A systematic literature search on hydrologic effects of historic earthquakes is already planned as part of Study Plan 8.3.1.8.3.2. Raney (1988) has produced a useful compilation of the effects of 28 intermontane western North American earthquakes during 1852-1983 on hydrology and underground workings. Although a few well documented worldwide events will be examined, particularly those in extensional tectonic settings, the emphasis will be restricted to the Basin and Range Province of the western U.S. Earlier studies indicate that many of the pertinent details, as listed in the recommendation, are rarely documented and may be difficult to reconstruct.

NAS Recommendation 21:

"...knowledge of the properties of the carbonate rocks [grain compressibility, bulk compressibility, Poisson's ratio, porosity, permeability] at depth at Yucca Mountain is essential to predicting water table behavior in response to changes in the regional crustal stresses produced by earthquakes. The panel recommends that more data on the elastic and hydrologic properties of the deep carbonate aquifer be obtained so that credible models can be developed." [p. 114]

DOE Response: See response to Recommendation 23.

NAS Recommendation 22:

"The panel recommends that additional modeling be done to aid in the understanding and prediction of the likely behavior of the water table at Yucca Mountain in response to earthquakes. However the models must be better constrained by data. Additional data are needed on the hydrologic and elastic properties of the deeper carbonate rocks and the chemical and isotopic composition of fluids in the saturated zone below the water table that underlies the proposed repository site." [p. 118]

DOE Response:

DOE agrees that additional modeling is appropriate to test the sensitivity of the water-table response to modeling assumptions and to a realistic range of stratigraphic conditions, as well as of hydrologic and elastic properties. Investigation 8.3.1.8.3 (Changes in Unsaturated and Saturated Zone Hydrology Due to Tectonic Events), tentatively will incorporate a specific activity for modeling hydrologic response to both mechanically and thermally driven systems. Under Study Plan 8.3.1.8.1.2 (Physical Processes of Magmatism and Effects on the Potential Repository), DOE also plans to investigate coupled poroelastic and thermal effects, using the FEHM code to build upon the work of Carrigan et al. (1991), who addressed the effects of seismic events on the water table. See also the responses to Recommendation 23 for discussion of hydrologic and elastic properties, and to Recommendation 11 for discussion of the use of hydrochemical and isotopic data.

NAS Recommendation 23:

"As the panel's independent analysis indicates, data are needed on rock compressibility, porosity, and permeability of the deep aquifer. Several deep core holes should be drilled well into the Paleozoic carbonates to obtain this information." [p. 118]

DOE Response:

The Panel's earlier recommendations for several deep holes to identify the cause of the steep hydraulic gradient and to support more realistic hydrologic modeling were discussed in response to recommendations 4 and 11. As noted there, the cost of a program of several holes that penetrate deeply into the carbonate aquifer would be very large, requiring strong justification and a staged approach that could be discontinued when enough information has been obtained. The tentatively planned penetration of Paleozoic rocks (i.e., of the carbonates if the Eleana Formation is not too thick) in the three G-series holes (see response to recommendation 4) is a part of this approach. Given the Panel's overall conclusions disputing Szymanski's theory and his proposed field evidence, such an expensive drilling program would not seem to be justified for purposes of more modeling tests solely to further examine the upwelling theory. However, additional deep drilling could prove to be justified for purposes of hydrogeology (for climate-effects and transport modeling), evaluating igneous activity, and natural-resource assessment. Should this be the case, then elastic parameters will be determined in addition to the hydrologic properties. However, the carbonate aquifer is composed of extensive marine limestone and dolomite, for which elastic and matrix-hydrologic properties are reasonably predictable from the literature, as supplemented locally from seismic properties, outcrop studies, and a limited number of core samples. This approach will result in looser constraints on the modeling discussed in Recommendation 22, but the need for greater constraint does not appear to be strong.

NAS Recommendation 24:

"Moreover, the dependence of the results [of modeling water-table response to earthquakes] on the unsaturated porosity of the vadose (unsaturated) zone requires that more knowledge of the properties, character and history of the unsaturated zone be obtained." [p. 118]

DOE Response:

Studies of unsaturated-zone hydrology comprise the most extensive set of site-characterization investigations. In addition to the data already available, large amounts of data on porosity, degree of saturation, permeability (as a function of saturation), and chemical and isotopic composition will be obtained from numerous drill holes at the site.

NAS Recommendation 25:

"The panel is aware that fault studies are in the site characterization plan. Considering the large uncertainties in fault slip rates, lengths of faults, and ages of offsets, the panel strongly endorses studies to obtain the data necessary to reduce the uncertainties in the probability estimates." [p. 124]

DOE Response:

DOE appreciates the Panel's endorsement and acknowledgement that the current site characterization program recognizes these information needs. Investigations of faulting are fundamental to the tectonics program, indeed to the entire geologic program. The planned studies include almost every conceivable means of gathering data that will address Quaternary fault slip rates and displacement history.

NAS Recommendation 26:

"The panel recommends studies aimed at an improved understanding of the in-situ properties and characteristics of the three-dimensional hydrologic system, the paleohydrological setting of Yucca Mountain, and the modern processes that control recharge of aquifers underlying the site to constrain better the models of the effects of increased precipitation. The hydrologic model that is used as a starting point and the results of three-dimensional modeling must be internally consistent with chemical and isotopic variations found in waters in the region." [p. 136]

DOE Response:

Several recommendations in the main body of the report are summarized here. DOE agrees with the panel that future work should focus on an integrated understanding of the behavior of the Yucca Mountain hydrogeologic system in three dimensions, the paleohydrology of this setting, and controls on aquifer recharge under present and possible future climates. DOE considers the steep hydraulic gradient to be principally a reflection of hydrogeologic conditions that may greatly influence the system's response to credible processes such as climate change or the development of new or refreshed fault-controlled flow paths.

NAS Recommendation 27:

"To provide a broader basis for predicting water table behavior related to volcanic intrusions, and for establishing probabilities for renewed volcanic activity during the life of the proposed repository, the panel recommends the following additional studies.

1. A study should be undertaken to model the coupling of the poro-elastic and thermal effects of an intruding dike on the water table. This may provide a more realistic basis for predicting the maximum potential effect on the water table in the vicinity of the intrusion. The likelihood of such an intrusion within a significant distance based on such analysis can then be refined accordingly.

2. Earthquake wave studies have identified a columnar zone of low velocity crustal material under Crater Flat extending from the Moho, about 30 km beneath the surface, to about 12 km below. This suggests the possibility of partially molten rock in the form of intrusions at lower crustal depths. To determine the presence or absence of molten rock, the panel recommends more detailed, higher resolution seismic measurements and analysis be undertaken, including the analysis of shear (S) waves, which are more sensitive to the presence of fluids, and the use of fluid-sensing seismic reflection profiling techniques." [p. 137]

DOE Response:

1. Study Plan 8.3.1.8.1.2 (Physical Processes of Magmatism and Effects on the Potential Repository) consists of three activities. One of these, Subsurface effects of magmatism, includes studies related to structural controls on intrusion paths, intrusion geometry, mechanical effects on wall rock, hydrothermal activity, and long-term hydrologic effects (e.g., blocking of flow paths by the presence of a dike). Coupled poroelastic and thermal effects, using the FEHM code, are addressed by the study.

2. As discussed in response to the Panel's Recommendation 18, DOE plans additional geophysical and other studies of the teleseismic anomaly. However, rather than committing at this time to the recommended studies, we believe that a thorough review of existing data as well as of the capabilities and reliabilities of candidate methods is a prudent first step. A very important data set will result from the seismic-reflection line across the Amargosa Valley; any firm decision as to future investigations must consider these results.

NAS Recommendation 28:

"The panel considers an understanding of the local hydrologic system and particularly the nature and source of the steep E-W trending hydraulic gradient located approximately 1.5 km north of the proposed repository site foremost among the problems that must be addressed early in the site characterization process. Existing hydrologic models of ground-water flow and the hydraulic gradient are somewhat simplistic because of lack of reliable information. ...Specific predictions regarding hydraulic head, head gradients, permeability, thermal gradients and in situ stress [throughout depths encompassing the Tertiary rocks and the deeper Paleozoic aquifer] need to be made to distinguish among competing models for the source of this gradient. The panel recommends that data relevant to these parameters be measured and collected in-situ in boreholes." [p. 140]

DOE Response:

DOE agrees in principle with this recommendation. However, please refer to the response to Recommendations 4, 10, and 11 for discussion of the caveats that dictate a phased and prudent approach. Uncertainties regarding the system can never be reduced to zero, so the need for additional knowledge must be evaluated within the context of the residual possibility of conditions that could credibly lead to a loss of waste isolation.

NAS Recommendation 29:

"The panel regards the general approach to acquiring the data needed for characterization of the Yucca Mountain regional flow system as given in the Study Plan 8.3.1.2.1.3 to be sound. Continued review of available data, coupled with the judicious use of preliminary modeling results, provides a useful framework for guiding and prioritizing future data collection. However, the panel cautions that the sole justification for data collection cannot be reduction in the uncertainties in existing models of the system. Adequate site characterization for Yucca Mountain will demand an understanding of vertical, as well as lateral, fluxes of ground water and so will require new modeling delineating the flow system in three dimensions, considering the carbonate aquifer, the volcanic aquifers and the unsaturated zone.

To address the hydrologic information needs, the panel recommends new and additional drill hole data. Planning the depth of such drill holes must be done with the above objectives of testing the flow systems in mind and not simply with the goal of better defining the water table.

Direct measurements of hydraulic head, head gradients, hydraulic parameters, and chemical and isotopic compositions of ground waters of both the Tertiary volcanic and Paleozoic carbonate aquifers are essential. They require a series of thoughtfully placed deep (about 2000 m or greater) wells extending well into the carbonate aquifer. These wells should be located both in the vicinity of the hydraulic gradient and elsewhere for regional characterization. Current plans for "deep" holes described in Study Plan 8.3.1.2.1.3 are, in the panel's view, inadequate: in the crucial area of the unexplained high hydraulic gradient just north of Yucca Mountain only relatively shallow water table wells are planned." [pp. 140-141]

DOE Response:

DOE agrees with the Panel's recommendation for an understanding of the three-dimensional hydrologic system, including coupling of the deep carbonate aquifer, the saturated volcanic section, and the unsaturated zone. Similarly, DOE agrees with the types of data required to support and constrain models of this system. DOE has reservations, however, in the degree to which the project can comply with the implied scope and extent of the Panel's recommendation (and, consequently, the cost), for (a) interference testing to provide hydraulic parameters, and (b) intensive hydrologic and mechanical testing of the deep carbonate aquifer. The required depths of investigation to achieve reasonable penetration of the carbonates would substantially exceed 2,000 meters in the site area itself. Drill hole UE25-p#1, which penetrated the Paleozoic rocks at a depth of 1280 meters, was intentionally sited on a gravity high. Westward from there across Yucca Mountain to easternmost Crater Flat, depths of 2,000 - 3,000 meters are to be expected to the top of the carbonate rocks. Farther north, in the zone of steep hydraulic gradient, both holes USW G-1 and USW G-2 were drilled to 1830 meters without reaching the base of the Tertiary section. It appears that substantial thicknesses of Eleana Formation clastics may be present between the Tertiary volcanics and the Paleozoic carbonate aquifer.

There has been a serious reassessment of the planned depths for water-table (WT-series) drilling as expressed in the SCP and pertinent study plans. Recommendations for greater penetration of the saturated zone must be balanced

against others calling for less penetration in order to hydrochemically sample and monitor the uppermost saturated zone. For several reasons, the balance favors moderate penetration of the Tertiary section beneath the water table for most of the WT holes. Drilling WT holes of the existing type can be accomplished less expensively and more quickly than holes planned for much greater depths, and those that are planned will help to define the large gradient more precisely, helping in siting holes to investigate its cause. The savings achievable by combining shallow and deep objectives are not large.

DOE believes that a reasonable first objective for defining the three-dimensional hydrologic system would be to develop a broad, spatial understanding of the hydraulic, hydrochemical (including isotopic), and thermal characteristics in order to develop fairly high certainty in our conceptual understanding. With the emphasis on breadth rather that density of study, there would be little opportunity for additional interference testing to improve hydraulic-properties tests of the rock mass. A second objective would be to reduce uncertainty as to the system hydraulics until that uncertainty is acceptable.

NAS Recommendation 30:

"With the foregoing considerations in mind, the panel strongly recommends that DOE appoint a scientist as site characterization project coordinator. Such a person should not be currently associated with any of the participating organizations. That scientist should have a reputation for independence and excellence, as well as the experience in managing and integrating interdisciplinary programs. Such a scientific leader would lend further credibility to these investigations and their results. No large scale multidisciplinary study of this type known to the panel has been undertaken without a strong scientific leader guiding the coordination and integration of the ongoing efforts of the various parts of the project. It is the panel's opinion that had there been such a leader at the inception of this program, the controversy that brought this panel into existence would most likely not have developed, as the various working hypotheses would have been considered and addressed in an earnest and well-coordinated approach early in the program. Moreover, an integrated program guided by a strong scientific coordinator would probably have identified the steep hydrologic gradient early on as a major project-wide concern and would have approached it from a multidisciplinary point of view." [p. 142]

DOE Response:

The problems of communication and integration cited by the panel are common to large, complex, multi-disciplined programs. DOE's site characterization program for Yucca Mountain is certainly not unique in this respect. An emphasis on data synthesis had not been expected in the eaerly years of site characterization, when the primary emphasis was to be data acquisition. At this time, DOE would agree with the panel that data synthesis of existing information for site characterization has been weak. DOE expects this situation to improve with a Management and Operating contractor now on the program. More emphasis on data synthesis of existing information would indeed help the project to better define questions about what information is needed from the characterization program, and how best to answer them with finite resources. DOE agrees with the Panel in that strong scientific leadership is necessary for the project to thrive.

Seeking one person, however, to provide this leadership is probably not a realistic option. The science coordinator advocated by the panel would be a difficult position to fill. The combination of experience, knowledge, and personality traits needed by such a person are sought by many companies, agencies, and universities. Frankly, it would be difficult to identify, hire, and retain such a candidate in government service with the DOE. Many fine scientists are investigators managers in our program, both within the federal service, the national labs, and in contractor organizations. They are, in effect, science coordinators. This expertise is our strongest asset and central to successful conduct of the site characterization program.

With respect to a complex management structure, the DOE agrees that the present spectrum of participants is potentially a difficult management problem. The present mix of participants did not evolve without a purpose, however. Some organizations involved in our program, for example the U.S. Geological Survey, provide a degree of independence and technical credibility that a contractor hired by DOE simply would not have in a program where there is such a high degree of public concern. In seeking to employ the best people possible to

conduct site characterization work, much of which involves unique or state-of-the-art technology, it is necessary to identify these men and women - and retain them. Consequently, they may not work for the usual national laboratories that DOE has historically drawn upon for technical expertise. DOE would need to retain them where they do work. It would be most efficient to bring all of these people under the umbrella of one dedicated organization, but such an expectation is not realistic.

In summary, DOE agrees with the Panel that the program would benefit greatly from more integration and coordination of the scientific focus for characterization. For the reasons explained above, DOE believes the problems are recognized or have been accepted as part of an inherently complex program. DOE is always looking for good scientists to become involved in the site characterization program. If the panel has any suggestions concerning potential candidates for science coordinators, DOE would be glad to hear them.

NAS Recommendation 31:

"The panel, therefore, wishes to register a plea for greater flexibility in allowing the scientists room to exercise their disciplines as they have been trained and as they know their expertise will be most effective. Within the framework of a well-coordinated program guided by a strong scientific leader, the panel believes such an approach can provide quality assurance and other regulatory needs while allowing scientific latitude to flourish. It can only result in greater enhancement of the scientific achievements of the program." [p. 143]

DOE Response:

DOE understands the Panel's recommendation that the program nurture a milieu that provides for inspired and intuitive work and maintains principal investigator (PI) flexibility to conduct site characterization. We believe that the program allows this now. This concern has been raised over the years as DOE has implemented a quality assurance (QA) program for site characterization. Really, all that the QA program requires is that, within the requirements, one works to approved plans and procedures. The mere existence of study plans is not detrimental to the scientific process and these plans can be changed. If a PI decides to depart from approved plans or procedures to pursue a different approach, the plans and procedures need to be revised to show this. Aside from the need for this documentation, constraints on a PI's latitude for how to conduct work are not excessive. The inspired work of these good scientists is why DOE has sought out their expertise in the first place. Where DOE management maintains awareness is in asking and answering the question of "How much is enough?" This question comes to the awareness of the entire program when budgets are drawn up, replanned, and finally approved. Site characterization is, after all, a goal-oriented, applied research program.

In years past, the QA program probably has tended to lean toward overprescriptiveness. With further experience, especially in the field, the need for documentation and the scientific research process has found a more workable balance. We will continue to become smarter in this respect as we proceed.

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