REVIEW OF STUDY PLAN 8.3.1.2.3.3 - SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

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1.0 INTRODUCTION

Performance assessment of a high-level waste (HLW) geologic repository will require an understanding of groundwater flow at the repository site in order to determine the transport of radionuclides from the repository to the accessible environment. Therefore, synthesis and modeling of the site saturated-zone hydrologic system is necessary before radionuclide transport can be estimated.

2.0 REVIEW CRITERIA

The review of this Study Plan (SP) follows on the procedure documented in "Review Plan for NRC Staff Review of DOE Study Plans, Revision 2" (NRC, 1993). The portion of the Review conducted at the Center for Nuclear Waste Regulatory Analyses (CNWRA) focuses on the ability of the activities, tests, and analyses proposed in the SP to provide the data for licensing that the study plan was designed to provide.

3.0 SUMMARY OF STUDY PLAN 8.3.1.2.3.3 AND GENERAL CONCERNS

Study Plan 8.3.1.2.3.3 follows the outline presented in the Site Characterization Plan (SCP; DOE, 1988), and is divided into three activities. These include:

> Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment;
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> Activity 8.3.1.2.3.3.2 - Development of fracture-network model;
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> Activity 8.3.1.2.3.3.3 - Calculation of flow paths, fluxes and velocities within the saturated zone to the accessible environment.

The study plan is comprehensive and generally broad in nature and is likely to provide the information needed for evaluating the site saturated-zone hydrologic system. However, the SP is not well organized and does not provide much detail on the specific type of work to be performed. To some extent, the lack of detail is justified because much of the outlined work depends on input from other studies, such as, Regional Hydrologic Investigation (SP 8.3.1.2.1), Site Unsaturated-Zone Hydrology Investigation (SP 8.3.1.2.2), Regional Hydrologic System Synthesis and Modeling (SP 8.3.1.2.1.4), Site Unsaturated-Zone Modeling and Synthesis (8.3.1.2.2.9), and Testing of C-Hole Sites with Reactive Tracers (SP 8.3.1.2.3.1.7).

Data consistency has to be maintained between all the studies mentioned above. In order for this to occur, the information base has to be reasonably complete and the models have to be the most appropriate. However, from this SP, it is not clear that the information base will be complete nor is it clear that the selected hypothesis (or hypotheses) will be the most appropriate to characterize groundwater flow through the site saturated zone.

Currently, in SP 8.3.1.2.3.3, the proposed method of hypothesis identification and testing is not adequately defined. The use of an equivalent porous medium (EPM) model is proposed in Section 3.1. However, without further elaboration, and irrespective of the findings of the previous activity, a fracture-network model is advocated in Section 3.2 as the model hypothesis of choice. Lastly, in Section 3.3, there is discussion of testing the proposed hypotheses to select the most appropriate to represent saturated-zone flow. Hypothesis identification and testing in the selection of information types and modeling approaches should be conducted at the onset of the study using available data without an *a priori* biased selection of modeling method. However, this SP predicates modeling methodology on preselection of technical approach and proposes alternative hypotheses in the last activity of the study, during the calculation of flow paths, fluxes and velocities. Hypothesis identification should be conducted early in the course of the study. The hypotheses of interest should be identified during the conceptualization portion of the study. All hypotheses which merit consideration should be formulated during activity 2, that is model development. The hypotheses can then be evaluated during the last activity when calculations are made using the models.

Essentially, all of the tasks in this study are predictive in nature. A more thorough study should also include hydrogeologic information to provide historical evidence of site-specific groundwater velocities and travel times. Although predictive modeling would remain the principal means of assessing the performance of a geologic repository, use of groundwater dating techniques could support or bound predictive calculations of groundwater flow and solute transport of conservative tracers.

3.1 Conceptualization of saturated-zone flow models within the boundaries of the accessible environment (Activity 8.3.1.2.3.3.1)

This activity presents a plan for developing conceptual and numerical models of groundwater flow in the saturated zone. The activity is to include the development of hypotheses concerning groundwater flow, hypothesis testing, incorporation of tenable hypotheses into one or more conceptual models, and the transformation of conceptual models into mathematical numerical models of groundwater flow. Although the overall approach described in Section 3.1 appears reasonable, there are areas that could be improved. In particular, the basic approach of hypothesis identification, testing and assessment is not presented in Section 3.1. This approach does not become apparent until Section 3.3. After stating the basic approach, the general hypothesis categories of fracture-network, equivalent porous medium (EPM) and combined (or hybrid) models should be presented.

In general, the section is difficult to follow because it is repetitive and not well organized. Its length could be significantly reduced without sacrificing technical content. The SP should include plans to use geochemical information (e.g., estimates of groundwater ages) as a means of evaluating the validity of the models. Also, neither the SP nor the Site Characterization Plan (SCP) addresses the question of whether measurements and samples collected in uncased wells are representative of targeted intervals.

3.2 Development of fracture-network model (Activity 8.3.1.2.3.3.2)

The essence of the development of a model of the site saturated-zone is predicated on representing the aquifer with a fracture-network model. The objectives of Section 3.2 are to (1) develop and evaluate flow and transport methods and (2) assess these methods using tracer tests. The approach is predisposed at formulating a model based upon discrete fractures and/or fracture networks. Construction of these models assumes, *a priori*, that the site fracture systems can be identified using geophysical or other measurement methods. The models are to be validated by comparing results predicted using the fracture-based models with pumping and/or tracer test results from the site (e.g., C-well tests) or other appropriate sites.

Assessment of an EPM model or comparison of the discrete-fracture models with an EPM model is not proposed as a priority task. Instead, an EPM model is only proposed as a possible alternative should the discrete model prove to be untenable or inadequate. Although an approach to assessing the merits of a continuum, discrete and hybrid modeling method is presented on page 3.3-9 of Section 3.3.3.1, this approach is not proposed when the models are conceptualized in Section 3.1 and formulated in Section 3.2.

3.3 Calculation of flow paths, fluxes and velocities within the saturated zone to the accessible environment (Activity 8.3.1.2.3.3.3)

This activity is intended to provide a comprehensive description of material properties by: (i) evaluating the validity/applicability of equivalent porous media and discrete fracture-network concepts; and (ii) estimating ground-water flow velocity fields to be used in groundwater travel time calculations. However, as also stated in the discussion of Section 3.2, the hypotheses should be tested earlier in the project, that is during the conceptualization of the study. Furthermore, as pointed out in this review, some of these analyses are proposed in the SP to be conducted under activities of Section 3.1. Therefore, it is evident that Sections 3.1, 3.2, and 3.3 were not written in a coordinated fashion.

As far as specific technical merit is concerned, Section 3.3 leaves several important issues not addressed. Specifically: (i) Even though the authors of the SP recognize the limiting effect of data sparsity in material properties, only a subtle reference (in the wrong section) to inverse modeling is made; (ii) The hypothesis of discretely defined fracture networks within fault-bounded rock, which is assumed to be an EPM is questionable; and (iii) the SP does not explain how the case of no unique hypothesis, for flow and transport modeling along faults, is to be treated numerically.

4 SPECIFIC OBJECTIONS, COMMENTS, AND QUESTIONS

4.1 Objections

None.

4.2 Comments

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 1

An appropriate approach toward determining the relative merits of discrete fracture network, continuum and hybrid modeling methods as presented in Section 3.3, should also be included in Section 3.1, the time during which the flow and transport models are hypothesized and conceptualized.

Basis

There are no specific hypotheses mentioned in Section 3.1 other than: "will examine the influence of the underlying Paleozoic aquifer on the Tertiary tuff aquifer and the impact of large-scale structural features on ground-water flow." The only explicit referral to the fact that an EPM approach is assumed in this activity is in Section 3.1.3.1, page 3.1-10, stating that "particularly because equivalent-porous-media concepts are being assumed on a site scale in this first activity."

The decision to use a discrete fracture network model is advocated *a priori* in Section 3.2 as evidenced by the title of the section, Development of Fracture Network Model, and in the organization of this section. An unbiased approach to assessment of conceptual models is defined in Section 3.3. A parallel unbiased approach should be included in Section 3.1, during model conceptualization and in Section 3.2, during model formulation.

In Section 3.3.2, page 3.3-1, it is stated that "It is crucial that a careful evaluation be made of the alternate concepts of equivalent-porous-media and fracture networks." Furthermore, in Section 3.3.3, page 3.3-1, it is stated that "Two analyses will be performed...previously: (1) characterization of spatial variation and scale effects in aquifer properties..." According to the SP (page 3.1-7) this activity should be conducted under 3.1.3.1 (data synthesis and preliminary hypothesis testing).

Recommendation

Section 3.1, Conceptualization of Saturated-Zone Flow Models and Section 3.2, Development of Fracture-Network Model, should be recast so that the general modeling approachs (e.g., discrete-network, continuum or combined) are identified and a single approach is not determined *a priori*. The modeling approach of choice should not be determined until all approaches are identified (Section 3.1), formulated (Section 3.2) and assessed (Section 3.3).

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 2

The conceptual model(s) should be evaluated using the same numerical code used in hypotheses analysis.

Basis

In Section 3.1, page 3.1-7, the SP states "The conceptual model(s) will be evaluated by a derived mathematical/numerical model that may or may not be the same numerical modeling code as used in analysis of the various hypotheses, based on the professional judgment of the investigator(s)." This statement makes sense only in the case of a rejected hypothesis. When a hypothesis is being considered tenable and, therefore included in the conceptual model, this reviewer believes that the same numerical model must be used, unless another model being used is "truly" satisfying the hypothesis which was studied previously.

Recommendation

The SP should be recast to either: (i) explain how a different code will be used and, at the same time, satisfy a hypothesis which it never tested; or (ii) make use of the same numerical code.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 3

Analyses that are classified as high-risk in terms of achieving the desired objectives should be identified in the SP.

Basis

In Section 2.1.4, page 2.1-11, it is stated, "Because of the nonstandard nature of some of the analyses, the possibility that one or more analyses may fail in achieving the desired objectives is recognized." Even though the SP suggests that the "use of multiple approaches for modeling analysis increases confidence that the failure...will not severely inhibit...the required information," it would be useful to know which approaches are considered as high-risk by the authors of the SP.

Recommendation

Clearly state which modeling approaches are considered high-risk and identify how other methodologies might accommodate in the case failure.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 4

Is the prospect of geophysical methods, other than cross-hole seismic, fracture stiffness assessment, or vertical seismic profiling, for the purpose of fracture assessment to be considered?

Basis

In Section 3.2.3.1.2, page 3.2-7, the application of cross-hole seismic tomography, fracture stiffness evaluation using shear waves or vertical seismic profiling is suggested as the means with which to constrain the geometry of the fractures and define the structure of the site saturated zone.

Recommendation

The potential of other geophysical methods (such as high-resolution seismic reflection, electrical, or electromagnetic methods) to characterize the structure and properties of the site saturated zone should be explored.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 5

Administrative Procedure Yucca Mountain Project (YMP) AP-5.9Q, "Qualification of Data or Data Analyses Not Developed under the Yucca Mountain Quality Assurance Plan," and U.S. Geological Survey (USGS) YMP procedures QMP-5.05, "Scientific Notebook System," and QMP 3.14, "Software Configuration Management System" should be identified in the Quality Assurance (QA) requirements matrix, Section 7.1.1, as documents addressing scientific investigations QA criteria.

Basis

Data collected or developed outside of an acceptable YMP QA program may be used in calculations or analyses in this activity. The USGS YMP Management Procedures Manual invokes YMP AP-5.9Q for existing data qualification.

This SP involves scientific investigations, which should be documented under the scientific notebook system (QMP-5.05), which applies to "all USGS and contractor personnel assigned to perform work related to QA-graded technical activities that produce data, maps, or support any other product that is a basis for the YMP site characterization or licensing."

The configuration of computer codes developed as a result of this study should be controlled as specified in QMP-3.14. QMP-3.03, "Scientific and Engineering Software," is correctly identified in the QA requirements matrix, however, the associated configuration control of that software is not identified in the QA requirements matrix.

Recommendation

Include procedures AP-5.9Q, QMP-5.05, and QMP-3.14 in the QA requirements matrix of Section 7.1.1 of the Study Plan.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 6

Correctly identify all investigations, studies, references, activities, tables, and associated captions that are relevant to the planned work.

Basis

In Section 3.1.3.2, page 3.1-10, Study 8.3.1.2.2.9 is misidentified as 8.3.1.2.9.9.

Table 2.1-1 is misidentified as Table 2.3-1 in Section 1.3 on page 1.3-2.

Table 1.1-1 has no caption on page 1.3-1.

Table 3.3-1 should read in the caption "(SCP 8.3.1.2.3.3.3)" and not "(SCP 8.3.1.2.3.3)" on pages 3.3-15 and 3.3-16.

Some studies are misidentified and/or mislabeled in the text:

— In Section 3.1, page 3.1-2 the activity of evaluating matrix diffusion is included as an objective only in SCP 8.3.1.2.3.1.5 and not in SCP 8.3.1.2.3.1.7.

— Figure 3.2-1, page 3.2-3, Study 8.3.1.4.2.2 (Development of geologic models of fracture-network geometry), is incorrectly identified as 8.3.1.4.2.1.

— Table 3.3-1, page 3.3-14, the potentiometric surface is classified as a site-characterization parameter of activity 8.3.1.2.3.3.3 and not of activity 8.3.1.2.3.3.1 (see SCP, page 8.3.1.2-36).

There are some errors in the text:

— Table 3.3-1, page 3.3-15, "Ground-water flux velocities" should read "Ground-water flow velocities."

— Table 3.3-1, page 3.2-19, "multiple-sell" should read "multiple-well."

Some references are not complete:

— Page 3.2-13, Geldon (in press) should have a date.

Recommendation

Make sure that all relevant investigations, studies, references, activities, tables, and associated captions are included and consistently referenced.

4.3 Questions

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 1

How are the developed model(s) to be submitted to peer review? Will this process also include models already in use? What specific measures, beyond standard QA software configuration control, are going to be incorporated?

Basis

In Section 2.1.7, page 2.1-14, it is stated that model(s) used in this study will be submitted to the peer review process. Does this also imply that until such process is completed the models cannot be used in the course of the study? Furthermore, on page 3.1-11 it is stated that "Peer review of the model(s) will also constitute part of the validation process."

Recommendation

Clearly state how the peer review process of model validation will be implemented.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 2

Will there be any coordination of schedules between this study and activity 8.3.1.4.2.2 (Characterization of the Structural Features within the Site Area)?

Basis

In Section 2.2.4, page 2.2-2, a description of how the schedule of this study and activity 8.3.1.2.3.1 is presented. An integral part of this SP is the fracture network study, which depends on fracture data collected under SCP activity 8.3.1.4.2.2 (Characterization of the Structural Features within the Site Area).

Recommendation

Enhance the SP to reflect the coordination of all relevant data collection activities (more specifically 8.3.1.4.2.2) within the conduct of this SP.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 3

No field data are to be collected under this SP. However, field data collected under other SPs will be used to formulate and calibrate the conceptual and numerical models developed under this plan. How much of this data will be derived from uncased wells that are open over hundreds of meters of the saturated zone?

Basis

Well construction details are presented in Table 3-24 of the Site Characterization Plan (SCP). In uncased wells, water from one saturated interval may invade another, thereby altering hydraulic heads and water chemistry in the invaded interval. Neither the SP nor the SCP contain a description of the steps that are to be taken to ensure that hydraulic head and water chemistry data are representative of the sampled interval.

Recommendation

The SP should be revised to include descriptions of procedures taken to ensure that data derived from uncased wells are representative of the sampled interval. If such procedures are not implemented, an explanation of why they were unnecessary, or an evaluation of the representativeness of the data should be provided.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 4

Since quantitative model validation will be an integral part of the hydrologic modeling strategy proposed in the study plan, should not a well-defined QA program be implemented to ensure that the data used for model calibration and model validation are not the same?

Basis

In Section 3.1.3, page 3.1-1, it is stated that "The resulting mathematical/numerical model will undergo a validation process as discussed in Section 2.1.6." The definition of model validation outlined in Section 2.1.6, page 2.1-13, states that the data used for calibration and sensitivity analyses must not be the same as the data used for model validation. The definition also states that for cases where data are insufficient cross-validation procedures may be used instead.

Recommendation

In order for a model to be accepted as having been quantitatively validated, DOE must be prepared to not only provide the results of the validation exercise, but also to prove beyond a reasonable doubt that the data used for validation were not the same as those used for calibration. Rigorous proof may require that a well documented, stringent data control system be implemented which will ensure that those in charge of developing and calibrating the models have had no access to the validation data.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 5

What specific approach or activities will provide the necessary information to examine the influence of large-scale structural features on groundwater flow?

Basis

In Section 3.1.3.1, page 3.1-6, it is stated that "Conceptual model development will include a three-dimensional (3D) layered approach that incorporates structural geology as observed from geophysical and borehole evidence. This approach will examine...ground-water flow." However, there is no direct mention of either the types of data or the SPs required to collect the data to test this hypothesis.

Recommendation

Clearly identify the types of data and the data collecting methods needed to test the impact of large-scale structural features on groundwater flow or cite the SPs where this information can be found.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 6

Will inverse modeling be used in this study? If so, in what form?

Basis

In Section 3.1.3.1, page 3.1-7, the SP states that "The only parameter for which there is a large enough data set is hydraulic head." In the same section it is repeatedly implied that some of the proposed methods may not be successful due to lack of data. The only reference of the possible use of inverse modeling comes in Section 3.3, page 3.3-7, where the SP states that "For flow properties, inverse modeling techniques may prove useful."

Recommendation

The SP should clearly state if inverse modeling is to be used. Moreover, this should be proposed in Section 3.1 and not in Section 3.3, when the conceptualization of the process has already been finalized.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 7

What method is to be used for incorporating soft information in the analysis? Are the authors of the SP going to use indicator kriging or perhaps more exotic techniques (e.g., Journel, 1983; 1986) for this analysis?

Basis

In Section 3.1.3.1, page 3.1-7, the SP suggests that in order to compensate for the sparsity of data, methods "to incorporate soft information into the analysis" can be implemented. Various types of soft data are suggested as useful sources of information, yet no specific technique of performing such a procedure is mentioned.

Recommendations

State what method(s) this study will use to incorporate soft information into the conceptual and numerical models.

References

Journel, A.G. 1983. Non-parametric estimation of spatial distributions. *Mathematical Geology* 15(3): 445-468.

Journel, A.G. 1986. Constrained interpolation and qualitative information - the soft kriging approach. *Mathematical Geology* 18(3): 269-286.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 8

Is it possible to use a method to test whether data density is sufficient and, at the same time, make assertions regarding the limitations that lack of data may impose?

Basis

In Section 3.1.3.1, page 3.1-7, it is stated "test that data density is sufficient to recreate the initial conductivity field." However, later on it is stated, "Lack of data, again, may prove to be the limiting factor in this analysis." This methodology is plagued by a conceptual contradiction, unless it is based on an iterative process, which gradually builds the data base, tests result reproducibility, etc..

Recommendation

Rephrase the SP to reflect the fact that only under an iterative process of data collection, synthetic field generation, and analyses, can data density adequacy be tested. Under such a framework, a certain amount of data is collected and some preliminary statistics are calculated. Then, synthetic generation of conductivity fields and analysis takes place. If the analysis reveals that more data are needed, the process should be repeated until the conductivity field can be statistically reproduced.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 9

Is the use of effective properties not being considered as an option in the numerical simulation, irrespective of the size of the features?

Basis

In Section 3.1.3.2, page 3.1-10, the SP states "The numerical-model mesh will be fine enough so that the major features of the system can be represented." Due to the fact that there exists specific code- and computational system-dependent constraints, is it appropriate to *a priori* claim that the mesh will be fine enough? It is obvious that if a feature is considered major from the hydrologic point of view, yet is moderately small in physical size, excessive computational requirements may render the simulation nonfeasible.

Recommendation

Rephrase the SP to relax the *a priori* selection of mesh size so that some form of effective properties is incorporated in case major hydrologic features are small in physical size, in the case the selected numerical code cannot handle such fine discretization.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 10

Is it necessary to use Monte Carlo simulations in the case of sufficient data availability?

Basis

In Section 3.1.3.3, page 3.1-12, it is stated "If enough data are available, Monte Carlo simulations may be made to evaluate the effect of changing a component's spatial distribution." In principle, Monte Carlo simulations can be used in situations where the only information known or assumed is some form of statistics of the component's distribution. It may not be necessary to rely on computationally expensive techniques, such as the Monte Carlo approach, when sufficient data are available.

Recommendation

Implement a method less expensive than the Monte Carlo approach, or rephrase the SP to reflect the fact that Monte Carlo techniques can be applied in situations where little data is available.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 11

The plan does not state whether the validity of conceptual or numerical models will be evaluated by comparing them with geochemical data. Are there to be analyses of environmental tracers such as carbon-14, tritium, oxygen-18, and deuterium that may provide information regarding sources of recharge, discharge areas, flow paths, the degree of mixing between hydrologic units, and groundwater travel times?

Basis

Section 3.1.3.2 discusses the development and validation of conceptual and numerical models. The only reference to using geochemical data occurs in the last paragraph on page 3.1-10. "Matching of simulated versus observed hydraulic heads, fluxes, gradients, and possibly geochemistry, and comparison of model results with past data will constitute the calibration process. Closeness of the simulated model results to the observed data will be judged by the investigators and by the methods discussed in Section 2.1.6." Section 2.1.6 refers to geochemical data only once: "In addition, the calibration process will involve an examination of the observed versus predicted water levels, gradients, fluxes, and possibly geochemistry produced from the flow model."

Recommendation

The Study Plan should explicitly include plans to evaluate the validity of the conceptual and numerical models by comparing them with geochemical data. If necessary, plans to collect additional geochemical data should be modified to ensure that necessary information will be obtained. This information includes estimates of groundwater ages and stable isotope ratios in recharge and discharge zones, in the vadose zone, with depth in the saturated zone, and along flow paths (Pearson and White, 1967; Bath et al., 1979; Freeze and Cherry, 1979; Fritz and Fontes, 1980; Kyser, 1987).

References

Bath, A.H., W.M. Edmunds, and J.N. Andrews. 1979. Paleoclimatic trends deduced from the hydrochemistry of a Triassic sandstone aquifer, United Kingdom. *Isotope Hydrology 1978*. Vienna, Austria: International Atomic Energy Agency 2: 545-568.

Fritz, P., and J.Ch. Fontes. 1980. The Terrestrial Environment. *Handbook of Environmental Isotope Geochemistry* 1: A: 66-67.

Freeze, R.A., and J.A. Cherry. 1979. *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Kyser, T.K. 1987. *Short Course in Stable Isotope Geochemistry of Low Temperature Fluids*. Toronto, Ontario, Canada: Mineralogical Association of Canada: 13.

Pearson, F.J., and D.E. White. 1967. Carbon-14 ages and flow rates of water in Carrizo Sand, Atascosa County, Texas. *Water Resources Research* 3(1): 251-261.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 12

How can data derived based on the EPM assumption be used for discrete fracture modeling?

Basis

In Section 3.2.2, page 3.2-1, the SP states that "Flow at Yucca Mountain is theorized to be dominated by the presence of fractures. On the scale of the site (km by km), it is doubtful whether porous-media equivalency will be able to be established in order to describe the flow system as completely as possible. This activity has been selected to develop methodology and models to describe fracture flow. The models will be initially tested at the C-well complex." This is in direct contradiction with Section 3.1, page 3.1-10, which states that "...parameters probably will depend on the scale of the model, as discussed...may or may not be closely related to the parameters that are measured at the boreholes, particularly because EPM concepts are being assumed on a site scale in this first activity. Flow on the local scale (for example, the C-well complex) may not be adequately represented by EPM concepts, whereas for flow at the site scale, porous media representation of the fracture formations may be acceptable." If it is doubtful whether porous-media equivalency can be established in order to fully describe the flow system, what is the purpose of using this approach?

Recommendation

Clarify whether the authors of the SP consider an EPM media approach appropriate for modeling the site.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 13

What is the scale of the fracture-network model discussed in the SP?

Basis

Section 3.2.2, page 3.2-1, refers to a "km by km" scale, and Section 3.2.3.1.3, page 3.2-11, refers to a scale of "100's of m." However, the proposed scale of the model is not explicitly stated in the text.

Recommendation

The proposed scale of the model should be identified.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 14

Are statistics of generated fracture networks to be compared with statistics obtained only from pavement data?

Basis

In Section 3.2.3.1.1, page 3.2-6, the SP states that "the measured statistics of the generated network will be compared to the statistics related to the pavement fracture network." There is no mention of a possible comparison with either borehole or drift fracture data.

Recommendation

The SP should be rephrased to reflect the fact that comparisons should be made between the generated fracture network statistics and fracture data obtained from pavements, boreholes, and drifts. Alternately, the SP may indicate the reasons for using only pavement data for comparisons.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 15

Can borehole data be used for applications such as conditioning fracture networks or validating models that generate fracture networks?

Basis

In Section 3.2.3.1.1, page 3.2-6, it is stated "Similarly, borehole-fracture data cannot be used to validate the model because knowledge of fracture lengths and interconnections will not be available." This is a generally correct, but not fully accurate statement, because one can estimate fracture lengths and connections from outcrop fracture data. Furthermore, if indeed "the generated fracture networks are (intended to be) statistically similar to those of Yucca Mountain," then it would be possible to make assertions regarding the lengths and connections using the generated, yet statistically similar, fracture network.

In Section 3.2.3.2.1, page 3.2-15, the SP states that "These networks will be conditioned so that fractures observed in the boreholes will be represented." However, there is no reference to a specific method that is to be used for this activity.

Recommendation

Specific reference to a numerical code or existing methodology capable of conditioning the generation of fracture networks or validating fracture network models, based on borehole data, should be made.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 16

At what separation are the boreholes that will be used to conduct the VSP and cross-hole seismic tomographic surveys? Since resolution declines as the separation increases, can fractures be detected using boreholes that are sufficiently separated so that the site is not excessively permeated with boreholes?

Basis

In Section 3.2.3.1.2, page 3.2-7, it is stated "The objective of geophysical conceptual-model development is...to refine the technique of mapping fracture properties between boreholes in the saturated zone," and "A three-dimensional seismic velocity map will be created by cross-hole tomography to examine vertical anisotropy as a result of the fractures in order to determine average fracture spacing."

In Section 3.2.3.1.2, page 3.2-9, it is stated that the seismic results will be used to constrain the geometry of the fractures. Since the depth or distance of resolution of the proposed geophysical methods is on the order of 10's of meters, or 100's of meters at most, a significant number of boreholes penetrating the saturated zone will have to be drilled even if only the most prominent of these features, such as the Ghost Dance Fault, is to be investigated, in order for these methods to be effective.

Recommendation

Provide an analysis that indicates the density of data collection and the scale of structure resolution using the proposed geophysical methods. From this analysis, model determination can be based upon the extent and resolution of data that will be reasonably expected, instead of incorrectly anticipating information that will not be made available.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 17

Are the concepts of discrete and stochastically derived fracture networks mutually exclusive?

Basis

In Section 3.2.3.1.3, page 3.2-10, it is stated "transport in a discrete or stochastically derived fracture network." This statement implies that a discrete fracture network cannot be stochastically generated.

Recommendation

Modify the identified statement to read "transport in a deterministic or stochastically derived discrete fracture network."

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 18

Why is a network of one-dimensional (1D) channels a more realistic representation of fractured rock than other possible conceptual models? Based on what data or theories did the authors of the SP conclude on the aforementioned statement?

Basis

In Section 3.2.3.1.3, page 3.2-10, it is stated that "A network of one-dimensional channels interconnected in three dimensions may be a more realistic representation of fractured rock." As an alternative, however, a network of interconnected planar features may provide a more realistic representation.

Recommendation

The SP should be rephrased to reflect the possibility that networks other than interconnected 1D channels, such as two-dimensional (2D) planar features, may be realistic representations of fractured rock. Alternatively, the SP may indicate references to literature or data that corroborate the stated assertion.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 19

Are solute transport modeling methods/techniques to be developed in Activity 8.3.1.2.3.3.2?

Basis

In Section 3.2.3.1.3, page 3.2-10, the third paragraph describes the solute transport modeling activities. Most of the solute transport modeling methods and techniques mentioned (i.e., adaptive griding) are areas of active research. It is not clear if all these techniques are to be developed and tested under this specific activity. If algorithms are to be adopted and utilized, an exhaustive description of the methods is not necessary. However, a selection of references should be provided.

Recommendation

Clarify whether the solute transport modeling methods/techniques mentioned in Section 3.2 are to be developed under this activity or not. If not, provide appropriate references.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 20

What does convective dispersion mean?

Basis

In Section 3.2.3.1.3, page 3.2-12, the SP states "...and investigating the character of convective dispersion." Do the authors mean "mechanical dispersion?"

Recommendation

Clarify what is exactly meant by the term "convective dispersion."

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 21

Is it possible to estimate fracture length distribution from outcrop data?

Basis

In Section 3.2.3.1.3, page 3.2-12, it is stated "fracture data to describe the distribution of fracture lengths...are not available specific to the C-well complex. Therefore, initial studies will consider fracture networks with uniform lengths and apertures." This is an appropriate initial estimate. In fact, it may be argued that length variability is not a crucial parameter. However, the statement in the SP, as presented, is not fully accurate since one can estimate fracture length distributions from locations where the formation of interest crops out.

Recommendation

Rephrase the SP to reflect that it is mostly due to the initial and preliminary nature of the studies that uniform lengths are considered and not lack of information. Also, make it clear that, in principle, fracture length distributions can be estimated from outcrop data.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 22

What exactly does the "statistical sense" imply in terms of the bounds of predicted results? Is some sort of confidence limit, based on hypothesis testing, going to be used?

Basis

In Section 3.2.3.2.2, page 3.2-17, it is stated "If the models are valid...actual results should be bounded in a statistical sense by predicted results." However, the SP does not explain exactly what to use for testing the validity of results.

Recommendation

Provide an explanation of how these "statistical sense" bounds will be calculated and used to check result validity.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 23

Will the SP consider well-test results point estimates of aquifer properties in the hydrological or geometrical sense? If a hydraulic well test with a radius of influence of 10 to 100's is considered a point estimate, why aren't geophysical tests with a depth of penetration of 10 m - 100 m also considered point estimates?

Basis

In Section 3.3.3.1, page 3.3-2, it is stated "At the scale of modeling in this activity...well-test results are essentially point estimates of aquifer properties." This is true in the context of physical scale only. Hydrologically, this measurement is incorporating a process of averaging of properties within a well's zone (radius) of influence. The radius of influence, in some cases, may be 10's or 100's of meters. However, in Section 3.2.3.12, page 3.2-7, VSP and cross-hole seismic tomography with an effective depth of penetration of no greater than 100's of meters are used to construct a 3D model of the subsurface.

Recommendation

The SP should clarify the context under which the "point estimate" assumption has been made with respect to well tests and "global estimates" made using geophysical measurements.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 24

Have recent findings regarding the correlation between seismic and hydrologic properties been reviewed?

Basis

In Section 3.3.3.1, page 3.3-6, it is stated "...would depend on...and success relating seismic-wave propagation to hydrologic properties." The authors should review the papers by Rubin et al. (1992) and Journel et al. (1992), or other similar documents with regard to recent applications of the relationship between seismic and hydraulic properties.

Recommendation

Update the SP in terms of recent literature citations, particularly for applications when novel techniques are proposed.

References

Journel, A., W. Xu, and T. Tran. 1992. Integrating seismic data in reservoir modeling: The collocated cokriging alternative. *Report 5*. Stanford, CA: Stanford Center for Reservoir Forecasting.

Rubin, Y., G. Mavko, and J. Harris. 1992. Mapping permeability in heterogeneous aquifers using hydrologic and seismic data. *Water Resources Research* 28(7): 1809-1816.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 25

Would a solute transport model with the longitudinal dispersivity different than the transversal dispersivity adequately represent the preferential direction of transport along fractures?

Basis

In Section 3.3.3.1, page 3.3-8, the third paragraph states that the available "models often cannot account adequately for dispersion." However, for example, if a solute transport model is used with $\alpha_L >> \alpha_T$, it may be possible to reflect the fact that orientation of fractures is in the longitudinal rather than in the transverse direction. Furthermore, since $D = \alpha V$, the flow velocity is taken into account and, therefore, fractures which are more efficient conduits for flow and solute transport are accommodated.

Recommendation

Reword the third paragraph to provide for alternative fracture flow solute modeling concepts.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 26

Why should local variability induced by the fracture networks within fault-bounded blocks of rock be considered significant when the whole rock, with the system of faults inclusive, is assumed to be an EPM?

Basis

In Section 3.3.3.2, page 3.3-10, the third hypothesis essentially proposes representing a system of faults as an EPM and the fault-bounded rock as a discrete fracture network. This representation is contrary to that suggested by Bear (1979), Freeze and Cherry (1978), and de Marsily (1986) in which a larger volume can be more appropriately represented by an EPM than a smaller volume.

Recommendation

Reconsider the hypothesis of EPM as proposed or provide an explanation and references.

References

Bear, J. 1979. *Hydraulics of Groundwater*. New York, NY: McGraw-Hill.

de Marsily, G. 1986. *Quantitative Hydrology*. New York, NY: Academic Press.

Freeze, R.A., and J.A. Cherry. 1979. *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 27

Isn't the case of no unique hypothesis for flow and transport along faults a separate hypothesis deserving to be tested?

Basis

In Section 3.3.3.2, page 3.3-10, last paragraph, it is stated "In the preceding...in which case, no unique hypothesis may be needed to describe flow and transport along faults." It is not clear what modeling activities will be conducted in the case when this hypothesis prevails.

Recommendation

Explain how the case of no unique hypothesis for flow and transport along faults will be numerically treated.

STUDY PLAN 8.3.1.2.3.3 SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 28

Does the SP propose to develop models capable of reproducing complex heterogeneities?

Basis

In Section 3.3.3.2, page 3.3-11, it is stated as hypothesis 1 that "three-dimensional numerical models capable of reproducing complex heterogeneity may be needed." However, it is not clear whether such models are to be developed as part of this SP. Moreover, it is not clear whether the SP is going to assume that such codes are validated or not.

Recommendation

Clarify whether models capable of reproducing complex heterogeneities are to be developed under activities of this SP. If not, state explicitly what existing numerical code is going to be used for the generation of complex heterogeneous fields.