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LPDR-WM-10 (2)

Department of Energy
Washington, DC 20585

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MAY 13 1987

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Mr. Robert Browning
Director, Division of Waste Management
Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Browning:

Enclosed is the report of the NRC-DOE meeting on the BWIP pre-ES geohydrology program, held in Richland, Washington during April 7-9, 1987. The report includes the summary of the meeting prepared by the participating groups at the end of the meeting along with copies of all other information presented at the meeting.

As you are aware, the comments by participants and responses by DOE were revised a number of times during the preparation of the report. Accordingly, your staff should discard earlier versions they may have collected during the meeting and use the materials in the enclosure.

If you have any questions about the report, please call me at 586-5792 or Dr. Owen Thompson at 586-5003.

Sincerely,

J. Knight

James P. Knight, Director
Siting, Licensing and Quality
Assurance Division, Office of
Civilian Radioactive Waste Management

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PDR WASTE
WM-10 PDR

Enclosure: "Report of the Nuclear Regulatory Commission - Department of Energy Meeting of the Geohydrology Testing Program before Construction of the Exploratory Shaft," April 9, 1987, with 16 attachments.

cc: J. Antonnen
J. Neff
D. Vieth
J. Leahy (20 copies)

WM Record File 101.2

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Report of the Nuclear Regulatory Commission - Department of Energy Meeting of the Geohydrology Testing Program before Construction of the Exploratory Shaft

April 9, 1987

A meeting was held on April 7 - 9, 1987, at the Rivershore Motel, Richland, Washington. The purpose of the meeting was (1) for the Department of Energy (DOE) to present the planned program of geohydrologic testing at the Hanford site that would precede construction of the exploratory shaft; (2) for the DOE to respond to concerns raised by the Nuclear Regulatory Commission (NRC) staff, States and Tribes at the December, 1985, meeting on the Basalt Waste Isolation Project's (BWIP) geohydrology program and in the staff's letter dated April 10, 1986; and (3) for all interested parties to reach agreement on the planned testing program or to reach agreement on how to resolve any major concerns with the planned program.

The DOE opened the meeting at 8:30 a.m. with introductions of the key representatives (including contractors) from DOE, NRC, State of Washington, State of Oregon, Nez Perce Indian Tribe, Confederated Tribes of the Umatilla Indian Reservation (CTUIR), and Yakima Indian Nation. The listing of registered participants is provided in attachment 11. The DOE then introduced the members of the task force (attachment 12) which prepared the option paper (attachment 13).

As the first order of business, the DOE announced that the DOE presentations in the 9:00 a.m. - 12:15 p.m. time period on April 7, 1987, would be rearranged from the published agenda (attachment 14) and presented in the following order:

1. Options Paper for Pre-ES Testing, by A. Jelacic
2. Planned ES Testing Program, by M. Thompson
3. Overview of Geohydrology Program, by D. Dahlem
4. Geohydrologic Testing Program, by R. Stein

The DOE presentations were based on the pre-meeting material that was distributed to attendees.

Additionally, the Yakima Indian Nation representative requested time to make a presentation. His presentation, based on the material in attachment 16, was given after lunch on April 7, 1987. The agenda was rearranged accordingly.

On the morning of April 7, 1987, the DOE described the work that needs to be done to meet the four objectives of the pre-ES testing program.

The pre-Exploratory Shaft (ES) testing program was the primary focus of the meeting, but a general description of the overall geohydrology program was provided to show that the pre-ES work is only the first piece of a much larger program. The remainder of the first day provided time for each participating group to caucus and for group discussions. The representatives from all the participating groups were active in the discussions and provided valuable contributions.

On April 8, 1987, the DOE presented the status of concerns previously raised by NRC, based on attachment 1(b). The meeting participants contributed to the discussion on the DOE presentation.

On the afternoon of April 8, 1987, the participants were asked to prepare comments on the pre-ES testing program and on the status of NRC concerns. Written comments were provided by the NRC, State of Washington, State of Oregon, Yakima Indian Nation, Nez Perce Indian Tribe and Confederated Tribes of the Umatilla Indian Reservation (CTUIR).

The DOE prepared responses to the written comments which were discussed on April 9, 1987. The comments and responses, as revised following the discussions, are presented in the following pages.

<u>Written Comments by NRC</u>

See Attachment 1.

<u>DOE Response to NRC</u>

See Attachment 2.

<u>Written Comments by State of Washington</u>

See Attachment 3.

<u>DOE Response to State of Washington</u>

See Attachment 4.

<u>Written Comments by State of Oregon</u>

See Attachment 5.

<u>DOE Response to State of Oregon</u>

See Attachment 6.

<u>Written Comments by Yakima Indian Nation</u>

See Attachment 7.

DOE Response to Yakima Indian Nation

See Attachment 8.

Written Comments by Nez Perce Indian Tribe and CTUIR

See Attachment 9.

DOE Response to Nez Perce Indian Tribe and CTUIR

See Attachment 10.

List of Additional Attachments

11. List of Attendees April 7 - 9, 1987.
12. Working Group Members for preparation of Option Paper.
13. Pre-meeting Materials: Letter, J. Knight (DOE) to R. Browning (NRC) March 26, 1987, and the Working Group's Option Paper.
14. Final Agenda (Letter, J. Knight (DOE) to R. Browning (NRC) March 26, 1987).
15. Viewgraphs presented by DOE.
16. Submittals by Yakima Indian Nation:
    a. Role of the Yakima Indian Nation in the LHST Meeting, by Russell Jim
    b. "Hanford Site Baselining and LHST Scheduling: Review/Assessment/ Independent Verification", by A. Djerrari, et al.
    c. Critical Comments:

       "Review of Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site", Terra Therma/Nuclear Waste Consultants (June 13, 1986).

       "Re-Review of Clifton's BWIP Groundwater Travel Time Analysis", Terra Therma/Nuclear Waste Consultants (January 13, 1987) by G. Dagan, et al., dated April 3, 1987.
    d. YIN comments on GWTT Generic Technical Position (July 30, 1986).
    e. "Evaluation of DOE Analysis of GWTT Hanford Site", by A. Djerrari, et al., July 1986.
    f. "Evaluation of Hydraulic Head Data of Selected Hydrogeologic Units at the Hanford Site, Washington", by A. Djerrari, et al., dated February 6, 1987.

Acknowledgement

The undersigned representatives from the participating groups agree that the preceeding report represents an accurate summary of the presentations and written observations of the participants at the meeting. Although the representatives do not necessarily endorse the comments by other groups or the corresponding DOE responses, all groups were able to participate fully in the meeting and were provided adequate opportunity to present their views. The meeting provided a valuable technical interchange between DOE, NRC, and affected States and Indian Tribes.

R. Stein,
DOE

R. Browning,
NRC

State of Washington

State of Oregon

Nez Perce Indian Nation

Confederated Tribes of the Umatilla Indian Reservations

Yakima Indian Nation

Written Comments by NRC on DOE Pre-ES Hydrologic Testing Program

a. Pre-ES Hydrologic Testing Program

1. The NRC agrees that the proposed hydrologic testing program, as described in Option "D", is a reasonable approach for the next step in hydrologic characterization of the Hanford site, and provides a frame-work for hydrologic testing prior to sinking of the Exploratory Shaft (ES). Based on data obtained from the proposed test program, DOE should evaluate their hydrological conceptual model for the site and determine whether or not additional testing is warranted prior to sinking of the exploratory shaft. In performing this evaluation DOE will evaluate the data against the test objectives, including how the data affects their conceptual model of the site, and the criteria in Exhibit IV of the concept paper. Following this evaluation DOE will consult with NRC, the States, and Tribes prior to proceeding with sinking of the ES or additional testing.

The NRC staff feels that while the proposed hydrologic testing strategy is consistent with the general intent of STP 1.1, additional testing, such as Option "E", or other testing as appropriate will be required to satisfy the information needs of STP 1.1.

The DOE will develop detailed test plans, both quality assurance and technical, for implementing Option "D". These plans will include technical criteria for hydraulic-head baseline, pre-test conditions, and magnitude and duration of the LHS and tracer tests. Such plans will be provided to the NRC at least 6 months prior to the proposed start of testing.

The proposed testing under Option "D" will provide a better understanding of the hydrology of the site. It will also provide a better data base for determining additional testing needs to resolve the GWTT and post-closure repository performance issues.

2. The DOE will provide the rationale for how the limited pre-ES hydrochemical testing fits in with the overall Site Characterization geochemistry program. Specifically, DOE will address the basis for the testing to be performed, the selection of parameters to be analyzed, and DOE's determination that data to be collected after the ES is not "perishable". The hydrochemical sampling objectives presented by DOE in the meeting (see Attachment 13) are reasonable.

3. Quality Assurance

   - The DOE will provide the criteria used to classify the pre-ES hydrologic testing activities, equipment and instrumentation into different quality levels. The DOE will also address how the lessons learned from the DOE evaluation of equipment and instrumentation problems (such as piezometers, transducers, and Westbay system, etc.) have been factored into the development of these criteria.

4. Consistent with the NRC-DOE "Procedural Agreement", DOE will ensure that a current data catalogue will be available for all hydrologic data. This catalog will enable involved participants to select and request data for detailed review. Such data will be made available 45 days after a test has been completed.

5. The meeting agendas for future meetings will specifically reference relevant pre-meeting materials.

6. The DOE will develop decision criteria for all major decision points in the pre-ES hydrology testing program.

7. The DOE will provide for consultation and review of the progress of the pre-ES hydrologic testing program at the following decision points:

    1. At the issuance of the study plans and the draft TDCS.
    2. Before proceeding to drill the DC-24 and DC-25 observation wells.
    3. At the completion of the baseline monitoring program.
    4. Before and after each hydrologic zone is tested.
    5. At the planned termination of the pre-ES testing program.
    6. At anytime that a major change is contemplated to the pre-ES testing program.

The DOE Geohydrology Planning Schedule will be revised to incorporate these consultation points.

Written Comments by NRC*

b. Notes on Previous NRC Comments

During the meeting, and in materials provided prior to the meeting, the DOE responded to previous NRC comments about the geohydrology testing program at Hanford. The DOE commented on 16 items raised in NRC's letter from Linehan to Olson, dated April 10, 1986. The relative status (open/closed) of each item was reviewed during the meeting.

1. MONITORING LOCATIONS AND FREQUENCIES (Status: Open).

This item remains open. DOE will respond in their detailed hydrologic testing program plan and supporting documents. NRC agrees with the approach outline in Attachment 13.

2. CEMENT EFFECTS ON RRL-2A AND RRL-6 (Status: Open).

NRC has not yet reviewed DOE's recently received response.

3. BOREHOLE INTERFLOW (Status: Open)

It is noted that the DOE plans to describe the approach used to estimate the effects of borehole interflow in the Site Groundwater Study Plan (SGSP), expected to be released by July 1987.

Particular attention should be given to borehole DC-16A and 16C if they are to be used as monitoring wells as suggested by A. Lu (1985). Borehole RRL-14 also should be given particular attention because it has remained open since the Westbay packers failed. In addition, RRL-2A appears to be completed with bridge plugs which runs the risk of interconnection problems.

4. MONITORING FACILITIES FOR THE RATIO TEST (Status: Open)

This item remains open because questions about past piezometer compliance during tests remain unresolved. DOE will address in the test plan.

5. GROUT PERMEABILITY AND PIEZOMETER PERFORMANCE (Status: Open)

The status of this item remains open until the program of piezometer integrity testing is satisfactorily completed.

6. WESTBAY INSTALLATION (Status: Open)

The status of the Westbay device remains open until its use is demonstrated to be both feasible and satisfactory at RRL-14. The potential for borehole interflow effects during the intervening period should be assessed.

7. LHS TESTING FOCUS (Status: Open)

As discussed in the meeting NRC agrees with the approach for LHS in Option "D". DOE will address specific concerns in the detailed hydrologic testing program plan. These plans should incorporate contingency plans for possible scenarios that may arise in the course of testing.

8. PUMP SELECTION (Status: Open)

Selection of the pump is considered an open item pending dry run tests on pump operation by DOE.

9. CRITERIA FOR LHS TESTING (Status: Open)

This item remains open because criteria have not yet been developed for:

- o hydraulic head baseline acceptance;
- o initiating and terminating pumping and recovery portions of LHS tests;
- o initiating and terminating tracer test; and
- o locations of new observation wells (DC-24, -25, -32, and - 33).

10. DEVELOPMENT OF RRL-2B (Status: Open)

This item is considered open because details of developing RRL-2B in the Cohassett and Birkett flow tops have not been received by NRC.

11. MECHANICAL EFFECTS (Status: Closed)

The DOE's presentation provided adequate information to resolve NRC's concern about the possibility of anomalous head responses in close proximity to the pumping well during testing.

12. VESICULAR ZONE TESTING (Status: Closed)

The DOE's proposal to evaluate the potential for conducting a pumping test in this zone satisfies NRC's previous concerns about this issue.

13. CONVERGENT TRACER TEST (Status: Open)

This issue is open because of the complex nature of tracer tests and their interpretation, and because detailed test plans are not available.

14. PERTURBATIONS TO HYDROLOGIC BASELINE (Status: Open)

This issue is open because detailed criteria for baseline have not been provided by the DOE.

15. HYDROCHEMICAL SAMPLING (Status: Open)

This item is open pending the release of criteria for hydro-chemical sampling and subsequent interactions between DOE and NRC geochemistry staff. Refer to specific comment.

16. DATA RELEASE (Status: Open)

The DOE noted that it will comply with the Site Specific Agreement (re: release of data) to the best of its ability.

* Revised late in meeting; all participants did not receive copies of these final comments.

DOE Response to NRC

A. Pre-ES Testing Program General Comments

1. The DOE agrees with the NRC comment subject to the following clarifications made verbally by NRC staff during discussions on April 8, 1987.

    - In the second paragraph, the additional testing required to satisfy the informational needs of STP 1.1 may be either pre-ES testing, such as identified in the logic process outlined in appendix C of the Option Paper on the pre-ES geohydrologic testing program, or post-ES testing as part of the total geohydrology testing program to be presented in the Site Ground-water Study Plan accompanying the SCP.

    - In the third paragraph, the types of plans mentioned by the NRC will be provided by DOE at least six months prior to the start of testing in the Rocky Coulee flow top.

2. The DOE agrees with the NRC comment and will provide the rationale for how the pre-ES hydrochemical testing fits into the overall site geochemistry program in Section 8.3.1.4 of the SCP and related study plans.

3. The DOE agrees with the NRC comment and will provide the basis for quality level assignments of the pre-ES hydrologic testing activities, equipment, and instrumentation. This material will be provided as part of the design package for review prior to the start of drilling of DC-24 and -25.

4. The DOE agrees with the NRC comment. A comprehensive data catalog is being developed and will be available upon issuance of the SCP. An Option "D" data catalog will be available prior to the start of testing in the Rocky Coulee flow top.

5. The DOE agrees with the NRC comment and will specifically reference directly relevant pre-meeting materials on future meeting agendas.

6. The DOE agrees with the NRC comment and will develop decision criteria for all major decision points shown in the schedule for the pre-ES geohydrology testing program. The decision criteria will be provided to all parties at least six months prior to the start of testing in the Rocky Coulee flow top.

7. The DOE agrees with the NRC comment subject to clarification that the type of interaction may differ for the six identified decision points, especially since DOE will make decision criteria available for review at least six months prior to testing the Rocky Coulee flow top and because DOE has invited the NRC, States, and Indian Tribes as observers to the testing. The observers will have real-time access to the data and will have ample opportunity for face-to-face staff-level discussion of the issues in advance of the decision points. The DOE anticipates a less formal interaction at the decision points for testing of the Cohassett flow top and the Cohassett vesicular zone than the interaction needed at the conclusion of the planned pre-ES geohydrologic testing program.

B. Previous NRC Comments

The comments NRC indicated as open will be addressed in appropriate planning documents which will be available to NRC, States, and Indian Nations prior to pre-test interactions. The comments will be tracked and the documents in which they are addressed identified. Clarification to NRC notes on DOE responses to previous NRC comments follow.

1c. Monitoring Location and Frequency

The DOE has performed integrity tests at existing multiple-level piezometers DC-19, -20, -22, and RRL-2C. The results of integrity tests that were performed will be provided to the NRC. Plans for future analyses and tests will be provided prior to pre-tests interactions.

2. Cement Effects on RRL-2A and RRL-6.

For clarification RRL-6 is not planned for use of trace injection.

4. Monitoring Facilities for the Ratio Test

See clarification to comment 1c.

5. Grout Permeability and Piezometer Performance

See clarification to comment 1c.

7. LHS Testing Focus

As part of the Options Paper, a logic chart was developed (figure 1, Appendix C) which provides a process for dealing with all unexpected hydrologic responses. In addition, evaluation criteria (Exhibit 4, Option Paper), which if exceeded, would result in reconsideration of the planned testing have been identified (Exhibit B). This approach is preferable to attempting to identify all possible testing scenarios in advance.

9. Criteria for LHS Testing - Fourth Bullet

The location of observation wells DC-24 and DC-25 have been established and site preparation has begun. The locations of DC-32 and DC-33 are tentative. The basis for locating these facilities (DC-32 and DC-33) will be provided prior to pre-test interaction. The DOE will provide the documentation for DC-24 and DC-25.

Washington State's Preliminary Comments
April 8, 1987

Preliminary to our comments on the hydrology program, since these will be considered our formal comments. I must repeat so that the record will reflec that we believe DOE should not have selected Hanford as one of the 3 final sites - least safe - most costly of those under consideration and we submit that Hanford should be eliminated before the program goes forward - we are and will continue to aggressively pursue this object in the congress and the courts.

However, until we are successful in those efforts, we will continue to participate fully in the site characterization process and carry out our role as called for in the NWPA.

1. Based on the objectives of the pre-ES Hydrology Testing program, we cannot accept the DOE recommended approach. In our opinion, a "yellow flag" is already flying (1000 yr GW TT issue) and the testing program must be designed accordingly. We understand that DOE does not agree that a yellow flag is flying, we believe the responsible approach requires that DOE immediately request the Hydrology Task Force to develop a testing program designed to resolve the 1000 GWTT issue prior to beginning to drill the exploratory shaft. (The Task Force work product should include a description of the testing required and a schedule which is integrated with the overall pre-ES hydrology program schedule).

2. The proposed strategies to investigate disqualifying conditions lists evaluation criteria which are defined as conditions that are so severe as to be indicated of potential disqualification. The criteria listed are severe conditions which if found should require disqualification. The final hydrology criteria should include the following:

Criteria 1: Severe conditions, which if found, should require disqualification (red card).

Criteria 2: A range of conditions, which if found, are indicative of serious problems requiring further evaluations and/or investigations prior to continuation of pre-ES hydrology studies (yellow card).

Criteria 3: The expected range of conditions.

The state of Washington's position is that, data from earlier BWIP studies have already identified a range of conditions indicative of serious problems.

3. The schedule must be redone to include adequate opportunity for meaningful consultation with states/tribes. Meaningful consultation includes:

a. Materials provided in advance.
b. Face to face discussion of issues (right people)
c. Response to concerns.

Consultation points should be agreed upon based on the concepts laid out in STP 1.1. Scientific study must not be compromised by management driven schedules.

4. Premature drilling of ES

The hydrology program we have been discussing is called the pre-ES hydrology program. To us that meant that drilling of the ES will not commence until the test program is satisfactorily completed and the results are analyzed. If USDOE Headquarters decides to consider beginning to drill prior to completion of the pre-ES hydrology testing program, before they add such activity to the schedule DOE Headquarters will:

1. Immediately notify states/tribes that the idea is under consideration, and
2. Request the hydrology task force to assess the potential impacts of such actions on the pre-ES hydrology program, and
3. Distribute the task force study to the states and tribes, and
4. Consult with states and tribes after adequate opportunity to review the task force study.

5. Hydrologic studies are being conducted with insufficient attention to geologic structures which could provide pathways. Groundwater movement on faults and shears appears to be discounted. Drillers' logs of all holes in basalt should be reviewed for lost circulation and where it exists the cause(s) should be determined. Non-darcian flow and fracture porosity should be evaluated and, if possible, modeled to determine its effect on 1000 year and 10,000 year travel time standards. Existing and new geophysical information on the CASZ should be analyzed for discrete structures and these should be drilled.

6. USDOE must make a commitment to comply with all state permits and regulations related to the hydrology program.

DOE Response to State of Washington

1. The DOE current information on geohydrologic conditions suggests with high probability that GWTT will exceed 1000 years, and thus DOE did not orient the pre-ES testing program solely around this issue. The DOE has documented its position in detail in its final Environmental Assessment (EA) for the Hanford site. In making findings in the EA, DOE considered fully comments from all interested parties. Because of this, the task force has addressed the problem appropriately, and did not focus on resolving the issue of GWTT prior to ES construction.

2. The DOE cannot agree with the Washington State Comment. We believe that the evaluation criteria provided in the Options Paper are suitable to meet the objectives of providing an early indication of the presence of a disqualifying condition.

   The geohydrologic data derived from the pre-ES testing program may be representative of only that part of the "Controlled Area Study Zone" (CASZ) in proximity to the RRL-2 pumping center. Therefore, if the data collected in the proposed pre-ES testing program (Option D) equal or exceed any of the evaluation criteria, the possible presence of a disqualifying condition may be indicated, but not necessarily throughout the CASZ. Disqualification of the site on such information alone would not be appropriate. However, as illustrated in the logic diagram in Figure 1 of Appendix C of the Option Paper, reanalysis of available data may be deemed necessary. Reanalysis may result in additional tests not previously included in the pre-ES test plan. The reanalysis and additional testing would be directed toward determining whether geohydrologic characteristics that combine to indicate a disqualifying condition are sufficiently pervasive in the CASZ to warrant terminating site characterization. The DOE considers that the evaluation criteria as presented in Exhibit IV of the Options Paper are appropriate for carrying out such an evaluation.

3. The DOE agrees with this comment and will revise the schedule to indicate adequate opportunities for meaningful interactions with the States and Indian Tribes. As indicated in the DOE response to the NRC on this subject, DOE will interact with the NRC, States, and Indian Tribes at the following decision points:

- issuance of study plans and draft TDCS;
- prior to proceeding to drill DC-24 and -25;
- at completion of the hydrologic baseline monitoring program;
- before and after each hydrologic zone is tested;
- at the planned termination of the pre-ES testing program; and
- at any time that a major change is contemplated to the pre-ES geohydrologic testing program.

These proposed interactions are consistent with the concepts laid out in STP 1.1.

4. Premature drilling of ES

The Department has not made a decision to drill the ES through the sedimentary layers prior to completion of the pre-ES testing. The DOE will not initiate such drilling if it will compromise the integrity of pre-ES test program as described in the Options paper.

Further, the Department has not decided to evaluate the technical aspects of this drilling, in particular the effects on the pre-ES test program. If a decision to evaluate the technical aspects of this drilling is made, the Department will inform the States and other participants of the decision and its plans to implement the evaluation, keeping in mind the steps proposed by the State to implement the process.

5. Geologic structures potentially affecting groundwater flow will be characterized in the pre-ES and post-ES components of the characterization effort. At least two Large-Scale Hydraulic Stress (LHS) tests will be performed in the pre-ES period. It is expected that these tests will be able to indicate the presence of hydrologically significant geologic features in the near-repository area that may affect site performance. Post-ES LHS tests are specifically designed to assess the hydrologic behavior of structural features that are suspected boundaries of the site groundwater flow system. The LHS and small-scale tests are expected to provide sufficient data to formulate defensible conceptual and numerical models to assess site performance. Test data will be analyzed to evaluate the potential for non-Darcian flow. Evaluation of lost circulation and other drilling data for their geohydrologic significance is a normal field operation practice at BWIP.

6. The issue of state permits was not the subject of the workshop and was not

discussed. However, the Department of Energy plans to fully comply with all applicable Federal, State, and Local regulatory and permitting requirements during the conduct of the BWIP hydrology program. The BWIP environmental regulatory compliance plan will define the broad-base approach to assuring that all site characterization activities are conducted in a manner consistent with applicable regulations. A key element in the environmental compliance planning process is the BWIP environmental review procedure. This procedure, which is currently in place, requires a full regulatory compliance review prior to approving the conduct of any BWIP site characterization activity.

Attachment 5

STATE OF OREGON COMMENTS

ON

GEOHYDROLOGY TESTING PROGRAM

FOR THE HANFORD SITE

BEFORE CONSTRUCTION OF THE EXPLORATORY SHAFT

1. The State of Oregon has a unique position of not being officially designated an affected state in the Hanford geologic repository program.

   But, because of Oregon's close proximity to the Hanford location, the nearness of the possible repository location to the Columbia river and the fact that Oregon aquifers may be connected to the repository aquifers, Oregon feels a vital concern with all aspects of the repository siting.

   We of the technical staff sincerely appreciate the courtesy and technical help given us by the NRC, the State of Washington, and the three Indian nations.

2. The State of Oregon's greatest concern is the groundwater travel time issue. We feel it has not been properly addressed to date. We are reserving further comment until we have reviewed the SCP.

STATE OF OREGON

COMMENTS ON

DOE RESPONSE TO NRC COMMENTS

DOE appears to have made a significant effort to address the NRC concerns based on the presentation this morning. Many of the 16 concerns on the list will more fully be addressed in the Site Characterization Plan Hydrology section. Since we have not seen the SCP yet, we are not going to make detailed commments on the DOE response to the NRC until after reviewing the SCP.

The State of Oregon representative is satisfied for the present that DOE has made a good faith effort to address the NRC comments, and will make his comments upon reviewing the SCP.

Attachment 6

DOE Responses to State of Oregon

No comment.

YAKIMA NATION OBSERVATIONS
ON DOE RESPONSE TO NRC
COMMENTS FROM APRIL, 1986 LETTER

NRC
COMMENT#

1. Comment Re: Nature of NRC Concern

   - Comprehensiveness Assessment of Monitoring Adequacy

     The determination of monitoring adequacy should be made prior to and for each of the stress tests. This assessment must be made available in advance of the initiation of the tests.

     The determination of sampling frequency should be made prior to each of the tests. This should also be made available to the affected parties prior to the initiation of sampling.

     We agree that this is an open item.

2. Cement Effects

   To our knowledge, the Yakima Indian Nation has not been provided the documentation referred to in the handout, and therefore, we cannot make any statements about the adequacy of DOE's response.

   We feel that this item is open.

3. We agree that this is an open item.

4. We agree that this is an open item.

5. Agree

6. Agree

7. LHS Testing Focus

   The YIN agrees that this is a closed item contingent upon the effective execution of the formal consultation points during the geohydrology planning schedule and the effective transfer of information during the testing program.

8. We agree that this is an open item

9. Criteria for LHS Testing

Numerical and analytical models used in the design of the tracer tests should be made available for verification by the YIN. Current DOE tracer tests do not appear to consider the concentration of mass for tracer concentration. Justification must be made to explain the utility of the break-through curve. Therefore, we agree that this item should remain open.

10. Development of Pumping Well RRL-2B

We consider this item open because we have not received the hydrochemical sampling plan.

11. We agree

12. We agree

13. Convergent Tracer Tests

Neglecting lateral dispersion may lead to a conservative estimate of transport parameter, but would create problems in using a model to interpret the break-through curves (see comment on #9).

The matching of the predicted vs. observed test values using EPM models is a necessary but not significant to validate the underlying porous medium assumption. In order to sufficiently demonstrate the validity of the EPM model, the statistical parameter used to define the goodness of fit should be set a priority.

We suggest that geostatistical analysis be used in conjunction with EPM models to address the problem of spatial variability. A scientific strategy for the use of different approaches should be made available for evaluation.

Perturbations of Baseline

14. We agree that this is a closed item dependent upon the effectiveness of the mechanism allowing YIN independent analysis and verification.

15. Agree

Data Release

16. We consider this item open pending DOE's response to YIN April 7, 1987 presentation comments.

OBSERVATIONS OF YAKIMA INDIAN NATION AT DOE-NRC MEETING ON THE GEOHYDROLOGY TESTING PROGRAM FOR THE HANFORD SITE BEFORE CONSTRUCTION OF THE EXPLORATORY SHAFT

Richland, Washington
April 7-9, 1987

1. The Department of Energy (DOE) will formally respond to contractor comments submitted on August 4, 1987, entitled "Evaluation of DOE Analysis of Groundwater Travel Time, Hanford Site."

    a. The Yakima Indian Nation (YIN) suggests that there be a reasonable time for such a response (30 days). Without such a formal response we will be unable to actively or substantively participate in the NWPA process.

    b. If appropriate, either party should be in the position to suggest interfacing meeting dates to resolve outstanding issues.

2. The YIN understands that the DOE will provide a description of the rationale for locating hydrologic monitoring facilities 6 months prior to the start of testing. Accordingly, the DOE will send the document(s) describing the siting of DC-24 and 25 to the YIN in a timely manner.

3. The DOE will formally assure the availability of any computer codes to be used in interpreting the data collected in the regional and site geohydrologic studies, both pre and post ES, in a timely manner.

4. The DOE will make the data collected in the pre-ES geohydrologic tests available as soon as it is provided to the DOE-BWIP subcontractors. After independent analysis, resolution of issues raised (yellow flags) will be through interfacing meetings and/or formal written response.

5. The DOE agrees that affected parties should observe the LHST.

6. The DOE agress that any change in the LHST schedule, as described in the hand-out material entitled "Geohydrology Planning Schedule" will be communicated to the affected parties. This communication will be timely, contain all technical rationale for such a change. The DOE agress that No Changes will be contemplated without effective consultation with the affected parties.

7. DOE will identify a single contact for the pre-ES geohydrologic testing program.

8. The YIN agrees that the formal pre-ES geohydrologic consultation points suggested by the DOE are reasonable, provided that they are complemented by an ongoing review and analysis of the data as it becomes available.

9. The NRC will respond to the comments provided by the YIN on the groundwater travel time GTP as a part of the formal comment response documentation.

DOE Response to Yakima Indian Nation

A. General Comments

1. The DOE will respond within 30 days of receipt of specific comments provided by letter. The response will identify arrangements for any technical meetings needed to address unresolved issues.

2. Agreed.

3. Computer codes being used by the project will be provided upon request. Commercially available (proprietary) codes can be purchased with grant funds.

4. Agreed.

5. Agreed.

6. Agreed.

7. Agreed. The DOE designated contact point for hydrology is D. H. Dahlem. Participants are requested to provide a single technical contact point. The NRC has identified Tilak Verma as its technical contact point.

8. Agreed.

9. NRC agreed with this comment.

B. Observations on DOE Response to NRC Comments from April, 1986 letter

The comments of the Yakima Nation will be addressed in appropriate planning documents which will be available prior to pre-test interaction. The comments will be tracked and the documents in which they are addressed identified.

Council of Energy Resource Tribes

NUCLEAR WASTE POLICY ACT PROGRAM

1933 Jadwin — Suite 135
Richland, Washington 99352
(509) 943-5301

COMMENTS FROM THE NEZ PERCE TRIBE AND CTUIR PERTAINING TO THE PRE-ES HYDROGEOLOGIC TESTING PROGRAM

April 8, 1987

1. We concur that Option D for the LHST is an appropriate first step toward the elimination of some of the uncertainties of the hydrogeologic nature of the CASZ. However, should any "yellow flags" arise using Option D, Option E should be required prior to the start of the ES.

2. We understand that scheduling is very important in terms of management of the program. Scheduling should, however, be done in such a way that:

   o Sufficient time be allowed for evaluation of the hydrogeologic data prior to ES start to determine the adequacy of Option D and need for additional testing.

   o It does not jeopardize the technical credibility of the overall program.

   o Significant time is allowed for testing of the equipment (we feel that the one week periods as shown in the existing schedule are not long enough).

   o Significant time is allowed for consultation with and comments from the affected parties at the appropriate decision points.

   o The ES schedule <u>not</u> be driven by the pre-ES testing program.

3. Based on the data available, we feel that it is

DOE Response to Nez Perce Indian Tribe and CTUIR

1. The Department agrees that Option D is an appropriate option. If a yellow flag arises, then additional testing may be appropriate as illustrated in Appendix C of the Option Paper.

2. We agree with the scheduling objectives. If the one week equipment testing periods are not sufficient, then longer tests will be conducted.

3. We agree with the comment.

4. The Department agrees that there should be a decision point after the Birkett test to determine if the objectives of the pre-ES testing program have been met and subsequent characterization can proceed as planned.

5. We agree with the comment which is consistent with the third objectives of the pre-ES test program.

6. The pre-ES testing program is not intended to evaluate the Yakima flow impediment. However, the characterization program calls for construction of additional borehole facilities to assess the hydraulic significance of primary geologic structures during and after construction of the ES.

7. We agree.

8. We agree and will meet with the on-site representatives to work out arrangements.

too early to obtain a consensus on travel time and that data generated from the LHS test would be a more appropriate starting point.

4. There should be an appropriate decision point during or after the LHS test for deciding to proceed with the characterization program.

5. Plans should be made to assess the impact of the sinking of the ES on the groundwater regime at the site.

6. The hydrogeology program contains an insufficient number of wells west of the Yakima "flow impediment" to determine its impact on any hydrogeologic model or on the ES.

7. DOE analysis of the NRC, Yakima, or any other non-DOE reports pertaining to BWIP should be made available to all affected parties.

8. The Tribal On-Site Representative should be made aware of all upcoming technical "interactions" between any affected party and DOE.

9. The definition of "pre-ES" testing period needs to be agreed upon by NRC/DOE/affected parties.

10. Test plans for the hydrogeology program need to be made available to the affected parties as soon as possible, as well as part of the SCP.

11. A geostatistical approach may be inadequate due to the statistically small population represented by the wells in the DOE hydrogeologic testing program.

9. The definition of the pre-ES period is that period preceding the initiation of construction of the ES.

10. We agree.

11. We agree that the small data populations that will be available, limit the usefulness of geostatistical analyses. However, geostatistics used in conjunction with scientific data and professional judgement may be useful, and should not be rejected out-of-hand.

NRC PRE-ES HYDROLOGIC TESTING
PROGRAM WORKSHOP
APRIL 7, 8, 9, 1987
ATTENDANCE LIST

NAME	PHONE NUMBER	ORGANIZATION
Abdul Alkezweeny	509-943-5301	CERT/On-site Tribal Rep
Phil Brown	303-832-6600	CERT
Steve Hart	303-832-6600	CERT
Philip Berger	301-992-4000	Energetics/DOE-EH
Karos Cartwright	217-333-5113	DOE-HQ, Consultant
Glen L. Faulkner	202-896-1464	USGS/DOE HQ
S. H. Kale	FTS 896-9694	DOE-HQ
J. P. Knight	202-586-9300	DOE/HE
Thomas Longo	FTS 896-1223	DOE-HQ
Ralph Stein	202-586-5355	U. S. DOE
Owen Thompson	FTS 896-5003	DOE-HQ-Lic
Allan Jelacic	202-586-9362	DOE/HQ
D. H. Dahlem	509-376-3022	DOE-RL
C. Kasch	509-376-5183	DOE-RL
F. K. Kasch	509-376-5183	DOE-RL
Tony Knepp	509-376-4934	DOE-RL
Jim Mecca	FTS 444-5038	DOE/BWIP
Lee Olson	509-376-7591	DOE/RL
Mike Talbot	509-376-7501	U.S. DOE-RL
K. Michael Thompson	509-376-6421	DOE-RL
A. Djerrari	612-332-0000	EWA/Yakima
V. V. Nguyen	612-332-0000	EWA/Yakima
Bill Hanson	FTS 444-8603	GAO
V.E. Hanson	8- 399-5725	GAO
Jerry Rowe	206-883-0777	Golder
Charles Wilson	206-883-0777	Golder
Timothy D. Steele	303-987-1877	In-Situ, Inc
Troy Javandel	FTS 451-6106	Lawrence Berkeley Lab
Dave Gross	509-943-6976	MACTEC
Ruthann Knudson	509-943-6976	MACTEC
Floyd K. Kugzruk	208-843-2253	Nez Perce
F. X. Cameron	301-492-8689	NRC
Donald L. Chery Jr.	301-643-7665	NRC/RES/WMB
Neil M. Coleman	301-427-4131	NRC/WM
F. R. Cook	509-943-4669	NRC
Greg Cook	415-943-3809	U.S. NRC
S. John Linehan	301-427-4177	NRC
Teek R. Verma	301-427-4053	NRC

Adrian Brown	303-973-7495	Nuclear Waste Consultants
Bill Burke	503-276-0293	NWSP/Umatilla
Ralph Patt	503-378-8456	Oregon Water Resource
Marcel Bergeron	FTS 444-8410	PNL
John Smoot	509-376-8321	PNL
Harry Babad	FTS 444-0957	RHO STRT-System BWIP
S. M. Baker	FTS 444-4764	Rockwell/BWIP
Phil Bussey	509-376-7551	RHO
Peter Clifton	509-376-5722	Rockwell
M. P. Connelly	509-376-4092	RHO/BWIP
L. R. Fitch	FTS 444-6339	RHO/BWIP
D. L. Forsberg	509-376-9796	RHO/BWIP
Paul Frankel	509-376-8817	Rockwell
Louis Garvey	509-376-8627	Rockwell
M. C. Hagood	509-376-8655	Rockwell/BWIP
S. H. Hall	509-376-0887	Rockwell/BWIP
Susan Harris	509-376-8456	Rockwell/BWIP
Mary Hartman	509-376-1351	Rockwell
Bob Hiergesell	509-376-6473	RHO/BWIP
S. B. Hunt	509-376-2258	Rockwell/BWIP
J. H. LaRue	FTS 444-0546	RHO Defense Waste
Leo S. Leonhart	509-376-1885	Rockwell/BWIP
F. N. McDonald	FTS 444-6168	RHO/BWIP
M. W. Parsons	509-376-0266	RHO/BWIP
Phil Rogers	509-376-0669	Rockwell
B. Sagar	509-376-8250	Rockwell
Fred Sargent	509-376-2377	Rockwell
J. E. Shapley	509-376-8768	RHO/BWIP
Steve Strait	509-373-5120	Rockwell/BWIP
Paul Thorne	509-373-1756	Rockwell
Michael Teubner	FTS 575-1741	SAIC/LV-NNWSI
Dave Stewart-Smith	503-378-3187	State of Oregon
James Kohler	801-538-554	State of Utah HLNW
George A. Dinwiddle	703-218-5719	U. S. Geological Survey
Brian Drost	FTS 390-6510	U.S.G.S./Tacoma
Paul Hsieh	FTS 467-7167	USGS/Menlo Park, CA
Ren Jen Sun	703-648-5005	U.S.G.S.
Bill Brewer	206-459-6670	WA Ecology NWP
Ellen Caywood	206-866-6000 x 6454	WA ST Institute for Public Policy
Terry Husseman	206-459-6670	Washington State
Don Provost	206-459-6718	Washington State
David Back	202-646-6652	Weston
S. Panno	202-464-6648	Weston
Jack Robertson	202-646-6800	Weston
David Siefken	202-646-6617	Weston

Gerry Winter	208-883-0153	Williams & Assoc. NRC
Roy E. Williams	208-883-0153	Williams & Assoc. NRC
Brian Dick	509-946-8968	Woodward Clyde Cons.
Dennis R. McCrumb	509-943-6976	Woodward Clyde
Jack Wittman	509-865-5121 x-393	Yakima Indian Nation Representative
Russell Jim	509-865-5121	Yakima Indians

WORKING GROUP MEMBERS
FOR PRESENTATION OF
OPTION PAPER

Allan Jelacic (Chairman)	DOE/HQ
Glen Faulkner	DOE/USGS
David Dahlem	DOE/RL
Michael Thompson	DOE/RL
David Siefken	Weston
John Robertson	Weston
Sam Panno	Weston
Phil Rogers	RHO
Peter Clifton	RHO

Department of Energy
Washington, DC 20585

MAR 1 8 1987

Mr. Robert Browning
Director, Division of Waste Management
Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Browning:

We have arranged with your staff a technical meeting on the geohydrology testing program proposed for the Hanford Site before the start of construction of the exploratory shaft.

The meeting will be held April 7-9, 1987 at the Rivershore Motel, Richland, Washington, starting at 8:30 am. A tentative agenda and background information are attached. Note that the meeting may extend longer than stated, depending on the final agenda.

If you have any questions please contact me or Dr. Owen Thompson at 586-5003 (FTS 896-5003)

Sincerely,

Owen Thompson

for James P. Knight, Director
Siting, Licensing & Quality
Assurance Division, Office of
Geologic Repositories

Attachments: As stated

cc: J. Anttonen
J. Leahy (20)

Department of Energy
Washington, DC 20585

MAR 26 1987

Mr. Robert Browning
Director, Division of Waste Management
Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Browning:

Attached is the final agenda for the technical meeting on the geohydrology testing program proposed for the Hanford Site before the start of construction of the exploratory shaft.

The meeting will be held April 7 - 9, 1987, with a possible extension to April 10 if necessary to complete the Summary Meeting Minutes. The meeting will be at the Rivershore Motel, Richland, Washington, starting at 8:30 am.

Note that the final agenda is essentially the same as the agenda provided by my letter of March 18, 1987, except for April 9 activities which are shown on the final agenda in more detail, with additional time allowed for interactions between DOE, NRC, States and Indian Tribes.

If you have any questions, please contact me or Dr. Owen Thompson at 586-5003 (FTS 896-5003).

Sincerely,

James P. Knight, Director
Siting, Licensing & Quality Assurance
Division, Office of Civilian
Radioactive Waste Management

Attachment A: As stated

cc: J. Anttonen
J. Leahy (20)

ENCLOSURE A

DOE-NRC MEETING
ON
THE GEOHYDROLOGY TESTING PROGRAM
BEFORE CONSTRUCTION OF THE EXPLORATORY SHAFT

Richland, Washington
April 7-9, 1987

-AGENDA-

The purpose of this meeting is: (1) for the DOE to present the planned program of geohydrologic testing at the Hanford site that would precede construction of the exploratory shaft; (2) for the DOE to respond to concerns raised by the NRC staff, States and Tribes at the December, 1985, meeting on BWIP's geohydrology program and in the staff's letter dated April 10, 1986; (3) for all interested parties to reach agreement on the planned testing program or to reach agreement on how to resolve any major concerns with the planned program.

April 7, 1987

8:30 - 9:00	Introduction - Welcome - Identification of participants - Scope and Objectives of meeting - Procedures to be followed - Review of agenda - Identification of Representatives to prepare summary	DOE/NRC DOE/NRC/ States/Tribes
9:00 - 9:30	Geohydrologic Testing Strategy - Issue resolution strategy - Geohydrologic issues in Site Characterization Plan (SCP) - SCP organization	DOE
9:30 - 10:15	Overview of Geohydrology Program - Planning Logic - Components of pre-exploratory shaft (pre-ES) program - Program integration - Implementation procedures	DOE

10:15 - 10:30	Break	
10:30 - 11:15	Options Paper for Pre-ES Testing Program - Background - Approach - Identification of options - Recommendation	DOE
11:15 - 12:15	Planned Pre-ES Testing Program - Baseline monitoring - Large-scale hydrologic testing and associated data collection - Implementation procedures (Readiness reviews, test criteria, QA plans, interactions) - Schedule	DOE
12:15 - 1:30	Lunch	
1:30 - 2:30	Open - Caucus Time	All parties
2:30 - 3:30	Presentation of Preliminary Comments on Pre-ES Testing Program	NRC/States/ Tribes
3:30 - 5:00	Discussion of Preliminary Comments on Pre-ES Testing Program	All parties
5:00 - 6:00	Identification of Concerns for Further Discussion	All parties

April 8, 1987

8:30 - 9:00	Initial Response to Concerns Raised During First Day	DOE
9:00 - 12:00	Response to Previous NRC Concerns - Meeting of December 1985 - Letter of April 10, 1986	DOE
12:00 - 1:30	Lunch	
1:30 - 2:30	Open - Caucus Time	All parties
2:30 - 3:30	Presentation of Preliminary Comments on Response to NRC Concerns	NRC

3:30 - 4:30	<u>Discussion of Preliminary Comments on Response to NRC Concerns</u>	All parties
4:30 - 6:00	<u>Identification of Preliminary Observations, Agreements, and Open Items</u>	All parties
6:00 - 8:00	Dinner	
8:00 - 11:00	<u>Open</u> - Caucus Time <u>(NRC to Identify and Draft Observations, Agreements, and Open Items)</u>	All parties

April 9, 1987

8:30 - 10:00	Exchange and Discussion of Observations, Agreements and Open Items	All parties
10:00 - 10:30	Break	
10:30 - 12:30	Discussion amongst All Parties (including senior DOE & NRC management) - Discussion of agreements, observations and open items - Discussion of agreements on what follow-up activities are necessary to resolve the open items	All parties
12:30	Closure of Formal Meeting	DOE/NRC
12:30 - 1:30	Lunch	All parties
1:30 - 5:00	Preparation and Signing of Summary Meeting Minutes (To be extended to April 10 if necessary)	Reps from DOE/ NRC/States/Tribes

DOE-NRC Meeting on the Geohydrology Testing Program for the Hanford Site Before Construction of the Exploratory Shaft

Richland, Washington

April 7-9, 1987

Attachment 15

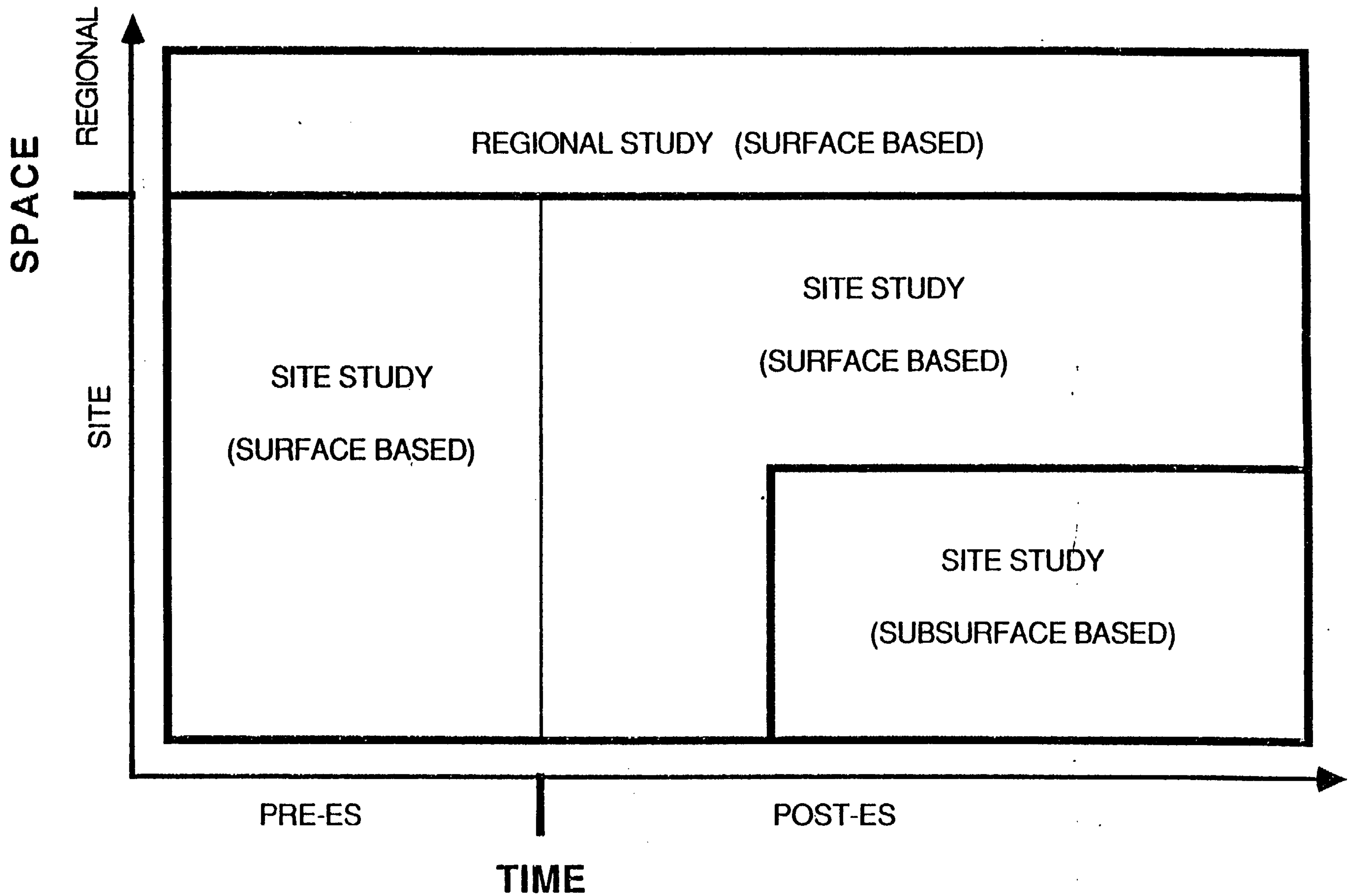
PS87-2153-9

WORKSHOP OBJECTIVES

- Present the option paper on the pre-exploratory shaft geohydrology program to the NRC, States, and Indian Tribes in order to receive comments from the participants, and to prepare for start of surface based testing.

- To discuss and come to closure on NRC comments of April 10, 1986 concerning the previous geohydrology testing program at Hanford.

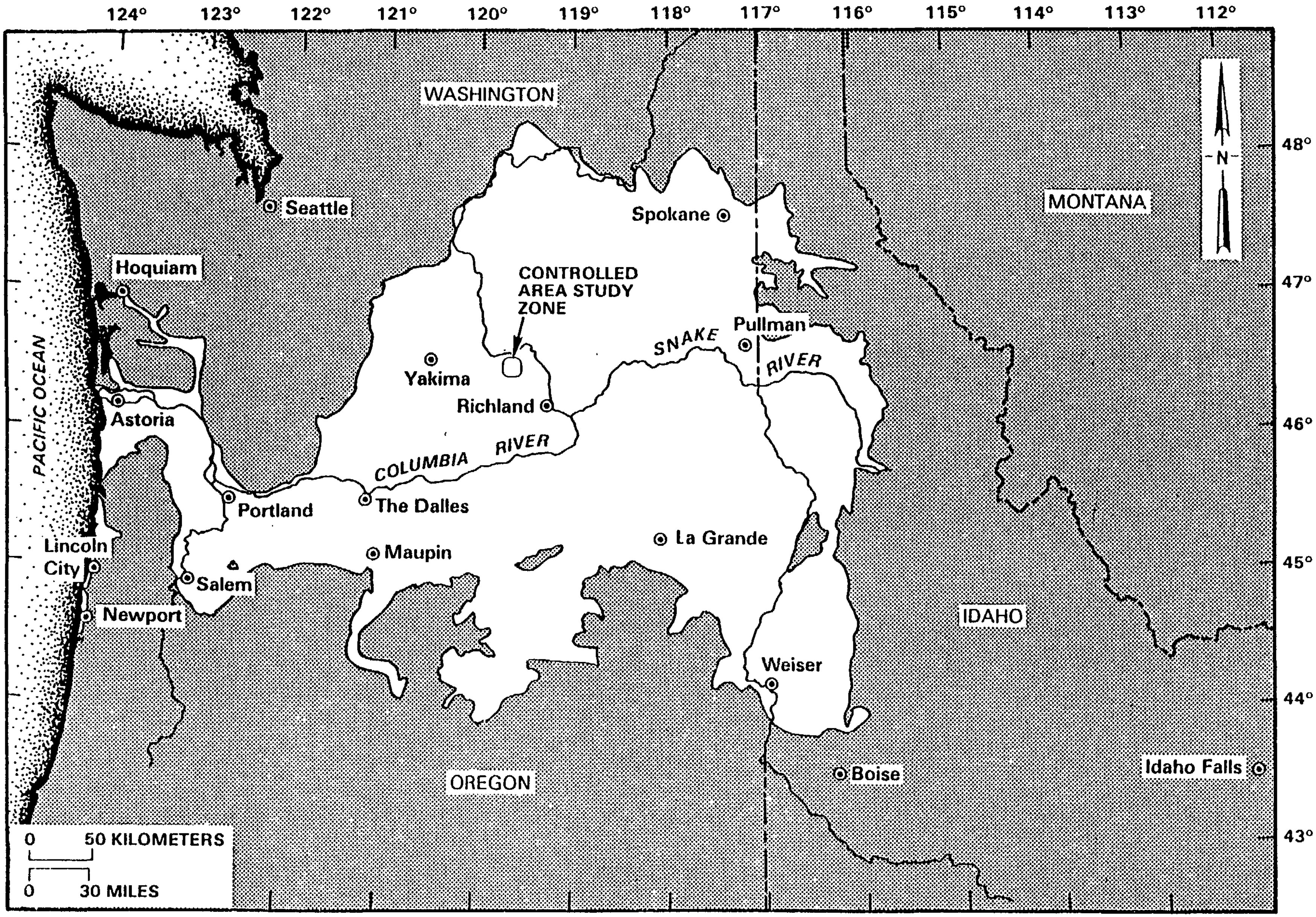
- To lay the ground-work for a follow-up workshop with the NRC, States, and Indian Tribes that will focus on the full geohydrology testing program at Hanford.



TIME-SPACE RELATIONSHIP BETWEEN THE SITE AND REGIONAL GEOHYDROLOGIC STUDIES

OPTION PAPER

GEOHYDROLOGIC TESTING PROGRAM FOR THE HANFORD SITE BEFORE CONSTRUCTION OF THE FIRST EXPLORATORY SHAFT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Pullman
SNAKE
RIVER
Yakima
Richland
Astoria
COLUMBIA
RIVER
Portland
The Dalles
La Grande
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Boise
Idaho Falls
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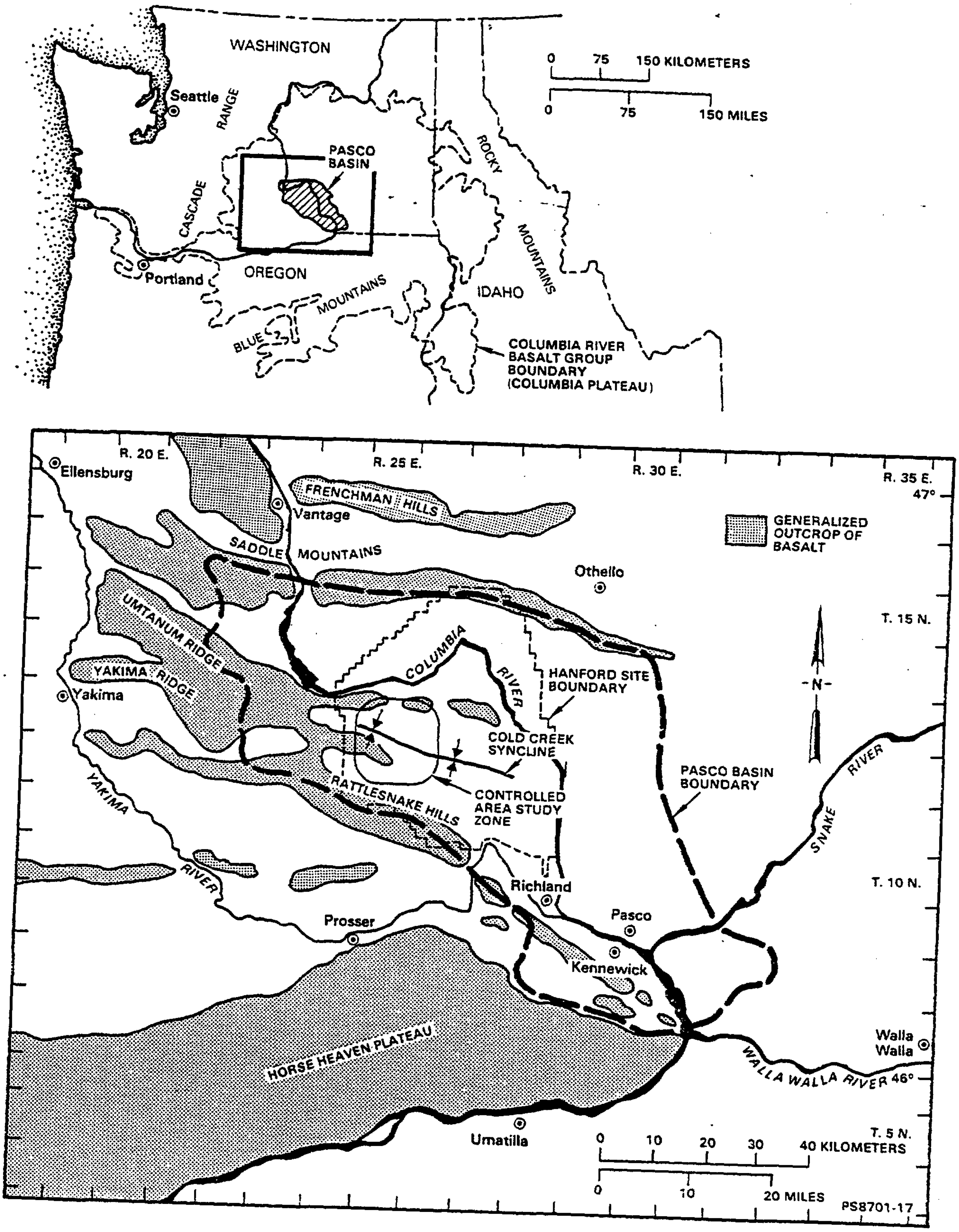
PS8609-150

Background


WASHINGTON
Seattle
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PASCO
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COLUMBIA RIVER
BASALT GROUP
BOUNDARY
(COLUMBIA PLATEAU)
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R. 30 E.
R. 35 E.
47°
Ellensburg
Vantage
FRENCHMAN HILLS
SADDLE MOUNTAINS
GENERALIZED
OUTCROP OF
BASALT
Othello
T. 15 N.
UMTANUM RIDGE
YAKIMA RIDGE
Yakima
COLUMBIA
RIVER
HANFORD SITE
BOUNDARY
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COLD CREEK
SYNCLINE
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AREA STUDY
ZONE
RATTLESNAKE HILLS
PASCO BASIN
BOUNDARY
SNAKE
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YAKIMA
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Richland
T. 10 N.
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Pasco
Kennewick
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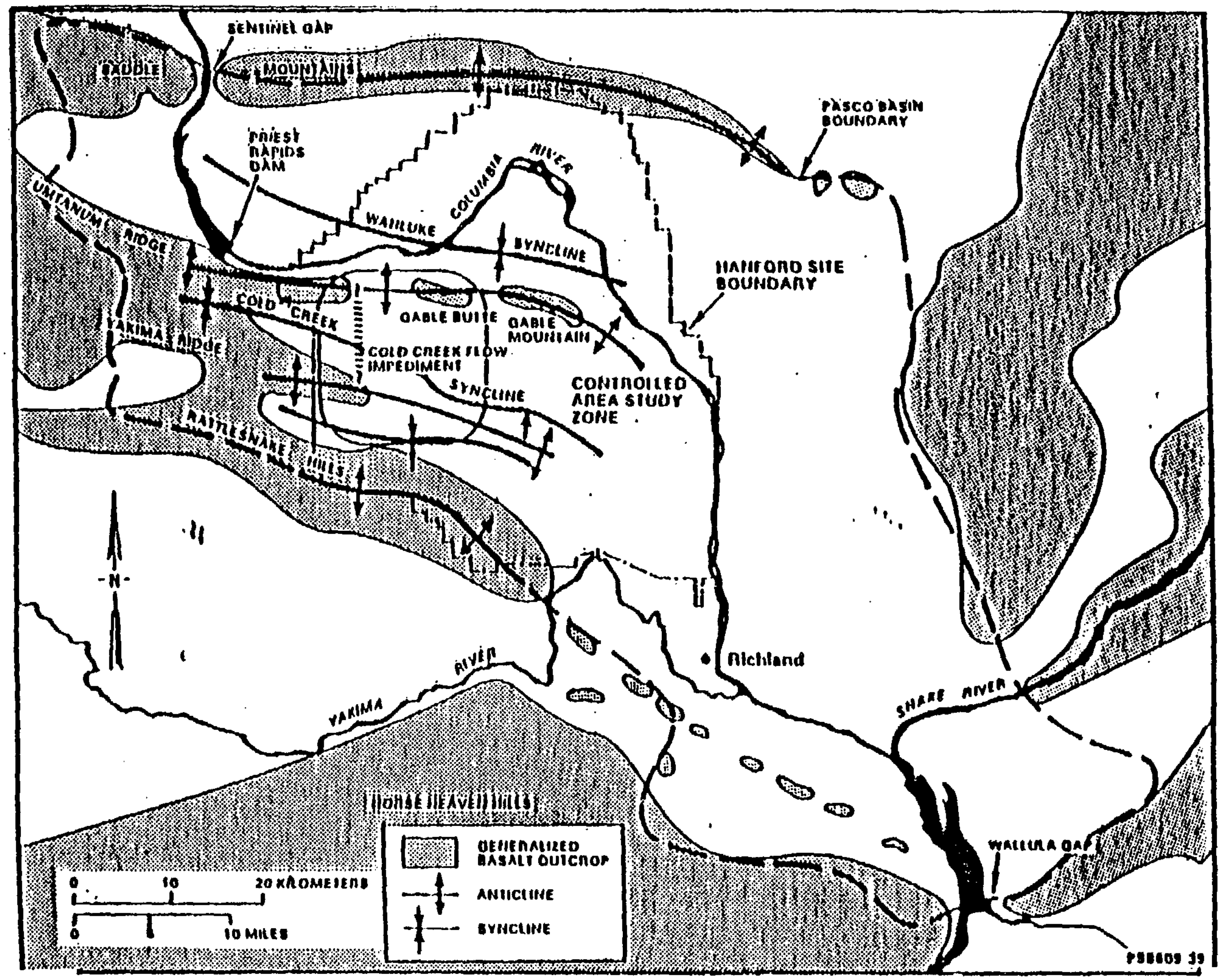
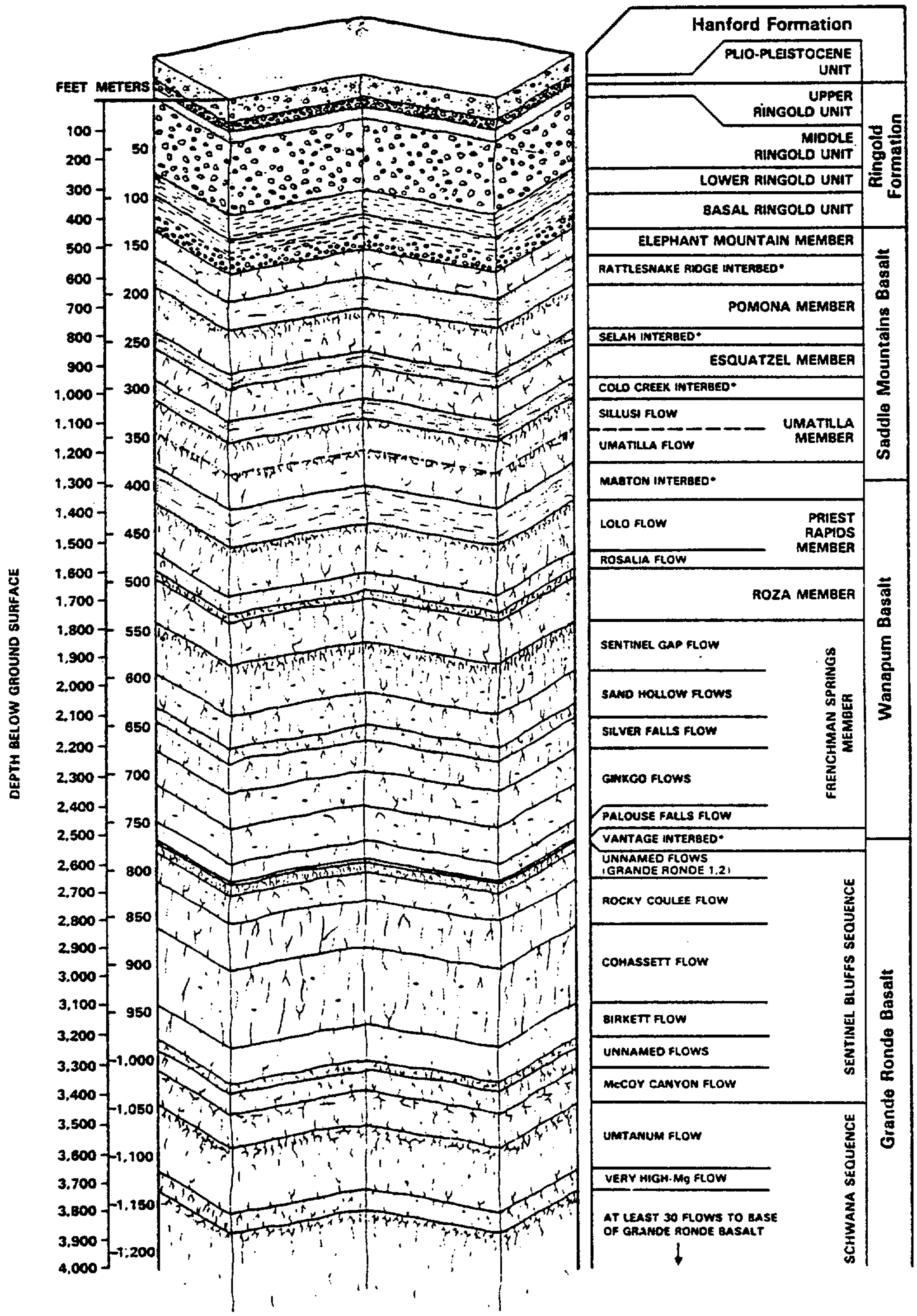


LOCATION MAP OF HANFORD SITE SHOWING MAJOR STRUCTURAL FEATURES

STRATIGRAPHIC UNITS FOUND WITHIN RRL-2



*INTERBEDS ARE STRATIGRAPHICALLY CONTAINED IN THE ELLENSBURG FORMATION

RCP8207-4L

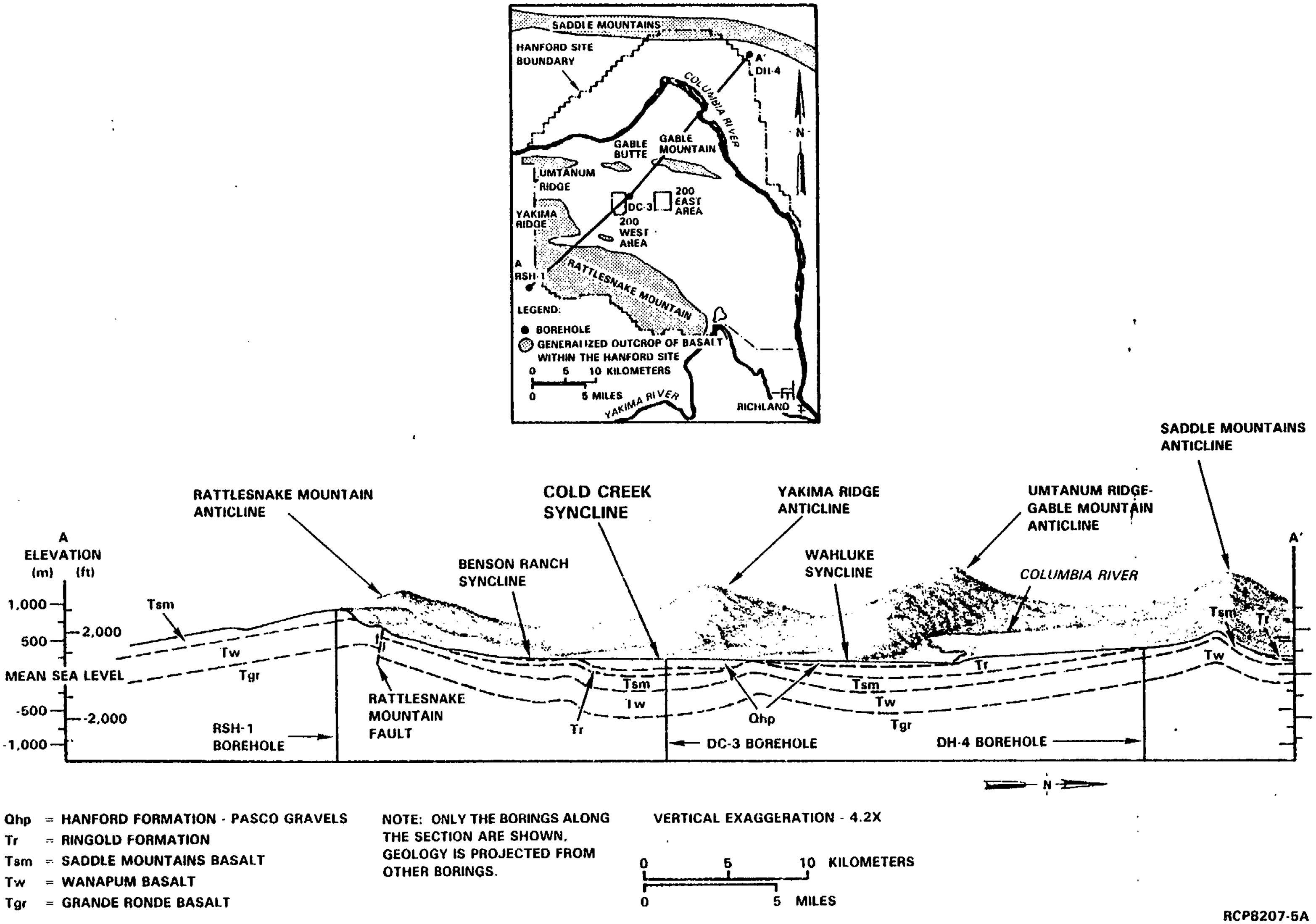
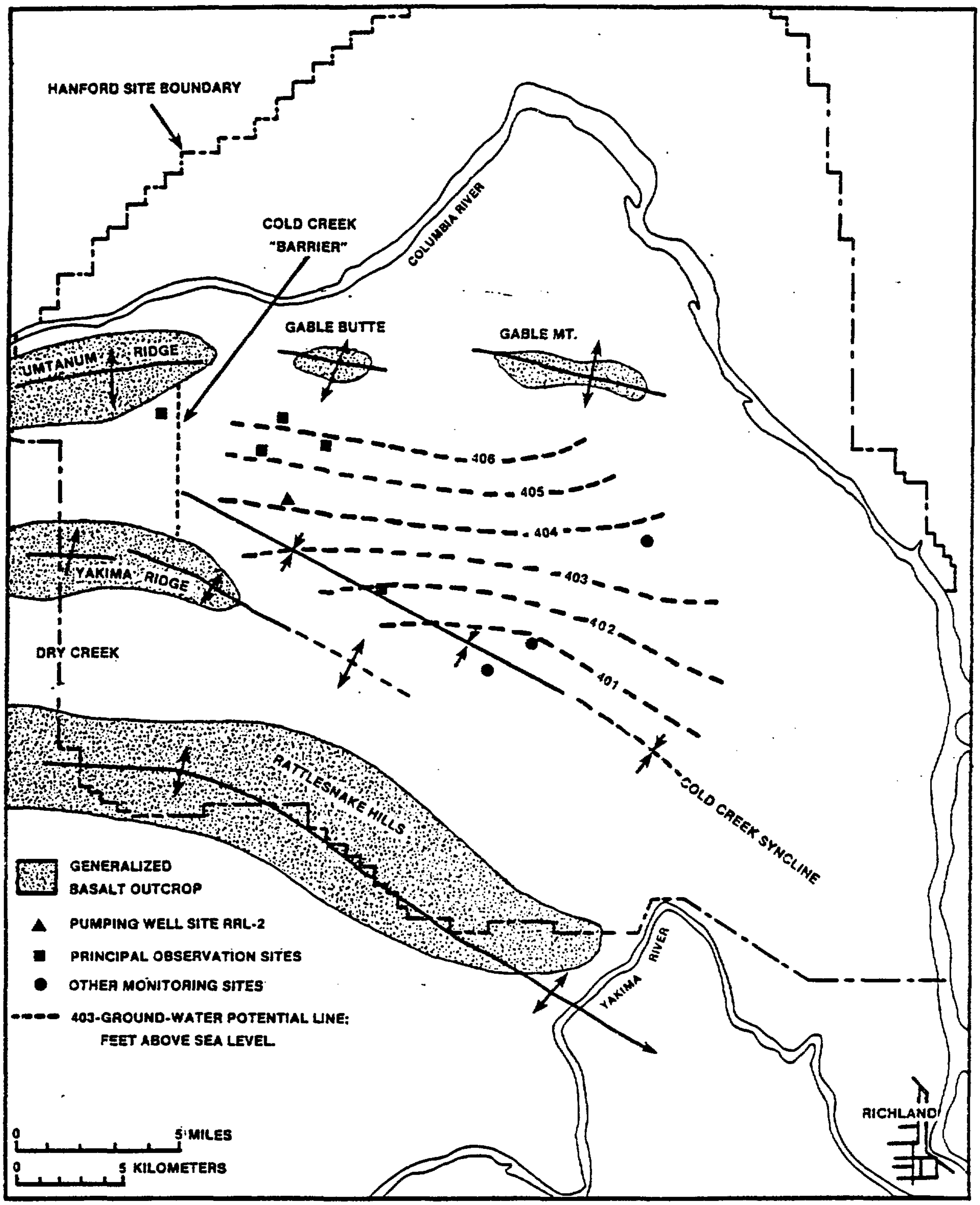
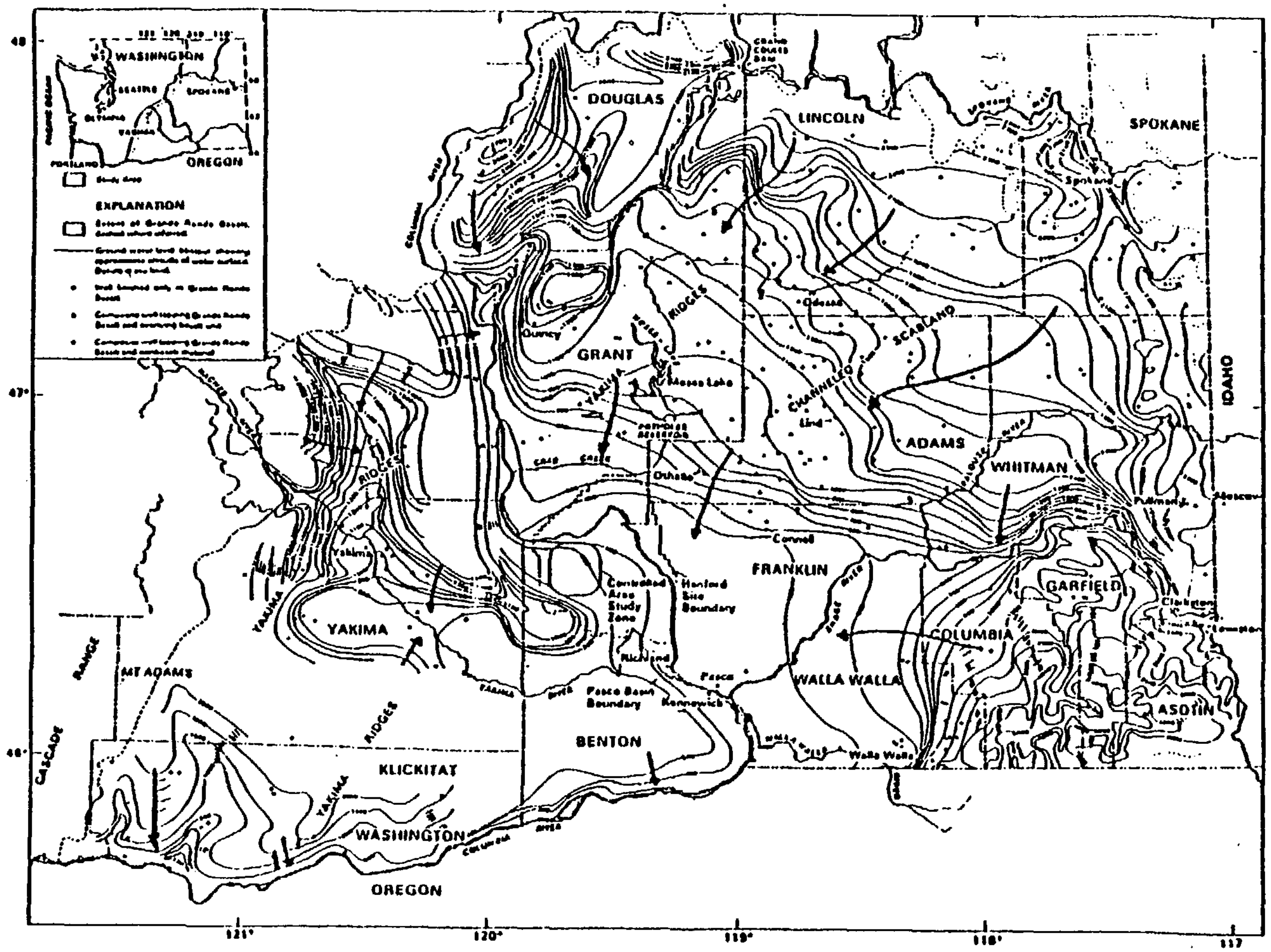


FIGURE 1-5. Generalized Cross Section Through the Pasco Basin.



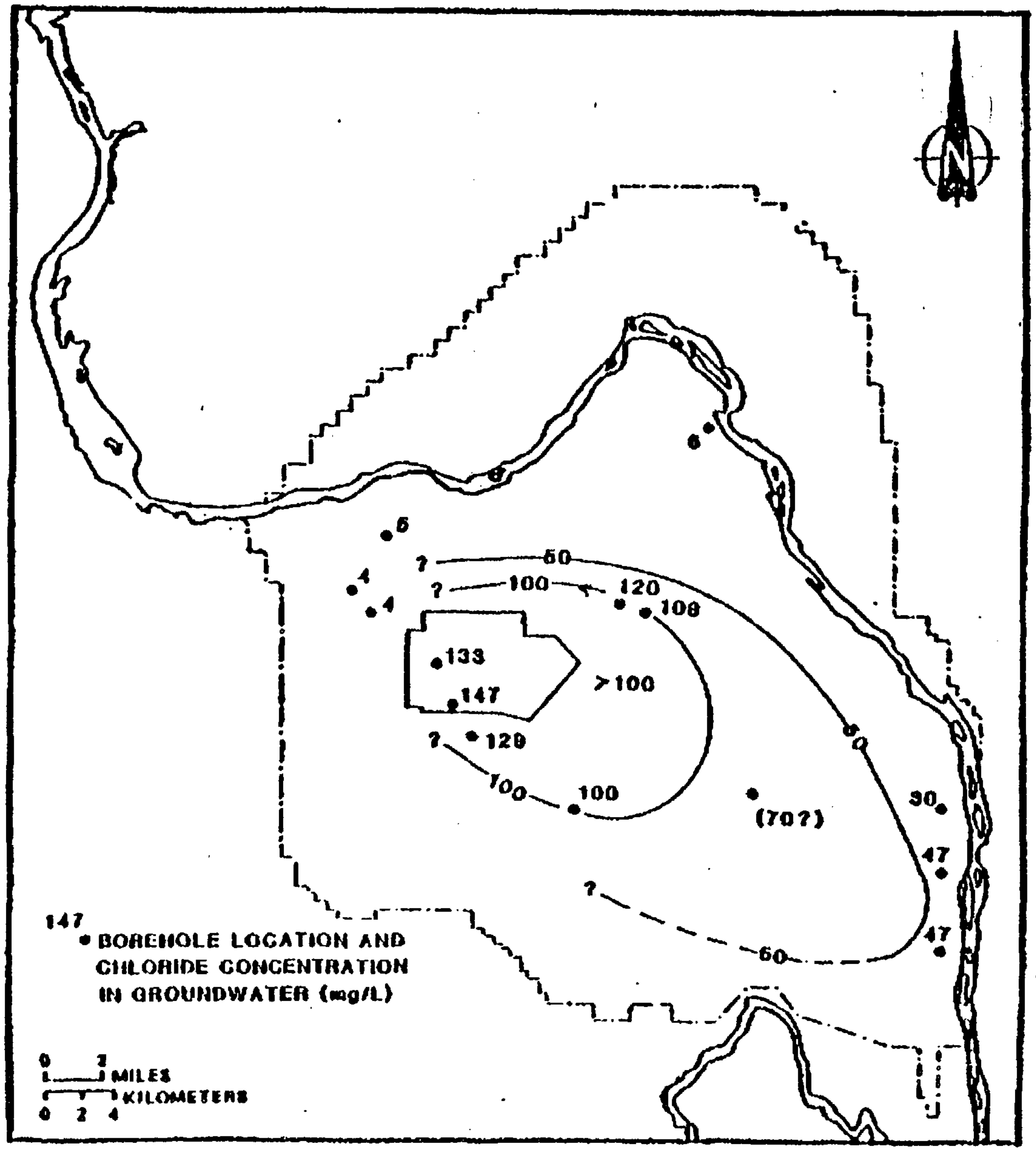
CONCEPTUALIZED POTENTIOMETRIC SURFACE NEAR TOP OF GRANDE RONDE BASALT, COLD CREEK SYNCLINE, FALL 1986 WATER LEVELS

0216-0024DS 3/16/87



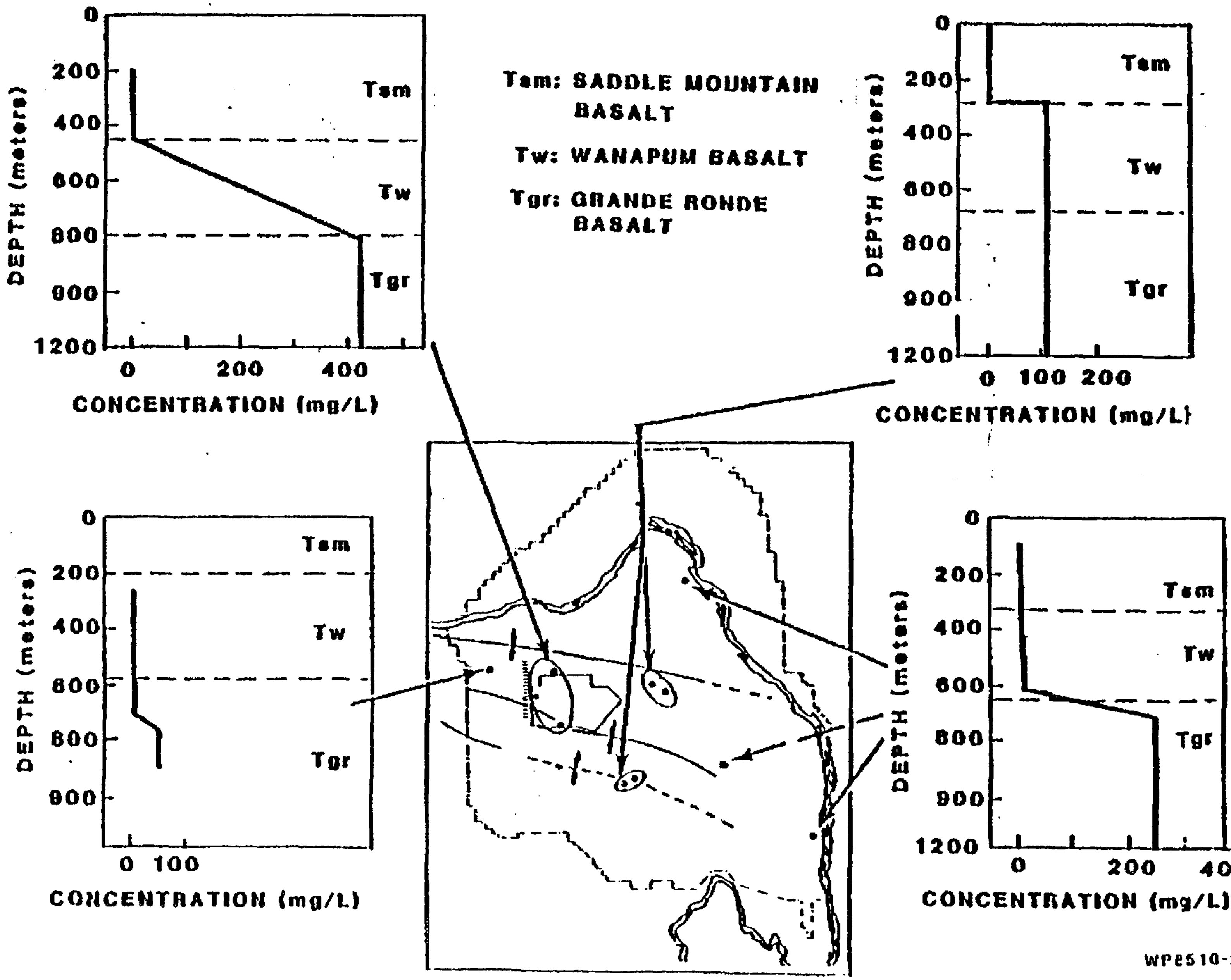
GENERALIZED AREAL GROUNDWATER FLOW PATHS IN THE GRONDE RONDE BASALT WITHIN THE COLUMBIA PLATEAU

CHLORIDE IN UPPER WANAPUM GROUNDWATERS

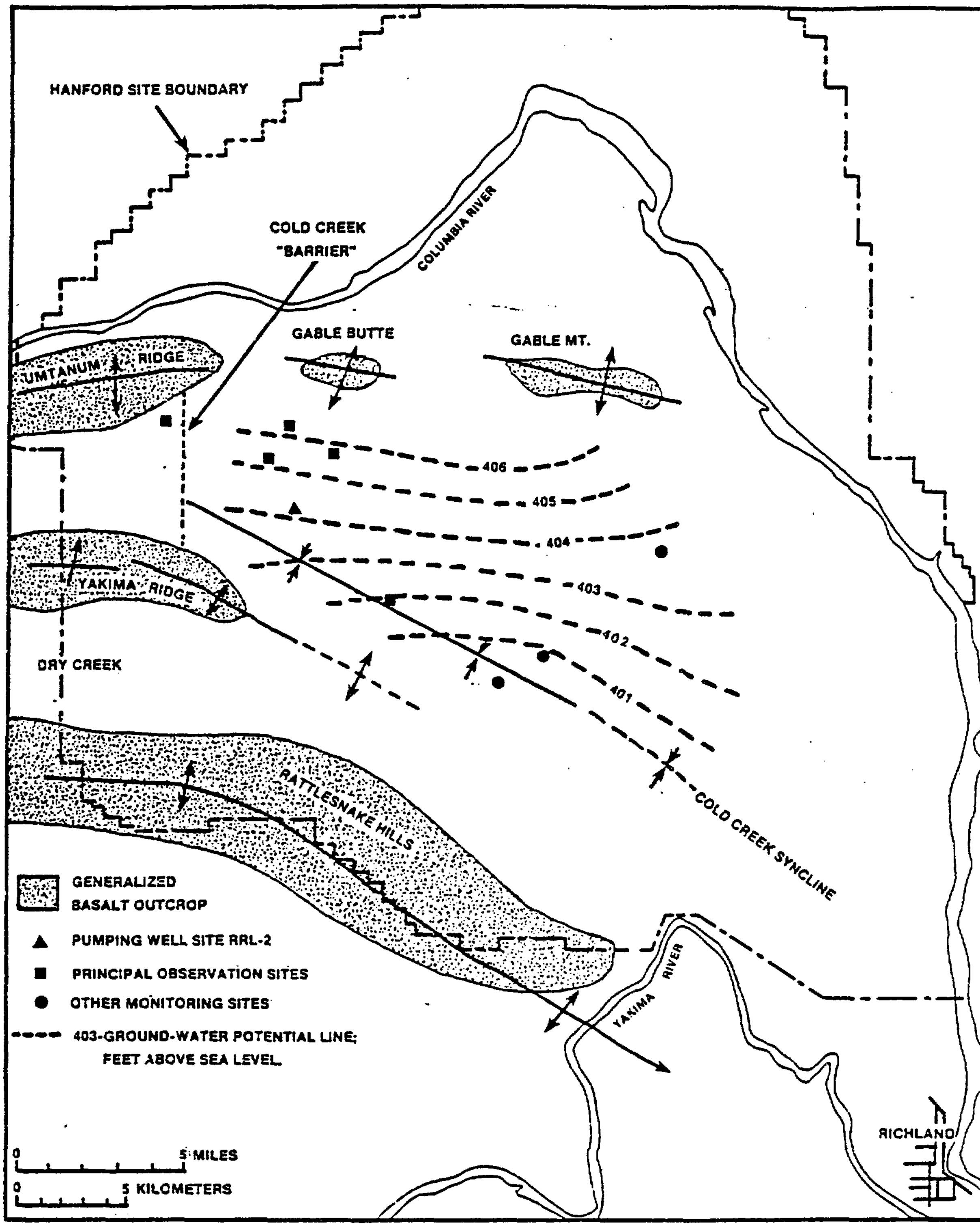


WP8510-43

SCHEMATIC CONCENTRATION-DEPTH PROFILES FOR CHLORIDE IN GROUNDWATERS FROM SELECTED HANFORD BOREHOLES



WPE510-38



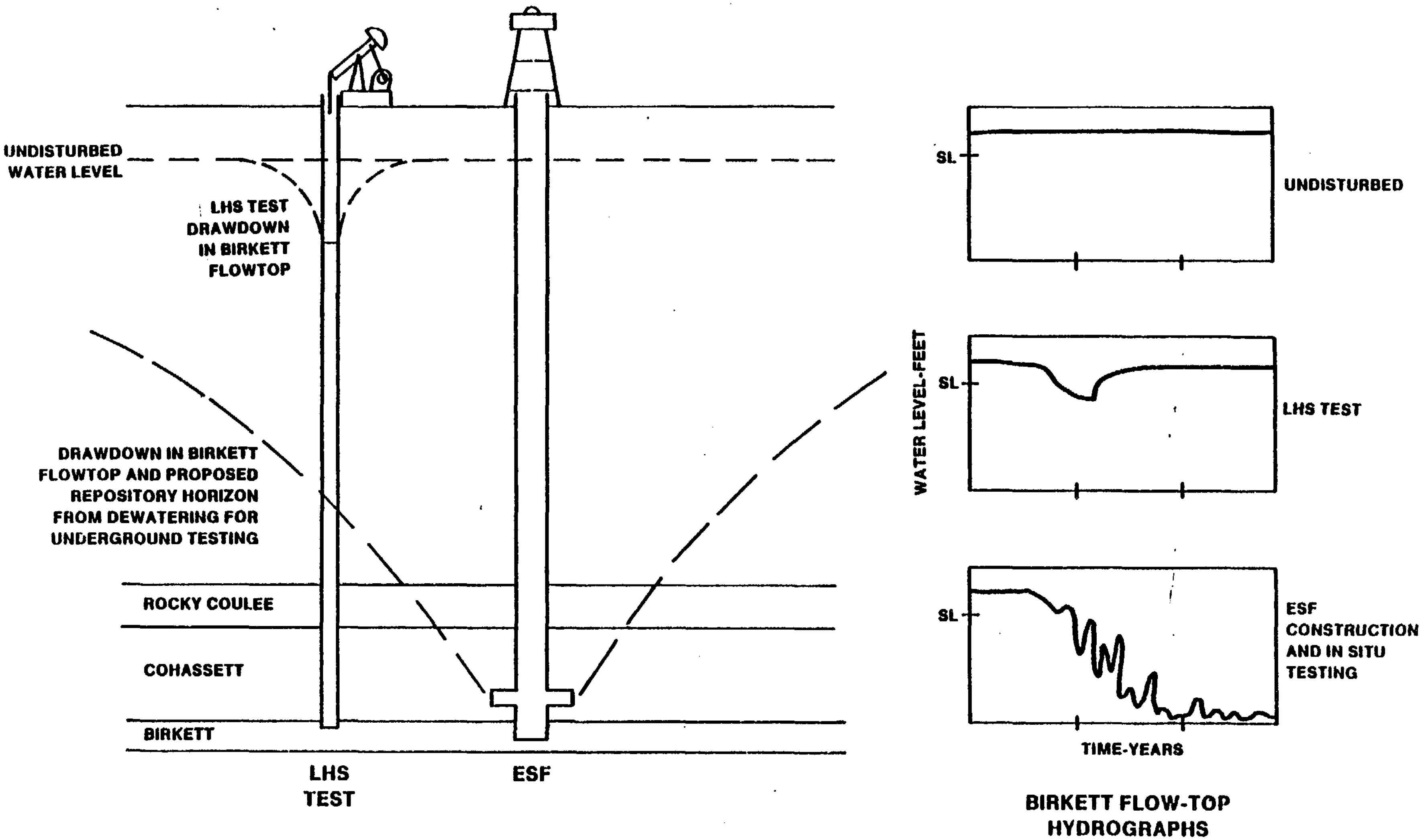
CONCEPTUALIZED POTENTIOMETRIC SURFACE NEAR TOP OF GRANDE RONDE BASALT, COLD CREEK SYNCLINE, FALL 1986 WATER LEVELS

0216-0024DS 3/16/87

Approach

JUSTIFICATION FOR PRE-ES TESTING PROGRAM

The construction and operation of an exploratory shaft facility (ESF) at the Hanford site will significantly alter the existing geohydrologic system. These changes could compromise the results of some key geohydrologic tests if performed after the start of ESF construction. Given this circumstance, it is necessary to define a pre-ES geohydrologic testing program which provides necessary data before the disruptive events caused by the ESF and provides reliable information for resolving licensing issues.



SCHEMATIC OF RELATIVE EFFECTS OF SITE CHARACTERIZATION ACTIVITIES ON GROUND-WATER LEVELS IN PUMPED INTERVALS

0216-0024DS 3/16/87

STEPS TAKEN TO PLAN A PRE-ES GEOHYDROLOGIC TESTING PROGRAM

- Organized a small working group of geosciences specialists consisting of two or three representatives each from DOE Headquarters, Roy F. Weston, DOE Richland Operations, and Rockwell International.
- Working group identified all issues from the Issues Hierarchy that require hydrologic testing to meet relevant information needs.
- Identified information needs for each geohydrology related issue and the parameters and tests needed to meet the information needs.
- Determined what tests must be run before and what ones can wait until after the first Exploratory Shaft is started.
- Developed a set of pre-Exploratory Shaft Geohydrologic Testing Program options.
- Recommended an option for implementation.
- Reviewed options with independent consultants.

OBJECTIVES OF PRES-ES TESTING PROGRAM

- To collect data on geohydrologic conditions that will be changed by site characterization activities.
- To collect data having the potential for providing an early indication of the presence of a disqualifying condition.
- To collect data on geohydrologic conditions in order to identify the effects of the ESF on the geohydrologic system and on subsequent geohydrologic tests.
- To collect data on geohydrologic conditions that may affect the design of the ESF or the repository.

Issues Containing Hydrologic Testing and Disqualifying Conditions

Issue		Hydrologic Testing	Disqualifying Condition
1.1	Release to A.E.	Y	N
1.2	Individual Protection	Y	N
1.3	Ground Water Protection	N	-
1.4	Performance Objectives-Containment	Y	N
1.5	Performance Objective-Engineered Barriers	Y	N
1.6	Ground-Water Travel Time	Y	Y
1.7	Performance Confirmation	Y	N
1.8	Favorable and Adverse Conditions	Y	N
1.9.0	Postclosure Guidelines	Y	N
1.9.1	Postclosure Geohydrology	Y	Y
1.9.2	Postclosure Geochemistry	Y	N
1.9.3	Postclosure Rock Characteristics	Y	N
1.9.4	Postclosure Climate	Y	N
1.9.5	Postclosure Erosion	Y	N
1.9.6	Postclosure Dissolution	N	-
1.9.7	Postclosure Tectonics	Y	N
1.9.8	Postclosure Human Interference	Y	N
1.10	Waste Package Design (Postclosure)	N	-
1.11	Repository Design (Postclosure)	Y	N
1.12	Seals Design (Postclosure)	Y	N
2.1-2.5	Radiation Safety	N	-
2.6	Waste Package Design (Preclosure)	Y	N
2.7	Repository Design (Preclosure)	Y	N
2.8-2.11	Characterization Issues	N	-
4.1.0	Performance Issues		
4.1.1	Ease and Cost	Y	N
4.1.2	Surface Characteristic	Y	N
4.1.3	Rock Characteristic	Y	N
4.1.4	Preclosure Hydrology	Y	Y
4.1.5	Preclosure Tectonics	N	-

LICENSING ISSUES RELATED TO GEOHYDROLOGY

1.1 Release to the accessible environment
1.2 Individual protection
1.4 Waste-package life
1.5 Release rates
1.6 Ground-water travel time
1.7 Performance confirmation
1.8 Favorable and adverse conditions
1.9 Postclosure guidelines
1.11 Repository design
1.12 Seals postclosure
2.6 Waste package design preclosure
2.7 Repository design preclosure
4.1.1 Ease and cost of construction
4.1.3 Rock characteristics
4.1.4 Preclosure hydrology
4.2 Repository design: nonradiological worker safety
4.4 Repository design: adequate technolgy for repository construction,operation, closure,decommissioning
4.5 Repository design: cost of waste package and repository

SUMMARY OF HYDROLOGIC TESTS TO RESOLVE ISSUES HAVING GROUND WATER INFORMATION NEEDS

Issue	Information Needs	Parameters	Tests	Timing Need	Comments
1.1 Release to accessible environment	Diffusion in dead-end pore (matrix diffusion)	Diffusion coefficients	Multiple well tracer tests; Lab tests on rock samples	Post ES, should be incidental with other tracer tests	
	Flow & mass transport through fractures versus continuum	Kh (horizontal hydraulic conductivity) of flow tops or T(transmissivities); Kv (vertical hydraulic conductivities) and Kh of flow interiors; response shapes of hydrographs	LHS tests; borehole cluster tests in ESF	Pre ES at RRL2 Post ES for others	Pre ES for: perishable conditions; identify disqualifying conditions
		Effective thickness of flow tops; Dispersivities; Storativity of flow tops and specific storage of flow interiors	Multiple well tracer tests; borehole cluster tracer tests in ESF; core analyses	Pre ES at RRL-2; Post ES, coordinate with other tracer tests	Pre ES for: same as above for 1.1

STRATEGIES TO INVESTIGATE DISQUALIFYING CONDITIONS

	ISSUE	DISQUALIFYING CONDITION	PARAMETERS	EVALUATION CRITERIA*	TESTS
1.9.1	Post-Closure Geohydrology	Groundwater travel time less than 1000 years	a. Hydraulic properties of flow tops	$\frac{Ti}{nb} > 5$ m/yr	
			• Hydraulic gradient (i)		Spatial and temporal distribution of hydraulic head
			• Transmissivity (T)		LHS tests in flow tops
			• Effective thickness (nb)		Multiwell tracer tests
			• Storativity		LHS tests in flow tops
			b. Hydraulic properties of flow interior	$K'v \leq 10^{-8}$ m/s	
			• Vertical hydraulic conductivity (K'v) of dense interior		LHS tests in flow tops
			• horizontal hydraulic conductivity (Kh) of flow		LHS Tests in flow tops
			• Specific storage		Estimated from tests of core samples
			• Effective porosity		Estimated from tests of core samples
			c. Presence or absence of discrete, highly transmissive features which cross-cut flows	Unexpected vertical response to LHS, such as responses across several intervening flow interiors	
			• Leakance	Recharge boundary within 5km	LHS tests in flow tops
			• Hydraulic boundaries		LHS tests in flow tops
			d. Radioisotope content of ground water	Presence of recent meteoric water:	Sampling and analysis
			• Radioisotope concentrations	$H\text{-}3 \leq 0.2$TU $C\text{-}14 \leq 80\%$ modern $I\text{-}129 \leq 10^{-8}$ pCi/L	

EXHIBIT IV

STRATEGIES TO INVESTIGATE DISQUALIFTYING CONDITIONS (Cont'd)

	ISSUE	DISQUALIFYING CONDITION	PARAMETERS	EVALUATION CRITERIA*	TESTS
4.1.4	Pre-closure Hydrology	Engineering conditions beyond reasonably available technology	a. Hydraulic properties of Cohassett dense interior	$K'v \geq 10^{-9}$ m/s	
			• Vertical hydraulic conductivity		LHS test in Birkett flow top
			• Specific storage		Estimated from tests core samples
			b. Hydraulic properties of adjacent flow tops	N.A.	
			• Transmissivity		LHS test in flow tops
			• Storativity		LHS test in flow tops
			• Head distribution		Spatial and temporal distribution of hydraulic head
			c. Gas content of groundwater	$CH_4 \geq$ 1200mg/L	
			• Gas concentration		Sampling and analysis

*Conditions that are so severe as to be indicative of potential disqualification. Futher evaluations and/or investigations to resolve the conditions will be necessary.

PRE-AND POST-ES GEOHYDROLOGIC TESTS

PRE-ES	POST-ES
Baseline head monitoring	Multi-well tracer tests (several locations)
LHS Tests RRL-2B	Lab tests on rock samples
Pulse Tests RRL-2B	LHS Tests (non RRL-2) (several)
Convergent Tracer Tests	Borehole cluster tests in ESF
Hydrochemical sampling and analysis	Single-well tests for hydraulic properties
	Dual well hydraulic & tracer tests
	Hydrochemical sampling and analysis
	Drill and tests piezometer installations
	Porthole tests in ES
	Various in-situ ESF tests
	Hydraulic stress and tracer tests on well and shaft seals

Options

OPTIONS CONSIDERED FOR THE PRE-ES GEOHYDROLOGY TESTING PROGRAM

A. Baseline hydraulic-head

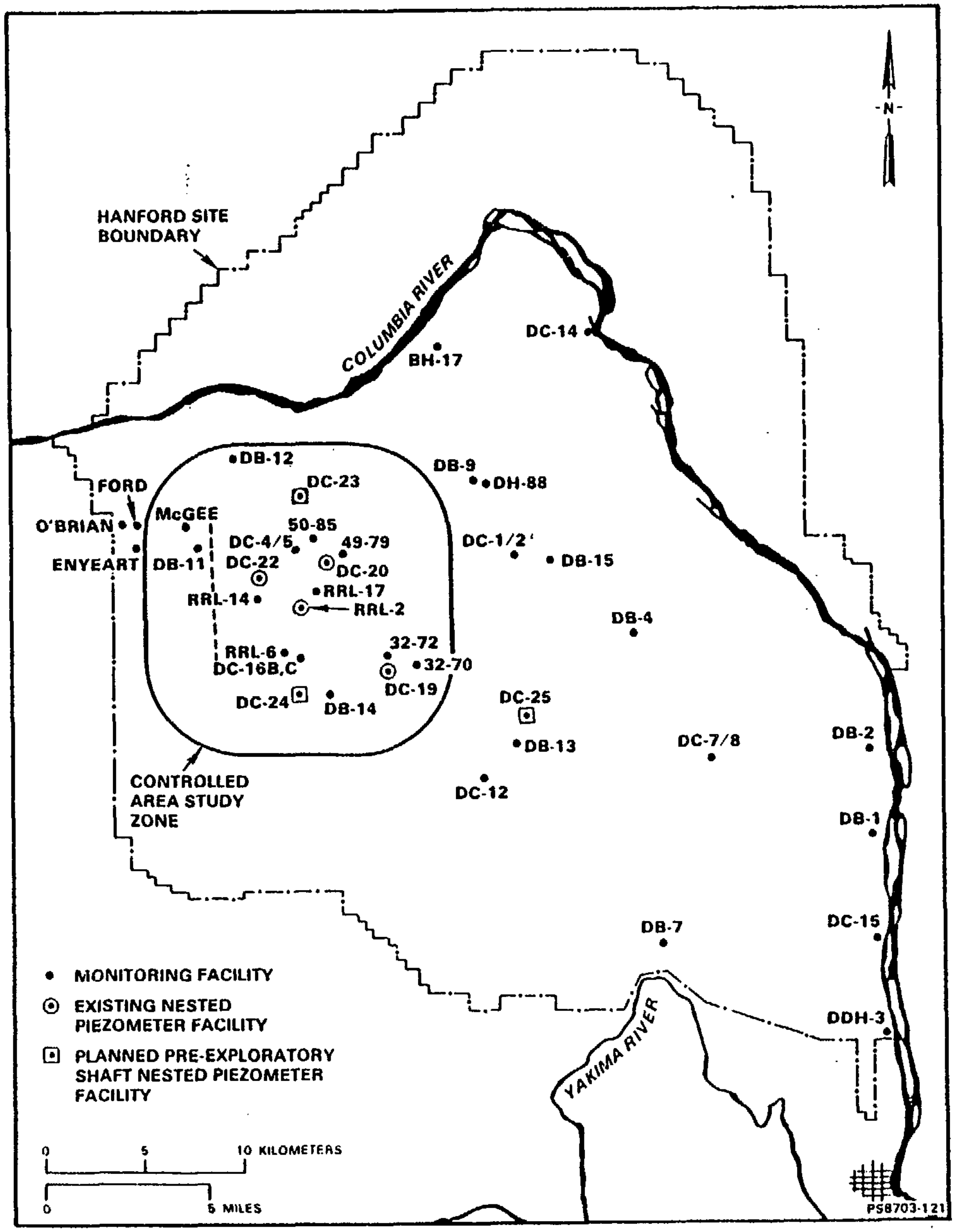
B. Baseline hydraulic-head and LHS testing of one flow top (Rocky Coulee) with hydrochemical sampling and tracer tests

C. Baseline hydraulic-head and LHS testing of one flow top (Birkett) with hydrochemical sampling and tracer tests

D. Baseline hydraulic-head and LHS testing in multiple horizons at the RRL-2 location with hydrochemcial sampling and tracer tests

E. Baseline hydraulic-head and LHS testing in multiple horizons at multiple locations with hydrochemical sampling and tracer tests

OPTION A--Establish a hydraulic-head baseline only
Drill and equilibrate DC-24, -25



Pros

- **Minimal schedule disruption on start of ES**
- **Least cost impact**
- **Yield data on perishable head conditions**

Cons

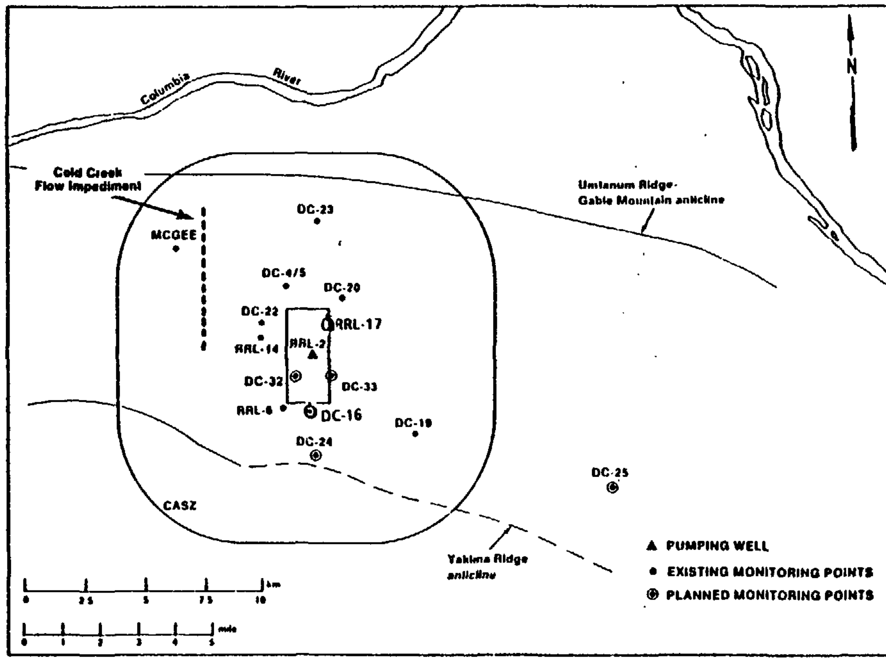
- **Provide insufficient information about disqualifying conditions**
- **Provides no information to support engineering design**
- **Potential compromise of interpreting future test results**
- **Probably not credible with technical community**
- **Subject to severe programmatic criticism**
- **Gains no experience with testing procedures and equipment**
- **Potential change of hydraulic parameters in vicinity of ES not detectable**
- **Provide little or no information on hydraulic boundaries**

— OPTION B —

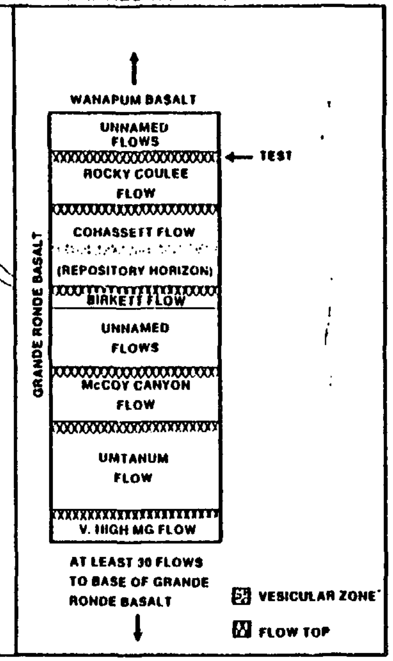
Establish hydraulic-head baseline and test Rocky Coulee flow top

- Drill and equilibrate DC-24,-25
- Drill DC-32,-33
- Pump RRL-2B
- Collect water samples (hydrochemistry)
- Conduct tracer tests

PRIMARY LHS TEST MONITORING FACILITIES IN THE ROCKY COULEE FLOW TOP



STRATIGRAPHY OF THE GRANDE RONDE FORMATION



Pros

- No reprogramming necessary; conform to current test plan and facilities
- Yields data on perishable conditions and hydraulic parameters of Rocky Coulee
- Provides some information on disqualifying conditions
- Expedites start of ES construction

Cons

- Provides little information to support engineering design
- Provides little information on impact of ESF on future tests
- May not be credible with technical community
- Provide little or no information on hydraulic boundaries

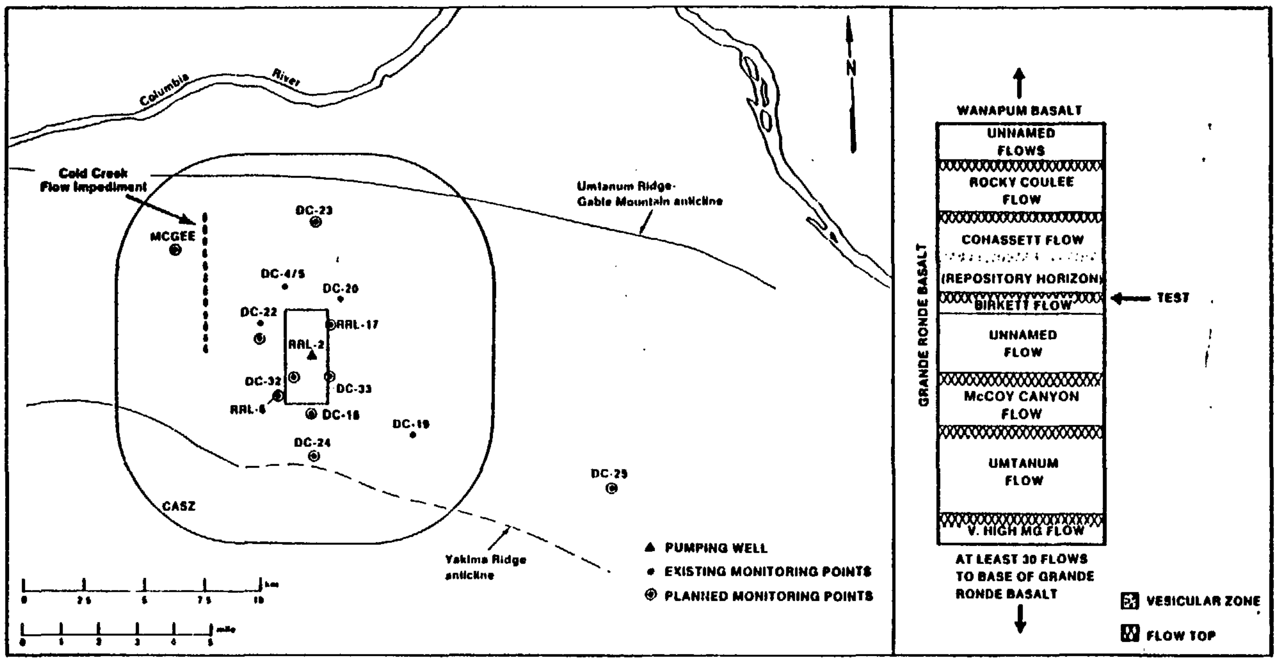
— OPTION C —

Establish hydraulic-head baseline and test Birkett flow top

- Drill and equilibrate DC-24,-25
- Drill DC-32,-33
- Pump RRL-2B
- Collect water samples (hydrochemistry)
- Conduct tracer tests

PRIMARY LHS TEST MONITORING FACILITIES IN THE BIRKETT FLOW TOP

STRATIGRAPHY OF THE GRANDE RONDE FORMATION



Pros

- Provides some information for engineering design
- Yields data on perishable hydraulic properties and conditions of Birkett flow top and Cohassett interior
- Provides some information on disqualifying conditions
- Provides some information on impacts of ESF on future tests

Cons

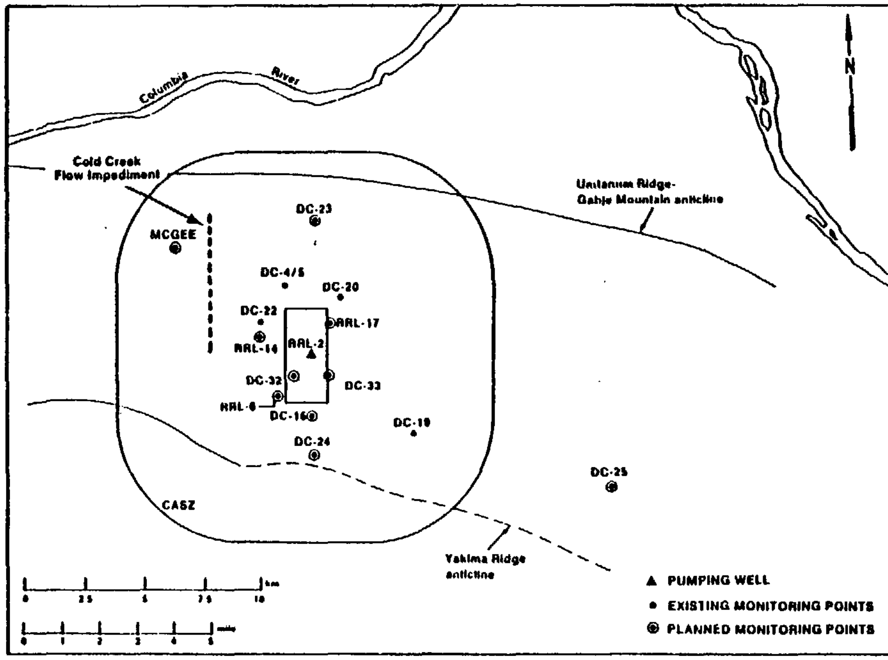
- Limited credibility with technical community
- May delay ES construction schedule
- Requires modification to pumping well and additional monitoring facilities
- Some reprogramming required
- Provide little or no information on hydraulic boundaries

— OPTION D —

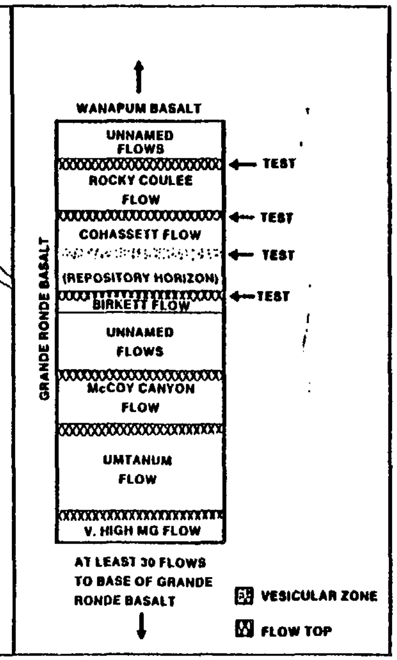
Establish hydraulic-head baseline and test multiple flow tops (Rocky Coulee, Cohassett, and Birkett and Cohassett vesicular zone

- Drill and equilibrate DC-24, -25
- Drill DC-32,-33
- Pump RRL-2B
- Collect water samples (hydrochemistry)
- Conduct tracer tests

PRIMARY LHS TEST MONITORING FACILITIES IN MULTIPLE FLOW TOPS



STRATIGRAPHY OF THE GRANDE RONDE FORMATION



Pros

- Yields data on perishable conditions in Grande Ronde
- Provides substantial information for engineering design at RRL-2 site
- Provides information on disqualifying conditions at RRL-2 site
- Enhances credibility with technical community
- Provide baseline information to predict impacts of ES on future geohydrologic tests

Cons

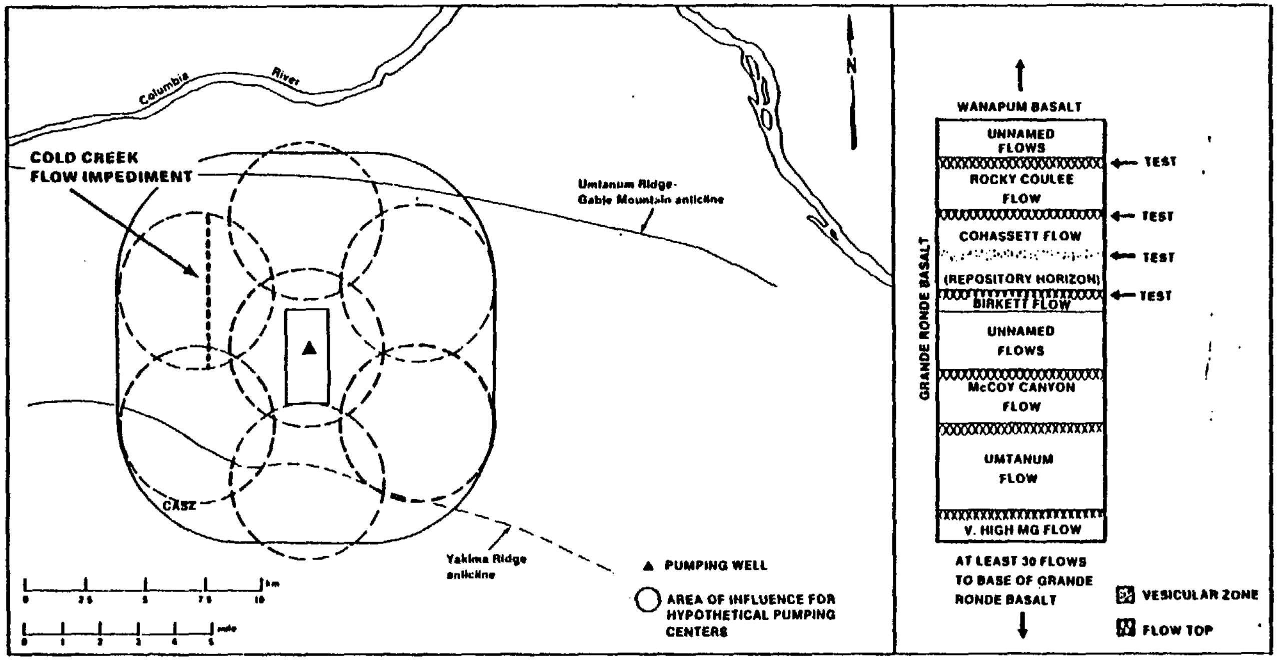
- Delays ES construction schedule
- Near-term site costs increase
- Requires additional monitoring facilities
- Reprogramming required
- Provide little or no information on hydraulic boundaries

— OPTION E —

Establish hydraulic-head baseline and test multiple flow tops (Rocky Coulee, Cohassett, and Birkett) and Cohassett vesicular zone at several additional pumping centers and monitoring wells

- Drill and equilibrate DC-24, -25
- Drill DC-32,-33
- Pump RRL-2B
- Drill and pump other pumping centers and monitoring wells
- Collect water samples (hydrochemistry)
- Conduct tracer tests

CONCEPTUAL LHS TEST PUMPING CENTERS IN MULTIPLE FLOW TOPS **STRATIGRAPHY OF THE GRANDE RONDE FORMATION**



Pros

- Yields definitive data on perishable conditions in Grande Ronde
- Provides definitive design information over wide area of Cohassett flow
- Provides definitive information on disqualifying conditions over much of CASZ
- Provides some information on flow system boundaries
- Avoids interference from ESF activities and attendant interpretation problems
- High credibility with technical community

Cons

- Major delays in ES construction schedule
- Near-term site costs increase substantially
- Major reprogramming required
- Requires considerable monitoring and pumping facilities

RECOMMENDATION

-OPTION D-

Top-down large-scale hydraulic stress (LHS) testing of the Rocky Coulee flow top, the Cohassett flow top, the Cohassett vesicular zone, and the Birkett flow top.

- Pre-emplacement hydraulic-head baseline monitoring
- Large-scale hydraulic stress tests at RRL-2B
- Ground-water sampling for hydrochemistry
- Radial-convergence tracer tests

Planned Pre-ES Testing Program

Proposed
Option D
Pre-exploratory shaft
Test Program

Objectives

- To collect data on geohydrologic conditions that will be changed by site characterization activities
- To collect data having the potential for providing an early indication of the presence of disqualifying conditions
- To collect data on geohydrologic conditions in order to identify the effects of the ESF on the geohydrologic system and on subsequent geohydrologic tests
- To collect data on geohydrologic conditions that may affect the design of the ESF or the repository

PRE-ES SURFACE BASED PROGRAM CONTENT

- o Install Required Monitoring Facilities
- o Establish Potentiometric Baseline
- o Perform Hydraulic Tests at RRL-2B
  - Rocky Coulee Flow Top
  - Cohassett Flow Top
  - Cohassett Vesicular Zone
  - Birkett Flow Top
- o Perform Adjunct Tests
  - Radial-Convergent Tracer Tests with LHS Tests
  - Hydrochemical Samples of Pump Test Discharge

MONITORING FACILITIES

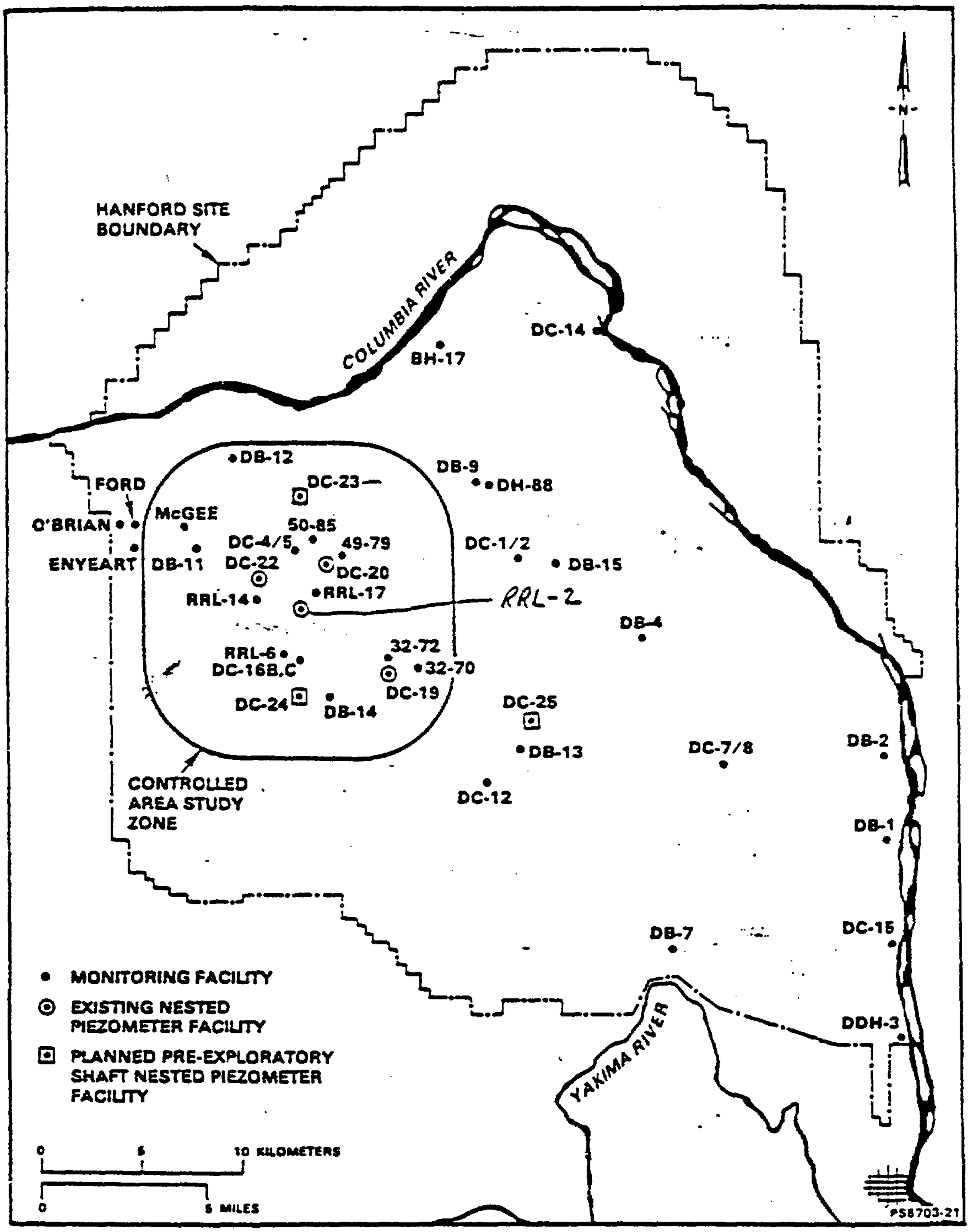
BASIS OF FACILITY LOCATION

- o Conceptual Flow Model Discrimination
  - SW Throughgoing Flow
  - Flow Convergence to Syncline
- o LHS Test Monitoring
  - Intermediate Zone Monitoring
  - Boundary Tests (Post-ES)
- o Lack of Head Data on South Side of Syncline
- o Need for Eastern Constant Head Boundary
- o Vertical Head Distribution Away From Recharge Mounds

HYDRAULIC BASELINE

- o Seven nested piezometers primary data sources
- o 35 mostly single piezometer boreholes - secondary data sources
- o Three years of data at DC-19, DC-20, DC-22
- o Two years of data at RRL-2
- o Install three additional nested piezometers
- o Baseline termination based on acceptance criteria and Technical Review

HYDRAULIC-HEAD BASELINE MONTORING LOCATIONS AT THE HANFORD SITE



HYDRAULIC-HEAD MONITORING FACILITIES FOR OPTION - D	ROSALIA	SENTINEL GAP	GINKGO	VANTAGE INTERBED	GRANDE RONDE-2	ROCKY COULEE FLOW TOP	ROCKY COULEE DENSE INT.	COHASSETT FLOW TOP	COHASSETT VES. ZONE	COHASSETT DENSE INT.	BIRKETT FLOW TOP	BIRKETT DENSE INT.	UMTANUM FLOW TOP	LOW MG. FLOW TOPS
I. Existing Boreholes														
A. Multi-level														
DC-19C	X	X	X			X		X					X	
DC-20C	X	X	X			X		X					X	
DC-22C	X	X	X			X		X					X	
DC-23W	X	X	X											
RRL-2C						X	X	X		X	X	X		
B. Single-level														
DB-1	X													
DB-11	X													
DB-12	X													
DB-14	X													
FORD	X													
ENYEART	X													
O'BRIAN	X													
DC-18			X											
DDH-3			X											
DC-1													X	
DC-14														X
C. Composite														
DB-2 (Rosalia-Roza)														
DB-15 (Wanapum)														
DC-1 (Wanapum)														
DC-7 (Grande Ronde)														
DC-12 (Grande Ronde)														
DC-15 (Grande Ronde)														
II. Planned Boreholes														
A. Multi-level														
DC-23 GR						X		X			X		X	
DC-24	X	X	X			X		X			X		X	
DC-25	X	X	X			X		X			X		X	
DC-32	X	X	X			X		X			X		X	
DC-33	X	X	X			X		X			X		X	
III. Reconfigured Boreholes														
A. Multi-level														
DC-4/5						X					X			
RRL-2A						X		X	X		X			
RRL-6						X					X			
RRL-14						X					X			
RRL-17						X					X			
B. Single -level														
DC-16A											X			

HYDRAULIC HEAD BASELINE

PURPOSE	ACCEPTANCE CRITERIA	CURRENT STATUS
1. Pumping Response	Verified water-level recovery prediction for the period of pump test in wells affected by pump test	Trends are predictable for LHST duration DC-19, 20, & 22
2. Gradient for velocity field estimates (horizontal & vertical)	Verify predicted recovery trend at DC-23, 24, 25 to estimate equilibration	Established at DC-19,20, & 22
3. Conceptual Model/System Dynamaics	Identify role of Baseline data in development or use of conceptual model. Technical review required	Being evaluated

PRE-ES HYDRAULIC TESTS

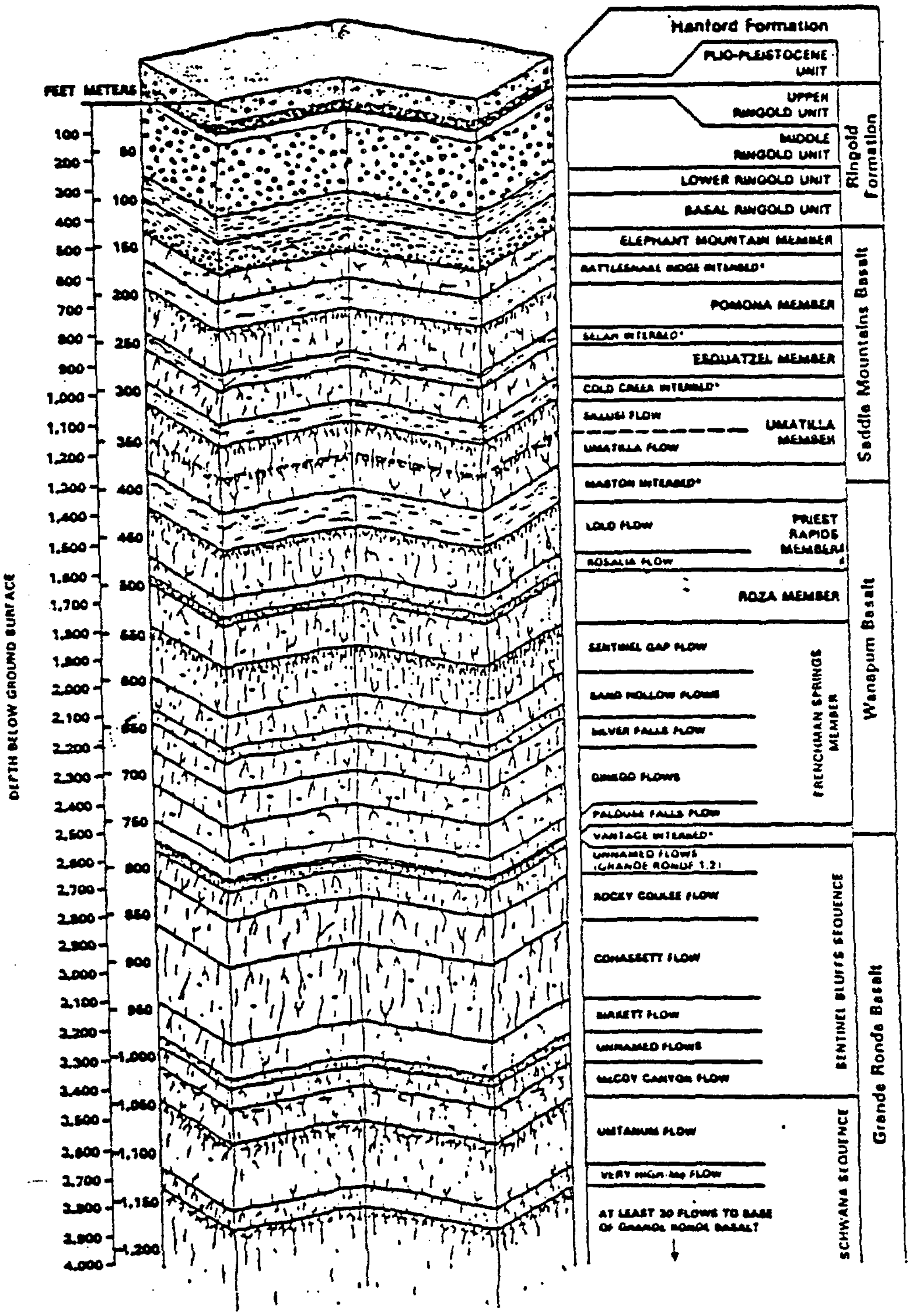
PROGRAM CONTENT

- o Test four zones - sequentially, top to bottom
  - Rocky Coulee Flow Top - LHST
  - Cohassett Flow Top - Pulse (pump if possible)
  - Cohassett Vesicular Zone - Pulse (pump if possible)
  - Birkett Flow Top - LHST

FACILITIES

- o Pump from RRL-2B
- o Monitoring Wells
  - Nine Nested Piezometers
  - Thirty-Five Monitoring Wells
  - Reconfigure selected wells for Rocky Coulee and Birkett Tests RRL-6, RRL-14, DC-4, DC-5, RL-17, McGee
  - Configure DC-16 for Birkett Monitoring

STRATIGRAPHIC UNITS FOUND WITHIN RRL-2



*INTERBEDS ARE STRATIGRAPHICALLY CONTAINED IN THE ELLENSBURG FORMATION

RCP8304-44

ROCKY COULEE & BIRKETT FLOW TOP LHS TESTS

OBJECTIVES

- o Stress across repository area
    - Hydraulic properties (Transmissivity & Storativity)
    - Assess potential presence of discontinuities
- o Induce sufficient drawdown to assess vertical conductivities in dense interiors
- o Assess leakage from dense interiors into flow top
- o Provide data to assist in determining representativeness of existing data
- o Adjunct Tests

PLANNING ASSUMPTIONS IN DEFINING OBJECTIVES

- o Bounding anticlinal structures and Cold Creek syncline flow impediment boundaries will be tested from other pumping centers subsequent to ES construction
- o Full data base for range and distribution of hydraulic parameters will be obtained in post-ES testing program

LHS TEST

INITIATION / TERMINATION

- o Re-establish testing purpose baseline prior to each test
- o Test termination will be predicated on acceptance criteria that are based on test objectives

FACTORS under consideration include:

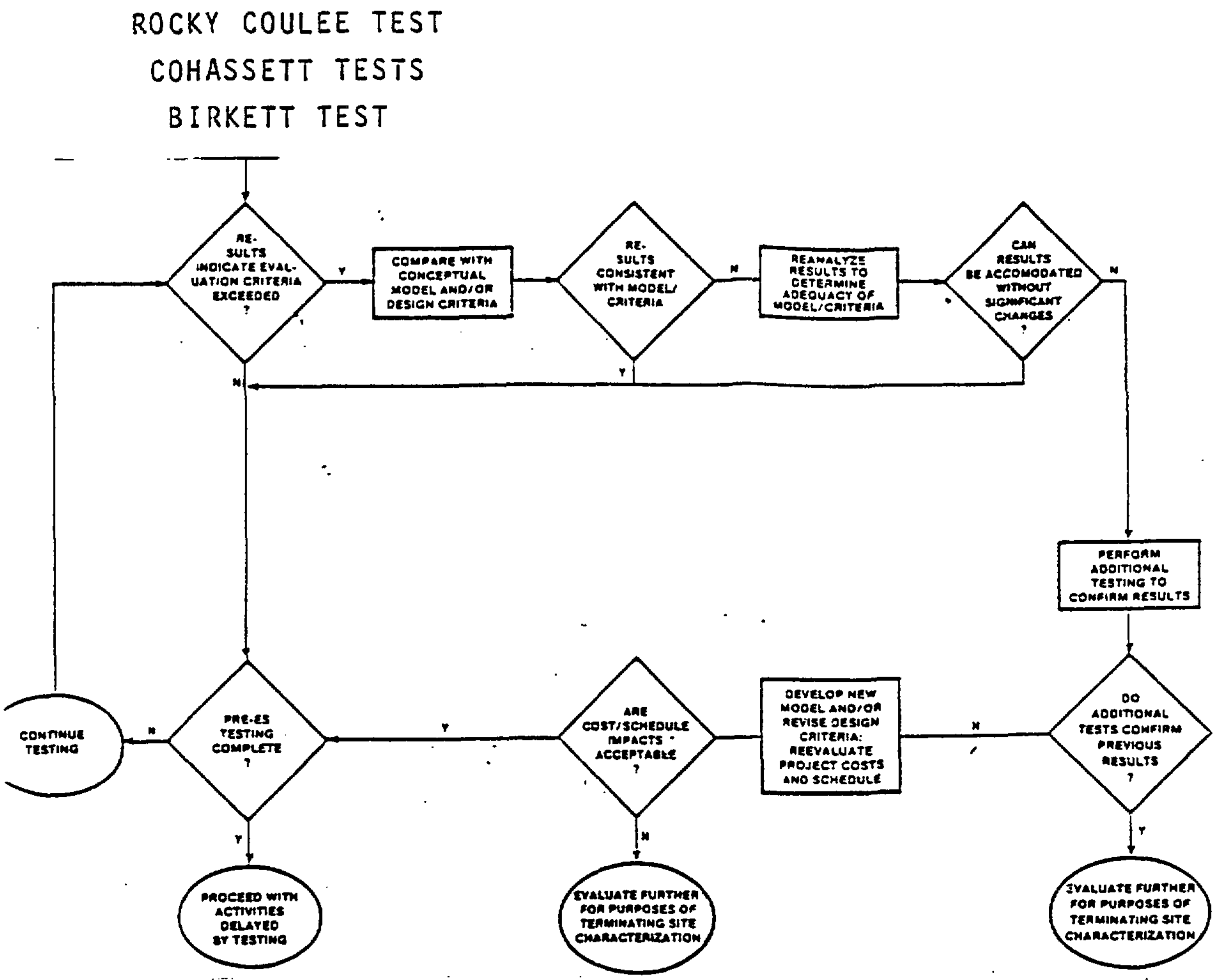
- Reaching Quasi-steady state conditions
- Observation well data match to type curves (T, S & Leakance)
- Analysis of propogation of pressure response
- Measurable drawdown at DC-32, 33, 20 & 22
- Vertical response to estimate Kv

ASSUMPTIONS

- Expected duration of pumping is 30 days, with 60 days of recovery
- Hydraulic objectives will be met prior to injecting tracers - option of injecting tracers prior to start of test is being considered

TERMINATION OF PRE-ES TESTING PROGRAM

(OPTION PAPER LOGIC)



ADJUNCT TESTS

- o Hydrochemistry sampling
- o Tracer Tests

COHASSETT FLOW TOP AND VESICULAR

ZONE SMALL-SCALE TESTS

OBJECTIVES

- o Determine if zone can yield sufficient water to sustain a pumping test

- o Small-scale hydraulic parameters

COHASSETT FLOW TOP / VZ TESTING

- o Isolate test interval
- o Establish Pre-test trend
- o Small-scale test(s)
  - Pulse
  - Constant head injection
- o Evaluate testing results
- o Determine if transmissivity is high enough for LHS testing
- o Conduct LHS test if sufficient transmissivity exists, otherwise, drill to next test interval

Program Implementation

FACILITY DESIGN
DC-24CX, DC-25CX, DC-32CX, AND DC-33CX

TABLE 1

ITEMS IDENTIFIED AND
QUALITY ASSURANCE LEVEL ASSIGNMENT

ITEM	QA LEVEL
Site Evaluation and Preparation (BHL-001)	
Site Excavation	3
Survey Borehole Coordinates	1
Drilling (BHL-002)	
Mobilization/Demobilization	2
Cable Tool Drilling	2
Set Conductor Pipe	2
Rotary Drilling	1
Spot Cementation	2
Set Casing/Cement	2
Fluid Circulation Monitoring	3
Drill Cuttings	1
Workover Rig	2
Set Pump - Clean Hole	3
Piezometer (BHL-003)	
Set Cement Plug (Top and Bottom)	1
Assemble, Measure, and Place Piezometer (Includes Welding Centralizers)	1
Tubing Test (Joint and Composite Test)	1
Filter Pack Placement	1
Develop Piezometer	1
Install and Monitor Transducer	1
Materials	3
Geologic/Geophysical Logging (BHL-004)	
Open and Cased Hole Logs	1
Developmental Logs	3
Borehole Geologic Logs	3

Geohydrology Program Overview

PS87-2153-8

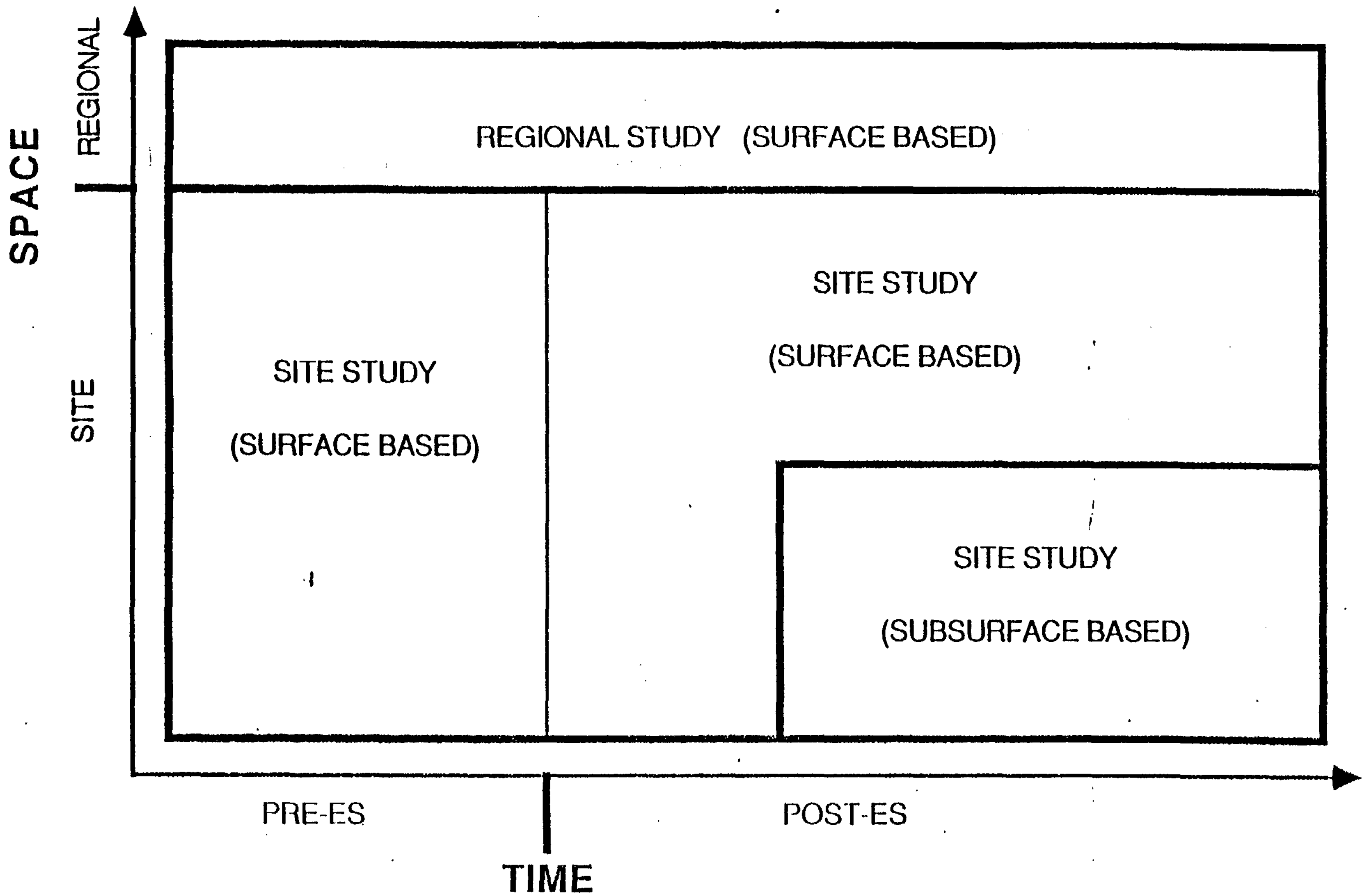
GEOHYDROLOGY PROGRAM OVERVIEW

- o Planning Logic
- o Pre-Exploratory Shaft Surface-Based Testing
- o Post-Exploratory Shaft Surface-Based Testing
- o Regional Program
- o Subsurface Testing Program
- o Geohydrology Program Integration

GEOHYDROLOGY PROGRAM

PLANNING LOGIC

1. Develop Issue Resolution Strategies
2. Identify Geohydrologic Parameters Required by the Issue Resolution Strategies
3. Develop Testing Program to Provide Estimates of Parameter Values at the Appropriate Level of Confidence
4. Identify Program Components
    - o Pre-Exploratory Shaft Surface-Based Testing
    - o Post-Exploratory Shaft Surface-Based Testing
    - o Subsurface Testing
    - o Regional Testing / Data Collection



TIME-SPACE RELATIONSHIP BETWEEN THE SITE AND REGIONAL GEOHYDROLOGIC STUDIES

Pre-ES Surface-Based Testing

OBJECTIVES

- To collect data on geohydrologic conditions that will be changed by site characterization activities
- To collect data having the potential for providing an early indication of the presence of disqualifying conditions
- To collect data on geohydrologic conditions in order to identify the effects of the ESF on the geohydrologic system and on subsequent geohydrologic tests
- To collect data on geohydrologic conditions that may affect the design of the ESF or the repository

TESTING PROGRAM DESCRIPTION

- Pre-Emplacement Groundwater Level Baseline
- Large-Scale Hydraulic Stress Tests at RRL-2
- Radial-Convergent Tracer Tests in Conjunction with each Large-Scale Hydraulic Stress Test
- Hydrochemical Sampling of Discharge During Large-Scale Hydraulic Stress Testing

Post-ES Surface-Based Testing

TENTATIVE OBJECTIVES

- o Obtain Hydraulic Property Range and Distribution in the Controlled Area Study Zone (Hydraulic Conductivity, Specific Storage, Effective Porosity, Dispersivity)

- o Determine the Hydraulic Significance of Geologic Features Affecting Groundwater Flow in the Controlled Area Study Zone

- o Obtain Groundwater Samples for Hydrochemical Characterization

Post-ES Surface-Based Testing
(continued)

Testing Program Description

- o Large-Scale Hydraulic Stress Test Series in and Near the Controlled Area Study Zone for
  - Nature and Extent of Boundaries
  - Range and Distribution of Large-Volume Hydraulic Properties
- o Small-Scale Hydraulic Testing for
  - Range and Distribution of Hydraulic Properties
- o Tracer Testing for
  - Range and Distribution of Transport Parameters
- o Groundwater Sampling for
  - Hydrochemical Characterization

Regional Study

OBJECTIVE

- o Evaluate Regional Geohydrologic Conditions that might effect Site Groundwater Flow Conditions

TESTING PROGRAM DESCRIPTION

- o Regional Flow Model Development vis

  - Geology
  - Regional Groundwater Levels
  - Hydraulic Properties
  - Recharge
  - Hydrochemistry
  - Climatology

- o Sensitivity Analysis of Regional Hydrologic Changes from

  - Climatic Changes
  - Man-Induced Changes
  - Flow System Geometric Changes

Subsurface-Based Testing

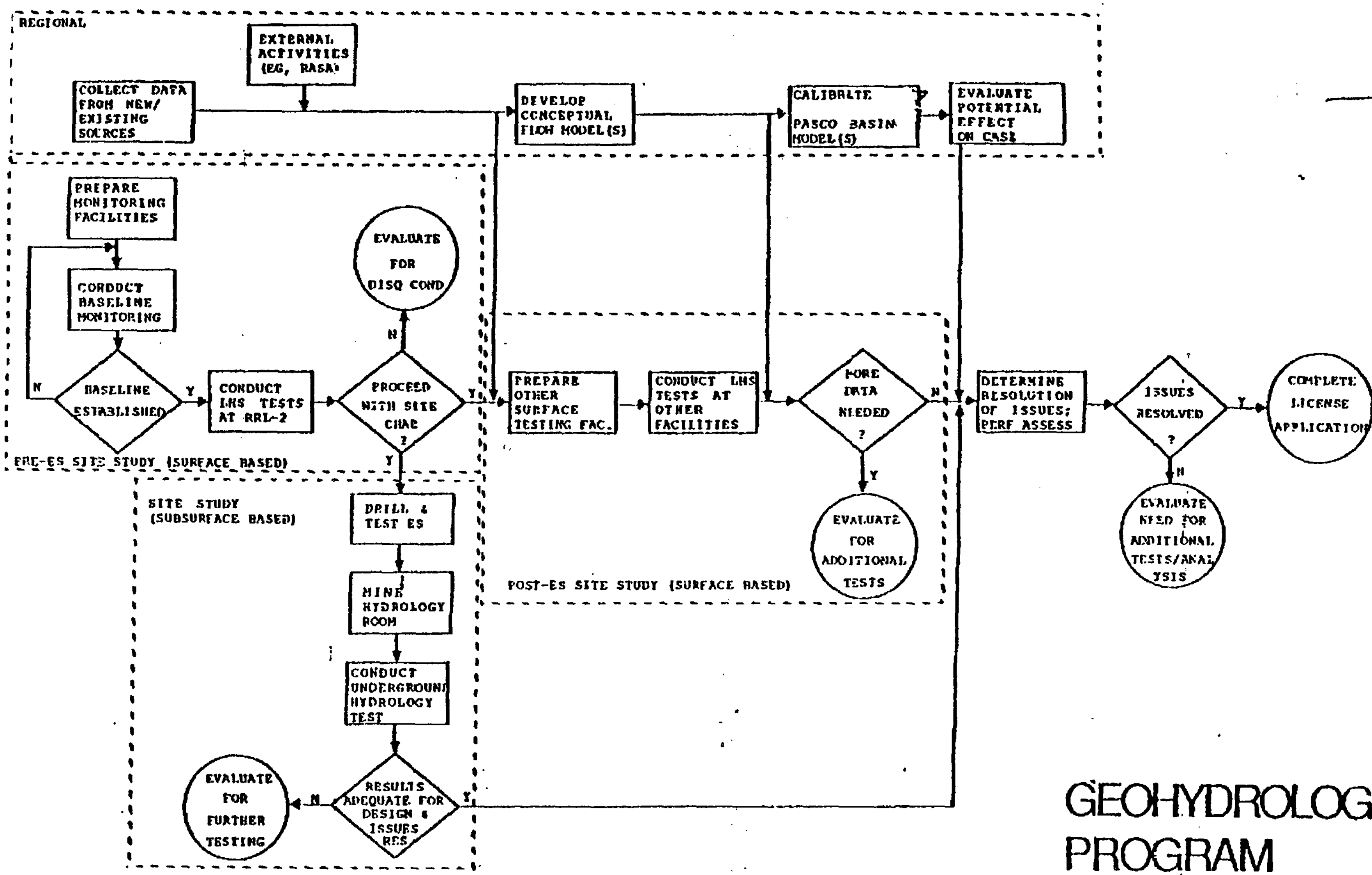
<u>Objective</u>

- To Obtain Estimates of Hydraulic Parameters within the Cohassett Flow Interior

<u>Testing Program Description</u>

- Single Borehole Tests for
  - Safety
  - Disturbed Rock Hydraulic Properties
- Chamber Tests for
  - Hydraulic Conductivity of Dense Interior
- Cluster Borehole Test for
  - Small-Scale Hydraulic Properties of the Dense Interior
- Cluster Tracer Test for
  - Effective Porosity and Dispersivity of Dense Interior

Geohydrology Program Integration



GEOHYDROLOGY PROGRAM INTEGRATION

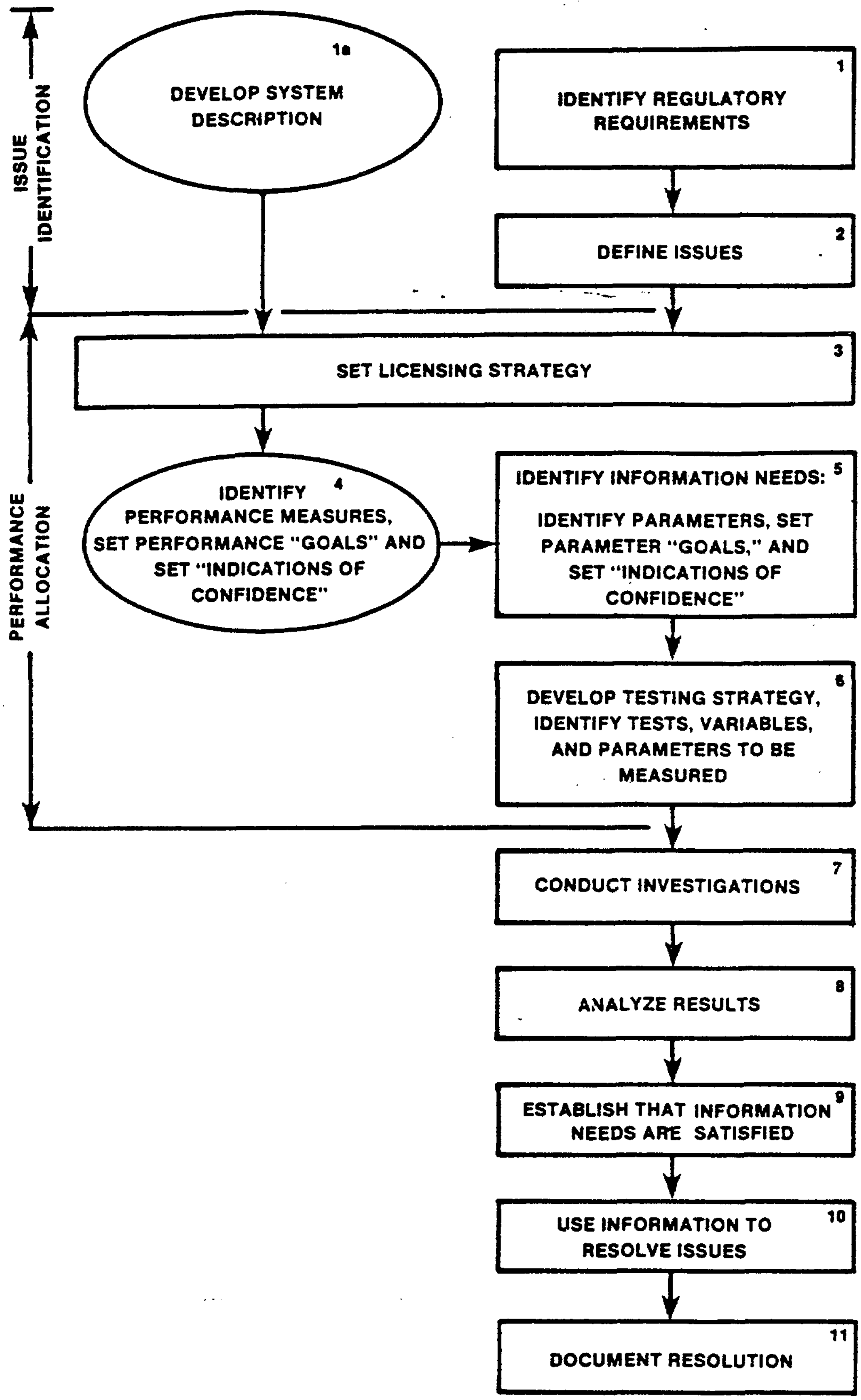
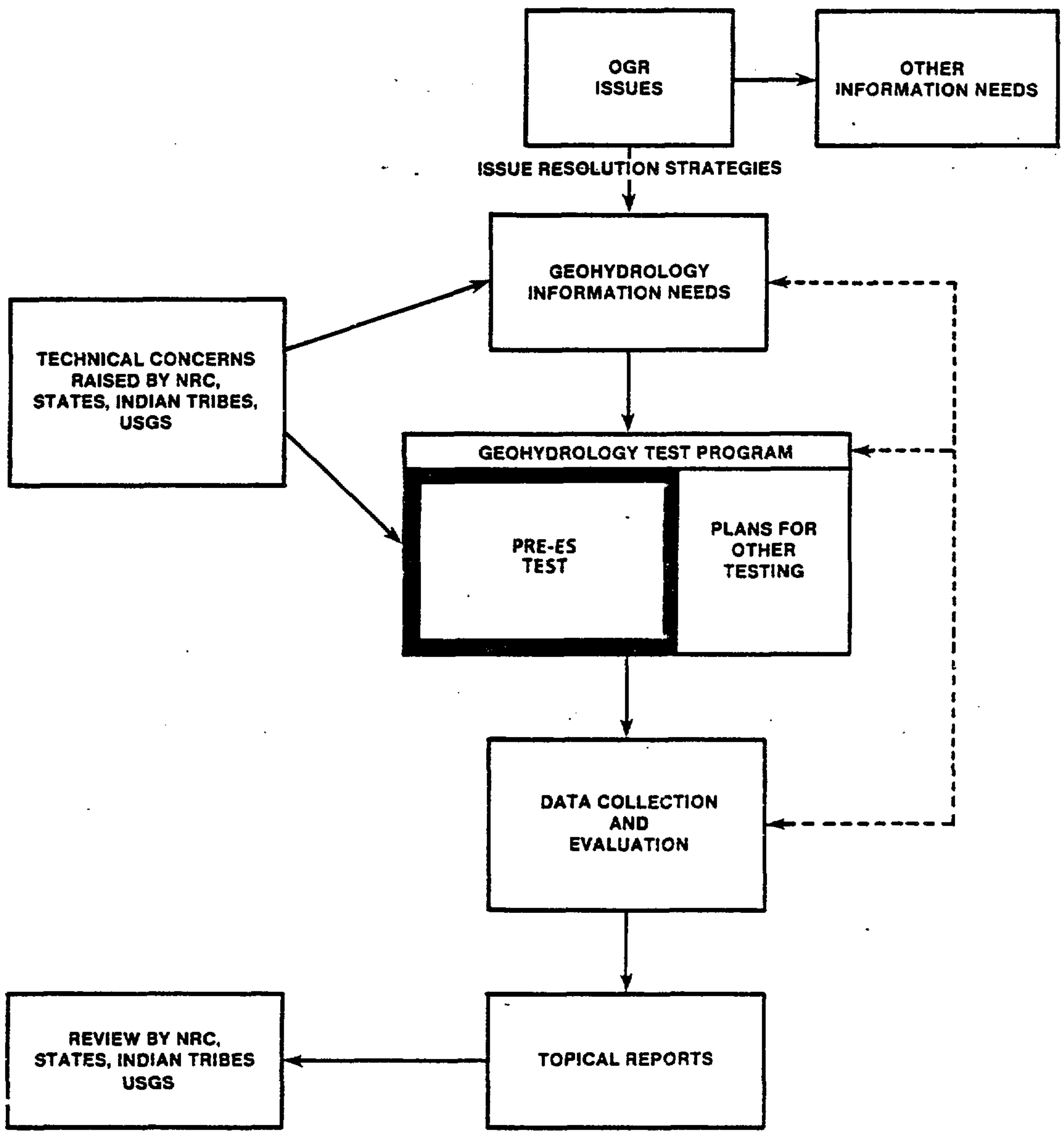


Figure 5. Issue resolution strategy.

SCP ORGANIZATION
FOR THE HANFORD GEOHYDROLOGY PROGRAM

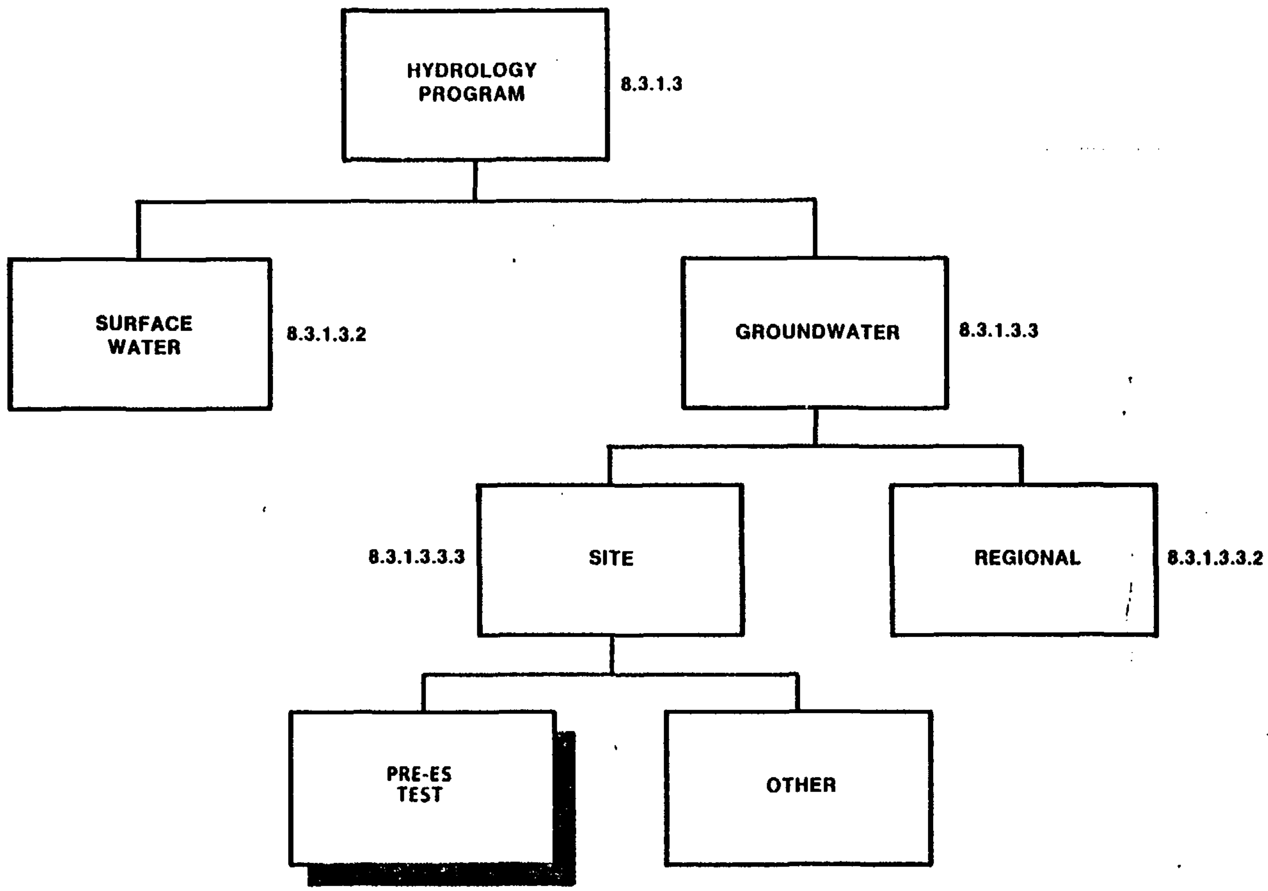
Chapter 8.0 Site Characterization Program

- 8.1 Rationale for the Planned Site-Characterization Program
- 8.2 Issues to be Resolved and Information Required During Site Characterization
- 8.3 Planned Investigations
  - 8.3.1.3 Hydrology
    - 8.3.1.3.1 Introduction
    - 8.3.1.3.2 Surface Water Investigation
      - 8.3.1.3.2.1 Purpose and Objective
      - 8.3.1.3.2.2 Rationale
      - 8.3.1.3.2.3 Description
        - 8.3.1.3.2.3.1 Surface Water System Study
        - 8.3.1.3.2.3.2 Site Flooding Study
    - 8.3.1.3.3 Groundwater Investigation
      - 8.3.1.3.3.1 Purpose and Objectives
      - 8.3.1.3.3.2 Rationale
      - 8.3.1.3.3.3 Description of Studies
        - 8.3.1.3.3.3.1 Regional Groundwater Study
        - 8.3.1.3.3.3.2 Site Groundwater Study



RELATIONSHIPS OF PRE-EXPLORATORY SHAFT TESTING PROGRAM TO ISSUE RESOLUTION STRATEGIES

0216-0024RJ 4/3/87



RELATIONSHIP OF PRE-EXPLORATORY SHAFT TESTING PROGRAM TO OVERALL HYDROLOGY PROGRAM IN SCP

0216-0024RJ 4/3/87

NRC Response Assignments

Comment No.	Description	Assignment
1	Monitoring Locations and Frequencies	P. D. Thorne
2	Cement Effects on RRL-2A and RRL-6	P. D. Thorne
3	Borehole Interflow	P. M. Rogers
4	Monitoring Facilities for the Ratio Test	P. M. Rogers
5	Grout Permeability and Piezometer Performance	S. M. Baker
6	Westbay Installation	S. M. Baker
7	LHS Testing Focus	K. M. Thompson
8	Pump Selection	P. M. Rogers
9	Criteria for LHS Testing	L. S. Leonhart
10	Development of RRL-2B	P. D. Thorne
11	Mechanical Effects	P. D. Thorne
12	Vesicular Zone Testing	P. D. Thorne
13	Convergent Tracer Test	L. S. Leonhart
14	Perturbations to Hydrologic Baseline	L. S. Leonhart
15	Hydrochemical Sampling	S. H. Hall
16	Data Release	K. M. Thompson

PS87-2153-27

Monitoring Locations and Frequencies

NRC Concerns

- Uneven Distribution of Monitoring Facilities Around RRL-2
- Lack of Monitoring Points at "Intermediate Scale"
- Lack of Birkett Monitoring Points
- Comprehensive Assessment of Monitoring Adequacy

DOE Response

Monitoring Locations

- Five New Multi-Level Piezometers
- Eight Boreholes Planned for Modification
- Packers Used at Seven
- One Permanent Modification
- Uneven Distribution Filled In
- Two Permanent and One Multi-Use Facility at "Intermediate Scale"
- Birkett Monitoring Points Added

Monitoring Locations and Frequencies

DOE Response (cont.)

Monitoring Frequencies

- Frequency will be Increased as Necessary During Testing

Comprehensive Monitoring System Assessment

- Analyses Started but not Complete. Plans for Completion Presented in Site Groundwater Study Plan

Proposed Status

Open

LOCATION OF MULTIPLE-LEVEL PIEZOMETER FACILITIES

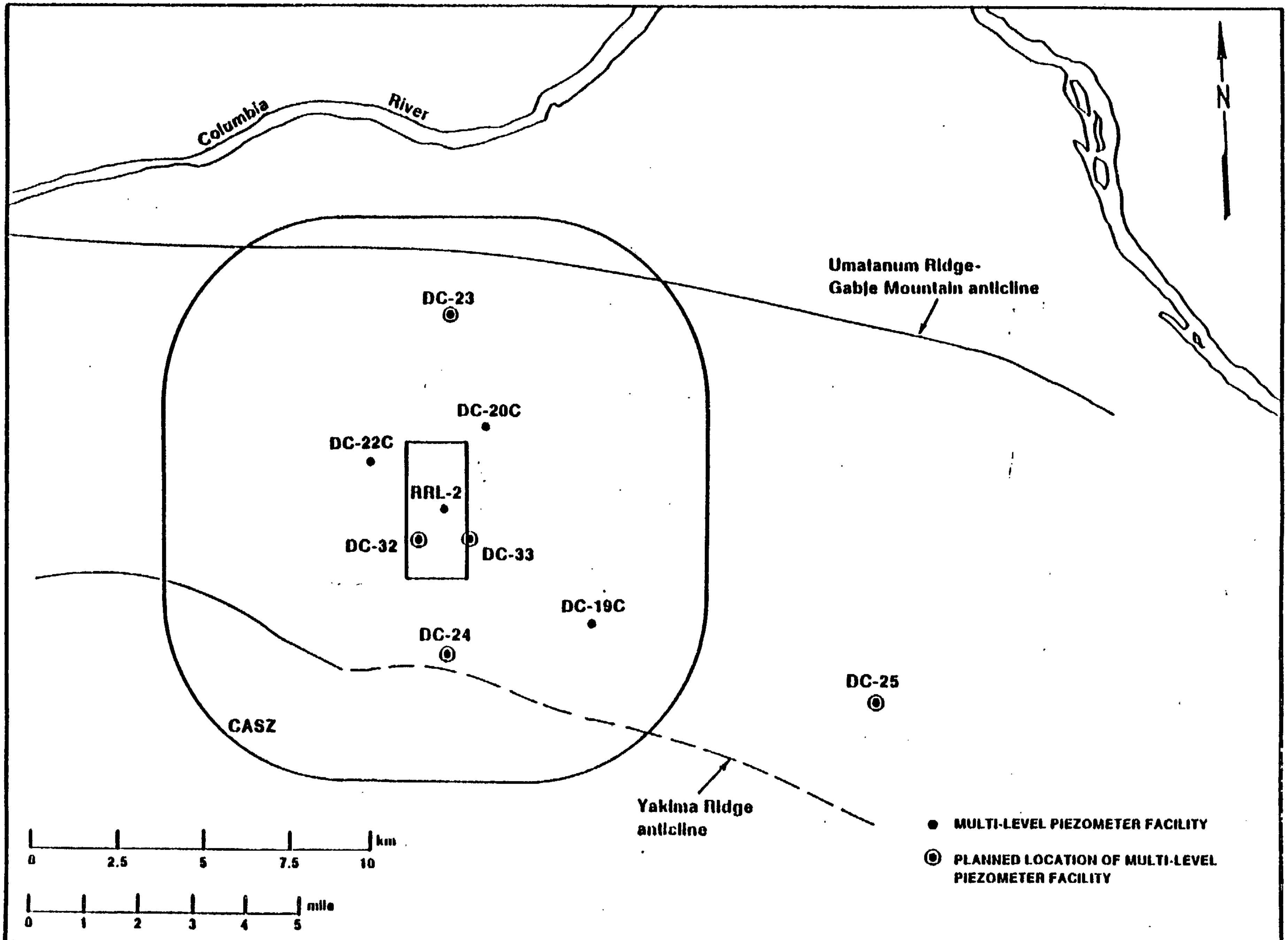


FIGURE 1

Cement Effects

NRC Concern

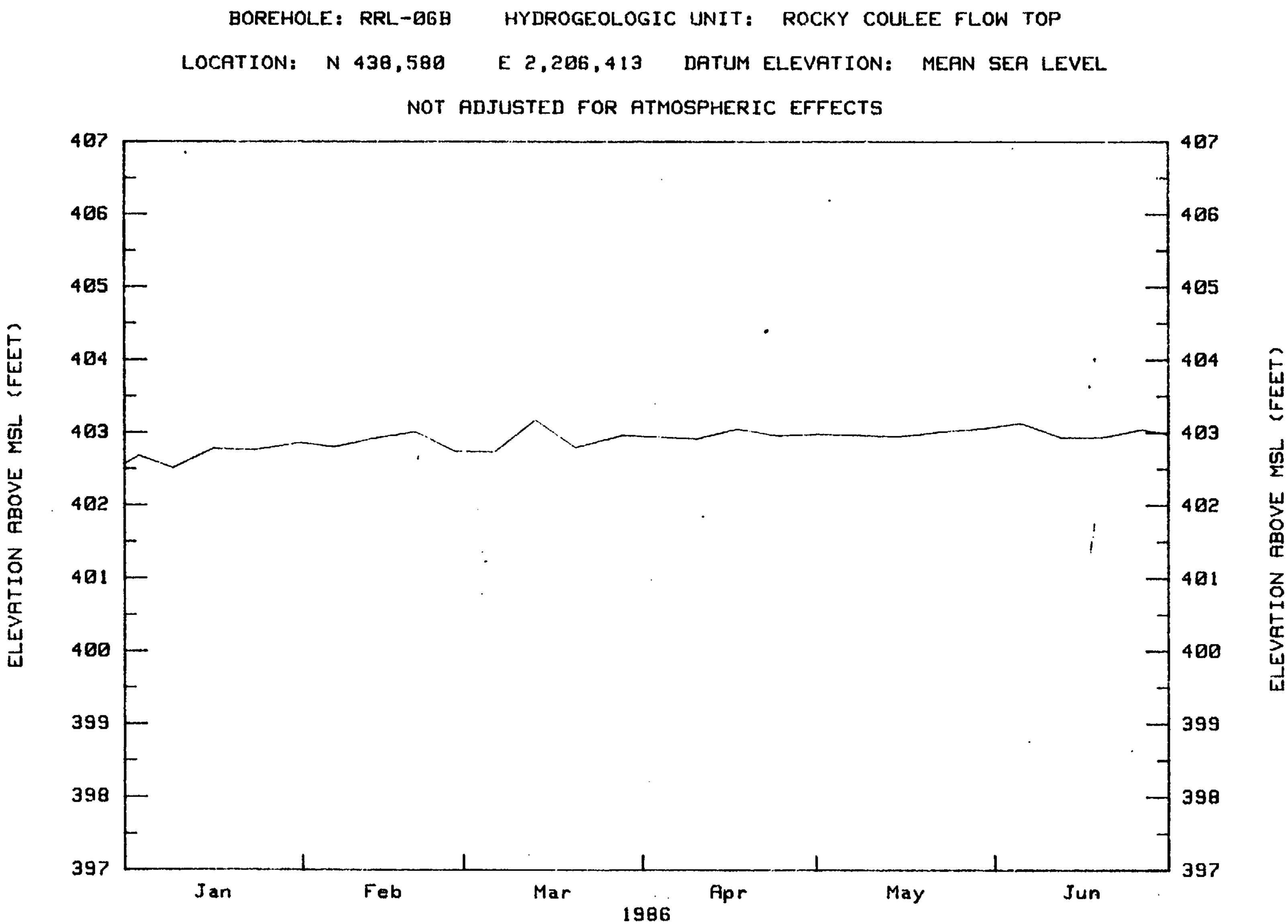
- BWIP did not Document the Basis for Concluding that Cementing of the Rocky Coulee Flow Top at RRL-2A and RRL-6 During Construction does not Significantly Inhibit Hydraulic Communication

DOE Response

- BWIP has Provided the Requested Documentation
- Spot Cementing of Rocky Coulee Flow Top at RRL-2A had Minimal Effect on Hydraulic Properties
  - Transmissivity Estimates for Hydraulic Test Performed Pre- and Post-Cementing are of Similar Magnitude
  - Dynamic Temperature Logs Indicate Water Production from the Rocky Coulee Flow Top
- Cementing Effects on Hydraulic Properties of the Rocky Coulee Flow Top at RRL-6 not as Well Known
  - Time-Series Water-Level Data from Subsequent Monitoring are Consistent with Data from Other Rocky Coulee Flow Top Observation Points
  - Addition of Monitoring at DC-32 Makes Measurements at RRL-6 Less Critical

Proposed Status

Closed

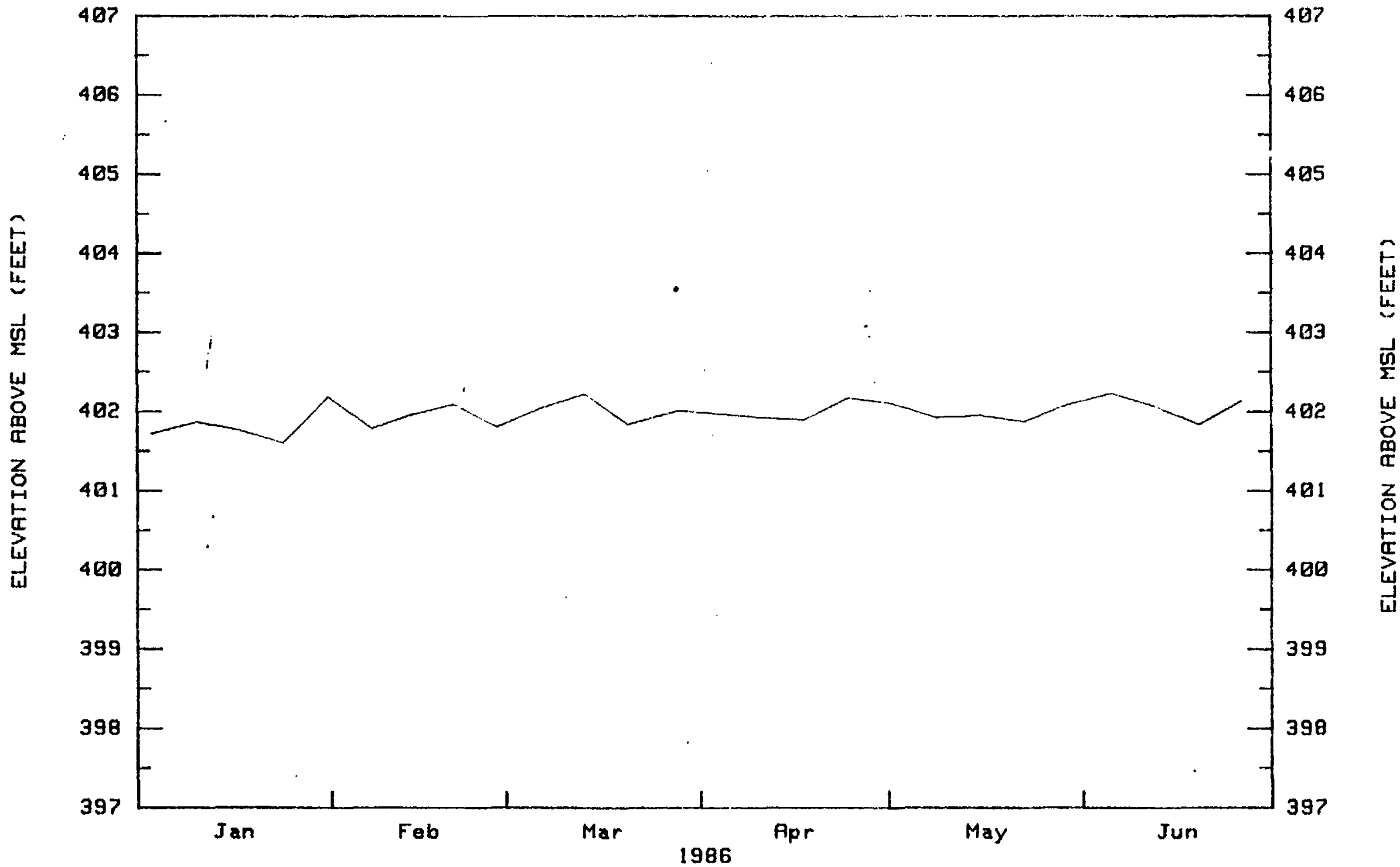


Program WHYDAT Rev 6.3 FILE: RRL_6BGRC
Produced on: 6 Apr 1987 12:29

BOREHOLE: DC-19C HYDROGEOLOGIC UNIT: ROCKY COULEE FLOW TOP

LOCATION: N 433,933 E 2,225,012 DATUM ELEVATION: MEAN SEA LEVEL

NOT ADJUSTED FOR ATMOSPHERIC EFFECTS



Program WHYDAT Rev 6.3 FILE: ROCKYTEMP
Produced on: 6 Apr 1987 12:43

Borehole Interflow

NRC Concerns

- Borehole Interflow Above Straddle Packers Might Interfere with Large-Scale Hydraulic Stress (LHS) Test Interpretation
- BWIP Should Perform Analyses to Evaluate this Effect

DOE Response

- Planned Test Sequence Calls for "Top-Down" Testing
- Removal of Bridge Plugs will also be "Top-Down," Following the Testing
- Borehole Interflow Effects are not Expected to be Significant at Horizons and Locations Other than Where the Interflow Occurs Based on Limited Analyses Performed to Assess the Effect of Interflow Between Flow Tops above the Test Flow Top at DC-16
- Additional Analyses (Modeling) will be Performed Prior to Testing to Estimate Borehole Interflow Effects

Proposed Status

Open

Monitoring Facilities for the Ratio Test

NRC Concerns

- Lack of Monitoring Point Above the Rocky Coulee Precludes Determination of Diffusivity for the Flow Interior Above the Rocky Coulee Flow
- Piezometer Compliance Might Cause Non-conservative Estimates of Hydraulic Diffusivity

DOE Response

- Several Approaches will be Used to Estimate Flow Interior Diffusivity
- The Diffusivity of the Flow Overlying the Rocky Coulee (Grande Ronde #2) Cannot be Estimated with the Ratio Method with the Current Instrumentation Because Piezometer(s) have not been Completed in the Dense Interior of the Grande Ronde #2
- The Diffusivity of Selected Regions of Flow Interiors of the Rocky Coulee, Cohassett, and Birkett Flows will be Estimated with the Ratio Method
- Time Lag of Head Response due to Compressibility of Water and Sand Pack in the Monitored Dense Interior will be Estimated Prior to Testing

Proposed Status

Open

Grout Permeability

NRC Concerns

- BWIP Should Present Its Analyses of Grout Permeability and Piezometer Seal Integrity to NRC

DOE Response

- Grout Tested in Laboratory
  - Permeability Comparable to Basalt Dense Interior
  - Hydraulic Conductivity Less Than 8.0 E-11 Meters per Second
  - Results Reported in Completion Report for RRL-2B/C (Jackson et al. 1986, pp. 44-45)
- Piezometer Integrity Testing
  - Individual Tubes Pumped to Check for Response in Other Tubes
  - Thermal Response Prevents Test Interpretation
  - Other Types of Local Integrity Tests Being Considered
  - Large-Scale Hydraulic Stress (LHS) Tests Designed to Quantify Vertical Continuity Near Piezometers

Grout Permeability

<u>DOE Response</u> (cont.)

- Vertical Isolation Observed Between Some Monitored Flow Tops (Wilson, 1987 p. 29)
- Vertical Connections Observed
  - Distributed Leakage in Upper Wanapum
  - Discrete Vertical Connection Between Rocky Coulee and Cohassett Near DC-20
    - Most Likely to be Natural
    - Could be Faulty Piezometer Seal
- Numerical Modeling of the Data will be Performed to Evaluate Significance

<u>Proposed Status</u>

Open

Westbay Installation

NRC Concerns

- Time Required to Complete a Pressure Profile of all Ports
- Installation in Additional Boreholes

DOE Response

- Significant Time (Hours) Required to Complete a Groundwater Pressure Profile
  - Tests are Long-Term (Months)
  - RRL-14 is a Significant Distance (About 1.5 Miles) from the Pumping Well RRL-2B
  - RRL-14 is Close (About 1,800 Feet) to DC-22
- Equipment was Installed for Development Purposes
- Original Packer Material Failed
- Manufacturer is Replacing Packer Material for Another Equipment Test
- Use of Westbay Systems at Other Sites will be Considered if Demonstrated Feasible at RRL-14

Proposed Status

Open

LHS Testing Focus

NRC Concerns

- Approach to Repository Performance Assessment Appears to be Inconsistent with "Real Focus of Large-Scale Hydraulic Testing in the Grande Ronde Basalt at the RRL-2 Site is the Cohassett Flow Interior"
- LHS Testing Should Develop a Far-Field Perturbation in Response to Controlled Stress, Which can Best be done in the Units of Highest Transmissivity
- Determine the Appropriate Focus of LHS Testing at RRL-2 with Respect to its Approach for Performance Assessment and the Objectives for LHS Testing
- Evaluate LHS Testing of the Cohassett Flow Top

DOE Response

- The BWIP Hydrology Testing Strategy has Evolved Resulting in a Four Part Geohydrologic Characterization Program which will Provide Hydraulic Data to Support Licensing Assessment of Repository Performance
  - Pre-ES Surfaced-Based Testing Program
  - Post-ES Surface-Based Program
  - Regional Program
  - Subsurface Program

LHS Testing Focus

DOE Response (cont.)

- The Pre-ES Testing Program (See Options Paper for Objectives) Consists of Five Tests:
  - Establish a Groundwater Level Baseline Before Potential Disturbance of LHS Testing and ES Construction
  - LHS Test of the Rocky Coulee Flow Top
  - Small-Scale Test of the Cohassett Flow Top (LHS Test will be Performed if Transmissivity Sufficient to Support a LHS Test is Encountered at RRL-2B)
  - Small-Scale Test of the Cohassett Vesicular Zone (LHS Test will be Performed if Transmissivity Sufficient to Support a LHS Test is Encountered at RRL-2B)
  - LHS Test of the Birkett Flow Top

Proposed Status

Closed for Pre-ES Testing

Pump Selection

NRC Concerns

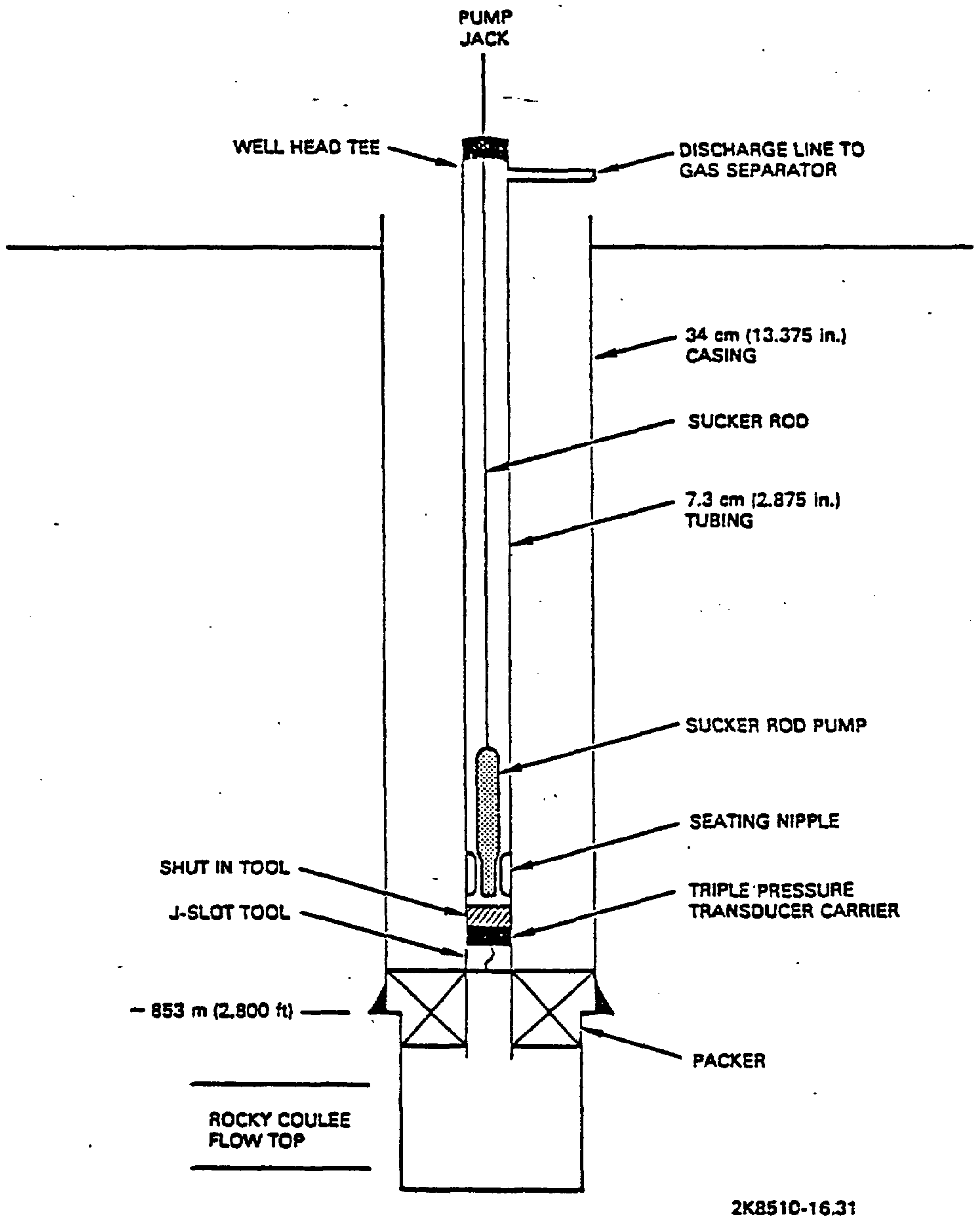
- Pressure Fluctuations in the Pumping Well and Nearby Observation Wells RRL-2C and RRL-2A Complicate Test Interpretation
- Changes in Pumping Rate are Difficult to Accomplish

DOE Response

- Hydraulic Head Fluctuation at Nearby Observation Points is not Expected to have an Adverse Effect on the Interpretation of the Test
- Data from the Pumping Well During the Drawdown Part of the Test is not Regarded as Particularly Useful Because of Frictional Losses Near the Well Bore
- Use of the Positive Displacement Pumping System is Expected to Mitigate Problems such as Gas Lock Associated with Submersible Centrifugal Pumping Systems
- Test must be Stopped to Change Discharge Rate
- Dry Run Checks will Afford Opportunity to Check Pump Operation Prior to LHS Test

Proposed Status

Open - Pending Results of Dry Run(s)



Configuration of well RRL-2B for testing the Rocky Coulee basalt flow top.

Criteria for LHS Testing

NRC Concerns

- Premature Termination of Pumping may Limit the Ability of the Test to Fulfill Its Objective
- Objective Criteria Should be Developed in Greater Detail to:
  - Determine When Pumping Should be Terminated
  - Determine When Transient Responses Caused by LHS Testing have Sufficiently Subsided to Allow Subsequent LHS Tests to Begin
  - Determine When Pressure Trends have been Reestablished After the First Tracer has been Injected but Before the Transducer is Pulled Out of the Second Piezometer

Criteria for LHS Testing

DOE Response

- Criteria will be Established Prior to LHS Testing and Presented in the Site Groundwater Study Plan (and Subordinate Documents) for the Following:
  - Hydraulic Head Baseline Acceptance
  - Initiating Pumping Tests
  - Terminating Pumping Tests
  - Initiating Tracer Tests
  - Terminating Tracer Tests
- Problems Associated with Tracer Injection Procedure Presented at the December 1985 Workshop are Mitigated (See Response to NRC Comment 13)

Proposed Status

Open

Development of Pumping Well RRL-2B

NRC Concerns

- The LHS Test Plan Discussed December 1985 did not Discuss Development of RRL-2B
- Cleanup Using Air-Lift Pumping Might give a Better Basis for Selecting LHS Pumping Rate than Planned Pulse Testing
- Hydrochemical Sampling Should be used to Support Cleanup

DOE Response

- RRL-2B was Developed (Jackson et al., 1986, p. 39)
  - Development Involved Circulating Hanford System Water Followed by Air-Lift Pumping of Approximately 1,000 gal Then Flush Again with Approximately 48,000 gal
  - Video Survey Indicates Only Minor Amounts of Suspended Particals in Borehole

Development of Pumping Well RRL-2B

DOE Response (cont.)

- Rocky Coulee at RRL-2B is not Transmissive Enough to be Developed Only by Air Lift Pumping Only - Transmissivity Estimate was Obtained During Pumping that was Performed
- Hydrochemical Sampling is and will Continue to be a Primary Source of Cleanup Information

Proposed Status

Closed

Mechanical Effects

NRC Concern

- Stress Due to Large Drawdown may Cause Anomalous Head Responses Near the Pumping Well

DOE Response

- Agree that an Effect may be Observed at the Pumping Well
- Drawdown Data from the Pumping Well will not be as Useful as Data from Observation Wells
- Expected Drawdown at the Nearest Observation Well is Less than 100 m.

Proposed Status

Closed

Vesicular Zone Testing

NRC Concern

- BWIP Should Consider Large-Scale Hydraulic Stress (LHS) Testing of the Cohassett Vesicular Zone

DOE Response

- Expected Transmissivity is Very Low (10^{-5} m^2/d Measured at RRL-2A)
- Small Scale, Single Borehole Tests will be Conducted to Estimate Transmissivity at RRL-2B
- Pumping Test will be Conducted if Transmissivity is Sufficiently High

Proposed Status

Closed

PS87-2153-42

Convergent Tracer Tests

DOE Response (cont.)

- Lateral Component of Dispersion
  - Not an Objective of the Tests
  - Not Considering Lateral Dispersion is Conservative
- Steep Hydraulic Gradients
  - Tests will be Performed at Several Gradients (Post-ES)
  - The Approach to Analyses of Effects of High Gradient on Test Interpretation will be Discussed in Updates to the Site Groundwater Study Plan
- Porous Medium Assumption
  - Validity will be Assessed by Comparing Test Predictions with Test Results
- Spatial Variability
  - Tests will be Conducted at Several Locations During Subsequent Stages of Site Characterization as Described in the Site Groundwater Study Plan

Proposed Status

Open

Perturbations to Hydrologic Baseline

NRC Concern

- Drilling, Construction and Testing may Perturb Hydraulic Heads, Delaying Pre-emplacement Groundwater Flow System Characterization

DOE Response

- The Project has been Rescheduled so that Perishable Pre-emplacement Data are Obtained Prior to Unnecessary Additional Disturbance

Proposed Status

Closed

Hydrochemical Sampling

NRC Concerns

- Objectives for Sampling
- Method for Measuring Carbonate and Bicarbonate

Sampling Objectives

- Test Groundwater Flow Concepts
  - Flow Paths (Distributions of Major Hydrochemical Parameters)
  - Velocities (Radionuclide/Helium Accumulation Age Determination)
- Identify Geochemical Environment
  - Effect on Released Radionuclides (Redox, Solubility)
  - Stability of Repository/Waste Package Materials of Construction
- Environmental Baseline for Future Performance Monitoring

ROLE OF THE YAKIMA INDIAN NATION IN THE LHST MEETING

RUSSELL JIM
PROGRAM MANAGER

I. THE YAKIMA NATION WILL RELEASE DOCUMENTS DESCRIBING TECHNICAL REVIEWS AND ASSESSMENTS OF THE DOE AND NRC WORKS. THE GOAL IS TO ESTABLISH A GOOD FAITH COOPERATION AND CONSULTATION.

II. IN CONJUNCTION WITH POINT I ABOVE, THE YAKIMA NATION IS REQUESTING TECHNICAL INTERFACING MEETINGS BETWEEN THE DOE/SUBCONTRACTORS AND YIN TO DISCUSS STANDING ISSUES RELATED TO LHST.

III. THE YAKIMA NATION WILL ESTABLISH A MUTUAL UNDERSTANDING WITH THE DOE CONCERNING THE ROLE OF YIN.

HISTORIC AND CURRENT INVOLVEMENT OF THE YIN IN THE HYDROLOGIC INVESTIGATION AT HANFORD

Jack Wittman

ISSUES OF CONCERN

ACCESS AND UTILITY OF RECENT DATA/DOCUMENTS/CODES REQUEST

1. BACKGROUND INFORMATION

* NOVEMBER 13, 1986: LETTER TO MR. JACK KEATING OF BWIP
  REQUEST FOR WATER LEVEL AND WATER PRESSURE INFORMATION FOR HYDROLOGIC BASELINING.

* DECEMBER 2, 1986: LETTER TO MR. K. M. THOMPSON OF DOE.
  REQUEST FOR COMPUTER PROGRAM HEADCO.

* DECEMBER 2-5, 1986: NRC/DOE DATA REVIEW MEETING
  REQUEST FOR (1) DATA/DOCUMENTS PRESENTED AT THE MEETING,
  (2) BWIP QA PROCEDURES CONCERNING DATA/DOCUMENTS/MAPS RELEASE
  (3) QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTS CONCERNING
    (a) INTERNAL/TECHNICAL/PEER REVIEW
    (b) INTERNAL MECHANISMS TO RECORD DISSENTING OPINIONS,
    (c) STEP-BY-STEP PROCEDURE SUPPORTING JOINT MANAGEMENT/TECHNICAL DECISION MAKING PROCESS,
    (d) RECORD KEEPING PRACTICES FOR PRE-SIGNED OFF OR DRAFT DOCUMENTS (AND RECORDS)

2. DOE RESPONSES

* JANUARY 9, 1987: BWIP MEMO ACKNOWLEDGING THE THREE DATA REQUESTS

* MARCH 2, 1987: RELEASE OF DISK CONTAINING HEADCO TO YIN ALONG WITH THE DOCUMENT (RHO-BW-ST-71P) DESCRIBING THE CODE

* MARCH 12, 1987: RELEASE OF THREE BOXES OF DATA/DOCUMENTS REQUESTED BY YIN DURING THE NRC/DOE DATA REVIEW MEETING.

3. STATUS

3.1. A LIST OF BWIP/DOE HYDROLOGIC DATA (WATER LEVEL AND PRESSURE MEASUREMENTS WERE NOT RECEIVED

3.2. CONCERNING THE CONFINED AQUIFERS, WATER-LEVEL DATA AT PRIMARY MONITORING FACILITIES, ADJUSTED FOR ATMOSPHERIC PRESSURE WERE NOT RECEIVED

3.3 SEVERAL DOCUMENTS REQUESTED WERE NOT RECEIVED

3.4 NONE OF THE QUALITY ASSURANCE PROCEDURES REQUESTED DURING THE NRC/DOE DATA REVIEW MEETING HAVE BEEN RECEIVED

4. ISSUES

4.1 AVAILIBILITY OF REFERENCES FOR SCP REVIEW

4.2 AVAILIBILITY OF DATA FOR INDEPENDENT ANALYSIS DURING AND AFTER TESTING

4.3 QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES FOR RELEASE OF DATA/ DOCUMENTS (THAT HAVE BEEN REQUESTED AND NOT RECEIVED BY YIN)

4.4 PROPRIETRY COMPUTER CODES

* YIN PARTICIPATION IN COMPUTER CODE GROUP THAT THE DOE/NRC ARE GOING TO CREATE

4.5 REVIEW AND INTERACTION BASED ON SITE GROUNDWATER STUDY PLAN (SD-BWI-047) EXPECTED TO BE RELEASED BY JULY 1987

* THIS DOCUMENT IS CONSIDERED TO BE A KEY DOCUMENT FOR THE TECHNICAL ASSESSMENT OF THE DOE ANALYSIS OF THE DATA COLLECTED DURING LHST

Attachment 16(b)

HANFORD SITE

BASELINING AND LHST SCHEDULING:

REVIEW/ASSESSMENT/INDEPENDENT VERIFICATION

A. Djerrari
V. V. Nguyen
G. Dagan
P. K. Kitanidis

EWA, Inc.

EWA

RESEARCH • ENGINEERING • PLANNING • MANAGEMENT

BASELINING AND LHST SCHEDULING:

REVIEW/ASSESSMENT/INDEPENDENT VERIFICATION

I. LOGISTIC AND RATIONALE OF PROPOSED MONITORING LOCATIONS

1.1 PRIOR TO CONDUCTING LHST, BWIP NEEDS TO DEMONSTRATE HOW PROPOSED MONITORING FACILITIES (QUANTITY AND LOCATIONS) WILL PROVIDE NECESSARY HYDRAULIC HEADS AND RESPONSE DATA NEEDED FOR SITE CHARACTERIZATION

1.2 BWIP SHOULD ASSESS THE LIMITATIONS OF THE PRESENT NETWORK AT HANFORD AND IMPROVE THE NETWORK TO ACCOMPLISH THE OBJECTIVES OF LHS TESTING

* GEOSTATISTICAL ANALYSIS ON EXISTING NETWORK
* TIME SERIES ANALYSIS TO CHARACTERIZE THE ADEQUATE MEASUREMENT SAMPLING FREQUENCY

1.3 ESTABLISHING THE BASELINE SHOULD NOT BE RESTRICTED TO THE NEIGHBORHOOD OF THE ES BUT SHOULD EXTEND TO THE PASCO BASIN BETWEEN THE RRL AND THE COLUMBIA RIVER.

2. PROPOSED SCHEDULING AND TIME FRAME FOR PRE-ES TESTING AND MONITORING

2.1 BASELINE MONITORING AFTER DRILLING OF NEW BOREHOLES

2.1.1 SUFFICIENCY OF THE FOUR MONTH PERIOD PLANNED FOR ALLOWING NOISE DUE TO DRILLING ACTIVITIES TO DECAY

2.1.2 IMPACT ON SCHEDULING

ASSESSMENT OF NOISE IDENTIFICATION TECHNIQUES

DELAY ON SCHEDULING

2.2 RATIONALE BEHIND THE LENGTH OF TESTING

FOUR LAYERS TO BE TESTED IN 12 MONTHS

TWO KINDS OF TESTS WILL DISTURB THE SYSTEM

* TRACER TESTS
* LHS TESTING

2.2.1 TRACER TEST

QUASI-STEADY STATE ESTABLISHMENT

TEST DURATION

* CONDUCT TEST UNTIL THE TRACER CONCENTRATION IS AT THE BACKGROUND CONCENTRATION OR BELOW DETECTION LIMIT

RECOVERY TO PRE-TRACER TEST CONDITIONS

2.2.2 LARGE-SCALE PUMPING

DURATION OF TEST - DURATION OF OBSERVATION

IN CASE OF HYDRAULIC CONNECTION

* TIME OF RECOVERY OF PRE-PUMPING CONDITIONS

2.2.3 PLAN OF EMERGENCY ACTION IN A FORM OF A DECISION TREE

IMPACT ON SCHEDULING

2.3 IDENTIFICATION OF PARAMETERS

2.3.1 ASSUMPTIONS UNDERLYING THE TEST DESIGN

EQUIVALENT POROUS MEDIUM IS ASSUMED IN THE DESIGN OF THE TRACER AND PUMPING TESTS

2.3.2 TEST INTERPRETATION AND PARAMETER IDENTIFICATION

MODELING FOR TEST INTERPRETATION

* CONCEPTUALIZATION
* NUMERICAL ANALYSIS APPROACH WILL NOT YIELD A UNIQUE SOLUTION
* DOE SOLUTION FOR THIS LAST CONCERN: INCREASED DATA BASE
  - INCREASED DATA BASE MAY NOT HELP IF THE SYSTEM IS VERY COMPLEX
  - TIME CONSTRAINT (HOW MUCH CAN WE INCREASE THE THE DATA BASE WITH THE PROPOSED SCHEDULING?)

3. ASSESSMENT OF THE PROPOSED LHST IN TERMS OF OBJECTIVE ONE

CAN OBJECTIVE ONE BE MET?

OBJECTIVE ONE: COLLECT DATA ON GEOHYDROLOGIC CONDITIONS THAT WILL BE CHANGED BY SITE CHARACTERIZATION ACTIVITIES

* AMONG THESE GEOHYDROLOGIC CONDITIONS IS THE HYDRAULIC HEAD FIELD
* IS THE PROPOSED MONITORING NETWORK ABLE TO PROVIDE ADEQUATE PREDICTION OF THE HEAD FIELD?

TO ANSWER THIS QUESTION, WE CONSIDERED THE PRIEST RAPIDS MEMBER

THIS LAYER IS THE ONE THAT HAS THE MOST MONITORING FACILITIES

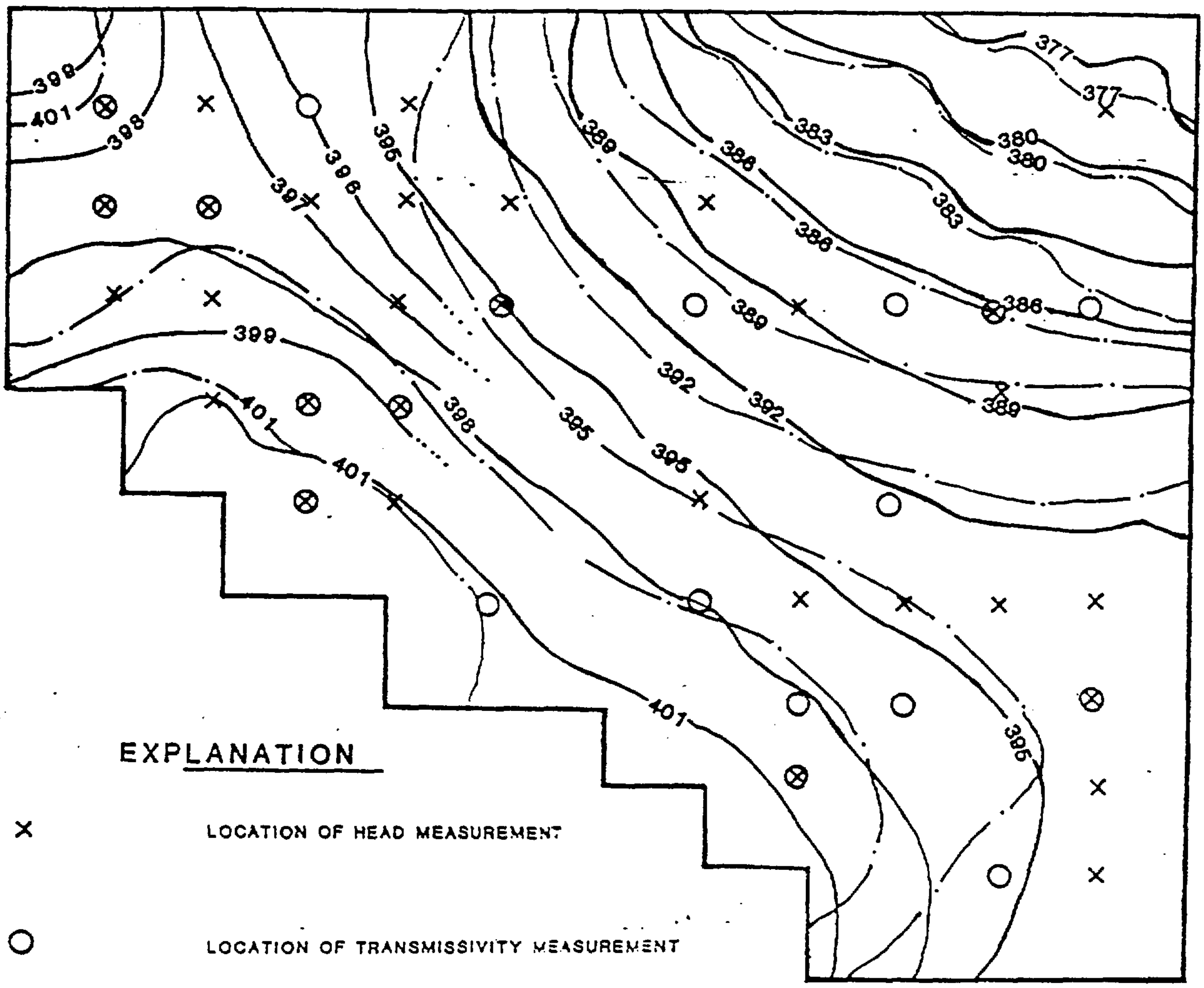
(1) WE USED THE STATE-OF-THE-ART SOLUTION OF THE INVERSE PROBLEM TO ESTIMATE THE PARAMETERS DESCRIBING THE SPATIAL VARIABILITY OF THE TRANSMISSIVITY FIELD USING TRANSMISSIVITY AND HEAD MEASUREMENTS

(2) ONCE THE SPATIAL VARIABILITY HAD BEEN CHARACTERIZED, WE USED THE RECOGNIZED PARAMETERS TO GENERATE HEAD AND TRANSMISSIVITY FIELDS THAT ARE POSSIBLE REALIZATIONS HAVING THE SAME VARIABILITY CHARACTERISTICS AS THE IDENTIFIED FIELD

(3) WE USED DIFFERENT SETS OF HEAD AND TRANSMISSIVITY MEASUREMENTS RANDOMLY PICKED FROM THE GENERATED FIELD AND RE-ESTIMATED FROM THESE MEASUREMENTS THE PARAMETERS THAT DESCRIBE THE SPATIAL FIELD

(4) WE COMPARED THE EXPECTED HEAD FIELD PREDICTED FROM THE DIFFERENT SETS OF MEASUREMENTS CONSIDERED AND THE ORIGINAL HEAD FIELD THAT SHOULD HAVE BEEN RETRIEVED

PREDICTION OF HYDRAULIC HEAD FIELD USING 30 HEAD AND 20 TRANSMISSIVITY MEASUREMENTS



EXPLANATION

× LOCATION OF HEAD MEASUREMENT

○ LOCATION OF TRANSMISSIVITY MEASUREMENT

401 —·—·—·· HYDRAULIC HEAD TO BE PREDICTED

401 ——— EXPECTED HYDRAULIC HEAD FIELD USING 30 HEAD AND 20 TRANSMISSIVITY MEASUREMENTS

CONTOUR ELEVATION IN FEET (MSL)

N

SCALE

0 5 10 15 MILES

0 5 10 15 20 KILOMETERS

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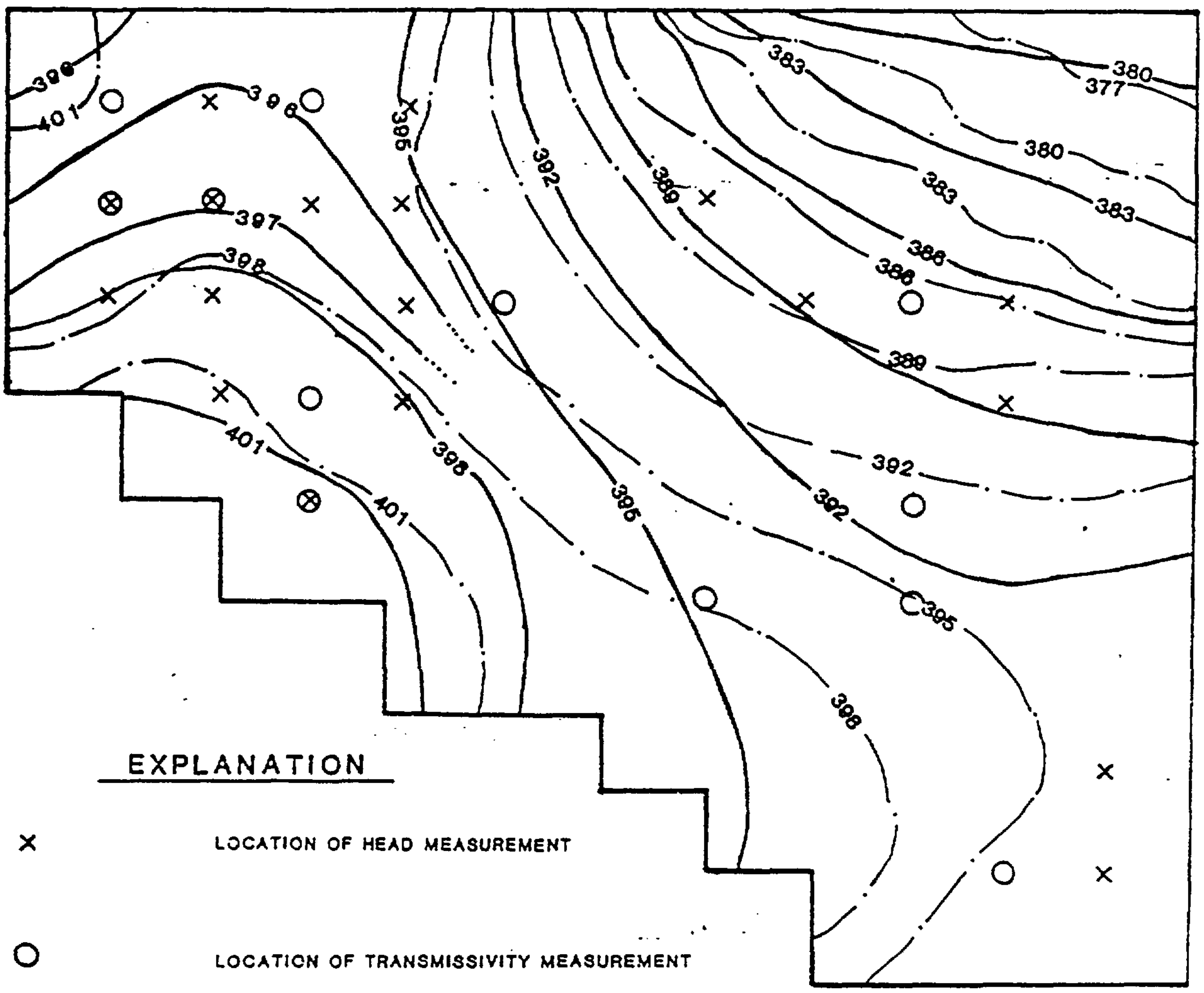
PREDICTION OF HYDRAULIC HEAD FIELD USING 18 HEAD AND 12 TRANSMISSIVITY MEASUREMENTS



EXPLANATION

× LOCATION OF HEAD MEASUREMENT

○ LOCATION OF TRANSMISSIVITY MEASUREMENT

401 —·—·—·· HYDRAULIC HEAD TO BE PREDICTED

401 ——— EXPECTED HYDRAULIC HEAD FIELD USING 18 HEAD AND 12 TRANSMISSIVITY MEASUREMENTS

CONTOUR ELEVATION IN FEET (MSL)

N

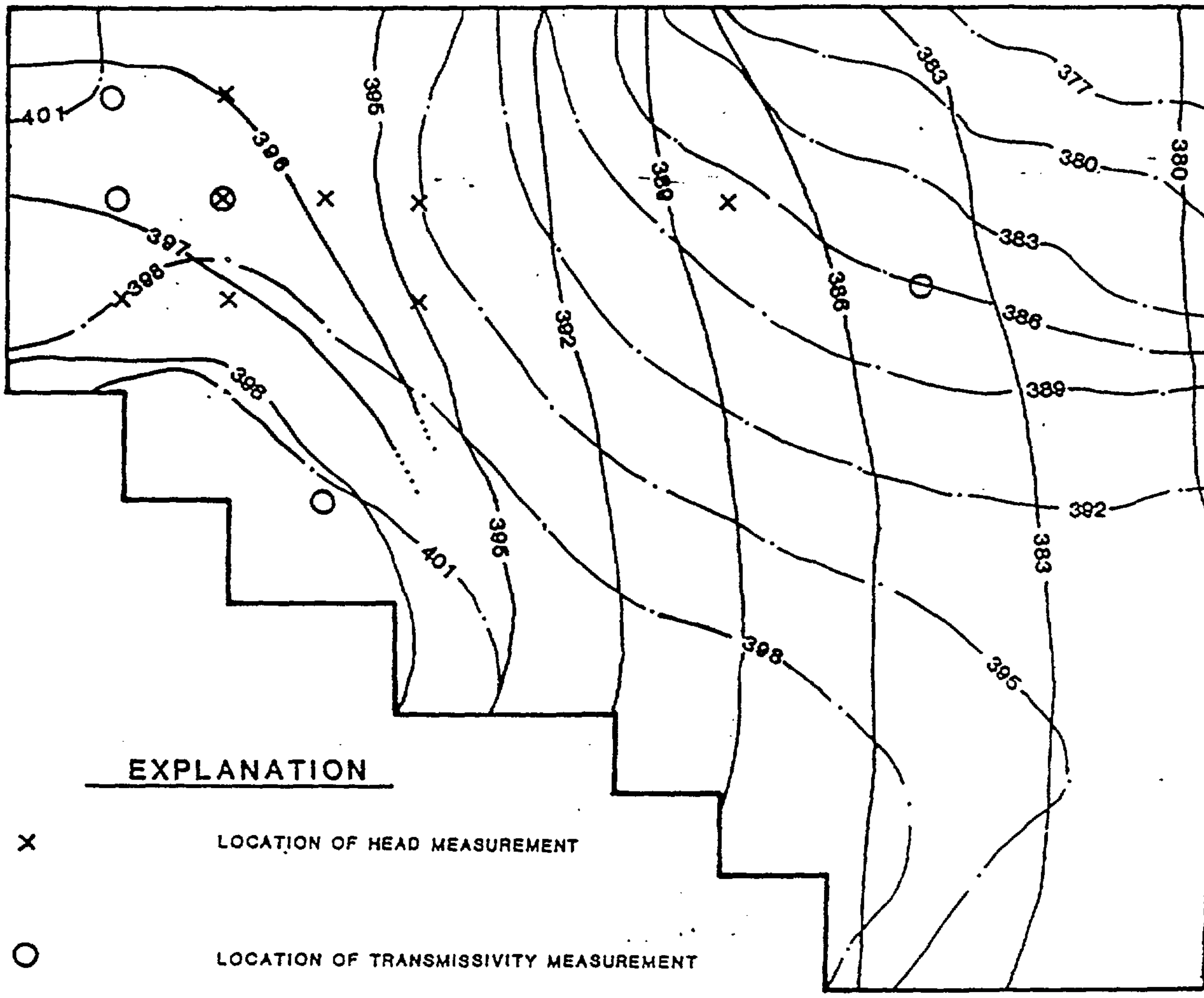
SCALE

0 5 10 15 MILES

0 5 10 15 20 KILOMETERS

ENGINEERING FOR EARTH • WATER • AIR RESOURCES

PREDICTION OF HYDRAULIC HEAD FIELD USING 8 HEAD AND 5 TRANSMISSIVITY MEASUREMENTS



EXPLANATION

× LOCATION OF HEAD MEASUREMENT

○ LOCATION OF TRANSMISSIVITY MEASUREMENT

401 —·—·· HYDRAULIC HEAD TO BE PREDICTED

401 ——— EXPECTED HYDRAULIC HEAD FIELD USING 8 HEAD AND 5 TRANSMISSIVITY MEASUREMENTS

CONTOUR ELEVATION IN FEET (MSL)

N

SCALE

0 5 10 15 MILES

0 5 10 15 20 KILOMETERS

ENVA

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CRITICAL COMMENTS ON

"REVIEW OF GROUNDWATER TRAVEL TIME ANALYSIS FOR THE REFERENCE REPOSITORY LOCATION AT THE HANFORD SITE", Terra Therma/Nuclear Waste Consultants (June 13, 1986)

AND ON

"RE-REVIEW OF CLIFTON'S BWIP GROUNDWATER TRAVEL TIME ANALYSIS", Terra Therma/Nuclear Waste Consultants (January 13, 1987)

By:

G. Dagan
A.M. Djerrari
G.V. Abi-Ghanem
P.K. Kitanidis

EWA, Inc.

Submitted to:

YAKIMA NATION

Date:

April 3, 1987

EXECUTIVE SUMMARY

Two reports prepared by Terra Therma/Nuclear Waste Consultants (TT/NWC) for the Nuclear Regulatory Commission (NRC) were reviewed in detail. The first report, entitled "Review of

Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" was submitted on June 13, 1986 as TT/NWC Communication No. 65 in response to written direction from the NRC Project Officer (Mr. J. Pohle (NRC)). The second report is entitled "Re-Review of Clifton's BWIP Groundwater Travel Time Analysis". This second report is a review of the previous review and replies to the NRC Staff's request that:

(1) assumptions made in the TT/NWC evaluation be documented and their impact on the result be evaluated;

(2) an assessment be made of the uncertainties associated with the TT/NWR computed groundwater travel time; and

(3) an evaluation be made of the sufficiency of the data base used for calculating groundwater travel time (GWTT) in both the TT/NWC and the Clifton (1986) reports.

This report will mainly review the second TT/NWC report, which supersedes and corrects an error present in the first one. In these two documents, TT/NWC submit that the computations of total travel time by Clifton (1986) are not conservative and that "... there is significant likelihood that the BWIP will fail the 1000 year travel time rule" (TT/NWC, 1987, p. 9). Our present comments address the main contentions of the two TT/NWC reports. Although TT/NWC raises some valid points, their two main conclusions, namely that: (1) the effective porosity value is overestimated, and (2) that further investigations should be focused on measurements of effective porosity, are open to serious criticism.

A. INTRODUCTION

This is a detailed discussion and critical evaluation of the "Review of Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" (dated June 13, 1986) and the "Re-Review of Clifton's BWIP Groundwater Travel Time Analysis" (dated January 13, 1987), prepared by Terra Therma/Nuclear Waste Consultants (TT/NWC) for the Nuclear Regulatory Commission (NRC). Our comments deal mainly with the Re-review report, which supersedes and corrects an error present in the first report.

In the first part of our review, an analysis of the approach employed by TT/NWC to evaluate groundwater travel time (GWTT) in regards to compliance with Department of Energy (DOE) 10 CFR 960.4.2.1(d) and NRC 10 CFR 60.113.B.(2) is presented. In the second part of our review, the main arguments of the TT/NWC reports are discussed. Finally, recommendations are made concerning future field investigations needed to evaluate GWTT in regards to compliance with cited regulations.

B. MAJOR COMMENTS ON TT/NWC APPROACH

I. "Conservative" Approach and "Statistical" Approach

In their Re-review report (TT/NWC, 1987), TT/NWC discuss the differences between the "conservative" and the "statistical" approaches. The objective of this discussion is to distinguish between the conservative and the statistical approach in reliability analysis, and in particular, in the calculation of GWTT. Their discussion successfully makes this distinction, which after all, is well accepted in reliability or risk analysis. However, a few comments can be made on the TT/NWC work.

On page 13 of the Re-Review (TT/NWC, 1987), it is stated that

> "Both the Clifton and the NWC analysis use a mixture of the 'conservative' approach and the 'statistical' approach: both use the 'statistical' approach for the inclusion of parametric variability and uncertainty into the analyses, and both use the 'conservative' approach for the inclusion in the analysis of uncertainty about flow paths and conceptual models."

If both Clifton (1986) and TT/NWC (1987) use the conservative approach for inclusion of uncertainty about flow paths and conceptual models, it is not correct that TT/NWC use the statistical approach for inclusion of uncertainty into their analysis. For instance, TT/NWC (1987) use the simple formula

$$t = nL/Ki \qquad (1)$$

where n is the effective porosity, L is the distance to compliance surface, K is the hydraulic conductivity, and i is the hydraulic gradient, to evaluate the GWTT probability distribution P(t) in the flow top of interest. To obtain P(t), TT/NWC (1987) assume that n and K are lognormal and subject to estimation errors only. Consequently, t is lognormally distributed with known mean and variance. As shown in the Yakima Nation comments on the DOE GWTT analysis (Djerrari et al., 1986), this model presumes a vanishing integral scale of transmissivity (as compared to the travel distance). TT/NWC (1987) is aware of this limitation. Furthermore, as demonstrated (Djerrari et al., 1986), the resulting P(t) leads to travel times larger than the one corresponding to a large integral scale. TT/NWC (1987) assumes, ~~correctly,~~ that if the site does not pass the regulatory requirements for the above model, it will definitely fail in the case of a finite integral scale, all other assumptions being the same. This, therefore, demonstrates that the TT/NWC (1987) approach of uncertainty is a conservative approach rather than a statistical aprroach.

On page 13 of TT/NWC (1987), it is stated that the uncertainty (presumably quantified by a variance or confidence interval) in the estimate of uncertainty is usually small compared to the uncertainty in the computed quantity. This statement is erroneous. The estimation variance of the variance or the range can be anything but small. Consequently, the uncertainty regarding estimation variances and confidence intervals can be quite significant.

II. Proper Accounting for Uncertainties In Parameters and Analyses

On page 14 of TT/NWC (1987), it is stated that

> "... the variance of the log of the GWTT is greater if any of the components are positively correlated with each other..."

This implicitly assumes that all components appear with the same sign in the equation which determines the logarithm of GWTT. However, if one considers the following relationship

$$\log(GWTT) = c + \log(be) - \log(T) \tag{2}$$

where c is a constant, be is the effective thickness, and T is the transmissivity, and also considers the relation defining the variance,

$$\mathrm{Var}[\log(GWTT)] = \mathrm{Var}[\log(be)] + \mathrm{Var}[\log(T)] - 2\,\mathrm{Cov}[\log(be), \log(T)] \tag{3}$$

it can be seen from relation (3) that a positive correlation between be and T (which may be the most likely case), if taken into account, would reduce the variance of log(GWTT). This fact was illustrated in Clifton (1984).

TT/NWC (1987) concluded:

> "It is significant that the application of this simple approach does indeed produce values of variance for the GWTT that are close to those derived from the Clifton numerical analyses (Appendix D). That these two radically different approaches produce essentially the same estimate of variability in the result is considered to be generally supportive of both, and indicative that the method of computing variance in GWTT does not introduce significant uncertainty into the evaluation of regulatory compliance."

TT/NWC (1987) clearly presented the differences between Clifton's conservative approach and their conservative approach. These differences arise from the two different hypotheses tested. While Clifton tests the hypothesis that there is a high probability that the GWTT exceeds 1,000 years, TT/NWC (1987) test the hypothesis that there is a significant probability that GWTT does not exceed 1,000 years. TT/NWC (1987) appear satisfied that their simple approach produces values of variance for the GWTT that are close to those derived from the Clifton numerical analysis. Obviously, TT/NWC (1987) did not weigh the implications of such a result. Presently, the GWTT cumulative probability distribution functions (CDF) are computed with some degree of uncertainty. The impact of this uncertainty on the outcome of the tested hypothesis is less dramatic in Clifton's case than in the TT/NWC case. This is because Clifton is testing the extreme tail of the GWTT CDF, whereas TT/NWC are testing a higher probability.

For the outcome of the TT/NWC test to hold true, even in the case of large uncertainty in GWTT-derived CDF, the derived CDF must be steep (i.e., small GWTT variance). At the present time, this is unfortunately not the case.

1. Consideration of conceptual models

TT/NWC (1987) discuss four simplifications which, according to them, tend to yield results that overestimate the GWTT. Since the objective of TT/NWC is to reject the hypothesis that the favorable requirement is met, these assumptions are deemed "conservative". A brief discussion of these assumptions follows.

1.1 Flow takes place in the Grande Ronde Basalt

Since the hydraulic conductivity in the flow tops tends to increase as one moves upward from the repository horizon, this assumption tends to underestimate the GWTT. As a result, TT/NWC (1987) claim that the assumption of a flow path occurring in the Grande Ronde Basalt is very unconservative, with respect to Clifton's hypothesis. However, cited evidence indicates that the probability of paths penetrating far into the overlying layers of higher permeability is small. Thus, a probabilistic analysis in which this assumption is removed and a wider range of possible flow paths is taken into account, appropriately weighted by their probabilities of occurrence, might show that the error associated with this assumption is minor. It is recommended that such an analysis be performed since it is the only way to resolve this dispute.

It is noted that the TT/NWC (1987) argument is based on a partial interpretation of NRC regulatory rules and Department of Energy (DOE) siting guidelines. TT/NWC (1987) claim on page 18 that

> "As the regulatory rule (10 CFR 60) is written in terms of the 'fastest path' and the siting guidelines (10 CFR 960) are written in terms of 'any pathway', it might be reasonable when considering the regulatory test to look at pathways that enter the Wanapum as likely being the fastest, and to therefore include them in the analysis."

This is a quite singular interpretation of the regulatory text.

The regulatory rule (NRC 10 CFR Part 60 paragraph 60.113.B.(2)) states:

> "Geologic Siting:
> The geologic repository shall be located so that the pre-waste-emplacement groundwater travel time along the fastest pathway of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such a travel time as may be approved or specified by the Commission."

whereas the siting guidelines (DOE 10 CFR Part 960 paragraph 960.113.B.(2)) state:

> "A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel."

In the above regulations, the term "likely" has been clearly cited. This means that the "fastest pathway" or "any pathway" should be weighted by its probability of occurrence. Obviously, if the "fastest path" is considered, no matter how small its probability of occurrence, it is highly probable that no site would qualify. For the usually assumed forms of probability distributions of hydraulic conductivity (e.g., lognormal), there is a finite (although very small) probability that each and every layer will be penetrated.

TT/NWC (1987) state on page 9 that

> "It is considered that the fastest path would in all likelihood involve the higher permeability flows of the Wanapum formation."

This statement has not been substantiated by any evidence and is gratuitous. TT/NWC (1987) should substantiate such a statement by demonstrating that the total travel time along such a path (which must account for (i) the travel time through the layered sequence of Grande Ronde Basalts, and (ii) the horizontal travel time in the Wanapum) is effectively less than the travel time along a pathway that occurs in the Cohassett flow top, for example, as considered by Clifton (1986).

1.2 Flow is mainly in the flow tops

If one ignores the delay caused by flow in the dense basalt interiors, the resulting GWTT would be underestimated. TT/NWC (1987) cited studies in which the degree of underestimation is presumed to be in the range of 5% to 10%. Consequently, this assumption would be on the conservative side in Clifton's testing hypothesis. It should be noted, however, that among the referenced studies, TT/NWC cited Clifton (1986). Figure 6 of Clifton (1986) displays the CDF of GWTT in basalt dense interiors (for different values of vertical to horizontal hydraulic conductivity ratios identifed as alpha). In Figure 7, Clifton shows the CDF of GWTT in Grande Ronde flow tops (for two sets of transmissivity statistical paramaters, calculated from a sample of transmissivities, including and not including data from boreholes DC-14 and DC-15). In order to assess the nonconservatism of the simplification that TT/NWC undertook by ignoring the GWTT in the flow interior, a GWTT characterized by a 60% chance of being exceeded has been derived from these curves. Following TT/NWC conservatism, the GWTT in basalt interiors has been extracted from the curves that overestimate the travel time (i.e, alpha equal to one). Whereas, the GWTT in Grande Ronde flow tops has been derived from the curve corresponding to the statistics obtained by excluding DC-14 and DC-15 transmissivity values. This simple operation yielded a GWTT of 35,500 years for the flow interiors and 79,400 years for the flow tops. The time spent in the flow interiors (following the TT/NWC conservative approach) is not a small percentage of the travel time spent in the flow tops, as stated by TT/NWC. This percentage has been found equal to be equal to 44% for the case of a 60% exceedance probability, and is even higher for greater exceedance probabilities. It is not a coincidence that TT/NWC turned to the regulations and stated that

> "Thus from a regulatory point of view, it seems reasonable to ignore the GWTT in the flow interiors on the grounds that it will never be able to be supported."

1.3 Flow in the vicinity of the RRL may be in any direction

The meaning of and/or justification for this assumption is not clear.

1.4 Flow path is highly heterogeneous with respect to flow parameters

It is not clear as to what is meant by "highly heterogeneous flow paths". A reasonable justification for the use of all Grande Ronde hydraulic conductivity data is presented in Appendix F of the TT/NWC (1987) report. Beyond that, however, it is stated on page 21 (TT/NWC, 1987) that

> "there is great heterogeneity in the point values of transmissivity in any flow top, and that any path of flow will pass through a wide variety of different transmissivity sections."

The point intended in the quoted statement is unclear. However, it certainly provides no justification for neglecting spatial variability or for using the average value of measured log transmissivity as effective log transmissivity, as done in TT/NWC (1987).

It is claimed on page 22 that

> "If the analysis performed using these simplifications produces a result which has an acceptable level of regulatory confidence, then the uncertainty associated with the conceptualization used in the analysis is not significant, no matter how large."

The quoted statement is, at best, unclear. In fact, it appears to be in contradiction to the purpose of the conservative assumptions associated with the TT/NWC hypothesis, as presented on page 11. A more correct statement would be as follows:

> "If the analysis performed using these simplifications produces a result on the basis of which the basalt site is disqualified, then the uncertainty associated with the conceptualization used in the analysis is not significant",

since presumably, relaxing these assumptions would tend to further reduce GWTT.

However, if some important assumptions made in the Re-review (1987) were relaxed, they would result in a significantly increased GWTT. Consequently, the GWTT would not be conservative with respect to the hypothesis tested in the reviews. For example:

a. As noted earlier, a positive correlation between transmissivity and effective thickness would reduce the variance of the probability distribution of GWTT.

b. Relaxation of the assumption of a spatially constant transmissivity or hydraulic conductivity would tend to increase GWTT. In the calculations presented in the reviews, spatial variability is neglected. The effect of accounting for spatial variability, as clearly seen from theoretical studies and as illustrated in Clifton's report (1986), would be to increase flow resistance which would result in a larger GWTT.

2. Representativeness of parameters along flow paths

TT/NWC (1987) state on page 28:

> "... early evaluation of the large scale perturbations resulting from drilling indicate that the geometric means of the spot date do indeed give a reasonable estimate of the gross hydraulic conductivity of flow tops in the Grande Ronde."

This statement is incomprehensible.

Clifton (1986) used the geometric mean of all measurements from Grande Ronde flow tops, 0.153 m2/day, or according to TT/NWC, 0.150 m2/day. TT/NWC (1987) note, as one case, the geometric mean of the Strait and Mercer (1986) Grande Ronde data, 0.12 m2/day (page 29), and the geometric mean of the Cohassett flow bottom, Cohassett flow top, and Rocky Coulee flow top, 0.101 m2/day. This last set was the one preferred by TT/NWC.

Furthermore, TT/NWC (1987) decided to deal with hydraulic conductivities and effective porosities rather that the transmissivities and effective thicknesses used by Clifton (1986). Since flow-resistance data are in terms of transmissivity, hydraulic conductivities are calculated by assuming that the flow top thickness is 10 meters, even though data indicate a highly variable thickness. For the case examined in the TT/NWC re-review, the geometric mean conductivity is equal to 1.17 x 10E-7 m/sec and the standard deviation (SD) of log (base 10) conductivity is equal to 1.87. Since the sample contained 16 measurements, the SD of the estimation error of the mean log hydraulic conductivity is 1.87/15, namely 0.483.

Regarding the hydraulic gradient, Clifton (1986) assumes a constant value of 0.0002. TT/NWC (1987) use this value as the geometric mean with a SD of the log gradient equal to 0.3. For illustration, if the gradient is assumed to be lognormally distributed, the 95% confidence interval would be 0.00005 to 0.0008. Representation of the gradient as a random variable with these moments accounts for the lack of knowledge concerning the exact value of the actual gradient and is, in principle, quite appropriate. Furthermore, the assumed values would not have a major effect on the calculated CDF of GWTT. For example, the variance of log (GWTT) would be increased by about 3% as a result of accounting for variability in the gradient. This fact has been acknowledged by TT/NWC (1987).

The section on effective porosity is confusing. A detailed review of this section appears in Section C.II of this report.

On page 38 of the TT/NWC (1987) report, the reviewers return to the issue of the fastest path and claim that since the transmissivity of the lower Wanapum flow top is about one hundred times greater than the transmissivity of the upper Grande Ronde flow tops, the groundwater velocity in the Wanapum must be one hundred times greater as well. Of course, such a statement cannot be made with reference to the effective porosity. It is conceivable that the effective porosity in the lower Wanapum flow top is much higher than that of the upper Grande Ronde flow tops. It is also reiterated that focusing on the fastest path, no matter how small its probability of occurrence, might lead to overly conservative results.

3. Comments on Appendix A

Appendix A of TT/NWC (1987) contains the original TT/NWC (1986) review. Discussion of this review will be less detailed than that of the re-review and will be limited to issues not already addressed.

On page 4 of TT/NWC (1986), it is stated that

> "Clifton calculates that the probability of exceedance of 10,000-year travel times is greater than 99 percent for all variations of parameter uncertainty and spatial variability ..."

This statement is not accurate.

Section 5.2.1 seems pointless and Equation (3) is incorrect.

Section 5.2.2.3, porosity of flow tops, is of considerable interest since, as discussed earlier, the assumed median value of porosity is the most important reason for producing a result different from that of Clifton's. TT/NWC (1986) argues that the effective porosity should be lognormally distributed. Lognormality is more reasonable than normality since, if nothing else, it accounts for the skewness of the distribution. Given the large coefficient of variation, normality would result in a very sizeable probability of negative porosities.

There are several limitations associated with the rough check on the calculation of the horizontal GWTT (Section 5.2.3.1). First, hydraulic conductivity is taken to be equal to the sample average value. Depending on the value of the correlation length, the variance, and the boundary conditions, the effective hydraulic conductivity can be considerably larger than the sample average value. The numerical simulations by Clifton (1986) calculate the effective transmissivity much more accurately. Second, there may be considerable positive correlation between log transmissivity and log effective thickness which would reduce the variance of computed travel time.

4. Comments on Appendix C

Appendix C of TT/NWC (1986) reviews some basic results related to the calculation of means and variances of variables which are the summation of other variables with known means, variances, and correlation coefficients. TT/NWC (1987) actually deal with the sample moments. The relations presented by TT/NWC (1987), however, hold for the population moments only if the sample size N is assumed to increase without bound. Some comments:

a. Equation (8) should be written

X'' = SUM(square(Xi))/(N-1) - (N/N-1) square(X'2)

b. In calculated sample moments (e.g., equation 8), it is assumed that measurements are uncorrelated. This is often not the case. For example, if the range is about 3 km and two measurements are located within 1 km of each other, they are correlated. In this case Equation (8) underestimates the variance of the stochastic process. Unbiased estimators, which can be seen as generalizations of this equation, are described in Kitanidis and Lane (1985).

C. COMMENTS ON MAIN TT/NWC CONCLUSIONS

The following section will mainly refer to the TT/NWC (1987) Re-review, which supersedes and corrects an error present in the first review. In these two documents, TT/NWC submits that the computations of total travel time by Clifton (1986) are not conservative and that "there is a significant likelihood that the BWIP site will fail the 1000 year travel time rule" (p.9). In the following comments, the main contentions of the TT/NWC reports are discussed.

I. General Comment

TT/NWC (1987) use the simple formula (equation (1))

$$t = nL/Ki$$

where n is the effective porosity, L is the distance to compliance surface, K is the hydraulic conductivity, and i is the hydraulic gradient to evaluate the GWTT CDF, P(t), in the flow top of interest. To obtain P(t), TT/NWC (1987) assume that n and K are lognormal and subject to estimation errors only. As a result, t is lognormally distributed with known mean and variance.

As discussed earlier, this model presumes a vanishing integral scale of transmissivity. The resulting P(t) leads to larger travel times than the ones corresponding to a large integral scale. TT/NWC (1987) assumes, incorrectly, that if the site does not pass the regulatory requirements for this model, it will definitely fail them in the case of a finite integral scale, all other factors being equal.

However, based on equation (1), the TT/NWC (1987) conclusion that the 1000 year criterion is not likely to be satisfied does not seem to be warranted. Since TT/NWC (1987) divergence from the data adopted by Clifton (1986) is minor with respect to the path length, the hydraulic conductivity, and the hydraulic gradient, our discussion will focus on the effective porosity, or equivalently the effective thickness, which is the cornerstone of TT/NWC argument.

II. Effective Porosity

The range of effective porosity adopted by Clifton (1986), namely 0.0001 to 0.01 is based on the analyses of five, and later, of eight experts (Runchal et al., 1984a, 1984b). Most of the experts regard the value determined by the tracer test at DC7/8 as relatively low and presume that at the megascale, the effective porosity is larger. It is true that in the Runchal et al. (1984a) report, which summarizes the results of five external experts, the detailed calculations underlying the proposed probability distribution function (PDF) of effective porosity are not reproduced. Nevertheless, in view of their reputation and experience, one is entitled to presume that the experts have used the best available tools in order to assess the PDF of the effective porosity.

The TT/NWC (1986) cast doubts on the reliability of the experts, saying for instance, "it is suggested that nobody is an 'expert' in this particular field" (p. 19). In contradiction to this statement, TT/NWC (1987) indulge, however, in speculating about the PDF of effective porosity at great length. These speculations will now be reviewed.

The largest divergence between Clifton (1986) and TT/NWC (1987) is in the assumed geometrical mean of the effective porosity which is given in TT/NWC (1987, p. 34) at the bottom, namely 0.00016. In contrast, Clifton (1986) assumes a value of

0.005. It should be noted first that the geometric mean for Clifton's distribution, i.e., rectangular between a minimum of 0.0001 and a maximum of 0.01, is equal to 0.0039, rather than 0.005. Still, the ratio between the two, i.e., 0.0039/0.00016, is approximately 24.

To support this difference in estimation, TT/NWC (1987) invoke two reasons:

a. They quote a recent article on effective porosity of fractured granodiorite by Brotzen (1986, see TT/NWC, 1987, p. 31). A correlation between these data and hydraulic conductivity are plotted in Figure 2 of TT/NWC (1987, p. 33) as a dark band. Strangely enough, if the geometric mean of hydraulic conductivity, namely K=0.00000014 m/sec is plotted on the graph, the corresponding effective porosity lies between 0.0006 and 0.0036, with an average of 0.002. This value is smaller than Clifton's average only by a factor of 2.5. Thus, TT/NWC (1987) ignore the same data that they are using to support their claim.

b. The second line of reasoning is based on the use of a parallel plate model relationship between hydraulic conductivity and effective porosity, which is forced to pass through the only measured value for DC-7/8, namely n=0.00016. It should be mentioned first that in the analysis of the tracer test the effective porosity is given a broad range, depending on the assumed value of the contributing thickness. The one adopted by TT/NWC (1987) is a lower bound, based on the assumption that the entire thickness of the flow top contributes equally to conveying the fluid. In the analysis of the well log, it was shown that it is possible that only one tenth of the thickness conveys fluid effectively, leading to a value of effective porosity ten times larger (Leonhart et al., 1985). Besides, the parallel plate model is a gross oversimplification which does not account for the fact that fractures are filled or for the complex geometry of the fracture system. If the fracture aperture, a, is computed from the parallel plate theory by using the formula

a = square root of (12 x niu x T/g/be) (4)

where niu is the coefficient of kinematic viscosity (0.00000055 m2/sec), T is the transmissivity (0.000000081 m2/sec), g is the gravity (9.81 m/sec2), and b e is the effective thickness (0.0025 m), the result is a=0.015mm, which is much lower than the average of 0.226 mm reported by Lindberg (1986). Furthermore, the use of the model is precluded by the main findings of Lindberg (1986), namely that fissures were filled and very few voids were detected. A model of flow through fissures that are filled with clay (which could be the case for 89% of the fissures at Hanford, as reported by Lindberg, 1986) leads to different results from those of the parallel plate theory.

Concluding the discussion of this point, it seems that the arguments employed by TT/NWC (1987) to refute the range of effective porosity values adopted by Clifton (1986) are untenable.

III. Porosity Probability Distribution

TT/NWC (1987) argue at length that the estimate of the effective porosity is lognormal, whereas they say that Clifton (1986) has adopted a normal one (p.34). As mentioned before, Clifton (1986) assumes a rectangular distribution, for reasons he makes clear. It is true that on the basis of existing data, it is difficult to recognize the nature of the PDF. A lognormal PDF is reasonable to assume if n is fully correlated to K, but such a correlation is not warranted. Besides, lognormality avoids the negative values present in a normal distribution of sufficiently large variance. In view of this uncertainty, the salient question is whether the assumed shape of the PDF has a major impact upon the GWTT CDF. It was shown (Djerrari et al., 1986) that the impact is quite small, but TT/NWC (1986) claim that the difference between the normal mean and lognormal mean may be quite large (p. 20). This divergence stems from the way in which various PDF's are compared. In Djerrari et al. (1986), it was assumed that the influence of the shape should be assessed by taking various PDF's with the same mean and variance. The raison d'etre of such an approach is that in the absence of sufficiently many data to validate the shape of the PDF, at best one can extract the mean and the variance from a few measurements. In contrast, TT/NWC (1987) fit the PDF of the effective porosity by assuming that the two bounds of Clifton's rectangular distribution, i.e., nmin=0.0001 and nmax=0.01, represent the range for the 95% interval of confidence, which pulls the highly asymetrical lognormal distribution towards the lower effective porosities. This manipulation of the bounds (taken quite arbitrarily by Clifton (1986) for a rectangular distribution) is highly questionable.

D. MINOR COMMENTS

In Table 2 of TT/NWC (1987), under STATISTICS OF LOGARITHMS, GEOM MEAN should be replaced by MEAN. TT/NWC (1987) seem to refer to Figure 4 rather than 5 (p. 29, line 10 from the bottom). The geometric mean transmissivity is in units of m2/day and not in units of m2/s as mentioned on page 29 (TT/NWC, 1987, 8 lines from the bottom) and page 30 (8 lines from the top). On page 30, line 13 from the top of TT/NWC (1987), "log mean hydraulic conductivity" should be "mean of the log hydraulic conductivity". The same comment applies to page 31, "log mean gradient" should be "mean log gradient". Finally, the date of the report should be January 13, 1987 rather than January 13, 1986.

E. CONCLUSIONS AND RECOMMENDATIONS

The main differences between the TT/NWC reviews and Clifton's report are in the assumed geometric mean of the effective porosity. TT/NWC uses a value 24 times smaller than the value assumed in Clifton's report. As a result of this assumption groundwater travel times calculated by TT/NWC would be about 24 times shorter than those calculated by Clifton.

TT/NWC neglect spatial correlation in the log transmissivity and thus, overestimates effective log transmissivities. As a result, travel times calculated by TT/NWC are on the low side.

Although TT/NWC raise some valid points, the arguments they employed to refute the range of effective porosity adopted by Clifton are untenable.

There is a consensus among various investigators that additional field tests are needed in order to arrive at more reliable estimates of GWTT. It is obvious that additional information must be obtained regarding appropriate values and variability of effective thickness and porosity. However, at the same time, a more complete probabilistic analysis is required. This analysis would also suggest the kind of data that would be most useful in the analysis.

In view of the cost and duration of such tests, it is crucial to concentrate the efforts on those tests which have a large impact on the estimation of GWTT. As a result of their conclusions concerning the effective porosity, TT/NWC (1987, p. 39) recommend that field investigations focus on measurements of effective porosity.

In contrast, Clifton's (1986) simulations and the analytical approach of GWTT CDF (Djerrari et al., 1986) show that the probability distribution of GWTT is very sensitive to the assumed correlation length. Therefore, the determination of the transmissivity integral scale, by measurements of transmissivity, is regarded as of paramount importance. Although a few more values of measured $\bar{n}$ are recommended, by no means should they come at the expense of transmissivity. The danger is that if the porosity data are such that the site passes the GWTT requirement for a zero integral scale, as assumed by TT/NWC, the opposite might be true for a finite integral scale.

Uninformed conservativism does not necessarily lead to good decisions. In the case of the nuclear waste isolation projects, it could easily lead to the decision to disqualify all sites. For the Hanford Site, a combination of conservative assumptions about the flow path, the value of the effective porosity, the correlation length of the log transmissivity, lack of correlation between log transmissivity and log effective thickness, and the unconditional probabilities approach followed would yield results which would suggest that the site should be disqualified. Instead, what is needed is to pursue a more complete probabilistic analysis in parallel to site characterization efforts.

Regulatory agencies should specify the needed safety levels more accurately (e.g., in terms of probabilities that the pre-emplacement travel time exceeds 1,000 years). Then the nature of uncertainties should be understood and incorporated in the analysis. For example, no matter how many measurements are obtained, the uncertainty about the correlation length of log transmissivity would always be large.

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Attachment 16(d)

DRAFT

COMMENTS OF THE

YAKIMA INDIAN NATION

ON THE

DRAFT GENERIC TECHNICAL POSITION

ON GROUNDWATER TRAVEL TIME

JULY 30, 1986

SUBJECT: Comments on "Draft Generic Technical Position on Groundwater Travel Time, by Richard Codell" (NRC 7/86)

DATE: July 30, 1986

EXECUTIVE SUMMARY

This report is a critical review of the NRC paper entitled "Draft Generic Technical Position on Groundwater Travel Time". The purpose of this NRC paper is to provide general guidelines for the relevancy and quality of research affecting the groundwater travel time (GWTT) objective. These research guidelines are important for the evaluation of high-level waste (HLW) repository performance and are not adequately covered by the NRC.

I. INTRODUCTION

One of the NRC performance objectives for HLW repositories, the GWTT objective, is stated as:

" The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1000 years or such other time as may be approved or specified by the Commission." (10 CFR 60.113 (a)(2))

The Disturbed Zone definition (10 CFR 60.2) and GWTT objective were established as part of a multiple barrier approach to HLW isolation. Since groundwater is the most likely means by which significant quantities of radionuclides could escape a HLW repository, transport of radionuclides to the biosphere depends on factors which are directly related to the travel time of groundwater from the repository to the environment.

The following comments point out several problems with and inadequacies of the GWTT analysis and methods described in this NRC technical position paper.

II. REVIEW OF THE NRC TECHNICAL POSITION

1.0 What is Groundwater Travel Time?

Page 4, Equation (1)

Equation (1) should read:

$$T = \int_{D.Z.}^{A.E.} \frac{n_e}{U} ds$$

Page 5, Equation (2)

The material balance and the assumptions that lead to equation (2) cannot be justified when simulating the transport and capture of colloidal particles. Accurate modeling of radioactive and natural colloidal particles in a high-level nuclear waste repository environment would require the inclusion of complex phenomena such as electrical interactions between the particles and the walls of the surrounding rocks. Furthermore, the presence of these interactions may lead to a system which is not in thermodynamic equilibrium. In any case, equation (2) cannot be used as a basis to model colloids and to describe their potential to move faster than the average pore velocity (Avogadro and De Marsily, 1984). When this latter situation occurs, the travel time definition calculated using equation (1) is no longer valid.

Page 5, Paragraph 4

" The immobile phase occupies the fraction ($n - n_e$) of the rock."

Page 7, Paragraph 3

" This fact tends to support the notion ... groundwater travel time."

Page 9, Paragraph 1

" Groundwater travel time also could be interpreted ... less than 1000 years."

The concept of "immobile water" is ambiguous. As a matter of fact, the dispersion coefficient is supposed to account for the tortuous paths of fluid particles, including the slow ones through zones of low velocity. It is difficult to conceive how one would derive experimentally the various terms of eq. (2), other than n_e and $\underline{D}$, from the equation

$$n(\partial c/\partial t) = n_e \operatorname{div}(\underline{D} \text{ grad } C - \underline{U}C)$$

Although in later discussion the influence of adsorption is discarded, the need for future incorporation is noted (p.7, paragraph 3; p.9, paragraph 1). What is not mentioned is the fact that the theory relating travel time to adsorption, decay, etc. has not yet been developed; and the concept has been applied only to relating concentration to adsorption, decay, etc.

Page 6, Equations (5) and (6)

These equations do not follow from equations (3), (4) and (5). The relationship between G and C is missing.

Page 7, Paragraph 2

> " Tracer particles considerably larger than molecules will not exhibit the same diffusive behavior as molecular tracers, and will be transported at a speed more typical of the average groundwater seepage velocity."

This argument may not hold true for radiocolloids, which tend to travel in regions of higher than average fluid velocities within the streamflow (Bonano and Beyeler, 1985; Avagadro and De Marsily, 1984).

Page 7, Paragraph 2

> " Tracer particles considerably larger than molecules ... groundwater movement is very slow (Blencoe and Grisak, 1984)."

The description of the outcome of the experiment by Cathles in lines 7-13 does not agree with the statement in lines 3 through 7.

Page 7, Paragraph 3

" It should be noted that ... estimated to be 2.7 x 10 $^{-5}$ cm^2/sec."

The distinction between self-diffusion of water molecules and traces is artificial. Tracing is required to detect the self-diffusion of water molecules.

2.3 Groundwater Travel Time Along the Fastest Path

Page 11, Section 2.3

Page 21, Paragraph 6
Page 22, Paragraph 1

"Interpretation of Sparse Data. The temporal and spatial distribution of hydrogeologic field data ... the variance of the hydraulic conductivity (e.g., Neuman and Yakowitz, 1979, Hoeksema and Kitanidis, 1984)."

Page 23, Paragraph 4

" Field data for hydraulic conductivity and porosity ... to apply to these data in this step (Mantoglou and Gelhar, 1985)."

In all of these sections an important source of uncertainty has been ignored, namely the uncertainty manifested in the estimation of the parameters which characterize the probability distribution functions of various properties. In the case of scarce data, this may be a major source. The quantitative evaluation of variances of estimation has been developed in an important series of articles by Hoeksema and Kitanidis (1984), Kitanidis and Lane (1985), and Kitanidis (1986).

A.1 Travel Time Distributions

Page 18, Paragraph 1

The definition of mechanical dispersion applies to pore-scale nonuniformity. The large scale heterogeneities encountered in aquifers can cause solute spreading which may be termed "megadispersion" only under restrictive conditions. These conditions, in essence, require

(i) ergodicity for solute concentration and

(ii) travel distance much larger than the heterogeneity correlation scale (see discussion in Part I of Dagan, 1984).

Page 19, Paragraph 2

> "Stochastic approaches to modeling are at a much less developed state than Monte Carlo techniques, although it is an area of rapid development ... They apparently have not yet been used to calculate directly such spatially integrated properties as GWTT."

The literature on stochastic modeling is much richer than implied here. For comprehensive reviews, see Sposito et al. (1986), Dagan (1985), and Gelhar (1985).

A.3.1 Treatment of Uncertainties in Site Characterization

Page 22, Paragraph 2

> " Computer codes should be verified with analytical solutions, validated with real field data, and compared or benchmarked with other similar computer codes (Silling, 1983)."

The validation of computer codes by comparison with analytical solutions is highly desirable. Such comparison is not possible at present for GWTT because, to the best of our knowledge, there are no analytical solutions available for GWTT in two- or three-dimensional flows.

A.4 Estimating GWTT from Deterministic Models with Randomly-Generated Input

Page 23, Paragraph 1

> " This solution generally is accomplished ... then counting their arrival times as they reach the accessible environment."

The computation of travel time by these techniques may be plagued by large discretization errors due to the need to numerically differentiate the head in order to derive the velocity, to integrate along the velocity vectors in order to determine the trajectories, and to integrate along trajectories in order to calculate time (eq. 1). A better streamfunction technique (Frind and Matanga, 1985) developed for two-dimensional, steady flow, is not mentioned.

A.4.1 Treatment of Spatial Variability

Page 23, Paragraph 3

> " This method has been applied to 2-dimensional steady state, saturated flow models for equivalent porous media (e.g., Delhomme, 1979, Clifton and Neuman, 1982), but it could be adapted to three dimensions (Mantoglou and Gelhar, 1985). The procedure is outlined below for the 2-dimensional, steady state case (Clifton, 1984)".

This paragraph gives the misleading impression that Delhomme (1979) and Clifton and Neuman (1982) have employed conditional simulations of GWTT. These papers do not deal with transport. Similarly, it is not true that Clifton (1984) has carried out conditional simulations of GWTT, as implied by the NRC (p.24, lines 10-12), and the conclusion regarding the considerable reduction of the variance is unproven, if not gratuitous. The subject of the effect of conductivity conditioning upon transport has been addressed for a particular case, using numerical methods, by Smith and Schwartz (1980), and the combined effect of conditioning of both conductivity and head has been discussed in a general manner by Dagan (1984, Part 2).

Page 24, Paragraph 1

> " Two widely-used procedures for generating these random fields ... otherwise, the parameter fields are "unconditional"".

In addition to these methods, the ready-made generation of multi-variate normal variables is available in most computer libraries.

A.5 Simplified Analysis

Page 24 (bottom line)
Page 25, Paragraph 1

> " If the medium is assumed to be spatially uniform (i.e., infinite spatial covariance), then it must be assumed that all variations of the parameters are caused by measurement error."

There is no real need for the correlation scale to be infinite. It is sufficient for it to be large compared to the distance traveled by particles from the disturbed zone to the compliance surface. Furthermore, the variations of parameters cannot be attributed only to measurement errors, but also to interpretation, modeling, etc. and spatial variability at large scale.

III. CONCLUSIONS AND RECOMMENDATIONS

Some important issues in addition to those mentioned above, are not discussed in the draft. Here are a few such issues:

(1) Does the cummulative probability distribution function for groundwater travel time represent uncertainty, as is the case for a single particle, or does it represent the actual partition of travel times of a large number of particles simultaneously released from the boundary of the disturbed zone, as is assumed in diffusion or dispersion theories? The answer to this question is intimately related to ergodicity of transport, which in turn is related to the scale of the initial zone of release, correlation scale and travel distance (for a discussion concerning concentration see Dagan, 1984 Part 1). This is an important topic which requires serious consideration and investigation in order to adequately address the question of simultaneous release of a number of particles in each realization. It should also be noted that, whereas uncertainty can be reduced by increasing the quantity and improving the quality of

measurements and by subsequent conditioning, the dispersive effect of spatial variability cannot be diminished this way.

(2) The fact that Monte-Carlo techniques have not yet been applied to complex three-dimensional flows (except, Warren and Price, 1961) is not mentioned. Furthermore, the inclusion of three-dimensional effects in a two-dimensional scheme by introducing a diffusive (dispersive) term in the computation of the travel time, is not considered. The Monte-Carlo simulations used by Clifton (1984) and advocated in the draft are not able to account for these effects.

(3) The Monte-Carlo and numerical scheme referred to in the draft GTP (i.e., Clifton, 1984) is not able to account for random velocity fluctuations whose correlation scale is smaller or comparable to the grid scale (so called subgrid diffusion). These fluctuations cause uncertainty in GWTT and they will show up as a dispersive term in a concentration formulation.

(4) Little is said about the uncertainty associated with boundary conditions for the flow field, i.e., the selection of the boundaries of the domain to be modeled in Monte-Carlo simulations and of the appropriate boundary conditions.

In conclusion, it is believed that this document, rather than attempting to define criteria of GWTT only, emphasizes too heavily a particular technique applied in the last few years. This may lead to the impression that this technique is flawless and furthermore, that it is the one preferred by NRC. From the above critical comments, it is clear that further scientific developments and improvements are needed to adequately address the NRC GWTT performance objective.

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CENTENNIAL JUNE 9, 1955

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Yakima Indian Nation

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August 4, 1986

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EWA INC.

Mr. John J. Linehan, Acting Chief
Repository Projects Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Mail Stop 623-SS
Washington, D. C. 20555

Dear Mr. Linehan:

A review of the NRC "Draft Generic Technical Position on Groundwater Travel Time" has been completed by the Yakima Indian Nation. Attached please find a copy of our comments.

Your attention to this matter is greatly appreciated. If you have any questions, please do not hesitate to contact me.

Sincerely,

YAKIMA INDIAN NATION

Russell Jim

Russell Jim, Manager
Nuclear Waste Program

Enclosures

RJ/skC

Attachment 16(e)

DRAFT

EVALUATION OF DOE ANALYSIS OF GROUNDWATER TRAVEL TIME HANFORD SITE

By:

A. M. Djerrari
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EWA, Inc.

Submitted to:

YAKIMA NATION

Date:

July, 1986

To: Yakima File, Task: 2.e.3 and 2.h.5.c

From A.M. Djerrari, G. Dagan, V.V. Nguyen and G.V. Abi-Ghanem/EWA, Inc.

Subject Evaluation of DOE Analysis of Groundwater Travel Time, Hanford Site.

Date: July 29, 1986

EXECUTIVE SUMMARY

The U.S Nuclear Regulatory Commission (NRC) has established performance criteria for the qualification of a high-level nuclear waste repository. One of these criteria is referred to as the pre-waste-emplacement groundwater travel time objective. To study the compliance of DOE to meet the NRC objective (i.e.; groundwater travel time (GWTT) exceeding 1,000 yrs), Clifton and Arnett (1984) and Clifton (1984) carried out Monte Carlo simulations using a two-dimensional model. This report reviews the two studies cited previously with respect to the overall method of estimation of the GWTT distribution. It is found that i) the domain in which the groundwater flow problem is solved influences the GWTT distribution, which makes the resulting outcome uncertain, and ii) the GWTT distribution, as derived by the DOE, does not account for uncertainties in the statistical parameter estimates.

The possible range of GWTT exceedance probability for 1,000 yrs has been derived analytically. Due to the scarcity of the available data representing the transmissivity field heterogeneity, the exceedance probability for 1,000 years can be any value between 75% and 99%. Hence, no conclusion on the compliance with the NRC regulation can be made at this time. Several recommendations to improve future numerical simulations are presented. These numerical improvements, however, can not be a substitute for the field effort needed to gain a better knowledge of the field heterogeneity.

I. INTRODUCTION

The objective of the Basalt Waste Isolation Project (BWIP) is to locate, test and construct a deep geologic repository for the terminal storage of high-level nuclear waste at Hanford, Washington. Among the criteria used by BWIP to assess the long term performance of a repository is the predicted groundwater travel time to the accessible environment. Over the past few years, a number of preliminary numerical modeling studies have evaluated potential groundwater flowpaths and travel time estimates (DEA, DOE 1984). These studies presented a broad range of travel time estimates. The variance in estimates has been attributed to measurement and model uncertainties. Since modeling was always carried out in a deterministic way in the previous studies, stochastic modeling was considered to be an appropriate technique for calculating groundwater travel times (DEA, DOE 1984). Stochastic modeling was performed in two studies by Clifton and Arnett (1984) and Clifton (1984). This report will review the overall approach used by these authors. The method for evaluating the groundwater travel time distribution is presented in the first section. The DOE/BWIP approach is evaluated and its limitations discussed in the second section, while the third section contains conclusions and recommendations.

II. GROUNDWATER TRAVEL TIME DISTRIBUTION: APPROACH AND RESULTS

A. Summary of the General Approach

The technique proposed for generation of random variables is the Monte Carlo technique. The quantities generated by this technique are subsequently used in the groundwater flow and groundwater travel time equations. The stochastic quantities under consideration are i) transmissivities, ii) effective thickness and/or iii) boundary conditions through the hydraulic head gradient. Monte Carlo analysis produces a series of groundwater travel time realizations that are used to construct probability distribution of the groundwater travel time.

1. Governing equations

Assuming steady state conditions and a heterogeneous porous medium with no internal sources or sinks, the groundwater flow system is described by the following equation,

$$\nabla.(\ T \quad h) = 0 \qquad (1)$$

subject to prescribed head and flux boundary conditions, using the following notations

∇ = the two-dimensional vector diferential operator,

T = transmissivity (L^2/T),

h = hydraulic head (L).

Groundwater travel times are calculated using the solution of equation (1) and the following relationship,

$$T_i = \int_L \frac{dL}{|q_s|} \qquad (2)$$

where

T_i = ground-water travel time (T)

$|q_s|$ = magnitude of the seepage velocity vector (L/T)

dL = curvilinear elemental length along the direction of $\underline{q}_s$ (L)

The seepage velocity vector is given by

$$\underline{q}_s = - T \nabla h /(bxn_e) \qquad (3)$$

where

b = aquifer thickness (L),

n_e = effective porosity (dimensionless).

The quantity be (=bxn_e) is called "effective thickness" and represents the area of pore space available to flow, in a vertical cross section of an aquifer of unit width and thickness b. To determine ground-water travel time using equation (2), a transmissivity field and boundary conditions are specified and used to solve equation (1). The numerical solution of equation (1) is accomplished by means of either a finite element (Clifton and Arnett, 1984) or a finite difference technique (Clifton 1984). Both techniques lead to a matrix equation of the general form:

$$\underline{\underline{A}} (\underline{T}) \underline{h} = \underline{b}_c \qquad (4)$$

where

$\underline{\underline{A}} (\underline{T})$ = square matrix of order N,

$\underline{h}$ = N-dimensional vector of hydraulic head,

N = number of node points used to represent the flow domain,

$\underline{T}$ = N-dimensional vector of transmissivities,

$\underline{b}_c$ = vector of known constants incorporating boundary conditions,

Each zone of the flow domain is assigned a unique transmissivity. Hence, the number of zones considered characterizes the degree of heterogeneity of the system. When solving for the travel time, in the context of the stochastic approach, transmissivity, effective thickness and boundary conditions are viewed as random variables having specific probability distributions. The generated realizations of the input parameters are constrained by the prescribed statistics of the field. By accounting for the uncertainty of the input parameters and boundary conditions, the statistics of the groundwater travel time are obtained.

2. Random field generation technique

Equation (4) is regarded as a stochastic matrix equation which depends on the random input paramaters (T and be) and/or boundary conditions. The discretized form of equation (3) is also regarded as a stochastic equation with random input parameters for T and be. The GWTT probability distribution is determined using a Monte Carlo technique which involves repeatedly solving equations (2), (3) and (4) for the input parameters, subject to prescribed distributions. The technique used to generate values of the transmissivity at each node of the computational grid is underlain by the following assumptions: i) $Y = \log T$ is a random stationary space function, ii) Y is normal, i.e. T is lognormal, iii) Y, hence T, is completely defined, in a statistical sense, by its mean $m_Y = \log T_g$, where T_g is the geometric mean, and its two-point isotropic autocovariance C(r), where r is the distance between the two points, and iv) consequently, the values of Y at the grid nodes constitute a multivariate normal vector Y of mean m_Y and covariance matrix $C(r_{ij})$, (i,j=1,..,N), where r_{ij} is the distance between two nodes.

The generation of the random values of a multivariate normal vector is a routine procedure. Clifton and Arnett (1984) use an unconditional probability distribution of $\bar{Y}$ and assume a spherical covariance function,

$$C(r) = \begin{cases} C_0 - C_0[\, 1.5\, r/s_0 - 0.5\, (r/s_0)^3 \,] & \text{for } r < s_0 \\ 0 & \text{for } r > s_0 \end{cases}$$

where C_0 is the variance of Y.

Hence, the entire statistical structure of Y (and T) is given in terms of three parameters: m_Y, C_0 and the correlation range s_0. Clifton and Arnett (1984) assume that these parameters are known in a deterministic manner. m_Y and C_0 have been derived by linear regression on measurements of T at 13 locations in the Hanford site area, whereas the range s_0 has been given a few arbitrarily selected values.

To implement the stochastic method for GWTT estimation, additional parameters remain to be fixed. These are parameters used to solve the deterministic flow problem (e.g., geometry of the flow domain, type of boundary condition and size of numerical mesh).

B. Numerical Results

In the two reports (Clifton and Arnett, 1984 and Clifton, 1984), the DOE method of evaluation is applied to a particular set of input parameters (Reference Case).

1. Reference case

a. <u>model input</u>

In the Reference Case, the domain under study is a rectangle with dimensions 20 km by 10 km. Impermeable boundary conditions are set along the two longer dimensions. Constant head boundaries are set along the shorter dimensions so that the regional hydraulic head gradient is 10^{-3}. Effective thickness is deterministically set at a uniform value of 0.04 m. Figure 1 shows the flow domain and deterministic input as defined for the Reference

Case. The log-transmissivity is the only input parameter considered to be uncertain. The unbiased estimate of mean log-transmissivity required by the unconditional estimator is the logarithm of the geometric mean of the available data in Grande Ronde flow top (e.g., $\log_{10}(0.153\ m^2/day)$). The variance is 3.35 and the correlation range chosen is 5 km. The numerical grid is defined by 1 km x 1 km square domains.

b. <u>results</u>

With the above unconditional estimates of mean log-transmissivity and unconditional covariance matrix, the MNG was used to construct a suite of 600 random log-transmissivity fields in Clifton and Arnett (1984) and a suite of 10,000 random log-transmissivity fields in Clifton (1984). A finite element computer code, the MAGNUM-MC, was used by Clifton and Arnett (1984) while Clifton (1984) used a finite difference code, the PORMC. Clifton and Arnett (1984) found a GWTT distribution with a median of 17,000 yrs and standard deviation of $\log_{10}$(GWTT) of 0.71 while Clifton (1984), solving the same Reference Case, found for these two paramaters values of 21,500 yrs and 0.81, respectively.

The discrepancy between the two GWTT statistics in these studies raises several questions. The differences may have resulted from the fact that 600 simulations were not sufficient to converge toward a stable travel time distribution even though the authors assumed that the transmissivity field had been adequately sampled. The difference may have also resulted from the use of two different codes, as suspected by Clifton (1984). In that case, further investigations must be carried out to determine which code provides reliable results.

Several problems that arise on the median travel time become more crucial at the tail of the probability distribution. For example, it can be seen from Clifton (1984) (see Figure 2) that the median travel time does not stabilize even after 6,000 simulations. This problem would be more amplified in the tail of the GWTT distribution and a greater number of realizations would be needed to accurately assess the probability exceedance of 1,000 yrs. As a matter of fact, the number of Monte Carlo realizations utilized in order to depict the tail is probably small. As pointed out by Nguyen (1985), presentation of the GWTT probability distribution as a smoothed curve may be imprecise near the tail, which is the zone of interest. The investigators should provide an enlargement graph of the tail of the GWTT empirical distribution derived from the Monte Carlo analysis. A separate assessment of the interval of confidence, similar to that of Figure 2, should be provided for the tail region.

2. Sensitivity analysis to regional hydraulic head gradient and effective thickness

Clifton and Arnett (1984) present a sensitivity analysis of the GWTT distribution to uncertainty on regional hydraulic head gradient (G) and effective thickness (be). Uniform probability distributions were assumed to describe G and be. The ranges chosen were 10^{-4} to 10^{-3} for G and 10^{-3} to 10^{-1} for be. To demonstrate the progressive effect of additional parameter variability, two cases were considered:

Case 2: Stochastic transmissivity, regional hydraulic head gradient values and deterministic effective thickness.

Case 3: Stochastic values for transmissivity, regional hydraulic head gradient and effective thickness.

The GWTT distributions for these two cases were compared with those of the Reference Case. The median and log-travel time standard deviation are 86,000 yrs and 0.77 for case 2 and 81,000 yrs and 0.96 for case 3. In these two cases, the authors did not expand on the procedure used. The results are stated without any discussion. The number of Monte Carlo realizations is not given and the generation technique is not described. The only description of a generation technique in the case of a stochastic modeling of G and be is given in Clifton et al.(1983). The authors pointed out that a multivariate normal generator is used to construct a random field of a vector Y, where Y can be either log-transmissivity, effective thickness or regional head gradient. In the development, the vector Y is assumed to be normally distributed. However, if the same normal distribution was used for generating (be) and (G) in Case 2 and 3, its applicability to uniformly distributed variables had to be proved.

III. EVALUATION OF THE DOE APPROACH

A. Comments on the Method of Evaluation of GWTT Statistics

In this section, the DOE approach is evaluated. Their method relies on two assumptions: i) a Cohassett flow top that provides the fastest pathway to the accessible environment, ii) a GWTT probability distribution, derived from Monte Carlo simulations carried out in a numerical domain representing a restricted area of the formation, that is adequate to assess the actual occurrence of travel time in the Cohassett flow top. These two assumptions will be subsequently discussed.

1. Fastest probable pathway to the accessible environment

In the DOE's GWTT studies, the most likely pathway for radionuclide transport is assumed to go through the Cohassett flow overlying the preferred candidate horizon. This assumption has been substantiated by computations carried out by Clifton and Arnett (1984).

Clifton and Arnett (1984) computed the steady state groundwater velocity field in the Grande Ronde and the Wanapum formations. An overall vertical gradient of $2x10^{-3}$ was assigned to the Grande Ronde Basalt while a vertical gradient of 10^{-3} was assigned to the Wanapum. The computations were performed using the finite element computer code MAGNUM-MC. Four values for the ratio of the dense interior vertical conductivity to the flow top horizontal conductivity were considered ($1.5x10^{-6}$, $5x10^{-6}$, $5x10^{-5}$ and $5x10^{-4}$) in 4 successive simulations. It was found that i) a ratio of $5x10^{-5}$ or less is not sufficient to induce upward flow beyond the overlying Cohassett candidate horizon within the 10 km horizontal distance, ii) a conductivity ratio of $5x10^{-4}$ is sufficient to induce upward flow within the 10 km lateral distance. The authors concluded that the fastest pathway must be provided by the overlying flow top, since the travel time must be greater when an upward movement is induced.

In their simulations, the authors have only taken into account the effect of vertical hydraulic gradient. The actual post-closure conditions encountered in the repository are far removed from the isothermal conditions implicitly assumed by Clifton and Arnett (1984). A proper analysis of the post-closure natural barrier performance should account for the coupled thermo-hydrological processes. This problem may be of importance since the accessible environment lies only 250 m above the repository at a downgradient distance of 2 km (DEA, DOE 1984) (see Figure 3).

2. Method of evaluation of the GWTT probability distribution

The overall method of estimating GWTT statistics using stochastic modeling has been described in the previous section. As was pointed out, several parameters must be chosen. Parameters that describe the geostatistical transmissivity field must be identified. Flow domain geometry and boundary conditions must be prescribed in order to simulate the actual groundwater flow in the field.

The statistics of the travel time, obtained by considering the ensemble of travel times calculated in the various Monte Carlo simulations and its interpretation, depend on whether i) the ergodic hypothesis is obeyed, ii) the GWTT probability distribution derived from simulation over the restricted domain adopted in computations is close to the one derived for the actual domain, and iii) the identified statistics of the transmissivity (i.e., geometric mean, variance and correlation range) reflect accurately enough the transmissivity field heterogeneity.

These three aspects and their treatment in the forementioned DOE reports are discussed below.

a. ergodicity

Ergodicity for a stationary random function implies that all states of the ensemble are encountered in each realization (Beran, 1968). Whether this requirement is obeyed or not depends on the particular random function of concern. Starting with the transmissivity and the dependent velocity field, ergodicity prevails if the extent of the simulated domain is larger by factors of ten than the spatial correlation range. Since the range was selected to be 5 km, and the simulated area is a rectangle with dimensions 10 km by 20 km, it is quite improbable that ergodicity applied to these fields.

Even if the velocity field is stationary and ergodic, ergodicity is not necessarily obeyed by transport, i.e., concentration and travel time. For ergodicity to be obeyed, both input zone and compliance surface must have dimensions normal to the flow direction much larger than the concentration scale, or the travel distance has to be very large compared to the correlation scale to permit dispersion to ensure spreading over a large area (these conditions are discussed in Dagan, 1984). In terms of travel time, ergodicity would imply that the probability distribution obtained for a particle in an ensemble of realizations is close to the one derived for a large number of particles traced from the input zone in each realization.

The effect of non-ergodicity upon the interpretation of the GWTT distribution curve, P(t), obtained from Monte Carlo simulation, is quite dramatic. In the first extreme case of an integral scale of the transmissivity and velocity much smaller than the input and output zones, P(t) can be interpreted as a deterministic curve representing with certainty the relative number of solute particles launched at t=0 which have crossed the compliance surface at time t. In the opposite non-ergodic case, P(t) is a measure of uncertainty and represents the probability for all particles launched at t=0 to cross the compliance surface at time t. These two different interpretations may have a quite different impact upon the decision making process.

This important point of principle is discussed only briefly and superficially in the DOE reports. From the above discussion, it is clear that for a correlation range of 5 km, even if the repository were assumed to leak over its entire area (i.e., 1.6 km by 3.35 km), ergodicity would not have been obeyed. Since simulations were carried out for a single particle in each realization, ergodicity could not be verified empirically along the lines discussed above. It is therefore quite probable that the GWTT probability distribution, P(t), derived in DOE reports, should be viewed as representing uncertainty. This is generally the interpretation adopted by Clifton (1984), although in Clifton and Arnett (1984, pp 25 lines 1-17) it is claimed that the

GWTT probability distribution could be representative of the actual spatial distribution of GWTT.

b. influence of domain boundary

There are at least two approaches to selecting boundaries and boundary conditions in Monte Carlo simulations. The first is the case in which the layout of the boundaries and the conditions satisfied by head on them is known, and they are modeled accordingly. In the second case, in which the flow domain is of an extent which is large compared to the correlation scale and conditions of average uniform flow prevail, one may model only part of the formation with the belief that the results are insensitive to the size selected for the domain. In the latter case, the GWTT probability distribution would have been insensitive to the size of the formation, which was selected to be 10 km by 20km, for the condition of no flow through lateral boundaries. This is apparently not the case and the point is illustrated in Figure 4 (reproducing Fig. 25 in Clifton,1984) which shows the large impact of the domain width upon travel time distributions and particularly upon median time. Thus, this problem cannot be regarded as settled.

c. impact of variance of transmissivity statistical parameters

In any identification procedure, only estimates of the various parameters are obtained and those estimates are subject to uncertainty (This point has been discussed in the present context e.g., by Hoeksema and Kitanidis, 1984). This is particularly true in the case in which data are scarce or missing. On the 42 transmissivities compiled by Strait et al.(1984), 34 were given with a range of uncertainty of one order of magnitude when the transmissivities are expressed in ft^2/s, 3 were given by a deterministic value and 5 were given by a maximum or a minimum value. The geometric mean and the standard deviation are assumed to be deterministic by Clifton and Arnett (1984) and Clifton

(1984), but given the original data, the estimates of these quantities are subject to uncertainties. While the authors recognized this uncertainty for the case of the regional hydraulic head gradient, G, and the effective thickness, be, they did not consider it for the estimates of the log-transmissivity distribution. This inconsistency has already been pointed out by Nguyen (1985). Incorporating the estimation variance of all parameters simultaneously is bound to lead to larger variance of GWTT estimates. Some calculations along these lines will be carried out in the next section.

B. Analytical Assessment of the GWTT Probability Distribution

The GWTT probability distribution can be derived analytically for two particular values of the correlation range. The two curves obtained may suggest a bounding range for the probability of occurrence of the shortest travel times. The analytical derivation accounts for the uncertainty of the estimate of the transmissivity geometric mean as well as for the uncertainty of the hydraulic head gradient and the effective thickness. The two cases under study are mentioned by Clifton (1984), without considering uncertainty of the transmissivity geometric mean.

1. Small integral scale

The first case considered is of a transmissivity integral scale much smaller than the distance to the accessible environment. In this limit case, spatial variability does not affect the trajectories (except for a small dispersive effect), which become almost straight. The travel time t is then given by

$$t = \frac{L}{G} \frac{be}{T_g} \qquad (5)$$

where

T_g = transmissivity geometric mean,

be = effective thickness,

L = distance to the accessible environment (10 km),

G = regional hydraulic head gradient.

Unlike Clifton (1984), we shall follow the lines indicated by Nguyen (1985), namely, not only be and G, but also T_g is regarded as a random variable. Following Clifton and Arnett (1984), be and G are assigned uniform distributions, i.e.,

$$f(be) = 1/(be_M - be_m) \quad (\text{for } be_m < be < be_M) \qquad (6)$$
$$f(be) = 0 \quad (\text{for } be < be_m \text{ or } be > be_M)$$

$$f(G) = 1/(G_M - G_m) \quad (\text{for } G_m < G < G_M) \qquad (7)$$
$$f(G) = 0 \quad (\text{for } G < G_m \text{ or } G > G_M)$$

where be_M, be_m and G_M, G_m are the upper and lower values of the possible range for be and G respectively. Following Nguyen (1985), T_g is assumed to be log-normal. The distribution of $Y = \text{Ln } T_g$ is normal with mean m_Y and standard deviation σ_Y i.e.,

$$f(Y) = \frac{1}{\sqrt{2\pi}\,\sigma_Y} \exp\left[-(Y-m_Y)^2/2\,\sigma_Y^2\right] \qquad (8)$$

Under these conditions, the probability that the GWTT is smaller than t is given by the general formula

$$P(t) = \int_{be_m}^{be_M} f(be) \int_{G_m}^{G_M} f(G) \int_{A}^{\infty} f(Y)\, dY\, dG\, dbe \qquad (9)$$

where $A = Ln(Lbe / Gt)$ and Ln stands for the natural logarithm.

Integration over Y using equation (8) yields

$$\int f(Y)\, dY = 1/2 \text{ erfc } \left(\frac{A-m_Y}{\sqrt{2}\,\sigma_Y}\right)$$

Using the auxilary formula (Abramowitz et al., 1972, p 304)

$$\int \exp(ax) \text{ erfc}[b(x+c)]\, dx = \frac{1}{a} \exp(ax) \text{ erfc}[b(x+c)]$$

$$+ \frac{1}{a} \exp((a/2b)^2 - ac) \text{ erf}[b(x+c) - a/2b] \quad (10)$$

(where erf and erfc stand for the error function and the complementary error function), the integration over (G) and (be) can be carried out in a closed form. With f(be) and f(G) given by (6) and (7), P(t) results in the following closed form

$$P(t) = \frac{F(G_M,be_M) - F(G_m,be_M) - F(G_M,be_m) + F(G_m,be_m)}{(G_M - G_m)(be_M - be_m)} \quad (11)$$

The function F(G,be) is given by the following relationship,

$$F(G,be) = \frac{be\ G}{2} [\text{erfc}(Ln(B/\sqrt{2}\,\sigma_Y)) + \frac{B}{2} \exp(\sigma_Y^2/2) \text{ erf}(Ln(B/\sqrt{2}\,\sigma_Y) + \sigma_Y/2)$$

$$- \frac{1}{2B} \exp(\sigma_Y^2/2) \text{ erfc}[Ln(B/\sqrt{2}\,\sigma_Y) - \sigma_Y/ 2] \quad (12)$$

where $B = L\ b\dot{e} / (\ t\ G\ T_g)$

Using equations (18) and (19), P(t) can be plotted, the pertinent data being:

$$b_m = 10^{-3}m \ ,\ b_M = 10^{-1}m,$$

$$G_m = 10^{-4} \ ,\ G_M = 10^{-3}, \quad (13)$$

m_Y = Ln(0.153 m^2/day),

L = 10 km,

and σ_Y is given the value suggested by Nguyen (1985),

$$\sigma_Y = \text{Ln}(10)\ \sigma_{\log T}\ /\ (N)^{1/2} \qquad (14)$$

$$= .65$$

where $\sigma^2_{\log T}$ is the variance of the base 10 log-transmissivity found by Clifton and Arnett (1984) (i.e., 3.35) and N the number of observations (i.e., 42). It should be mentioned that (14) is not conservative since it implies that the measurements of T are independent.

2. Large integral scale

The second extreme case is the one in which the integral scale I is much larger than the distance L. The transmissivity may then be assumed to be constant in the zone between the input and the compliance surface, and the GWTT is given again by equation (5). Since the variance of T_g (14) is much smaller than that of T and we neglect it, the cumulative probability distribution, P(t), is then given by the same equations (11) and (12) in which σ_Y is now replaced by the one derived by Clifton and Arnett (1984), i.e.,

$$\sigma_Y = (\text{Ln } 10)\ (3.35)^{1/2} \qquad (15)$$

$$= 4.21$$

The probability distributions, P(t), for the limit cases are presented in Figure (5). An enlargement of the tail is shown on Figure (6). The tail of the curve depicting P(t) for a finite integral scale presumably falls between these two curves for the shortest travel times. Because the actual value of the integral scale is unknown, the probability of GWTT exceeding 1,000 yrs may fall between 93% and 73%. For the value of the integral scale chosen by Clifton and Arnett (1984), the results are closer to the upper limit.

3. Sensitivity to be and G distribution

The actual distribution of the effective thickness and the regional hydraulic head gradient are actually unknown. A different assumption on the distribution may lead to a different uncertainty range on the 1000 yrs probability of exceedance. To investigate such an effect, lognormal distributions, besides the uniform ones, were considered for be and G.

Equation (5) of the GWTT still holds for the two extreme cases. By taking the logarithm of each side of equation (5), we obtain

$$Ln(t) = Ln(L) + Ln(be) - Ln(G) - Ln(T_g)$$

With the normal distribution assumed for Ln(be), Ln(G) and $Ln(T_g)$, Ln(t) as a sum of three independent normal variables, has a normal distribution of mean

$$\langle Ln(t)\rangle = \langle Ln(L)\rangle + \langle Ln(be)\rangle - \langle Ln(G)\rangle - \langle Ln(T_g)\rangle \qquad (16)$$

and variance,

$$\sigma^2_{Ln(t)} = \sigma^2_{Ln(be)} + \sigma^2_{Ln(G)} + \sigma^2_{Ln(T\ )} \qquad (17)$$

For the purpose of comparison, the mean and standard deviation of the variables be and G are assumed to be equal to the ones derived from a uniform distribution, i.e.,

$$\begin{aligned} \langle X\rangle &= (X_M + X_m)/2 \\ X^2 &= (X_M^3 - X_m^3)/(3*(X_M - X_m)) - (\langle X\rangle)^2/4 \end{aligned} \qquad (18)$$

where

X stands for either G or be

X_M, X_m are the upper and lower values of the possible range of G or be.

The mean and the standard deviation of Ln(be) and Ln(G) are then derived using the relationships that exist between the two first moments of a variable (X) and its logarithm (Z=Ln(X)) i.e.,

$$\begin{aligned} \langle Z \rangle &= \text{Ln}\left[\langle X \rangle / (1 + C_v^2)^{1/2} \right] \\ \sigma_Z &= \left[\text{Ln}(1 + C_v^2) \right]^{1/2} \end{aligned} \qquad (19)$$

where

$$C_v = \sigma_X / \langle X \rangle$$

With the set of data considered already and described by the relations (13), (14) and (15), the lognormal distribution leads to a probability of a GWTT exceeding 1,000 yrs ranging from 99.8% to 74%. The comparison between these values and the ones obtained previously shows that the range of uncertainty on the probability of exceedance of the 1,000 yrs is not very sensitive to the distribution of the hydraulic gradient and the effective thickness (see Figure 5 and 6). Based on actual knowledge of the transmissivity field, the uncertainty range on the exceedance probability of 1,000 yrs cannot presumably be narrowed more than the 25% range found above. Hence, at this preliminary stage, the only conclusion that can be reached is that experiments to better characterize the pertinent parameters to the GWTT problem (e.g; transmissivity field, effective thickness..) are needed to reduce the present uncertainty on the exceedance probality for 1,000 yrs.

IV. CONCLUSIONS AND RECOMMENDATIONS

The DOE method of evaluating the GWTT distribution, presented by Clifton and Arnett (1984) and Clifton (1984), has been reviewed in this report. Several question marks have been raised. Different computer codes used to solve the groundwater flow problem for the same case yield different groundwater travel time distributions. The GWTT distribution derived by carrying out Monte Carlo simulations in a relatively small numerical domain is influenced by the domain size and the arbitrary choice of the impervious boundaries that confines the groundwater flow. The overall method of determining the GWTT distribution does not provide complete results, since the uncertainty of statistical parameters describing the transmissivity field has to be taken into account. The choice of a value for the integral scale has a large influence upon the results, and the particular value selected by the DOE is questionable. Analytical groundwater travel time distributions were derived for two extreme cases. These cases provide the upper and lower limit for the GWTT exceedance probability for 1,000 yrs. The results show that no justifiable conclusion on compliance with the GWTT objective can be made.

A few possible improvements to the numerical simulations developed by Clifton and Arnett (1984) and Clifton (1984) are suggested. These can lead to both increased accuracy and savings in computer time. They are mainly concerned with i) an improved simulated domain, ii) an increase in accuracy on the GWTT distribution tail area and iii) a better representativeness of the GWTT distribution obtained by simultaneously tracking a few particles.

The selection of the flow domain as a rectangle of restricted area bounded by two lines of constant head and two impervious boundaries may lead to different results from those obtained for a larger domain. To save computer time, simulations may be carried out in an extended domain in which the central zone is spatially variable and its transmissivity is simulated numerically, while the embedding matrix has a constant transmissivity equal to the geometric mean (see Figure 7).

Since we are interested mainly in the exceedance probability for 1,000 - yrs, which corresponds to the tail of the GWTT distribution, the detailed calculation of travel time beyond a certain value (say, 2,000 yrs), is wasteful. It is suggested that the number of realizations of transmissivity field be increased to a very large number. The realizations in which transmissivities in the zone between the input and the compliance surface are sufficiently high should be separated from the rest of the realizations. The groundwater flow problem should be solved mainly for these latter realizations and for a sufficiently large number of times to ensure an accurate representation of the GWTT distribution tail zone. In order to improve the interpretation of the GWTT distribution, it is suggested that a cloud of particles on a line be followed in each realization.

All of these improvements can lead to a more precise travel time distribution only if the pertinent parameters entering the GWTT problem are accurately assessed. Better estimates of the statistical parameters describing the heterogeneous transmissivity field and the effective thickness remain, however, the key to any improvement.

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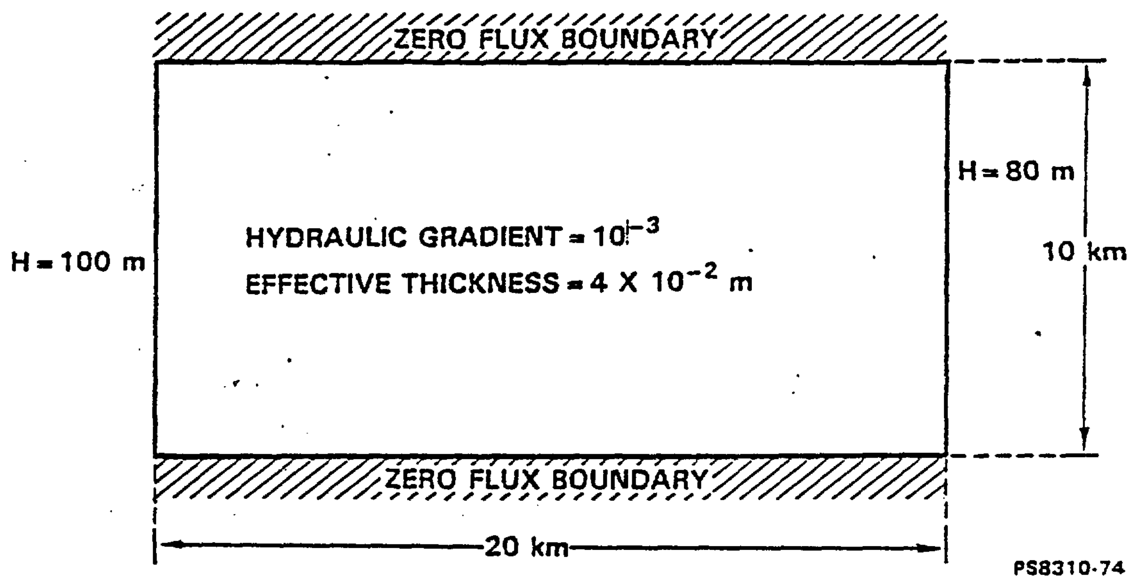
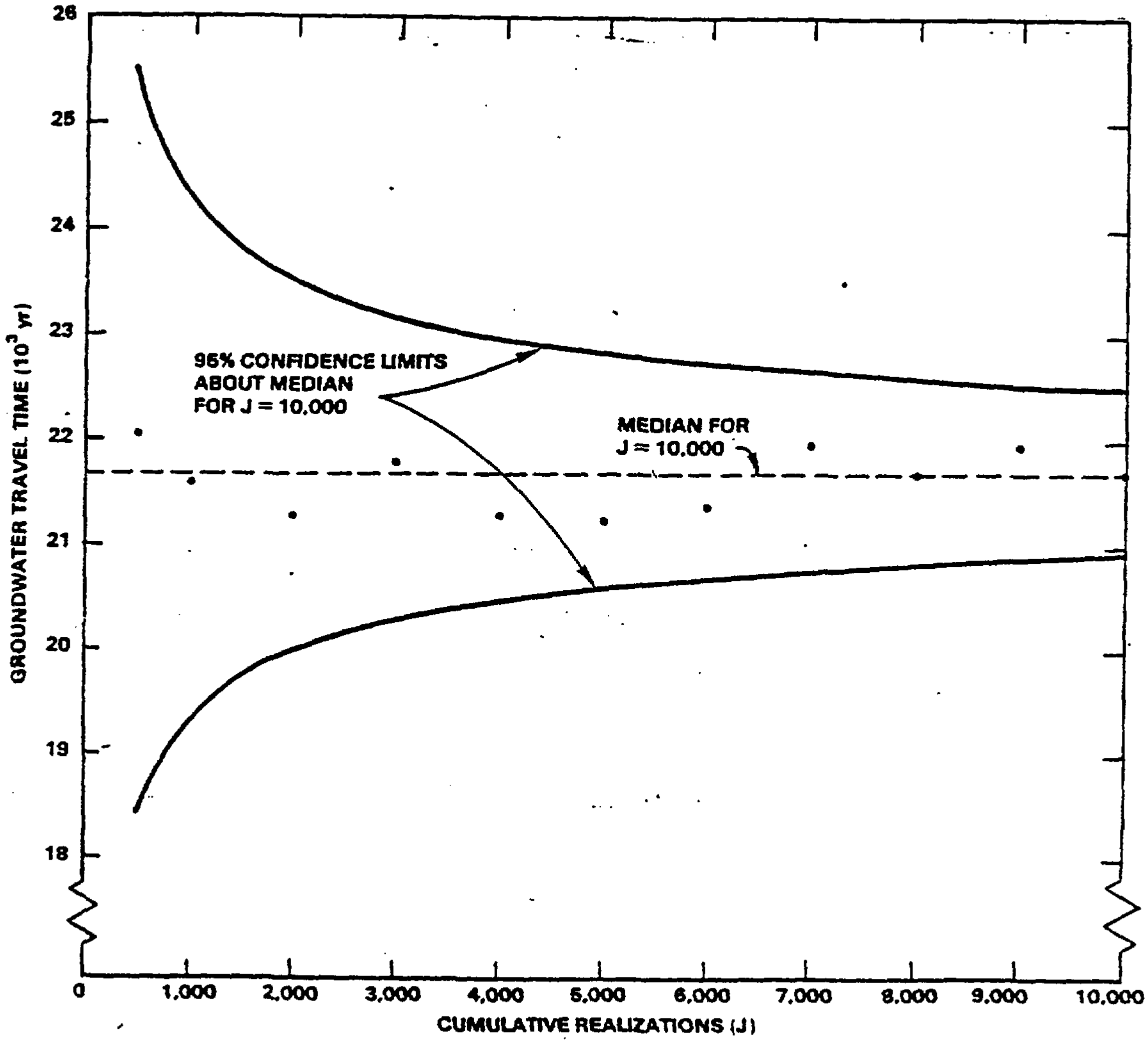


Model Domain and Deterministic Inputs For the Pre-Waste-Emplacement Stochastic Groundwater Travel Time Analysis

(ADAPTED FROM CLIFTON ET AL., 1984)



(ADAPTED FROM CLIFTON, 1984)

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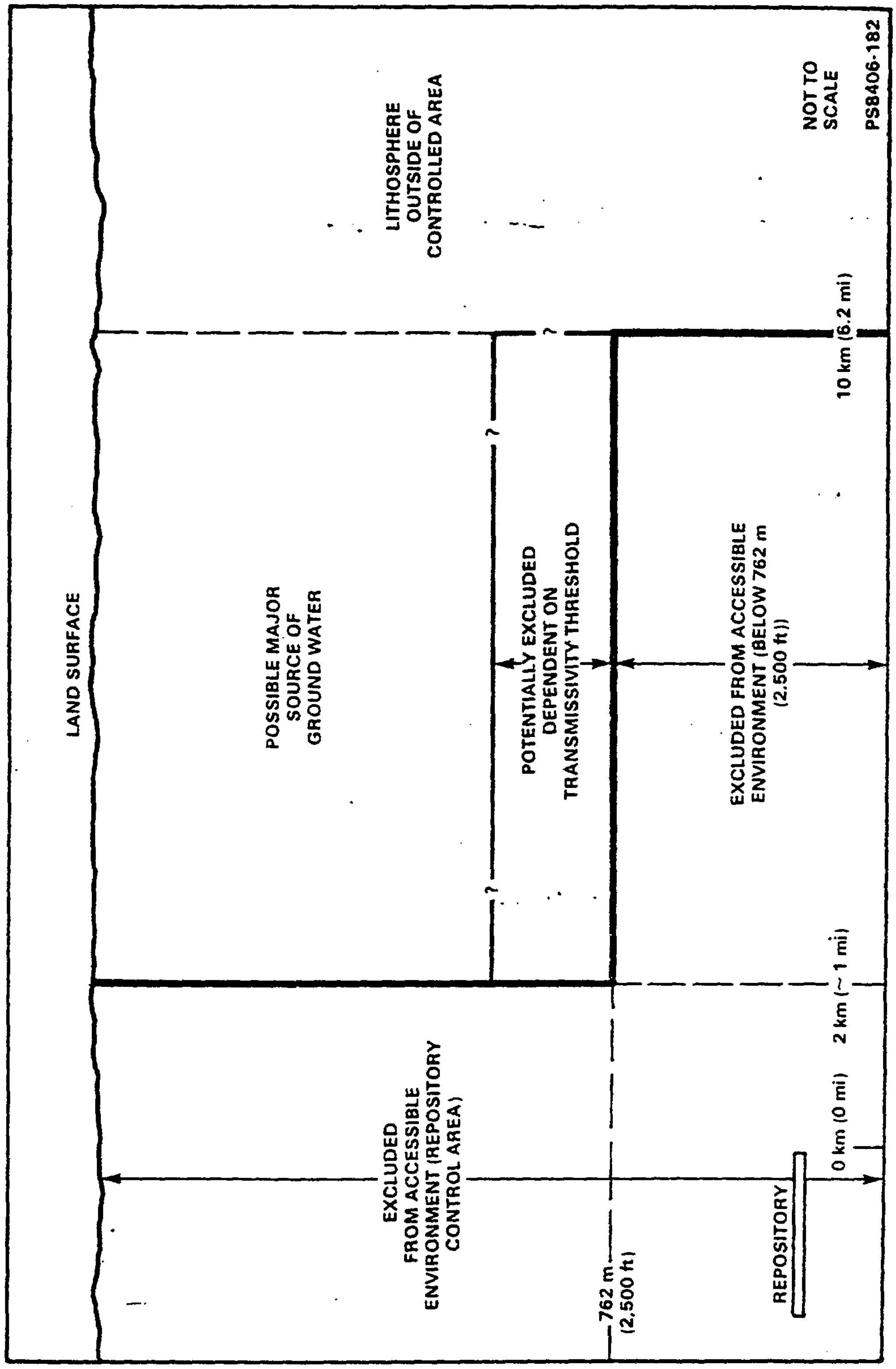
Median Groundwater Travel Time 95% Confidence Interval, Reference Case Analysis.

2



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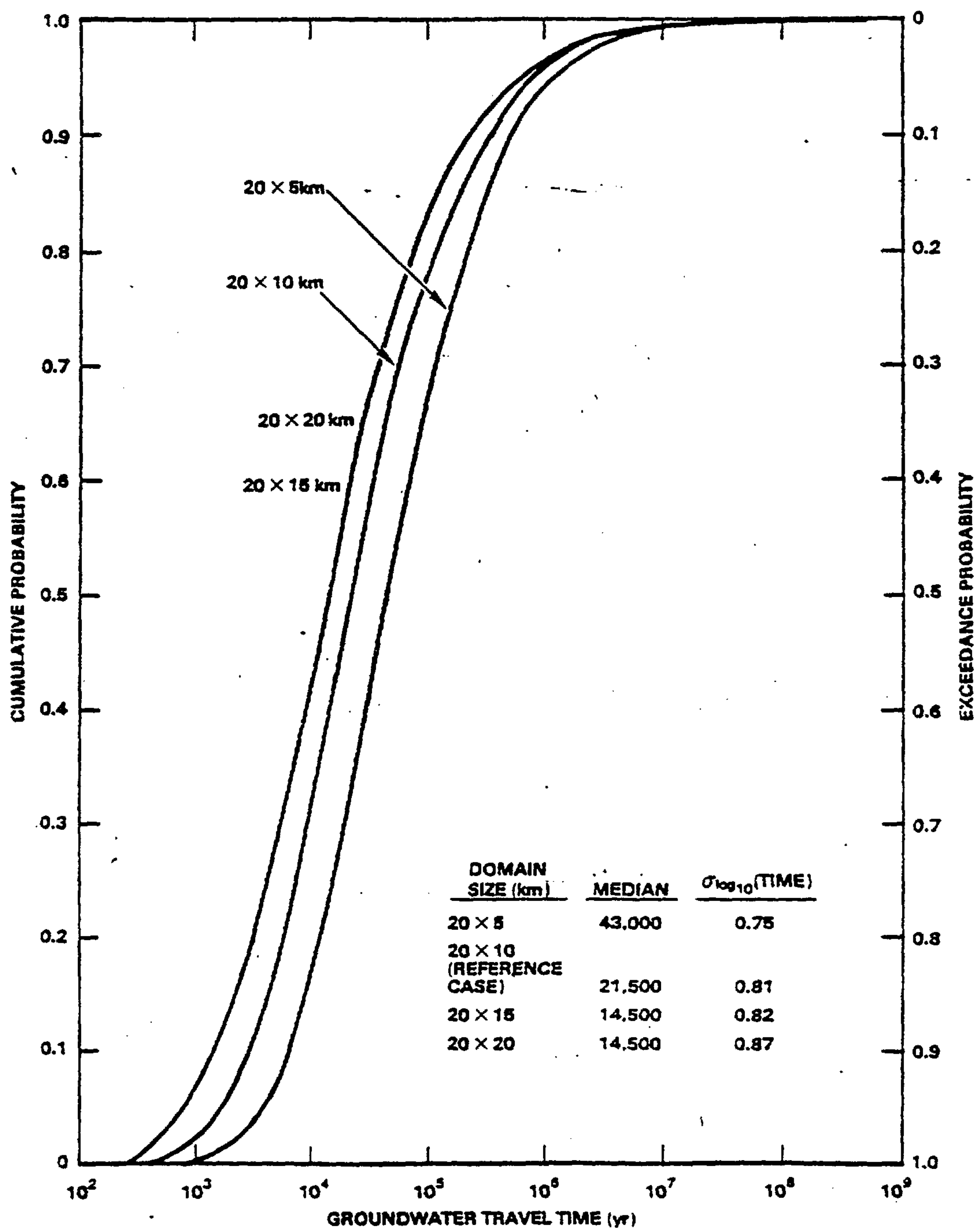
Definition of accessible environment boundary.

3



(ADAPTED FROM FIGURE 25 OF CLIFTON, 1984)

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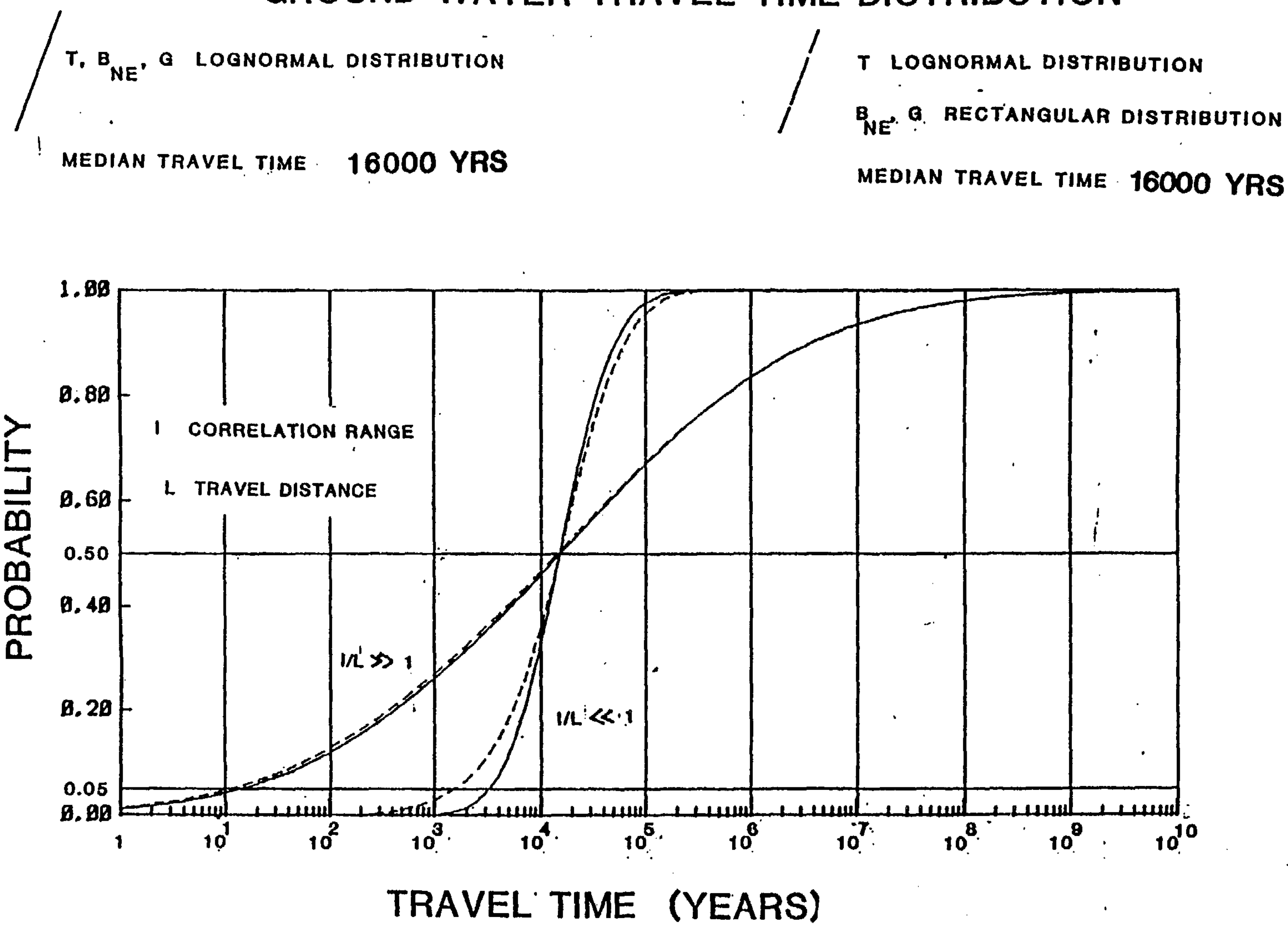
Distribution of Groundwater Travel Times from Models with Different Domain Widths.

4

GROUND WATER TRAVEL TIME DISTRIBUTION



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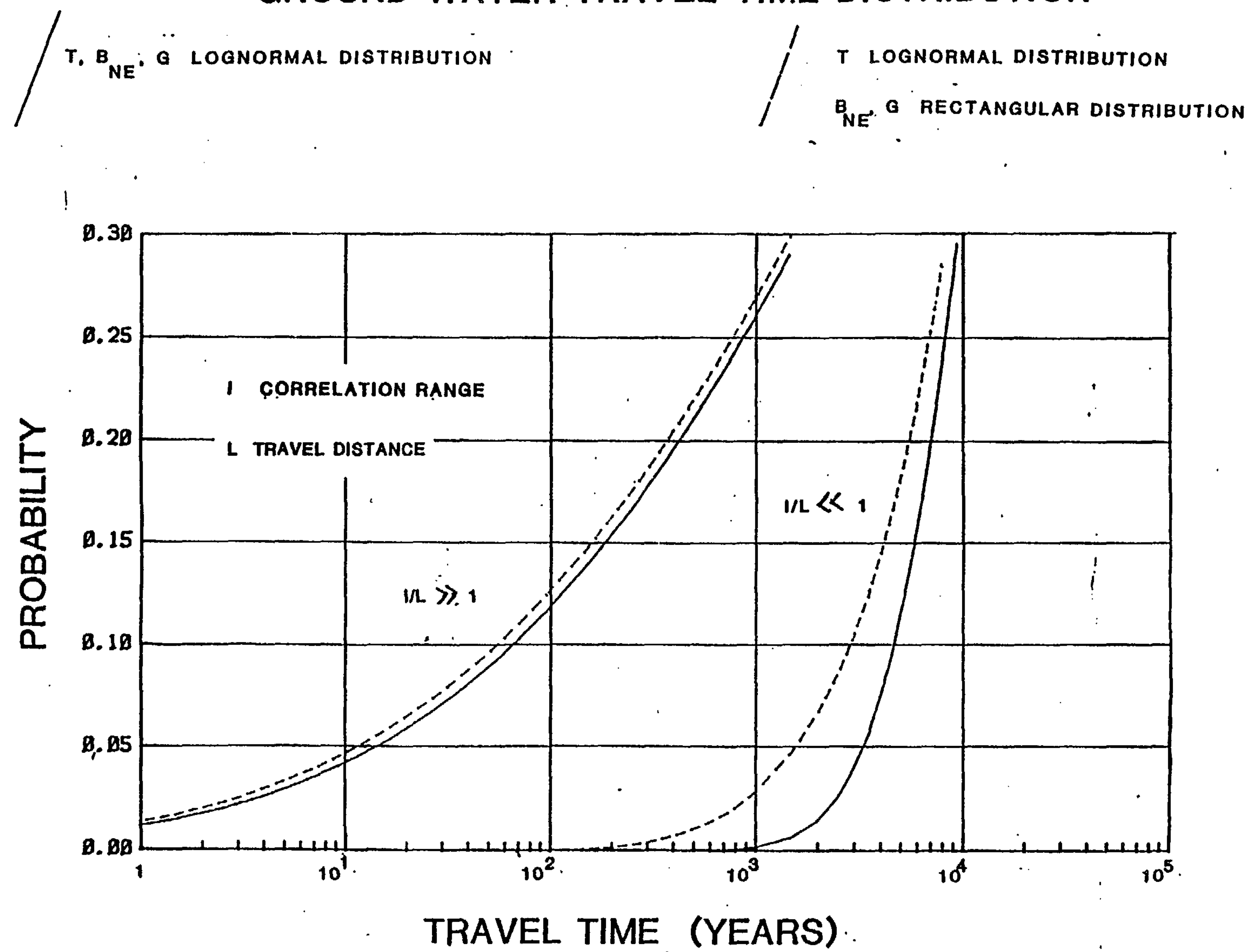
5

GROUND WATER TRAVEL TIME DISTRIBUTION



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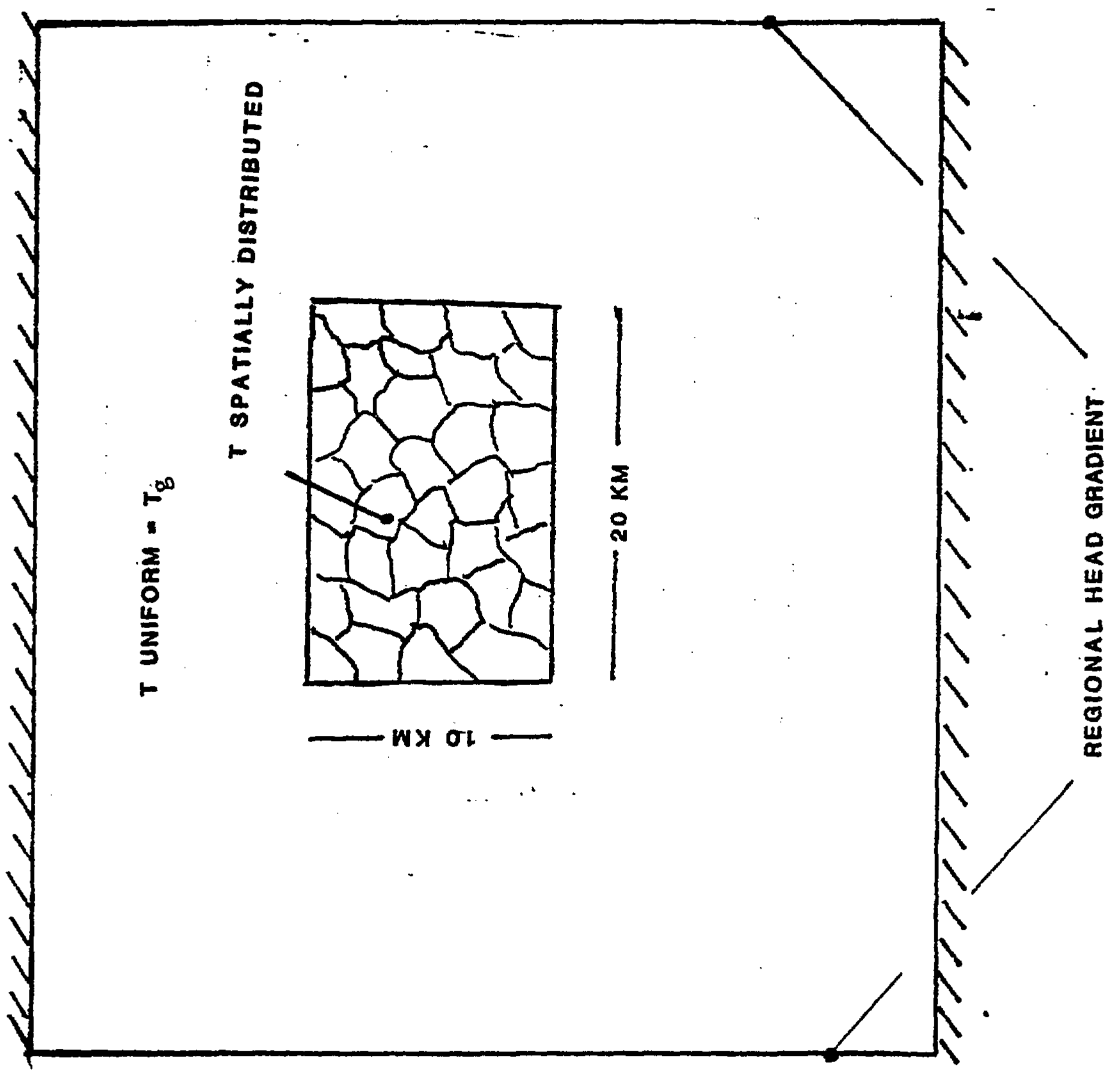

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IMPROVED SIMULATION DOMAIN

7

ESTABLISHED BY THE
TREATY OF JUNE 9, 1855
CENTENNIAL JUNE 9, 1955

CONFEDERATED TRIBES AND BANDS

Yakima Indian Nation

POST OFFICE BOX 151
TOPPENISH, WASHINGTON 98948

GENERAL COUNCIL
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August 4, 1986

Mr. O.L. Olson, Project Manager
Basalt Waste Isolation Project Office
Department of Energy
Richland Operations Office
P.O. Box 550
Richland, WA 99352

Dear Mr. Olson:

In regard to the review of the BWIP hydrogeology works, our technical consultants have submitted to our office the enclosed report on DOE Analysis of Groundwater Travel Time.

Because the groundwater travel time is an important indicator of the geologic suitability of the Hanford Site, I hope you shall consider these comments and let us know of your response to our concerns.

If you have any questions, please do not hesitate to contact me.

Sincerely,

YAKIMA INDIAN NATION

Russell Jim, Manager
Nuclear Waste Program

Enclosures

RJ/skC

EVALUATION OF HYDRAULIC HEAD DATA OF SELECTED HYDROGEOLOGIC UNITS AT THE HANFORD SITE, WASHINGTON

BY

A.M. Djerrari
V.V. Nguyen
P.K. Kitanidis
EWA, Inc.

Submitted to:

YAKIMA NATION

Date:

February 6, 1987

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To : Yakima File Task VI. b
From : A. M. Djerrari, V. V. Nguyen and P. K. Kitanidis/EWA, Inc.
Subject: Evaluation of Hydraulic Head Data of Selected Hydrogeologic Units at the Hanford Site, Washington.
Date : February 6, 1987.

EXECUTIVE SUMMARY

Under the Nuclear Waste Policy Act of 1982, the U.S. Department of Energy (DOE) has been charged with identifying the site at which the first nuclear waste repository will be constructed. The Hanford Site, located in Washington, is one of the three sites (the other two being Yucca Mountain, NV and Deaf Smith County, TX) recently recommended by DOE and nominated by the President of the United States for site characterization. The ultimate goal of the site characterization is to determine the suitability of each site for deep geologic nuclear waste disposal. The important criteria in determining whether the site is suitable for the construction of a nuclear waste repository include: (1) groundwater travel time between the disturbed zone and the accessible environment; and (2) release rate of waste radionuclides to the accessible environment.

To assess and define the repository performance for licensing purposes, the DOE will make intensive use of computer modelling of the groundwater system. This requires that the groundwater flow patterns and directions in the vicinity of the proposed repository location be delineated from the hydrologic data collected at the Hanford Site.

The present study evaluates available water head elevation data for their sufficiency to provide reliable groundwater flow directions. Geostatistical analyses were performed for two geologic formations and one hydrogeologic unit which may be of importance in the transport of radionuclides between the disturbed zone and the accessible environment: the Grande Ronde Formation, the Wanapum Formation and the Mabton Interbed. The geostatistical technique of kriging was used to provide interpolated values of hydaulic head elevations, as well as the uncertainty associated with each interpolated value. Interpolated hydraulic head elevations are used to construct contour maps from which groundwater flow directions are inferred.

Preliminary results showed that, in the Wanapum Formation, radionuclides can be transported northwesterly from the Reference Repository Location (RRL) toward the Columbia River, between the Umtanum-Gable Mountain anticline. In the Grande Ronde Formation, the water head elevation map did not support the DOE conceptualization of an overall southeasterly groundwater flow toward the Columbia River. More monitoring wells are needed, however, to ascertain this result.

Due to the great level of uncertainty associated with the interpolated water head elevations, groundwater directions were not interpretated in the Mabton Interbed. The failure to obtain satisfactory results suggests that the hydrogeology within this unit is too complex to be described using the existing sparse data, raising concerns about the selection of the Hanford Site as a nuclear waste repository.

High levels of uncertainty on the estimated head elevations were also observed for the Grande Ronde and Wanapum Formations. Additional monitoring wells, screened in these formations, are needed south of the RRL. East of the RRL, the Cold Creek "barrier" should also be carefully addressed by DOE. The existing data analysed could not account for such an anomaly.

A. INTRODUCTION

Under the Nuclear Waste Policy Act of 1982, the DOE has been charged with identifying the site at which the first nuclear waste repository will be constructed. The Hanford Site, located in Washington, is one of the three sites (the other two being Yucca Mountain, NV and Deaf Smith County, TX) recently recommended by the DOE and nominated by the President of the United States for site characterization. The ultimate goal of the site characterization program is to acquire site information for each of the three sites nominated to support a licensing application and the accompanying environmental impact statement.

A large scale hydraulic testing is planned as part of the site characterization program. However, prior to the hydraulic testing, the DOE must demonstrate that the existing data are sufficient to reliably predict the hydraulic baseline. The baseline in hydrologic monitoring programs, refers to the data that describe a hydrologic system prior to being disturbed or impacted. Use of the term baseline commonly assumes that (1) the baseline data should account for both spatial and temporal variability, (2) data should be adequate for use as a basis for comparison or interpretation, and (3) data should be sufficient and accurate enough for stated purposes (Sorooshian et al., 1984).

Hydraulic baseline predictions will be made using models fitted to observations obtained prior to hydraulic testing. The predicted hydraulic baseline heads along with the actual heads observed during testing will be used in the analysis to determine aquifer characteristics. These characteristics, in turn, will be used in assessing and defining the repository performance for licensing purposes. Computer modelling of the aquifer system will be intensively used in performance assessment. Interpretation of the groundwater flow system is used in developing an overall conceptualization of flow patterns and directions across the Cold Creek Syncline. This conceptualization is subsequently used to construct the models. Besides defining proper aquifer characteristics, (e.g., hydraulic conductivities, effective porosity), groundwater flow direction and adequate boundary conditions (e.g., hydraulic head gradient) must be derived from the spatial distribution of piezometric heads.

A preliminary analysis has been conducted to study the spatial distribution of piezometric data in basalt formations. The selected formations are expected to be of significance in determining the flow of groundwater and subsequent transport of radionuclides between the disturbed zone and the accessible environment. Because of the spatially discrete nature of data, the minimum variance unbiased linear estimation technique (or kriging) was used to identify the spatial distribution of water head elevations, as well as the degree of confidence of the estimated head elevations. The overall stochastic interpolation procedure is briefly outlined in Section B. Water head elevations were estimated for two geologic formations and one hydrogeologic unit of the Columbia River Basalt at the Hanford Site. The interpolation results are discussed in Section C.

B. PREDICTION OF HYDRAULIC HEAD BY LINEAR ESTIMATION

I. Linear Estimation Theory

Hydraulic heads in a defined region are estimated using minimum variance unbiased linear estimation theory or kriging. Kriging is a method for optimizing the estimation of a property which is distributed in space and sampled at a number of locations. Let $\underline{x}_1$, $\underline{x}_2, \ldots, \underline{x}_n$ be the locations of the measurements and z_i the value measured at the location $\underline{x}_i$. The property z is called a regionalized variable. The problem of linear estimation lies in determining an estimate $\hat{z}_0$ of the value z_0 for any location $\underline{x}_0$. By continually modifying the position of the point $\underline{x}_0$, it is thus possible to estimate the whole field of the property z.

In the general case of linear estimation with variable drift (Matheron, 1971), the regionalized variable is given by the linear model

$$z(\underline{x}) = \underline{g}^T.\underline{b} + \mathcal{E}(\underline{x}) \tag{1}$$

where $\underline{g}$ is a known vector of the spatial coordinates and $\underline{b}$ is a vector of parameters. In the case of a stationary field, $\underline{g}$ reduces to the scalar 1 and b to the mean m. In the case of a linear drift (e.g., $m(\underline{x})$ is a linear function of the vector $\underline{x}$), $\underline{g}$ is given by the vector

$$\underline{g} = \begin{bmatrix} 1 \\ x_1 \\ x_2 \end{bmatrix} \tag{2}$$

where x_1 and x_2 are the two cartesian coordinates of location $\underline{x}$.
The estimate $\hat{z}_0$ of the value z_0 at location $\underline{x}_0$ is defined as a linear combination of the measurements

$$\hat{z}_0 = \sum_{i=1}^{n} \lambda_i . z_i \tag{3}$$

The coefficients $\lambda_1, \lambda_2, \ldots, \lambda_n$ are selected so that the estimate is unbiased for any value of the unknown coefficients $\underline{b}$, i.e.,

$$E[\hat{z}_0] = \sum_{i=1}^{n} \lambda_i . \underline{g}_i{}^T . \underline{b} = \underline{g}_0{}^T . \underline{b} \tag{4}$$

and the variance of estimation

$$E[(\hat{z}_0 - z_0)]^2] \tag{5}$$

is minimum. The unbiasedness condition (4) may be rewritten

$$g_0 = \sum_{i=1}^{n} \lambda_i . g_i \qquad (6)$$

In the case of a linear drift, the universality condition (6) may be rewritten in terms of three scalar equations

$$\sum_{i=1}^{n} \lambda_i = 1 \qquad (7.a)$$

$$\sum_{i=1}^{n} \lambda_i . x_{i1} = x_{01} \qquad (7.b)$$

$$\sum_{i=1}^{n} \lambda_i . x_{i2} = x_{02} \qquad (7.c)$$

where x_{i1} and x_{i2} are the cartesian coordinates of location x_i.

If we assume that the covariance function of $z(\underline{x})$ is $R(\underline{x}_1, \underline{x}_2)$, the coefficients $\lambda_1, \lambda_2, \ldots, \lambda_n$ are estimated by solving the following minimization problem

$$\min \{ \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_i . \lambda_j . R(\underline{x}_i, \underline{x}_j) - 2 \sum_{i=1}^{n} \lambda_i . R(\underline{x}_i, \underline{x}_0) + R(0) \} \qquad (8)$$

subject to linear constraints given by the set of equations (7).

The coefficients are selected by solving the following system of n+3 equations with n+3 unknowns, $\lambda_1, \lambda_2, \ldots, \lambda_n, \nu_1, \nu_2, \nu_3$,

$$\sum_{j=1}^{n} {}_j . R(\underline{x}_i, \underline{x}_j) - \nu_1 - \nu_2 \underline{x}_{i1} - \nu_3 x_{i2} = R(\underline{x}_j, \underline{x}_0), \quad i=1,\ldots,n \qquad (9.a)$$

$$\sum_{i=1}^{n} \lambda_i = 1 \qquad (9.b)$$

$$\sum_{i=1}^{n} \lambda_i . x_{i1} = x_{01} \qquad (9.c)$$

$$\sum_{i=1}^{n} \lambda_i . x_{i2} = x_{02} \qquad (9.d)$$

In the case of a stationary field, the terms in ν_2 and ν_3 in the n equations (9.a) drop and the kriging system reduces to the simplified set of equations (9.a) along with equation (9.b).

The variance of the error of estimation can be computed from equation (8). If one assumes that the error of estimation is normally distributed, the 95% confidence interval is $z_0 \pm 2\sigma$; σ being the standard deviation, i.e., the square root of the variance.

The linear estimation problem is therefore entirely solved once the first two moments of the stochastic field $z(\underline{x})$ are identified, e.g., a functional form for the mean and the covariance function $R(\underline{x}_1,\underline{x}_2)$ chosen.

II. Choice of a Functional Form for the Mean and the Covariance Function

A functional form of the mean and the covariance function must be selected and their parameters statistically estimated from available data. Among the possible functional models for spatially distributed fields, the class of intrinsic functions of order 0, 1 and 2 with polynomial generalized covariance functions was selected. Delfiner (1976) found that almost all sets of data that appear in practice can be satisfactorily (for purposes of interpolation) described as intrinsic functions of order 0, 1 and 2 with polynomial generalized covariance functions given by

$$R(d) = c.\delta(d) + a_1.d \qquad (10.a)$$

$$R(d) = c.\delta(d) + a_1.d + a_3.d^3 \qquad (10.b)$$

$$R(d) = c.\delta(d) + a_1.d + a_3.d^3 + a_5.d^5 \qquad (10.c)$$

respectively, where $\delta(d)$ is Dirac's delta function, d is the separation distance between measurement locations, and c, a_1, a_3, a_5 are the unknown parameters of the polynomial generalized covariance function. $\delta(d)$ is 1 when d=0 and 0 in all other cases. Due to the restricted number of available data points, only intrinsic functions of order 0 and 1 were considered in this study.

III. Statistical Estimation of the Parameters

Parameter estimates are obtained by an iterative regression approach described by Kafritsas and Bras (1981). A brief review of this estimation method is given by Kitanidis (1983). In this approach, authorized linear combinations (or generalized increments) of the measurements are formed from the original data z_i,

$$z_m = \sum_{i=1}^{n} \lambda_{mi} \cdot z_i \tag{11}$$

The variance of the authorized combination z_m is estimated from the generalized covariance function R,

$$E[\, z_m^2 \,/\, \underline{\theta}] = \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_{mi} \cdot \lambda_{mj} \cdot R(\, d_{ij} \,/\, \underline{\theta}) \tag{12}$$

where $\underline{\theta}$ is the vector of parameters (e.g., c, a_1, a_3), and d_{ij}, the separation distance between the locations of measurement z_i and z_j. The parameters are estimated by minimizing the sum of squares of the differences of measured authorized combinations,

$$z_m^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_{mi} \cdot \lambda_{mj} \cdot z_i \cdot z_j \tag{13}$$

and their expected values $E[\, z_m^2 \,/\underline{\theta}]$ as defined by equation (12). That is, the criterion of performance is:

$$\min \{ \sum_{m=1}^{n} [z_m^2 - E[z_m^2 / \underline{\theta}] \} \quad (14)$$

In the iterative regression approach, first generalized increments are created using a generalized covariance function R(d) = - d. Coefficients are calculated by minimizing the expression (14) using these generalized increments. These coefficients are then used to create new generalized increments, and the procedure is repeated until the coefficients converge.

IV. Selection of the Best Model

The parameter estimation procedure is applied to all possible models described by equations (10.a) and (10.b). There are ten possible models which are described by

$$\begin{aligned} R(d) &= c.\ \delta(d) \\ R(d) &= a_1.d \qquad (15) \\ R(d) &= c.\ \delta(d) + a_1.d \end{aligned}$$

for the intrinsic field of order 0, and by

$$\begin{aligned} R(d) &= c.\ \delta(d) \\ R(d) &= a_1.d \\ R(d) &= a_3.d^3 \\ R(d) &= c.\ \delta(d) + a_1.d \qquad (16) \\ R(d) &= c.\ \delta(d) + a_3.d^3 \\ R(d) &= a_1.d + a_3.d^3 \\ R(d) &= c.\ \delta(d) + a_1.d + a_3.d^3 \end{aligned}$$

for the intrinsic field of order 1. The parameters for each of the ten models are estimated using the procedure outlined previously. The models that are proper (i.e., conditionally positive definite) generalized covariance functions are compared to select the best one. The best model is obtained through a ranking procedure (Kafritsas and Bras, 1981): the models are used to estimate values of z at points where z values are available; they are then ranked according to their error of estimation at each data point (1 for the best, 2 for the second best, etc); the ranks are averaged over the total number of data points; the best model is the one that has the lowest average rank.

C. HEAD ELEVATION ESTIMATION FOR THREE BASALT FORMATIONS

Two geologic formations and one hydrogeologic unit of the Columbia River Basalt at the Hanford Site were selected for this study: The Wanapum Formation, the Grande Ronde Formation, and the Mabton Interbed. The selection was based on the potentiality of these formations to act as discharge zones for the groundwater system under the operating conditions of the repository. Selection of the whole geologic formation (e.g., Wanapum and Grande Ronde) instead of selected hydrogeologic units has been dictated by the insufficient number of observations available for each hydrogeologic unit within these formations. The linear estimation technique is used to estimate hydraulic heads. Structural models of the hydraulic head field are identified and subsequently used in the kriging system. Hydraulic head estimates are obtained at each node of a grid that overlays the southern part of the Hanford Site boundaries (Figure 1).

I. Description of the Data Used

Rockwell Hanford Operations is monitoring water levels at three piezometer cluster sites at the RRL and at 35 additional boreholes at the Hanford Site (Figure 1). The water-level information is being used to evaluate time variant hydraulic head behavior and to establish a head baseline for selected hydrogeologic units.

The water level data for the three piezometer cluster sites, DC-19, DC-20 and DC-22, used in this analysis were taken from a data package published by the DOE (Bryce and Yeatman, 1984). The water level data for the 35 Basalt Waste Isolation Project (BWIP) monitoring wells were provided in a data package prepared by Swanson and Wilcox (1985).

The monitoring boreholes are screened ~~in~~ several hydrogeologic units in the Columbia River Basalts. In order to have enough water level observations to apply the geostatistical approach described earlier, the boreholes that are screened in different members of the Wanapum and Grande Ronde geological formations were grouped together. Since the screens of some boreholes intersect more than one member in the same formation, classification of these boreholes in terms of the whole formation seems justified. In the Grande Ronde Formation, only boreholes screened in the upper members (i.e., Sentinel Bluffs Sequence) were considered. The classification led to three groups of boreholes which were screened in the Mabton Interbed and the Wanapum and the Grande Ronde basalts, respectively (Table 1). The water levels used in the analysis were measured from October 1, 1984 to October 5, 1984. The borehole locations and the water level measurements are presented in Tables 2 through 4.

II. Estimation of Hydraulic Heads

1. Wanapum Formation

a. Identification of a structural model

Sixteen boreholes are monitored in the Wanapum Formation (Table 1). Most of the boreholes are screened in the Priest Rapids member. During the period of interest, only thirteen water level measurements were available (Table 3). Among these 13 observations, the water levels observed at Ford and O'Brian wells were 500 feet higher than those in the rest of the boreholes. The hydraulic heads in the upper Wanapum Basalt of the Cold Creek Valley are

Table 1: Borehole Distribution

Mabton Interbed	Wanapum	Grande Ronde
DB-4	DB-1	DC-2
DB-7	DB-2	DC-4/5
DB-9	DB-12	DC-7/8
DB-13	DB-14	DC-12
DC-16	DB-15	DC-15
DC-19	DC-1	RRL-2A
DC-20	DC-16C	RRL-6B
DC-22	DC-19	RRL-14
	DC-20	DC-19
	DC-22	DC-20
	DDH-3	DC-22
	ENYEART	
	FORD	
	O'BRIAN	
	DB-11	
	McGEE	

Table 2: Water level measurement in the Mabton Interbed on the 1 through 5 October, 1984.

Borehole#	Location North	Location East	Water level (feet)
DB-4	439,903	2,267,800	418.30
DB-7	388,963	2,271,833	400.59
DB-9	467,360	2,238,509	403.88
DB-13	422,511	2,247,964	420.46
DC-16	436,353	2,211,520	420.75
DC-19	433,849	2,225,136	420.84
DC-20	452,008	2,215,170	414.04
DC-22	448,530	2,204,074	410.59

Table 3: Water level measurement in the Wanapum on the 1 through 5 October, 1984.

Borehole#	Location North	East	Water level (feet)
DB-1	406,971	2,308,893	392.8
DB-2	420,657	2,308,000	394.2
DB-12	468,067	2,200,144	397.4
DB-14	430,190	2,215,764	400.1
DB-15	452,503	2,253,430	404.7
DC-1	453,178	2,247,000	403.8
DC-16	436,377	2,211,009	401.9
DC-19	433,933	2,225,012	399.8
DC-20	451,884	2,215,288	401.4
DC-22	448.600	2,204,188	400.4
DDH-3	374,957	2,304,900	391.1
ENYEART	454,397	2,183,844	908.19*
FORD	458.009	2,183,788	912.34
O'BRIAN	457,656	2,181,139	912.05
DB-11	454471	2,194,850	----
McGEE	457,773	2,191,775	----

* observed on October 17,1984.

Table 4: Water level measurement in the Grande Ronde on the 1 through 5 October, 1984.

Borehole#	Location North	Location East	Water level * (feet)
DC-2A2	453,144	2,246,946	409.43
DC-4	454,467	2,209,995	422.69
DC-7/8	420,175	2,280,448	402.14
DC-12	415,290	2,241,612	401.39
DC-15	389,808	2,309,775	401.54
RRL-2A	444,298	2,211,184	401.83
RRL-6B	438,580	2,206,413	401.39
RRL-14	446,541	2,203,992	-
DC-19	433,933	2,225,012	400.80**
DC-20	451,884	2,215,288	402.21**
DC-22	448,600	2,204,188	401.90**

* All water level data are taken from Swanson and Wilcox (1985), except for the borehole clusters DC-19, DC-20, and DC-22 for which data were taken from Yeatman and Bryce (1984).

** These water levels are an average of the water elevations observed in the Rocky Coulee Flow Top and in the Cohassett Flow Top.

generally higher than the head elevations in the same stratigraphic horizon within the RRL east of the Cold Creek "Barrier" (Figure 2). This anomaly is interpreted by DOE as a no-flow or low-flow lateral boundary (DOE, 1986). However, this interpretation has not yet been substantiated by sufficient evidence. Since the water levels at the Ford and O'Brian wells behave differently than those at the other wells, and since such anomalies cannot be accounted for by a covariance function derived from a limited number of observations, these observations were dropped in the model identification procedure.

As shown on Figure 1, most of the boreholes screened in the Wanapum Formation are located in the vicinity of the RRL. Only DB-1, DB-2 and DDH-3 are located in the southeastern part of the Hanford Site. The effect of incorporationg these three boreholes in the analysis on the estimated hydraulic head has been investigated. Structural models have been identified in two cases: (1) using observations from all eleven boreholes, and (2) not accounting for observations at boreholes DB-1, DB-2, and DDH-3.

b. Prediction of hydraulic head using eight measurements

The identification of a model has been performed using the procedure outlined previously. Only observations from boreholes DB-12, DB-14, DB-15, DC-1, DC-16, DC-19, DC-20, and DC-22 were used. Due to the paucity of data, it was not possible to select with sufficient confidence a single polynomial generalized covariance function as best describing the spatial structure of the hydraulic heads. Two models were therefore ranked equally in the ranking procedure: an intrinsic function of order 0 with polynomial covariance function given by

$$R(d) = -0.264\ d, \qquad \text{(Model 1)}$$

and an intrinsic function of order 1 with generalized covariance function

$$R(d) = -0.241\ d. \qquad \text{(Model 2)}$$

These two models were used to estimate, using point kriging, the hydraulic heads over a domain that overlays the southern part of the Hanford Site boundaries. Kriging also provided the variance of estimation error. The maps of hydraulic head estimates and variances of estimation error for the first and second models are shown in Figures 3, 4 and 5, 6, respectively. The results from both models show an overall groundwater flow in a southwestward direction (Figures 3 and 5). These kriging results, based only on information from eight boreholes, do not support the DOE interpretation of a southeasterly regional groundwater movement. It should be noted that due to the high variance of hydraulic head estimates, the model predictions in the southeastern portion of the Hanford Site boundaries is unreliable.

At the RRL, the models indicate a groundwater flow direction to the northwest. This change in flow direction agrees with part of the DOE (1982) interpretation of the groundwater movement: "Because the existence of a hydraulic low near the Umtanum Ridge-Gable Mountain anticline, shallow groundwater from the northern portion of the RRL may flow north rather than east to southeast...".

c. Prediction of hydraulic heads using eleven measurements

The observed water levels at boreholes DB-1, DB-2, and DDH-3 have been used in conjunction with the information from the above eight boreholes. The identification procedure was applied using this set of 11 data points. The best model that described the spatial structure of hydraulic head is an intrinsic function of order 0 with generalized covariance function given by

$$R(d) = -0.201\ d. \qquad \text{(Model 3)}$$

The identified generalized covariance function was used to obtain estimates of hydraulic heads, as well as variance of estimates, in a domain overlying the southern portion of the Hanford Site boundaries. The maps of predicted heads and variance of estimation error are shown in Figures 7 and 8, respectively. The comparison between the potentiometric maps shown in Figures 3, 5, and 7 lead to some remarks: (1) All three models predict a northwestward groundwater flow in the northern portion of the RRL, and (2) the differences in groundwater flow direction occur in the eastern portion of the Hanford Site boundaries; on Figure 7, the groundwater is shown to flow southeasterly between DB-15 and DB-2.

In the eastern portion of the RRL, the groundwater flow direction is not well defined. The three models predicted a southeastern to southwestern local groundwater flow direction. The presence of a groundwater flow divide in the RRL vcinity induces a certain amount of uncertainty in directional gradient estimates. The DOE used observed water levels at DC-19, DC-20 and DC-22 to estimate the directional gradients (DOE, 1986, Sorooshian et al., 1985). Borehole clusters DC-19, DC-20, and DC-22, however, may not be adequately located to provide accurate estimates of directional gradients. DC-22 is located downgradient of the groundwater flowing north; whereas DC-19 is located downgradient of the groundwater flowing south. As a result, hydraulic gradients calculated using observations from these three monitored boreholes may be underestimated. The actual hydraulic gradients of the groundwater flowing north and south in and near the RRL are probably more important.

2. Grande Ronde Formation

a. Identification of a structural model

Eleven boreholes are screened in the Grande Ronde Formation (Table 1). Only 10 of the 11 boreholes had been monitored during the period of interest.

No data is available for borehole RRL-14. In addition, the water elevation observed at borehole DC-4 is too high compared to those observed at neighboring boreholes DC-20 and DC-22. This measurement has been dropped and only the nine remaining observed water elevations have been used in the structural model identification procedure.

b. Prediction of hydraulic heads

Again, due to the paucity of the data observations, two structural models were identified: an intrinsic field of order 0 with generalized covariance function

$$R(d) = -0.359\ d, \qquad \text{(Model 1)}$$

and an intrinsic field of order 1 that assumes a linear southwestern drift, with generalized covariance function

$$R(d) = -0.335\ d. \qquad \text{(Model 2)}$$

Using point kriging, these two covariance functions were used to estimate the water head elevation over a domain overlying the southern portion of the Hanford Site boundaries.

The maps of water heads and variance of estimation errors are shown in Figures 9 and 10 for the first model and in Figures 11 and 12 for the second model. The kriged hydraulic head estimates obtained from the two models are again very consistent in the northwestern part of the model domain. The maps of variance shows that the estimation error is the smallest in this region. This result was expected since most of the monitoring boreholes are concentrated in this region. Contrary to what was found in the Wanapum Formation, no northwesterly groundwater movement is shown to occur near the RRL. Both models indicate a southwesterly groundwater flow in the vicinity of the RRL. It should be noted, however, that in the case of the Wanapum, the head elevation was observed at DB-12 which is located on the northwestern portion of the domain, whereas in the case of the Grande Ronde Formation, no such observation is available. According to the DOE 1986, an examination of hydraulic head distribution near the Umtanum Ridge-Gable Mountain anticline and between the northern border of the RRL and the Columbia River is planned. These future observations will be very helpful in the understanding of the groundwater flow movement, north of the RRL.

The two models predicted an overall southwesterly groundwater flow movement. However, this regional groundwater direction may be accurate only in the northwestern portion. Due to the high variance of the estimation error, the heads in the northeastern and the southeastern part of the domain are predicted with ±8 to ±11 feet uncertainty for a 95% interval of confidence (Figure 10 and 12). These last values along with the low differences in hydraulic head (of approximately 1 foot) observed at boreholes DC-7/8, DC-12 and DC-15 demonstrate the limitations of predicting a groundwater flow direction based on observed hydraulic head at only a few locations.

3. Mabton Interbed

a. Identification of a structural model

Eight boreholes are screened in the Mabton Interbed hydrogeologic unit (Table 1). Most of these boreholes are located in the vicinity of the RRL. Only borehole DB-7 is located in the southeastern portion of the Hanford Site boundaries. The identification procedure described earlier has been applied to this set of data.

b. Prediction of hydraulic head

The hydraulic head field seems to be described by an intrinsic function of order 0 with polynomial generalized covariance function

$$R(d) = -3.239\ d.$$

The head elevations obtained by using this generalized covariance function are far from satisfactory. The predicted water elevation and estimation error maps are shown on Figures 13 and 14, respectively. The variances of estimation errors are much higher than those calculated for the Wanapum and Grande Ronde Formations. The 95% confidence interval is at least ± 14 feet over the whole domain. In the case of the Mabton Interbed, the potentiometric map is very uncertain; therefore, no tentative interpretation has been made. However, the difficulty in matching a model that can predict the potentiometric map with a reasonable degree of confidence may be a sign of a more complicated groundwater flow movement in the Mabton Interbed.

D. CONCLUSION

The BWIP site at Hanford, Washington, has been selected for site characterization to determine its suitability for deep geologic nuclear waste disposal. A preliminary analysis of available water level data was made for two geologic formations and one hydrogeologic unit of the Columbia River Basalt at Hanford Site: the Wanapum Formation, the Grande Ronde Formation and the Mabton Interbed.

Kriging was employed to interpolate water head elevations and estimate associated levels of confidence. From the interpolated map of water head elevations, groundwater flow directions are inferred for the Wanapum and Grande Ronde Formations. For the Mabton Interbed, no interpretation of groundwater flow direction was attempted because of the great amount of uncertainty associated with interpolated values. The DOE believes that the overall deep groundwater flow direction for the Cold Creek Syncline is southeast along the synclinal axis. The regional southeasterly groundwater flow direction in the Wanapum Formation was confirmed by the interpolated potentiometric map only when the observations at the boreholes DB-2, DB-1 and DDH-3, which are located in the southeastern portion of the Hanford Site boundaries, were used in the interpolation prodedure. In the Grande Ronde Formation, the interpolated potentiometric map showed a south to southwesterly groundwater flow movement. However, a great amount of uncertainty was associated with the water head estimates over major part of the modeled domain. Despite this level of uncertainty, it is believed that the groundwater movement is more complicated than simply a southeasterly groundwater flow along the Cold Creek Syncline axis as believed by DOE 1986.

In order to develop a reliable overall conceptualization of flow patterns and directions across the Cold Creek Syncline more monitoring boreholes are needed. New boreholes are needed not only east of the RRL along the structural trend of the Cold Creek Syncline axis but also northeast of the RRL to investigate the potential for the discharge toward the Columbia River, between the Umtanum Ridge and Gable Mountain.

Boreholes screened in the Grande Ronde Formation are also needed south of the RRL in order to develop a better understanding of the groundwater movement in this geologic formation.

Finally, the anomaly referred to by the DOE as the Cold Creek hydrologic "barrier" has not been addressed in this study. Understanding the nature of the Upper Cold Creek Syncline anomaly is important due to its potential for affecting the present and future groundwater flow regime in the RRL.

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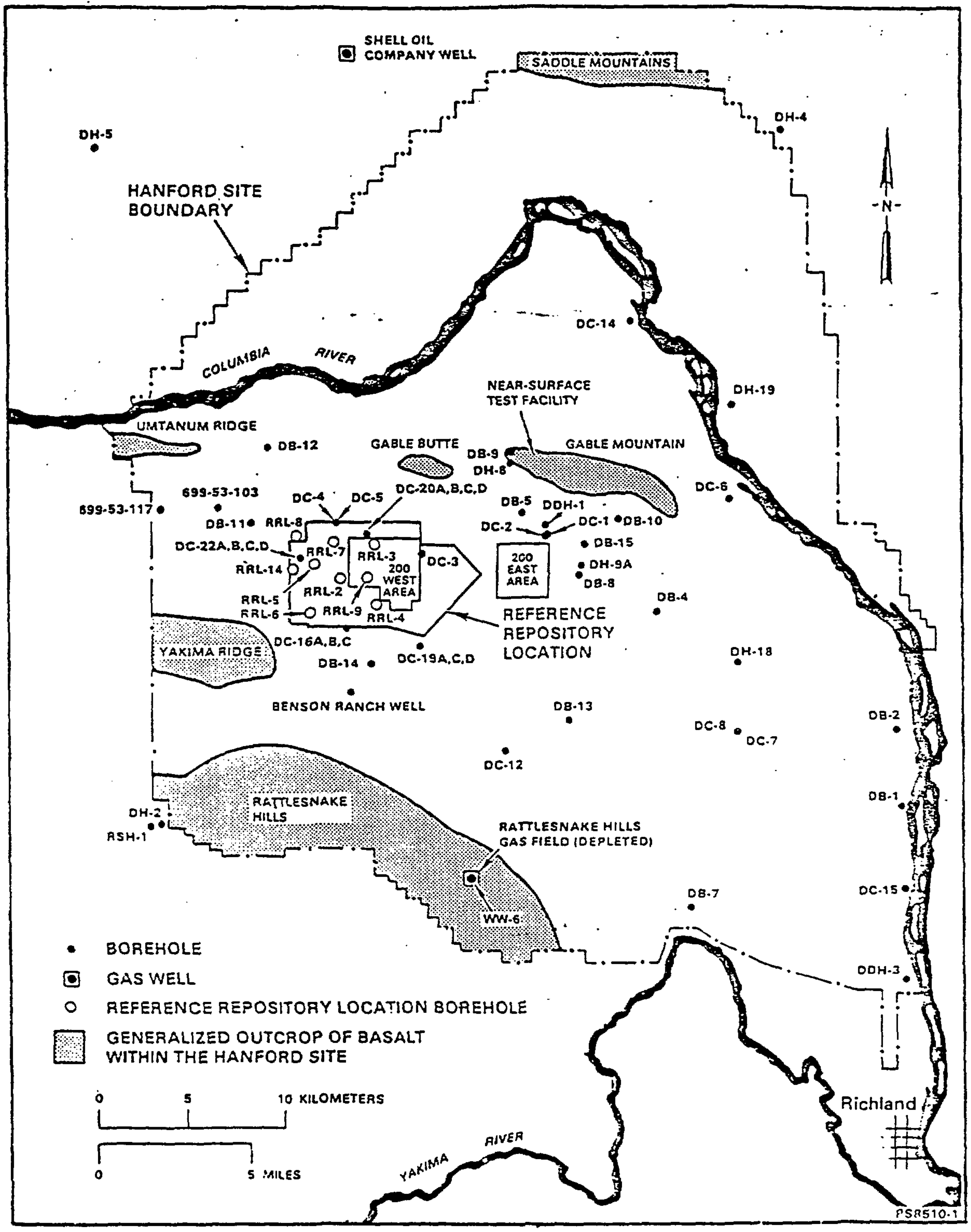

FIGURE 1: LOCATION MAP FOR SELECTED BOREHOLES

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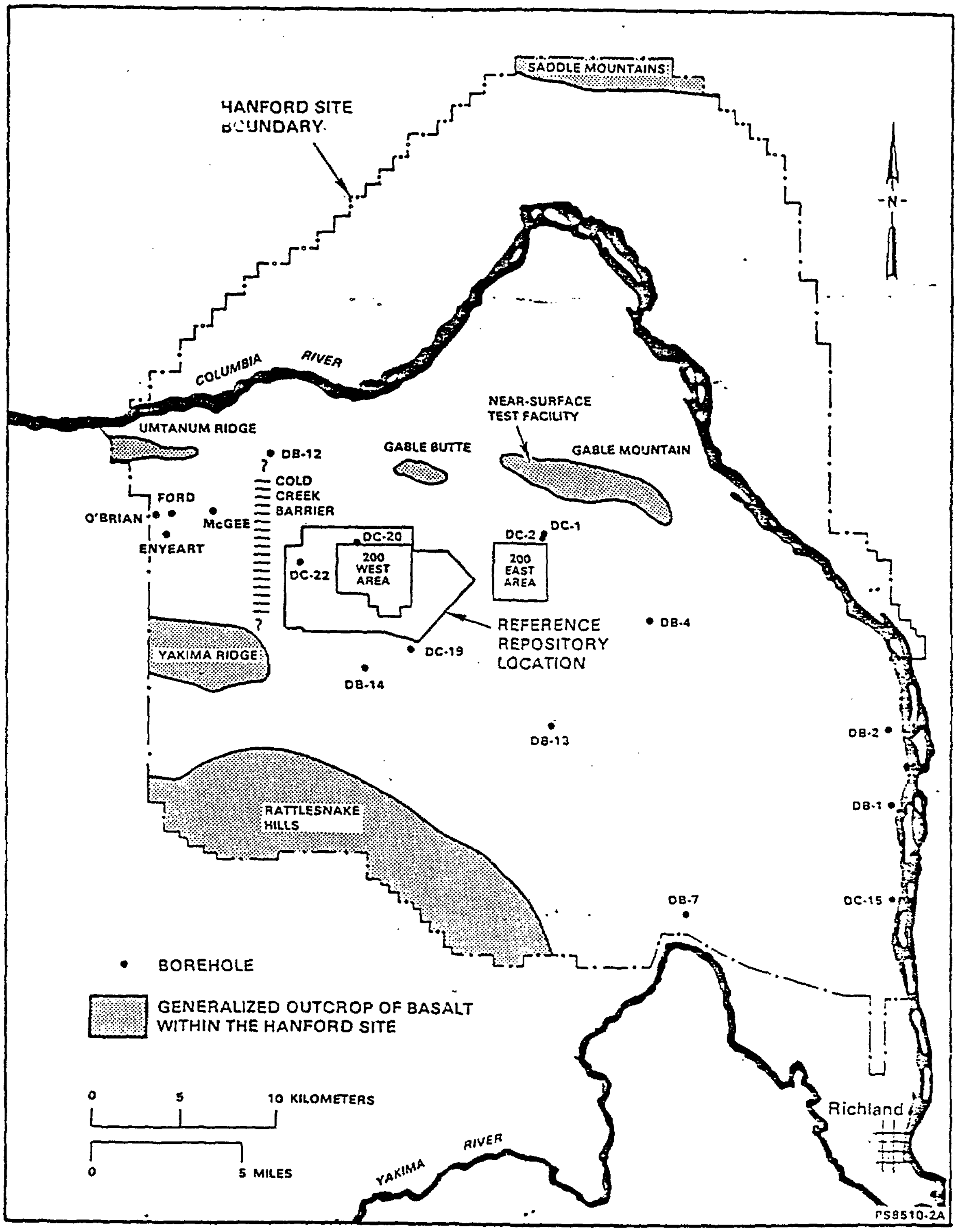

FIGURE 2: LOCATION MAP FOR SELECTED BOREHOLES

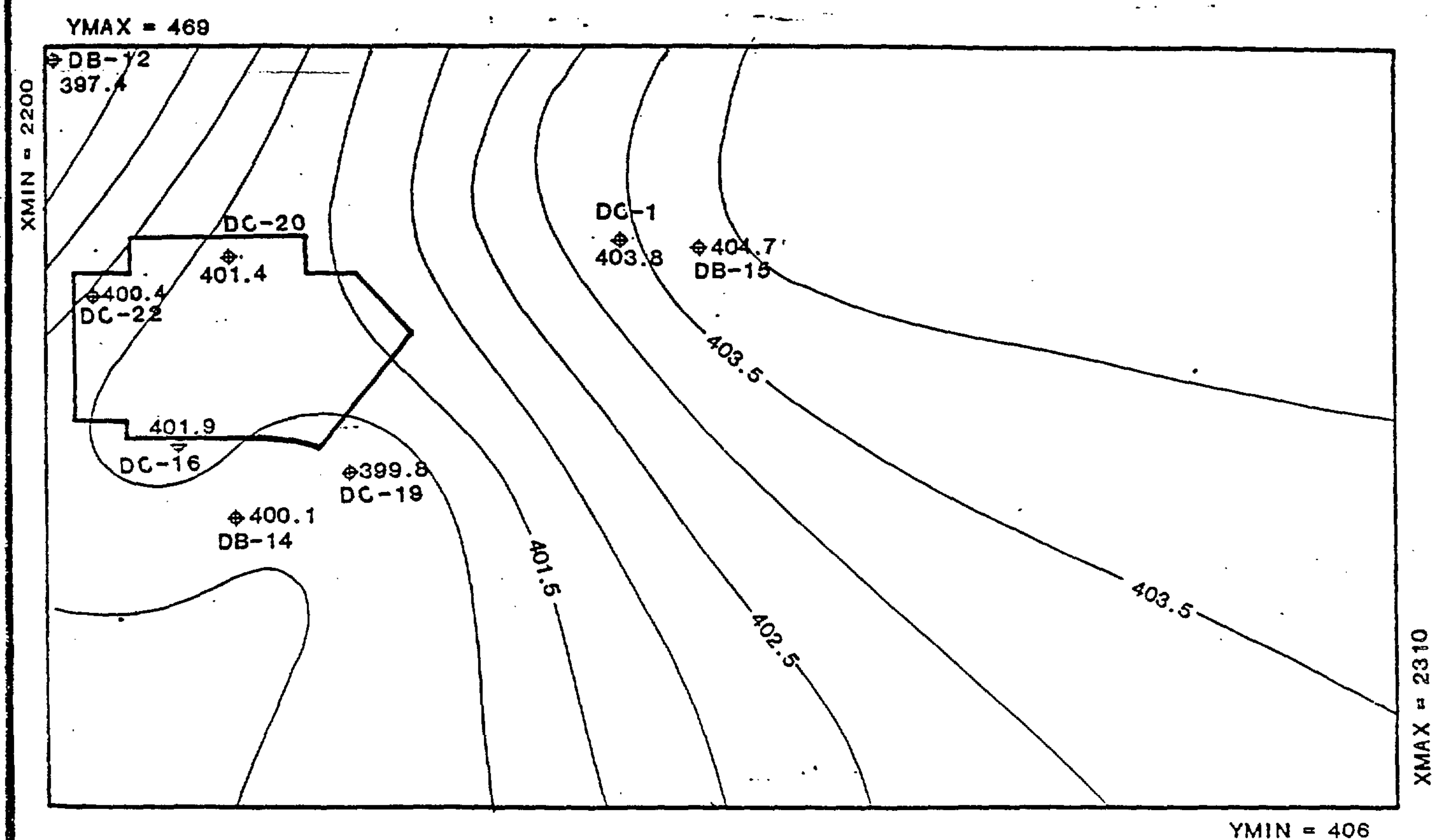

FIGURE 3: WANAPUM (MODEL 1)

MAP OF HEAD ELEVATIONS

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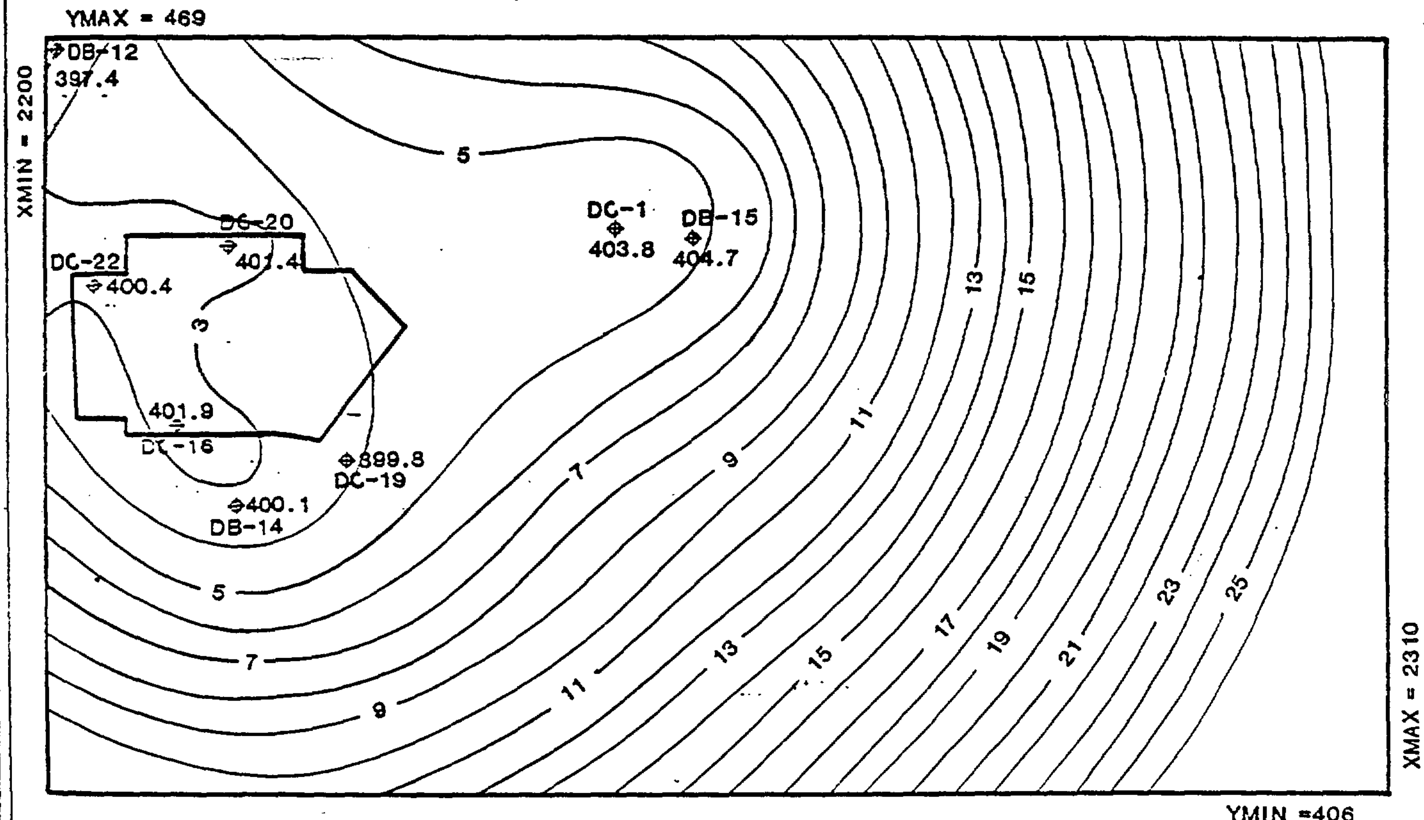

FIGURE 4: WANAPUM (MODEL 1)

VARIANCE OF ESTIMATION ERROR

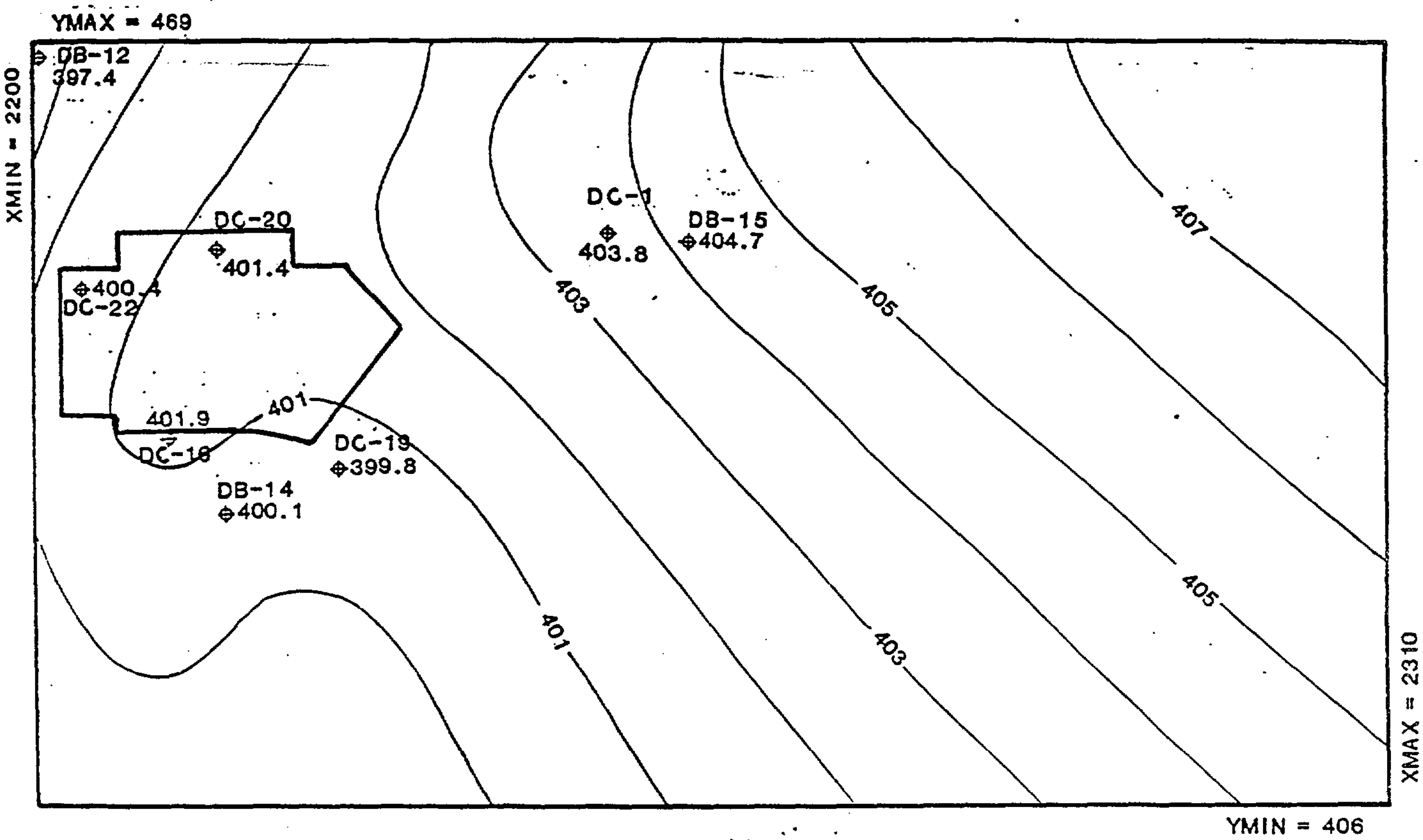

FIGURE 5: WANAPUM (MODEL 2)
MAP OF HEAD ELEVATIONS

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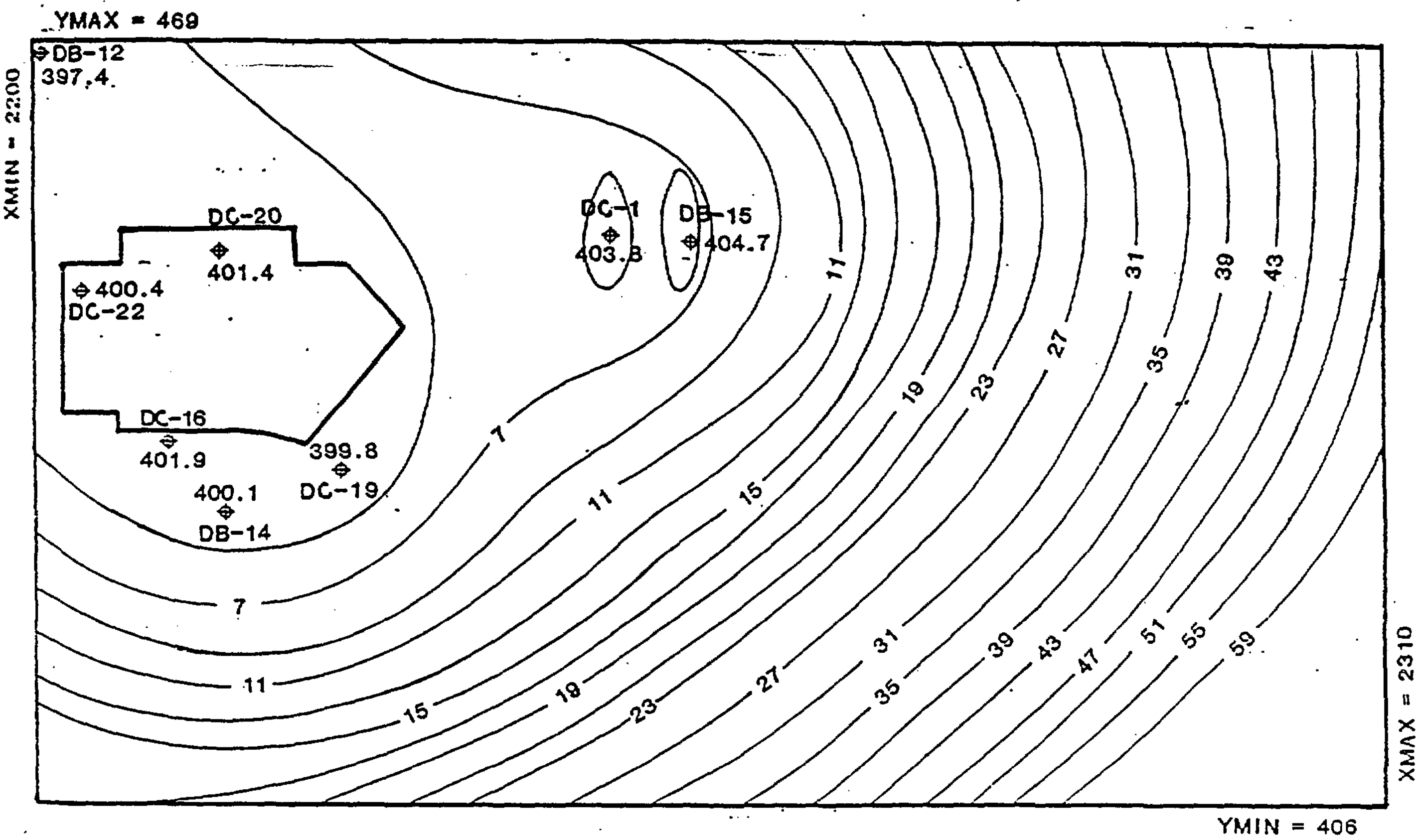

FIGURE 6: WANAPUM (MODEL 2)
VARIANCE OF ESTIMATION ERROR

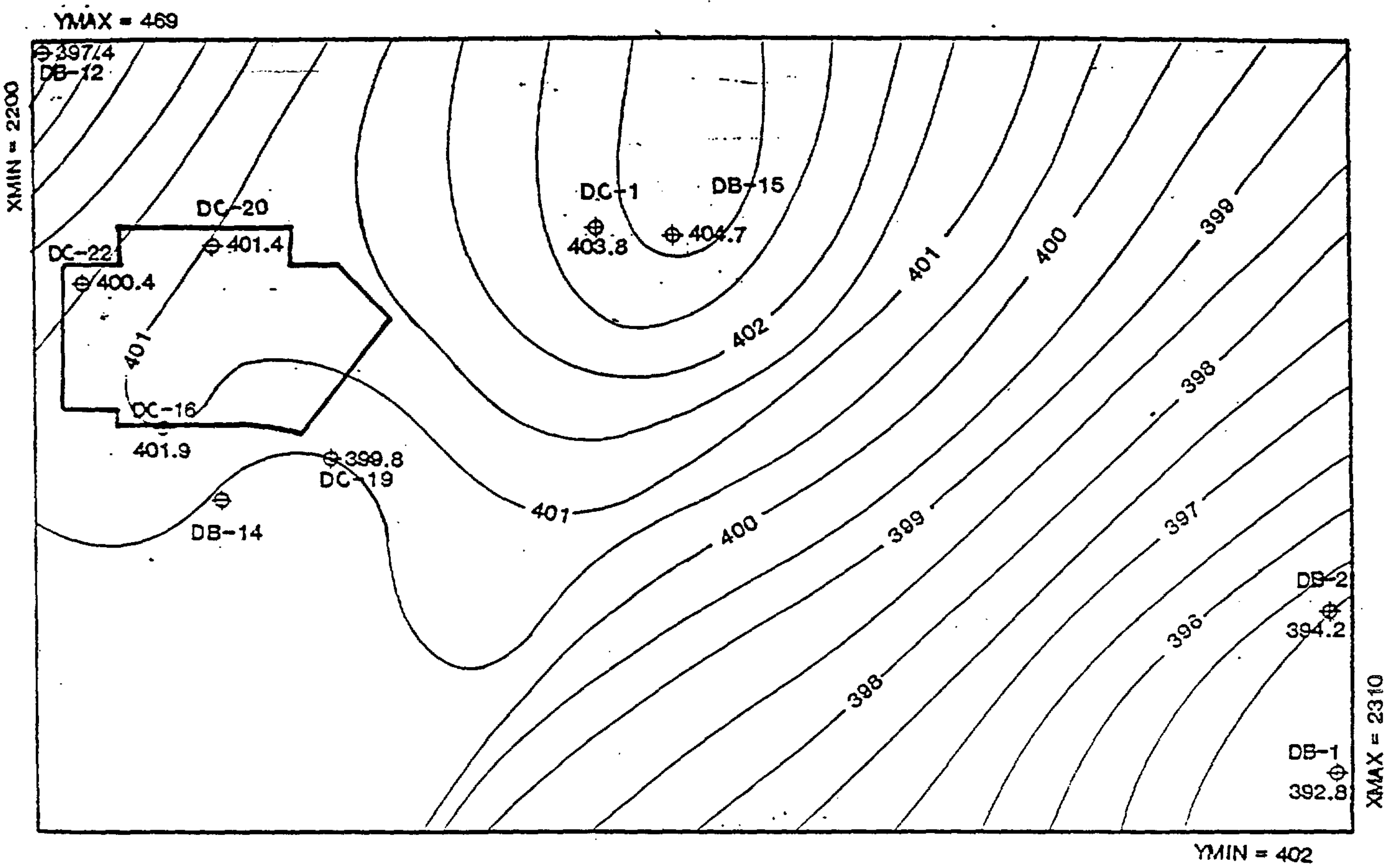

FIGURE 7: WANAPUM (MODEL 3)
MAP OF HEAD ELEVATIONS

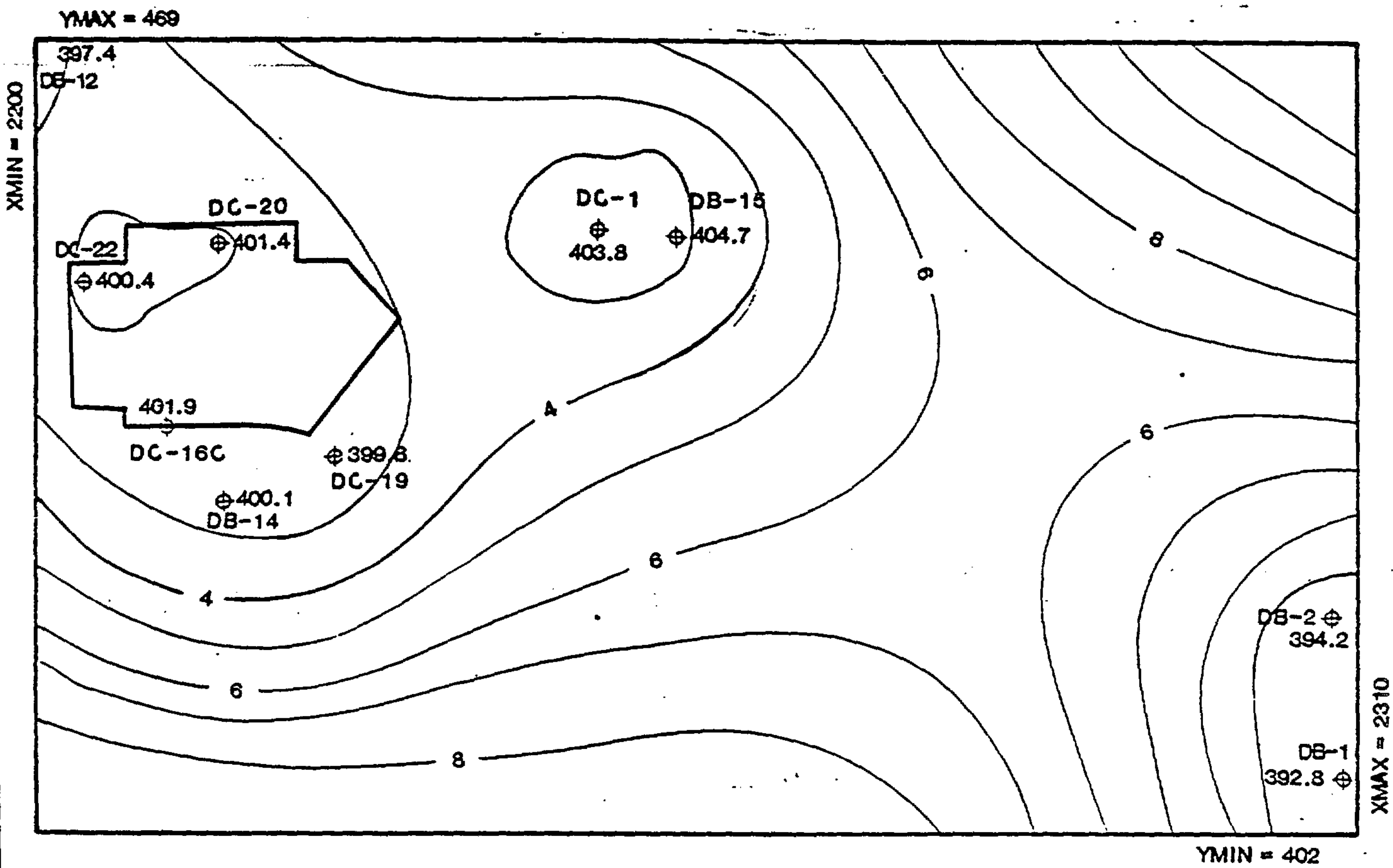

FIGURE 8: WANAPUM (MODEL 3)
VARIANCE OF ESTIMATION ERROR

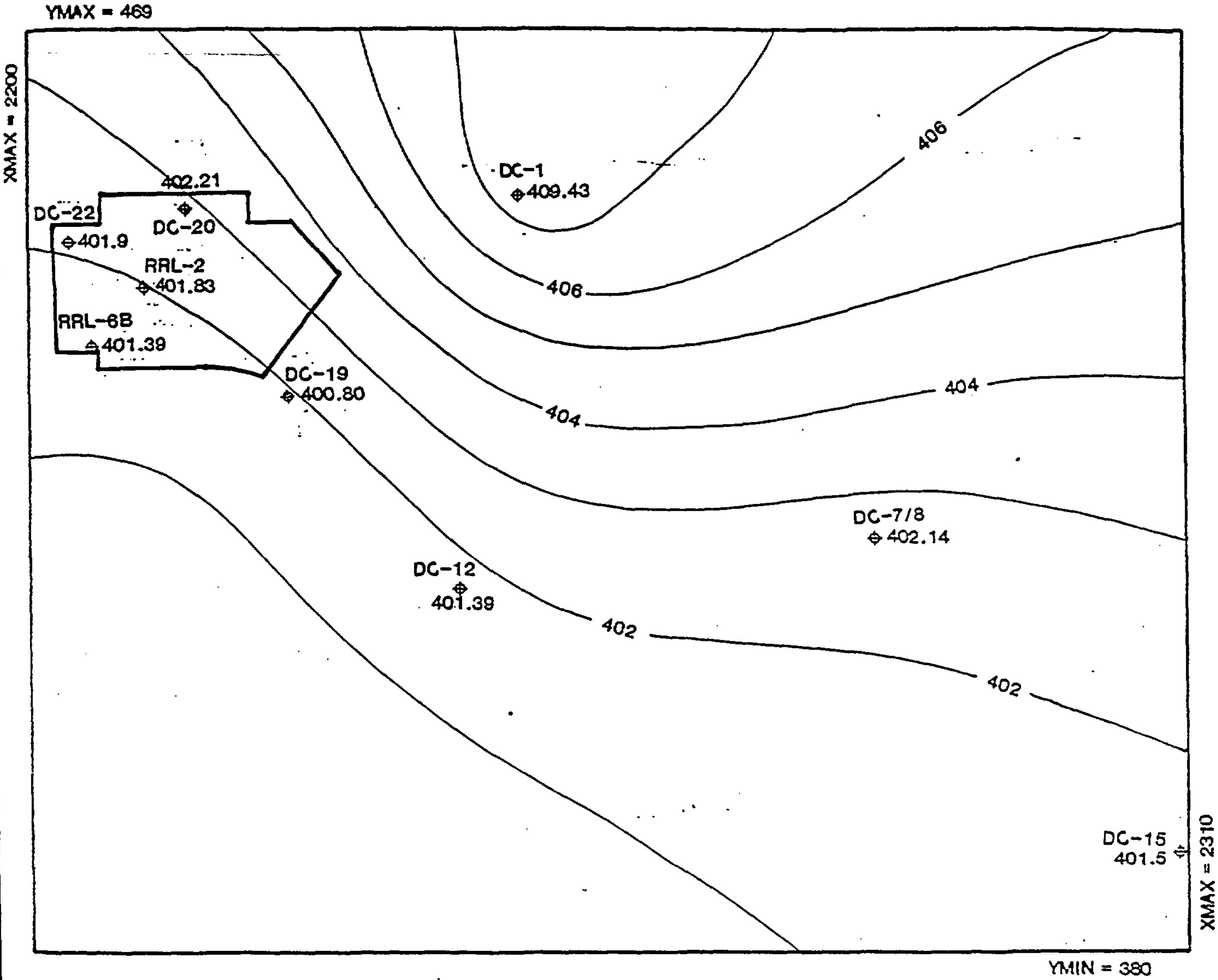

FIGURE 9: GRANDE RONDE (MODEL 1)
MAP OF HEAD ELEVATIONS

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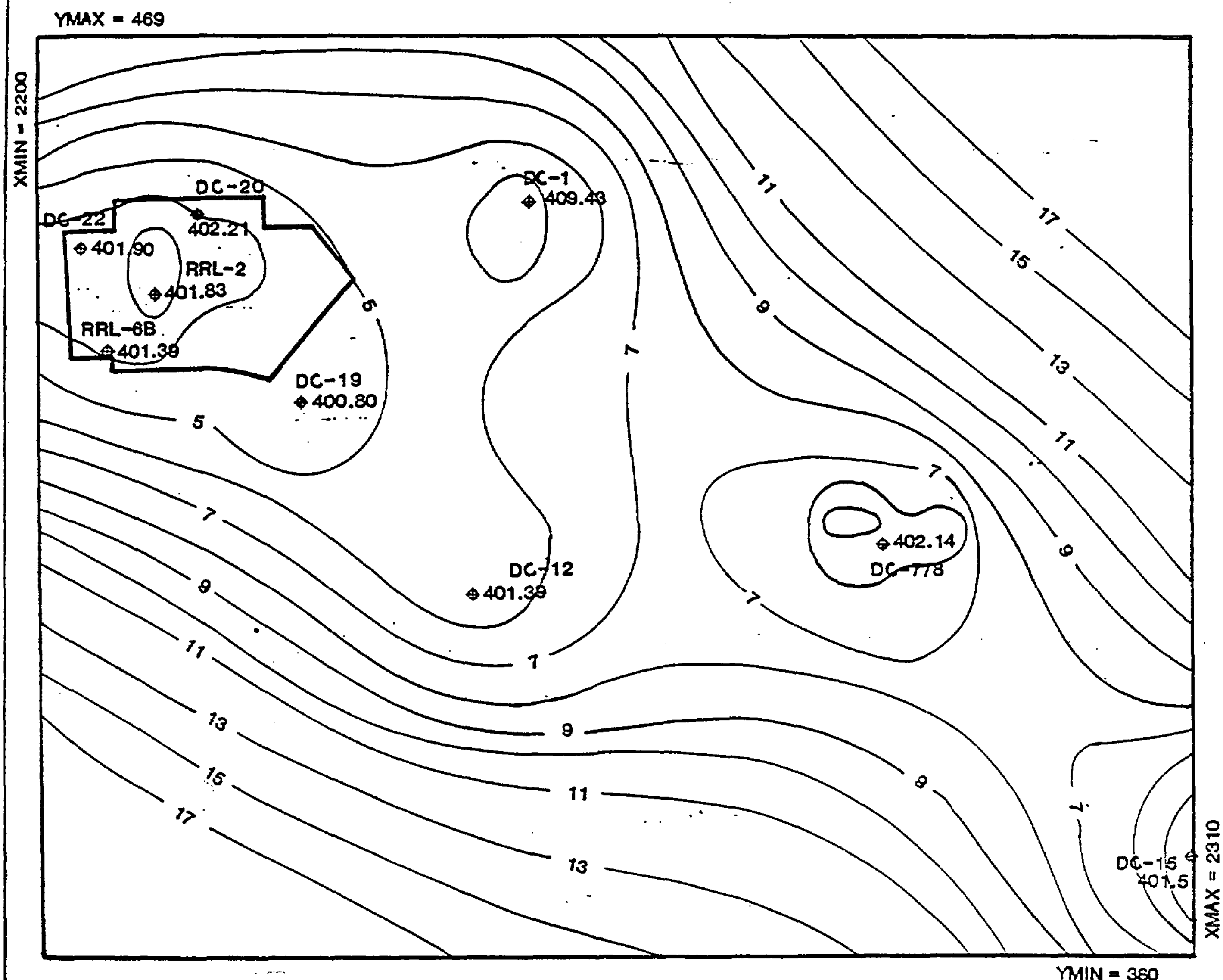

FIGURE 10: GRANDE RONDE (MODEL 1)
VARIANCE OF ESTIMATION ERROR

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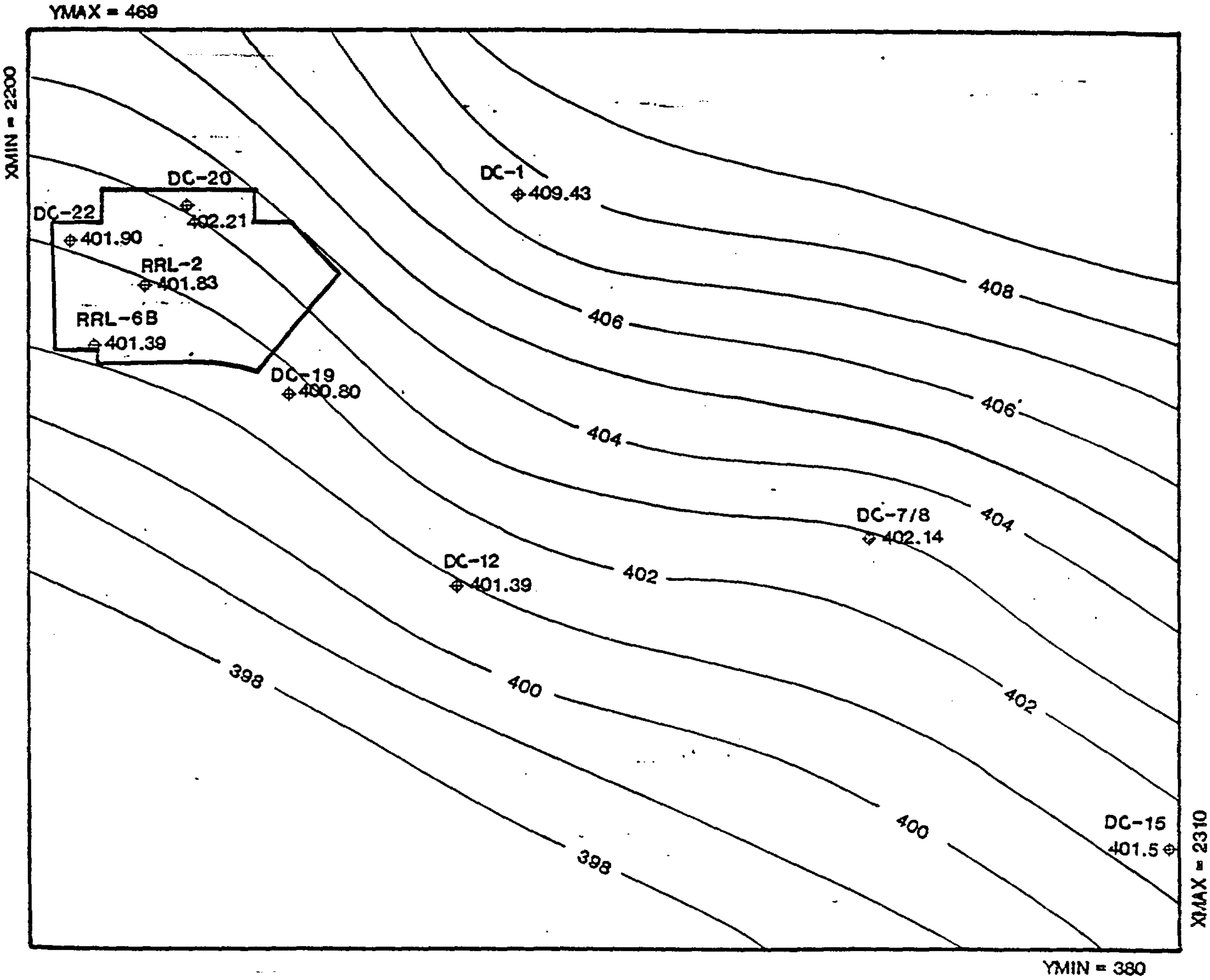

FIGURE 11: GRANDE RONDE (MODEL 2)
MAP OF HEAD ELEVATIONS

EWA

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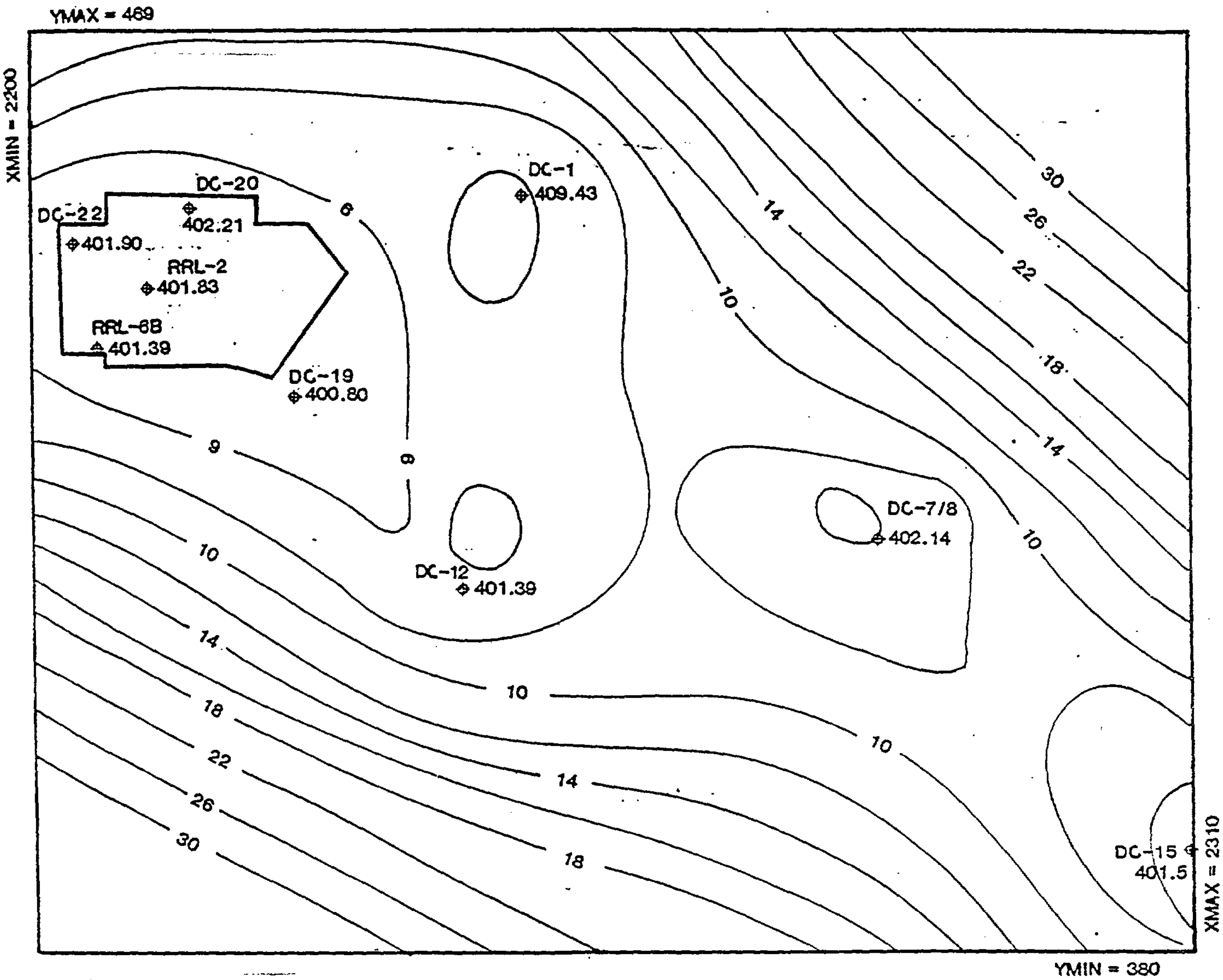

FIGURE 12: GRANDE RONDE (MODEL 2)
VARIANCE OF ESTIMATION ERROR

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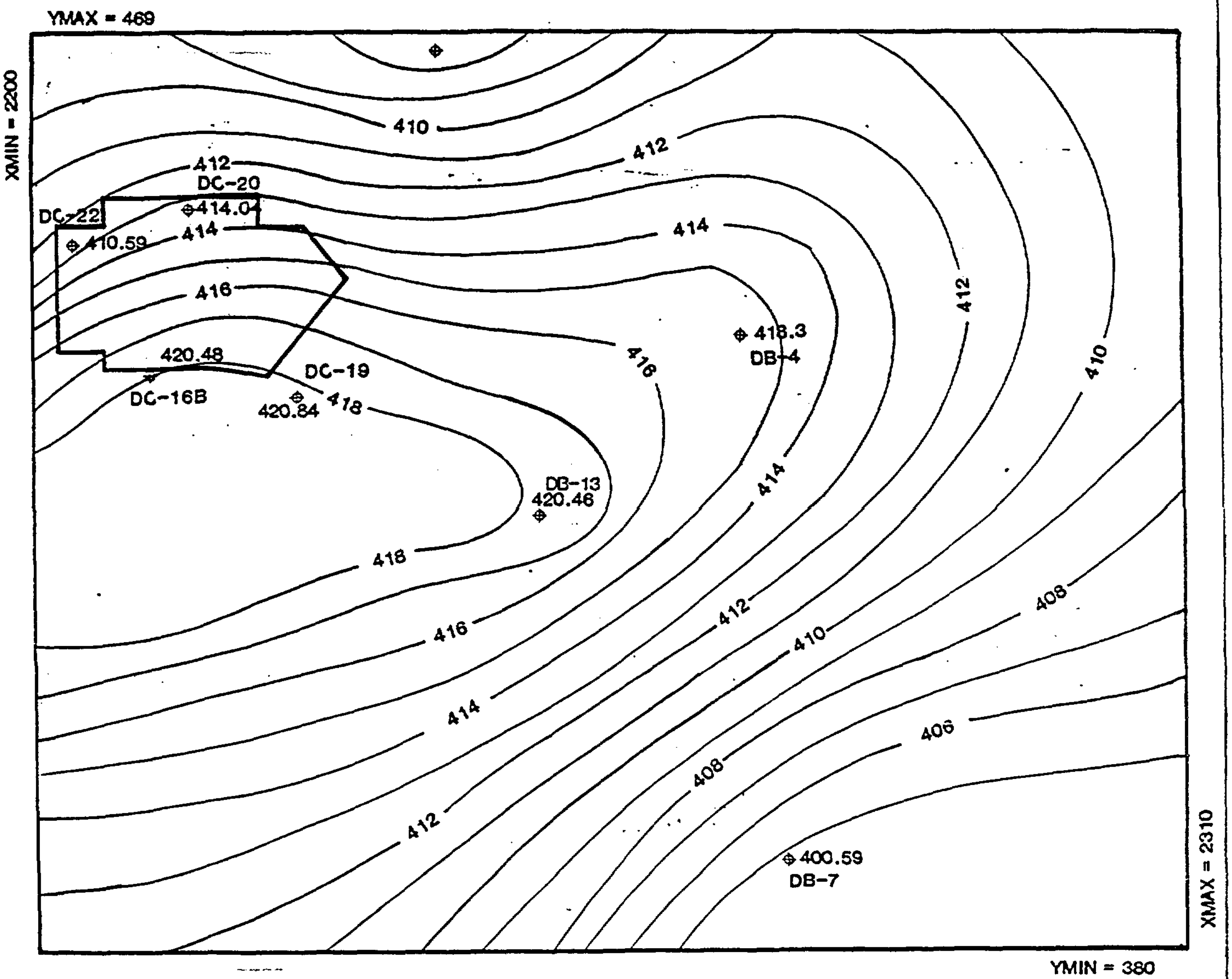

FIGURE 13: MABTON INTERBED
MAP OF HEAD ELEVATIONS ..

ENVA

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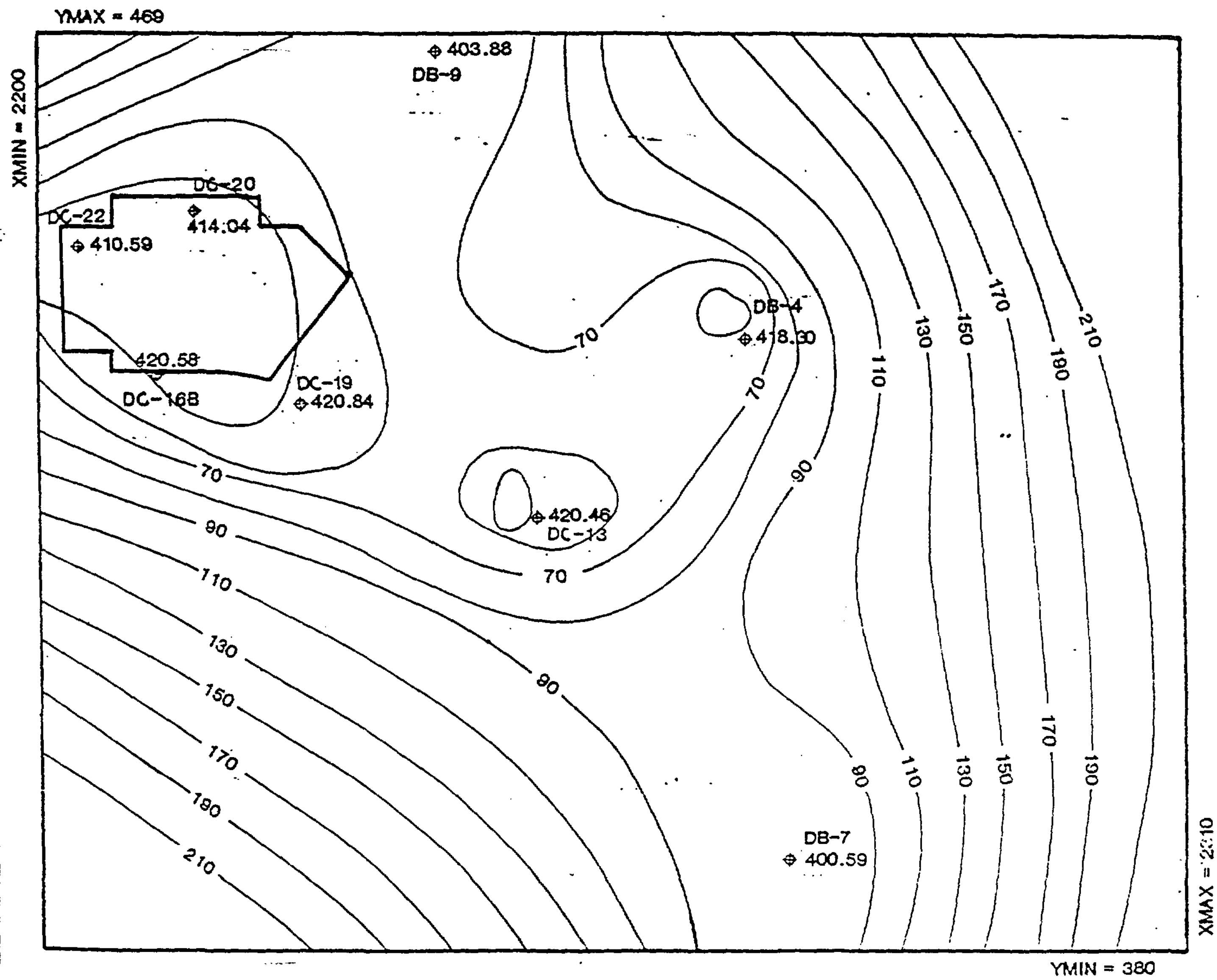

FIGURE 14: MABTON INTERBED
VARIANCE OF ESTIMATION ERROR

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