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Hydrogeology • Mineral Resources Waste Management • Geological Engineering • Mine Hydrology

November 10, 1987
Contract No. NRC-02-85-008
Fin No. D-1020
Communication No. 159

Mr. Jeff Pohle
Division of Waste Management
Mail Stop 623-SS
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: BWIP

Dear Jeff:

Our report describing the numerical modeling study of groundwater flow using hydraulic gradients measured at the BWIP site is attached. We have proceeded with this study to a point at which we believe further efforts in numerical modeling are not warranted. We believe our report explains the limitations of the data base and of the simulation techniques which are available for investigating hydraulic gradients as low as those at the BWIP site. Please call if you have any questions regarding the content of the attached report.

Sincerely,

Gerry

Gerry V. Winter

NUMERICAL MODELING INVESTIGATION OF HYDRAULIC GRADIENTS BASED ON THE BOREHOLE CLUSTER SITES DC-19, DC-20, AND DC-22 AT THE BWIP SITE

Background

This report is based on our review of the hydraulic head data available for the BWIP site as presented in our Communication No. 29, dated February 13, 1986. The hydraulic head data base which we reviewed extends over the period April of 1984 through April of 1985. In Communication No. 29 we commented on the apparent relationships of hydraulic heads in the borehole cluster sites. We examined the nature of the hydraulic gradients as derived from the hydraulic head data for these three cluster sites. We suggested that an attempt be made to conduct a modeling exercise along a vertical cross-section extending from cluster DC-20 in a direction perpendicular to the equipotential line determined from a three point analysis of the distribution of head. The NRC subsequently requested an estimate of the man-hours required to conduct such a modeling study. We submitted a proposal as Communication No. 48 (April 10, 1986). We subsequently received authorization to proceed with this modeling study on August 19, 1986. It was understood that efforts toward completing the modeling study were secondary to other higher priority items which undoubtedly would occur during the period of the study. Attempts at completing the modeling effort and this resulting report have been interrupted on several occasions by meetings and higher priority document reviews requested by the NRC. The following report describes the modeling effort and the results of that effort.

Purpose

The purpose of this investigation is to investigate the relationship between the subject hydraulic gradient and the ratio of proposed horizontal and vertical hydraulic conductivities within the basalt flow interiors at the BWIP site. Specifically, the intent of the modeling study is to examine the effect of proposed values of vertical and horizontal hydraulic conductivity on volumetric ground water flow rate under the driving force of the gradients that have been measured at the BWIP site. The values of vertical and horizontal hydraulic conductivity input into the model were derived from values that have been proposed by the U.S. Department of Energy.

Data Base

Hydraulic Heads

We selected April 30, 1985, as the effective date for the calculation of hydraulic gradients and for the date that the assumption of steady state heads in the flow tops of interest can be considered most valid. The head values used in this report are values that have been measured by surface techniques using a steel tape and chalk.

The hydraulic head data for the April 30 date have been corrected for barometric effects by Rockwell Hanford Operations. The elevations of the hydraulic head in the Priest Rapids, Sentinel Gap, Gingko, Rocky Coulee, Cohassett, and Umtanum flow tops are presented in table 1. The horizontal hydraulic gradients, derived from the solution to a three-point analysis using the hydraulic heads in the borehole clusters DC-19, DC-20, and DC-22 also are presented in table 1. The vertical hydraulic gradients between the monitored flow tops within cluster DC-20 are presented also. Hydraulic heads are not presented for borehole clusters DC-19 and DC-22 because these heads are used only for calculating the hydraulic gradient within the horizontal plane of each flow top. The DC-19 and DC-22 heads are not used in the calculation of vertical gradient. Borehole cluster DC-20 is used as the data source for the right side of the mesh that is discussed below. The vertical flow directions are indicated in table 1 based on measured hydraulic heads. It should be noted that the true direction of vertical groundwater flow between the aforementioned basalt flows is not reflected accurately by the use of hydraulic heads measured from the ground surface. The directions of flow shown by the arrows in table 1 are provided as an indication of the probable direction of groundwater flow. The values of head that are of interest for this study are those for the Priest Rapids and Sentinel Gap flow tops. The simulations conducted and reported in this study represent the Priest Rapids and the Sentinel Gap flow tops that are separated in the model by an intervening basalt flow interior.

The as-built drawing (SD-BWI-TI-226, p. 96-99) indicates that two additional unnamed basalt flows exist within the Rosa Member of the Wanapum Basalt Formation. These unnamed flows lie between the Priest Rapids Member of the Wanapum Basalt Formation and the Sentinel Gap flow of the Frenchman Springs Member of the Wanapum Basalt Formation. We obviously were unable to include the two intervening basalt flows as separate flow tops and flow interiors in our simulations. This decision was made because of the absence of data for the intervening flow tops and flow interiors.

Hydraulic Conductivities

The flow tops and interbeds of the Saddle Mountains and Wanapum Basalts exhibit reported ranges of hydraulic conductivity from 10^{-4} to 10^{-7} meters per second (10^{1} to 10^{-2} feet per day) (U.S. Department of Energy, May 1986,

p. 3-119). The geometric mean of the measured hydraulic conductivities of the flow contacts and sedimentary interbeds is 10^{-5} meters per second (10^{0} feet per day). The U.S. Department of Energy also reports values of hydraulic conductivity as large as 10^{-2} to 10^{-3} meters per second (10^{3} to 10^{2} feet per day) (U.S. Department of Energy, May 1986, p. 3-119). The Department of Energy states that "Large hydraulic conductivity values are commonly associated with the Priest Rapids Member of the upper Wanapum Basalt."

The U.S. Department of Energy (May 1986, p. 3-119) states that most values of hydraulic conductivity within the Grande Ronde Basalt Formation range between approximately 10^{-5} and 10^{-9} meters per second (10^{0} to 10^{-4} feet per day). The report states that the geometric mean is approximately 10^{-7} meters per second (10^{-2} feet per day). The Department of Energy states further that hydraulic conductivity values as large as 10^{-3} to 10^{-4} meters per second (10^{2} to 10^{1} feet per day) and as small as 10^{-10} to 10^{-11} meters per second (10^{-5} to 10^{-6} feet per day) have been reported.

The (horizontal) hydraulic conductivities reported for the basalt flow interiors range from 10^{-10} to 10^{-16} meters per second (10^{-5} to 10^{-11} feet per day) (Strait and Mercer, March 1987). The Department of Energy (May 1986, p. 3-114) reports that 17 tests have been conducted across the dense entablature and the colonnade portions of individual flow interiors; the tests were conducted at depths ranging from approximately 360 to 1,200 meters (1,200 to 3,900 feet). The Department of Energy states that the median of the horizontal hydraulic conductivity of the flow interiors is 10^{-13} meters per second (10^{-8} feet per day). The Department states also that the lower limit of detection is considered to be 10^{-13} to 10^{-14} meters per second (10^{-8} to 10^{-9} feet per day).

A single test has been attempted at the site using the "ratio method" for the measurement of vertical hydraulic conductivity of a basalt flow interior. Spane et al. (1983) suggest that the value of vertical hydraulic conductivity is less than 10^{-10} meters per second (10^{-5} feet per day). The ratio method test was applied to the interior of the Rocky Coulee Basalt flow. The Department of Energy (May 1986, p. 3-114) states that uncertainty cannot be assigned to the value measured using the "ratio method" at this time. The Department of Energy states (p. 3-116) that "once several field measurements become available, it is believed vertical hydraulic conductivity of undeformed flow interiors will likely be within a factor of 10 of horizontal conductivity values currently reported."

Geometry of the Basalt Flows in the Vicinity of the Cluster Sites DC-19, DC-20, and DC-22

The vertical distances between basalt flows and between piezometers used herein are derived from a completion report by Jackson et al. (1984). Our initial mesh constructed for modeling included three flow tops for which hydrogeologic data are available. This three flow top modeling scheme was abandoned early in the process because of the difficulty in establishing the necessary defensible boundary conditions that are required to portray accurately such a hydrogeologic regime. In essence the three flow top model requires so many arbitrary assumptions about so many unknown variables that the effort cannot be justified. Instead, a second mesh was constructed which includes two flow tops that are separated by 'a' flow interior. The mesh shown in figure 3 constitutes the finite element mesh used for UNSAT2. The mesh dimensions are 311 feet vertically by 870 feet horizontally. This mesh includes the Priest Rapids flow top, the Priest Rapids flow interior, and the Sentinel Gap flow top. The mesh depicts a geologic cross-section that extends southwest from borehole DC-20.

The height of the mesh is based on the distance from the top of the borehole gravel pack opposite the Priest Rapids flow top to the bottom of the borehole gravel pack opposite the Sentinel Gap flow top at borehole DC-20. Two intervening, unnamed basalt flows occur between the two simulated basalt flow tops. These intervening flow tops were not simulated because we have no data on them.

The basalt flows are assumed to be horizontal within the dimensions of the finite element mesh. Dip of the basalt flows being modeled was not incorporated because it appears that the dip is sufficiently low that the effect is negligible.

Model Description

The finite element model UNSAT2 developed by Neuman, Feddes, and Bresler (July 1974) was used in this study. UNSAT2 is a finite element program which may be operated in an areal planar mode, a 2-D cross-sectional mode, or an axisymmetrical mode. The two-dimensional cross-sectional version of the program was used for this effort. The program may approach solutions using either the backward difference scheme or a time-centered scheme. The time-centered scheme was used for our simulations. UNSAT2 is capable of modeling a seepage surface; however, this option was not required because the rocks remained saturated at all times. UNSAT2 also is capable of modeling unsaturated flow conditions but this option was not needed in this effort. The calculated low hydraulic gradients (10^{-4}) at the site required changing the format statements within the program in order to generate head data to within one one-thoundsandth (0.001) feet. Format statements in UNSAT2 were changed in conjunction with corresponding format statements in our preprocessor called MBUILD and our postprocessor called FEDIT. The preprocessor MBUILD and postprocessor FEDIT were created by Dr. Bloomsburg and Mr. Rinker (1983).

The preprocessor MBUILD was used to create the input file which includes the input values of hydrogeologic coefficients and the finite element mesh. The postprocessor FEDIT was used to continue simulations after termination of a run. The postprocessor picks up the final values of hydraulic heads (pressures) and converts these values to a new data file for subsequent simulation, along with any changes in the finite element mesh or hydraulic properties. The postprocessor was used to continue the simulation and assure that the simulations reflect steady state flow conditions.

Model Formulation

Rectangular Mesh

A finite element mesh was constructed using rectangular elements (fig. 3); the mesh contains 121 nodes and 100 elements. The dimensions of the elements were chosen to simulate a basalt flow top (Priest Rapids) at the top of the mesh, a flow top at the bottom of the mesh (Sentinel Gap), and a flow interior (Priest Rapids) between the flow tops. The top two rows and the bottom two rows of the mesh represent the flow tops.

Boundary Conditions

A constant value of head was assigned to the top left corner of the mesh (nodes 10 and 11). A constant value of head also was assigned to the bottom right corner of the mesh (nodes 111 and 112). The value of head assigned to the bottom right hand corner is derived from the value of head measured in borehole DC-20 in the Sentinel Gap flow top. The value of head assigned to the top left corner is derived from the hydraulic gradients shown in table 1 and the hydraulic head measured in the Priest Rapids flow top in borehole DC-20.

A constant volumetric ground water inflow rate ($+8.8X10^{-2}$ cubic foot/day = $+2.5X10^{-3}$ cubic meter/day) into the model was assigned to the top right corner of the finite element mesh. This value was calculated from the assigned vertical hydraulic conductivity (discussed below under material properties) and hydraulic gradient through the cross-sectional area that represents the Priest Rapids flow top in the model. A constant volumetric rate ($-1.0X10^{-1}$ cubic foot/day = $-2.9X10^{-3}$ cubic meter/day) of discharge was assigned to the bottom left corner of the mesh; the constant rate of discharge is derived from the assigned hydraulic conductivity (discussed below), the hydraulic gradient, and cross-sectional area of the Sentinel Gap flow top. The volumetric rates of assigned inflow and outflow are not equal because the thicknesses of the two flow tops are different. The assignment of constant heads and constant volumetric rates of inflow and outflow allows the model to simulate a change in vertical volumetric ground water flow rate through the basalt flow interior. This variation in rate is dependent primarily upon the vertical hydraulic conductivity of the flow interior but to some extent on the ratio of K_h to K_v. The volumetric inflow rate of groundwater that enters the bottom right corner of the mesh can increase as the vertical hydraulic conductivity of the flow interior increases, thereby permitting groundwater to flow toward the top left corner of the mesh. This procedure allows the volumetric discharge rate from the top left corner of the mesh to vary with the only constraint being the vertical hydraulic conductivity of the flow interior for any fixed value of horizontal hydraulic conductivity, as expressed in figures 4 and 5. The procedure also maintains the calculated vertical and horizontal hydraulic gradients across the flow interior.

The left column of the nodes numbered 3 through 9 and the right column of the nodes numbered 113 through 119 were assigned a code number which designates these nodes as no-flow boundaries. The top row of nodes numbered 22, 33, 44, 55, 66, 77, 88, 99, and 110 were assigned code numbers that designate these nodes as no-flow boundary nodes. The bottom row of nodes numbered 12, 23, 34, 45, 56, 67, 78, 89, and 100 were assigned a code number which designates these nodes as no-flow boundary nodes. This establishment of boundary nodes produces the effect that flow through the basalt flow interior is vertical. This boundary arrangement also assures that this problem can be modeled accurately by portraying a single flow interior located between two flow tops; vertical flow within the flow tops is eliminated by this configuration of boundary nodes.

Material Properties

This study assumes that the two basalt flow tops have identical values of horizontal and vertical hydraulic conductivity (10 feet/day = 3 meters/day). The values of hydraulic conductivities for the basalt flow tops were not varied during these simulations. The values of horizontal and vertical hydraulic conductivity for the flow interior were varied among different model runs. Two values of horizontal hydraulic conductivity were assigned to the interior ($1X10^{-6}$ foot/day = $3X10^{-7}$ meter/day and 1 foot/day = 0.3 meter/day); the values assigned to vertical hydraulic conductivity of the flow interior were varied over several orders of magnitude ($1X10^{4}$ to $1X10^{-6}$ feet/day, $3X10^{3}$ to $3X10^{-7}$ meters/day). Unsaturated flow properties were not required for the basalts; the system did not become unsaturated during any of the simulations.

The value of storativity used in the simulations is not an important factor in this study because the simulations were run to steady state. A value of $1x10^{-5}$ was used for specific storage, which is a reasonable value for basalts at the Hanford site. Steady state conditions were achieved by running the model for approximately 11 years (4,000 days). The total period of simulation was achieved during two separate simulation runs.

Modeling Procedures

The finite element mesh (fig. 3) was constructed using the preprocessor called MBUILD. Values for hydrogeologic coefficients were input using MBUILD. A 2,000-day run was conducted using the model. Heads were spot checked for consistency within the ranges of hydraulic gradient measured at the site. The head values were checked for sequential runs over selected time spans to determine whether or not steady state flow conditions had been achieved. Generally, steady state flow conditions had been achieved within a 2,000-day time span. However, in order to assure that steady state flow conditions were achieved, a second run was made using a second time period of 2,000 days. The postprocessor FEDIT was used to pick up the data file from the first run and to generate a new input file. The heads (in the form of pressures) were obtained from the preceding run and incorporated into the new data file. The second file was run for 2,000 days; heads again were spot checked to assure that steady state flow conditions was achieved. After assurance was obtained that steady state flow conditions existed, the values of volumetric inflow and outflow groundwater flow rates were calculated and tabulated.

Subsequent runs were made using the same mesh but different input values for the hydraulic conductivities of the basalt flow interior. The vertical hydraulic conductivity was varied over several orders of magnitude for each of the two values of horizontal hydraulic conductivity. As explained above, only two values were assigned for horizontal hydraulic conductivity of the flow interior. The ratios of hydraulic conductivity in the interior were varied in order to investigate the sensitivity of vertical volumetric groundwater flow rate to variations in the ratio of vertical or horizontal hydraulic conductivities. Output from the model simulations are graphed on figure 4 and figure 5. These graphs illustrate the range of total volumetric groundwater flow rate that can occur with the simulation constrained by the boundary conditions described above. Total volumetric flow rate indicates the changes that occur in the vertical volumetric flow rate because the volumetric flow rate into the Priest Rapids flow top and the volumetric flow rate from the Sentinel Gap flow top are assigned constant values. The only volumetric flow rate that can change is that portion of the total volumetric flow that passes through the basalt flow interior and discharges from the top left corner of the mesh which is the Priest Rapids flow top.

Modeling Results

The graphs of volumetric groundwater flow rate versus the ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity are illustrated in figures 4 and 5. The graphs show that the volumetric rate of inflow into the mesh, which must equal the volumetric discharge rate from the mesh, is dependent primarily upon the vertical hydraulic conductivity of the flow interior and to some extent upon the ratio of horizontal hydraulic conductivity of the flow interior to the vertical hydraulic conductivity of the flow interior. The graphs show that the volumetric discharge rate, Q, from the mesh (fig. 3) is not very sensitive to changes in the vertical hydraulic conductivity of the flow interior.

The volumetric rate of groundwater flow through the basalt flow interior is constrained to some degree by the horizontal hydraulic gradient imposed upon each flow top and the hydraulic conductivity of the flow tops. Simulations were not run using alternate values for the hydraulic conductivity of the flow tops.

The minimum volumetric discharge rate from the mesh was first reached with a vertical hydraulic conductivity of the flow interior of approximately 0.01 foot/day (0.003 meter/day). This minimum volumetric discharge rate of approximately 0.19 cubic feet/day (0.0054 cubic meter/day) was achieved with both values of horizontal hydraulic conductivity assigned to the basalt flow interior. The volumetric discharge rate did not decrease with lower vertical hydraulic conductivities because this volumetric discharge rate equals the constant values of outflow and inflow assigned to the lower left and upper right corners of the mesh respectively. At this point in the simulations the basalt flow interior is essentially impermeable.

The maximum volumetric discharge rate from the mesh was first reached with a vertical hydraulic conductivity of the flow interior of approximately 100 feet/day (30 meters/day). The maximum volumetric discharge rate is about 0.26 cubic feet/day (0.0074 cubic meter/day) using a horizontal hydraulic conductivity of the interior of 1 foot/day (0.3 meter/day). The maximum volumetric discharge rate is about 0.23 cubic foot/day (0.0065 cubic meter/day) using a horizontal hydraulic conductivity of the interior of $1X10^{-6}$ foot/day ($3X10^{-7}$ meters/day). The maximum volumetric discharge rates do not increase with higher values of vertical hydraulic conductivity.

The minimum and maximum volumetric discharge rates from the mesh were achieved with the same values of vertical hydraulic conductivity of 0.01 foot/day (0.003 meter/day) and 100 feet/day (30 meters/day) respectively. The minimum volumetric discharge rate should not reflect any constraints by the homogeneous and isotropic hydraulic conductivity of the basalt flow tops. However, the maximum volumetric discharge rates may be constrained by the hydraulic conductivity of the flow top. The higher volumetric discharge rate with the higher horizontal hydraulic conductivity of the basalt flow interior probably is attributable to the higher horizontal hydraulic conductivity of the flow interior. The simulation is more efficient in allowing groundwater to flow from the bottom right corner to the top left corner of the mesh; there is less resistance to the horizontal component of groundwater flow within the basalt flow interior.

Problems Associated With Modeling Effort

One of the most significant problems associated with this modeling effort is the low magnitude of the hydraulic gradients in both the horizontal and vertical directions. The hydraulic gradients are approximately 10^{-4}. It is difficult also to formulate the modeling problem because heads in the intervening flow tops and flow interiors are unknown; only selected flow tops are monitored at the various BWIP sites. Several intervening basalt flows may exist between monitored intervals.

The volumetric rate of groundwater flowing horizontally and vertically is unknown at the BWIP site. Obviously the volumetric rate of groundwater moving through the basalt formations is not measurable directly. The volumetric rate of groundwater flow is usually calculated based on the thickness of the zone through which flow occurs, the hydraulic conductivity of that zone, and the hydraulic gradient across it.

The problem of simulating the measured hydraulic gradients is complicated further by the fact that the hydraulic conductivities of the individual flow tops are not known with sufficient accuracy at the sites of interest. To date, only single well, small scale tests have been conducted at the site with one or two exceptions. These exceptions included only a single observation well and the tests were small scale.

The horizontal and vertical hydraulic conductivity of the basalt flow interiors basically are unknown. Some tests have been conducted, using small scale, single well tests, to measure the horizontal hydraulic conductivity of flow interiors. The single test that was attempted to measure the vertical hydraulic conductivity of a basalt flow interior was complicated by several problems. The most defensible value that can be derived from that vertical hydraulic conductivity test is a value that is believed to be less than 10^{-10} meters per second (10^{-5} feet per day). It remains to be shown by field tests whether the volumetric rate of flow of groundwater across the basalt flow interiors is significant. Field data obtained to date are not conclusive with respect to the volumetric rate of flow of groundwater across the basalt flow interiors.

The greatest problem associated with formulating the finite element mesh and the associated boundary conditions is a consequence of the necessity for assigning specific boundary conditions to the simulation problem. The hydraulic heads may be set at a predetermined value which allows the volumetric flow rate, Q, to vary according to the limits of the assigned hydraulic conductivity value(s) and the measured hydraulic gradient. The quantity of inflow or outflow from a node can be fixed at a constant value which allows the heads to vary at that node according to the limits of the assigned hydraulic conductivity(s) and hydraulic gradient(s). The most defensible formulation of this modeling effort required that a mixed set of boundary conditions be applied to the finite element mesh. The boundary conditions require constant head and constant inflow and outflow rates at designated nodes. These mixed boundary conditions were assigned to insure that the hydraulic gradients simulated by the program fell within the range of values that has been determined from the field measured hydraulic head data as described above.

The boundary conditions imposed on the basalt flow interior restrict the flexibility of the model under specific flow conditions. These conditions include a high horizontal hydraulic conductivity in the flow interior and no flow boundaries on each side of the mesh in those elements and nodes that represent the flow interior. The no flow boundaries prevent lateral movement of groundwater through the sides of the mesh although lateral movement of groundwater can occur within the flow interior between the boundaries. The assumption that only vertical flow occurs through the flow interior is violated unavoidably when high values of horizontal hydraulic conductivity are input into the flow interior.

Conclusions

This study demonstrates very conclusively that the current absence of field data regarding the hydrogeologic coefficients severely limits the utility of modeling groundwater flow at this stage of site investigation. In particular the sparseness of defensible data limits ones ability to simulate vertical flow conditions without being forced to input data estimates that artificially predetermine the solution to the simulation problem. In this study at least two intervening flow tops that occur between monitored intervals cannot be simulated at all due to the absence of data. This deficiency makes it difficult to simulate reliably the response of the two flow tops of interest to changes in the hydrogeologic coefficients of the 'interior' under conditions of measured gradient. This deficiency is a result of the fact that hydraulic head data and hydraulic conductivity data do not exist for the intervening basalt flow tops and their respective flow interiors.

The necessity to designate (essentially estimate) constant head boundaries, constant flow (Q) boundaries, or zero flow boundaries limits the flexibility of the simulation. The aforementioned necessity to change the format statements in the programs in order to accommodate the low measured values of gradient illustrates the very sensitive nature of the hydrogeologic system at the BWIP site to hydraulic gradient.

The existence of variable fluid densities also may be a significant factor at the BWIP site. Variable fluid density is not accommodated in UNSAT2. The series of simulations presented herein was conducted under the minimum justifiable vertical separation that is defensible based on available data in order to minimize the effects of variable fluid density.

These constraints, when viewed with scientific discretion, do illustrate the context in which the results presented in figures 4 and 5 must be viewed. The graphs reflect the results of a sensitivity study of the influence of the ratio K_h to K_v (primarily of K_v) on the rate of transfer of fluids between an upper flow top and a lower flow top through a flow interior.

In addition, the discussion presented under "Modeling Results" and "Problems Associated with Modeling Effort" illustrates the absolute necessity for carefully evaluating the influence of model boundary characteristics on groundwater flow in any modeling study. Model boundary characteristics usually are known very poorly. This statement is particularly true for groundwater inflow rates and groundwater outflow rates. "No" flow boundaries and constant head boundaries that control these variables in the model frequently are derived from some larger scale modeling effort which also was based on a wide variety of estimated inputs. This study shows that these effects absolutely preclude reliance on the results of a model unless the model can be calibrated and validated in the usual manner (see Wang and Williams, 1984, for discussion of calibration and validation). It is for this reason that we assert that this modeling effort be viewed as a sensitivity study.

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Table 1. Hydraulic heads and gradients used in this modeling study based on data obtained from cluster borehole sites DC-19, DC-20, and DC-22.

Geologic unit	Elevation of head in DC-20 (feet)	Horizontal gradient from 3 point problem calculation	Vertical gradient at DC-20	Apparent direction of vertical flow
Priest Rapids	401.67	$1.7X10^{-4}$		
			$7.0X10^{-4}$	↑
Sentinel Gap	401.69	$1.4X10^{-4}$		
			$4.0X10^{-4}$	↑
Gingko	401.76	$1.2X10^{-4}$		
			$9.3X10^{-3}$	↑
Rocky Coulee	404.73	$1.2X10^{-4}$		
			$9.7X10^{-4}$	↓
Cohassett	404.62	$2.1X10^{-4}$		
			$1.9X10^{-3}$	↑
Umtanum	405.69	$2.5X10^{-4}$		
average horizontal gradient		$1.9X10^{-4}$		

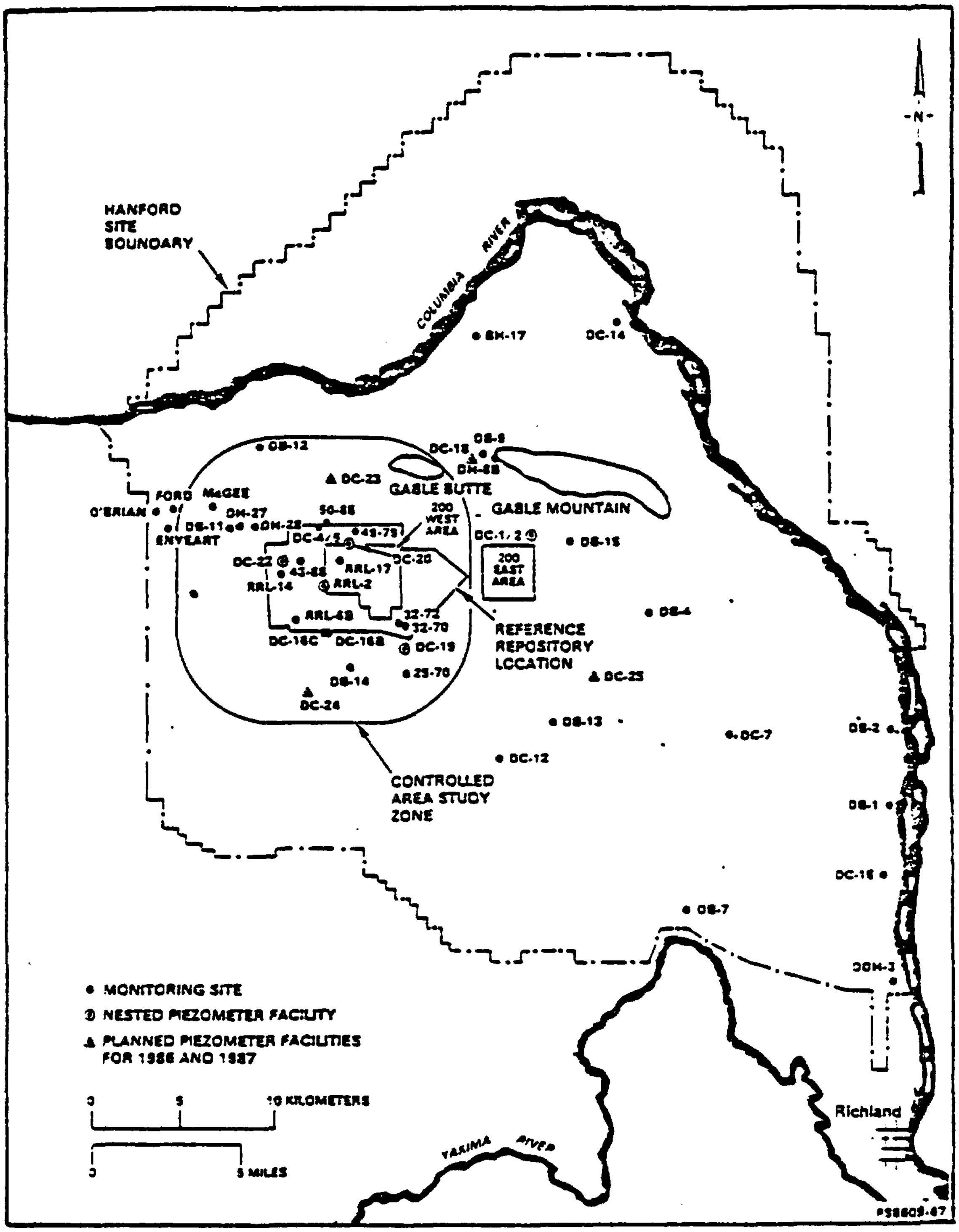

Figure 1. Location of piezometers, wells, and boreholes in which groundwater level and (or) fluid pressure are measured on the Hanford Site for the Basalt Waste Isolation Project.

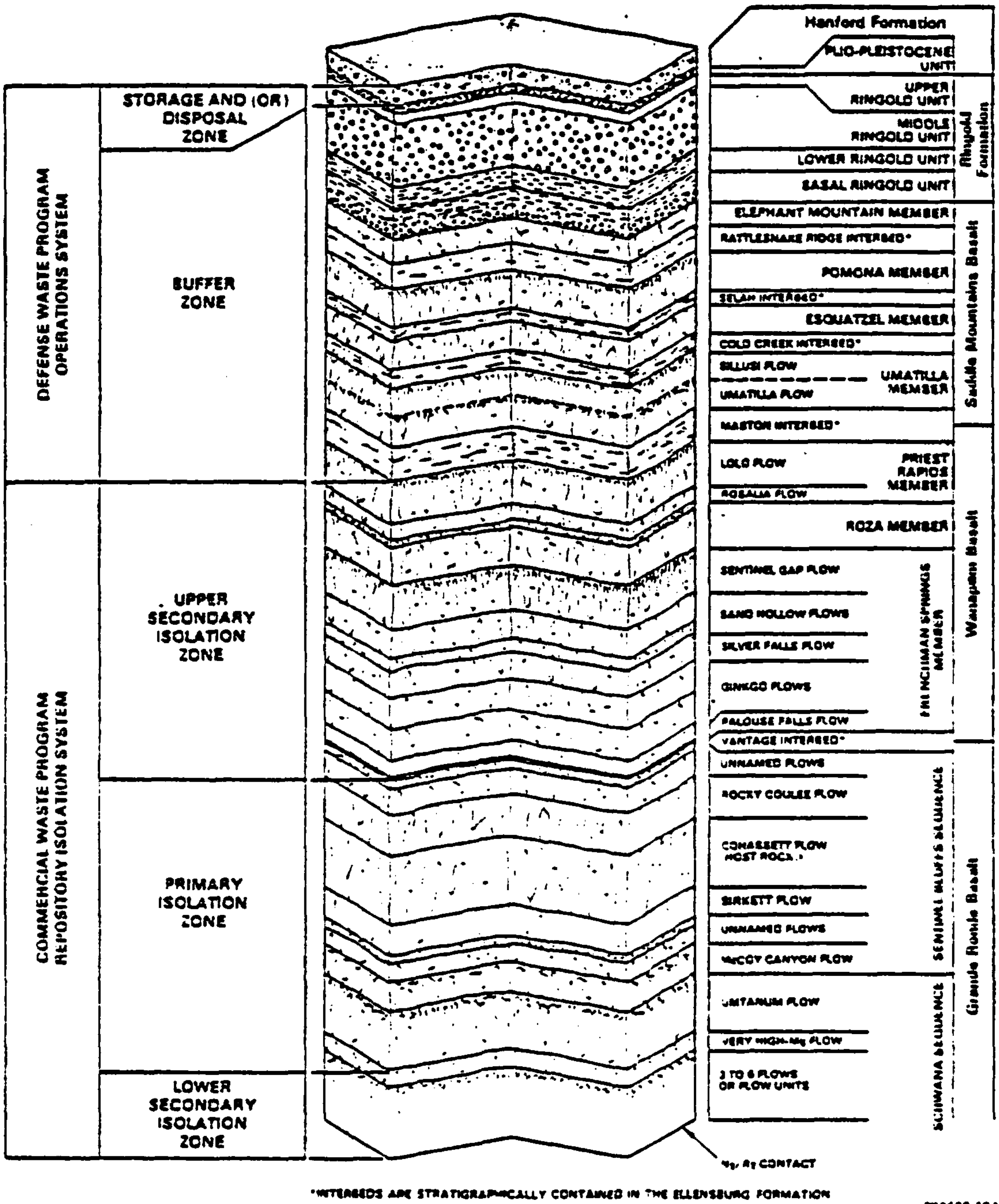

Figure 2. Stratigraphic intervals within the controlled area study zone that are pertinent to the commercial waste program.

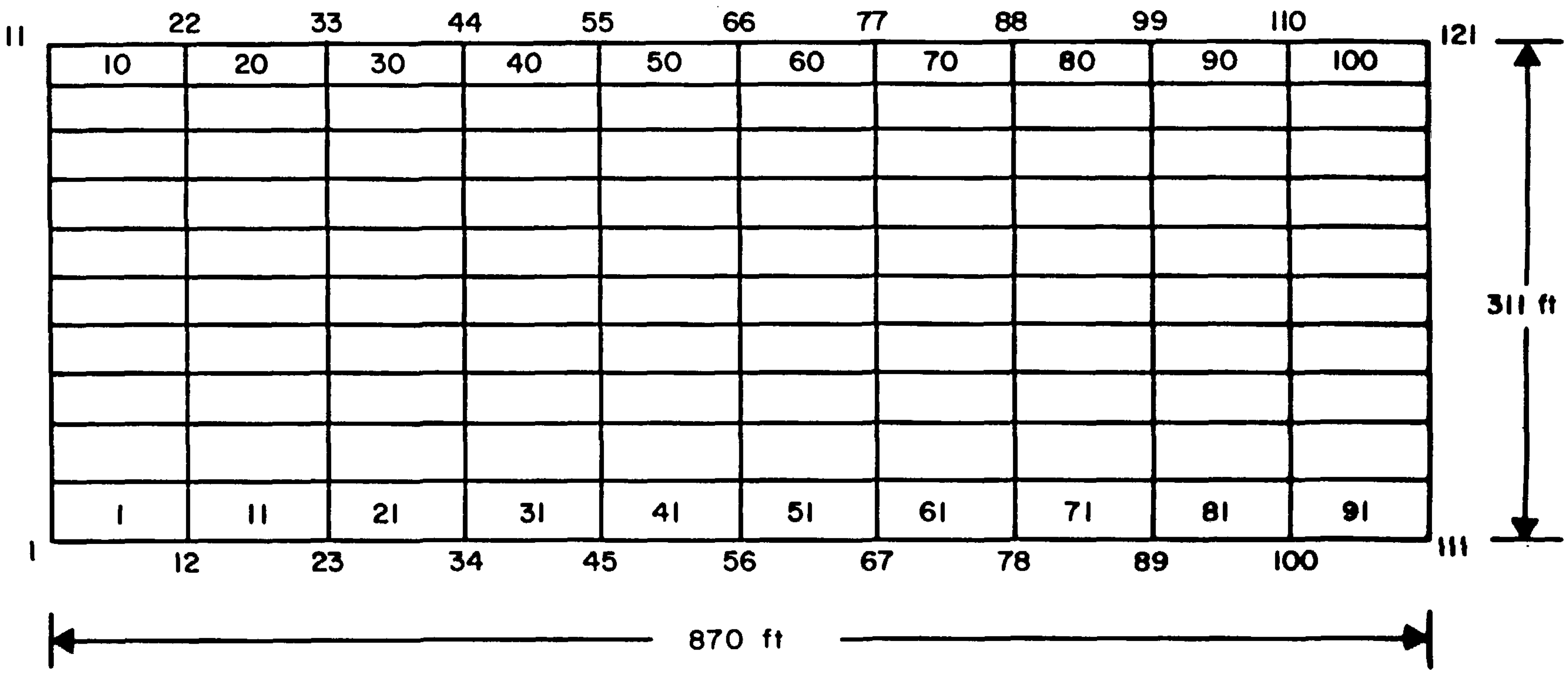

Figure 3. Finite element mesh used to investigate relationship between horizontal and vertical hydraulic conductivities and horizontal and vertical gradients; the mesh is designed to model the Priest Rapids flow top and flow interior and the Sentinel Gap flow top.

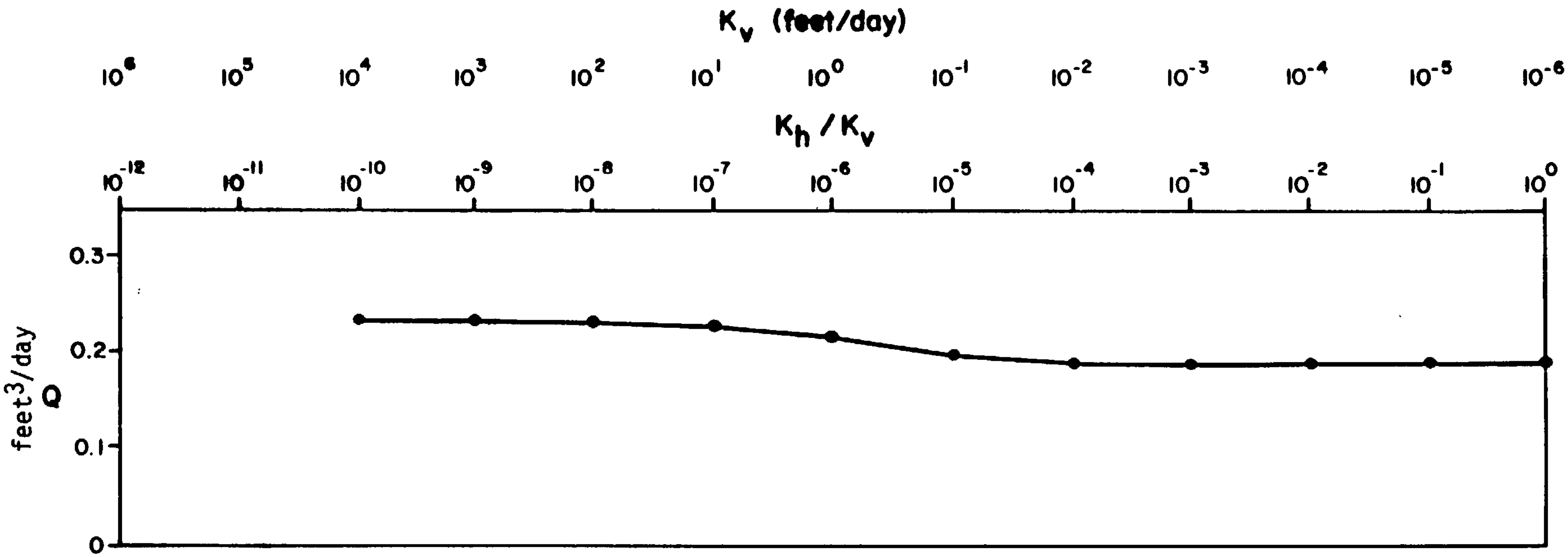

Figure 4. In this figure the variation in total volumetric flow rate is derived as a function of a constant value of horizontal hydraulic conductivity (1×10^{-6} ft/day = 3×10^{-7} m/day) and a varying value for vertical hydraulic conductivity of the flow interior. The values of hydraulic conductivities are expressed as a ratio (no units).

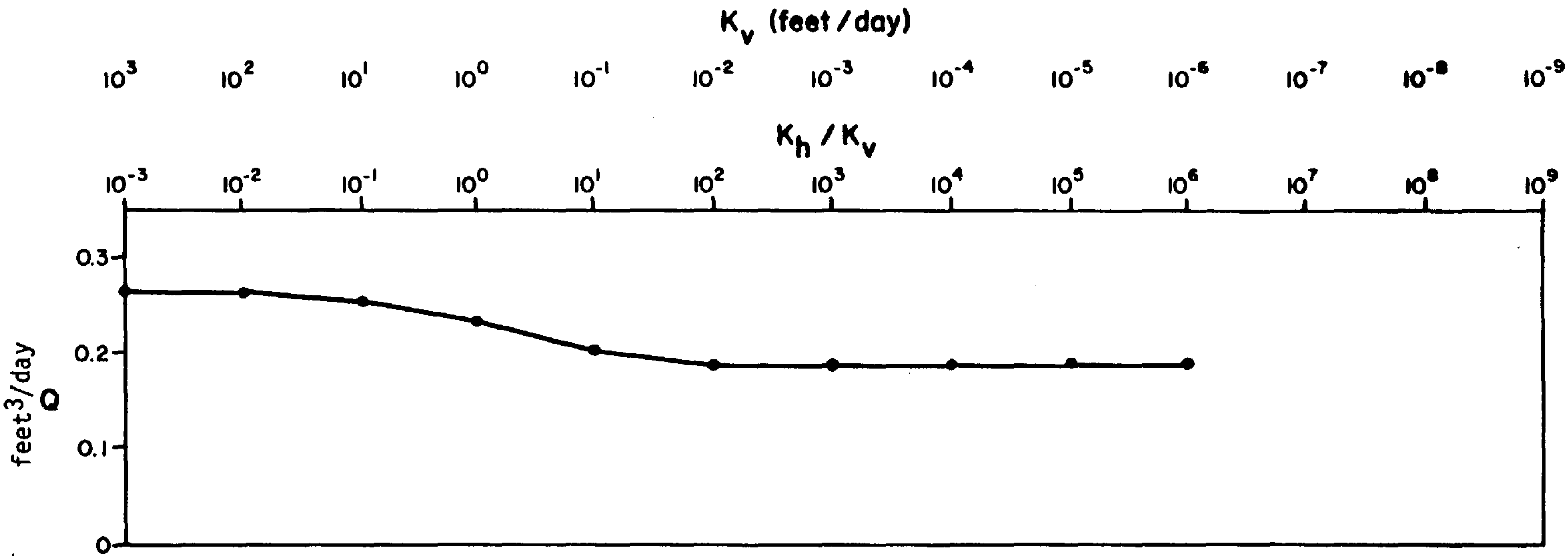

Figure 5. In this figure the variation in total volumetric flow rate is derived as a function of constant value of horizontal hydraulic conductivity (1 ft/day = 0.3 m/day) and a varying value for vertical hydraulic conductivity of the flow interior. The values of hydraulic conductivities are expressed as a ratio (no units).

DOE has Brock in the dumps

Associated Press

WASHINGTON — You might call it the search for a word to describe the search for a dump.


BROCK ADAMS

Dump as in nuclear dump. The kind no state wants.

Sen. Brock Adams, D-Wash., held the Senate floor last week and deplored the decision-making process at the Department of Energy, which is responsible for selecting a site — somewhere — for a nuclear waste dump.

The state of Washington is on the department's short list of three states — Nevada and Texas are the others — of final candidates to house the nation's first permanent underground dump for nuclear waste.

No way, said Adams, speaking for his state.

He noted that a colleague, Sen. Harry Reid, D-Nev., has characterized the Energy Department's behavior in the selection process first as "rude," then as "obnoxious."

That doesn't even begin to express his feelings, Adams said.

The words that would do that, he said, probably could not be printed in the Congressional Record or a family newspaper.

"I am tempted to say that the Department of Energy's behavior has been 'inappropriate' but somehow that does not capture the full range of emotions I feel my constituents feel," Adams said.

So he said he had turned in desperation to his office's copy of Webster's Collegiate Thesaurus.

"There I found words like 'lumpy,' 'raw,' 'rough,' 'unpolished,' 'primitive,' 'imperfect,' 'lacking in social refinement,' 'disrespectful,' 'uncouth,' 'ungracious,' 'brusque,' 'crusty,' 'surly,' 'boorish' and even 'loutish.'

"But they do not really do the job," the senator said.

"In fact, the word that came closest to being both printable and expressive is the word 'vulgar,' he said.

"At least it is suggestive of what I feel."

Adams picks up support in nuke dump fight

Associated Press

WASHINGTON — Sen. Brock Adams temporarily called off a filibuster after winning several "tactical victories" Tuesday in his effort to derail a bill that would narrow the list of sites being considered for the nation's first high-level radioactive waste dump.

"They have given in to the filibuster," the Washington Democrat said in an interview. "This is a victory in what could still be a long battle. But it's a good one."

Adams was quick to add that while he was setting aside the delaying tactics for now, he would continue to oppose the proposed overhaul in the search for a permanent nuclear waste repository and didn't rule out the use of other parliamentary maneuverings if necessary.

The decision to call off the filibuster came after a day of negotiations involving Adams, Senate Majority Leader Robert Byrd and Sen. J. Bennett Johnston, D-La., chairman of the Senate Energy Committee.

Earlier in the day, Adams had picked up support from several key members of the Senate Environment and Public Works Committee, including the chairman and ranking Republican member.

On a 87-0 vote, the Senate approved a motion to cut off debate on an amendment to the $16 billion energy and water appropriations bill. The amendment would direct the Department of Energy to exhaustively study one site rather than the three now under consideration as the location for the nuclear waste dump.

Adams supported the so-called cloture motion, but only after Senate leadership agreed that the amendment would be brought to a separate vote rather than included in one overall vote on the entire appropriations bill.

The bill contains funding for projects in virtually every senator's homestate and has overwhelming support. Adams had said that many senators would be reluctant to vote no on the bill, even if they disagreed with the nuclear waste provisions.

"We will have a straight up or down vote on the nuclear waste program," Adams said. That vote is scheduled Thursday.

Johnston, considered one of the most powerful members of the Senate, has said his amendment would save $3.9 billion.

But Adams said he fears that the Hanford nuclear reservation in Washington state will be picked for further study and added he thinks the Energy Department's site selection program has so far been dominated more by politics than scientific data.

Other sites under consideration by the department are in Texas and Nevada.

In addition, Adams said the Johnston proposal is a "major piece of authorizing legislation" that violates Senate rules by being attached to an appropriations measure.

Adams said earlier he was concerned that if the amendment remained attached to the energy and water appropriations bill, the House-Senate conference committee that would consider the measure would be dominated by congressmen more interested in the budget deficit than the nation's nuclear waste program.

On Tuesday, Johnston agreed that senators concerned about the department's nuclear waste program should be allowed to participate in a conference committee.

Conference committees are responsible for ironing out differences in bills passed by the House and the Senate.

The House is considering legislation that would create an independent commission to review the waste program and recommend changes. Adams supports the House proposals and believes Johnston's amendment could be deep-sixed in a conference committee.

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