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

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Distribution:
Pohle

(Return to WM, 623-SS)

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

Dear Mike:

This letter constitutes a request to discuss further a proposal that Williams and Associates, Inc. sent to the NRC in April of 1985 (Communication No. 123). This proposal was discussed with Mr. Matthew Gordon, Project Officer, at that time. A follow-up communication was sent to Mr. Gordon (Communication No. 126) discussing several questions raised by Mr. Gordon about our proposal. We would like for you to reconsider our proposal in light of the additional information included in this letter. Copies of the previously mentioned communications are appended to this letter.

The subject of the proposal we sent to Mr. Gordon was that barometric and earth tide data be reviewed for the possible calculation of effective porosity at the BWIP site. The proposal suggests that the methodology be investigated because the BWIP site will have a number of parameters quantified which have not been quantified at the sites, noted in our Communication No. 123, where such analyses have been conducted previously. The parameters that will be quantified include storativity and transmissivity, which will be obtained from the large-scale pumping tests at the site. As you know, these pumping tests are scheduled to begin late in 1985. We believe that these parameters, when they are provided to us, may be used in conjunction with the analysis of earth tide data and barometric efficiency data to estimate effective porosity for representative flow tops. The possibility exists that the methodology can be extended to the determination of effective porosity for basalt flow interiors.

One of the points discussed with Mr. Gordon was the type of porosity that would be quantified by a methodology that uses barometric efficiency and earth tide data. We believe that the

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type of porosity quantified may be effective porosity although it is possible that the porosity would be a larger value of porosity which has been referred to as apparent porosity in previous communications and discussions between the NRC and DOE. It is not clear which type of porosity would be quantified should the methodology prove applicable as we believe it may be to the BWIP site. The relationship between these two types of porosity has not yet been "hashed out" in the literature.

The methodology may be applicable to the other sites. The BWIP site has been chosen for investigation of the methodology because this site is further along in testing and data acquisition than any of the other sites. This site also is restricted to considerations of the saturated zone which is required for a methodology using barometric efficiency and earth tide data.

We believe this effort is a worthwhile endeavor because currently tracer tests provide the only means of quantification of effective porosity at any of the sites at this time. As noted by DOE (Rockwell Hanford Operations) the tracer tests conducted at the DC-7/8 site are the only tracer tests conducted to date. In our opinion tracer tests are not conclusive in that they will not reflect large scale heterogeneities in the hydraulic properties of the porous medium. Time constraints preclude resolution of this problem.

Leonhart et al. (1984) point out that the tracer test conducted at DC-7/8 yielded a quantification of effective or flow porosity which is primarily an estimate (p. 22). They also point out (p. 26) that "the range of possible contributing zone thicknesses is very broad." The analysis of tracer test data and the application of the values obtained from the test to larger scale modeling must be viewed with caution. Leonhart et al. (1984, p. 28) point out that heterogeneities are apparent vertically through the McCoy Canyon flow top at the DC-7/8 site. They note that it is reasonable to assume that heterogeneities may also be encountered over "similar lateral distances." We believe that this concern is authenticated by the lack of symmetry between the cone of depression at DC-7, which was on the order of 77 feet, and the cone of impression at DC-8 which was approximately 2 feet. This great difference in the cones of impression and depression infers that a significant degree of heterogeneity exists between these two locations which are approximately 55 feet apart at depth. Leonhart et al. point out "that lateral heterogeneities may also be present in the vicinity of the two boreholes" (p. 29).

Neretnieks (1985) has conducted a study of the distribution of water inflow into a tunnel located in Sweden. The study is similar in many respects to research work being conducted by graduate students at the University of Idaho at the inactive Bunker Hill Mine located in the silver mining district of northern Idaho. Observations similar to those of Neretnieks can be made at the Bunker Hill Mine. We also have observed similar mine water inflow characteristics at other mines but we have not published our observations. Neretnieks points out that tunnel inflow is extremely variable over the lengths of the tunnel; the tunnel is located in fractured granitic rock. Neretnieks points out that water is unevenly distributed over "the 100 meter long tunnel section." This inflow rate is distributed as follows: 1) a third of the water flow takes place in about 2 percent of the area, and 2) 70 percent of the area does not produce water flow. We believe the observations from this research and our own observations indicate that heterogeneity is a major factor with respect to both velocity of water movement along different flow paths and to solute transport rate in fractured media. The performance of fractured media at depth may be even more difficult to characterize due to possible decreasing fracture frequency with depth. The observations make by Neretnieks are consistent with the results of the smaller scale tracer tests conducted at the DC-7/8 site.

Long et al. have conducted a research effort on the nature of flow and transport in discontinuous fracture networks. They examine these factors by using two and three dimensional numerical models. They examine departures from porous media behavior as a function of interconnectivity and heterogeneity. These authors have arrived at an interesting conclusion based upon this work. They note that values of V_b greater than 0.0 can "yield values of hydraulic effective porosity ϕ_e which are directionally dependent and significantly larger than both the connected porosity, ϕ_R and the total porosity ϕ_T." The parameter V_b is defined as the coefficient of variation of the aperture which is the standard deviation over the mean. Long et al. note that heterogeneous systems exhibit break-through curves with long tails. The long tails occur because some particles travel along slower and longer paths which causes the mean travel time to increase significantly. It is not clear to us how the connected porosity can be less than the hydraulic effective porosity as noted by the authors of this paper. This article should be considered for further review because its implications to solute transport may be significant.

We request that you consider our proposal in light of the additional information we have presented in this letter. Please feel free to call us concerning these communications as we believe this proposal deserves further consideration. The question of the proposal was not completely discussed due to the termination of the contract shortly after the initiation of discussions regarding our proposal.

Sincerely,

Gerry Winter

Gerry V. Winter
Hydrogeologist

GVW:sl

Attachments

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WILLIAMS & ASSOCIATES, INC.

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

April 15, 1985
Contract NRC-02-82-044
FIN #B7372-3
Communication #123

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

Dear Matt:

This letter and attachments constitute a request that Williams and Associates, Inc. be granted permission to pursue an NRC methodology for evaluating the effective porosity of basalts at the BWIP site. This parameter is a critical licensing issue in that it is required for travel time calculations. Ultimately the NRC must evaluate the validity of effective porosity values presented in license application documents.

We have conducted a brief literature search and review on the subject of barometric and tidal (earth) efficiencies as related to porosity. The purpose of this effort was to investigate the feasibility of extending barometric efficiency and tidal efficiency testing methodologies to an important field application at the BWIP site. Specifically, the intent of our effort was to explore the feasibility of using barometric and earth tide data to estimate effective porosity values for basalt flow tops and flow interiors. The testing and data analysis approach currently under consideration by RHO and the NRC relies solely on the results of tracer tests. A corroborative methodology does not exist. From a licensing point of view the failure of the current tracer test scheme could have significant negative impacts. Failure is possible because tracer testing technology is not well established in terms of field application. The theory is well understood but applications have been fraught with problems.
Effective porosity is recognized as a key variable required for the calculation of groundwater velocities and travel times. A basic premise in our effort to date rests on the availability of rock property data from the rock mechanics group and the calculation of hydraulic properties from in situ tests. The necessary variables can be quantified at the BWIP site. The availability of on-site barometric data and continuous records of downhole fluid pressures and water levels presents a fairly unique opportunity because of the configuration of the completed multi-piezometers

at the site. We propose to use this unique opportunity to corroborate effective porosity values obtained from tracer tests. This effort could preclude the Agency being placed in the position of having no back-up position if the tracer tests yield questionable results.

Our literature search revealed several key articles on this subject. A reference list is appended to this letter. This letter presents our findings from a review of the references cited. Our synopsis is organized as follows:

1. Introduction,
2. Basic theory,
3. Critical comments on the theory,
4. Case studies and limitations cited therein, and
5. Conclusions and recommendations.

Please note that this literature search and review is preliminary in nature. We have not conducted a complete search; consequently some important articles may be discovered later.

Sincerely,

Roy E. Williams (KW)

Roy E. Williams

INTRODUCTION

Current efforts to quantify storativity and porosity (effective) are based on either injecting or removing a quantity of fluid from a well(s). The quantification efforts for effective porosity at the BWIP site are based on the injection of a tracer in one well (borehole) with the simultaneous withdrawal of water from an adjacent well (borehole). The ability to conduct tracer tests at the BWIP site is limited either to sites that have two adjacent wells with compatible well completions or to sites at which additional wells are drilled for the specific purpose of conducting tracer tests. It is desirable to evaluate any methodology that minimizes the necessity for additional drilling. It also is desirable to evaluate methodologies that can provide corroborative data to the measurement of effective porosity by tracer tests which currently is the sole means of measuring effective porosity at the BWIP site. The evaluation of barometric and tidal data is based on the natural fluctuations that occur in fluid pressures without injecting or removing fluid from the well.

BASIC THEORY

It has long been recognized that water level-fluid pressure fluctuations in wells open to artesian aquifers may be the result of stress-strain changes caused by barometric changes and earth tides. Bredehoeft (1967) summarizes the basic concepts involved in considering the effects of barometric effects and earth tides on fluid pressures. The basic theory assumes an extensive, saturated porous aquifer that is overlain and underlain by impermeable strata (aquicludes). The aquifer is assumed to be artesian. The aquifer may be compressed by external forces such as barometric pressure changes or earth tides. It is generally assumed that when the aquifer is compressed the change in volume of the solid material is small in comparison to the volume change of the water. The change in pore volume is accommodated primarily by the water. Bredehoeft (1967) points out that this assumption may not be valid for limestone or basalt aquifers.

Nearly all the volume change associated with the dilatation of the aquifer results in an equal volume change of the water (Bredehoeft, 1967). "The change in pressure head in the aquifer, -dh, due to a given dilatation, $\triangle$, is therefore

$$-dh = -dp/\rho g = (\triangle E_w/n)/\rho g$$

where h is defined as positive upward" (Bredehoeft, 1967).

The variables are defined as:

p = fluid pressure at the base of the column (M/LT^2),
ρ = fluid density (M/LT^2),
g = acceleration due to gravity (L/T^2),
Δ = given dilatation (dimensionless),
E_w = bulk modulus of elasticity of water (M/LT^2), and
n = porosity (dimensionless).

The common assumption in well hydraulics is made that the well has an infinitesimal diameter. A finite diameter well creates inertial and storage problems that must be considered. These factors can magnify or diminish the pressure fluctuations in the aquifer. These factors will not be addressed in this letter. Suffice it to say that they can be handled.

Tidal deformation relates the actual displacements of the earth's crust to the change in fluid pressures created by this deformation. Five waves are of primary importance to the analysis of pressure fluctuations due to these harmonic motions. These waves are of lunar and solar origin and are designated as M_2, S_2, N_2, K, and O. The tidal dilatation is related to pressure changes as follows:

$$\Delta_t = n\, dp/E_w + dp/E_s.$$

The variables are defined as follows:

Δ_t = tidal dilatation (dimensionless),
n = porosity (dimensionless),
dp = change in pressure (M/LT^2),
E_w = bulk modulus of elasticity of water (M/LT^2), and
E_s = modulus of compression of soil skeleton confined in situ (M/LT^2) (Bredehoeft, 1967).

Specific storage is defined as:

$$S_s = \rho g(1/E_s + n/E_w).$$

The variable "S_s is defined as the quantity of water that is released or taken into storage from a unit aquifer volume" (1/L) (Bredehoeft, 1967). All other variables were defined previously. The change in head is related to tidal dilatation as follows:

$$-dh = \Delta_t/S_s \text{ (Bredehoeft, 1967).}$$

By combining equations Bredehoeft (1967) determined that the tidal effect on fluid pressures can be expressed as:

$$-dh = 1/S_s\, [(1-2v)/(1-v)][\{(2\bar{h}-6\bar{l})/ag\}\, dW_2].$$

The variables are defined as follows:

v = Poisson's ratio (dimensionless),

$\bar{h}$ = Love number at earth's surface (dimensionless),
$\bar{l}$ = Love number at earth's surface (dimensionless),
a = radius of the earth (L),
W_2 = lunar/solar disturbing potential (L^2/T^2).

The specific storage and Poisson's ratio are the two unknowns in the previous equation. Specific storage can be determined if Poisson's ratio is known. Rock mechanic data are necessary for this purpose.

The porosity can be determined based on the relationship between barometric efficiency and specific storage. This relationship is as follows:

$$B = \rho g n / E_w S_s \text{ (Bredehoeft, 1967).}$$

The variable B, not previously defined, is the barometric efficiency (dimensionless). Specific storage can be quantified if Poisson's ratio is known. In addition, the porosity (n) can be quantified if the barometric efficiency is known. Bredehoeft (1967) states that the porosity calculated in such a manner represents "an average value for a large aquifer volume in the vicinity of the well". This value is precisely what is needed at the BWIP site.

CRITICAL COMMENTS ON THE THEORY

The discussion and subsequent development of equations relating barometric and earth tide effects on water level or fluid pressure fluctuations are dependent on the definition of specific storage. Narasimhan and Kanehiro (1980) discuss the various definitions of storage coefficient under the various divisions of earth science using different volume normalizing schemes. The phrase 'storage coefficient' is synonymous with the term storativity; storativity is the product of specific storage, as used in this letter, and the thickness of the unit in question. Narasimhan and Kanehiro (1980) state that the phrase 'storage coefficient' pertains only to drained loading. Kanehiro (1983) defines undrained loading as referring only to "conditions where fluid is neither introduced nor removed from the system." They state further that "The undrained response of a porous medium is outside the scope of the transient groundwater flow equation (diffusion-type equation) normally used in hydrogeology or petroleum engineering."

Bredehoeft and Cooley (1983) took exception to these statements. They stated that "These statements seem, at best, misleading." Bredehoeft and Cooley (1983) state that the transient flow equation has been proven to be quite general and that the equation does apply to the undrained case. These authors also derive the "undrained" phenomenon of tidal efficiency by manipulating the general flow equation. This concern, expressed by Narasimhan and Kanehiro (1980), appears to be unfounded.

Narasimhan, Kanehiro, and Witherspoon (1984) addressed the problem of quantifying aquifer variables by use of barometric and tidal information. They formulated their approach differently than Bredehoeft (1967) because they believe that there is an assumption in Bredehoeft's approach that is suspect. Narasimhan, Kanehiro, and Witherspoon (1984) believe Bredehoeft's assumption that tidal strains "are independent of the elastic properties of the aquifer and are almost entirely determined by the elastic properties of the earth as a whole" is suspect. Bredehoeft's assumption appears to be in contradiction with his statement that the tidal dilatation is related to specific storage. Specific storage is clearly related to the parameters of the aquifer. Narasimhan, Kanehiro, and Witherspoon (1984) state that if Bredehoeft's assumption is invalid then the analysis of barometric data will lead to the estimation of the same set of aquifer parameters derived from tidal data.

CASE STUDIES AND LIMITATIONS CITED THEREIN

Narasimhan, Kanehiro, and Witherspoon (1984) use a reformulated approach to evaluate field data from three geothermal sites. The sites are located in Idaho, Montana, and California. The Idaho data were obtained from a relatively shallow well (1525 meters). The Idaho well is completed in tufaceous sandstones, siltstones and conglomerate. The Montana data were obtained from a 2,000 meter deep well completed in fractured quartz porphyry. The California data were derived from a well completed to a depth of 2,000 meters in poorly consolidated sandstones, siltstones, and shales. Narasimhan, Kanehiro, and Witherspoon (1984) estimated the ratio of specific storage to porosity for these field cases. Narasimhan, Kanehiro, and Witherspoon (1984) believe the estimated properties show reasonable agreement with estimates made from independent pumping tests. They also conducted a parametric study to evaluate the role that permeability and specific storage play in the expected response created by earth tides.

Hanson (1980) calculated the porosity-compressibility product based on tidal strain data. The locations are the same as the California and Idaho sites used by Narasimhan, Kanehiro, Witherspoon (1984). It is not clear if the same wells were used because the wells are not identified by Narasimhan et al. Hanson (1980) states that the results compare favorably with results based on conventional pumping techniques.

Rhoads and Robinson (1979) estimated values for specific storage, barometric efficiency, porosity, and matrix bulk modulus from data obtained from three wells located in Virginia. Rhoads and Robinson claim that the values calculated are "physically reasonable". They note that the accuracy of these values is limited by the imprecise measurements of water levels and barometric pressures. Accuracy also may be limited by leakage from "imperfectly confined aquifers". Well depths range from 61 to 146 meters. The wells are located in rocks characterized by fracture dominated porosity. Rhoads and Robinson (1979) state that their results may be affected by leakage from partially confined aquifers. The calculated values for specific storage and porosity are increased by this effect.

Marine (1975) investigated the effect of earth tides on a slightly fractured crystalline rock. Marine noted that water level fluctuations due to earth tides were not detected in the wells completed in Triassic rocks "because of the very low permeability." The coefficient of storage (storativity) was determined from a pumping test; the permeability was estimated from "packer tests" and a pumping test. The elastic moduli were derived from the geophysical logs. Laboratory analysis of rock samples resulted in an average porosity of about 0.13%. A two year tracer test resulted in a calculated "fracture porosity" of 0.08%. Bredehoeft's (1967) methodology was applied to observations of water level fluctuations in three deep wells (about 1,000 feet deep) in South Carolina near the Savannah River. Four calculations were made for each well at different times of the year. The calculated porosities ranged from 4 to 20%. This range exceeds the porosities measured by other means. Marine (1975) believes that the porosity should not exceed 1%. Marine points out that the calculation of porosity is very sensitive to the accurate determination of specific storage and barometric efficiency.

CONCLUSIONS AND RECOMMENDATIONS

Our literature review suggests that this approach to quantifying porosity should be researched in greater detail and evaluated using data from the BWIP site. The use of earth tide and barometric data could prove to be a useful tool for corroborating effective porosity measurements made by tracer tests at the BWIP site. The limitations pointed out in this letter require additional research. The good quality of the data currently being acquired at the BWIP site suggests that the use of effective porosity data derived from barometric and tidal efficiency data probably would be fruitful and useful for evaluating proposed travel time calculations at the BWIP site. Some of the problems encountered by other investigators at other sites as noted in the articles we have reviewed may be minimized due to the quality of the data that are being derived from the implementation of the principles in STP 1.1. For this reason we would like to pursue this effort. The benefit to the NRC lies in the fact that this effort will provide a corroborative estimate of one of the hydraulic properties required for calculations required for licensing.

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

May 30, 1985
Contract NRC-02-82-044
Fin No. B7372-3
Communication No. 126

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

Dear Matt:

We appreciate the time and effort you have placed into reviewing our Communication No. 123. As you recall, this communication referred to a request that we investigate a methodology for evaluating the effective porosity of basalt at the BWIP site using barometric and earth tide data. We believe this methodology deserves further investigation and therefore we are answering the questions posed in your letter of May 6.

Your first question suggests that BWIP should investigate this methodology rather than Williams and Associates, Inc. as an NRC contractor. We suggest that it is appropriate for the NRC to investigate the methodology under the understanding that should the methodology <u>not</u> appear practical that it <u>not</u> be suggested to DOE for consideration at BWIP. It is not our intent to apply the methodology to the entire Pasco Basin or the Cold Creek Syncline. It is our intent to investigate the applicability of the method to basalt hydrostratigraphic units. This application has not been attempted.

You question whether the analysis can be applied to the multi aquifer system at the BWIP site. You also question whether the relationship between measured barometric efficiency, measured specific storage and effective porosity can be determined for the individual hydrostratigraphic units. This question is one we propose to answer in our review of the methodology. It was not our intent to try and answer this question in the brief proposal we prepared for your review. We suggest that this be a topic that would be considered for further evaluation. No one has attempted the application of this methodology to basalts; consequently we do not know whether it will be successful.

Question 3 asks whether effective porosity, apparent porosity, or total porosity would be derived from analysis of barometric and earth tide data. We acknowledge that the porosity value obtained may be something other than effective porosity. However, it is not clear that the porosity value obtained would not be effective porosity either. Barometric effects are a borehole phenomena. Water must move into and out of the borehole in order for the water level or pressure to respond. Presumably movement or transfer of pressure requires hydraulic connectedness of pore spaces, which implies effective porosity. Consequently we do not believe that the porosity that would be obtained from analysis of such data would be total porosity. The "apparent porosity" as you noted in your letter appears to be the most probable result of such an analysis. One should realize however that apparent porosity may in fact be effective porosity. We believe that the quantification of apparent porosity would serve as an upper bound on the quantification of effective porosity via tracer test analysis. The literature does not consider this issue. As you know, this parameter is required for evaluation of travel time. We believe this is a very useful approach since there is no other ready method for corroborating the effective porosity values obtained from the analysis of tracer tests, which we believe to contain substantial uncertainties. The last point in our argument for the wisdom of this approach is that the real difference between effective porosity, apparent porosity and total porosity values is inconsequential compared to the differences that can be expected from different tracer tests or among other methods (if they are available). Effective porosity and total porosity may differ by a factor of two or three. Differences in effective porosity among tracer tests may be orders of magnitude.

You point out that Narasimhan et al. (1984) question the ability of the method to yield porosity without independent measurements of storativity. This issue is one for which the BWIP site offers a distinct advantage. The large-scale tests to be conducted at the BWIP site should yield the most reliable values obtainable for storativity for the basalt flow tops. This advantage eliminates one of the primary problems with the application of this methodology at sites studied previously, as noted in our literature review. The BWIP site appears to offer a unique opportunity to test the methodology in a multi-layered aquifer system and in a system from which multiple well test data are available.

Your question 5 deals with the possible effect of wellbore storage on the data collected with respect to measured barometric efficiencies. We acknowledge that well bore storage is noted in the literature as being a potential problem with respect to data acquisition. It was not our intent to evaluate this problem in the brief review we sent to you. We propose that this question be addressed in our review of the methodology. We will try to derive a method for correcting for wellbore storage effects.

Question 6 deals with the applicability of the methodology to basalts, which was questioned by Bredehoeft (1967) and the assumption that the well equilibrates instantaneously to fluid pressure changes in the aquifer. The latter issue is related to your previous question about connectedness of pore spaces (effective porosity vs total porosity). These are questions we propose to consider in our evaluation of the methodology should you authorize such work. Bredehoeft does not substantiate his claim regarding the applicability of the methodology to basalts. The question requires further investigation. The question of instantaneous equilibration is a theoretical question which must be evaluated prior to suggesting the methodology for the BWIP site. The lag time issue may not be an important source of error in basalts. We may be interested in monitoring those pore spaces that are connected in the short run only. Storativity measured by pumping test probably would reflect only those pore spaces. We propose that these questions be addressed in evaluation of the methodology. We can only raise them in our proposal.

Question 7 questions the determination of specific storage by the analysis of earth tide data. We do not suggest that the analysis of earth tide data is more appropriate for the calculation of specific storage than is the analysis of the large scale pump test data. We propose that specific storage be calculated from the analysis of the large scale test data to be conducted at the BWIP site. The single well tests conducted to date cannot be relied upon for measuring storativity, $\rho gm(\alpha+n\beta)$. The large scale test data at the BWIP site will provide the information necessary to eliminate α (coefficient of compressibility), one of the variables in specific storage, $\rho g(\alpha+n\beta)$. Our proposal would incorporate this value of α in order to use tidal and barometric data for the determination of n, the value of whatever version of porosity we are measuring.

Question 8 refers to Bredehoeft (1967). Dr. Bredehoeft notes that values of porosity determined from the analysis of barometric and tidal data are representative of large scale portions of the aquifer. Bredehoeft does not quantify this statement. We propose to investigate it. However we do not propose to quantify the areal representation of a porosity value calculated by such means except to the extent that large scale pumping tests will provide values of α. We suspect that the portion of the aquifer characterized is a function of the amplitude and period of barometric pressure changes, the bulk modulus of elasticity of the hydrostratigraphic units involved and the transmissivity and storage of the monitored units.

You note that tracer testing is relatively successful at the BWIP site. We are not yet that confident in the results. We will study future results before reaching a conclusion. We agree that a corroborative methodology is desirable.

We propose that this effort be continued if you find our answers to your questions appropriate. We suggest that this would be an effort which would be initiated by a thorough literature search. We will review the literature found through the literature search. The time required to conduct the literature search and review the appropriate articles should be initiated prior to the long term pumping tests. Williams and Associates Inc. team members have conducted large-scale aquifer tests in the basalts of the Grande Ronde Formation at sites where barometric efficiency has been determined. We propose including these results in our analysis. Four to six weeks worth of effort is proposed to evaluate and prepare a report discussing the methodology outlined in our Communication No. 123. The report, editing, and drafting are anticipated to be completed within the total six-week period of time as suggested in this proposal.

Sincerely,

Roy E. Williams/kw

Roy E. Williams

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