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June 6, 2000

Keith Henn
Tetra Tech NUS, Inc.
661 Andersen Drive
Pittsburgh, PA 15220-2754

RE: Response to comments on aquifer test AT5A

Dear Mr. Henn:

Thanks for taking the time to do a thorough review of the aquifer test.

Tetra Tech Comment 1. Site Description and Description of the Test (Page 4) and Figure 4: There is no mention of when these water levels were taken. It is important to note that they were taken prior to the test and under non-pumping conditions. Perhaps this section should include a brief discussion of the operations prior to the test (e.g., when the wells were shut off; the time that has elapsed since the water levels were taken; time elapsed until the pump test started).

Response: The water levels were taken before pumping began and that is now stated in the report. In addition, the length of the non-pumping period prior to starting the test was discussed.

Tetra Tech Comment 2. Site Description (Page 4) and Figure 4: The term 'gradient' is incorrectly used. Gradient refers to the change in head over a given distance and is represented as a dimensionless (i.e., unit-less) number. What is being referred to here are hydraulic head differences. This should be corrected.

Response: The term gradient was replaced with "water-level differences".

Tetra Tech Comment 3. Description of Test (last sentence, Page 4): How was this "regional trend" removed from the data. What corrections were made to remove this regional trend. For example, it was noted that the water level data (on the CD) was corrected for barometric pressure. What other factors were addressed? This should be discussed.

Response: This discussion was expanded in the report.

Tetra Tech Comment 4. Aquifer Property Determination (Page 5) Paragraph 1: Why was MS-38S not analyzed? An explanation should be included in the report.

Response: Well MS-38S has been added to the analysis, however it did not have a pressure transducer installed in it, so that only a few hand measurements were available.

Paragraph 2 and Figures 5 and 10: Why is there no early data shown for AT-5A on Figure 10? Figure 5 shows the full set of data over the entire time period.

Response: All of the drawdown data for AT5A is plotted on Figure 10. The log axis compresses the data from the well making it appear to be less.

Tetra Tech Comment 5. Figures 5 and 6: Place the X Duration of Pumping" label on Figures 5 and 6 as shown on Figures 7 through 9.

Response: "Duration of pumping" was added to Figures 5 and 6.

Tetra Tech Comment 6. Discussion of Test, (Page 6): first paragraph: The statement that"...the aquifer is relatively homogeneous and anisotropic" contradicts with the text in next paragraph and analysis indicating that the aquifer is not anisotropic. This should be corrected for consistency and to alleviate any confusion.

Response: This was a typo in the copies sent out for review, the statement now reads "...the aquifer is relatively homogenous and isotropic" .

Second paragraph: Perhaps it would be good to illustrate this symmetry by plotting out the well array and contours of drawdown.

Response: I do not think that there is sufficient data to contour the cone of depression.

Tetra Tech Comment 7. Discussion of Test, last paragraph, last sentence (Page 6): Little water level change observed in the deep wells while pumping AT-5A indicates that (1) there is good hydraulic separation between the water bearing zones (above and below the low-permeability material), and (2) that this low-permeability material is laterally continuous (in the vicinity of the test). These points should be added to the point already stated in the report suggesting that lack of response was due to "the low-permeability of the clay".

Response: This was added to the text.

Tetra Tech Comment 8 (a). Discussion of Test, last paragraph, last sentence (Pages 6-8 and Figure 10): We agree that the final result (180 feet/day) falls in the expected range for a medium to coarse sand present in the vicinity of AT-5A. However, we do not agree with

the approach used to determine the aquifer parameters. The fact that the Theis (1935) curve-fitting method was used on the "combined" data set (time versus drawdown) is the basis for our disagreement. The following items discuss this further:

Response: The method that I used is same as described by Theis and is the method described in the following publications:
Dawson, K.J. and Istok, J.D., 1991, Aquifer Testing Design and Analysis of Pumping and Slug Tests, Lewis Publishers, Inc., 344 p.
Lohman, S.W., 1979, Ground-Water Hydraulics, U. S. Geological Survey Professional Paper 708, 70 p.
Kruseman, G.P. and deRidder, N.A., 1990, Analysis and Evaluation of Pumping Test Data, International Institute for Reclaimed Land Reclamation and Improvement, The Netherlands, 377 p.

Attached is a copy of the text from Dawson, K.J. and Istok, J.D., 1991, on page 98 is a plot showing the matching of the Theis curve to multiple monitoring wells. This is exactly the same method that I used.

Tetra Tech Comment 8 (b)* When matching to the "combined" data set the well specific response to pumping is lost or "clouded" significantly as the type curve matches are poor for certain well data and marginally for other well data. For example, several wells including 14-IS, MS-39S, and MS-41S have very poor type curve matches.

* Please see our comments regarding emails transmitted on the subject in the next section.

Response: See discussion below.

Tetra Tech Comment 8 (c)* It is unclear how specific yield (Sy) value was calculated when using multiple wells at multiple radial distances. As you know, to calculate Sy, a radial distance (r) is required. Using multiple wells at multiple radial distances it is unclear what value of r was used. An explanation of what r is used and how it was determined should be included.

Response: In the attached text from Dawson, K.J. and Istok, J.D., 1991, they explain the Theis method, on page 95 is a step by step procedure for the method. Item iv (page 95) explains the determination of the match point. The match point determines a 1/u value that corresponds to a $t/r^2$ value. These are substituted into the equation on page 98 to determine S (or in this case Sy). Thus the r for individual wells is not required.

Tetra Tech Comment 8 (d)* Based upon our industry experience we have not seen this technique discussed in peer-reviewed journals and/or texts as an accepted approach. If such documentation exists, we would be pleased to review it and re-comment on the evaluation discussed.

Response: See discussion above.

Tetra Tech Comment 8 (e)* It appears that the early, middle, and late type curve match was determined from different wells. Yet none of the individual wells fall entirely on the type curve. If the test was run longer maybe certain wells (e.g., MS-39S, MS-40S, and MS-41S) would have matched up along the entire type curve.

Response: If you look at the plot on page 98 of Dawson and Istok (1991) they used wells at radial distances of 30, 200, and 1000 ft. The reason that different radial distances are used is that each well measures different things. The near well is the least influenced by storage and thus is best to define the part of the curve that determines transmissivity. The far well is most influenced by storage within the aquifer and thus defines the early part of the curve. When all of these are combined they define the entire curve. This one of the basic strengths of the Theis method and allows for shorter duration tests.

Based upon our experience we suggest performing the analysis using one of three other methods: Tetra Tech Comment 8 (f)* Evaluating the individual well drawdown versus time data independently. That is, using the Theis (1935) curve-fitting method to determine the transmissivity (T) and Sy for each well individually. Using the individual results "comprehensive" aquifer parameters can then be determined by calculating the geometric mean of all of the independent values. This is the preferred approach because it takes into account the well specific responses independently (of the response measured in other wells). Based upon our industry experience and a review of peer-reviewed journals/texts this procedure is standard. Examples of evaluating the data in this way are shown by Ritzi and Andolsek, 1992.

Response: The paper by Ritzi and Andolsek (1992), which I have included with this letter, does not calculate the transmissivity using the method that you are suggesting. They do not calculate the transmissivity using individual wells and then take the mean. They use the method described by Popadopllos (this paper is also included with this letter). Using the method by Popadopllos determines the directions and values for the principle components of the transmissivity tensor using a rather complicated and involved technique. The reason they developed this method is described in the first sentence of the paper which states "Equations presently used in analyses of pumping tests and predictions of water levels have been derived under the assumption that the aquifers are isotropic. These existing (meaning the Theis and similar methods) are not applicable to anisotropic aquifers..." If you want to determine transmissivity values in different directions then you must use the methods described by Popadopllos and summarized in the above paper that you referenced. I think the method you are suggesting is non-standard and I do not know of any articles describing it.

The essentially equal drawdown shown in the AT5A test in two directions indicates that the cone of depression is nearly round (and not oblong) which is necessary to resolve the transmissivity into the component tensors. For this reason I do not think this method is applicable. But if you want to determine the magnitude and direction of T and K (which is what will be done if you use individual wells) then you need to use the methods described by Popadopllos.

Tetra Tech Comment 8 (g)* Using a distance-drawdown analysis using the Cooper and Jacob (1946) method (see discussion below).

Response: (see discussion below).

Tetra Tech Comment 8 (h)* Another analytical approach would be to combine the data by plotting drawdown versus time/radius2 for all of the wells and using one type curve match. Kruseman and deRidder (1990, Chapter 3) have shown that combined data sets can be analyzed using the Theis (1935) method when the data are plotted in terms of drawdown versus time/radius2. Once the data set is plotted, a type curve (e.g., Theis) or a straight line (e.g., Cooper and Jacob method) can be drawn through the data. Thus, determining a "comprehensive" set of aquifer parameters.

Response: This is exactly the method I used.

Tetra Tech Comment 8 (i) Using the data set provided on the CD, we performed an analysis on "individual" well data for MS-39S, MS-40, and MS-41S using the Theis (1935) method. We determined hydraulic conductivity (K) values to be 106 feet/day, 125 feet/day, and 85 feet/day, respectively. Analysis of these wells was selected because they appear to have the most complete data sets. A distance-drawdown evaluation was also performed (using wells MS-38S, MS-39S, and MS-41S) yielding a K of 142 feet/day. This indicates that the 180 feet/day presented in the report may be biased high. Two implications of a high K are a linearly biased high groundwater and contaminant velocities and travel times and capture zone widths biased low. Although 180 feet/day was used in the groundwater model, sensitivity analysis will be run to determine its affect on the capture zone of AT-5a.

Response: (to use of individual wells). See discussion above.

Response: (to distance drawdown discussion). I feel that the distance drawdown method is not valid for this test. This method requires that the aquifer reach near steady state conditions and this condition is not met by this test. To illustrate this, I followed Procedure 3.1 given on page 57 of Kruseman and deRidder (1990, a copy of the text is included with this letter). The suggested plot for the AT5A test is shown in Figure 1. These wells did not reach a straight line condition, and thus are not close to steady state (compare this plot to Figure 3.3 of Kruseman and deRidder (1990) that illustrate wells that have reached steady state).

The straight line method generally works only for confined aquifers where near steady state is reached rather quickly and not for unconfined aquifers where near steady state is much slower to develop. The reason this method does not work for this test is that a large portion of the water is coming out of storage in the vicinity of the pumping and monitoring wells (a slowly developing cone of depression). The effect on the analysis is that it will determine a slope on the cone of depression that is steeper than the one that would eventually develop once steady state conditions are reached. Because the slope that you calculated for the distance drawdown is too steep the K value will be lower than the true value, thus true value would be expected to exceed 142 ft/day.

The Cooper and Jacob method also requires near steady state conditions, and will not work for this test. As seen in figure 1, the wells do not reach the straight line segment that is necessary for this method to be applied.

Tetra Tech Comment 9. General Comment: Was a recovery test performed? As stated in our comments on the preparation of the test (emailed December 29th) this test would provide a "check" on the pumping test results.

Response: A recovery test was not done because (1) only 2 wells (that had experienced drawdown) had the recovery data recorded, thus there was a limited data set; and, (2) recovery data requires 2 corrections (instead one for the pumping data). The second correction is an extrapolation of the drawdown that would have occurred if the pumping had continued. Because of the additional correction (which is not known and must be estimated), the recovery data is more susceptible to error if these corrections are not correct.

The greatest strength of recovery analysis is that it can provide better data if the pumping rate is somewhat variable during the pumping part of the test. Because the pump is off during the recovery period, the recovery of water levels in the aquifer is smoother, thus could be a better data set. However, this test used an electric pump (which instantly went to a pumping rate of 167 gpm) and thus did not have a varying pumping rate.

Tetra Tech Comment 10. General Comment: As a minor comment, there are several misspelled words and incorrect phrases in the report. For example on page 3, Prairie du Chien and Jordan are misspelled as "Prairie du Chen" and "Jordon", respectively. On page 6, the Theis (1935) method is inconsistently misspelled as "Thies". The wells discussed on pages 6 and 7 should be described as having a given number of "feet of radial distance from the extraction well instead of having a "radius of X feet".

Response: The corrections you suggested were made.

If you have any questions please do not hesitate to call me at (850) 942-9500 X3038.

Sincerely,

Hal Davis

Hal Davis
Hydrologist

Enclosures - as cited

cc: Cliff Casey
Joel Sanders