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May 1, 2012

CERTIFIED MAIL
(Return Receipt Requested)

Billy M. Ray
Manager Closure Execution
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Subject: Montgomery & Associates (2012) Final Work Plan, Supplemental Site Assessment to Address Out-of-Compliance Status at Trend Wells RL-1 and EF-8, Lisbon Facility, Prepared for: Rio Algom Mining LLC, April 13, 2012: **Request for Information**

Dear Mr. Ray:

The Utah Division of Radiation Control (DRC) has recently reviewed a draft copy of Montgomery & Associates (2012) Final Work Plan, Supplemental Site Assessment to Address Out-of-Compliance Status at Trend Wells RL-1 and EF-8, Lisbon Facility, Prepared for: Rio Algom Mining LLC, April 13, 2012. Overall, this is a very impressive advancement in the work-plan product. The DRC acknowledges the high levels of coordination and cooperation that both Rio Algom (RAML) and Montgomery & Associates (M&A) have had with the DRC on this project. Most of the changes suggested previously have already been incorporated into this draft Final Work Plan.

There remain, however, a number of points that, from the perspective of the DRC, still need attention. These are listed below, with paper copy page numbers or other identifiers listed on the left, and electronic page numbers, RAML statements, and DRC responses listed subsequently.

P8 RAML Statement (p. 13 of the electronic copy)

TABLE 2. COMPARISON OF GROUNDWATER LEVEL AND SCREENED INTERVAL IN WELLS

WELL NAME	MAY 2011 GROUNDWATER LEVEL ELEVATION (ft msl)	TOP OF SCREEN ELEVATION (ft msl)	BOTTOM OF SCREEN ELEVATION (ft msl)	TOP OF SCREEN SUBMERGENCE [a] (feet)	SATURATED THICKNESS [b] (feet)
MW-5	6,589.38	6,577	6,547	12	30
H-63	6,552.43	6,545	6,515	7	30
OW-UT-9	6,580.04	6,584	6,566	-4	***14***
LW-1	6,575.28	6,517	6,487	58	30
MW-13	6,547.63	6,513	6,433	35	80
EF-3A	6,496.19	6,408	6,378	88	30
EF-8	6,498.49	6,361	6,331	137	30
EF-6	6,495.50	6,464	6,434	32	30
RL-1	6,536.17	6,547	6,527	-11	***9***
RL-3	6,534.11	6,539	6,519	-5	***15***
RL-5	6,534.05	6,535	6,498	-1	***36***
RL-4	6,524.69	6,543	6,503	-18	***22***
ML-1	6,487.33	6,468	6,448	19	20
		6,378	6,363	109	15
RL-6	6,444.08	6,452	6,442	-8	***2***

Notes:
ft msl – feet above mean sea level
[a] negative submergence values indicate water table below top of screen
[b] bold italics indicate water table within screened interval of well

DRC Response:

As shown in Table 2 above, the portion of screen that is in contact with groundwater is called the "saturated thickness". Normally, the term "saturated thickness" refers to the thickness of the aquifer that is fully saturated. Please revise the language here (e.g., "saturated screen length" would be acceptable) to be consistent with normal usage.

P9 RAML Statement (p. 14 of the electronic copy):

"Well ML-1 reportedly has a single-casing with two separate screened intervals. The rationale for this construction method is unknown. The lithologic log and well schematic for ML-1 is included in Appendix A. The two hydrostratigraphic zones screened by ML-1 are separated by about 70 feet. The degree of hydraulic communication between the two screened intervals is unknown. Water level data from ML-1 represent the average hydraulic head of the two screened zones. Borehole flowmeter testing in ML-1 could provide information on hydraulic gradients near the well. Depth specific sampling in ML-1 could provide information on deep and shallow groundwater quality."

DRC Response:

There's some question about how Well ML-1 is constructed. How it is constructed will make a difference as to how sampling and analysis results for this well will be interpreted.

Page 1 of the well log as shown in the Appendix shows that drill cuttings were left in the borehole from a depth of 80 feet down to 97 feet before a screen was emplaced from a depth of 70 feet down to 80 feet.

On the other hand, Page 2 shows blank PVC, with a cement annular seal, not well cuttings, from 87 feet to 97 feet and beyond that, as well, down to 145 feet. Below 145 feet, a screen was emplaced.

Construction of this well or this set of wells is not clear.

(i) Was there one well created in a single borehole with a single in-line series of casing elements with two screened intervals?
(ii) Were there two wells installed in one borehole?
(iii) Were there were two boreholes, each containing a well?

It is hard to reconcile that there was a single casing with two screened intervals, since Page 1 of the well log presentation shows drill cuttings left between 80 and 97 feet, and Page 2 shows straight PVC and cement seal present at this depth interval with no drill cuttings.

Page 1 of the boring log states that the depth to first water was encountered at 85 feet. Yet, an upper screen and sand pack was supposedly set between 60 and 80 feet, which is above the water table.

The DRC requests that RAML investigate this and report back the results to the DRC, since a knowledge of whether sampled fluids are coming from a screened interval of 60-80 feet of depth (as shown on Page 1), from a screened interval of 145-167 feet of depth (as shown on Page 2), or both will make a big difference in how reported heads or water quality indicators are interpreted.

P9 RAML Statement (p. 14 of the electronic copy):

"Well RL-6 is approximately 18 feet deep; the depth of the other 13 existing wells ranges from 124 to 242 feet. Well RL-6 appears to be located in or near an ephemeral wash. A well schematic and lithologic log for RL-6 are not available; therefore, the rationale for the shallow well depth is unknown. It is unclear whether water level data from this well are meaningful given the small saturated thickness (about 2 feet) in the well. In addition, it is unclear if groundwater from this well is from the same hydrostratigraphic zone(s) screened by the other wells."

DRC Response:

The DRC approves of further investigation of this area at greater depths, down to the base of the Burro Canyon Formation (BCF) after starting to drill into the Brushy Basin Member (BBM). Please proceed to do this carefully. It is doubtful that the BCF has a thickness of less than 18 feet in this area, since southeast, parallel to the Lisbon Valley Anticline (LVA), BCF thicknesses of more than 150 feet are found (e.g., in the area of Well ML-1). If the thickness does turn out to be 18 feet or less in this area, then an appropriate conceptual model needs to be developed to account for this, and the potential impacts of structural and stratigraphic features in this area on groundwater flow and contaminant fate and transport need to be investigated further, in greater detail.

P16 RAML Statement (p. 21 of the electronic copy)

"All wells will be constructed under the supervision of a licensed Professional Geologist and by a State of Utah licensed well driller. M&A is in the process of licensing a geologist in Utah. This process should be completed before initiation of field work. If not, the M&A project manager is an Arizona and California licensed Professional Geologist and RAML would request approval from DRC to allow the M&A project manager to oversee well design and construction."

DRC Response:

As RAML may well be aware, in Utah, the PROFESSIONAL GEOLOGIST LICENSING ACT, Title 58, Chapter 76 Utah Code Annotated 1953, As Amended by Session Laws of Utah 2011, Issued May 10, 2011, is the law that governs who can legally practice geology before the public in Utah. Information is found at http://www.dopl.utah.gov/laws/58-76.pdf.

This law specifies that "a license is required to engage in the practice of geology before the public except as specifically provided in Sections 58-1-307 and 58-76-304." The DRC is not permitted under Utah law to modify or change the provisions of this act.

The rule pertaining to this act, R156-76, known as the Professional Geologist Licensing Act Rule, can be reviewed at http://www.dopl.utah.gov/laws/R156-76.pdf. This rule does appear to allow potential applicants having specified experience and licensing under another jurisdiction to apply for licensure in Utah.

General information on licensing in Utah is found at http://www.dopl.utah.gov/licensing/geology.html.

P19 RAML Statement (p. 24 of the electronic copy)

"DRC expressed concerns about the adequacy of low-flow sampling at the Site in their comments on the initial work plan. DRC's primary concern is that samples collected using the low-flow method from deep, submerged screened intervals are not representative of the entire saturated groundwater zone near the wells. RAML agrees with this concern and recognizes that these samples are only representative of the groundwater zone screened by the wells. As pointed out by DRC, a companion shallow well would be needed to sample the shallower groundwater zones. RAML agrees and has included shallow wells in the field program to address this concern."

DRC Response:

Upon further consideration by DRC, and in order to be consistent with requirements at other Utah Uranium Mills and at 11e.(2) disposal sites, the DRC is requiring that, unless an exception is granted in writing for special circumstances on a case-by-case basis, all new monitoring wells intended in part for general detection of contaminants must provide screens (either in one well or in a closely spaced cluster of wells) that fully penetrate the saturated zone of the aquifer, as well as extend five feet above the saturated zone. Wells with shorter screen lengths may in some instances be requested once contamination is generally detected so as to enable accurate sampling and analysis of contaminant concentrations in relatively narrow depth-specific zones. Furthermore, all existing wells must be accompanied by additional wells (drilled in a cluster) so as to provide, individually or collectively, a screened interval providing full penetration of the saturated zone, and extending five feet above. The DRC is concerned that providing only relatively short screens at the top and bottom of a thick saturated zone will not provide monitoring over the full depth of the saturated zone and may thus miss potential preferential hydraulic pathways.

Such wells, as with all other non-low-flow sampled wells, must be purged with three casing volumes of water, and the groundwater that is pumped to the surface must be stabilized in terms of key groundwater quality parameters before sampling begins.

Alternately, if RAML wishes to pursue low-flow sampling at a location, then monitoring wells, each with a maximum screen length of 10 ft (3 m), must be installed such that full-screen coverage is provided collectively over the full saturated zone thickness, plus five feet above. A maximum length of 10 feet for a screen for a well sampled via low-flow sampling is prescribed by the U.S. EPA Superfund/RCRA Ground Water Forum in U.S. EPA (2002). Even shorter lengths may be recommended in some settings for narrower plumes (Puls and Barcelona, 1996).

The DRC thus concurs with RAML concerning the assessment of a need to add companion shallow wells in several areas to allow for sampling and analysis of shallower groundwater. MW-107S is an example.

Table 2 in the RAML work plan (p. 8, or electronic page 13) shows that several wells exist where a sizeable column of groundwater overlies the existing screened interval. A copy of the table is shown here:

TABLE 2. COMPARISON OF GROUNDWATER LEVEL AND SCREENED INTERVAL IN WELLS

WELL NAME	MAY 2011 GROUNDWATER LEVEL ELEVATION (ft msl)	TOP OF SCREEN ELEVATION (ft msl)	BOTTOM OF SCREEN ELEVATION (ft msl)	TOP OF SCREEN SUBMERGENCE [a] (feet)	SATURATED THICKNESS [b] (feet)
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Notes:
ft msl – feet above mean sea level
[a] negative submergence values indicate water table below top of screen
[b] bold italics indicate water table within screened interval of well

Well ML-1 is of uncertain construction, as previously stated. If both apparent screened intervals exist are open to sampling, then each should be sampled separately.

Each well from the following group, Wells MW-5, H-63, LW-1, MW-13, EF-3A, EF-8, EF-6 and ML-1, has groundwater existing outside of the well with a hydraulic head existing above the top of the existing screen. Unless otherwise proven, it is assumed that this groundwater resides in an unconfined aquifer. Thus, the DRC requests RAML to install one or more companion wells next to each of these existing wells to allow representative sampling of the entire saturated thickness.

In the drilling of these wells, as of all others, it will be important for each well to be stable, to have its gravel pack or sand pack properly constructed so as to provide support for and to prevent silting or sanding in the screened zone, and to allow for influx of groundwater from all contacted water-bearing zones.

P22 RAML Statement (p. 27 of the electronic copy)

"The Phase 2 probabilistic numerical model will be used to evaluate system behavior and reestablish ACLs at the Site."

In the opinion of the DRC, the Phase 2 probabilistic numerical model will provide information, which, along with other sources of site data, i.e., field and laboratory data, may contribute to making significant decisions about the Site. It is doubtful that results of the probabilistic model themselves, especially if they were in conflict with or were unsupported by field and laboratory data, will be controlling.

Tbl#1 RAML Statement (p. 29 of the electronic copy)

In Table 1, 4B, RAML states, "RAML will provide cross-sections in the final report when data from the new wells are available."

DRC Response:

The DRC reminds RAML that one of the major purposes of cross-sections is to evaluate "assumptions of unsaturated zones across the crest of the LVA." This will require linking data from existing wells and also that from any new wells drilled especially to help evaluate the nature and extent of the assumed unsaturated zone.

One well recommended for drilling for this purpose, which does not appear to have been included yet in the current RAML work plan, is a well that would be located due east from the currently proposed Well MW-110, and north-northwest of Well H-63. Its purpose in part is to assess a historically identified saturated zone found in, around or near former well H-14 in what is sometimes characterized in reports, as in the current work plan, as an unsaturated zone located near the crest of the LVA. This location is also downgradient from one or both of the former tailings ponds. Please be sure to drill and complete such a well. On page 8 of the original DRC review, the DRC stated that the "DRC recommends . . . wells . . . near Wells DM89-1 and H-14."

Tb1#1 RAML Statement (p. 29 of the electronic copy)

In Table 1, 4S, RAML states, "RAML agrees that additional wells are needed northeast of EF-3A, and has included them in the work plan; refer to Section 3.2.1 for additional information."

DRC Response:

The DRC, in its Section 4S of the original review, states, "It is also advised that RAML and M&A install and screen one or more monitoring wells in the Brushy Basin Member NE of Well EF-3a. This would appear to be under the dry zone of the Burro Canyon Formation near the crest of the LVA . . . "

A well drilled in this location and sampled for contaminants of concern would help establish the hydraulic head value for groundwater present in the Brushy Basin Member and also help evaluate whether contamination is moving through the BBM directly downgradient (albeit at a slow rate) from suspected sources toward the west or west-southwest.

The DRC recognizes that finding access in the NE direction from Well EF-3A near the crest of the LVA may not be feasible due to the presence of the covered tailings piles. However, the well requested to be drilled near former Well H-14, as discussed in the previous response, would, while being more to the east, satisfy this requirement if the zone there is actually dry. If the zone is saturated, then this also provides useful information in understanding potential westward contaminant migration.

Proposed Well MW-107DB, while lying NE of Well EF-3A and proposed to be drilled down into the Brushy Basin Member, does not lie "under the dry zone of the Burro Canyon Formation near the crest of the LVA" and it does not appear to be able to meet the aforementioned needs. It lies in a zone where ample groundwater exists in the Burro Canyon Formation and where groundwater contamination is also abundant and measured.

Please reconsider where RAML would like to drill northeast of EF-3A to address its own needs and those of the probabilistic model, and also meet the DRC's concerns.

Tb1#1 RAML Statement (p. 31 of the electronic copy)

"RAML does not agree that low-flow sampling is inappropriate in wells EF-3A, EF-8, and other wells where the groundwater level is more than 10 feet above the top of the screen. Samples obtained from these wells using proper low-flow methods are representative of groundwater quality within the screened interval of the well. RAML agrees that low-flow sampling is incapable of characterizing the entire vertical zone of saturation near the wells. To address this, RAML will install a shallow companion well near EF-3A and other shallow water table wells near EF-3A and EF-8 (refer to Section 3.2.1, Figure 6, and Table 3)."

DRC Response:

After several internal discussions, the DRC is willing to allow low-flow sampling to take place at the site upon the following conditions:

(i) DRC-approved work plan protocols are carefully followed.
(ii) Low-flow sampling conducted conforms to EPA prescriptions that low-flow sampling "*should not be used with well screen lengths greater than 10 feet (3 meters)*" (Yeskis and Zavala, 2002).
(ii) Field work is performed under the direction of a licensed Utah professional geologist, or, if appropriate, a licensed Utah professional engineer.
(iii) All individuals involved in sampling activities receive thorough training from an experienced individual proficient in low-flow sampling before sampling activities are commenced.
(iv) Field work practices and results are audited by an experienced individual proficient in low-flow sampling for the first two sampling rounds and periodically thereafter to ensure continued quality assurance and quality control.
(v) Companion wells are drilled and sampled near existing wells that do not by themselves provide full screened coverage of the saturated thickness of the aquifer and five feet above.
(vi) RAML provides representative sampling for the full thickness of the saturated zone of the aquifer plus five feet above.

Fig2-2 RAML Statement (p. 45 of the electronic copy)

The figure caption for Figure 2-2 on electronic page 45 says, " Figure 2-2. Boring log and well construction for RL-2."

DRC Response:

This figure does not show any well construction details and is indicated to be for a pilot hole, not a well.

Please provide the actual well log construction diagram, if possible, and, if not possible, then correct the figure caption.

ML-1 RAML Statement (p. 50 of the electronic copy)

This log for ML-1 has two pages.

DRC Response:

As indicated earlier, there are discrepancies between Pages 1 and 2 of this log for the depth interval between 80 and 97 feet. Please investigate and report back to the DRC.

TblB1 RAML Statement (p. 54 of the electronic copy; see also p. 59)

"The BCA is divided into four zones as shown on Figure B1. The BBM is represented as a single zone. Conductivities are assigned via stochastic modeling."

DRC Response:

Please consider a modification for subsequent modeling. The water-table aquifer actually consists in part of BCF and in part of BCM. The "dry zone" (the x-y area at and near the crest of the LVA where the BCF is not saturated) can be better represented in modeling by a lower-permeability BCM zone, since it is this zone that actually contains groundwater in this area. The current use of parts of two much higher-K-value BCF zones to represent the "dry zone" is not considered advisable.

AppB RAML Statement (p. 58 of the electronic copy)

"Additional changes – Any other changes deemed necessary for optimal development of ACL's may be incorporated into Phase 2 modeling."

DRC Response:

Please clarify the meaning, purpose, intent and limitations of this statement or remove it entirely.

AppC RAML Statement (p. 66 of the electronic copy)

Under the heading "BBM Wells" it states, "Wells completed in the BBM below saturated areas of the BCF are designated BBM wells. Boreholes will be advanced to approximately 10 feet below the estimated water table in the BCF."

DRC Response:

Originally, the idea for BBM wells was to look for the water table in the BBM if it was found that the BCF was NOT saturated. But, in the statement above, it speaks of "wells completed in the BBM below saturated areas". It's not clear what's meant here. Since reference is made to the water table existing in the BCF, it sounds like there is some confusion about why these specific wells are to be installed. Perhaps this is an area about which RAML and the DRC need to talk.

AppC RAML Statement (p. 72 of the electronic copy)

"Hydraulic testing will be conducted in a manner which prevents the following: ... 3. Alteration of the hydraulics of the subsurface in such a way that a nearby contaminant plume is enlarged or migrates to a formerly unimpacted location other than the clean test well."

DRC Response:

The DRC does not see a need for the phrase "other than the clean test well" in the above sentence, and does not approve of contamination of a formerly clean test well. Is there some sort of way to sample and analyze in the field to ensure that contamination is not being picked up by the clean test well on an extended basis during pumping?

AppC RAML Statement (p. 73 of the electronic copy)

"After completion of the step drawdown test, the well will be allowed to recover for a period at least as long as the duration of the step test."

DRC Response:

This is not sufficient time for the groundwater level to return to its initial state. In all likelihood, the time for recovery will need to be several times greater than the pumping period. For additional explanation, please see Appendix A. Also, please reference the applicable ASTM field method guidance for constant rate discharge tests in this section and insure that all field protocols conform to the applicable guidance.

AppC RAML Statement (p. 73 of the electronic copy)

"A constant rate discharge test will then be conducted for a period of up to 12 hours."

DRC Response:

12 hours is generally insufficient for a pumping test in an unconfined aquifer. Most experts recommend at least 72 hours (e.g., see Driscoll, 1986, p. 535; Watson and Burnett, 1983; Kruseman and de Ridder, 1990, p. 44). Please revise the pumping time to be consistent with standard practice or justify the extremely short pumping period.

Please specify in the work plan how the pump will be able to be maintained at a constant rate over the duration of the pumping test. Please discuss, in particular, how fuel will be supplied during the pumping test, how groundwater will be collected and transported and disposed of, how different shifts will be conducted, how a Utah certified professional geologist or Utah certified professional engineer will be able to supervise the entire testing process, how flow measurements will be made, how flow rates will be regulated and kept within 10% of the target rate, and how it will be ensured that the saturated thickness of groundwater in the well will not be drawn down below the level of the pump intake at any point during the test.

AppC RAML Statement (p. 73 of the electronic copy)

"Integrated pressure transducers/data loggers will be installed in the test well and nearby wells to record water levels during the discharge tests."

DRC Response:

The above statement has a problem in the opinion of the DRC because it does not seem that there are observation wells at depth in the BCF located close enough to the pumping well for water levels to be recorded in such wells. Because of relatively low permeability, the pumping well will need to be pumped at a relatively low rate. In an unconfined aquifer, the measurable radius of influence during pumping may only be several hundred feet.

If the only useful data obtained at depth from the BCF is from the pumping well, then only tranmissivity in the formation screened by that well can potentially be evaluated. Storativity typically cannot be assessed from such a test.

References

Yeskis, D. and Zavala B. (2002) Ground water sampling guidelines for superfund and RCRA project managers, Report 542-S-02-001, U.S. Environmental Protection Agency.

If you have any questions, please do not hesitate to contact me at 801-536-4250.

Sincerely,

David A Edwards

David Edwards
Environmental Scientist

DE/de

Appendix A

Time Required for Residual Drawdown to Attain a Given Fraction of Maximum Drawdown during Recovery

by David A. Edwards

Abstract: It is a common misconception that the time that it takes for groundwater to return back to its initial static level after having been pumped for a while is simply equal to the amount of time spent in pumping. This is not the case. Calculations shown below for an aquifer such as described by Theis (1935) indicate that the time required for nearly complete return to static groundwater levels may be much greater than the time spent in pumping, e.g., even by as much as an order of magnitude or more.

When a well is pumped for a period of time and then pumping stops at a time t_p, the maximum drawdown attained is s_m. The process of recovery then commences. As recovery progresses, residual, or remaining, drawdown decreases nonlinearly over time. This article shows that the time required during the recovery process for residual drawdown to attain a given fraction of maximum drawdown can be much greater than the initial pumping time. Although, for simplicity, analyses for testing of confined aquifers having characteristics such as those described by Theis (1935) are discussed here, the general conclusion made in this article may also be applicable to other types of aquifers and pumping tests, such as step tests.

For an idealized confined aquifer with values of $r^2S/4Tt_p < 0.02$, the approximate value of s_m is given by Cooper and Jacob (1946) as

$$s_{maz} = [Q/(4\pi T)]\ln[(2.25Tt_p)/(r^2S)] \quad (1)$$

where Q is flow rate, T is transmissivity, S is storativity, and r is radial distance to the pumping well, all expressed in consistent units. Q, T, S and r can vary over a wide range of values. The following symbols can be used to simplify the equation:

$$\alpha = Q/(4\pi T) \quad (2)$$

and

$$\beta = (2.25T)/(r^2S) \quad (3)$$

Thus, Equation (1) becomes

$$s_{max} = \alpha\ln(\beta t_p) \quad (4)$$

After the well recovers for a sufficient time, equal to t_r, when $r^2S/4Tt_r < 0.02$, the residual drawdown, s_{res}, is equal to (see Jacob, 1963)

$$s_{res} = [Q/(4\pi T)]\{\ln[(t_p + t_r)/t_r]\} \quad (5)$$

or, using (2),

$$s_{res} = \alpha\{\ln[(t_p + t_r)/t_r]\} \quad (6)$$

Dividing s_{res} by s_{max} gives the fractional residual drawdown F_{res}

$$F_{res} = s_{res}/s_{max} = \alpha\{\ln[(t_p + t_r)/t_r]\}/[\alpha\ln(\beta t_p)] \quad (7)$$

or

$$F_{res} = \ln[(t_p + t_r)/t_r]/[\ln(\beta t_p)] \quad (8)$$

This equation is useful for estimating how long it will take before groundwater levels begin to approach static equilibrium or to calculate how much of an approach to static equilibrium takes place in a given time.

A common misperception is that once the amount of recovery time equals the amount of pumping time, the groundwater levels will have returned to static conditions. This is not the case.

Say, for example, that the time of pumping is 50 hours. After a subsequent recovery of an equal amount of time, i.e., 50 hours, Equation (8) becomes

$$F_{res} = \ln[(50\text{ hrs} + 50\text{ hrs})/50\text{ hrs}]/[\ln(\beta*50\text{ hrs})] \quad (9)$$

or

$$F_{res} = 0.693/[\ln(\beta*50\text{ hrs})] \quad (10)$$

If $T = 6$ ft^2/hour, $r = 100$ ft, and $S = 0.001$, then

$$\beta = (2.25T)/(r^2S) = (2.25*6\text{ ft}^2/\text{hour})/[(100\text{ ft})(100\text{ ft})*0.001] = 1.35\text{ hr}^{-1} \quad (11)$$

and F_{res} then equals

$$F_{res} = 0.693/[\ln(1.35\text{ hr}^{-1}*50\text{ hrs})] = 0.16 \quad (12)$$

which means that if s_{max} at time t_p (i.e., after 50 hours of pumping) were 10 feet, then, after a comparable period of time in recovery (i.e., 50 hours of recovery), there would still be 1.6 feet of residual drawdown.

After a recovery of 100 hours,

$$F_{res} = \ln[(50\text{ hrs} + 100\text{ hrs})/100\text{ hrs}]/[\ln(\beta*50\text{ hrs})] \quad (13)$$

or

$$F_{res} = 0.405/[\ln(1.35\text{ hr}^{-1}*50\text{ hrs})] = 0.096 \quad (14)$$

This means that after a recovery period of twice the pumping period, there would still be 0.96 feet of residual drawdown at this well.

Assume that an objective is to achieve a residual drawdown of only 2% of the maximum attained, that is, for groundwater to return nearly to the original static groundwater level. Thus, F = 0.02. First, Equation 8 can be arranged, and then Equation 11 and some parameter values inserted:

$$F_{res} = \ln[(t_p/t_r + 1)]/[\ln(\beta t_p)] = \ln[(t_p/t_r + 1)]/[\ln(1.35\ hr^{-1}*50\ hrs)] = 0.02 \quad (15)$$

Rearranging gives

$$\ln[(t_p/t_r + 1)] = 0.02 * [\ln(1.35\ hr^{-1}*50\ hrs)] = 0.085 \quad (16)$$

And solving for t_r gives

$$t_r = t_p/\{[\exp(0.085) - 1]\} = 50\ hrs/0.0887 = 564\ hours$$

Thus, it takes much more time for groundwater to get back to static conditions than it takes to draw it down to some initial level. In this particular instance, to attain a residual drawdown of 2% of initial drawdown in this specific aquifer, the ratio of recovery time to pumping time is 11.3.

References

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