SAFETY EVALUATION REPORT
REVIEW OF APPLICATION TO AMEND LICENSE CONDITION 11.3(C), LICENSE SUA-1601, STRATA ENERGY, INC. ROSS IN SITU RECOVERY FACILITY, CROOK COUNTY, WY

DATE: January, 2018

DOCKET NO.: 040-09091

LICENSEE: Strata Energy, Inc.

SITE: Ross ISR Facility, Crook County, Wyoming

PROJECT MANAGER: Don Lowman

TECHNICAL REVIEWER: John L. Saxton

SUMMARY AND CONCLUSIONS:

Strata Energy, Inc., (Strata) submitted an application to amend License Condition 11.3(C), which specifies the minimum density of monitoring wells to be included in the designated underlying aquifer. The application is specific to monitoring at Mine Units 1 and 2. The application is based on the designated underlying aquifer wells not meeting the definition of an aquifer due to their low yield (transmissivity), posing logistical problems for sampling, having a poor water quality and distances to the next underlying water-bearing unit greater than 50 feet. The application concludes that monitoring at only one well out of 34 needs to be continued based primarily on the well yield analysis. In sum, the application requested relief from License Condition 11.3(C) regarding the number of wells to be monitored. The NRC staff verified Strata's proposed criteria and methodology for determining whether monitoring of a Deep Monitoring Zone (DM) unit well can be discontinued and determined that Strata's request for relief should be granted. The NRC staff concurred with Strata's proposed criteria and methodology except for Strata's application of the method used to evaluate slug test data for several wells (eight wells in total including the one Strata Energy, Inc. recommended for continuing monitoring). Consequently, the NRC staff recommends approval of Strata Energy, Inc.'s request, conditioned on Strata's continued monitoring at the eight wells of the current 34 wells.

1.0 Background

For a typical wellfield undergoing in situ uranium extraction, the U.S. Nuclear Regulatory Commission (NRC) generally requires routine monitoring of the surrounding aquifers, including the first overlying and first underlying aquifers, to ensure fluids do not migrate away from the production area. By license condition, that requirement for Strata Energy, Inc. (Strata) at its Ross ISR Facility includes monitoring groundwater in the first underlying aquifer at each wellfield using a specified well density of one well per four acres.

At the Ross facility, Strata has designated the first "water-bearing" lithology below the proposed ore zone as the first underlying aquifer. This lithology, referred to as the DM unit, is a thin (thickness of approximately 20 feet) siltstone located stratigraphically within a mudstone, which is the confining unit. Strata designated the DM unit as the underlying aquifer despite identifying the marginal ability of this lithology to transmit water to wells for the license application.

During development of the first mine units, Strata concluded that routine monitoring of the low-yielding wells was burdensome resulting in extreme efforts for sampling. By letter dated July 16, 2015 (Strata, 2015a), Strata submitted an application to the NRC amend its license to reduce that burden. Specifically, Strata sought to amend License Condition 11.3(C) in its Source and Byproduct Materials License SUA-1601. The amendment application proposed procedures to establish whether future monitoring of the underlying aquifer (DM unit) was necessary at a specific well location. The NRC's acceptance review identified that Stata's procedures were based on unverifiable methods or non-established criteria. Therefore, by email dated March 9, 2017 (NRC, 2017a), the NRC staff informed Strata that the application was unacceptable as proposed. By email dated March 29, 2017 (Strata, 2017a), Strata withdrew the application to address the technical deficiencies identified by the NRC staff.

By letter dated April 5, 2017 (Strata, 2017b), Strata submitted a second application to amend License Condition 11.3(C). This application is the subject of this review. The application addressed four areas of review that NUREG-1569 recommends staff review when eliminating the requirement for monitoring of an underlying aquifer (see Regulatory Requirements below). In its application, Strata provided a quantifiable analysis of potential yields for wells screened in the DM Unit at Mine Unit 1 (MU1) and MU2, and compared the average yield to the Wyoming Department of Environmental Quality/Land Quality, the Division's (WDEQ/LQD's) criterion for definition of an aquifer (i.e., a well yielding 0.5 gallons per minute (gpm) sustained for 24 hours). Strata stated that WDEQ/LQD's criterion was "very conservative" because: (1) well use in this aquifer will be predominantly for livestock watering and typical yields for this type of well, according to Strata, is from two to five gpm; (2) wells in the DM Unit yield poor water quality water; (3) the underlying aquitard(s) are thick with few drillhole penetrations; and (4) the wells in the DM Unit would increase the risk of a vertical excursion. Strata also provided an analysis of the environmental impacts should fluids migrate to the DM unit through an abandoned drillhole. Details of Strata's analyses are discussed below.

In the April 5 application, Strata proposed revised language to License Condition 11.3C as follows:

> *Overlying and Underlying Aquifers. Samples shall be collected from all monitoring wells in the first overlying and first underlying aquifer at a minimum density of one well per 4 acres of wellfield* ***unless wellfield-specific conditions***

> ***as described in the individual wellfield package demonstrates a lower density is justified. In the event that no viable underlying aquifer exists or there is more than 50 feet of shale between the OZ and next continuous sandstone interval no monitoring of the underlying aquifer will be required.***

By letter dated June 15, 2017 (NRC, 2017b), the NRC staff provided Strata with a request for additional information (RAI) in order to complete the review of the amendment application. The RAI focused on the rationale and justification for data used in Strata's analysis, and clarification of the methodology to be used especially if the analysis were to be applied to a future wellfield.

By letter dated August 11, 2017 (Strata, 2017c), Strata submitted responses to staff's RAI. In addition to responding to staff's RAI, Strata elected to revise the amendment application by (a) restricting the amendment request to the existing mine units (MU1 and MU2), (b) including five quantifiable criteria to be used for any analysis, and (c) revising the proposed language for License Condition 11.3(C) as follows:

> *Overlying and Underlying Aquifers. Samples shall be collected from all monitoring wells in the first overlying and first underlying aquifer at a minimum density of one well per 4 acres of wellfield**, except that monitoring wells in the first underlying water-bearing interval will not be required at locations in Mine Units 1 and 2 meeting the criteria specified in the submittal dated <<Date>> (ML17XXXXXXX).***

In its response, Strata provided information on the poor quality of the DM unit stating that the constituent concentrations, notably chloride but also total dissolved solids, sulfate and iron, are higher in the DM unit than those concentrations reported for aquifers above the DM unit.

In its April 5 application, Strata stated that the combined thickness of the confining units (between the ore zone and the DM unit and between the DM unit and next "water-bearing" zone (BFS1 sand) ranges between 40 and 76 feet, averaging 59 feet (Strata, 2017b). The NRC has accepted 50 feet of a low-permeable confining unit as sufficient to meet NUREG-1569's guidance of "large aquitard." In the response to staff's RAI (Strata, 2017c), Strata reports the results of the combined thickness of the underlying confining unit to the water-bearing horizon below the DM unit. In the area of MU1, Strata clarified that a combined thickness for the underlying confining units of at least 60 feet. In the area of MU2, Strata reports a combined thickness for the underlying confining units of 51 feet.

In its April 5 application, Strata stated that few borings extend through the underlying confining units (Strata, 2017b). Based on the information in its request, Strata reported that 122 historic boreholes (6.3 percent of the total number of boreholes) extend into the DM unit and only 44 historic boreholes (2.3 percent of the total) extend to the underlying BFS1 sand. Strata considered these values as few boreholes penetrating the confining unit. Staff's RAI questioned the likelihood of observing a response in the DM unit at multiple pumping tests with few boreholes. In its response, Strata reported that 220 drillholes (not counting monitoring wells and including the 122 previously discussed drillholes) penetrate through the DM unit (Strata, 2017c). Furthermore, Strata suggests that the absolute number of drillholes penetrating the DM unit is immaterial because, according to Strata, only two historic drillholes could have accounted for the responses observed in the DM wells during the regional pumping tests.

In its April 5 application, Strata stated that only the installation of the DM unit wells would increase the risk of a vertical excursion and provides three arguments to support this claim (Strata, 2017b). First, Strata reported that only six drillholes that extended to the DM unit were not abandoned within the perimeter well rings for MU1 and MU2. Only one drillhole is located within the production area but is 32 feet from the nearest operational well and the five other historical drillholes are located between the production area and perimeter well ring and the closest distance to a production unit is 79 feet. Given this historical drillhole re-abandonment success, Strata expected the risk of a downward migration of fluids from the ore zone to the DM unit to be low (Strata, 2017b). Second, Strata suggested the risk was increased because of the DM well installation should there be a bad well installation. While the risk of a bad well installation is minimized because of the required testing, staff considers the risk would be less if the DM unit wells were not installed in the first place. Finally, due to the excessive drawdown during sampling of the DM wells, the increased vertical gradient between the ore zone and DM unit would increase the risk of fluid migration if a leaky drillhole were present.

In its April 5 application, Strata quantifies the potential time of migration within the DM unit from a leaky drillhole assuming a constant rate of flow through that drillhole (Strata, 2017b). Based on the analysis, Strata estimates the migration time from the leaky drillhole for various distances. For distances of 20 and 200 feet, Strata reports a migration time between 57.3 and 257.2 days, and between 929.8 and 4329.3 days, respectively (i.e., if a monitoring well were located 200 feet from a leaky drillhole, the migration time to a monitoring well is between 260 and 4330 days.

Strata concluded in its analyses to the RAI responses (Strata, 2017c) that only one well, MU2-DM01, had an estimated yield greater than the 0.5 gpm criterion and requested authorization to discontinue monitoring at the other wells that met Strata's proposed criteria in MU1 (14 wells) and MU2 (19 wells).

2.0 Regulatory Requirements

2.1 Regulations

Section 40.44 of Title 10 of the Code of Federal Regulation (10 CFR) requires a licensee, who submits an application for amendment of a license, to file a Form 313 in accordance with 10 CFR 40.31, to specify the respects in which the licensee desires the license to be amended, and the grounds for such amendment. Section 10 CFR 40.45 requires NRC staff to apply the applicable criteria set forth in 10 CFR 40.32 when considering an application to amend a license. The applicable criteria in 10 CFR 40.32 are as follows:

- The application is for a purpose authorized by the Atomic Energy Act.
- The applicant is qualified by reason of training and experience to use the source material for the purpose requested in such a manner as to protect health and minimize danger to life and property.
- The applicant's proposed equipment, facilities and procedures are adequate to protect health and minimize danger to life or property.
- The issuance of the license will not be inimical to the common defense and security or to the health and safety of the public.

Section 19 CFR 40.41 specifies terms and conditions of licenses. Pertinent to the proposed license amendment applications, section 10 CFR 40.41(c) states:

> "*Each person licensed by the Commission … shall confine his possession and use of source and byproduct material to the locations and purposes authorized in the license*."

2.2 License Condition

The existing language for License Condition 11.3 in License SUA-1601 is as follows:

11.3 Establishment of Background Water Quality. Prior to injection of lixiviant in a wellfield, the licensee shall establish background water quality data for the ore zone, overlying and underlying aquifers. The background water quality sampling shall provide representative baseline data and establish groundwater protection standards and excursion monitoring upper control limits, as described in Section 5.7.8 of the approved license application and this license condition.

The data for each mine unit shall consist, at a minimum, of the following sampling and analyses:

A) Ore Zone. To establish a Commission-approved background concentration pursuant to Criterion 5B(5)(a) of 10 CFR Part 40 Appendix A, samples shall be collected from production and injection wells at a minimum density of one production or injection well per four acres of wellfield production area. If a portion of a wellfield production area is isolated by distance to other production areas within a wellfield or isolated hydraulically, as determined by the pumping tests, a minimum of one well in each of the isolated areas will be required for the baseline data if the isolated area is less than four acres in area. Wells selected for the baseline data will be the same ones used to measure restoration success and stabilization.

B) Perimeter Monitoring Wells. Samples shall be collected from all perimeter monitoring wells that will be used for the excursion monitoring program. The perimeter wells will be installed for a wellfield in accordance with information presented in Section 3.1.6 of the approved license application, as amended by the submittal dated December 21, 2015 (ML16004A032), with the following stipulations: the distance between the nearest production unit and perimeter well will be between 300 and 500 feet and the spacing between perimeter wells will be between 300 and 500 feet provided that the maximum angle from the closest unit to the two nearest wells is less than 75 degrees. In the event a perimeter well exceeds the 400-foot spacing from the nearest production unit, the UCLs for that perimeter well will be calculated in accordance with commitments in the submittals dated March 29, 2017 (ML17089A275) and April 5, 2017 (ML17095A893). In no case will the perimeter monitoring wells be installed outside of the exempted aquifer as defined by the Class III UIC permit issued by the Wyoming Department of Environmental Quality.

C) Overlying and Underlying Aquifers. Samples shall be collected from all monitoring wells in the first overlying and first underlying aquifer at a minimum density of one well per 4 acres of wellfield.

D) Sampling and Analyses. Four samples shall be collected from each well to establish background levels. The sampling events shall be at least 14 days apart. The samples shall be analyzed for parameters listed in Table 5.7-2 of the approved license application, as revised by the May 27, 2015 submittal (ML15149A023). The third and fourth sample events can be analyzed for a reduced list of parameters; the parameters that can be deleted from analysis are those below the minimum analytical detection limits (MDL) during the first and second sampling events provided the MDLs meet the data quality objectives for the sampling.

E) Background Water Quality. For the perimeter ring monitoring wells (Section B) and monitoring wells in the overlying and underlying aquifers (Section C), the background levels shall be the mean values on a parameter-by-parameter, well-by-well, wellfield or sub-set of the wellfield basis, as deemed appropriate, in accordance with Section 5.7.8.1 of the approved license application. The UCLs for monitoring wells in the perimeter ring and overlying and underlying aquifers are established per LC 11.4. For the ore zone monitoring wells, the background levels shall be established on a parameter-by-parameter basis using either the wellfield, sub-set of the wellfield or well-specific mean value. The established background value for each parameter shall be based on the mean value plus a statistically valid factor to account for spatial variability in the data, in accordance with Section 6.1.1.1 of the approved license application.

[Applicable Amendment: 2, 7]

2.3 Applicable Guidance

The Standard Review Plan (SRP) for In Situ Leach Uranium Extraction License Applications (NRC, 2003) contains guidance applicable to the proposed amendment requests. For evaluating the appropriateness of excluding monitoring for the underlying aquifer, Acceptance Criterion 5.7.8.3(3) provides the following guidance:

It may be appropriate to exclude the requirement to monitor water quality in the underlying aquifer if

(i) *the underlying aquifer is a poor producer of water,*
(ii) *the underlying aquifer is of poor water quality,*
(iii) *there is a large aquitard between the production zone and the underlying aquifer and few boreholes have penetrated the aquitard, or*
(iv) *deep monitor wells would significantly increase the risk of a vertical excursion into the underlying aquifer.*

The SRP provides general guidance on acceptable methods for compliance with the existing regulatory framework. As described in an NRC white paper on risk-informed, performance-based regulation (SECY–98–144), the applicant has the flexibility to propose other methods as long as it demonstrates how it will meet regulatory requirements (NRC, 2003).

3.0 Staff's Review

As discussed in detail below, The NRC staff reviewed Strata's amendment request, including the responses to the staff's RAI, and finds that Strata's proposed methodology and criteria 1, 2 and 5 to establish whether a DM unit well should be monitored at MU1 and MU2 acceptable with the following limitations: the NRC staff finds that monitoring at eight (8) wells (MU2-DM1, MU2-DM5, MU2-DM6, MU2-DM8, MU2-DM9, MU2-DM15, MU2-DM22 and MU2-DM23) is sufficient to protect human health and safety and the environment. The NRC staff finds that criteria 3 and 4 are not acceptable.

Strata's five proposed criteria are as follows (Strata, 2017c):

Criterion	
1	If the thickness of the confining unit between the ore zone and DM unit is greater than 50 feet, then no monitoring in the first underlying aquifer is required.
2	If no viable DM Aquifer exists and the combined thickness of the confining unit between the ore zone and the next underlying sandstone, then no monitoring in the first underlying aquifer is required.
3	If the measured recovery following purging of at least 300 gallons of water from a DM unit well is less than 300 gallons, then the DM unit will be determined to not be a viable aquifer.
4	If the measured recovery during the 24 hours after purging water from a DM unit well is less than 90 percent of the water removed, then the DM unit will be determined to not be a viable aquifer.
5	If the predicted yield for a well is less than 0.5 gpm, as estimated over 1 year, then the DM unit will be determined to not be a viable aquifer.

The NRC staff finds Strata's proposed criteria 1 and 2 acceptable. Criteria 1 and 2 are consistent with, and correctly apply, the long-standing practice of the NRC staff of accepting 50 feet of low permeable material in applying the SRP Acceptance Criterion 5.7.8.3(3)(iii). This practice assumes that migration through the lower confining unit is limited thus not requiring monitoring of the underlying aquifer because the vertical hydraulic conductivity of the confining aquifer is extremely low and limited preferential pathways (e.g., drillholes) exist.

In both the license application for the Ross ISR facility (Strata, 2011) and the current application being reviewed (Strata, 2017b), Strata did not provide a sample analysis of the vertical hydraulic conductivity for the underlying confining unit but stated that the vertical hydraulic conductivity would be similar to that for the underlying massive Pierre Shale. Strata reported published values for the vertical conductivity of the Pierre Shale are between $5x10^{-4}$ to $2.6x10^{-10}$ feet per day (ft/day) [$1.8x10^{-7}$ to $9.2x10^{-14}$ centimeter per second (cm/s)]. For the numeric groundwater flow model developed for the license application, Strata had used a vertical hydraulic conductivity of $6.5x10^{-6}$ ft/day [$2.3x10^{-9}$ cm/s] for the overlying confining unit (Strata, 2011). Staff agrees that such low vertical hydraulic conductivity values are expected in the lower confining unit and are consistent with the assumptions used by staff for the 50-foot rule. Furthermore, staff finds the number of boreholes consistent with the assumptions (also see discussions in Environmental Impacts below). Therefore, the NRC staff finds the proposed criteria 1 and 2 acceptable.

The NRC staff finds Strata's proposed criteria 3 and 4 unacceptable. Criterion 3 is an application of the "limited use groundwater" definition found in in 40 CFR 192(e)(3). The limited use groundwater is defined, in part, as

> ”*groundwater that is not a current or potential source of drinking water because … the quantity of water reasonably available for sustained continuous use is less than 150 gallons per day. The parameters for determining the quantity of water reasonably available shall be determined by the Secretary [of the Department of Energy] with the concurrence of the [Nuclear Regulatory] Commission.*"

The NRC staff finds Strata's application of the "quantity of water reasonably available for sustained continuous use" (i.e., 300 gallons recovery in a well within two days after pumping more than 300 gallons) a misapplication of the limited use standard. Pumping a well dry at one point in time and measuring the recovery during the following two-day period is not sustained continuous use. Furthermore, Strata provided no basis of two days were selected except that that was the approximate volume removed from the aquifer (i.e., 300 gallons).

Criterion 4 is an application of a "Rule of Thumb" guidance in the USGS (2006). The rule of thumb states: "[d]o not sample wells at which recovery of water level after purging to 90 percent exceeds 24 hours." The guidance was intended for general sampling of low-yielding wells in which the chemistry of the water may not be representative of the aquifer because of potential changes due to the prolonged contact with air as the water recovers within the well. The NRC staff agrees that the rule of thumb guidance should be considered but disagrees with Strata's conclusion that the well is not suitable for sampling. First, the rule of thumb is intended for general sampling protocols, e.g., the data quality objectives may be to obtain a one-time complete suite of water quality parameters. In this case, the wells are sampled routinely (bimonthly) for three parameters. Strata has not demonstrated that the limited recovery affects the levels of the three parameters measured. Furthermore, in lieu of eliminating sampling at a well in its entirety, an alternative may be to revise the sampling method. For example. If a pump is placed within or near the screened horizon, then the purging may be reduced to only evacuating a volume which would provide a sample from the aquifer in a short period of time and limited the exposure to air. Such a sample strategy is consistent with approved sampling methodologies (ASTM, 2013). Therefore, the NRC staff finds Strata's proposed criteria 3 and 4 unacceptable.

The NRC staff finds Strata's proposed criterion 5 acceptable because it is based on established State of Wyoming criteria. Furthermore, staff find the procedures used by Strata acceptable (with one caveat listed below) because they quantify a sustainable yield for a specific well based on (1) estimates of the hydraulic properties for the aquifer in the vicinity of the well using established slug testing methodology, (2) an appropriate period for sustainable pumping, (3) utilizing actual water column in the pumping well available for cumulative drawdown, and (4) established models for non-equilibrium radial flow to a well. The assumed parameters for Strata's analysis include storativity of the aquifer ($1x10^{-5}$), estimated available water column with a factor of safety (20 feet above the pump intake which is 30 feet above the top of the screened horizon) and the pumping duration (365 days). The measured parameters for Strata's analysis include radius of the well screen (0.4375 feet), radius of the well casing (0.1875 feet), aquifer thickness (13 to 25 feet), available water column (static water elevation minus the maximum safe drawdown elevation) (205.8 to 493.9 feet) (Strata, 2017c). The calculated parameters for Strata's analysis include transmissivity of the aquifer and well yield. The NRC Staff finds that the assumed and measured parameters are appropriate and confirmed that Strata's calculations for the well yield are correct using Strata's assumed, measured and calculated parameters (Table 1).

The caveat to the NRC staff approval of Strata's analysis is the appropriateness in the application of the Hvorslev (1951) method for the analysis of slug tests for all well responses under criterion 5. Slug test analysis provides a quantifiable estimate of the aquifer's transmissivity which is the essential parameter in determining a well yield. As discussed below, a bias may be imparted in an analysis of data which violates a basic assumption of the method used. In this case, for several wells, the Hvorslev method may have underestimated the aquifer transmissivity and thus underestimated the well yield. Other methods are available for the analysis of slug test data that are not based on assumptions used by Hvorslev.

While the Hvorslev method itself is acceptable (ASTM, 2017), the NRC staff finds that Strata incorrectly applied the Hvorslev's method to the recovery of water levels at 14 wells based on a verification analysis using other slug test methods (i.e., Papadopulos et al., 1973; Cooper et al., 1967); see discussions below). Of the 14 wells, the NRC staff's verification analysis indicated that the underestimation of the transmissivity for seven wells had no effect on Strata's conclusion (i.e., the calculated well yield was less than the 0.5 gpm criterion), whereas for seven wells, the underestimation resulted in a predicted well yield less than the criterion but the analysis using the other method predicted a well yield greater than the criterion.

In the RAIs, the NRC staff suggested the use of other methods in addition to Hvorslev.

In its response to the NRC staff's RAI, Strata provided justification for its sole use of the Hvorslev Method in its analyses of the slug test data (Strata, 2017c). The principal justifications are as follows:

- The small number of head-time data pairs for many tests conducted on MU2 wells is more amenable to a linear analysis (Hvorslev) than curve matching (Cooper or Papadopulos methods).
- Hvorslev method does not require an instantaneous removal of a slug of water and the swabbing (which yielded the slug test data) generally occurred over a 15-minute interval. An instantaneous removal of a slug is required by the Cooper and Papadopulos methods.
- Hvorslev method does not require an estimate of storativity which is required for the Cooper or Papadopulos methods.

The NRC staff finds that these justifications are lacking for several reasons. First, while small datasets may restrict an ultimate analysis (e.g., statistical analyses), in this case, collecting a larger dataset through additional testing would have been fairly easy. For example, the reported slug testing measurement for well MU2-DM-15 consists of two datapoints, one obtained at approximately 2 hours into the test at which time approximately 40 percent of the initial drawdown had been recovered and the other obtained at approximately 2 days into the test at which time approximately 95 percent of the initial drawdown had been recovered.[1] The collection of data at a more frequent basis would have yielded a better analysis, and, in fact, ASTM Standard 4044 states that it is essential to collect water levels frequent enough to define the water-level response curve (ASTM, 2015).

More importantly, though limited, the data for most wells indicate a non-linear (concave upward) response (see figures in Appendix J of Attachment 5 of Strata's MU1 and MU2 wellfield data packages (Strata, 2015b; 2016a)). Such behavior is attributed to non-steady state conditions (Hvorslev, 1951) or compressibility of the aquifer (Butler, 1998), either of which is not compatible with the Hvorslev method. Butler (1998) evaluated the appropriateness of applying the Hvorslev method to concave upward data. Butler found that that fitting a straight line to the normalized head data in the range of 0.15 to 0.25 would provide comparable results to a Cooper method. The commercial software used by Strata recommends use of this range of data.

The suggested Hvorslev methodology for curvilinear data, however, is not based on picking two data points and drawing a line, as was done by Strata, but using the tangent to the data curve over the recommended range of values. Use of the tangent line is important because the analysis is based on revising the initial displacement based on the y-intercept of this tangent line (Butler, 1998). Here, Strata's limited data for many wells (1) did not have data within the recommended range, (2) did not provide an appropriate tangent line, and (3) did not properly estimate a new initial displacement value.

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[1] Strata did not supply the NRC with the original data. The NRC staff estimated the data by scaling Strata's data from the supplied figures. This means of estimating leads to increase degree of uncertainty which staff included in its evaluation.

Therefore, the NRC staff finds that the small number of head-time data pairs is not an appropriate justification for using the proposed Hvorslev method. In fact, as discussed below, if the data quality is insufficient, then any analysis is not appropriate.

Second, Strata is correct that comments in the documentation for the commercial software used in its analysis states that the Hvorslev method does not require an instantaneous removal of slug of water as is required by the Cooper and Papadopulos methods. However, the NRC staff's review of the literature and common slug testing practice suggests this factor is not significant with respect to the selection of analytical method. First, established practices for performing slug tests recognizes that, as a practical matter, a finite time is required for removal of a slug of water or mechanical devise (ASTM, 2010; 2015). The staff finds that the 15-minute time frame is sufficiently quick compared to the time-frame for the observed responses. Furthermore, though Hvorslev (1951) did not use the term "instantaneous," he used the word "suddenly." Butler (1998) did state that the slug does not necessarily have to be introduced in an instantaneous fashion for the Hvorslev model (page 65), which is referenced by the commercial software and Strata (Strata, 2017c). On the other hand, Butler further states that if the response is non-linear (concave upward), then storage properties of the aquifer likely affect the response and a "non-instantaneous slug introduction will introduce error into the hydraulic conductivity estimate" (page 69). Finally, though the swabbing process did take some finite time, in essence the initial displacement from the swabbing method was instantaneous because water levels in the well should have been isolated from the water above the swabbing equipment at the start of swabbing procedure.

Therefore, the NRC staff finds that the justification of limiting the analysis because the slug removal was not instantaneous is not appropriate.

Third, Strata is correct that Hvorslev method does not require an assumption of storativity. Typically, such an assumption is required for a Cooper or Papadopulos analysis and it may introduce errors in the "typical" analysis. However, in this instance, Strata's proposed methodology requires an assumed value for storativity in the subsequent well yield calculations. The effect of the assumed storativity value on the well yield calculations is shown on Figure 1. Because a storativity value is required for the well yield calculations, an assumption of storativity for the slug testing is moot.

To establish whether Strata's proposal to eliminate any wells from monitoring was based on a flawed analysis, the NRC staff verified Strata's calculations by using the Cooper and Papadopulos methods to establish a transmissivity. The method typically consists of fitting the observed data to a model type curve and then establish a match point between the observed time and dimensionless time for the model curve (Dawson and Istok, 1991; Fetter, 1980). Because of the limited data, the NRC staff used a variant of the method by obtaining a match point for a selected normalized head. In this case, the NRC staff used a normalized head that was 25 percent of the initial head. To establish the normalized 25 percent head, curves were fitted to the data using Strata's graphs from the mine unit reports (for examples, see Figure 2).

In several cases, the limited data introduced an unacceptable degree of uncertainty in this analysis. If staff determined that Strata's data were insufficient for any analysis or the uncertainty in the curve assigned by staff yielded ambiguous results, then that well was eliminated from staff's verification process and, by default, included in the monitoring program.

The NRC staff determined that the data for wells MU2-DM01, MU2-DM05 and MU2-DM15 was insufficient of had sufficient uncertainty that the verification was deemed unnecessary and the wells were included in any proposed monitoring program. For the remainder of wells, the NRC staff estimated the time to the 25 percent normalized head varied between 0.2 and 13.7 days (Table 2).

For the verification analysis, a match point yielded three parameters β* (dimensionless time), α* and t*, where

$$\beta^* = {Tt^*}/{r_c^2}$$
$$\alpha^* = {Sr_w^2}/{r_c^2}$$
$$t^* = time\ at\ match\ point\ (day)$$
$$T = transmissivity\ (\frac{sq\ ft}{d})$$
$$S = storativity$$
$$r_w = radius\ of\ well\ screen\ (feet)$$
$$r_c = radius\ of\ well\ casing\ (feet)$$

The parameter α* is used to define which curve in the family of type curves that the data will be fitted. In this case, assuming the storativity is $1x10^{-5}$ and the diameter of the well casing and screen is 4.5 and 10.5 inches, respectively, then the value of α* is:

$$\alpha^* = {1x10^{-5}\ x\ 0.4375^2}/{0.1875^2}$$

$$\alpha^* = 5.44x10^{-5}$$

The model curves for α* values of $1x10^{-5}$ and $1x10^{-4}$ are shown on Figure 3a. Interpolation to the calculated value of $5.44x10^{-5}$ yields a β* value of 4.54 (Figure 3b). Using this value for β*, staff calculated the transmissivity of the aquifer at a well using the time to the normalized head of 0.25. An example calculation for well MU2-DM02 (where t* is 0.52 days) is as follows:

$$T = {\beta^* r_c^2}/{t^*}\ (\frac{sq\ ft}{d})$$

$$T = {4.54\ \ x\ 0.1875^2}/{0.52}\ (\frac{sq\ ft}{d})$$

$$T = 0.31\ (\frac{sq\ ft}{d})$$

The calculated transmissivities through the verification process varied from 0.01 to 1.28 square feet per day (Table 2). Using the estimate of transmissivity developed through the verification process, a safe yield was determined for each well using the method described above (Table 2). The NRC staff's estimate of the transmissivity during the verification process was consistent with Strata's calculations (within 0.05 square feet per day) for all wells in Mine Unit 1 and wells MU2-DM02, MU2-DM11, MU2-DM14, MU2-DM16 and MU2-DM19. For wells MU2-DM04a, MU2-DM12a, MU2-DM17, MU2-DM18, MU2-DM20 and MU2-DM21, staff's verification transmissivity differed from Strata's calculation (greater than 0.05 square feet per day) but did not result in a predicted well yield greater than 0.5 gpm. For those wells, staff finds that that Strata's conclusions are valid (Figure 4). For wells MU2-DM-06, MU2-DM-08, MU2-DM-09, MU2-DM-22 and MU2-DM-23, staff's verification transmissivity resulted in a predicted well yield greater than 0.5 gpm and thus did not verify Strata's calculations.

Therefore, the NRC staff finds that all DM unit wells in Mine Unit 1, and the DM unit wells in Mine Unit 2 except wells MU2-DM01, MU2-DM-05, MU2-DM-06, MU2-DM-08, MU2-DM-09, MU2-DM15, MU2-DM-22 and MU2-DM-23, have a predicted yield less than WDEQ/LQD criterion of 0.5 gpm and recommends those wells be removed from the monitoring program as requested by Strata. Staff finds that predicted well yields for wells MU2-DM01, MU2-DM-05, MU2-DM-06, MU2-DM-08, MU2-DM-09, MU2-DM15, MU2-DM-22 and MU2-DM-23 cannot be verified and thus continued monitoring is required (i.e., Strata's request is denied for these wells). Strata may elect to re-perform slug tests at the wells that yield insufficient data and resubmit a request for staff to evaluate the new data in the future.

As a result, the NRC staff will modify License Condition 11.3(C) as follows:

> Overlying and Underlying Aquifers. Samples shall be collected from all monitoring wells in the first overlying and first underlying aquifer at a minimum density of one well per 4 acres of wellfield. Based on wellfield specific analyses, the minimum density requirement for the first underlying aquifer at Mine Units 1 and 2 is modified as follows:
>
> Mine Unit 1: Monitoring at all wells is discontinued.
> Mine Unit 2: Monitoring is required at wells MU2-DM01, MU2-DM05, MU2-DM06, MU2-DM08, MU2-DM09, MU2-DM15, MU2-DM22 and MU2-DM23

4.0 Protection of Health and Safety of the Public and Minimize Danger to Life and Property

The NRC staff finds that, with the combined thickness of the low-permeable confining unit to be greater than 50 feet and the low transmissivity of the DM unit not providing a sustainable well yield of 0.5 gpm, the elimination of monitoring at the selected wells will not degrade the protection of human health and safety and the environment. In making this finding, the NRC staff agrees, in part, and disagrees, in part, with Strata's proffered arguments regarding impacts to the environment. As discussed below, although staff disagrees with specific attributes of Strata's arguments, staff is in agreement with Strata that the overriding environmental impact is minimal.

With regard to poor quality, the NRC staff agrees with Strata that the quality of the DM unit is poor. However, the poor quality is not a new development, it was identified by Strata in the license application in which they requested monitoring of the DM unit. Therefore, the poor quality is not the overriding issue as to whether to approve this amendment application or evaluation of the environmental impacts.

With regard to thickness of the lower confining unit, the NRC staff agrees with Strata that 50 feet of low-permeable shales with few borehole penetrations provide an adequate measure to contain fluids in the ore zone aquifer. This is true in this case in which the lower confining unit contains a 20-foot interval of more permeable material provided the transmissivity of the more permeable horizon (i.e., the DM unit) remains below that equivalent of transmitting 0.5 gpm of water to a well. For this finding, staff evaluated the potential for migration of fluids directly through the confining unit to the DM unit from the ore zone. Staff estimates that, without boreholes and given the range of transmissivities for the ore zone, lower confining unit and DM unit, the distance fluids migrate into the top of the lower confining unit are on the order of 0.75 to 1.0 inches.

With regard to the number of historic drillholes, the NRC staff disagrees that the number of drillholes is immaterial with respect to the observed responses during the pumping tests, but agrees with Strata that a mere two historic improperly abandoned drillholes may have contributed to the responses observed during the regional pumping tests. Therefore, the degree to which the re-abandonment occurs affects the probability of an unwanted release. In the respective mine unit packages, Strata reports 26 and 69 historic drillholes which were not abandoned and located within the perimeter well ring at Mine Unit 1 and Mine Unit 2, respectively (Strata, 2015b; 2016a). The numbers differ from those reported in this amendment application (one drillhole within the production area and 5 drillholes in the area between the production area and perimeter well ring) because the mine unit packages did not differentiate whether the historic drillhole penetrated to the DM unit. Given the fact that only one drillhole was not re-abandoned within the patterned areas for MU1 and MU2, the likelihood of an excursion through that single well is quite low. For the 5 drillholes located between the production area and perimeter well ring, no excursion monitoring wells are completed in the underlying aquifer in that area. Furthermore, even if a well were installed in the lower aquifer, the excursion would be detected first in the perimeter ring well rather that a well in the underlying aquifer. Therefore, the degree of re-abandonment success at MU1 and MU2, the NRC staff finds that elimination of the monitoring wells as discussed in this report does not pose a significant increase in risk to human health or the environment.

With regard to the increase in risk of a vertical excursion due to sampling of the DM wells, the NRC staff disagrees with Strata's arguments. Although it is possible that the risk is increased by installing an improperly constructed DM well, this possibility should not be a deciding factor in whether monitoring should be conducted otherwise any monitoring program should be eliminated. Strata argues that the induced drawdown by the sampling would create enhanced migration through an improperly abandoned drillhole thus increasing the risk of an excursion. As discussed above, the NRC staff verified and agrees with Strata's calculations on migration times of any plume migration through an improperly abandoned drillhole and through the DM unit. Further, the NRC staff's calculations also evaluated induced drawdown by sampling of a

DM well in its calculations. Those calculations did not change the migration times. Therefore, staff finds that the sampling of the DM wells would have no appreciable impact on inducing a vertical excursion and thus was not a factor in the NRC staff's analysis.

The NRC staff evaluated the impact of the induced drawdown from sampling of the DM wells on the vertical gradient resulting in increased penetration of fluids in the production zone into the top of the confining unit. The induced drawdown from sampling of the DM wells increased the depth of penetration slightly, from approximately 1 inch to 1.5 inches. This increase would not be detected by the operational monitoring programs; however, the increased to the depth of penetration would likely increase the time for restoration of the ore zone aquifer. During restoration, the migration of constituents from the top of the confining unit is expected to be slow due to primarily chemical diffusion processes. As a result, even though the depth of penetration in absolute numbers is relatively small, the increase would likely hamper the future restoration efforts. Therefore, staff finds that elimination of the wells with low transmissivities (and thus greater drawdown) would be beneficial for the restoration efforts.

Based upon the above, the NRC finds that with the lack of historical drillholes as a result of re-abandonment success at MU1 and MU2, a significant thickness of low permeable material within the lower confining unit, the excessive migrations times within the DM unit, and the removal of induced drawdown, the elimination of the monitoring requirement for wells in the DM unit with yields less than 0.5 gpm will not lessen the protection of human health and safety and the environment.

5.0 Environmental Review

The NRC staff prepared an Environmental Assessment (EA) on the amendment application in accordance with the requirements in 10 CFR Part 51, *Environmental Protection Regulations for Domestic Licensing ad Related Regulatory Functions*. NRC's regulations in 10 CFR Part 51 implement Section 102(2) of the National Environmental Policy Act of 1969, as amended. The EA includes an evaluation of the potential environmental impacts of the requested license amendment and alternatives to the proposed action (NRC, 2017c).

6.0 Conclusions

The NRC staff reviewed Strata's license amendment application to modify requirements of License Condition 11(C). The NRC staff finds that changes to the monitoring program affected by the amendment request, with the NRC staff's modification to the proposed license condition's language, remain effective in protecting human health and safety and the environment. As such, the NRC staff finds that the amendment request satisfies the applicable criteria in 10 CFR 40.32 for approval of an amendment:

- The application is for a purpose authorized by the Atomic Energy Act

  The amendment application affects the monitoring program that ensure the source material remains under the possession and control of the licensee.

- The applicant is qualified by reason of training and experience to use the source material for the purpose requested in such a manner as to protect health and minimize danger to life and property

  The amendment application does not modify the personnel training or experience from that previously analyzed and approved for issuance of the license.

- The applicant's proposed equipment, facilities and procedures are adequate to protect health and minimize danger to life and property

  As documented in this SER, the NRC staff finds that the proposed modified program is adequate to protect health and minimize danger to life and property.

- The issuance of the license will not be inimical to the common defense and security or to the health and safety of the public

  Issuance of the amendment, with the NRC staff's proposed license condition language, provides the same level of protection as was determined for the issuance of the initial license.

Therefore, the NRC staff approves the amendment application with the following license condition:

11.3 Establishment of Background Water Quality. Prior to injection of lixiviant in a wellfield, the licensee shall establish background water quality data for the ore zone, overlying and underlying aquifers. The background water quality sampling shall provide representative baseline data and establish groundwater protection standards and excursion monitoring upper control limits, as described in Section 5.7.8 of the approved license application and this license condition.

The data for each mine unit shall consist, at a minimum, of the following sampling and analyses:

A) Ore Zone. To establish a Commission-approved background concentration pursuant to Criterion 5B(5)(a) of 10 CFR Part 40 Appendix A, samples shall be collected from production and injection wells at a minimum density of one production or injection well per four acres of wellfield production area. If a portion of a wellfield production area is isolated by distance to other production areas within a wellfield or isolated hydraulically, as determined by the pumping tests, a minimum of one well in each of the isolated areas will be required for the baseline data if the isolated area is less than four acres in area. Wells selected for the baseline data will be the same ones used to measure restoration success and stabilization.

B) Perimeter Monitoring Wells. Samples shall be collected from all perimeter monitoring wells that will be used for the excursion monitoring program. The perimeter wells will be installed for a wellfield in accordance with information presented in Section 3.1.6 of the approved license application, as amended by the submittal dated December 21, 2015 (ML16004A032), with the following stipulations: the distance between the nearest production unit and perimeter well will be between 300 and 500 feet and the spacing between perimeter wells will be between 300 and 500 feet provided that the maximum angle from the closest unit to the two nearest wells is less than 75 degrees. In the event a perimeter well exceeds the 400-foot spacing from the nearest production unit, the UCLs for that perimeter well will be calculated in accordance with commitments in the submittals dated March 29, 2017 (ML17089A275) and April 5, 2017 (ML17095A893). In no case will the perimeter monitoring wells be installed outside of the exempted aquifer as defined by the Class III UIC permit issued by the Wyoming Department of Environmental Quality.

C) Overlying and Underlying Aquifers. Samples shall be collected from all monitoring wells in the first overlying and first underlying aquifer at a minimum density of one well per 4 acres of wellfield. Based on wellfield specific analyses, the minimum density requirement for the first underlying aquifer at Mine Units 1 and 2 is modified as follows:

Mine Unit 1: Monitoring at all wells is discontinued.
Mine Unit 2: Monitoring is required at wells MU2-DM01, MU2-DM05, MU2-DM06, MU2-DM08, MU2-DM09, MU2-DM15, MU2-DM22 and MU2-DM23

D) Sampling and Analyses. Four samples shall be collected from each well to establish background levels. The sampling events shall be at least 14 days apart. The samples shall be analyzed for parameters listed in Table 5.7-2 of the approved license application, as revised by the May 27, 2015 submittal (ML15149A023). The third and fourth sample events can be analyzed for a reduced list of parameters; the parameters that can be deleted from analysis are those below the minimum analytical detection limits (MDL) during the first and second sampling events provided the MDLs meet the data quality objectives for the sampling.

E) Background Water Quality. For the perimeter ring monitoring wells (Section B) and monitoring wells in the overlying and underlying aquifers (Section C), the background levels shall be the mean values on a parameter-by-parameter, well-by-well, wellfield or sub-set of the wellfield basis, as deemed appropriate, in accordance with Section 5.7.8.1 of the approved license application. The UCLs for monitoring wells in the perimeter ring and overlying and underlying aquifers are established per LC 11.4. For the ore zone monitoring wells, the background levels shall be established on a parameter-by-parameter basis using either the wellfield, sub-set of the wellfield or well-specific mean value. The established background value for each parameter shall be based on the mean value plus a statistically valid factor to account for spatial variability in the data, in accordance with Section 6.1.1.1 of the approved license application.

[Applicable Amendment: 2, 7, 8]

7.0 References

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Table 1 Staff's Confirmation Results of Strata's Predicted Yield Calculations

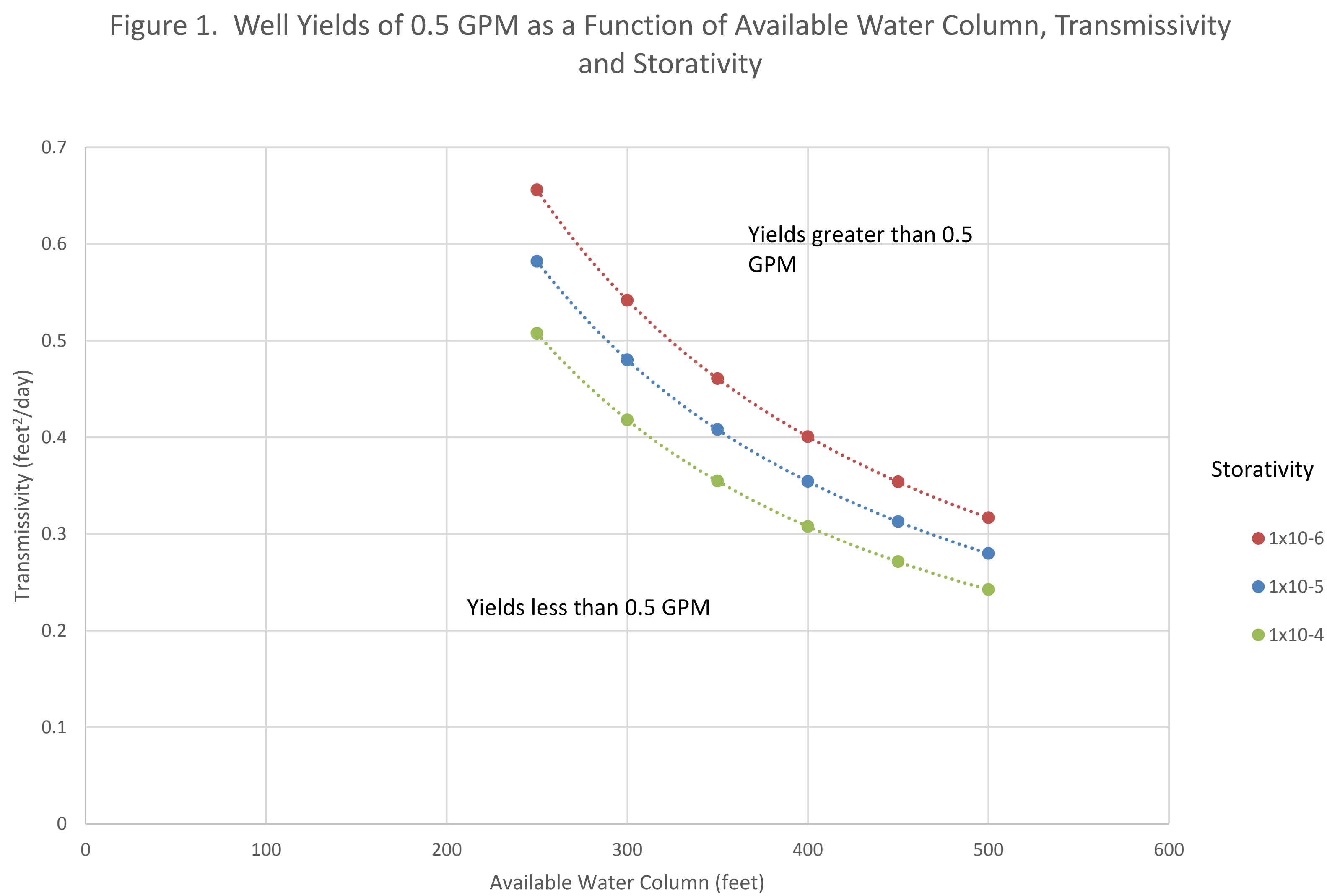
Well	Strata's Evaluation				Staff's Confirmation of Yield Calculations	
	Available Water (feet)	Transmissivity (ft2/day)	Predicted Yield (GPM)	Proposed Monitoring	Predicted Radius to Zero Drawdown at 0.5 GPM for 365 days (feet)	Calulate Yield (GPM)
Mine Unit 1						
MU1-DM1	380.5	0.05	0.07		2026	0.07
MU1-DM2	371.5	0.01	0.02		906	0.02
MU1-DM3A	367.8	0.02	0.03		1282	0.03
MU1-DM4	336.9	0.05	0.06		2026	0.07
MU1-DM5	358.3	0.02	0.03		1282	0.03
MU1-DM6	366.6	0.03	0.05		1570	0.04
MU1-DM7	335.6	0.02	0.03		1282	0.03
MU1-DM8	335.3	0.05	0.06		2026	0.07
MU1-DM9	205.8	0.01	0.01		906	0.01
MU1-DM10	354.1	0.06	0.08		2220	0.08
MU1-DM11	356	0.03	0.04		1570	0.04
MU1-DM12	271.6	0.01	0.01		906	0.01
MU1-DM13	316.8	0.02	0.03		1282	0.03
MU1-DM14	296	0.01	0.01		906	0.01
Mine Unit 2						
MU2-DM01	398.3	0.43	0.58	X	5943	0.59
MU2-DM02	398.4	0.25	0.35		4531	0.35
MU2-DM04A	390.5	0.1	0.14		2866	0.15
MU2-DM05	397.2	0.2	0.28		4053	0.28
MU2-DM06	404.4	0.32	0.45		5126	0.45
MU2-DM08	401	0.28	0.39		4795	0.40
MU2-DM09	402.5	0.29	0.41		4880	0.41
MU2-DM10A	398.1	0.09	0.13		2719	0.13
MU2-DM11	493.9	0.07	0.13		2398	0.13
MU2-DM12A	395.3	0.12	0.17		3139	0.18
MU2-DM14	409.8	0.12	0.18		3139	0.18
MU2-DM15	430.8	0.16	0.25		3625	0.25
MU2-DM16	436.4	0.13	0.21		3267	0.21
MU2-DM17	445.7	0.1	0.16		2866	0.17
MU2-DM18	429.5	0.1	0.16		2866	0.16
MU2-DM19	429	0.08	0.13		2563	0.13
MU2-DM20	428	0.16	0.25		3625	0.25
MU2-DM21	441.3	0.14	0.22		3391	0.23
MU2-DM22	414.6	0.2	0.29		4053	0.30
MU2-DM23	404.6	0.26	0.37		4621	0.37

Notes:
Strata's data from Table 5 of Strata (2017c).
Staff's calculations for predicted yield based on Strata's assumed values for storativity and time of pumping, and, calculated values for available water column and transmissivity. Staff used a radius for the well screen of 0.4375 feet.

Table 2 Staff's Verification Calculations

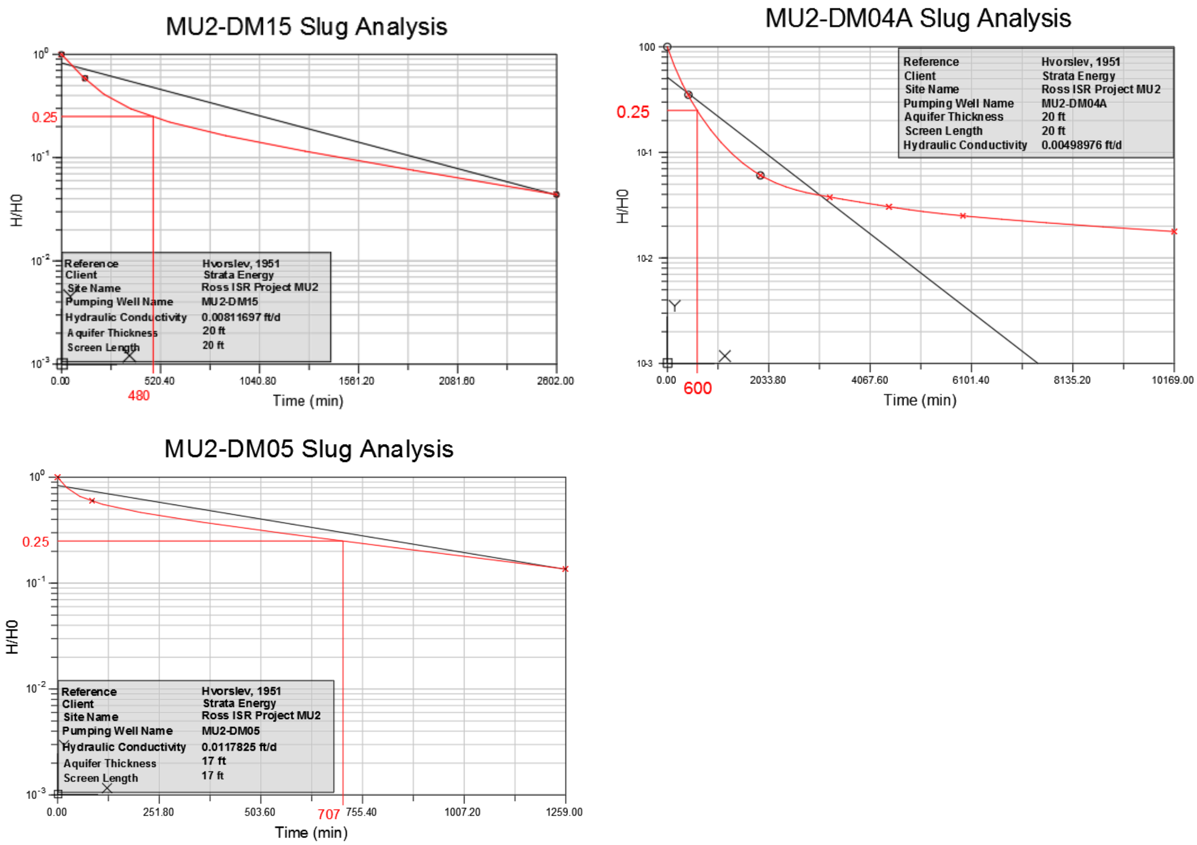
Well	Available Water (feet)	Time to 25% recovery of Slug Test (days)	Transmisivity (ft2/day)	Predicted Radius to Zero Drawdown at 0.5 GPM for 365 days (feet)	Predicted Yield GPM)	Required Monitoring	Comments
Mine Unit 1							
MU1-DM1	380.5	2.5	0.06	2290	0.09		
MU1-DM2	371.5	13.7	0.01	978	0.02		
MU1-DM3A	367.8	5.7	0.03	1516	0.04		
MU1-DM4	336.9	2.5	0.06	2290	0.08		
MU1-DM5	358.3	10	0.02	1145	0.02		
MU1-DM6	366.6	2.5	0.06	2290	0.09		
MU1-DM7	335.6	4.6	0.03	1688	0.05		
MU1-DM8	335.3	1.9	0.08	2627	0.11		
MU1-DM9	205.8	11.2	0.01	1082	0.01		
MU1-DM10	354.1	1.4	0.11	3060	0.15		
MU1-DM11	356	2.2	0.07	2441	0.10		
MU1-DM12	271.6	10.4	0.02	1123	0.02		
MU1-DM13	316.8	5.6	0.03	1530	0.04		
MU1-DM14	296	8.2	0.02	1264	0.02		
Mine Unit 2							
MU2-DM01	398.3					X	Due to ambiguous data, this well is included in the monitoring program
MU2-DM02	398.4	0.52	0.31	5021	0.43		
MU2-DM04A	390.5	0.416	0.38	5613	0.52		Note this well is not one of the compliance wells
MU2-DM05	397.2	0.49	0.33	5172	0.45	X	Due to uncertainty, this well is included in the monitoring program
MU2-DM06	404.4	0.125	1.28	10240	1.68	X	
MU2-DM08	401	0.2	0.80	8096	1.07	X	
MU2-DM09	402.5	0.24	0.67	7390	0.90	X	
MU2-DM10A	398.1	0.4	0.40	5724	0.55		Note this well is not one of the compliance wells
MU2-DM11	493.9	1.8	0.09	2699	0.16		
MU2-DM12A	395.3	0.5	0.32	5120	0.44		
MU2-DM14	409.8	1.1	0.15	3452	0.22		
MU2-DM15	430.8	0.33	0.48	6302	0.71	X	Due to uncertainty, this well is included in the monitoring program
MU2-DM16	436.4	1	0.16	3620	0.25		
MU2-DM17	445.7	0.5	0.32	5120	0.498		
MU2-DM18	429.5	0.8	0.20	4048	0.31		
MU2-DM19	429	1.7	0.09	2777	0.15		
MU2-DM20	428	0.7	0.23	4327	0.35		
MU2-DM21	441.3	0.8	0.20	4048	0.32		
MU2-DM22	414.6	0.3	0.53	6610	0.75	X	
MU2-DM23	404.6	0.3	0.53	6610	0.73	X	

Notes:
Avalable Water is from that reported in Strata (2017c).
Time to the 25% recovery during a slug test is based on a curve fitted by staff to Strata's data (see Figure 2).
The transmissivity is based on Cooper et al (1967) and Papadopulos et al. (1967) method. The calclated α^* and β^* values are 5.44×10^{-5} and 4.54. respectively, for a storativity of 1×10^{-5}, radius of the well caing of 0.187 feet, radius of the well screen of 0.4375 feet and normalized head of 25%.
The well yield is based on Cooper and Jacob (1946) approximation to the Theis radial flow curve and the distance-drawdown using a pumping period of 365 days and pumping rate of 0.5 gallons per minute.



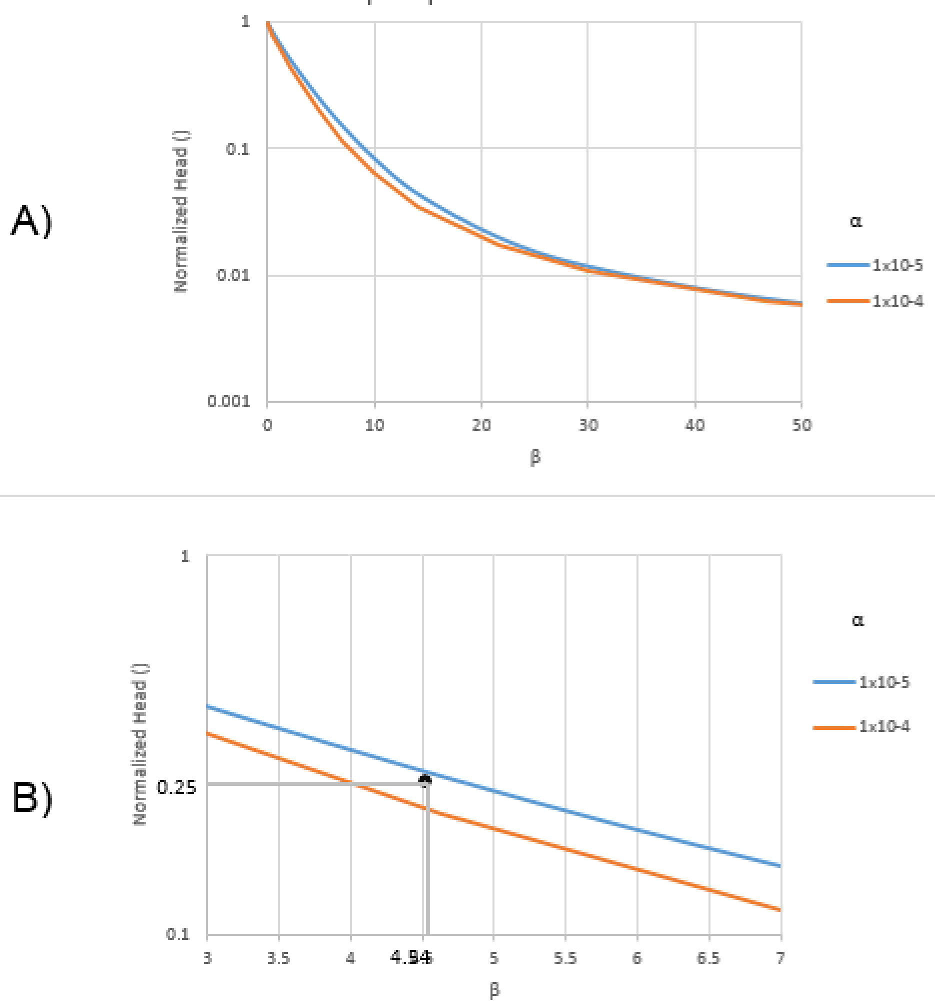
The family of curves depict a well yield of 0.5 gpm for the indicted storativity. Well yields are based on a Cooper-Jacob approximation to the Theis non-equilibrium radial flow to a well. The pumping duriation was 365 days and well radius was 0.5 feet.

Figure 2. Examples of Curve Fitting to Strata's Data and Estimation of Time to 0.25 Recovery



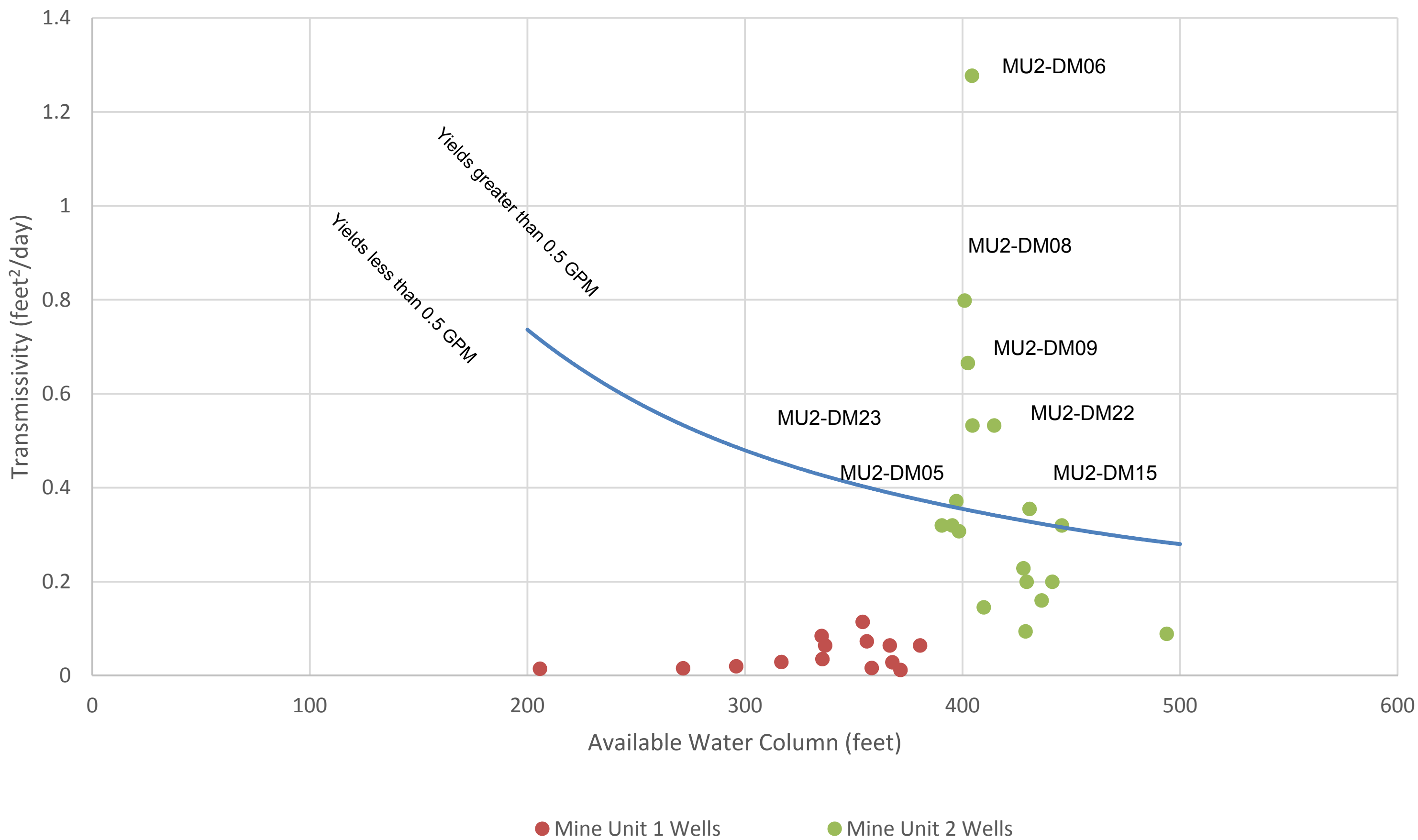
Note: Data adapted from Appendix J to Attachment 5 of the Mine Unit 2 Wellfield Package (Strata, 2016a). The red-color items are staff's addition. For MU2-DM04A, the data yields a well-fitted curve. For MU2-DM05 and MU2-DM15, the data allow a range of fitted curves and for these wells, the data was not verified (see text).

Figure 3 Slug Test Model Curves for the Cooper and Papodopulos Model



Note: Black-colored point is the intersection of horizontal line at a normalized head of 0.25 and model curve of $\alpha^* = 5.44\text{x}10^{-5}$ (not shown). The cordinate of this point is β^* = 4.54.

Figure 4. Mine Unit 1 and 2 Wells exceeding the Yield Criterion



Well yields based on Cooper-Jacob approximation to the Theis non-equilibrium radial flow to a well. The pumping duriation was 365 days and storativity of 1 x 10^{-5}. Well MU2-DM01 was not included in this analysis due to insufficient data.