ADDENDUM MP-H:

HANK NUMERICAL GROUNDWATER MODELING

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Acronyms and Abbreviations

gpd	gallons per day
gpm	gallons per minute
ID	inner (inside) diameter
ISR	In-Situ Recovery
UZF	unsaturated zone flow
WDEQ	Wyoming Department of Environmental Quality
WY	Wyoming

MPH.1 HANK SITE NUMERICAL GROUND-WATER MODELING

Several modeling techniques were employed to evaluate ground-water impacts by the proposed ISR mining operations. The products of this modeling included predictions of operational drawdown, gradient changes, recovery, horizontal wellfield flare, and vertical flare.

The primary modeling approach used a version of the MODFLOW model to evaluate ground-water flow and drawdown resulting from the planned mining operations. The MODFLOW model was developed by the USGS in 1988 and has been updated and revised several times. MODFLOW-2005 (Harbaugh, 2005) was used for modeling of the ground-water system at the Hank Project. MODFLOW-2005 was used for the Hank Project because it has provisions for modeling of unsaturated zone flow (UZF) under unconfined conditions. The names MODFLOW and MODFLOW-2005 are used interchangeably in the remainder of the addendum.

The horizontal flare from an operating ISR wellfield was evaluated with the contaminant transport model MT3DMS (Zheng and Wang, 2006) which utilizes cell by cell flow terms produced by the MODFLOW model. With this coupling to the MODFLOW model, MT3DMS and MODFLOW use a common model domain and configuration to evaluate the transport flare of mining solutions during conveyance between ISR injection and production wells. The use of a convection dispersion equation based numerical transport model allows a fairly sophisticated interpretation of the expected flare that will occur with the proposed injection and collection well operation.

The vertical flare of mining solution was evaluated by compiling multiple runs of an analytical radial well flow model (WTAQ (Barlow and Moench, 1999)) into a spreadsheet based matrix representing a paired ISR injection and extraction well. The WTAQ model incorporates partial penetration of both the injection and extraction wells, allows a large degree of anisotropy in the ratio of vertical to horizontal hydraulic conductivity and utilizes an implementation of the Neuman (1972) solution for unconfined aquifers. Predicted drawdowns from the WTAQ model were then compiled in a spreadsheet, and, using some additional programming to interpret the WTAQ model output, the results were converted to a matrix of heads and velocities for the aquifer interval between the paired wells.

The numerical model was also used to evaluate the potential for retrieval of excursions and the sufficiency of the monitor well spacing. Well stress rates for a local area were adjusted slightly to produce a stronger gradient reversal in simulating the proposed response to a local excursion. The magnitude of the gradient reversal was then compared with baseline simulations to evaluate the effectiveness in retrieval of an excursion.

MPH.1.1 Hank Project Modeling

MODFLOW-2005 was used to model the ground-water flow prior to, during and after operation of the wellfield(s). A model grid was developed to cover the proposed mine area with a relatively fine grid (30 foot by 30 foot cells) and extending the modeled area with increased cell size to encompass approximately 283 square miles. Injection and production wells were included as well stresses within the fine grid area. MODFLOW-2005 has the capability of modeling partially saturated flow through an unsaturated zone flow (UZF) module, and this was used for the single layer unconfined aquifer Hank model in the area around the active ISR mining. This module allowed incorporation of delayed drainage from the zone above the water table for the aquifer under unconfined conditions.

MPH.1.1.1 Model Configuration

The single layer model utilized an unconfined aquifer type, with a series of general head boundaries on the perimeter of the model grid. The initial potentiometric head in the ore sand was approximated as a uniform gradient across the model grid areas. This surface was developed using the typical gradient of 0.005 feet/feet and the general gradient is from east to west. The base of the aquifer in the immediate mine area was determined from drill hole based structural mapping. Outside of the mine area, the elevation of the base of the aquifer was extrapolated based on typical structural dip from the available structural mapping. The thickness of the aquifer was established as the typical thickness of 90 feet.

On the periphery of the model grid, selected cells were designated as general head boundary cells to stabilize the potentiometric surface. The head in each of the 106 designated general head boundary cells was set at the initial model head and the cell conductance was set at a relatively high level to provide a generally stable regional potentiometric surface.

MPH.1.1.1.1 Model Grid

The model grid consists of 274 rows by 98 columns and is rotated approximately 10.5 degrees counterclockwise from the orthogonal directions. The smallest cell dimension is 30 feet by 30 feet, and the largest cell dimension is 13,500 feet by 13,500 feet as shown in Figure MPH.1-1.

MPH.1.1.1.2 Aquifer Properties

The primary aquifer properties information used in the model included hydraulic conductivity and specific yield. The hydraulic conductivity was set at 1.0 foot/day and an effective specific yield of 0.14. The water level is near the overlying confining layer in some areas of the planned wellfields, and it is likely that a significant portion of the wellfield area will be under unconfined conditions both prior to and during mining. This results in a condition where there is potentially an impact by vertical partially saturated flow from areas where the wellfield bleed causes significant drawdown in the aquifer.

The partially saturated flow conditions require additional definition of hydraulic properties. The UZF module in MODFLOW-2005 utilizes the ratio of vertical to horizontal hydraulic conductivity and a Brooks-Corey function to approximate the hydraulic conductivity under partially saturated conditions. The ratio of vertical to horizontal hydraulic conductivity was estimated at 0.085. The Brooks-Corey function uses an exponent (epsilon) to define the shape of the partially saturated hydraulic conductivity as a function of volumetric moisture content and that was set at 3.5. The effective saturated volumetric moisture content was set at 0.30 and the UZF module uses the specific yield of 0.14 to approximate residual saturation.

MPH.1.1.1.3 Wellfield Configuration

The proposed mining sequence includes two distinct wellfields with an anticipated mining period of 1½ years for each wellfield. Each wellfield consists of a combination of staggered production and injection wells arranged generally in a line drive layout for the sinuous ore body. The number of wells and well locations are preliminary and will be refined with further definition of the ore body. Because the natural gradient is from east to west, the well arrangement for the typically narrow ore body places the injection wells on the upgradient side of the ore zone with the production wells on the downgradient side of the ore zone. Several model runs were conducted to evaluate horizontal flare, general wellfield operation, and post mining recovery. The model runs and wellfield configuration for the horizontal flare evaluation are described in a following section. Figure MPH.1-2 presents the wellfield #1 production and injection well layout. Figure MPH.1-3 presents the wellfield #2 production and injection well layout.

MPH.1.1.1.4 Operational Parameters

The anticipated production rates from the wellfield #1 wells range from 12.5 to 12.7 gpm. A total of 198 production wells were included in the full wellfield #1 operation. Total production rate was 2,500 gpm. Injection well operational rates ranged from 5.2 to 12.7 gpm with a total of 271 injection wells. Excess production or bleed rate was set at 3% of total production with a resulting injection rate of 2,425 gpm.

The anticipated production rate from the 93 production wells in wellfield #2 is 26.9 gpm with a resulting total production rate of 2,500 gpm. Injection well operational rates ranged from 15.6 to 20 gpm with a total of 119 injection wells. Excess production or bleed rate was set at 3% of total production with a resulting injection rate of 2,425 gpm.

MPH.1.1.1.5 Stress Periods

Numerous stress periods were included to allow comparison of predicted aquifer response to the wellfield operations at several times during the simulation period. A transient simulation also requires very small computational time steps after each significant change in aquifer stresses including startup or shutdown of well operation. This is necessary to prevent a failure to converge in the model computation. The initial stress period and time steps were set at a very small value (0.0001 day with 5 time steps) to produce a model output result that essentially reflects initial head conditions. The stress period lengths were then gradually increased until there was a significant change in model stresses, at which the sequence reverted to a short stress period followed by gradually increasing stress period lengths. A total of 12 stress periods were used in a total simulation period of six years which included 1.5 years of operation of each wellfield followed by a three year period of post-mining recovery.

MPH.1.1.2 Model Results

The MODFLOW model produces output in terms of predicted drawdown or predicted head at selected times within the simulation. The drawdown or water-level rise is calculated as the difference between head at a selected time and the initial head for the aquifer at the start of the simulation. Both results are useful in the interpretation of aquifer response to the mining and are used to evaluate the modeling predictions.

MPH.1.1.2.1 Wellfield #1

The configuration for wellfield #1 is show in Figure MPH.1-2. The modeled potentiometric surface prior to the start of mining is presented Figure MPH.1-4. The mining operation of the production and injection wells is expected to continue for 18 months, after which mining of wellfield #2 begins. Figure MPH.1-5 presents the predicted drawdown contours for wellfield #1 after one year of operation. Figure MPH.1-6 presents the predicted water-level elevation contours for wellfield #1 after one year of operation. The operation of the wellfield at a bleed rate of 3% of the planned 2,500 gpm production rate has resulted in development of a significant cone of depression around the operating wellfield. The area of gradient reversal extends approximately 800 to 1,300 feet to the west of wellfield #1.

MPH.1.1.2.2 Wellfield #2

The configuration for wellfield #2 is show in Figure MPH.1-3. The operation of wellfield #2 will begin after mining is completed in wellfield #1. Figure MPH.1-7 presents the predicted drawdown contours for the mine area after 18 months of operation of wellfield #1 and 18 months of operation of wellfield #2. The drawdown calculation is based on water level change from the pre-mining potentiometric surface and this drawdown reflects significant residual drawdown from the operation of wellfield #1. The drawdown at the end of mining shown in Figure MPH.1-7 is very similar to drawdown predictions produced by the analytical model. This similarity between the numerical and analytical model results demonstrates the adequacy of analytical modeling with an appropriate configuration. Figure MPH.1-8 presents the predicted water-level elevation contours for the mine area at the end of mining in wellfield #2. Wellfield #2 is planned to be operated at a bleed rate of 3% of the planned 2,500 gpm production rate. The area of gradient reversal extends approximately 1,200 to 1,600 feet to the west of wellfield #2.

MPH.1.1.2.3 End of Mining

The end of mining water level changes are reflected in Figures MPH.1-7 and MPH.1-8 as described in the previous section. The planned Hank area ISR project includes two adjacent wellfields operated in sequence for a period of 18 months per wellfield. Wellfield #1 encompasses a larger area, but the effective stress rate of 75 gpm still produces a significant impact on the potentiometric surface. Following cessation of mining in wellfield #1, the potentiometric surface exhibits some recovery in the northern portion of the mining project. Simultaneously, the operation of wellfield #2 causes drawdown in the southern portion of the project area.

MPH.1.2 Horizontal Flare Evaluation

Horizontal flare around the operating well field was evaluated by modeling transport of a generic solute that was introduced into the injection wells. The MODFLOW-2005 results for a selected ore zone within wellfield #1 were used as a basis for simulating flare of the lixiviant in the operating wellfield.

MPH.1.2.1 MT3DMS Modeling

The MT3DMS model is a convection-dispersion equation (CDE) based model that utilizes ground-water flow output from the MODFLOW model to simulate solute transport. This is accomplished using a routine in MODFLOW that produces a transfer file that includes cell by cell flow terms. This transfer file is then read by MT3DMS, and the solute transport processes are "superimposed" on the ground-water flow. The MT3DMS has features for solute adsorption, retardation, transformation, degradation, etc., but for this application, the solute was assumed to be conservatively transported and these features were not used.

In order to evaluate the flare, a generic solute was used with an elevated concentration of the lixiviant injectate. The ratio of lixiviant concentration to background concentration was 5, and the background concentration was set at 1.0 for simplicity. The lixiviant concentration was set at 5.0, and the increase in concentration in the area surrounding injection wells was used as the indicator of flare. Because the solute was generic and the magnitude of concentration changes is used to quantify flare, the units of concentration do not affect the evaluation.

MPH.1.2.1.1 Transport Model Configuration

The model grid, dimensions, and layout are the same as those established in the MODFLOW-2005 modeling.

MPH.1.2.1.2 Wellfield Configuration

The wellfield utilized in the MODFLOW-2005/MT3DMS modeling was limited to the lower ore zone of wellfield #1, This subset of wellfield #1 included 88 production wells operating at a rate of 12.5 gpm, and 125 injection wells operating at a rate ranging from 5.2 to 12.7 gpm. There was a 3% bleed in the well field operation with a resulting net extraction stress of approximately 33 gpm. The wells included in the horizontal flare modeling are shown along with the approximate boundary of the identified ore body in Figure MPH.1-9

MPH.1.2.1.3 Stress Periods

Because MT3DMS and MODFLOW-2005 are coupled through a transfer file, the stress periods for MT3DMS are the same as those used in MODFLOW-2005. A modeling period of 120 days was used in the interpretation of horizontal flare. This modeling period was selected as being sufficient to allow establishment of pseudo steady-state solution flow paths and gradients within the operating wellfield, while being a short enough period that the increased gradient reversal with longer operation will not appreciably change or reduce the flare zone. With only a subset of wellfield #1 included in the stress rate, total magnitude of drawdown and corresponding gradient reversal to the wellfield is also conservatively small so there should also be some degree of conservatism in the estimation of flare.

MPH.1.2.1.4 MT3DMS Inputs

The typical aquifer thickness for the MODFLOW-2005 modeling is 90 feet, but the anticipated completion interval for an ore body is roughly 15 feet. A cell thickness of 15 feet was specified in the MT3DMS model to represent the typical anticipated completion thickness. The effective porosity of the ore zone was estimated at 30%. The dispersivity was set at 2 feet, but it is not considered a critical factor because ISR mining is primarily a pseudo steady-state convection dominated process. The diffusion coefficient was set at zero. As discussed previously, the background generic solute concentration was set at one, with a lixiviant injectate concentration of five.

MPH.1.2.2 Model Results

The development of the drawdown around the operating wellfield area with the 120 day simulation period results in gradient reversal to the wellfield. Figure MPH.1-10 presents the predicted potentiometric surface for the horizontal flare wellfield operation. On the west side of the wellfield, the zone of gradient reversal generally extends a few hundred feet after 120 days of operation. Since the ore body is irregularly shaped and consists of two separate zones, the potentiometric surface is complex.

The MT3DMS simulation utilized the ground-water flow predictions from MODFLOW-2005 to simulate the transport of the generic solute from the injection wells to the production wells. The results of this simulation are presented in Figure MPH.1-11 as concentration contours centered around the operating injection wells. The contour interval is 0.5 units, and the outer contour is 1.5 times the natural background concentration of the aquifer. This is interpreted as a concentration change representing the extent of the lixiviant flare. In the model cells containing an active injection well, the concentration approaches the injectate concentration of five.

MPH.1.2.2.1 Flare Evaluation

As shown in Figure MPH.1-11, the combination of radial flow of the lixiviant immediately around the injection wells and the radial capture zone around production wells results in flow paths that extend throughout and slightly beyond the ore body. This horizontal flare is quantified as the ratio of the area contacted by the injectate to the area of the ore body under wellfield pattern (see Figure MPH.1-9). The area contacted by the injectate is represented by the contour line where there is a 0.5 unit concentration increase over the background concentration of 1.0. The ratio of the area within the 1.5 concentration contour to the area of the ore body within the well pattern is 1.39 and this is considered the horizontal flare factor. This flare factor is larger than a more typical estimate of 1.25, and this reflects the relatively narrow linear nature of the ore body and wellfield.

MPH.1.3 Vertical Flare Evaluation

The vertical flare was estimated using a combination of the WTAQ program to calculate heads through a cross section of the aquifer and a spreadsheet for compositing the heads to evaluate the resulting velocity field. The WTAQ program incorporates a two-dimensional analytic solution for axial-symmetric ground-water flow in both confined and unconfined aquifers. The solution allows simulation of partially penetrating wells for an unconfined aquifer, which is directly applicable for the Hank ISR mining project.

The product of the WTAQ model is prediction of observation well drawdown at specified time(s) after pump start and at specified distance(s) from the pumping well. For an injection well, the drawdown predictions are simply inverted to represent water-level rise. The WTAQ program was run multiple times and the results composited to generate a matrix of drawdown predictions with matrix rows representing one foot of vertical thickness and matrix columns representing radial distance from the well in increments of one foot. The matrix dimensions were 90 rows (90 feet aquifer thickness) by 68 columns (69 feet radial distance from well). The matrix was basically mirrored on a vertical axis to provide a matrix for both an operating injection and production well. The resulting matrices were then incorporated into the spreadsheet to represent a combination of an ISR injection and production well pair at a spacing of 69 feet in a 90 feet thick aquifer.

MPH.1.3.1 WTAQ Modeling

Inputs to the WATQ model define the completion interval for the simulated production and injection wells, and the required aquifer properties for the solution. Both the production and injection wells were located within a 90 foot thick water table aquifer. Horizontal hydraulic conductivity was 1.0 feet per day, and the ratio of vertical to horizontal hydraulic conductivity was 0.085. The aquifer storage properties included a storage coefficient of 2.1E-06 (ft/ft) and a specific yield of 0.14. The wells were assumed to be completed from a depth of 76 to 85 feet (inclusive) below the top of the aquifer for a ten foot ore body. This represents a likely configuration for a major ore body at the Hank site.

The observation well which represents the general aquifer was assumed to be fully penetrating. Drawdown was simulated for both 10 and 30 days since the start of injection, but only the 30 day simulation was used in the vertical flare analysis. This was considered sufficient time for development of the flow regime. Because the paired well arrangement reduces a typical wellfield arrangement to a simple pair of wells rather than a production well surrounded by multiple injection wells, the anticipated well production rate was reduced to approximately 6.2 gpm to represent the simplified configuration. The multiple runs of the WTAQ program were accomplished with an external shell program that incremented through the depth and distance from the well while compiling the predicted drawdown into the matrix. The matrices were then incorporated into the vertical flare spreadsheet.

MPH.1.3.2 Vertical Flare Spreadsheet

With the product of the WTAQ program in a matrix of predicted drawdown at one foot intervals in both horizontal and vertical dimensions for the hypothetical vertical cross section, an EXCEL spreadsheet with additional Visual Basic programming was used to evaluate the vertical flare. The matrix of drawdown values was inserted into the spreadsheet to represent the propagation of drawdown from a production well after 30 days of operation. A mirror image of the matrix was used to represent the injection well water-level rise. The summation of the drawdown due to the production well and water-level rise represents the head change in each cell representing a square foot of the aquifer between the wells.

An arbitrary water-level elevation value of 90 feet was added to the water-level change in order to produce a "head" matrix for the cross section between the two wells. This head matrix then allowed calculation of both a horizontal and vertical ground-water velocity for each cell using the head in surrounding cells to calculate a gradient. When combined with the horizontal and vertical hydraulic conductivities of 1.0 ft/day and 0.085 ft/day, respectively, the horizontal and vertical Darcy velocities can be calculated.

MPH.1.3.2.1 Velocity Field

The velocity field for the simple well configuration is used to interpret vertical flare. Because the differential between horizontal and vertical hydraulic conductivity is large, the vertical velocity is reduced very quickly with small vertical distance from the completion interval. The horizontal and vertical ground-water velocity tabulations in the two dimensional field are presented in Figure MPH.1-12. The tabulations are abbreviated to show only the lower portion of the aquifer where there is active injection and production. The vertical and horizontal velocities are presented in units of feet per day. The well completion is shown as the larger diameter interval in the schematic at each end of the section.

The direction of the vertical velocity is indicated by the sign with a positive value indicating upward flow and a negative value indicating downward flow. In close proximity to the injection well, the larger head values within the completion interval produce upward and downward flare. With increasing distance from the injection well, there is a gradual convergence from intervals above and below the completion interval to the completion interval. Near the production well, the vertical convergence to the completion interval becomes stronger.

The horizontal ground-water movement is from the injection well to the production well. The horizontal velocities are greatest near the injection and production wells because of the radial flow representation of the drawdown values produced by WTAQ. The radial flow calculation also results in a variable area represented by each column in the matrix. Each column can be viewed as one-half of a cylinder with a radius of the distance from the nearest of the two wells, and this makes the area proportional to the square of the radius. Hence, the calculation of composite flare is weighted to the square of the radius from the wells.

MPH.1.3.2.2 Flare Evaluation

The vertical flare is calculated as a ratio of the area (or volume) of the aquifer wherein there is a significant vertical velocity away from the completion interval to the actual completion interval. This area or volume is calculated as the thickness of cells in each column where the magnitude of the vertical velocity is significant multiplied by the fraction of the area/volume represented by each column in the matrix. Figure MPH.1-12 presents the vertical velocity matrix with a red boundary line indicating the 10 foot thick ore zone and cells above and below the ore zone where the velocity is 0.05 feet/day or greater away from the ore zone. Horizontal velocity is typically an order of magnitude or more larger than the vertical velocity and the threshold velocity boundary shown for a velocity is 0.50 feet/day or larger. The bounded area for horizontal velocity also includes the entire 10 foot thick ore zone, but does not include horizontal velocity greater than 0.50 feet/day where the vertical flow is convergent to the ore zone.

The proportional area/volume represented by each column increases with distance from the injection well or production well to a maximum at the midpoint between the injection and production wells. The column closest to the injection well represents only 0.043% of the area/volume included in the model, and each of the two columns bridging the midpoint between the wells represents 2.9% of the area/volume.

The number of cells included in each column that were within one or both of the bounded areas shown on Figure MPH.1-12 were summed and then multiplied by the fraction of the area/volume represented by the column. These products of cell counts and fractional area/volume where then summed and divided by the corresponded cell counts for the ore zone only. This ratio represents the estimated vertical flare for the specified configuration, and was calculated as 1.22. This is similar to the industry standard vertical flare of 1.25. Although there are necessary simplifications and uncertainties involved in this simulation approach, the results are reasonable and consistent with vertical flare estimates from existing ISR operations.

MPH.1.4 Excursion Control and Retrieval

The potential for excursion was considered in a MODFLOW-2005 modeling scenario by adjusting modeling parameters to produce a temporary and local imbalance in wellfield operation. The imbalance involves either insufficient production rate or excess injection rate for a local area such that the local bleed rate is zero or actually negative representing more injection than production. Limiting this condition to a local area of a few wells is considered appropriate because a wider scale imbalance with insufficient bleed is unlikely given continuous monitoring of production and injection rates.

Simulation of retrieval of an excursion is essentially a reversal of the process that created the excursion. Increasing the effective bleed rate for a local area will increase the local drawdown and cause an expansion of the area of gradient reversal. Within this zone of gradient reversal, ground water will be flowing to the production wells and any ground water that has been impacted by mining fluids will be retrieved.

MPH.1.4.1 MODFLOW Modeling Changes

The MODFLOW-2005 modeling configuration described in Section MPH.1.2 was used for the simulation of excursion and retrieval. The model included a wellfield for the lowest ore zone and consisted of 88 production wells operating at a rate of 12.5 gpm, and 125 injection wells operating at a rate ranging from 5.2 to 12.7 gpm. There was a 3% bleed in the well field operation with a resulting net extraction stress of approximately 33 gpm.

In order to simulate a local imbalance, the extraction rate for the four southernmost production wells was adjusted for two separate simulations. The first simulation included operation of the wellfield in a balanced condition for 30 days, followed by 30 days of operation with reduced production rates for the four southernmost production wells to produce a local imbalance. This was in turn followed by a 30 day period with increased production in the four designated wells to affect retrieval and restore gradient reversal. The magnitude of rate changes (both decrease and increase) was 1.04 gpm for each of the four wells. This is approximately an 8% change in the well production rate for the four wells, but only resulted in a wellfield bleed rate range of 2.6 to 3.4% of total wellfield production. The second simulation used the same sequence of balanced, decreased production, and increased production from the wellfield, but utilized a 60 day period for each of the phases.

MPH.1.4.2 30 Day Excursion and Retrieval Simulation

The results of a MODFLOW-2005 simulation of 30 days of normal wellfield operation are presented in Figure MPH.1-13. The cone of depression around the wellfield is expanding, and on the west side of the southern end of the wellfield, the area of gradient reversal extends more than 400 feet from the wellfield. At the end of the initial 30 day period, the production rates were reduced for four wells on the southern end of the wellfield. The potentiometric surface after 30 days of operation with this local imbalance is presented in Figure MPH.1-14. The reduction of production rates for this simulation has resulted in loss of the gradient reversal and a very flat potentiometric surface west of the southern end of the wellfield. The width of the zone where the gradient reversal is lost is more than 500 feet, and based on the very small ground-water gradient in this area, an excursion is possible but movement rates would be extremely slow. Based on the surface presented in Figure MPH.1-14, the potential excursion of mining fluids would also be spread over a width that is approaching the width of the interval where gradient reversal is lost. Figure MPH.1-15 presents the potentiometric surface after an additional 30 day stress period with increased well production rates. The gradient reversal has been regained and extends approximately 400 feet to the west of the wellfield. This indicates that retrieval will be effective, but the gradient reversal is still relatively mild and the rates of both excursion and retrieval will be slow.

MPH.1.4.3 60 Day Excursion and Retrieval Simulation

The second simulation used a period of 60 days for normal wellfield operation followed by 60 days with a local wellfield imbalance with a subsequent 60 days of overproduction in the affected area. After 60 days of balanced wellfield operation, there is distinct gradient reversal west of the wellfield. After an additional 60 days with local imbalance the potentiometric surface shown in Figure MPH.1-16 indicates that gradient reversal has been lost and that a very flat potentiometric surface extends for approximately 400 feet west of the southern end of the wellfield. When the production rates are increased to retrieve any mining fluid impacted ground water moving to the west of the wellfield, gradient reversal is regained within 60 days as shown in Figure MPH.1-17. The zone of restored gradient reversal extends beyond 500 feet from the edge of the wellfield.

MPH.1.4.4 Discussion of Excursion Model Results

The excursion and retrieval simulations indicate that development of excursion conditions under moderately imbalanced wellfield conditions will be relatively slow, and that regaining gradient reversal will also be a slow process. This is attributed in large part to the expected unconfined conditions for the Hank wellfield areas. The large volume of ground water released or stored with a unit change in head greatly extends the time frame for significant gradient changes. The width of the zone over which gradient reversal is lost is also relatively wide at approximately 500 feet. Mining fluids that are migrating away from the active wellfield will be spread over a width that is approaching the width of the area where gradient reversal is lost, and there will be additional flare as the impacted ground water moves away from the wellfield. This indicates that the anticipated monitoring ring well spacing of 500 feet will be sufficient to detect potential excursions.

MPH.2 REFERENCES

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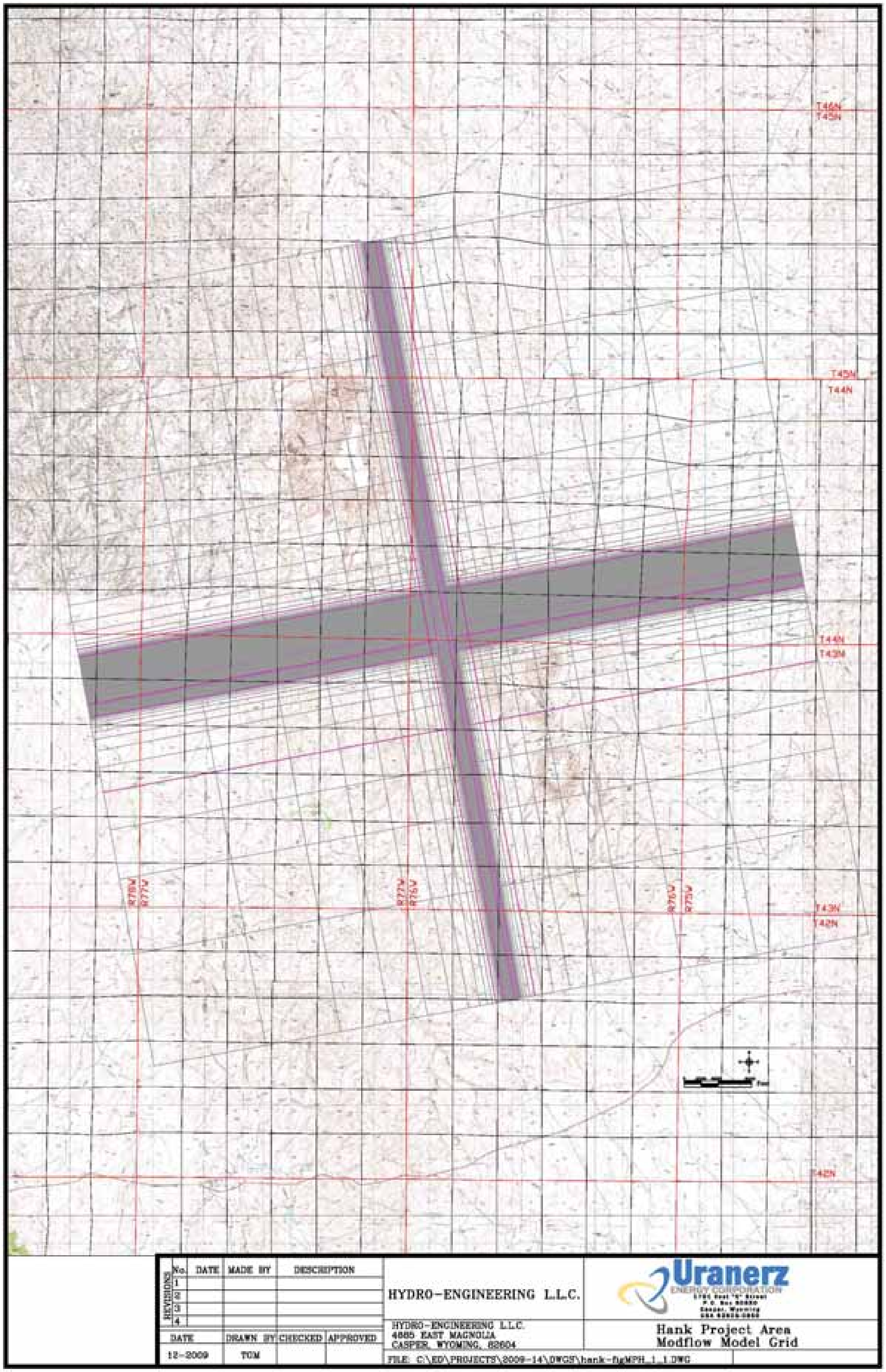


Figure MPH.1-1. Hank Project Area Modflow Model Grid

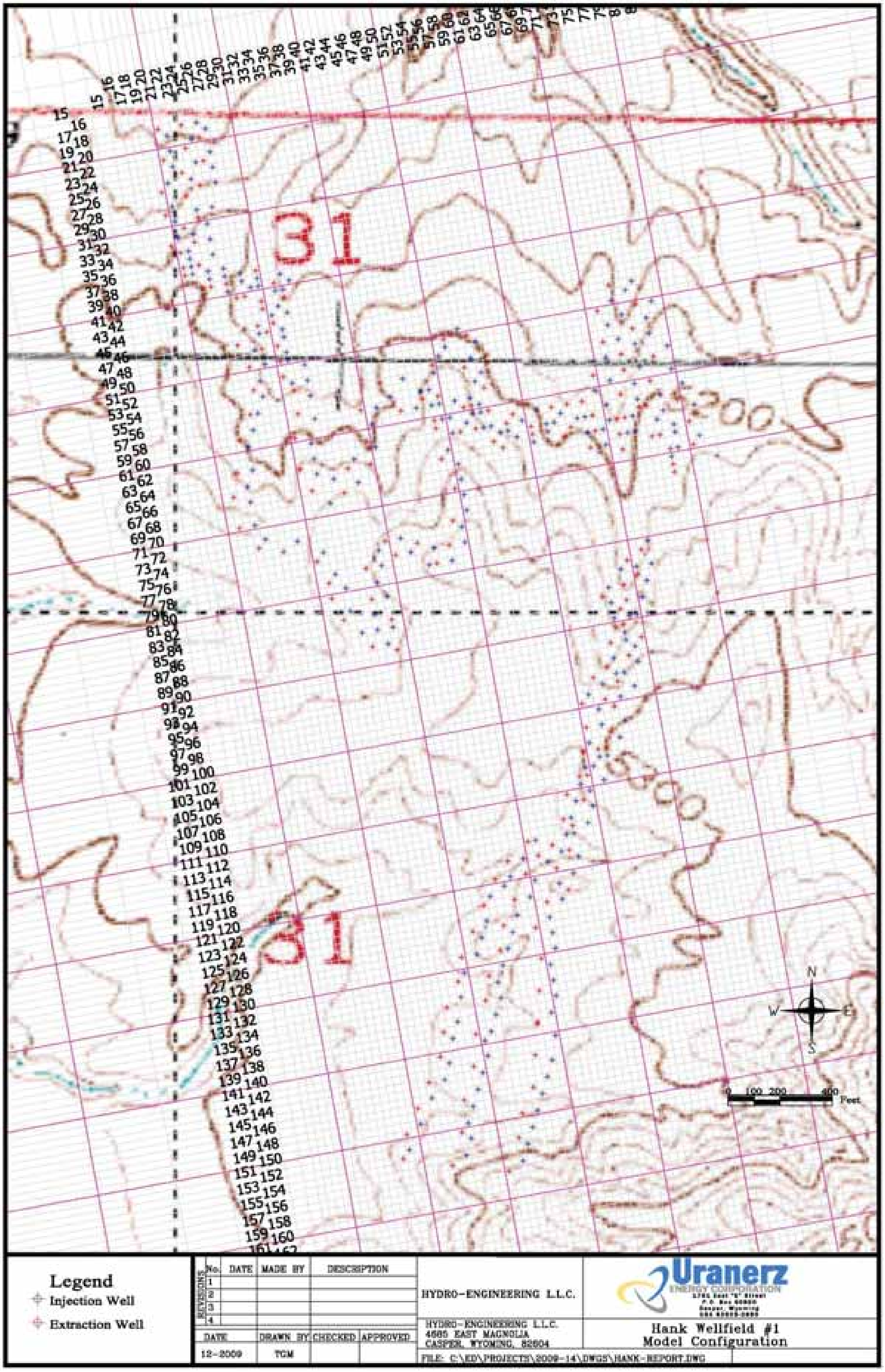


Figure MPH.1-2. Hank Wellfield #1 Model Configuration

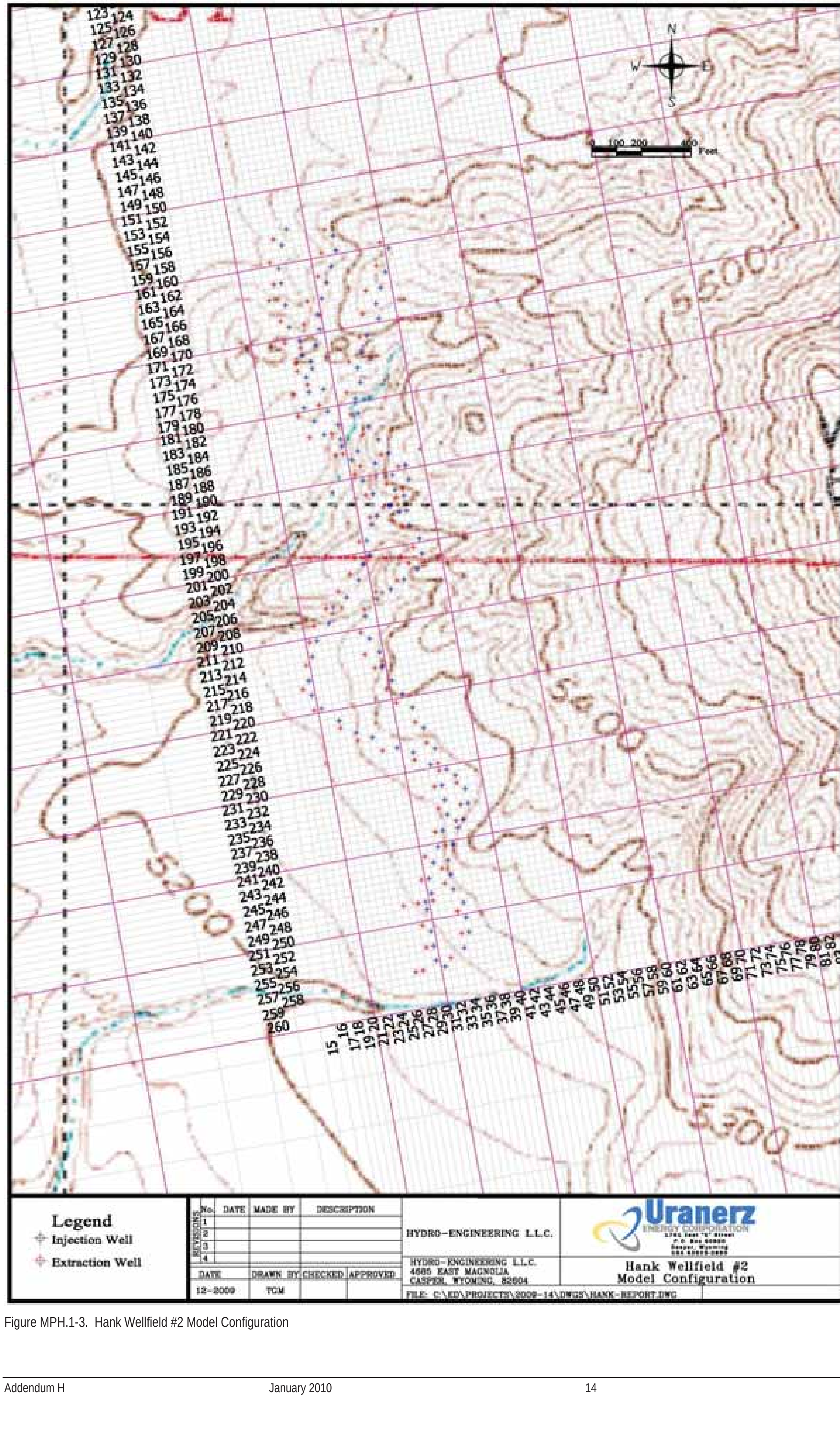


Figure MPH.1-3. Hank Wellfield #2 Model Configuration

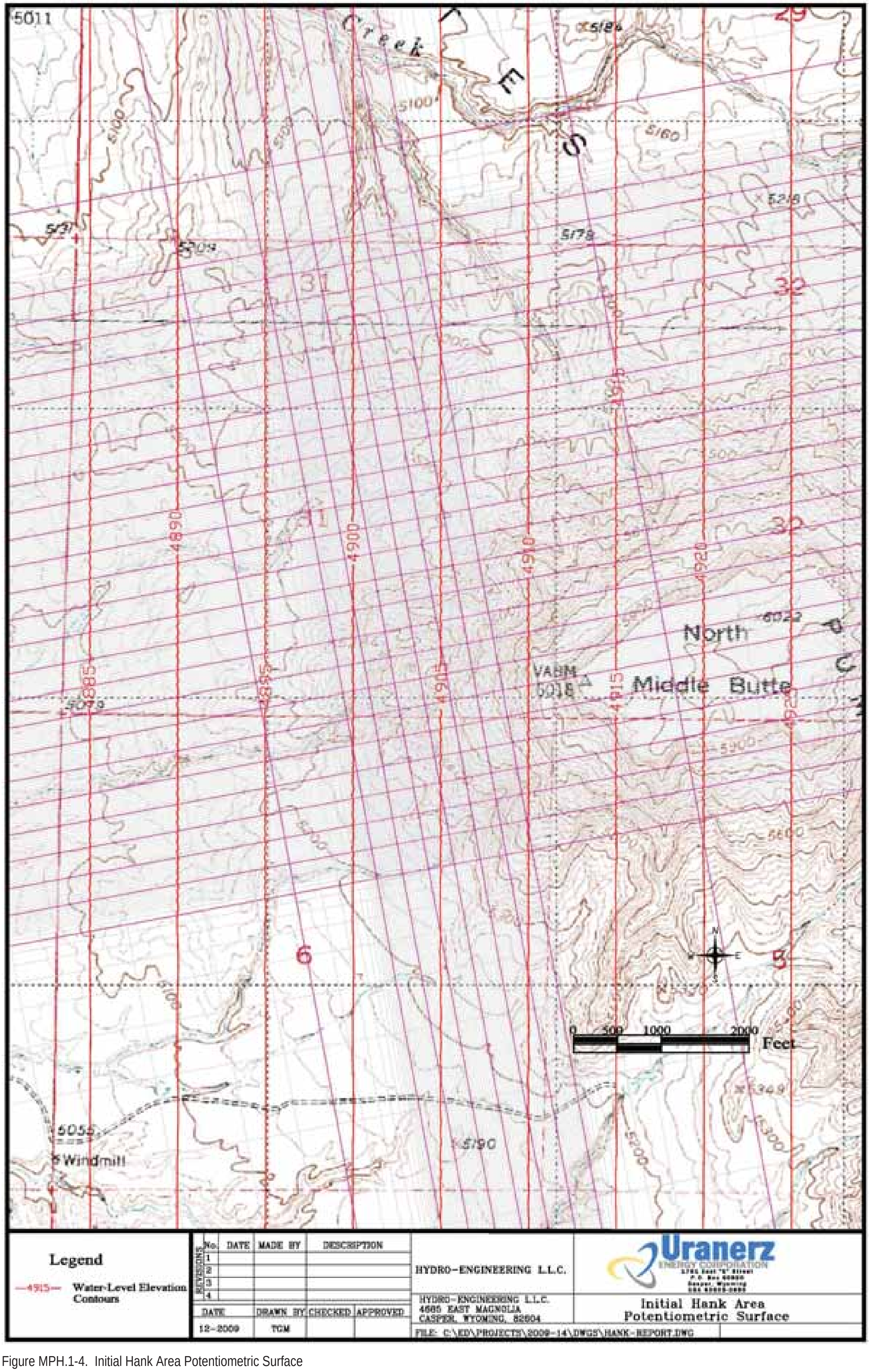


Figure MPH.1-4. Initial Hank Area Potentiometric Surface

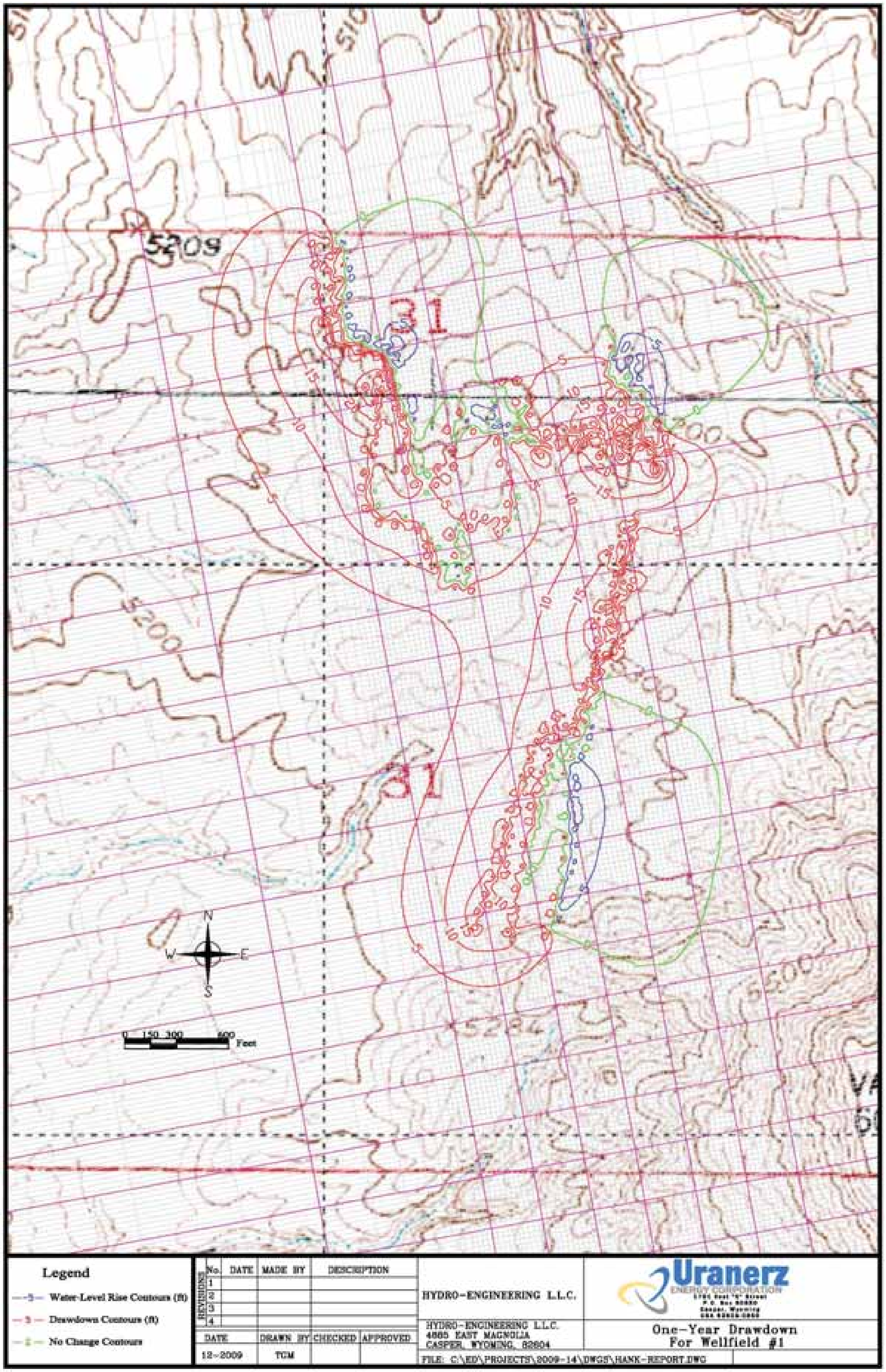


Figure MPH.1-5. One-Year Drawdown for Wellfield #1

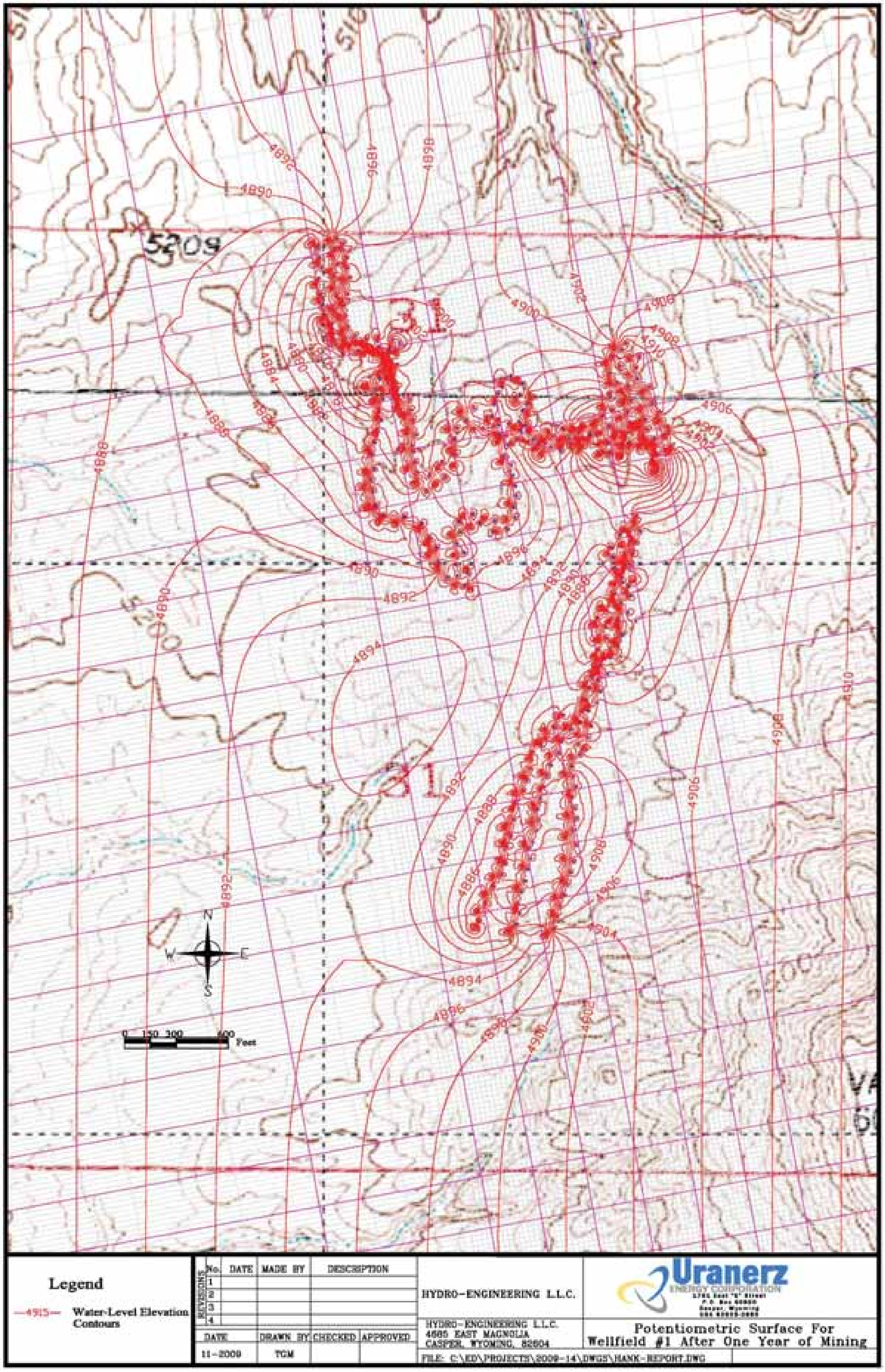


Figure MPH.1-6. Potentiometric Surface for Wellfield #1 After One Year of Mining

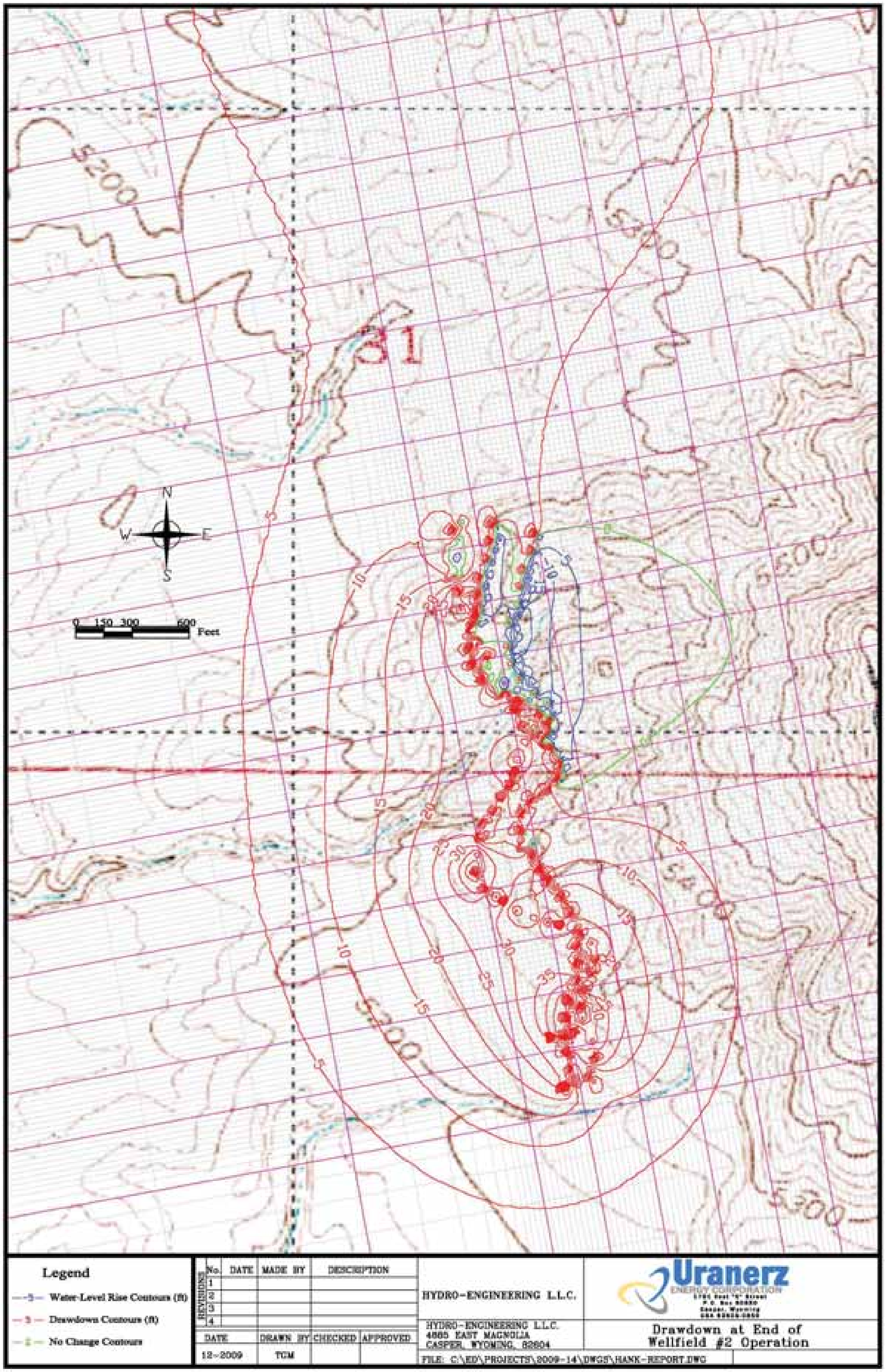


Figure MPH.1-7. Drawdown at End of Wellfield #2 Operation

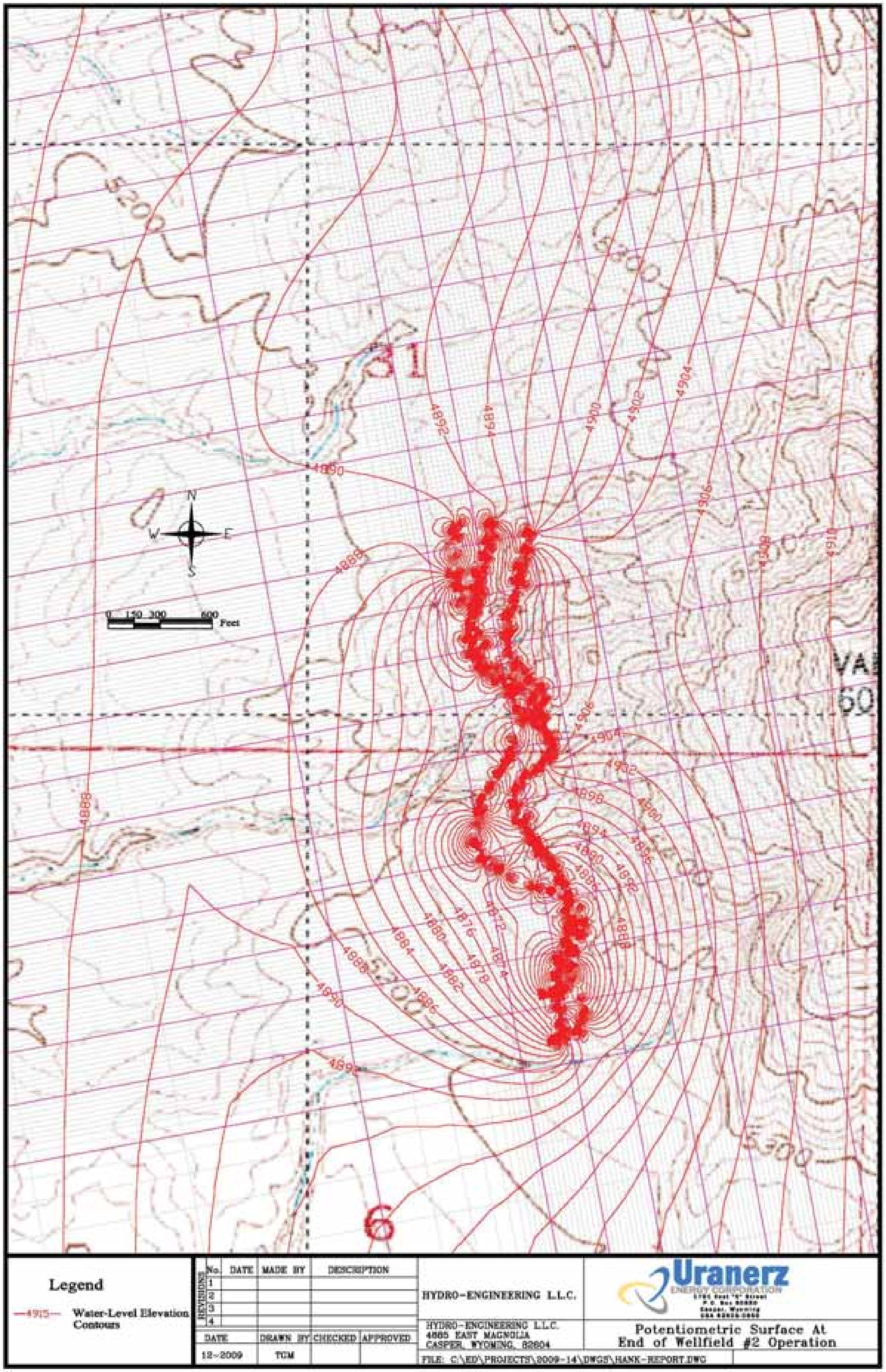


Figure MPH.1-8. Potentiometric Surface at End of Wellfield #2 Operation

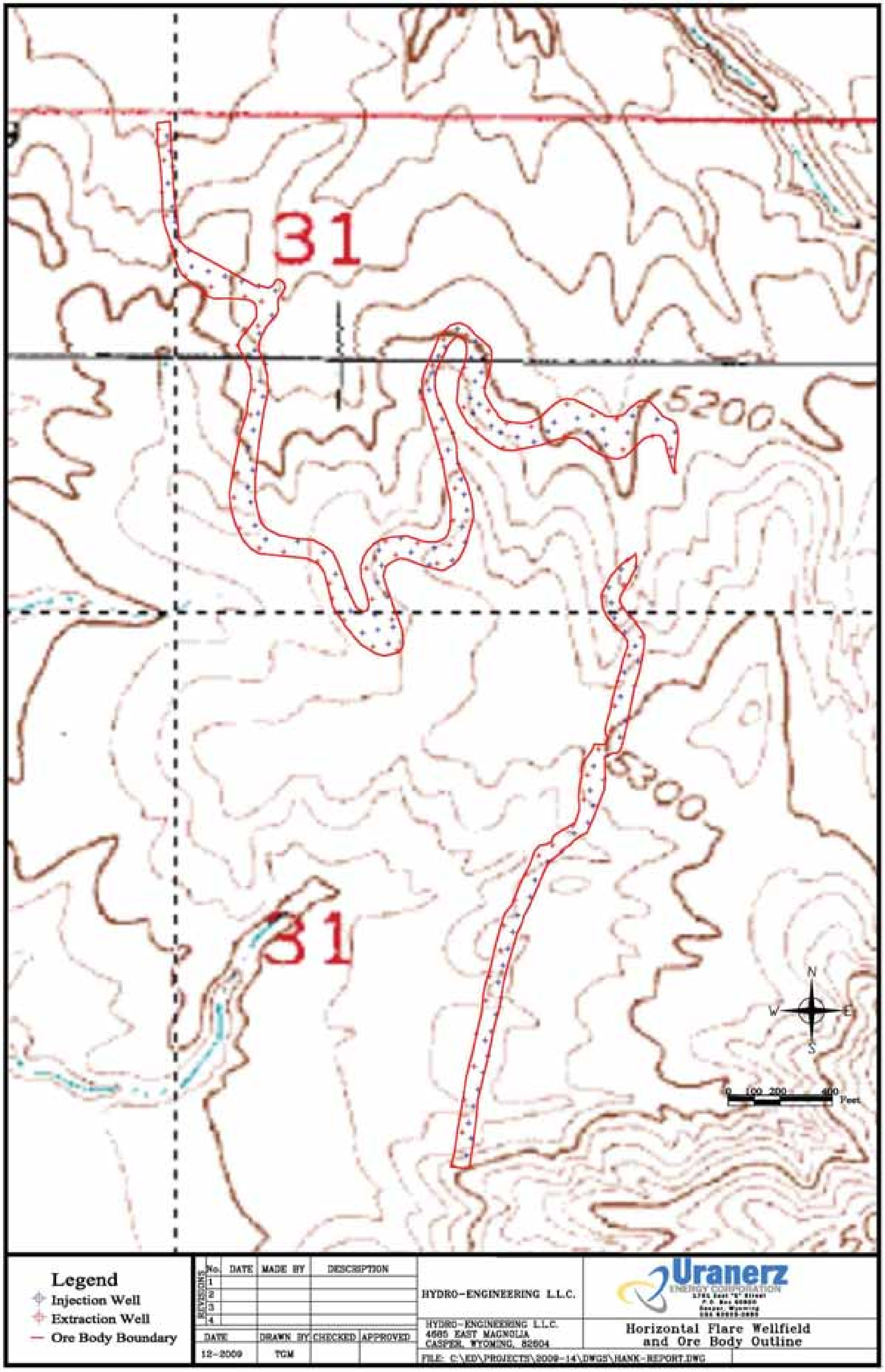


Figure MPH.1-9. Horizontal Flare Wellfield and Ore Body Outline

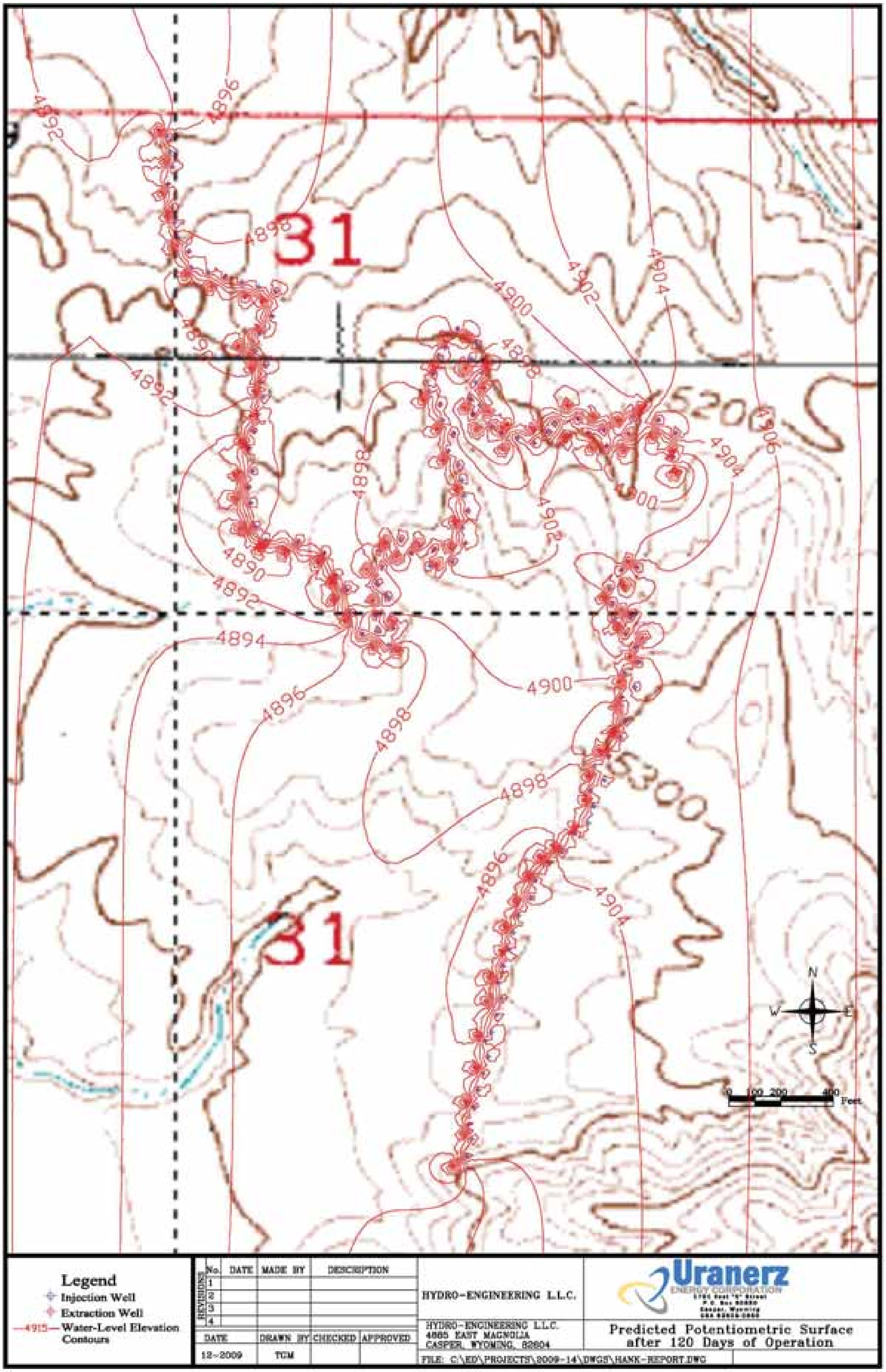


Figure MPH.1-10. Predicted Potentiometric Surface after 120 Days of Operation

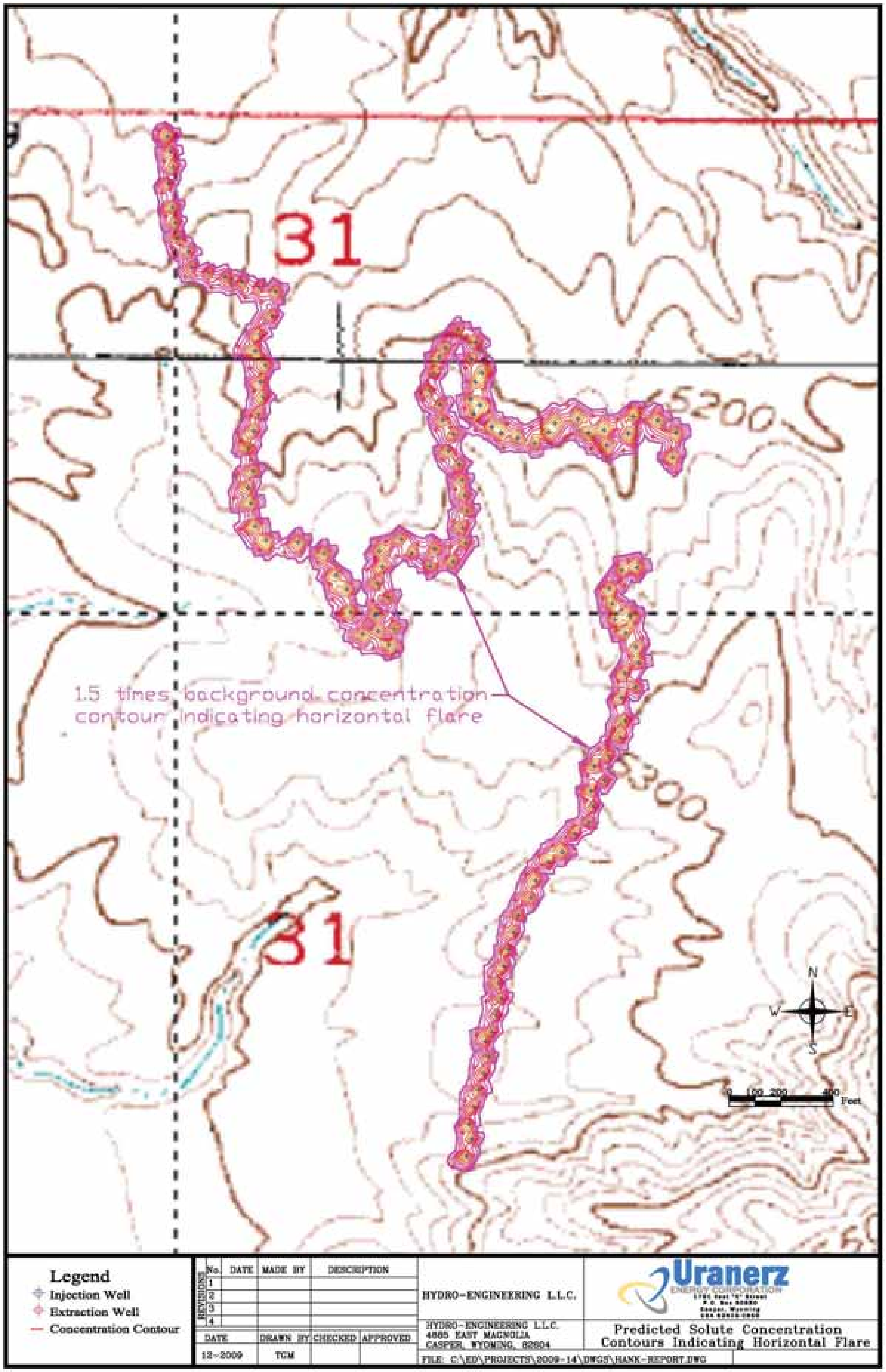
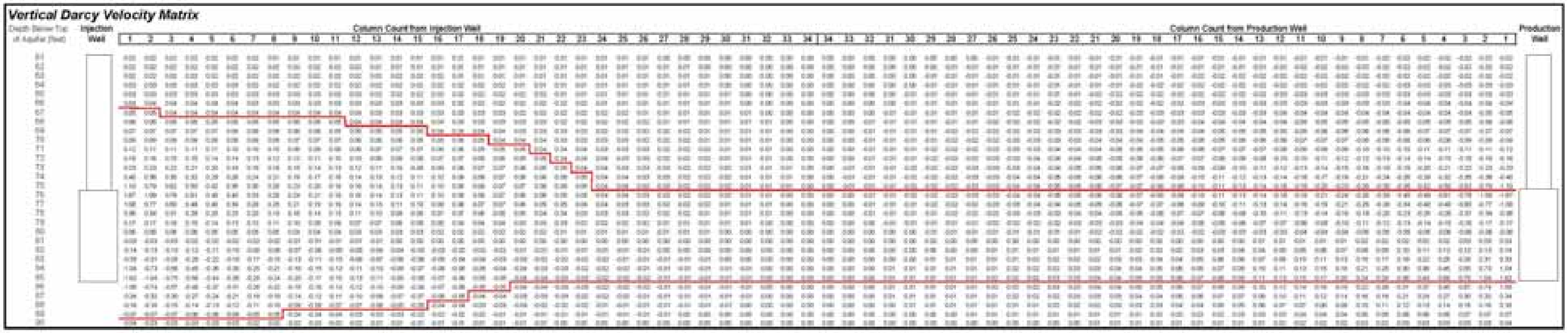
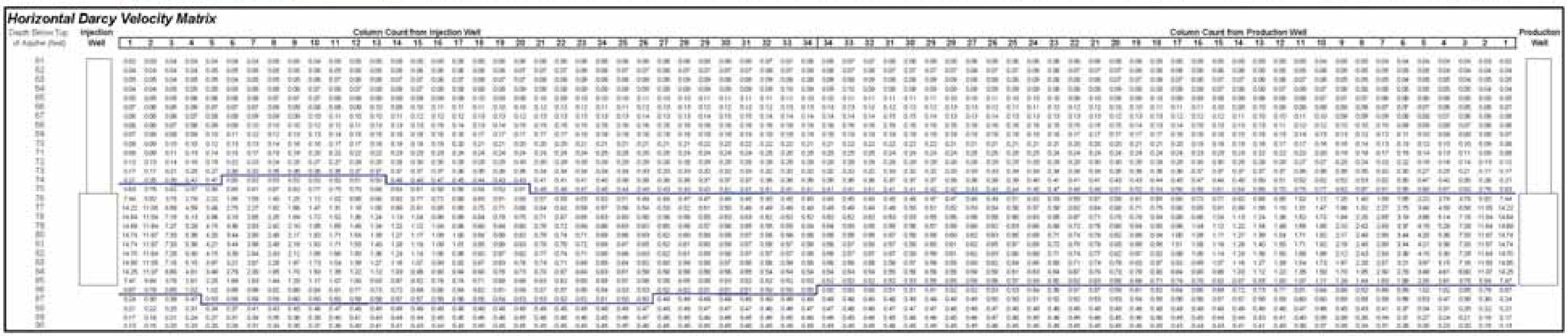


Figure MPH.1-11. Predicted Solute Concentration Contours Indicating Horizontal Flare

Figure MPH.1-12. Predicted Vertical and Horizontal Velocity Fields For Well Pair Simulation





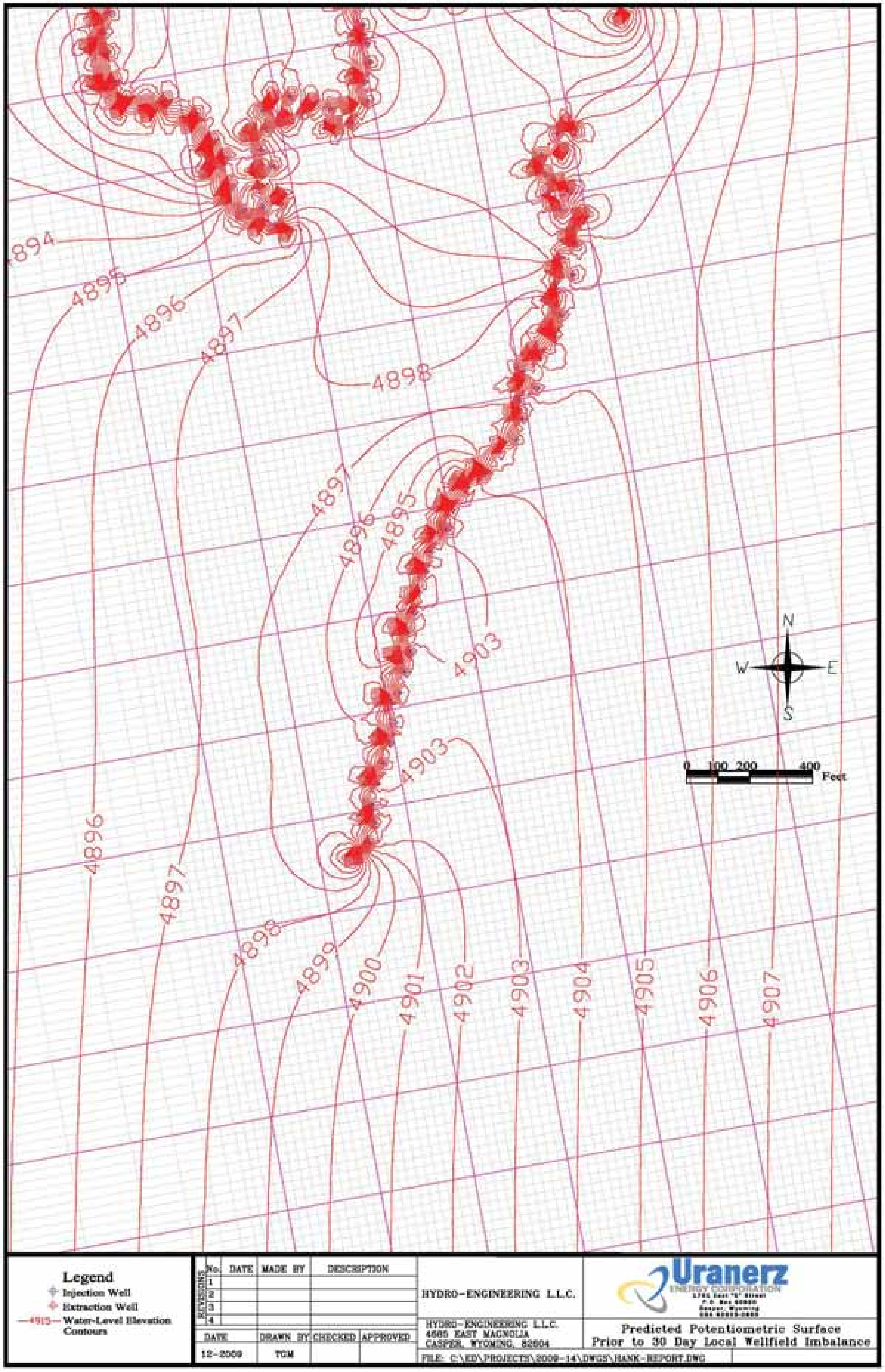


Figure MPH.1-13. Predicted Potentiometric Surface Prior to 30 Day Local Wellfield Imbalance

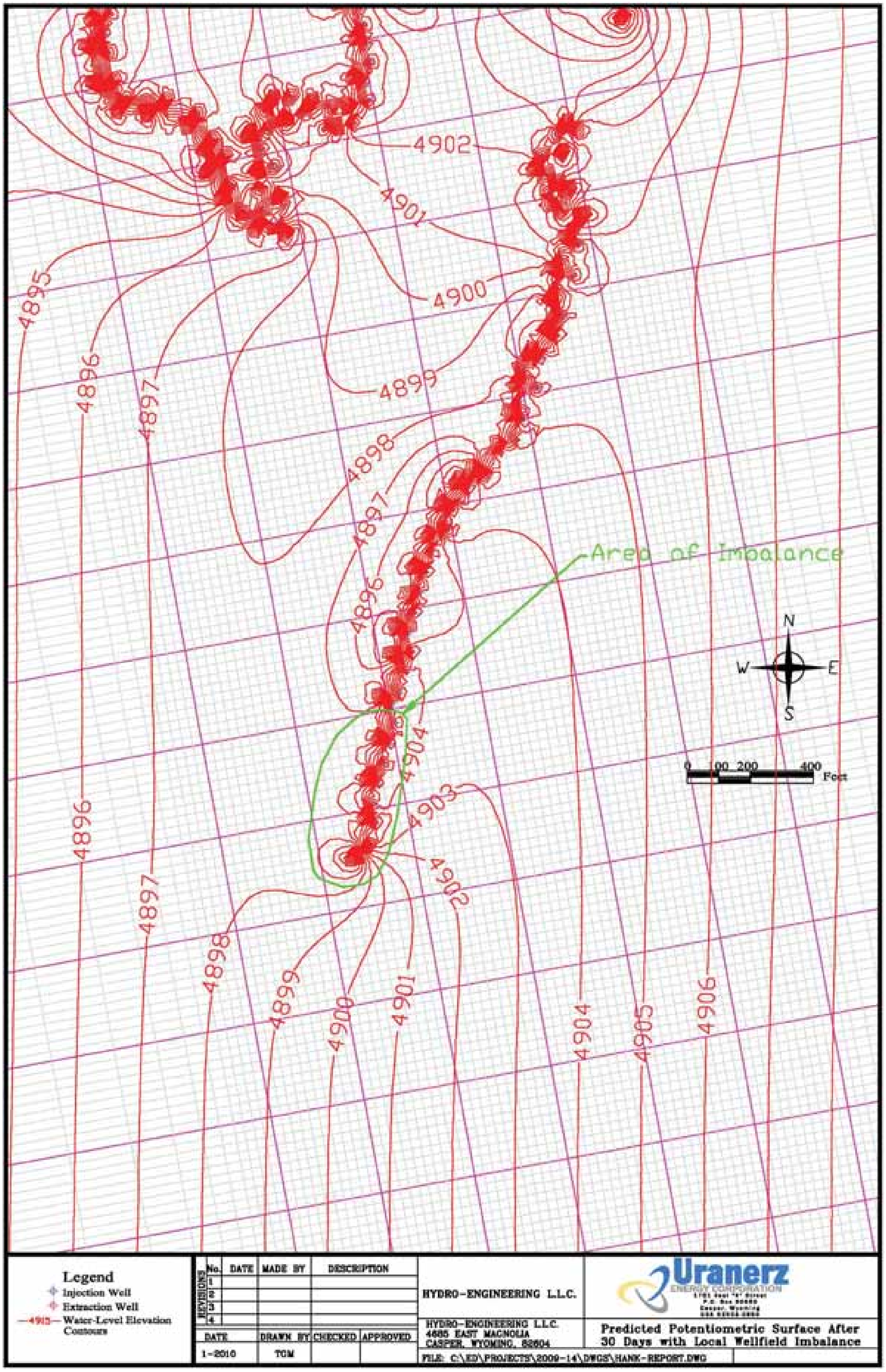


Figure MPH.1-14. Predicted Potentiometric Surface After 30 Day Local Wellfield Imbalance

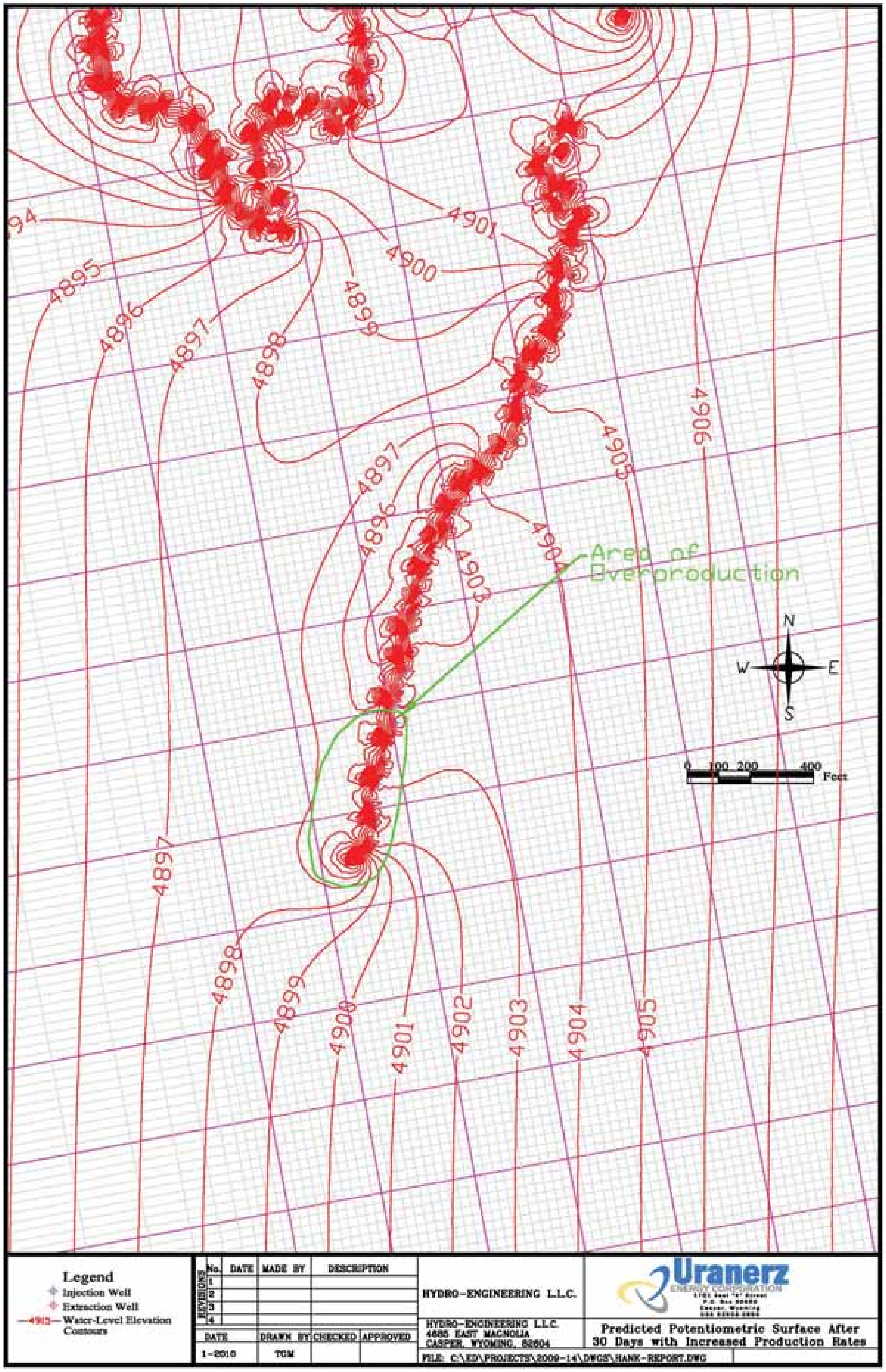


Figure MPH.1-15. Predicted Potentiometric Surface After 30 Days with Increased Production Rates

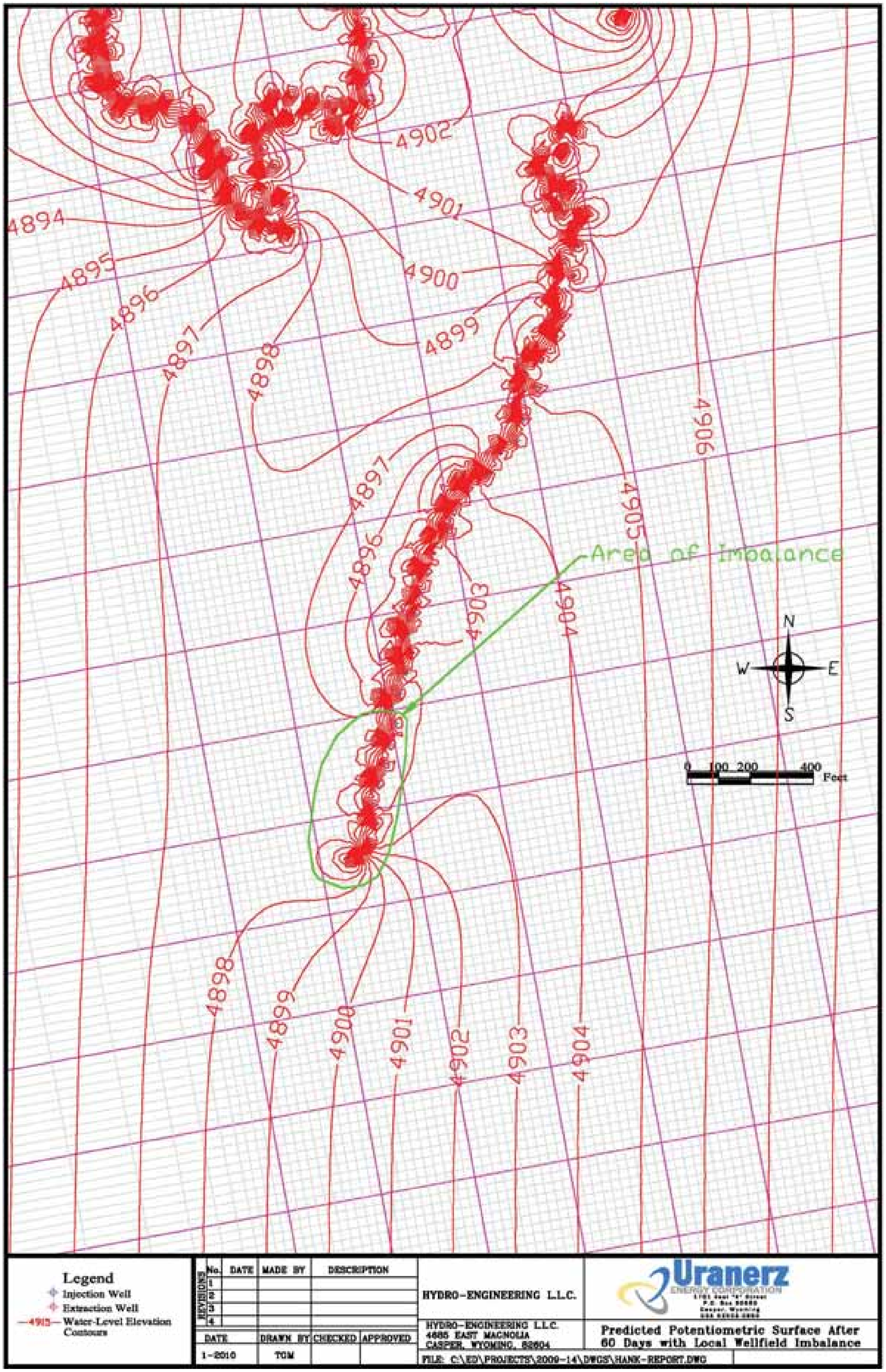


Figure MPH.1-16. Predicted Potentiometric Surface After 60 Day Local Wellfield Imbalance

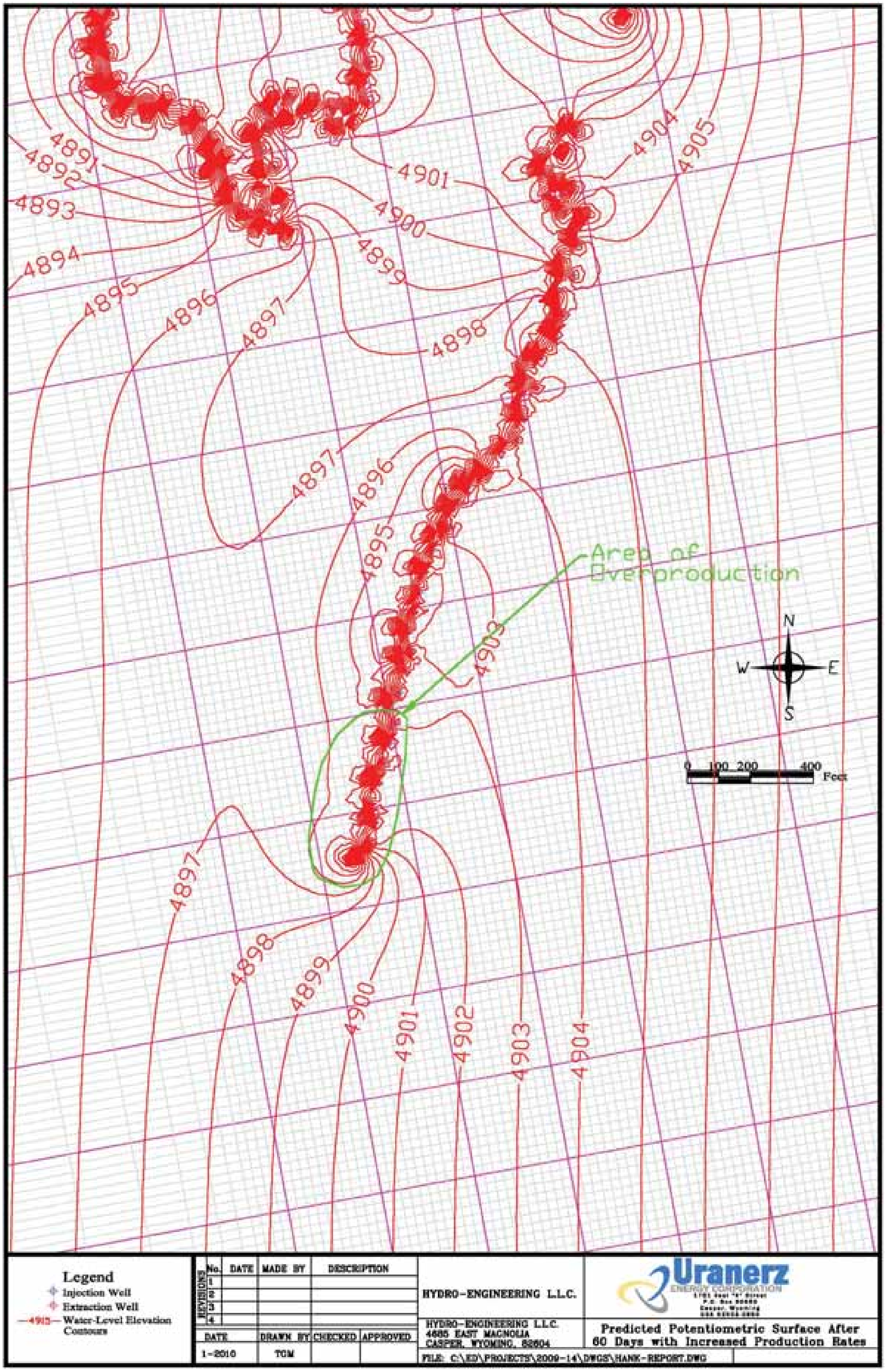


Figure MPH.1-17. Predicted Potentiometric Surface After 60 Days with Increased Production Rates