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PROGRESS REPORT NO. 2

UPDATED CONCEPTUAL HYDROGEOLOGY, EVALUATION OF CURRENT AND FUTURE DEWATERING, AND PROPOSED TESTING PROGRAM FOR SKYLINE MINE

Prepared for

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Helper, Utah

by

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1. In August 2001, a ground-water inflow of approximately 4,300 gpm was encountered in two entries for the planned 10-Left panel at Skyline Mine. The inflow was associated with a minor splay of the Diagonal Fault.

2. Two large diameter wells were drilled from surface in James Canyon immediately above the inflows in September-October 2001 in an attempt to intercept as much of the ground water as possible before it flowed into the 10-Left entries. The first well, JC-1, produces 2,200 gpm and is pump-limited (i.e., the formation and well could yield more). The second well, JC-2, is either well- or formation-limited, and produces only about 300 gpm.

3. The rate of inflow at 10-Left has not been adequately monitored through time. The rate was approximately 4,300 gpm shortly after the inflow began. Based on different methods of measurement, the rate appears to have decreased to about 3,400 gpm by early October, and to 3,200 gpm since then (all discounting the effect of James Canyon pumping).

4. The effect of pumping from JC-1 and JC-2 on the rate of ground-water inflow at 10-Left has been estimated three different ways, each yielding different values. A comparison of Doppler meter readings on the discharge line to stage volume changes, done prior to and described in Progress Report No.1, produced an estimate of 650 gpm. Subsequent examination of power-usage records suggests that the inflow rate has been reduced by only about 200 gpm. Finally, an estimate based on water level declines and a basic well hydraulics relationship suggests the effect is about 800 gpm.

5. When the lower part of the Level 2 mine is allowed to flood (after mining in the 8-Left and 9-Left panels is complete), the resulting decrease in hydraulic gradient is expected to decrease the rate of inflow at 10-Left by about 1,000 to 1,500 gpm.

6. The hydrostratigraphy described in Progress Report No.1 has been refined with more accurate isopachs of the Storrs and Panther Sandstones underlying the coal to be mined. More significantly, however, is the potential existence of a series of stacked sandstones up to 700 ft thick based on a recently obtained geophysical log of a nearby gas exploration drillhole. The presence of these deep sandstones could potentially explain the relatively large, sustained ground-water inflows to the Skyline mine along faults.

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7. As previously reported, the major inflows correlate with structural trend. Where north- to northeast-trending structures dominate, relatively large inflows have been encountered. Currently, large inflows have not occurred in areas where east-west structures dominate. Based on this factor alone, there is a greater risk of significant ground-water inflows in the Flat Canyon tract where northeast-trending faults have been mapped than in the Winter Quarters tract where CFC has mapped only east-west faults.

8. Final laboratory results of water chemistry analyses do not change previously reported chemical interpretations. On the basis of major ions, carbon-based age, and tritium content, the underground inflows and discharge from the James Canyon wells do not have any significant component of water from Electric Lake or from any other surface source.

9. Additional water level data from monitoring wells in the Flat Canyon tract suggest an even higher degree of interconnection among faults than previously recognized. In addition, a preliminary comparison suggests that the faults in the Flat Canyon tract are hydraulically similar to the Diagonal Fault and dewatering requirements could be similar.

10. HCI believes that an estimate of the amount of water that might have to be managed in the Flat Canyon tract and planning the timing of implementation and location(s) of a dewatering system will require a true feasibility-level study involving additional field testing, numerical ground-water flow modeling, and a detailed economic and environmental assessment of the various dewatering and water management options.

11. A numerical ground-water flow model of the Skyline Mine and vicinity is currently being constructed. The model will evaluate flow within the deeper confined aquifers and will not incorporate shallow ground-water effects. The model will be used to predict the amounts of water that will have to be removed, the timing of such dewatering, and optimal locations of pumping centers in the Flat Canyon tract.

12. Future work should include:

    a) Installation of additional water-level instrumentation in existing monitoring wells and shut-in boreholes in the Skyline Mine area.

    b) An underground drilling and testing program, to be initiated in April 2002, to obtain data on the hydraulic properties of the various sandstones beneath the 11-Left area (including some of the deep sandstones), the hydraulic conductivity of the 14-Left fault, and the potential leakance between the sandstones.

1.0 INTRODUCTION

Ground-water inflow of approximately 1,200 gpm was encountered in a previously unmapped splay fault associated with the Diagonal Fault (Plate I) at Skyline Mine on August 6, 2001 during development of an entry for the 10-Left panel. This was the fourth relatively large inflow that had occurred in the mine during the past 2.5 years.

On August 16, an additional inflow of approximately 3,100 gpm was encountered from an extension of the same structure in an adjacent entry, bringing the total inflow at 10-Left to approximately 4,300 gpm. Canyon Fuel Company (CFC) decided to try to intercept as much of this water as possible using an "emergency" dewatering well completed from the surface. A site in James Canyon was selected (Plate I), and CFC contracted Lang Exploratory Drilling of Salt Lake City to drill and complete a nominal 14-in diameter well. While drilling of the wellbore was in progress, CFC asked Hydrologic Consultants Inc. of Colorado (HCI) to assist in the design and testing of this well. HCI advised completing the well (JC-1) into the Storrs Sandstone alone (i.e., not extending it into the underlying Panther Sandstone).

Test pumping of JC-1, which then continued into production pumping at a rate of 2,200 gpm, began on September 16. CFC commissioned another larger diameter well, designated JC-2, which was installed from September 18 to October 4. Well JC-2 was found to be capable of producing only 300 to 500 gpm. With both JC-1 and JC-2 pumping, the inflow to 10-Left has apparently decreased only a relatively small amount.

A meeting was held at the CFC office in Midvale on October 31 among CFC, Arch Coal, Ark Land, NorWest Mine Services, Inc. (NorWest), and HCI to discuss the results of the dewatering to date (HCI, 2001a) and the ramifications relative to mining of 10-Left and the Flat Canyon tract. As part of that meeting, HCI and CFC agreed on a work plan (HCI, 2001b) to conduct a more comprehensive hydrogeologic study to:

1) Assess whether the inflow to the 10-Left entries can be stopped in a cost-effective manner.

2) Define the hydrogeologic conditions in the Flat Canyon tract, evaluate the potential need for dewatering in that area, and design, if deemed necessary, a dewatering system to be installed as timely and cost-effectively as possible.

3) Evaluate, on a preliminary level, whether the Winter Quarters area would constitute a better mining option in terms of hydrologic risk.

Findings, conclusions, and recommendations based on the hydrogeologic investigation through November 2001 were submitted to CFC in Progress Report No. 1 (HCI, 2001c). This second Progress Report summarizes the work completed since November and presents HCI's updated findings, conclusions, and recommendations. Much of the material from Progress Report No. 1 is included in this report to enable it to be a stand-alone document.

In summary, HCI has compiled, reviewed, and interpreted all of the hydrogeologic data and information that have been made available to us to date. These include the data and information described in Progress Report No. 1 (e.g., coal exploration drillhole logs, water chemistry data, water level data) as well as new water level data from other monitoring wells, stratigraphic data from nearby deep gas exploration wells, power usage records for the underground sump pumps, and additional water chemistry data. This second Progress Report includes a re-evaluation of the effectiveness of the two dewatering wells, JC-1 and JC-2, based on the most recent data. It also includes a significantly revised plan to install and test underground hydrostratigraphic testholes into sandstones beneath the LOA coal seam. Except for the identification of these underlying sandstones, the conceptual hydrogeologic model of the mine area described in Progress Report No.1 has not changed significantly.

2.0 SUMMARY OF HYDROGEOLOGIC INVESTIGATION TO DATE

The following is a point summary of the tasks completed to date as part of HCI's hydrogeologic investigation of the Skyline Mine area.

1) Compilation of general and anecdotal information on the location, timing, and rates of various inflows encountered during the history of mining at Skyline.

2) Installation of water level monitoring equipment in surface monitoring wells and in the horizontal drillhole in the 9-Left headgate (Plate I) and continuous collection of water level data since mid-September 2001.

3) Collection of water samples from various underground inflows, from the discharge from JC-1 and JC-2, and from Electric Lake in conjunction with CFC to help identify the source of the ground-water inflow and the water pumped by JC-1 and JC-2.

4) Review and analysis of the results of pumping from JC-1 and JC-2.

5) Compilation, review, and interpretation of all relevant geologic, water chemistry, and water level data from the files at Skyline Mine.

6) Meeting with Mark Bunnell of Ark Land and Alan Mayo of Mayo and Associates on December 7 to discuss a) the water chemistry data, structures, and hydrostratigraphy of the Skyline Mine area, and b) how that information can be incorporated into a numerical ground-water flow model.

7) Preparation and submittal of Progress Report No. 1 (HCI, 2001c).

8) Initial work on the numerical ground-water flow model including construction of the model grid and layering, defining hydraulic boundary conditions and significant hydrogeologic features, and preliminary assignment of hydraulic properties to the various hydrogeologic units.

9) Installation, in conjunction with CFC, of additional water-level monitoring instruments in monitoring wells west of Electric Lake and review of the initial data from them.

10) Compilation and review of power-usage data for the underground sump pumps and re-evaluation of the inflow to 10-Left.

11) Meeting with Idea Drilling Company at Skyline Mine on January 24, 2002 to discuss the procedures and requirements for underground drilling and testing.

3.0 UPDATED CONCEPTUAL HYDROGEOLOGIC MODEL

Using all of the available, relevant geologic, hydrologic, and water chemistry data, HCI has developed a conceptual hydrogeologic model to describe the occurrence and movement of ground water in the Skyline Mine area. This conceptual model, to be further refined with some additional drilling and hydraulic testing (to be described in Section 5.1), is currently being incorporated into a predictive numerical ground-water flow model. Together, the two models will be used to evaluate the necessity of dewatering the Flat Canyon tract and to design a dewatering system if active dewatering is deemed necessary.

3.1 HYDROSTRATIGRAPHY

The Skyline Mine is developed in the O'Connor and Flat Canyon coals of the Cretaceous Blackhawk and Starpoint Formations. The overburden consists primarily of siltstones, sandstones, coals, and shales of the Blackhawk Formation. Underlying units, primarily members of the Starpoint Formation, include interbedded siltstones and sandstones, and are interpreted to be a stacked transgressive-regressive shoreline assemblage.

The two proximal sandstone units beneath the coal seams, and hence the two most well known, are the Storrs and Panther Sandstones. The upper part of the Storrs Sandstone, as encountered at JC-1, consists of partly- to non-cemented sand that was probably deposited in an upper shoreface environment. The lower part of the Storrs Sandstone in this area is thinly bedded and calcareous, and could represent an overlapped lower shoreface or transition facies. The Panther Sandstone, which appears to be lithologically similar to the lower Storrs in the cuttings from JC-1, seems to be less permeable than the Storrs based on geophysical log data. The Panther Sandstone most likely represents an older transitional zone in the James Canyon area. As will be described in more detail below, numerous additional shoreface sandstone units locally underlie the Panther Sandstone.

HCI examined geologic logs of 45 exploration boreholes. In order to determine if there is any correlation between the sandstones, structures (to be described below), and ground-water inflows, a series of isopachs was constructed of the various sandstones and interburden beneath the Level 3 and Level 2 mine areas. Figures 1 and 2 show the areal distribution and thickness of the Storrs and Panther Sandstones, respectively. A comparison of the location of the major ground-water inflows to the isopachs in Figures 1 and 2 shows no obvious correlation between inflow and the thickness of either sandstone.

An examination of the interburden beneath the mine area, specifically the thickness of the low permeability units between the mined coal and the first significant sandstone (either Storrs or Panther) beneath the coal, shows no relationship between the occurrence of ground-water inflow and relatively thin interburden. In fact, the opposite appears to be true. In the Level 3 area, the LOA seam was mined just 0 to 10 ft above the Storrs Sandstone without any significant ground-water inflow. Conversely, in the current Level 2 area, ground-water inflows have occurred where interburden between the LOB and the Storrs Sandstone is 70 to 100 ft thick.

It is important to note that the storage capacity of the Storrs, Panther, and Trail Canyon Sandstones beneath the Skyline Mine is insufficient to account for the sustained ground-water inflows experienced in the mine (HCI, 2001a). Although exploration drilling by CFC has not gone significantly below the Starpoint Formation, Doelling (1972) indicates that on a regional scale, a thick, stacked sequence of shore facies sands can occur locally beneath the Starpoint Formation. In order to assess the potential occurrence of such sandstones beneath the Skyline Mine, CFC obtained geologic and geophysical logs of nearby gas exploration drillholes. The log of one nearby drillhole (Figure 3) shows a stacked sequence of sandstones totaling at least 700 ft in aggregate thickness beneath the Panther Sandstone (Plate III) in the vicinity of the northwest corner of the mine (near "The Kitchen" as shown on Plate I). CFC interprets the sandstones represented in the log to be of shoreface affinity (M. Bunnell, 2002, personal

commun.). This is a most significant finding. If present beneath the Skyline Mine, these sandstones could explain the sustainability of the five existing major inflows into the mine -- the missing source -- as well as pose risk to future mining. A field program to address this possibility will be described in Section 5.1

3.2 MAJOR FAULTS

Major north-south trending, regional-scale faults cut through the Skyline Mine area. The two most significant are the Pleasant Valley Fault Zone along Mud Creek to the east of the mine, and the Gooseberry Fault Zone, a segment of the Joes Valley Fault, in Gooseberry Creek to the west. The two faults juxtapose lower-permeability rocks of the Blackhawk Formation (on the east) and the North Horn Formation (on the west) against the Starpoint sandstones in the block beneath the mine area (Witkind and Weiss, 1991).

A number of lesser faults and fracture zones occur between the Pleasant Valley and Gooseberry Creek Faults, many of which have been encountered in the mine workings (Plates I and IV). In Mine 3 Level 2, the Connellville, 14-Left, and 16-Left Faults trend northeast-southwest, at an angle to the Pleasant Valley and Gooseberry Creek Faults. The Diagonal Fault trends north-south, parallel to the regional faults, and apparently intersects both the Connelville and 14-Left Faults. The Connelville Fault, with about 200 ft of vertical displacement, defines the southeast boundary of the mine. The Diagonal Fault displays up to 40 ft of vertical displacement, whereas the 14-Left and 16-Left Faults only locally show more than 10 ft of vertical displacement.

In the Mine 3 Level 3 area, no major north- or northeast-trending faults have been mapped. CFC's structural interpretation shows mostly east-west trending faults of minor displacement north of the LOB/LOA merge line (Plate I). The most prominent east-west fault, with 30 ft of vertical displacement, defines the merge line. The east-west faults are locally

accompanied by east-west trending igneous dikes. CFC's geological maps suggest that the north- and northeast-trending faults cut the dikes.

All of the significant ground-water inflows in the Skyline Mine to date have been associated with north- and northeast-trending faults in the Level 2 area. The east-west trending faults in the Level 3 area apparently have not produced large nor persistent inflows.

HCI is not aware of any regional-scale analysis of fault/fracture orientation and displacement. However, such a structural analysis might help determine why different orientations of structures are associated with different hydrologic conditions and help predict which structures might be more water-bearing than others. It is noteworthy that the inflow rates do not appear to have any relationship to fault displacement.

Ground-water inflows to other coal mines in the Wasatch Plateau and Book Cliffs have been characterized as highly compartmentalized (Mayo and Morris, 2000). Although there is definitely strong structural control of ground-water flow in the Skyline Mine area, measured changes in water levels over relatively large areas (to be described in more detail below) suggest the ground-water system might not be as compartmentalized as at other mines in the Wasatch Plateau or at the West Elk Mine in Colorado (Mayo and Koontz, 2000).

3.3 GROUND-WATER LEVELS

Shallow ground-water level data are currently available from four monitoring wells (W79-26-1, 79-10-1b, 79-14-2a, and 79-35-1b). The monitoring records are discontinuous in time, but indicate the shallow ground-water levels (most likely representative of the water table) fluctuate over a relatively large range. Locally, the water table in the area of the mine appears to have declined in the mid- to late-1990s, but to have since stabilized. HCI has not assessed whether the local decline was due to mining or to changes in recharge.

Records of deep ground-water levels are available from eight monitoring wells (79-35-1a, 98-2-1m, 99-4-1, 99-21-1, 99-28-1, 20-4-1, 20-4-2, and 20-28-1) and from one of the underground horizontal boreholes (in 9-Left, see Plate I). Older, but sparse, data from well 79-35-1a suggest that a general decline in the deep water levels occurred from the late-1980s to the mid-1990s. Local mine inflows have recently accelerated this general decline.

Most of the deep monitoring wells are screened in and just below the LOB seam (wells 99-21-1, 99-28-1, and 20-4-1 are screened in the Panther Sandstone just below the Flat Canyon coal; well 20-4-2 is screened in the Storrs Sandstone just below the LOA coal). Hydrographs for these wells (Figure 4) indicate a relatively large range of water levels. It is important to note that the water levels decrease with proximity to the four major mine inflows, regardless of the stratigraphic position of the screen in the monitoring well. The hydrographs also clearly show that, prior to the beginning of inflow at 10-Left in August 2001, the ground-water levels beneath the Flat Canyon area were already dropping at a rate of about 0.03 to 0.08 ft/day. This decline was most likely in response to the inflows at 14-Left, 16-Left, and the Fault Crossing. Since August 2001, the rate of water level declines in the Flat Canyon monitoring wells have, in most cases, significantly increased. The wells in the Flat Canyon tract are clearly responding not only to the 10-Left inflow, but also to the pumping from the James Canyon wells. The hydrograph of 99-4-1 (Figure 5) shows a distinct response to a shut down of JC-1 in January 2002.

Figure 6 shows the water levels as of October 2001 (the most recent comprehensive measuring event) in all available deep monitoring wells in the Level 2 and Flat Canyon areas. Figure 7 shows the interpreted drawdown in all wells due solely to the 10-Left inflow and pumping of the JC wells between August and October 2001. Because the water level contours shown in Figures 6 and 7 are based on relatively sparse data, they are very subjective and interpretive, especially in the broad area between the Diagonal and 14-Left Faults. These interpreted water levels and drawdowns suggest:

- Drawdown from the major inflows to the mine has propagated primarily along the larger, mapped fault zones. However, there is a broad area in the northeast corner of the Flat Canyon tract, centered on the three earliest inflows, where water levels have drawn down an estimated 200 to 300 ft since the original water "hits" in 1999.

- The inflow at 10-Left and pumping from JC-1 alone has resulted in more than 100 ft of additional drawdown locally since August 8 and between 10 and 35 ft of additional drawdown across the Flat Canyon tract.

- There are no apparent vertical gradients between the Storrs sandstone, Panther Sandstone, and LOB seam.

- All of the mapped faults in the Level 2 and Flat Canyon areas are hydraulically connected and have propagated drawdown into areas where faults have not yet been mapped (e.g., into the areas of 99-21-1 and 20-28-1).

3.4 WATER CHEMISTRY

Because it was concluded by HCI at the very beginning of the investigation that the ground-water storage in the Storrs and Panther Sandstones was not capable of sustaining the inflows at 10-Left, a significant effort was made to collect and analyze water samples in an attempt to identify the potential source(s) of the inflow. Water samples were collected, either by CFC or HCI, in the mine, from wells JC-1 and JC-2, and from Electric Lake (Plate I). The laboratory analyses included major cations (calcium, magnesium, sodium, and potassium) and anions (chloride, sulfate and alkalinity), trace components (iron, fluoride and barium), stable isotopes (^{2}H or deuterium, ^{18}O, and ^{13}C), and radiogenic isotopes (^{3}H or tritium and ^{14}C), and the data are summarized in Table 1.

A trilinear (or Piper) diagram was prepared to help define and compare the major ionic compositions of the various surface and underground waters (Figure 8). The surface-water samples from Electric Lake (green symbols) have an ionic composition quite distinct from the ground-water samples collected from the underground (red symbols). This is most readily

indicated by the lake waters having less magnesium and alkalinity than the waters from the underground. The total dissolved solids (TDS) concentrations of the samples are represented in the central diamond by the relative diameters of the circles. It is apparent that the TDS levels in the underground waters are greater than the TDS levels in the lake waters. Such differences in TDS, alkalinity, and magnesium (although, somewhat surprisingly, not calcium) are consistent with dissolution of carbonate materials (the cement in the sandstones) as recharge from precipitation and/or surface-water bodies moves through the subsurface.

The stable isotope ratios (or δ values) for ^{2}H and ^{18}O from selected samples are plotted on Figure 9 along with the so-called global meteoric water line. The three samples from Electric Lake are isotopically heavier than the four samples from the underground, indicating the two groups of water have different origins. The isotopic composition of the four samples from the underground suggest that the origin (rain or snowmelt) of these waters had a lower temperature than that of the lake water. This suggests that the underground waters originated at a higher elevation or from a colder time than the waters of Electric Lake. In either case, the waters are different.

Tritium (^{3}H) concentrations were analyzed in six of the samples. As indicated in Table 1, the two samples from Electric Lake both had measurable concentrations of tritium whereas the ground-water samples had concentrations that were near, or below, the detection limit. These data strongly indicate that the underground inflow at 10-Left and the discharge from JC-1 do not have a significant hydraulic connection with Electric Lake.

Analyses of ^{14}C concentrations also strongly indicate that the waters from the mine and Electric Lake are very different. The Electric Lake samples had percent modern carbon (pmc) values of 72.4 and 82.2 percent whereas waters collected from the underground or JC-1 had values ranging from 30 to less than 16 pmc.

In summary, the water chemistry data clearly indicate that the ground water flowing into the mine (specifically at 10-Left) and the water being pumped from dewatering wells JC-1 and JC-2 are significantly different from Electric Lake water. This precludes the existence of a direct "conduit" between Electric Lake and the 10-Left inflow and JC wells.

4.0 EVALUATION OF CURRENT AND FUTURE DEWATERING

Dewatering well JC-1 produces approximately 2,200 gpm, but is currently "pump limited." HCI estimates its maximum yield to be in the range of about 5,000 to 6,000 gpm. Well JC-2, only about 80 ft away (but 200 ft at the bottom) from JC-1, and also completed into the Storrs sandstone, produces only 300 to 500 gpm, much less than anticipated. Reasons for the very high and very low yields of the two wells and a discussion of unusual responses to pumping are provided in HCI (2001c). Pumping from the two wells has had a limited effect on the ground-water inflow at 10-Left, as described in Section 4.2, below.

The question of being able to stop, or at least significantly reduce, the 10-Left inflow with pumping has been partly answered by the disappointing results of the James Canyon wells. CFC's current plan is to flood the lower part of the Level 2 mine once mining has been completed in the 8-Left and 9-Left panels. The inflow at 10-Left is currently driven by the hydraulic gradient between the elevation of the potentiometric surface in the "aquifer" and the elevation of the discharge points in the 10-Left entries. As already described in HCI (2001c), if water were allowed to pond to the floor level at the north end of the Diagonal Mains (at an elevation of about 8,135 ft), the driving head differential would be reduced by about 95 ft. Based simply on "black boxing" the Darcy flow relationship, as described in HCI (2001c), such a reduction in the head differential would decrease the inflow at 10-Left by approximately 1,000 gpm. Conversely, using proportions illustrated in Figure 10 (to be discussed in more detail below), a "specific yield" estimate of the reduction in inflow would be closer to 1,500 gpm.

4.1 INFLOW TO 10-LEFT

The rate of ground-water inflow at 10-Left has not been monitored with an adequate degree of accuracy and precision over time. The inflow was approximately 4,300 gpm on

August 16 based on an assumed stage-volume relationship and the change of the "beachline" in the partially flooded entries. A stage-volume estimate of inflow, probably the most accurate of the methods used to date, has been made only one other time, on October 9, 2001. At that time the rate appeared to have fallen to 3,050 gpm, but well JC-1 was pumping during the measurement (see below).

An alternative estimate of the effect of pumping on the 10-Left inflow can be made with the power usage by the two vertical pumps SP43 and SP44. These pumps lift all the water from the 10-Left inflow, and recently, water emanating from the Connelville Fault and 9-Left gob (an estimated 200 gpm). Records of the power usage by the two pumps, though not continuous, are available beginning on September 4, 2001. According to the pump-specific and site-specific relationship developed by CFC (G. Kenzy, CFC, 2002, personal commun.), power usage can be converted to pumping rate by the relationship 1 amp = 6.83 gpm.

Power usage records (Figure 11) show that prior to about October 1, 2001, the power usage fluctuated greatly and for reasons HCI does not currently understand. The power usage dropped after completion and grouting of JC-1, but appears to have steadily increased from about 435 amps to about 500 amps in the first 2 weeks of pumping from JC-1 (which is also the period when JC-2 was being drilled). When JC-2 was completed about September 30, power usage by SP43 and SP44 began to decline from about 500 amps to about 475 amps over the subsequent 2 weeks. With continued pumping from JC-1 and intermittent pumping from JC-2, the power usage continued more or less steadily for 2 months at an average of about 475 amps. On November 17, the pumps in the James Canyon wells were turned off; and power usage increased back to an average of about 500 amps within 7 days. When the pumps in the James Canyon wells were re-started on December 17, the power usage again declined to about 475 amps. The beachline at 10-Left fluctuated during all of these periods of drilling and pumping, but storage gains and losses indicated by changes in the beachline were found to be insignificant when compared with the long-term pumpage rates.

Table 2 summarizes the estimated inflow to 10-Left based on the various methods of measurement and subtracting out the contribution to the sumps from other sources (i.e., the 9-Left gob and Mine 1). Assuming the estimates of inflow from the various methods can be compared, it appears that the inflow to 10-Left decreased from about 4,300 gpm in August 2001 to about 3,400 gpm in early October. It should be noted that the inflow rate had been estimated as high as 7,000 gpm in early September based on un-recorded power usage. That high inflow, if real, might have been a temporary condition due to the opening of a new "conduit" during the drilling of JC-1. By mid-October, the inflow to 10-Left had decreased to a relatively steady rate of about 3,000 gpm with the James Canyon wells pumping and about 3,200 gpm with the wells off. An alternative, and slightly higher, estimate of this inflow difference is described below.

In late December 2001 and early January 2002, the power used by SP43 and SP44 increased again (Figure 11) to a peak of about 545 amps as water was drained from Mine 1 through a drainhole in 8-Left B. The increase in amperage suggests that the two sump pumps were pumping an additional 500 gpm due to the Mine 1 drainage. Since January 4, 2002, the power usage has decreased back to about 490 amps, suggesting an essentially continuous drainage from Mine 1 of about 100 to 150 gpm.

4.2 EFFECT OF PUMPING OF JC-1 AND JC-2 ON INFLOW TO 10-LEFT

As described above, the power usage records suggest that pumping of the James Canyon wells is currently reducing the inflow to 10-Left by only about 200 gpm (Table 2), only about 6 percent of the inflow. However, as will be described below, such a small impact is questionable based on water level changes. Using both metered (with Doppler meters on the discharge lines) pumping rates and a stage-volume relationship for the strand line, HCI had earlier estimated (HCI, 2001c) that pumping from the James Canyon wells reduced inflow to 10-Left by about 650 gpm. Not surprisingly, a direct comparison of flow rates measured by

the Doppler meter readings and calculated from power use (on October 16, 2001; see Table 2) suggests that one or the other method is not very accurate. The Doppler meter measured about 500 gpm more flow than estimated from power usage. An estimate of the effect of pumping from JC-1 based on a third method, to be described below, suggests that the Doppler meter may be the more accurate of the other two methods.

The third method of assessing the effect of pumping of JC-1 is based on basic ground-water hydraulics and changes in local ground-water levels. Figure 10 shows the potentiometric surface within or near the Diagonal Fault zone as measured at three points (monitoring well 98-2-1m, 9-Left horizontal drillhole, and monitoring well 79-35-1A) when JC-1 was shut down in late December 2001 and again at the same three points plus the 11-L horizontal drillhole when JC-1 pumping resumed in January 2002. The water level data indicate that the water level in well 98-2-1m, about 4,200 ft north of JC-1, declined an additional 14 ft when pumping resumed. In the 9-Left drillhole, about 2,300 ft south of JC-1, the water level declined by an additional 26 ft over the same period. Assuming a linear hydraulic gradient based on the latter two water levels (a reasonable assumption in such a conduit-like fault zone), the decrease in water level at the 10-Left inflow point, just 150 ft from JC-1, would have been about 50 ft. It is noteworthy that this amount of drawdown is comparable to the drawdown measured in JC-1 itself which has been very consistently about 50 to 60 ft since the first week of pumping.

Using these declines in water levels, an estimate of the effect of the James Canyon wells on inflow to 10-Left can be made assuming a linear "specific capacity" (i.e., a well hydraulics concept defined as the discharge per unit of drawdown) for the 10-Left inflow area. If we assume a pre-inflow water level (based on the projected water level in 1998, see Figure 10) of about 8,520 ft and a water level of 8,320 ft in response to an inflow of 3,200 gpm in December 2001, the specific capacity would be about 16 gpm/ft. As described above, the minimum additional drawdown at the inflow points due to the pumping of JC-1 is about 50 ft.

Thus, the decrease in inflow at 10-Left associated with another 50 ft of drawdown propagated by JC-1 is estimated to be about 800 gpm.

In summary, an accurate and reliable measure of the effect of pumping from the James Canyon wells on the inflow at 10-Left has yet to be made. Estimates of the decrease in inflow based on three different methods range from about 200 to about 800 gpm. HCI is of the opinion that the higher end of the range provides the most reasonable estimate. If that is the case, the ratio of pumping (2,200 gpm) to reduction in passive inflow to 10-Left is about 2.8:1, within the 1.5 to 3 ratio often cited by dewatering practitioners.

The answer to the question of the effect of pumping the James Canyon wells on the 10-Left inflow has significant economic ramifications. CFC must decide whether to keep the wells pumping based upon the estimated reduction in inflow to 10-Left caused by pumping 2,200 gpm from the wells. The factors obviously include power costs and the trade-off of discharging 2,200 gpm into Electric Lake vs. reducing discharge to Eccles Creek by 200 to 800 gpm. The James Canyon wells are affecting water levels regionally (Section 3.3), but keeping the wells pumping solely for the purpose of regional dewatering is not justified.

4.3 FLAT CANYON TRACT

The hydrostratigraphy, structures, and water levels described in Sections 3.1, 3.2, and 3.3, respectively, present a preliminary understanding of the ground-water conditions that might be encountered during proposed mining of the Flat Canyon tract. The apparent current drawdown in the Flat Canyon area suggests that the various water-bearing units in the Starpoint Formation are reasonably well hydraulically connected, probably via the more prominent faults, throughout this area. The favorable aspect of interconnection, rather than compartmentalization, is that dewatering might be done at a limited number of dewatering "centers" rather than with wells into each of many compartments. Conversely, relatively large

quantities of water might have to be managed at the relatively large hydraulic heads that will exist in that down-dip area (Plate III).

There are still insufficient data from which to quantify the amount of water that might have to be managed and the timing of implementation and location(s) of a dewatering system that would produce acceptable mining conditions. To do that, more data will be needed on the hydraulic properties of the various sandstones (Section 5.1); and subsequent numerical ground-water flow modeling of the area needs to be conducted (Section 5.4). Nevertheless, a very preliminary comparison of drawdown relationships in the Flat Canyon tract versus the Diagonal Fault area can be made.

Monitoring well 99-4-1 at the south end of the Flat Canyon tract (Plate I) is probably screened within or near the fracture zone of the 16-Left Fault in Boulger Canyon. It should be noted that the geophysical "mapping" in this area, the basis of the fault location, is not considered to be very accurate (M. Bunnell, 2002, personal commun.). In any case, the hydrograph of 99-4-1 (Figure 5) shows rapid, distinct responses to both the temporary shut down of JC-1 and a recent inflow encountered on the 14-Left Fault in the East Submains (Plate I). The timing and magnitude of the water level responses suggest a relatively high hydraulic conductivity and possibly a relatively low storage coefficient of the "aquifer" between the piezometer and the pumping and inflow points.

Monitoring well 99-4-1 is located about two miles southwest of the East Submains inflow. Similarly, monitoring Well 98-2-1m is located on or near the Diagonal Fault, two miles south of the Fault Crossing inflow. Figure 5 shows that the East Submains inflow (visually estimated to be 300 gpm) resulted in an increase of 0.05 ft/day in the drawdown rate at 99-4-1. This corresponds to a "specific drawdown" of about 1.7×10^{-4} ft/day/gpm. In comparison, Figure 10 shows that the water level in monitoring well 98-2-1m declined 40 ft between June 2000 and June 2001 in response to the Fault Crossing inflow of about 1,000 gpm. This corresponds to a specific

drawdown of about 1.1 x 10^{-4} ft/day/gpm, a very similar number in such a comparison. The implication, though based on a simple semi-quantitative comparison, is that the hydrology of the two faults is similar, and by extension, dewatering challenges in the Flat Canyon tract might not be significantly different than those experienced by CFC in the current Level 2 mine.

As shown on Figure 5, the water level in monitoring well 99-4-1 is currently at about 8,550 ft, about 1,000 ft above the level of the LOB seam, and is currently declining at a rate of about 0.16 ft/day. At the current rate of ground-water extraction (i.e., from all current inflows and pumping affecting the water level in monitoring well 99-4-1), it can be estimated by simple linear extrapolation of the drawdown that it would take about 17 years for the water level to decline to the level of the coal in this area. In order to depress the water level 1,000 ft in just five years, the time by which mining will advance to the vicinity of well 99-4-1 under the current mine plan, a drawdown rate of about 0.55 ft/day would have to be induced. This is considerably higher than the rate at which water levels are declining in the Diagonal Fault area (0.43 ft/day) in response to current inflows and pumping (a total of about 6,000 gpm).

Planning the most appropriate dewatering system for the Flat Canyon area should consider:

- managing inflow passively vs. actively dewatering in advance of mining,
- development of a better method for predicting the occurrence and hydraulic nature of water-bearing faults,
- targeting faults vs. dewatering the "source" sandstones,
- the timing of implementing any active dewatering, and
- using wells drilled from surface versus from the underground wells.

HCI believes this will require a true feasibility-level study involving the proposed field investigation described in Section 5.1, numerical ground-water flow modeling (described in Section 5.4), and a detailed economic and environmental assessment of the various options.

4.4 WINTER QUARTERS TRACT

Whether mining should proceed west into the Flat Canyon tract or north into the Winter Quarters tract on the basis of hydrologic risk can only be addressed in a preliminary manner at this time. The current conceptual understanding of the hydrogeology of the entire Skyline Mine area suggests that defining the structural setting, rather than sandstone thickness and proximity, will be key to predicting ground-water inflow risks in a given area. As previously described, the sandstones are the source of and sustain the inflows to the mine via the faults; but the sandstones do not, by themselves, pose the risk.

As a preliminary observation, the major structures in the Flat Canyon tract are extensions of or parallel to the N-S trending structures in the wet Level 2 area. Conversely, structures currently mapped in the Winter Quarters tract are similar to those in the drier Level 3 mine.

By this simple analogy, the Flat Canyon tract has greater risk associated with structurally controlled ground-water inflows. Although there are even fewer existing hydrogeologic data for the Winters Quarter tract than for Flat Canyon tract, the hydrologic risk is intuitively lower in the Winter Quarters area.

5.0 PROPOSED ADDITIONAL HYDROGEOLOGIC INVESTIGATION

5.1 HYDRAULIC TESTING

HCI previously developed (HCI, 2001c) a relatively simple and inexpensive program to conduct flow and shut-in tests of the Storrs and Panther Sandstones in at least three locations. Those tests were to be fairly shallow, to depths of about 260 ft, just penetrating the first sandstone (Trail Canyon) beneath the Panther Sandstone. However, the recently obtained geologic information from nearby deep gas exploration drillholes indicates that there could be a very significant sequence of sandstones beginning at a depth of only about 75 ft below the Trail Canyon Sandstone. As discussed in Section 3.1, HCI believes these deep sandstones could be the "reservoir" providing water to and sustaining the five existing major inflows in the mine. There is no reason to doubt they could provide a similar role at any permeable faults intersected by future mining.

Consequently, HCI now highly recommends deeper drilling and hydraulic testing to determine if the deeper sandstones exist beneath future mining areas. If so, CFC needs to know what the hydraulic properties of these sandstones are relative to a) their potential ability to provide and sustain flow to faults encountered by future mining and b) the feasibility of dewatering at least some of the sandstones prior to mining.

The depth of new proposed testing would be to about 700 ft, and piezometers would be installed in specific, isolated horizons. This will require using either a multi-level packer system (such as a Westbay *MPP*™ or Solinst's *Waterloo Multi-Level System*™) or multiple coreholes (HCI's recommendation) for individual piezometers. Due to the increased costs of deeper drilling and piezometer installation, HCI recommends conducting only a single series of tests at one location at this time.

The three specific goals of the new proposed hydraulic testing are:

1) To determine the horizontal hydraulic conductivity and piezometric levels in the individual sandstones.

2) To assess the potential ability of the deeper sandstones to provide inflow to the mine. This is a function of the hydraulic conductivities of the faults and how they vary with depth.

3) To assess the leakance between the sandstones through the interburden units. We recognize the effects of the faults might totally mask this response under the hydraulic stress we will be able to put on the local ground-water system during the proposed test, but we will still attempt to collect the data required for such an assessment.

5.1.1 General Logistics

HCI visited potential underground sites for the proposed drilling and testing with Mark Bunnell of Ark Land and Dick Backstrom of Idea Drilling on January 24, 2002. The locations considered available (relative to ongoing mining) at that time were 1) in the #2 tailgate of 11-Left (about Crosscut 33) and 2) in the West Mains near the Fault Crossing inflow. Both sites are relatively near the Diagonal Fault and active inflow points. Subsequent to that site visit, HCI and CFC identified a third site in the East Submains near the 14-Left Fault. Any of the three sites would potentially yield valuable information on the sandstones. However, the 11-Left and Fault Crossing locations would most likely provide information about leakance on the Diagonal Fault, whereas only the East Submains location will yield information in future mining areas, specifically in the 14-Left Fault area. Consequently, HCI recommends that the drilling and testing be done at the latter; and it is our present understanding that CFC concurs.

At this selected test location, CFC will need to excavate a suitable drillstation out of the way of mine traffic; and the drillstation needs to be large enough to accommodate at least four closely spaced wells. There will also be considerable moving back and forth between the

coreholes (to be described below), so the corehole layout and the overall size of the drill station must take that into account.

The drilling and testing will be done using either CFC's diamond core rig, already on site, or a similar rig provided by the drilling contractor. The CFC rig is capable of drilling PQ core to shallow depths and NQ core to depths of at least 700 ft. The following description of drilling and testing assumes that multiple coreholes will be used rather than multi-level piezometer systems to isolate specific strata for testing and monitoring. HCI believes that multiple coreholes would ultimately be less expensive and easier to install under the anticipated artesian flowing conditions.

For each corehole/piezometer, a nominal 4-in diameter (PQ) hole will be drilled to a depth of 20 ft, into which nominal 4-in diameter threaded surface casing will be installed and sealed with cement. A wellhead with a stuffing box (Figure 12) will then be attached to the surface casing in order to control water discharges during subsequent drilling and testing. The wellhead (with the stuffing box removed) will remain in place after testing, to provide for long-term monitoring.

Flow and shut-in tests will be conducted and four permanent packer assemblies (to be supplied by the drilling contractor) will be installed and grouted in place to isolate the various sandstones for both testing and long-term monitoring. Although CFC's experience suggests that free flowing NQ coreholes in unfractured sandstones will not produce significant amounts of water (<100 gpm), it would be advisable to have a water disposal plan for the testing period.

Core samples of the various sandstone units will be selected during drilling and submitted to a suitable laboratory for testing to determine core-scale hydraulic conductivity and effective porosity. It is currently planned to submit 6 to 12 core samples for testing. HCI also

recommends collecting samples of the deeper ground water (up to four samples) for chemical analysis.

5.1.2 Drilling and Testing Program

The proposed details of the drilling and testing plan are based on the assumed stratigraphy, extrapolated from two miles away, as shown in Figure 3 and reproduced on Plate III and in Figure 13. HCI recognizes that the actual stratigraphy encountered by drilling at East Submains (or another location) could be significantly different, and maximum flexibility needs to be maintained during the drilling and testing program.

An initial NQ corehole will be drilled vertically downward through the wellhead and surface casing to a depth of approximately 700 ft (to the sandstone labeled "H" in Figure 13). As each significant (>20 ft thick) shoreface sandstone is penetrated, the core rods will be retracted to a point above the top of the sandstone. The corehole will then be shut-in with the wellhead assembly and valves until the shut-in pressure essentially stabilizes. Then the valve will be opened and the corehole will be allowed to flow for approximately 30 minutes. The discharge will be measured using a 5-gal bucket or 55-gal drum, depending on what is required. The corehole will then be shut-in again for about 30 minutes, and recovery water pressures will be recorded. This procedure will be repeated in each major sandstone until total depth, so drilling of the first corehole will be a relatively slow process. The corerods will then be removed from the initial deep corehole, and the corehole will be shut-in.

The drill rig will then move over, install another surface casing and wellhead assembly in a PQ corehole, and then core (again vertically) down to Sandstone "D". In this corehole, a permanent, grouted-in-place packer assembly as shown in Figure 14 will be installed as a point piezometer. This packer assembly and installation procedure is specially suited for artesian flowing conditions

A third vertical corehole will similarly be drilled and completed with a piezometer to the Panther Sandstone. The fourth and final corehole, an inclined corehole, will be drilled to intercept the 14-Left Fault at a low angle (Figure 13). The drilling will be the same as for the other coreholes, but a piezometer will not be initially installed in this corehole.

After the four coreholes have been drilled and the two piezometers have been installed and their grout seals have set, the drill rig will go back to the initial deep corehole. Depending on the findings from the preliminary flow and shut-in tests during the drilling of the corehole, the rods will be tripped in to above one or more of the sandstones. A relatively long-term (perhaps as long as 24 hrs) flow test will be conducted in which water is discharged from the deep corehole and water levels are measured in the two newly installed piezometers and the angle corehole into the fault. Depending on the hydrostratigraphic conditions encountered, there could be several such tests with the corerods set at different depths. Upon completion of this phase of the testing, a piezometer similar to the others (Figure 14) will be installed in the deepest sandstone in the deep corehole.

The final test will be a potentially large discharge and long-term test (again, approximately 24 hrs) of the corehole into the fault in which the discharge from the corehole and the water levels in the other three piezometers (including the newest one in the deep corehole) will be monitored. The fault corehole will then be shut-in, and recovery water levels will be measured for another approximately 24 hrs.

Upon completion of this test, a piezometer similar to the others will be installed in the fault corehole. All four of the piezometers will then be available for long-term monitoring of water levels in response to mining and mine inflow. It should be noted that HCI will furnish on a rental basis and utilize a series of transducers connected to a single datalogger for the testing program. Whether CFC wants to purchase and utilize this system for long-term monitoring or whether water levels will be monitored some other way (a single

transducer/datalogger in each piezometer, simply installing gages on the wellheads, etc.) can be decided when the testing is complete.

5.2 CONTINUED MONITORING

Transducers for recording water levels are currently installed in surface wells 79-35-1 (in Burnout Canyon), 98-2-1 (south of James Canyon), 99-4-1 and 20-4-1 (both in Boulger Canyon), and 20-28-1 (in Swens Canyon) and in the underground horizontal drillhole in 9-Left (Plate I). Gages have been installed, and are intermittently read, in shut-in boreholes in the #1 Tailgate of 11-Left.

It is recommended that water levels in other surface monitoring wells be measured monthly in order to quantify the effects of various stresses on the ground water system beneath the Flat Canyon tract.

5.3 DRILLING FROM SURFACE

The initial Work Plan (HCI, 2001b) recognized that additional hydraulic testing of the faults in the Flat Canyon tract is necessary and suggested that underground tests would be needed to evaluate the permeability and degree of connection between the various faults. Such testing can only be conducted cost effectively when mining progresses to within a few hundred feet of the faults.

However, the compilation of water levels in the surface monitoring wells (Figure 6) suggest a relatively good hydraulic connection among the faults, and the 14-Left Fault especially appears to be a significant conduit (Figure 5). Consequently, HCI recommended (HCI, 2001c) that hydraulic testing be conducted in the Flat Canyon faults from the surface. CFC is currently permitting the planned exploration borehole 02-33-1 (Plate I and Figure 6) as

a nominal 16-inch diameter borehole to 2,300 ft depth, and investigating the possibility of test pumping the well for several days this summer. In the longer term, a permit for a larger diameter well may be required. It should be noted that the central location of 02-33-1 relative to the Flat Canyon mine plan and its position astride the 14-Left Fault make it an ideal location for potential future mine dewatering.

5.4 NUMERICAL GROUND-WATER FLOW MODELING

The conceptual hydrogeologic model described in Section 3.0 is currently being incorporated into a fully three-dimensional numerical ground-water flow model of the Skyline Mine area. The numerical model will be used to predict the dewatering requirements for mining of the Flat Canyon tract in terms of how much water will have to be removed, the timing (i.e., how far in advance of mining will the dewatering have to be implemented), and the approximate locations of dewatering centers (which could be comprised of one or more wells).

The overall framework of the numerical model was discussed at length with Mark Bunnell and Alan Mayo at the meeting on December 7, 2001. As shown on Plate IV, the boundaries of the model to the east and west are defined by the large regional faults that juxtapose the target sandstones against thick sequences of low-permeability sediments. To the north and south, the model limits are a function of the continuity of the sandstones and will be defined by variable flux boundaries, a special feature within the *MINEDW* code utilized by HCI. The hydrostratigraphy that HCI is simulating in the model is shown in cross-section on Plate V.

The model currently utilizes 12 layers to simulate the overburden unit, LOB coal, four interbedded units, and three sandstone units (Storrs, Panther, Starpoint). A single layer with an approximate thickness of 500 ft is used to represent the deeper sequence of interbedded

sandstones. The model explicitly simulates the 16-Left, 14-Left, Diagonal, Conneville and O'Connor Faults, with the Pleasant Valley and Gosseberry Faults acting as model boundaries.

Surface-water features (such as Electric Lake and numerous perennial creeks and streams) are not simulated in the model. Primarily on the basis of the water chemistry data, the surface-water system does not appear to be hydraulically connected to the deeper ground-water system contributing to the mine inflows (Section 3.0). Consequently, the model treats the ground-water system in the Skyline Mine area as being separated into a shallow and a deep system in which the deep system is, for all practical purposes, independent of the shallow system, as described by Mayo and Morris (2000). This conceptualization implies that the majority of the ground water will be derived from storage within the confined sandstones and interburden. This concept is incorporated into the model by assigning a low vertical hydraulic conductivity to the overburden unit such that it essentially de-couples the shallow and deep ground-water systems.

HCI is currently conducting a steady-state calibration of the model. The purpose of this calibration is to obtain pre-mining water levels that will later be used as the starting point for transient simulations. After the steady-state calibration is complete, HCI will start conducting transient simulations and a transient calibration of the model, prior to starting predictive simulations.

As before, this ground-water flow model (or any other model) will not and cannot predict the location or the magnitude of inflows to the mine. These will always be hydrogeologic uncertainties. However, the model will be a very useful planning tool for designing a dewatering and water management program including:

- Determining the optimal general locations for dewatering wells,
- Predicting the amounts of water that will most likely have to be pumped,
- Assessing the time required to lower water levels at the working entries and panels to achieve acceptable, manageable inflow rates, and
- Predicting the potential hydrologic impacts on water resources (e.g., the magnitude and extent of drawdown propagated by the dewatering), if CFC desires such information.

6.0 REFERENCES

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[A] is the concentration of solute A in terms of mass per unit volume of liquid

[$\overline{A}$] is the amount of solute A adsorbed by ion exchange on a unit mass of sediment or soil.

When the exchanged ions are in equilibrium, the concentration of products and reactants at equilibrium is described by the ion-exchange selectivity coefficient, K_s:

$$K_s = \frac{[\overline{B}]^a\,[A]^b}{[\overline{A}]^b\,[B]^a} \qquad \textbf{(10–34)}$$

The **cation-exchange capacity** (CEC) is defined as [$\overline{A}$] + [$\overline{B}$] and the total solute concentration, C_0, is equal to [A] + [B]. When the concentration of one of the exchanging ions is very low, the adsorbed phase of the other (dominant) ion is approximately equal to CEC, and the total solute concentration is almost entirely that of the dominant ion. Equation 10–34 can be rewritten under these conditions, if A is the major species, as

$$K_s = \frac{[\overline{B}]^a\,C_0^b}{CEC^b\,[B]^a} \qquad \textbf{(10–35)}$$

The *ion-exchange distribution coefficient,* K_d, is the ratio of the adsorbed species concentration to the concentration of the solute:

$$K_d = \frac{[\overline{B}]}{[B]} \qquad \textbf{(10–36)}$$

A standard laboratory test is available to determine the cation exchange capacity of soils. A 100-g sample of dry soil is mixed with a solution of ammonium acetate to saturate the exchange sites with NH_4^+ ions. The pH of the pore water is adjusted to a value of 7.0. The soil is leached with a strong NaCl solution to replace the NH_4^+ on the exchange sites with Na^+ ions. The sodium content of the leaching solution is then determined and the CEC computed as the difference between the sodium in the original solution and the sodium in the leaching solution at equilibrium. It is reported in milliequivalents per 100 g of soil. The CEC is frequently used as an indication of the potential of a soil to attenuate pollutants with exchangeable ions.

10.12 ISOTOPE HYDROLOGY

Isotopes of a particular element have the same atomic number but different atomic weights due to varying numbers of neutrons in the nucleus. *Stable* isotopes are not

involved with any natural radioactive decay process. *Radioactive* isotopes undergo spontaneous radioactive decay to form new elements or isotopes. *Radiogenic* isotopes are the stable product of radioactive decay. Certain stable isotopes of hydrogen, oxygen, carbon, nitrogen, and sulfur can be used to study geologic processes that affect ground and surface water. Radioactive isotopes can be used to determine the age of ground water.

Environmental isotopes are those that are naturally occurring. Radioactive isotopes can also be introduced into the ground as part of a ground-water study, usually to determine the direction and/or velocity of ground-water flow.

10.12.1 Stable Isotopes

Stable-isotope studies are based on the tendency of some pairs of isotopes to *fractionate,* or separate into light and heavy fractions. This fractionation occurs during some geologic process, such as evaporation or heating. The five elements that are used in stable-isotope studies are able to fractionate readily, are fairly common, have a relatively large difference in mass between the two isotopes, and have one isotope that is much more abundant than the other. If R is the ratio of the heavy isotope to the light one, then the relative fractionation is expressed in del notation as:

$$\delta = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000 \qquad \textbf{(10–37)}$$

Results are expressed as deviation in parts per thousand (‰). If the value of δ is positive, then the sample is enriched with the heavy isotope relative to the standard; a negative sample is isotopically light.

There are two stable isotopes of hydrogen, ^{1}H and ^{2}H (deuterium), as well as three stable isotopes of oxygen, ^{16}O, ^{17}O, and ^{18}O. There are nine different combinations of these isotopes that make stable water molecules with atomic masses ranging from 18 to 22. The most abundant water molecule, $^{1}H_2{}^{16}O$, which is the lightest, has a much higher vapor pressure than the heaviest form, $^{2}H_2{}^{18}O$. During phase changes of water between liquid and gas the heavier water molecules tend to concentrate in the liquid phase, which fractionates the hydrogen and oxygen isotopes. Water that evaporates from the ocean is isotopically lighter than the water remaining behind, and precipitation is isotopically heavier; that is, it contains more ^{2}H and ^{18}O than the vapor left behind in the atmosphere.

The use of mass spectrometry can determine the ratio of isotopes in a water sample. Important isotope ratios include $^{18}O/^{16}O$ and $^{2}H/^{1}H$. These isotopic ratios from an environmental water sample can be compared with the isotopic ratio of standard mean ocean water (SMOW). The comparison is made by means of the parameter δ, which is defined as

$$\delta^{18}O\ (‰) = \left[\frac{(^{18}O/^{16}O)_{\text{sample}}}{(^{18}O/^{16}O)_{\text{SMOW}}} - 1\right] 10^3 \qquad \textbf{(10–38)}$$

$$\delta^2\text{H}\ (‰) = \left[\frac{(^2\text{H}/^1\text{H})_{\text{sample}}}{(^2\text{H}/^1\text{H})_{\text{SMOW}}} - 1\right] 10^3 \qquad \textbf{(10–39)}$$

When δ^2H is plotted as a function of δ^{18}O for water found in continental precipitation, an experimental linear relationship is found that can be described by the equation (Mayo, Muller, & Ralston 1985)

$$\delta^2\text{H} = 8\delta^{18}\text{O} + 10 \qquad \textbf{(10–40)}$$

This is known as the *meteoric water line*. Continental precipitation samples will tend to group close to this line. Precipitation falling in areas with lower temperatures or at higher latitudes will tend to have lower δ^2H and δ^{18}O values. Naturally, oceanic water will fall below the meteoric water line as it is isotopically enriched. Deviations from the meteoric water line can be interpreted as being caused by precipitation that occurred during a warmer or colder climate than at present or by geochemical changes that occurred when the water was underground (Craig 1961). Geothermal water tends to be isotopically enriched with respect to δ^{18}O owing to equilibration of the oxygen in the ground water with respect to oxygen in the rocks (Mayo, Muller, & Ralston 1985). Figure 10.5 shows the meteoric water line and the results of stable isotope analyses for a number of spring water samples from the Meade thrust area of southeastern Idaho.

In some ground-water studies the plot of δ^2H as a function of δ^{18}O forms a straight line that is parallel to but below the meteoric water line (Figure 10.6). This has been interpreted as a "local" meteoric water line (White & Chuma, 1987; Mayo et al. 1992).

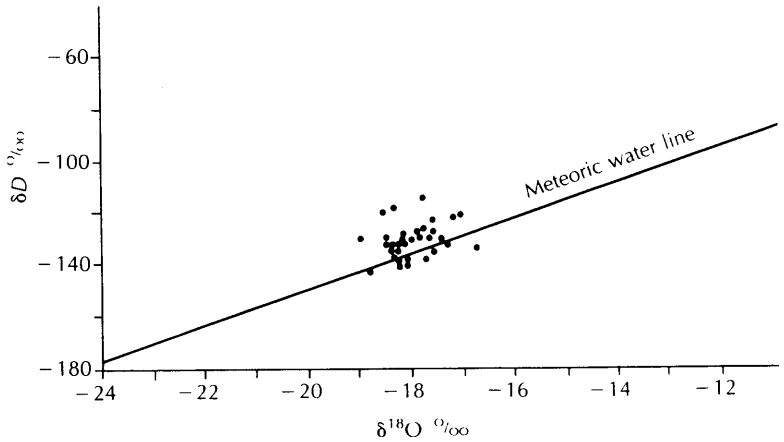

FIGURE 10.5 δD (δ^2H) and δ^{18}O values from spring and well waters in the Meade thrust area, southeastern Idaho. Source: A. L. Mayo. Ground-Water Flow Patterns in the Meade Thrust Allochthon, Idaho-Wyoming Thrust Belt, Southeastern Idaho. Ph.D. thesis, University of Idaho, 1982.

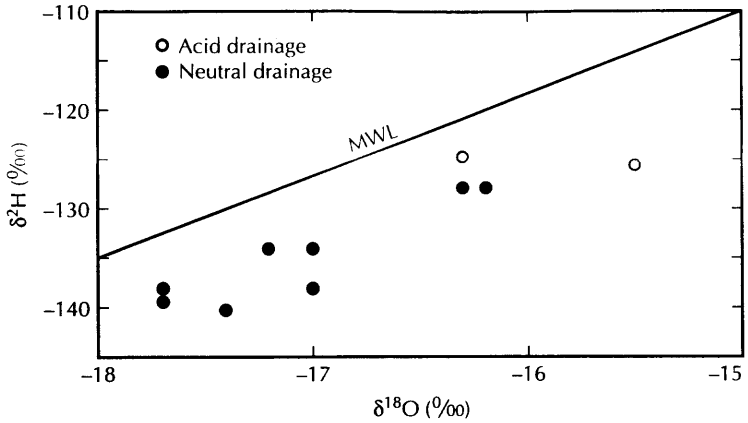

FIGURE 10.6 Plot of δ^2H versus $\delta^{18}O$ for ground water in the central Wasatch Range, Utah, showing a "local" meteoric water line parallel to the global meteoric water line. Source: A. L. Mayo et al., *Ground Water* 30, no. 2 (1992): 243–249. Used with permission. © 1992 Ground Water Publishing Company.

Mayo and Klauk (1991) studied the isotopic composition of ground and surface water in the Great Salt Lake area. They found most samples were grouped on the meteoric water line, but that deviations occurred due to evaporation (for example, the brine in Great Salt Lake) and due to heating in thermal springs (Figure 10.7).

Stable carbon isotopes are ^{12}C and ^{13}C, with ^{13}C being relatively rare. The standard for carbon isotopes is a marine belemnite from the Pee Dee formation of South Carolina (PDB). Inorganic carbon in ground water can come from atmospheric carbon dioxide, carbon dioxide generated by biota in the soil zone, and dissolution of carbonate materials. The $\delta^{13}C$ of dissolved inorganic carbon in the ocean is about 0‰ PDB. Soil gas carbon dioxide is about −20‰, whereas atmospheric carbon dioxide is about −7‰ (Drever 1988). The contribution of atmospheric carbon dioxide is small due to the low partial pressure of atmospheric carbon dioxide (Mayo et al. 1992). The $\delta^{13}C$ of carbonate rocks is about 0‰, which is understandable because they precipitated from the ocean, which has a similar value. Mayo et al. (1992) found a mean $\delta^{13}C$ for carbonate rocks of the Wasatch Range of Utah of +0.30‰, and Muller and Mayo (1986) found a mean value of −1.85‰ ± 1.85 PDB for the Redwall Limestone of Arizona.

The $\delta^{13}C$ of ground water is estimated to come in roughly equal amounts from soil-zone gas and carbonate rocks in most carbonate rock aquifers (Mayo et al. 1992). If this is true, it should be about −10‰ PDB. If the actual value is between about 0‰ and −10‰, then carbonate rocks are contributing a greater amount. If the value is less than −10‰, then soil-zone carbon dioxide is more important than carbonate rock as a source.

Sulfur isotope fractionation studies can be used to distinguish the origin of dissolved sulfur in ground water. The sulfur isotope pair that is used is $^{34}S/^{32}S$.

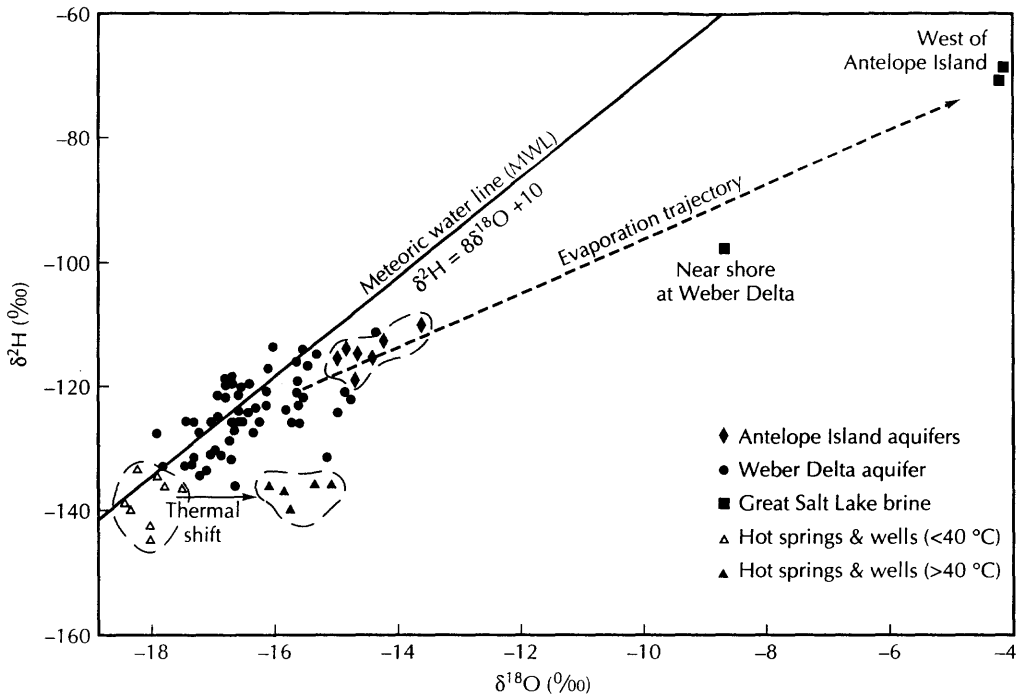

FIGURE 10.7 Plot of δ^2H versus $\delta^{18}O$ for brine from Great Salt Lake and nearby ground water showing deviations from the meteoric water line due to evaporation and heating. Source: A. L. Mayo and R. H. Klauk, *Journal of Hydrology* 127 (1991): 307–335. Used with permission.

The standard for $\delta^{34}S$ is the mineral troilite (FeS), which is found in the Canyon Diablo meteorite of Meteor Crater, Arizona. Sources of sulfur in ground water include atmospheric sulfur, dissolution of sulfate minerals such as gypsum, and oxidation of sulfide minerals, such as pyrite. The dissolution of gypsum will result in an enrichment of ^{34}S; that is, $\delta^{34}S$ becomes more positive. On the other hand, the oxidation of reduced sulfur species will result in an enrichment of ^{32}S, which means that $\delta^{34}S$ will decrease. Mayo and Klauk (1991) used sulfur isotopes to demonstrate that, although ground water from a sedimentary rock unit and a nearby crystalline rock unit had similar concentrations of dissolved sulfate, the ground waters had different sources because the $\delta^{34}S$ values of the two units were different.

The ratio of $^{15}N/^{14}N$ in inorganic nitrogen in ground water as compared with the ratio of atmospheric nitrogen, which is the standard, can be used to determine the source of the nitrogen. Kreitler and Jones (1975) used stable nitrogen isotopes to demonstrate that the source of nitrate contamination in a Texas aquifer was from natural soil nitrate. Kreitler, Ragone, and Katz (1978) demonstrated that in rural, eastern Long Island, New York, inorganic nitrogen in

ground water was primarily from inorganic fertilizer, whereas in western, more urbanized, Long Island, the nitrogen was mostly from septic tank wastes.

10.12.2 Radioactive Isotopes Used for Age Dating

Tritium, ^3H, is an unstable isotope of hydrogen with a half-life of 12.3 y. Tritium in the atmosphere is typically in the form of the molecule H^3HO and enters the ground water as recharging precipitation. Prior to 1953, rainwater had less than 10 tritium units (TU). Starting in 1953, the manufacturing and testing of nuclear weapons has increased the amount of tritium in the atmosphere, with a resulting increase in tritium in the ground water. As a result, ^3H can be used in a qualitative manner to date ground water in the sense that ground water with less than 2 to 4 TU is dated prior to 1953; if the amount is significantly greater than 10 to 20 TU, it has been in contact with the atmosphere since 1953. Because of the great temporal and spatial variations in ^3H injected into the atmosphere since 1953, it cannot be used with more precision. Tritium has been used to trace the seepage of contaminated ground water from low-level nuclear-waste disposal areas (Foster 1982).

Radiocarbon dating methods can be applied to obtain the age of ground water. Carbon exists in several naturally occurring isotopes, ^{12}C, ^{13}C, and ^{14}C. Carbon 14 is formed in the atmosphere by the bombardment of ^{14}N by cosmic radiation (DeVries 1959). The ^{14}C forms CO_2, so that the atmospheric CO_2 has a constant radioactivity due to modern ^{14}C. If the CO_2 is incorporated into a form in which it is isolated from modern ^{14}C, age determinations can be made from the ^{14}C radioactivity as a percent of the original. The half-life of ^{14}C is 5730 y, so that if one-fourth of the original activity is present, two half-lives, or 11,460 y, have elapsed. When precipitation soaks into the ground, it is saturated with respect to CO_2, with a known ^{14}C activity. Once the water has entered the soil, additional carbon may come from soil CO_2 and the solution of carbonate minerals. The modern carbon is diluted by the inactive carbon from carbonate minerals. The raw dates obtained must be adjusted for this dilution.

If A_C is the measured ^{14}C radioactivity and A_0 is the activity at the time the sample was isolated, then the following equation may be used:

$$A_C = QA_0 2^{-t/T_C} \tag{10-41}$$

where

- t is the age
- T_C is the half-life of ^{14}C
- Q is an adjustment factor to account for dilution by *dead carbon** (Wigley 1975)

*Dead carbon is carbon from a source old enough for any ^{14}C to have decayed below measurable limits.

The equation requires an estimation of initial value, A_0, and the adjustment factor, Q.

The value of A_0 will depend on the carbonate equilibria established under an open system in which the ground water was exposed to an infinite reservoir of CO_2. This occurs in nature in the soil zone and in shallow ground water. When the ground-water system becomes closed with respect to CO_2, then any added carbon would be only from carbonate rocks—i.e., dead carbon. The value of Q is generally in the range of 0.5 to 0.9. Carbon 14 dates of ground water thus tend to be somewhat less than raw dates as a result of the dilution by dead carbon from carbonate minerals. The determination of A_0 and Q is somewhat complex, and several different methods are available (Wigley 1975; Plines, Langmuir, & Harmon 1974). Radiocarbon dates of ground water of up to 50,000 to 80,000 y may be obtained, although the accuracy under the best of conditions is on the order of ±20% (Davis & Bentley 1982). Indeed, Muller and Mayo (1986) demonstrated that a variation of ±20% could be expected on the basis of variation of the ^{13}C content of the dead carbon in carbonate rocks.

A number of other isotopes have been used or have been proposed to be used to date ground water. Chlorine 36 is one of them (Bentley & Davis 1980). It has been proposed as a method to date ground water that is older than water that can be dated with carbon 14 as it has a half-life of 3.01×10^5 years. A ratio of ^{36}Cl to total Cl is determined; the higher the ratio, the younger the sample. Oceanic water is old enough that little, if any, ^{36}Cl is present. Young water near the coastline, which is likely to contain chloride produced as salt spray from the ocean, will appear to be much older owing to the large amount of "dead" chloride. Other isotopes with possible uses in age dating are ^{85}Kr, ^{81}Kr, ^{39}Ar, and ^{32}Si (Davis & Bentley 1982).

10.13 MAJOR ION CHEMISTRY

More than 90% of the dissolved solids in ground water can be attributed to eight ions: Na^+, Ca^{2+}, K^+, Mg^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, and CO_3^{2-}. These ions are usually present at concentrations greater than 1 mg/L. Silica, SiO_2, a nonionic species, is also typically present at concentrations greater than 1 mg/L. Direct analysis can be done for the first six ions. Bicarbonate and carbonate concentrations are found by titrating the sample with acid to an endpoint with a pH of about 4.4. This is reported as total alkalinity. Based on the pH of the sample, the proportion of carbonate and bicarbonate can be calculated from Equation 10–25B. Field measurements of pH, temperature, and specific electrical conductance are usually made at the time the sample is collected. Without field pH, the concentrations of carbonate and bicarbonate cannot be determined from the alkalinity.

Other naturally occurring ions that may be present in amounts of 0.1 mg/L to 10 mg/L include iron, nitrate, fluoride, strontium, and boron. Iron and nitrate are typically included in water-chemistry studies, with fluoride, strontium, and

boron being less commonly reported. Many other inorganic ions are important from a standpoint of water quality and are discussed in Chapter 11.

Total dissolved solids (TDS) can be determined by evaporating a known volume of the sample and weighing the residue. TDS can be estimated by summing the concentrations of the individual ions. This method does not account for any dissolved solids that might be present from unreported ions or other dissolved substances. For example, dissolved silica, SiO_2, may not be reported but contributes to TDS.

As a check on the chemical analysis, a cation-anion balance is usually performed. This is accomplished by converting all the ionic concentrations to units of equivalents per liter. The anions and cations are summed separately, and the results are compared. If the sum of the cations is not within a few percent of the sums of the anions, then either there is a problem with the chemical analysis or one or more ionic species that have not been identified are present in significant amounts.

10.14 PRESENTATION OF RESULTS OF CHEMICAL ANALYSES

Tables of data are the most common form in which the results of an analysis of water chemistry are reported. The data can be expressed in milligrams per liter (mg/L), milliequivalents per liter (meq/L), or millimoles per liter. For many purposes, the data may be also displayed in graphical form.

10.14.1 Piper Diagram

The major ionic species in most natural waters are Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-}. A trilinear diagram can show the percentage composition of three ions. By grouping Na^+ and K^+ together, the major cations can be displayed on one trilinear diagram. Likewise, if CO_3^{2-} and HCO_3^- are grouped, there are also three groups of the major anions. Figure 10.8 shows the form of a trilinear diagram that is commonly used in water-chemistry studies (Piper 1944). Analyses are plotted on the basis of the percent of each cation (or anion).

Each apex of a triangle represents a 100% concentration of one of the three constituents. If a sample has two constituent groups present, then the point representing the percentage of each would be plotted on the line between the apexes for those two groups. If all three constituent groups are present, the analyses would fall in the interior of the field. The diamond-shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions.

The cation point is projected onto the diamond-shaped field parallel to the side of the triangle labeled magnesium, and the anion point is similarly projected parallel to the side of the triangle labeled sulfate. The intersection of the two lines is plotted as a point on the diamond-shaped field.

As water flows through an aquifer it assumes a diagnostic chemical composition as a result of interaction with the lithologic framework. The term

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Third Edition

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EXPLANATION

SANDSTONE THICKNESS

- 0 – 30 ft
- 30 – 45 ft
- 45 – 60 ft
- > 60 ft.
- MAJOR INFLOW

STORRS SANDSTONE THICKNESS BASED ON FACIES INTERPRETATION BY CFC

Canyon Fuel Company, LLC

Skyline Mines

Isopach of Storrs Sandstone

JOB NO.	HCI-1787	DATE:	2/12/02
BY:	RLH	DWG FILE:	STORRS-02
DRAWN:	SAC	PLOT FILE:	STORRS-02
CHECKED:		PLOT DATE:	2/22/02

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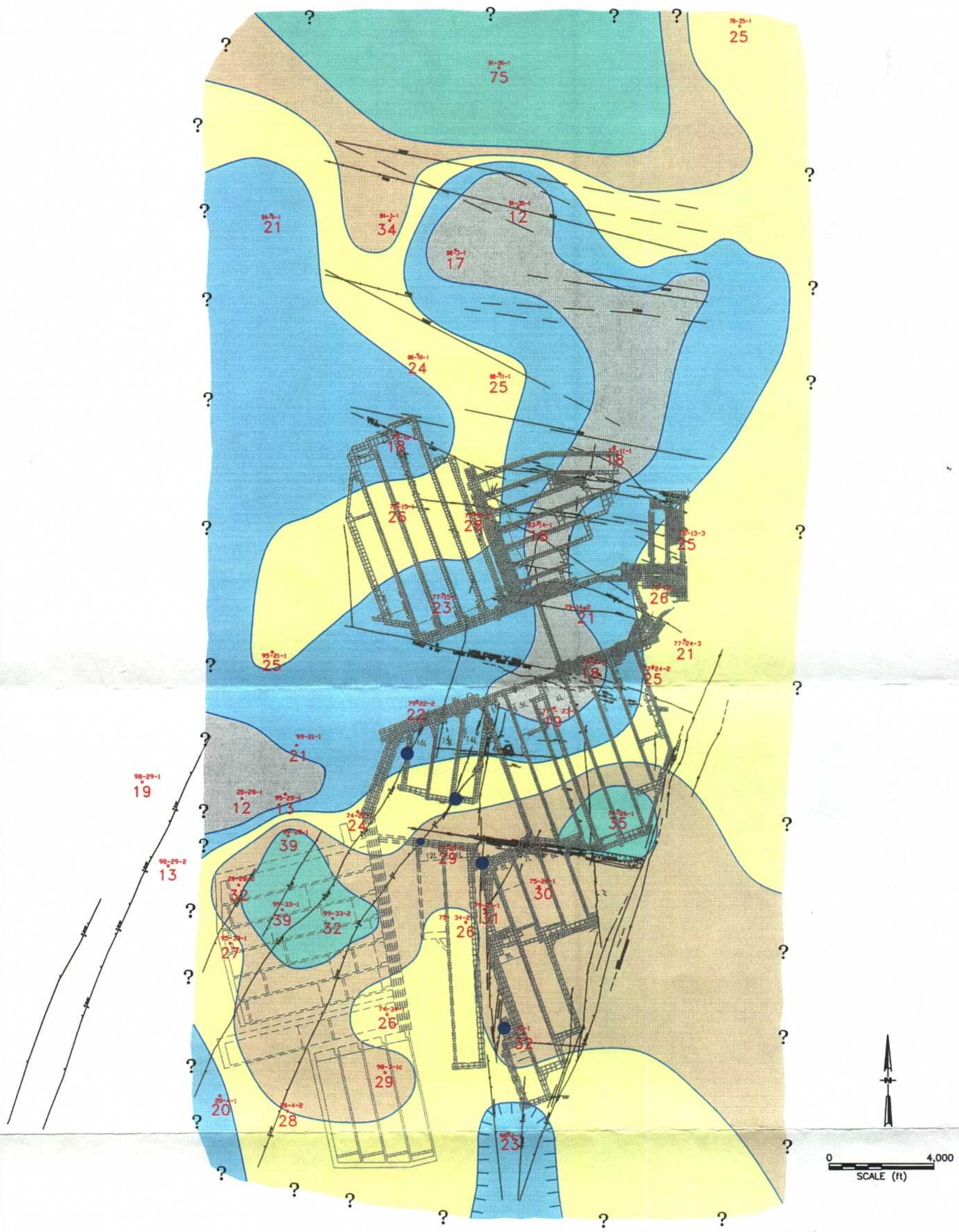
FIGURE 1



EXPLANATION

SANDSTONE THICKNESS

< 20 ft
20 – 24 ft
24 – 28 ft
28 – 32 ft
> 32 ft
MAJOR INFLOW

PANTHER SANDSTONE THICKNESS BASED ON FACIES INTERPRETATION BY CFC

Canyon Fuel Company, LLC
Skyline Mines

Isopach of Panther Sandstone

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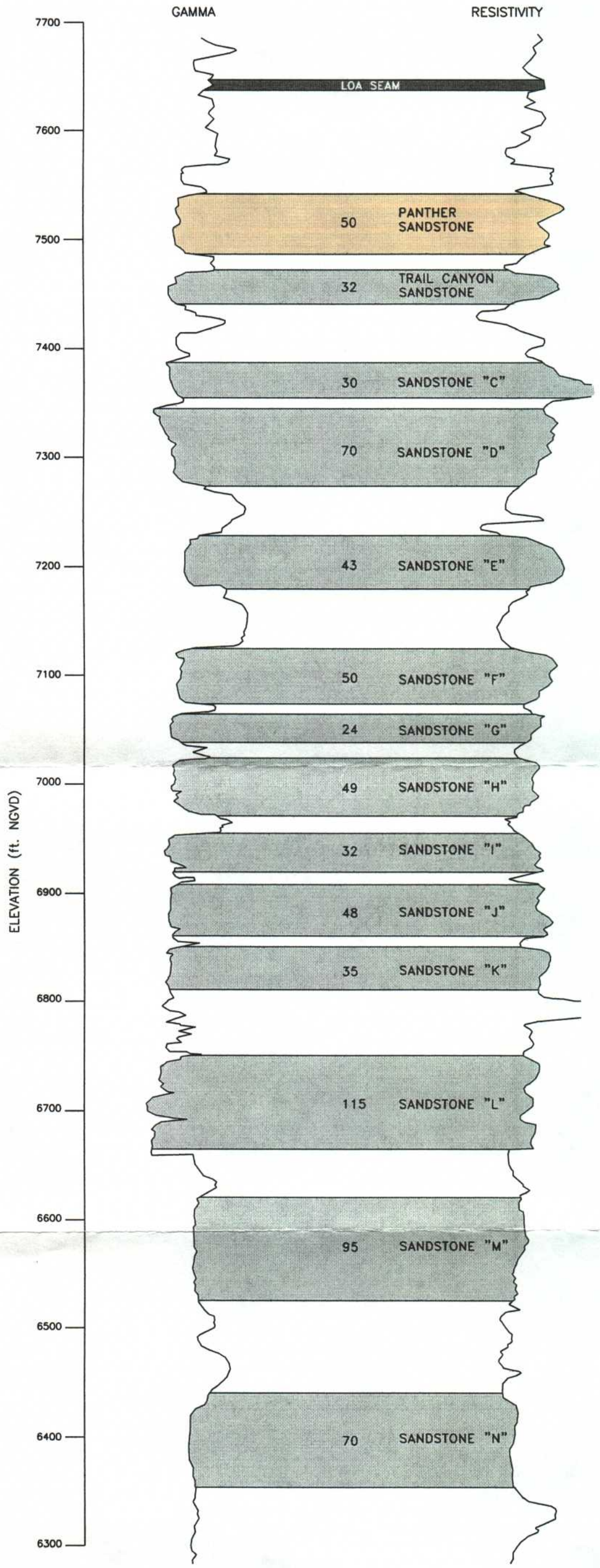
FIGURE 2



95 INTERPRETED SHOREFACE SANDSTONE (THICKNESS IN ft.)

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Geophysical and Interpreted Geologic Log of Carter Oil Well No. 1 in Upper Huntington Canyon

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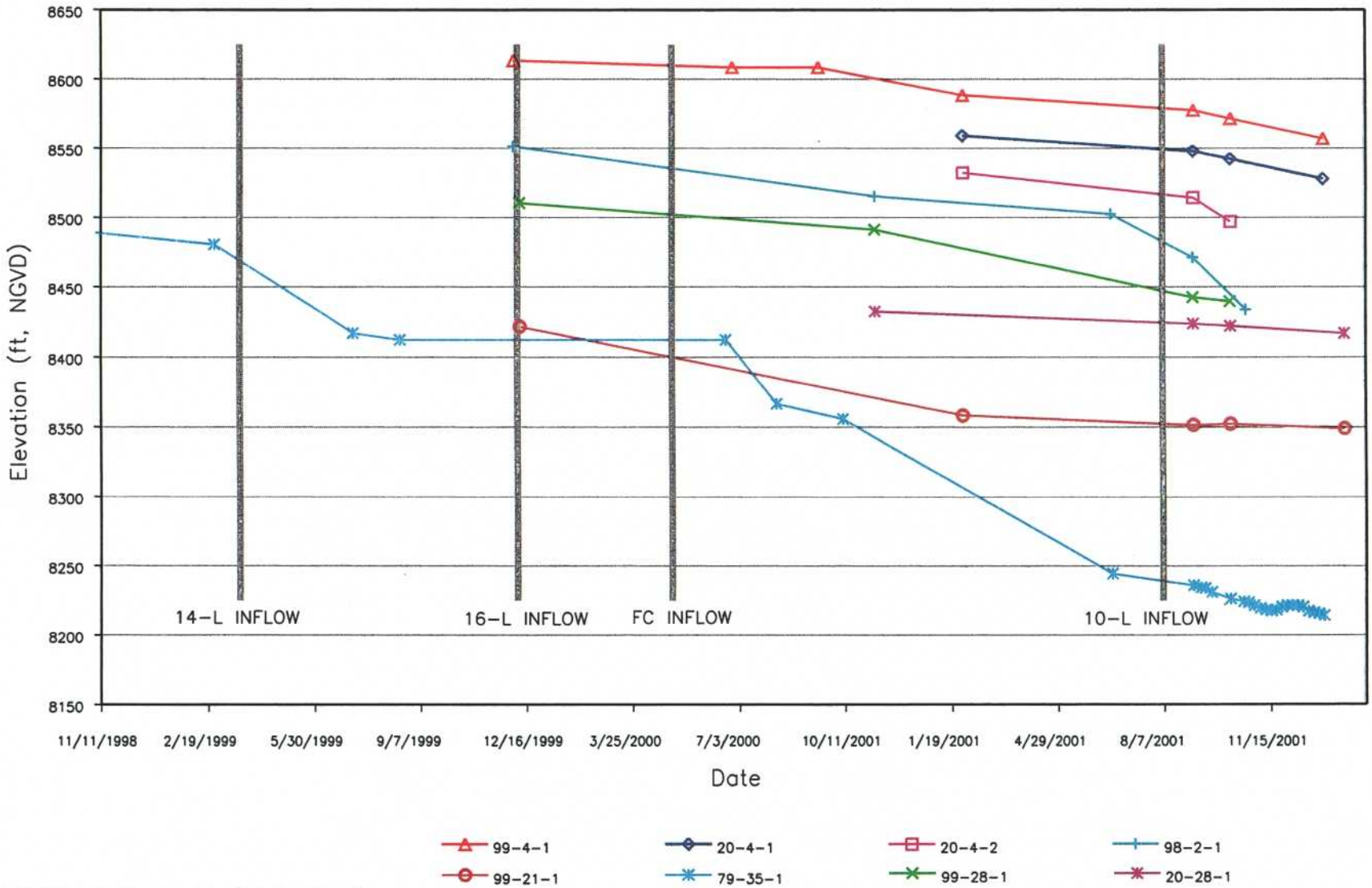
FIGURE 3



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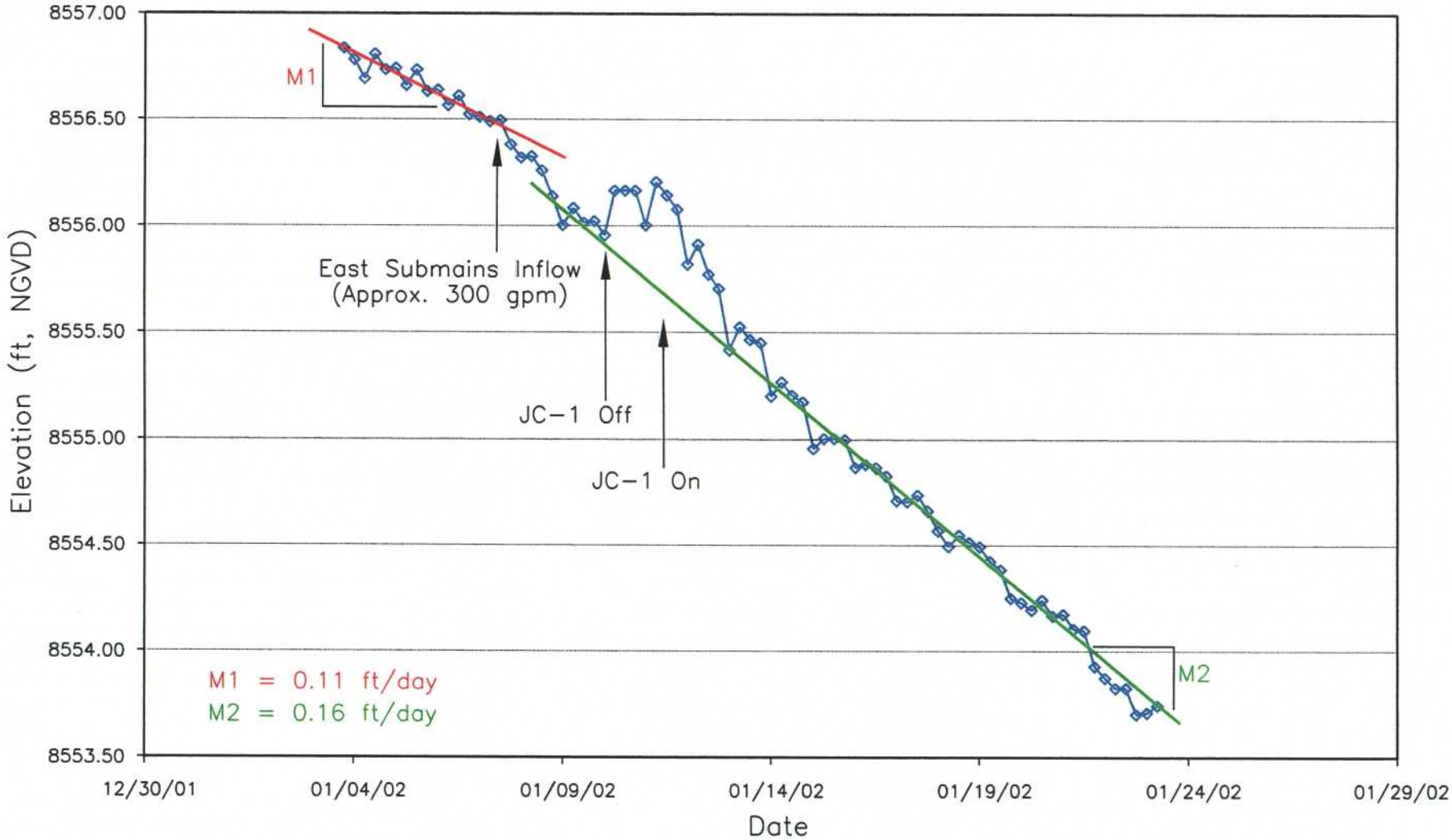
BY:	RLH	DWG FILE:	FC-WLEVELS
DRAWN:	SAC	PLOT FILE:	FC-WLEVELS
CHECKED:	JJM	PLOT DATE:	2/14/02

Water Levels in Flat Canyon Monitoring Wells

FIGURE 4



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DRAWN:	SAC	PLOT FILE:	WL-99-4-1
CHECKED:		PLOT DATE:	2/21/02

Water Levels in Monitoring Well 99-4-1

FIGURE 5

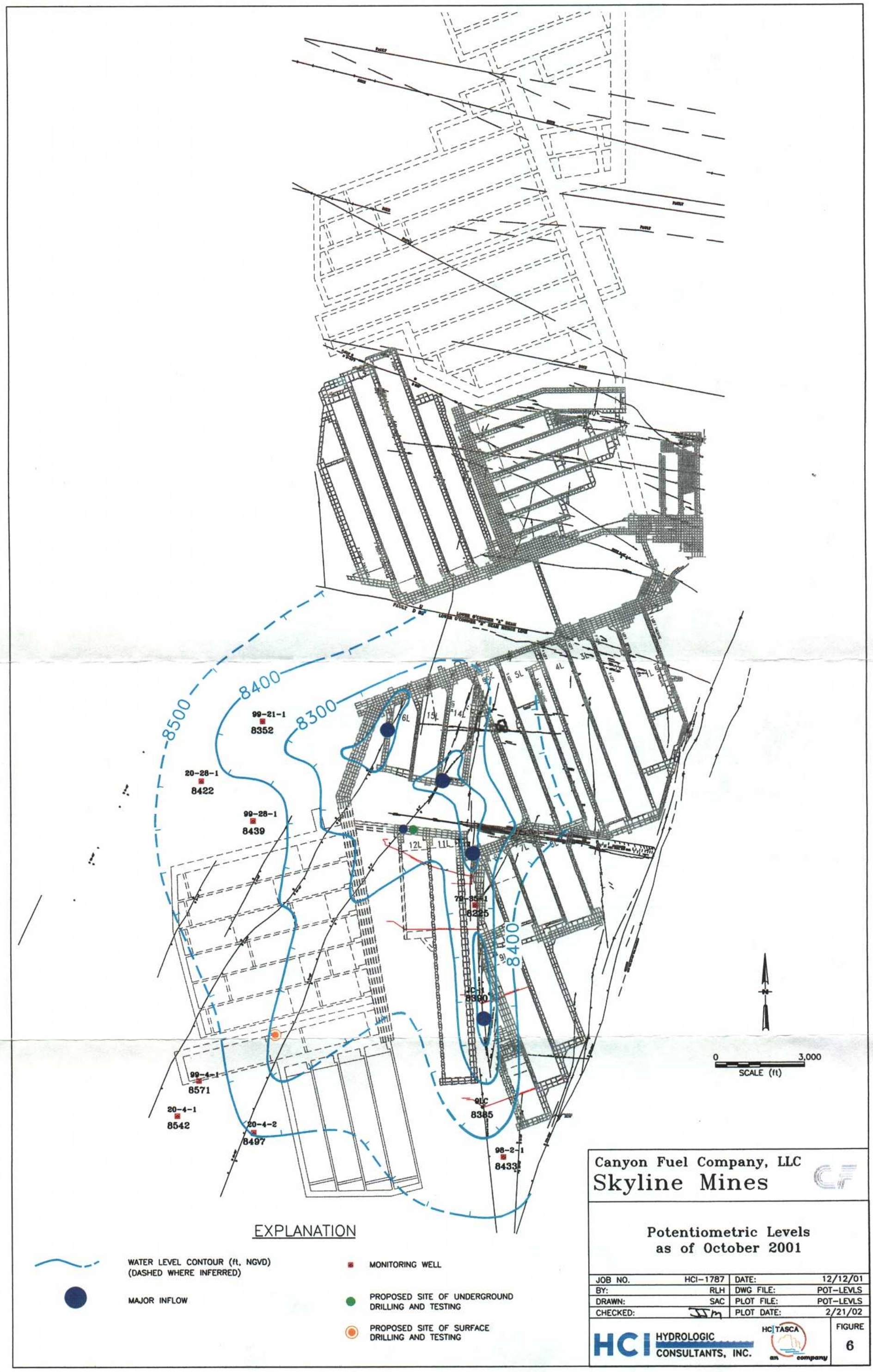
8500
8400
8300
8400
99-21-1
8352
20-28-1
8422
99-28-1
8439
99-4-1
8571
20-4-1
8542
20-4-2
8497
98-2-1
8433
JC-1
8390
9LC
8365
6225
6L
15L
14L
12L
11L
5L
4L
3L
1L
0
3,000
SCALE (ft)
EXPLANATION
WATER LEVEL CONTOUR (ft, NGVD)
(DASHED WHERE INFERRED)
MAJOR INFLOW
MONITORING WELL
PROPOSED SITE OF UNDERGROUND
DRILLING AND TESTING
PROPOSED SITE OF SURFACE
DRILLING AND TESTING
Canyon Fuel Company, LLC
Skyline Mines
Potentiometric Levels
as of October 2001
JOB NO. HCI-1787
BY: RLH
DRAWN: SAC
CHECKED:
DATE: 12/12/01
DWG FILE: POT-LEVLS
PLOT FILE: POT-LEVLS
PLOT DATE: 2/21/02
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FIGURE
6

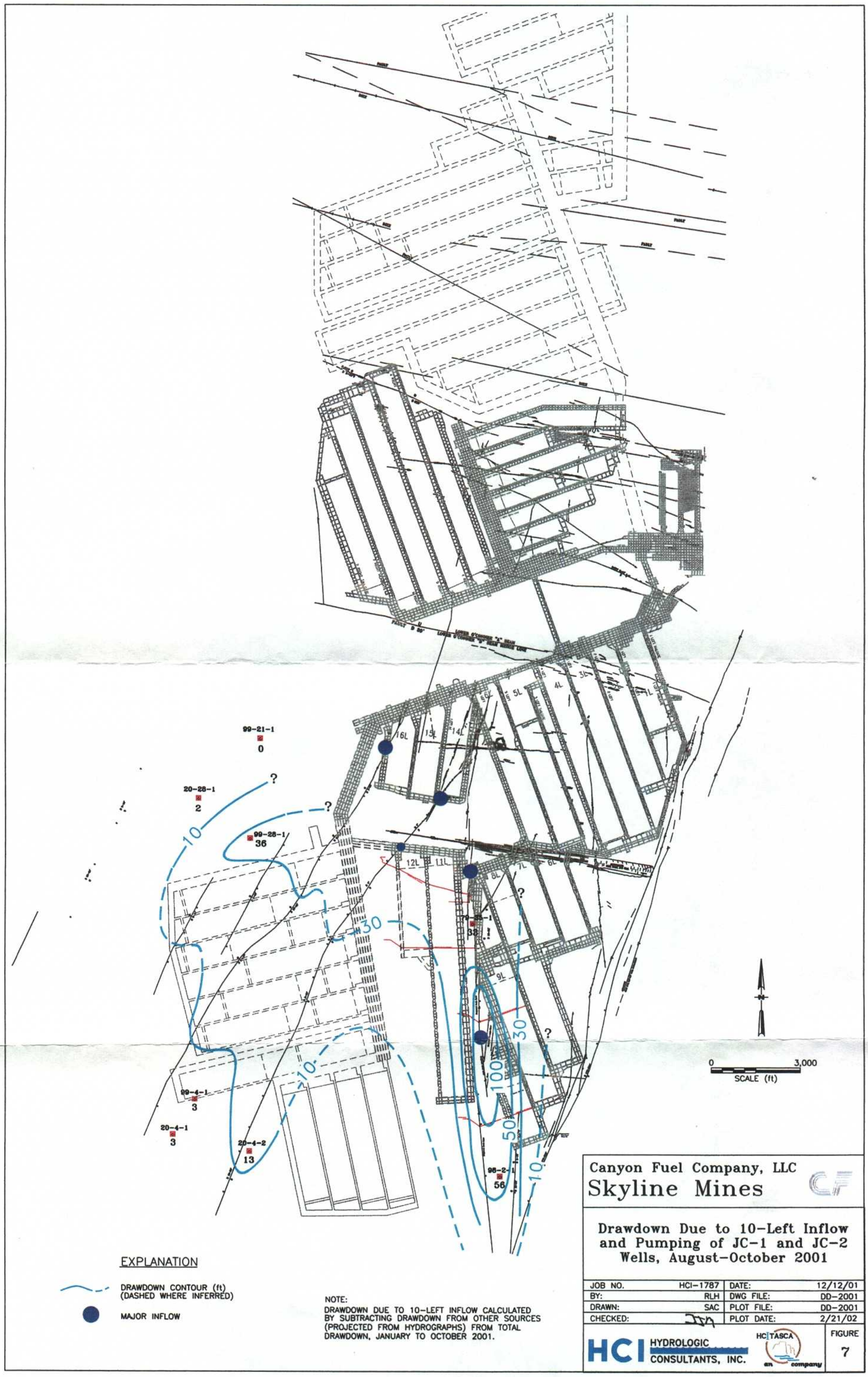
99-21-1
0
20-28-1
2
99-28-1
36
99-4-1
3
20-4-1
3
20-4-2
13
98-2-1
56
10
30
100
50
16L
15L
14L
12L
11L
8L
7L
6L
5L
4L
3L
1L
0
3,000
SCALE (ft)
EXPLANATION
DRAWDOWN CONTOUR (ft)
(DASHED WHERE INFERRED)
MAJOR INFLOW
NOTE:
DRAWDOWN DUE TO 10-LEFT INFLOW CALCULATED BY SUBTRACTING DRAWDOWN FROM OTHER SOURCES (PROJECTED FROM HYDROGRAPHS) FROM TOTAL DRAWDOWN, JANUARY TO OCTOBER 2001.
Canyon Fuel Company, LLC
Skyline Mines
Drawdown Due to 10-Left Inflow and Pumping of JC-1 and JC-2 Wells, August-October 2001
JOB NO. HCI-1787
BY: RLH
DRAWN: SAC
CHECKED:
DATE: 12/12/01
DWG FILE: DD-2001
PLOT FILE: DD-2001
PLOT DATE: 2/21/02
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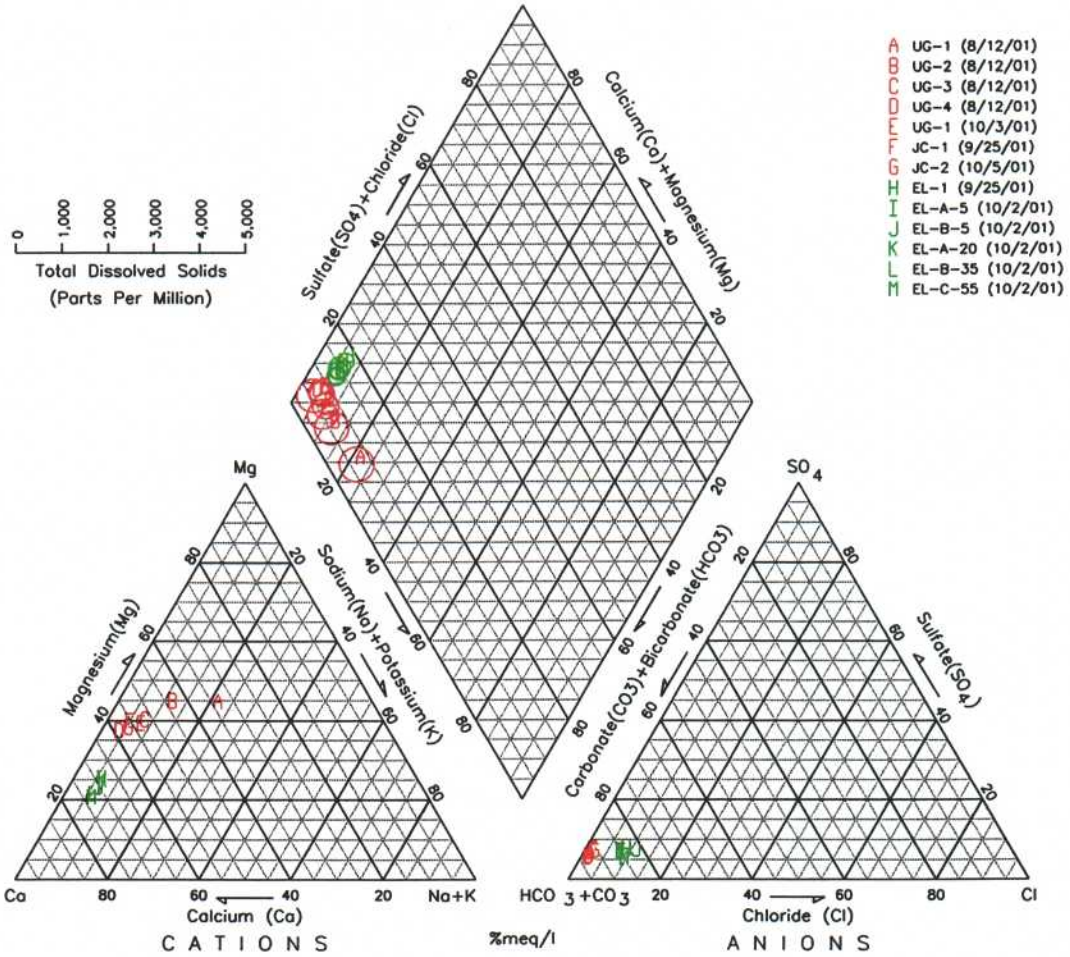
FIGURE 7



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DRAWN:	SAC	PLOT FILE:	PIPER02
CHECKED:	JJM	PLOT DATE:	2/15/02

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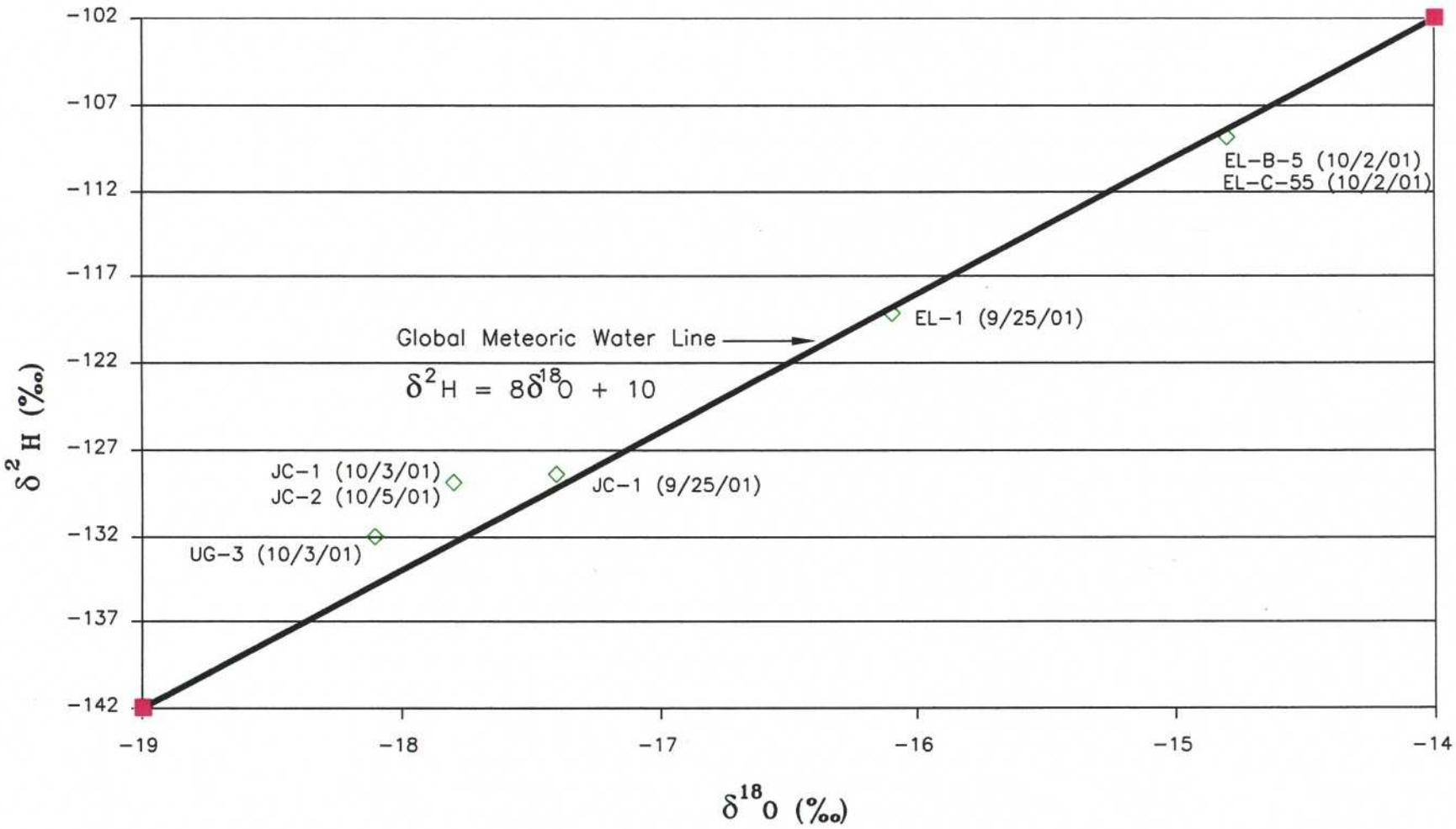
Trilinear Plot of Water Chemistry: Mine Inflows, Dewatering Wells, and Electric Lake

FIGURE 8



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BY:	RLH/MDB	DWG FILE:	MINE-INFLOWS02
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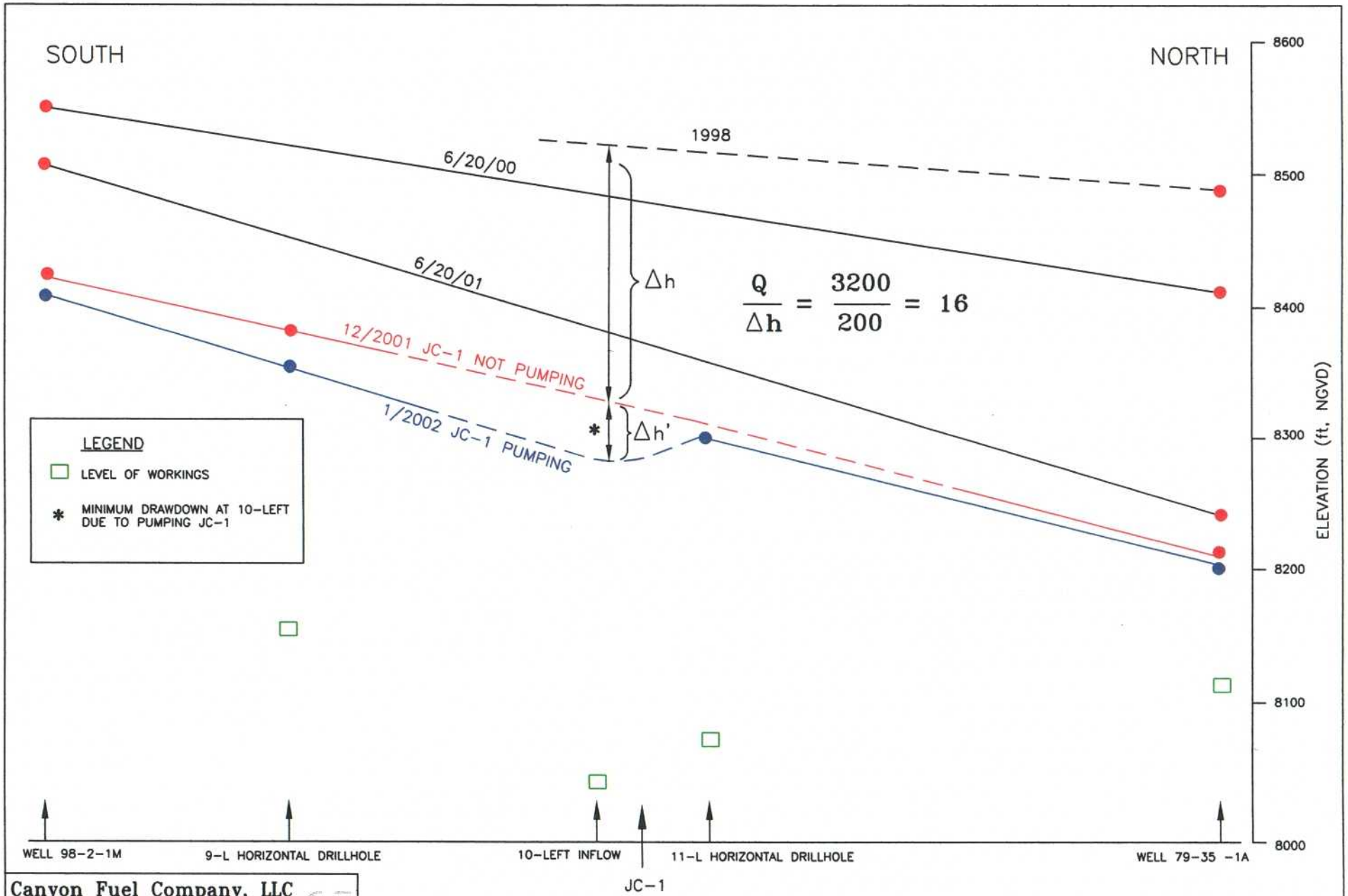
CHECKED:		PLOT DATE:	2/21/02

δ^2H and δ^{18}O for Mine Inflows, Dewatering Wells, and Electric Lake

FIGURE 9



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DRAWN:	SAC	PLOT FILE:	SCHEMATIC
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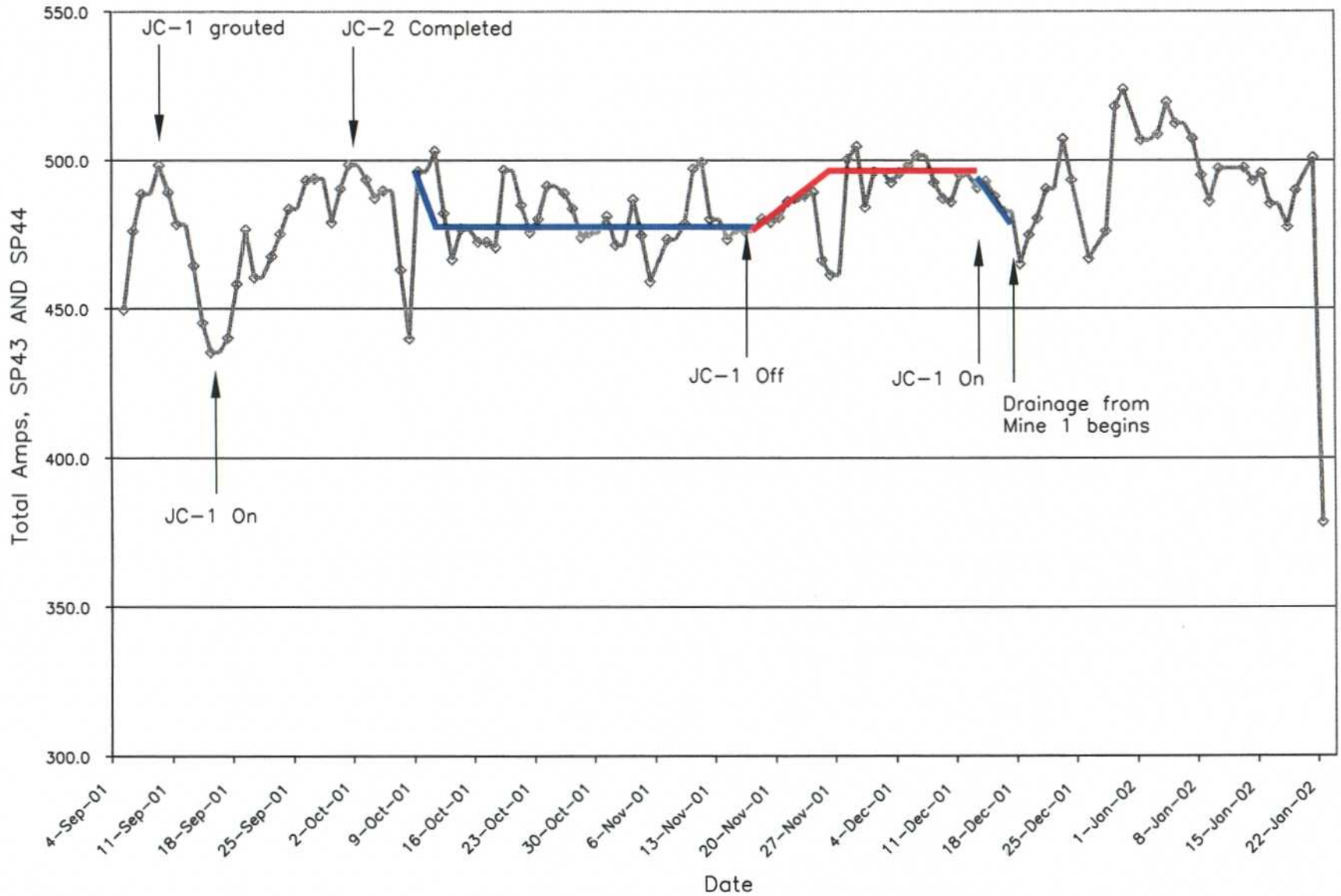
Water Levels Measured in and near the Diagonal Fault, 1998-2002

FIGURE 10



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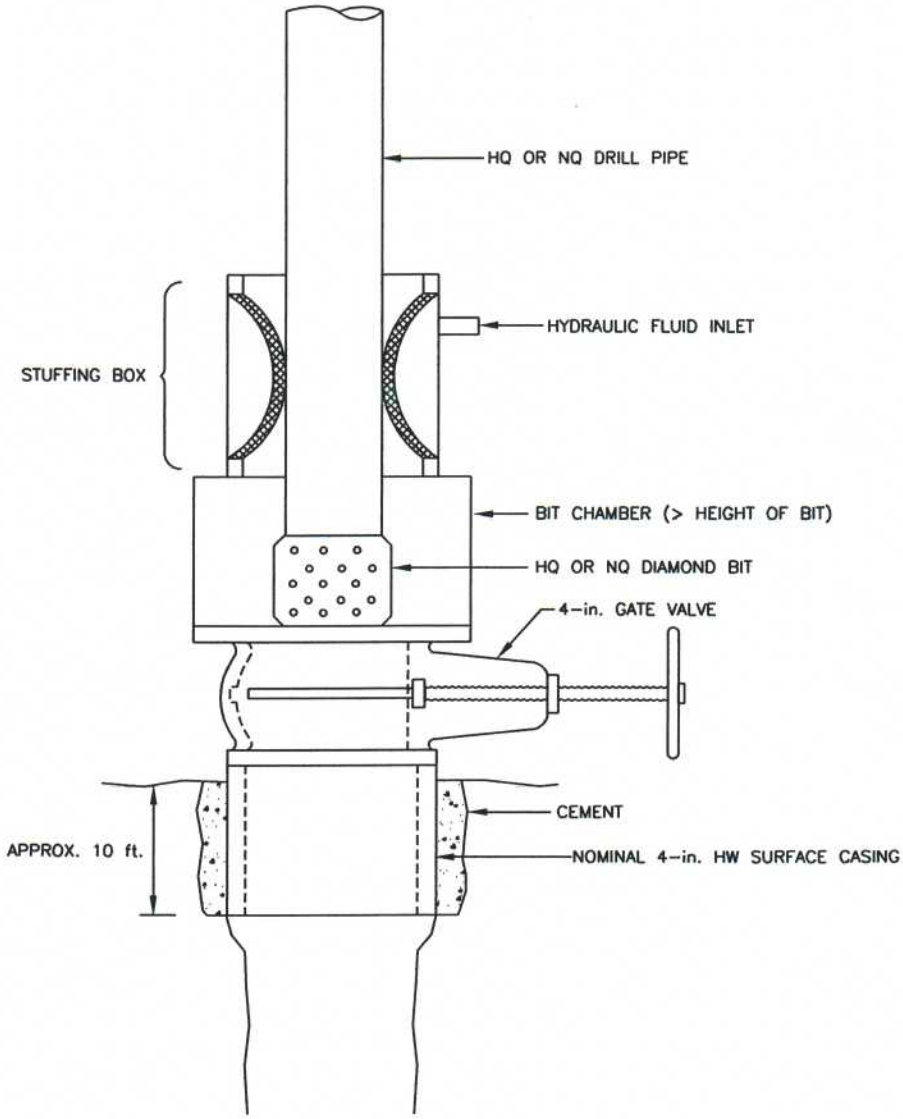
CHECKED:		PLOT DATE:	2/21/02

Average Total Power Usage by Sump Pumps at 10-Left

FIGURE 11



Core Drilling through Wellhead and Stuffing Box

Canyon Fuel Company, LLC Skyline Mines			
JOB NO.	HCI-1787	DATE:	12/11/01
BY:	RLH	DWG FILE:	UG-TESTWELL02
DRAWN:	SAC	PLOT FILE:	UG-TESTWELL02
CHECKED:	JJM	PLOT DATE:	2/21/02

NOT TO SCALE

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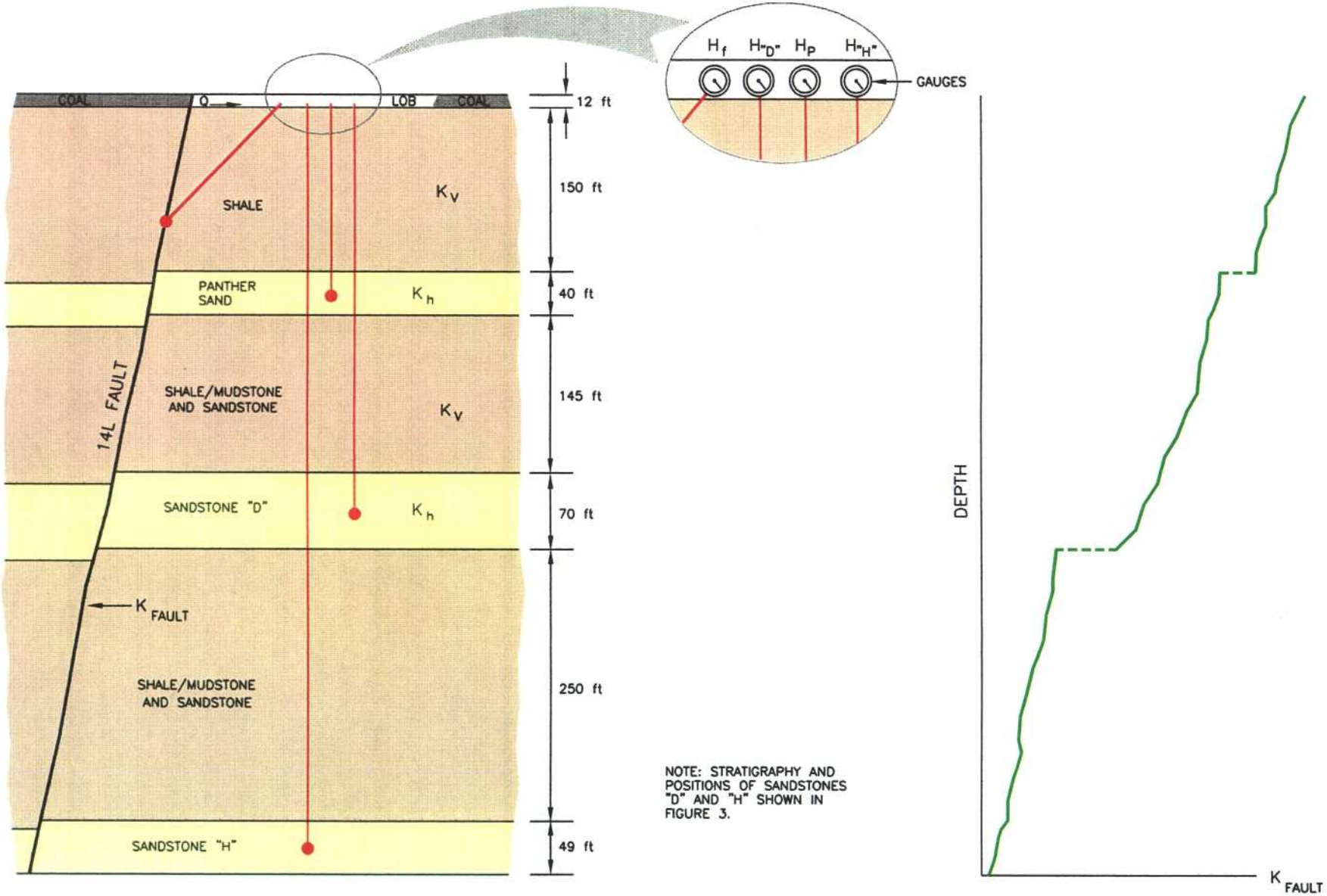
Wellhead for Underground Test Wells

FIGURE 12



NOTE: STRATIGRAPHY AND POSITIONS OF SANDSTONES "D" AND "H" SHOWN IN FIGURE 3.

Canyon Fuel Company, LLC
SKYLINE MINES

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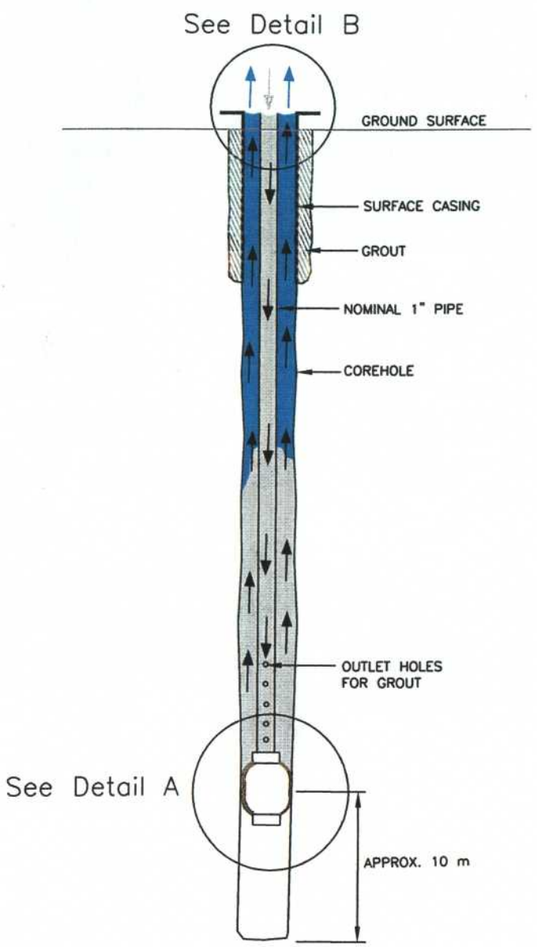
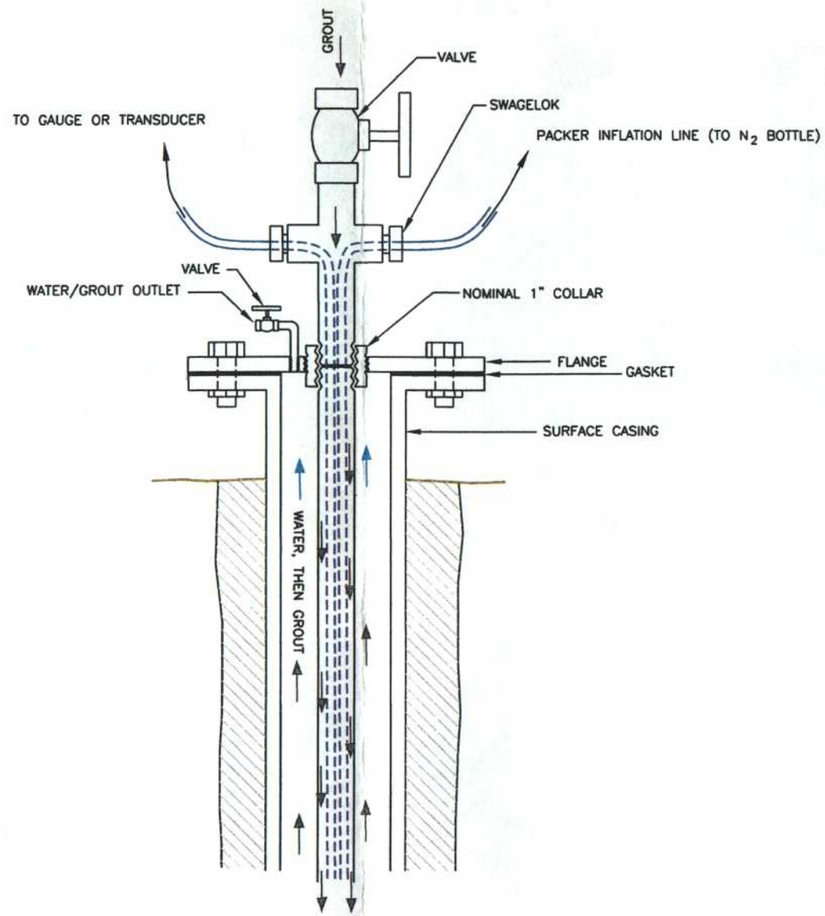
BY:	LCA\RLH	DWG FILE:	CROS-SEC
DRAWN:	SAC	PLOT FILE:	CROS-SEC
CHECKED:	JJM	PLOT DATE:	2/22/02

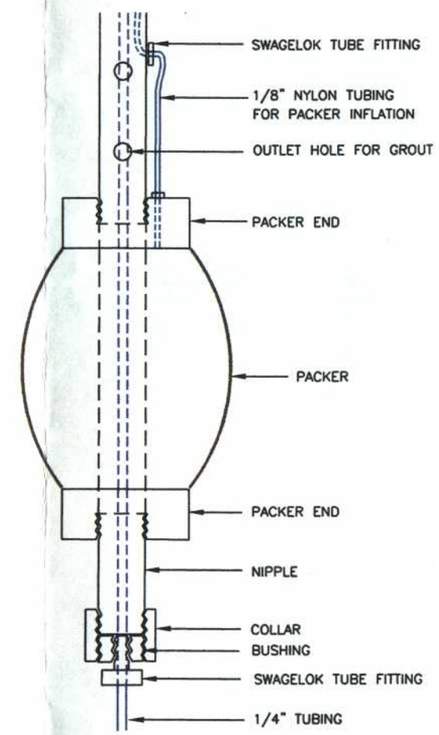
Planned Underground Drilling at East Submains

FIGURE 13





Detail B



Detail A

Canyon Fuel Company, LLC
Skyline Mines

Point Piezometer Construction in Artesian Flowing Corehole

JOB NO.	HCI-1787	DATE:	2/13/02
BY:	LCA/RLH	DWG FILE:	PT-PIEZO
DRAWN:	SAC	PLOT FILE:	PT-PIEZO
CHECKED:	JJA	PLOT DATE:	2/21/02

HCI HYDROLOGIC CONSULTANTS, INC.
HC TASCA an company

FIGURE 14

TABLE 1
Water Chemistry Data

	Sample	Mine Inflows[2]						Dewatering Wells in James Canyon[2]								Electric Lake[2]							
		UG-1	UG-2	UG-3		UG-4										Shallow					Deep		
	Parameter	Connellsville Fault	18 Left Entry #3 Borehole	Fault Crossing 3 West Submain		9 Left Headgate Horizontal Borehole	Average Mine Inflows	JC-1						JC-2	Average James Canyon	EL-1	EL-A-5	EL-[illegible]	EL-A-20	Average Shallow Lake	EL-B-35	EL-C-55	Average Deep Lake
	Date	8/12/01	8/12/01	8/12/01	10/3/01	8/12/01		9/19/01	9/21/01	9/23/01	9/25/01	9/28/01	10/3/01	10/5/01		9/25/01	10/2/01	10/2[illegible]	10/2/01		10/2/01	10/2/01	
Cations	Ca	34.1[3]	42.6[3]	44.5[3]	46.1	56.7[3]	44.8	NA	NA	NA	44.6	NA	NA	48.3	46.5	42.0	39.4	40.0	41.4	40.7	44.5	43.9	44.2
	Mg	25.1[3]	24.6[3]	19.3[3]	19.1	20.1[3]	21.6	17.7	18.5	18.6	18.0	16.8	17.1	18.3	17.9	8.6	7.2	7.2	8.3	7.8	7.2	6.7	7.0
	K	8.2[3]	8.9[3]	4.1[3]	3.4	2.1[3]	5.3	NA	NA	NA	2.6	NA	NA	3.0	2.8	1.0	0.87 J	0.88 J	1.6	1.3	0.82 J	0.78 J	0.8
	Na	19.8[3]	7.9[3]	5.6[3]	5.8	3.2[3]	8.5	NA	NA	NA	3.2	NA	NA	3.8	3.5	3.7	3.7	3.8	3.6	3.7	3.9	3.9	3.9
	Ba	0.2	0.4	0.3	NA	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.2	NA	0.2	NA	NA	NA	NA	NA	NA	NA	NA
Anions	Cl	2.7	2.8	2.4	2.5	2.9	2.7	2.6	2.3	2.7	2.2	2.6	4.0	2.8	2.7	10.1	7.3	10.1	7.3	8.7	7.9	8.2	8.1
	SO_4	11.3	8.9	7.2	8.3	8.8	8.9	9.0	9.2	8.8	8.8	8.7	8.6	8.6	8.8	8.9	6.6	7.0	6.8	7.3	6.2	< 4.0	5.1
	HCO_3^- as $CaCO_3$	225[4]	222[4]	196[4]	196.0	220[4]	249.8	186.0	184.0	182.0	182.0	188.0	188.0	186.0	185.1	133.6	106.0	108.0	116.0	115.9	128.0	126.0	127.0
	CO_3^{2-}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.1	16.0	10.0	10.0	9.0	< 2	< 2	2.0
	F	0.4	0.3	0.3	0.4	0.2	0.3	0.3	0.2	0.3	0.2	0.3	0.3	0.3	0.3	< 0.1	0.3	< 0.2	0.3	0.2	0.4	< 0.1	0.3
Physical	T (°C)	NA	NA	NA	NA	NA	NA	NA	NA	NA	14.7	NA	NA	NA	14.7	18.0	NA	12.6	NA	15.3	9.6	NA	9.6
	pH (units)	NA	NA	NA	NA	NA	NA	7.6	8.0	7.9	7.9	7.6	7.7	NA	7.8	8.6	8.8	8.7	8.7	8.7	8.1	8.0	8.0
	DO	NA	NA	NA	0.2	NA	0.2	NA	NA	NA	0.6	NA	NA	NA	0.6	7.3	7.4	7.0	6.9-8.6	7.4	0.25-0.47	0.4	0.4
	EC (μS/cm)	NA	NA	NA	NA	NA	NA	NA	NA	NA	354.0	NA	NA	NA	354.0	282.0	NA	NA	NA	282.0	NA	NA	NA
Radiologic	δ^2H (‰)	NA	NA	NA	-132.0	NA	-132.0	NA	NA	NA	-128.4	NA	-129.0	-129.0	-128.8	-119.2	NA	-109.0	NA	-114.1	NA	-109.0	-109.0
	$\delta^{18}O$ (‰)	NA	NA	NA	-18.1	NA	-18.1	NA	NA	NA	-17.4	NA	-17.8	-17.8	-17.7	-16.1	NA	-14.8	NA	-15.5	NA	-14.8	-14.8
	^3H (T.U.)	NA	NA	NA	0.1	NA	0.1	NA	NA	NA	0.2	NA	0.2	-0.2	0.0	13.0	NA	NA	NA	13.0	NA	11.7 & 12.3	12.0
	$\delta^{13}C$ (‰)	NA	NA	NA	-10.0	NA	-10.0	NA	NA	NA	-11.8	NA	NA	-10.7	-11.3	-8.3	NA	NA	NA	-8.3	NA	-9.2	-9.2
	^{14}C (pmC)	NA	NA	NA	15.8	NA	15.8	NA	NA	NA	30.4	NA	NA	24.3	27.4	72.4	NA	NA	NA	72.4	NA	82.2	82.2

Note: 1) All values in mg/L unless otherwise noted
2) Location shown on Plate I
3) Filtered Samples
4) Calculated from charge imbalance
J = Analyte detected below the PQL (Practical Quantization Limit)
NA = not currently available

TABLE 2

Estimates of Ground-Water Inflow at 10-Left

Date	Pumping Conditions	Method of Measurement	Inflow (gpm)			
			Total	9-Left gob	Mine 1	10-Left
8/16/01	JC-1 off	Stage-Volume	4,300	0	0	4,300
10/1/01	JC-1 recently on	Power Usage	3,400	0	0	3,400
10/8/01	JC-1 pumping	Power Usage	3,000	0	0	3,000
10/9/01	JC-1 pumping	Stage Volume	3,050	0	0	3,050
10/16/01	JC-1 off	Doppler Meters	3,700	0	0	3,700
10/16/01	JC-1 off	Power Usage	3,200	0	0	3,200
11/16/01	JC-1 pumping	Power Usage	3,200	200	0	3,000
12/13/01	JC-1 off	Power Usage	3,400	200	0	3,200
12/19/01	JC-1 recently on	Power Usage	3,250	200	0	3,050
12/29/01	Mine 1 inflow through 8 Left B; JC-1 pumping	Power Usage	3,750	200	500?	3,050
1/19/02	Waning inflow from Mine 1; JC-1 pumping	Power Usage	3,350	200	150?	3,000

Map(s) is kept with this report located in the Public Information Center of our Salt Lake City office.