MIDNITE URANIUM MINE - HYDROLOGIC RESEARCH AND CHARACTERIZATION[1]

by

Barbara C. Williams[2] and John A. Riley[3]

Abstract. U.S. Bureau of Mines hydrologic and geochemical investigations at the Midnite uranium mine include the following two objectives: predicting how excavated pits will refill after dewatering and determining head distribution at the site. This paper focuses on the influence of the local groundwater flow system on the two open pits (3 and 4) at the site. Uncertainties remain to be resolved regarding (1) whether pit 4 will refill when dewatered and (2) the quality of water that will naturally recharge pit 3 if it is dewatered. This information is required so that reclamation alternatives can be evaluated.

A comparison of potentiometric surfaces indicates that both pit 3 and pit 4 are hydraulically connected to the groundwater flow system. These potentiometric maps and other data indicate that both pits would probably refill if dewatered. The water qualities of the monitored and inferred sources of recharge to pit 3 and historical data from pit 3 indicate that if dewatered, pit 3 would be likely to be refilled with water of a quality that violates the NPDES standard for uranium.

Additional Key Words: hydrology, ground water, acid mine drainage, Midnite uranium mine, potentiometric map, metal ion migration.

Introduction

The Midnite uranium mine is on the Spokane Indian Reservation in northeastern Washington (figure 1). The site was leased from the Spokane Tribe of Indians by the Dawn Mining Co. beginning in 1954 and was mined from 1955 to 1965 and from 1969 to 1981. Approximately 130 of the 328 hectares within the lease boundary were disturbed, resulting in open pits, backfilled pits, stockpiles of soil, piles of both nonreactive and reactive waste rock, and stockpiles of low-grade uranium ore. The Bureau of Indian Affairs (BIA) and the Bureau of Land Management (BLM) acted as the permitting agencies during the more recent operations and are now the key agencies overseeing reclamation. The U.S. Bureau of Mines (BOM) has been conducting research at the site since 1989. This research began as a baseline study of metal ion migration, but has become more focused on the reclamation issues faced by several agencies within the Department of the Interior. U.S. Bureau of Mines hydrologic and geochemical research objectives are to (1) identify contaminant source areas and plausible migration pathways, (2) characterize the chemical mechanisms that release uranium and

[1]Paper presented at the 1993 National Meeting of the American Society for Surface Mining and Reclamation, Spokane, Washington, May 16-19, 1993

[2]Civil engineer and hydrologist, Spokane Research Center, U.S. Bureau of Mines, Spokane, WA.

[3]Consulting hydrogeologist, Post Falls, ID.

Proceedings America Society of Mining and Reclamation, 1993 pp 455-466
DOI: 10.21000/JASMR93020455

https://doi.org/10.21000/JASMR93010455

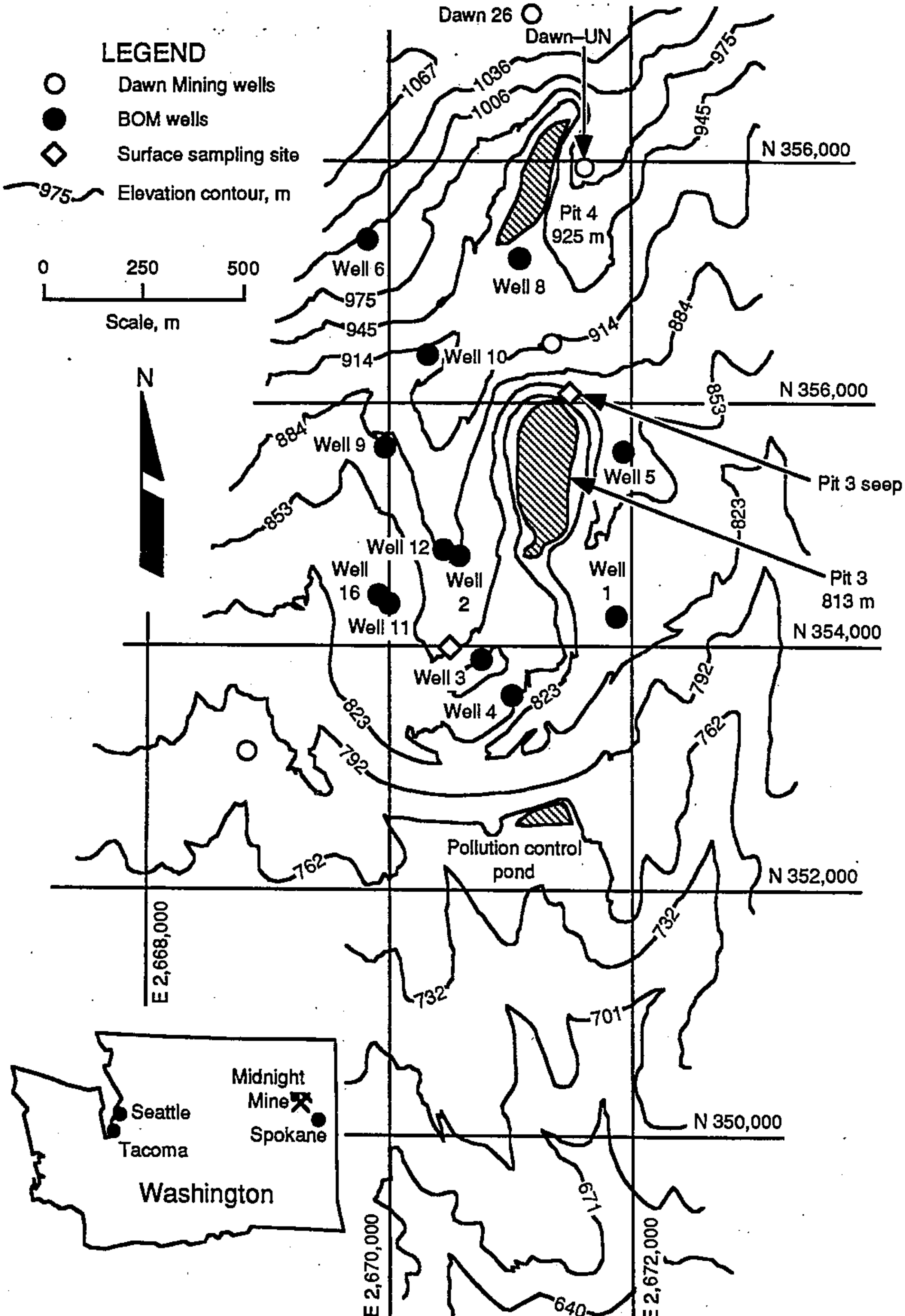

Figure 1. Site plan view and area location map.

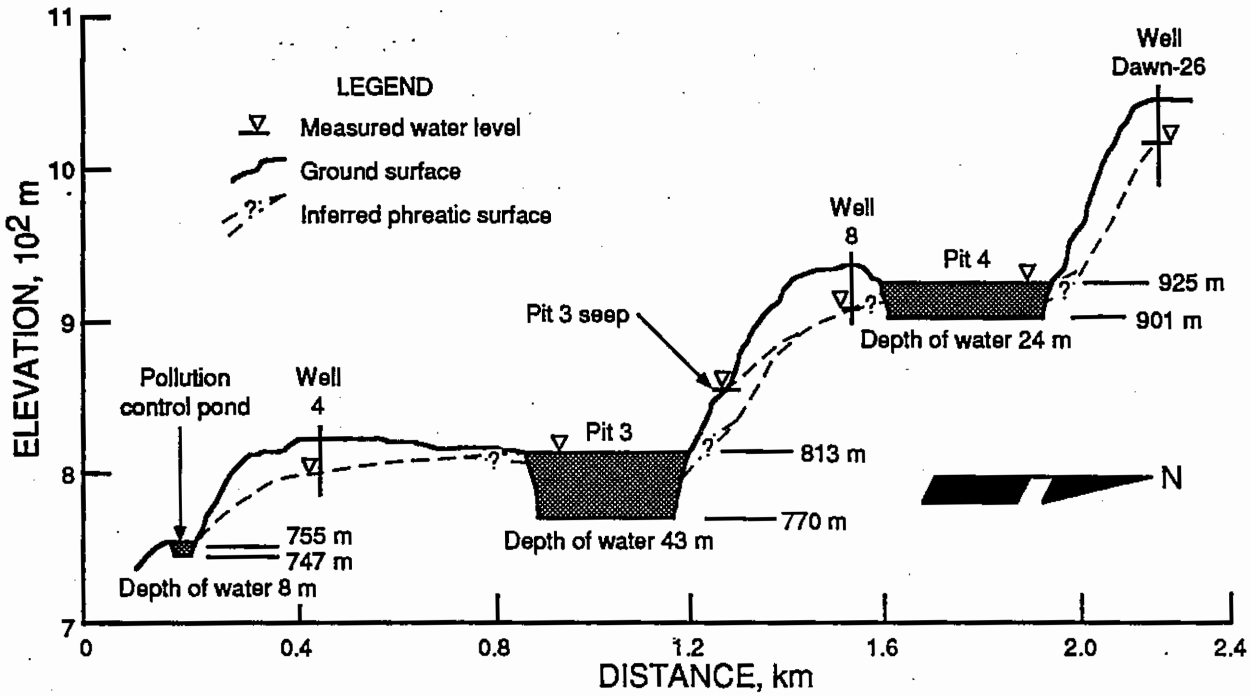

Figure 2. North-south cross section across Midnite Mine. Vertical exaggeration is 3 times.

other contaminants, (3) predict how pits will refill after dewatering, (4) determine the potentiometric surface in various hydrostratigraphic units at the site, (5) determine the residence times of meteoric water, and (6) develop means to decrease or redirect recharge to the most strongly contaminated zones. The first two objectives are addressed in Marcy (1993). The third and fourth objectives are addressed in this paper.

During the period the mine was active, six pits or subpits were opened. Four of these were subsequently backfilled with overburden and waste as mining progressed, while pits 3 and 4 were left open (figures 1 and 2). Pit 3 contains approximately 1.6 million m^3 water and is more contaminated than pit 4 (table 1). Pit 4 contains 0.72 million m^3 of water; it received a significant amount of water from the dewatering operations required to mine pit 3. When pit 3 was no

Table 1.--Average values of water quality characteristics at selected sampling locations. Averages are arithmetic means of 30 samples taken over 2 years (1990-1992).

Location	Specific conductance, µS/cm	pH	Eh, mV	$SO_4^{=}$, mg/L	Alkalinity, mg/L as HCO_3^-	U, mg/L
Well 6........	210	6.1	460	9.7	52	<DL
Pit 4..........	350	7.0	470	380	46	3.1
Pit 3..........	1,500	4.2	450	2,500	20	24
Pit 3 seep....	790	7.2	390	720	91	2.0
Well 3M.....	7,900	5.3	360	9,400	520	15
Well 3D......	1,100	6.5	390	650	170	2.7
Well 5M.....	230	7.2	330	32	140	<DL
PCP	2,000	4.0	480	3,600	16	29

DL = Detection limit.

was no longer mined (1981), some portion of the water accumulated in pit 4 was siphoned back into pit 3. No record of the water elevations in pit 4 is known to have been maintained during the period of these additions and withdrawals. A pollution control pond (PCP) was built in 1979 to hold contaminated water collected from various seeps and drains at the southernmost end of the permit area. In 1983, pumping of water from the PCP into pit 3 was initiated and has continued until the present at a rate of about 0.15 m^3/min.

Site Geology

The Midnite Mine is located on the southwest slope of Spokane Mountain on the western edge of the metasedimentary Togo Formation in the Belt Supergroup. This Precambrian sequence is at least 900 m thick and contains graphitic and pyritic mica phyllite and muscovite schist with interbeds of marble, calc-silicate, hornfels, and quartzite (Nash, 1977). Ore deposition was hydrothermal in a contact metamorphic-metasomatic system that produced sulfide minerals, which causes acid rock drainage when exposed to oxidation. This is very unusual for a uranium deposit. Disseminated uranium minerals occur along foliations in muscovite schist, phyllite, and hornfels (Nash and Lehrman, 1975) and within fractures, shear zones, and clay-rich layers within the calc-silicate rock (Ludwig et al., 1981). Uranium ore-bearing phyllite schist is the predominant rock type on the northern wall of pit 3.

A Late Cretaceous porphyritic quartz monzonite intrusion crops out along the west side of the mine (Fleshman and Dodd, 1982) and underlies the eastern portion of the mine. The contact between the quartz monzonite and the ore-bearing metasediments appears to run north-south from the middle of pit 4 through pit 3 near the west wall. Intrusive rock forms the west highwall of pit 4 as well as the ridge above that highwall. Intrusive rock also forms part of the west highwall of pit 3.

The general trend of the structural features in the area is north-northeast (Ludwig et al., 1981); these features include fractures, the Midnite mineral trend, and dikes and sills associated with the quartz monzonite intrusion.

Monitoring Wells and Surface Water Sampling

Thirty-one monitoring wells at 15 locations were drilled in two phases. In 1989, 15 monitoring wells were installed at 7 locations; these wells and 14 surface-water sampling locations have been monitored since December 1989. An additional 16 wells at 8 locations were constructed in the summer of 1992. Wells drilled in 1989 were constructed to document the distribution of water elevation and quality in three dimensions, whereas wells drilled in 1992 were constructed to collect specific information determined as needed after the first set of wells had been installed. Geophysical techniques were used to optimize the placement of holes for the 1992 drilling program. Holes with an inside diameter (ID) of 0.2 m were drilled, and steel casing was driven as needed to stabilize the hole during drilling. After completion, the steel casings were pulled, leaving only 3 to 5 m of permanent steel casing. All monitoring wells were constructed with 0.05-m threaded polyvinyl chloride (PVC) casing and factory-slotted screens. One, two, or three monitoring wells were installed inside the 0.2-m drill hole. Clean silica sand was poured into the drilled hole in the interval around the screened section. A bentonite sealing material was pumped into the hole with a tremie line to seal the sections between the screened intervals. Either the bentonite slurry or bentonite chips were used to seal the well from the top of the shallowest sandpack to the surface. Lithologic logs and completion depths are shown in figure 3. General descriptions of field sampling methods and laboratory analytical procedures are provided in detail in a BOM Report of Investigation to be published in 1993 and also in Marcy (1993).

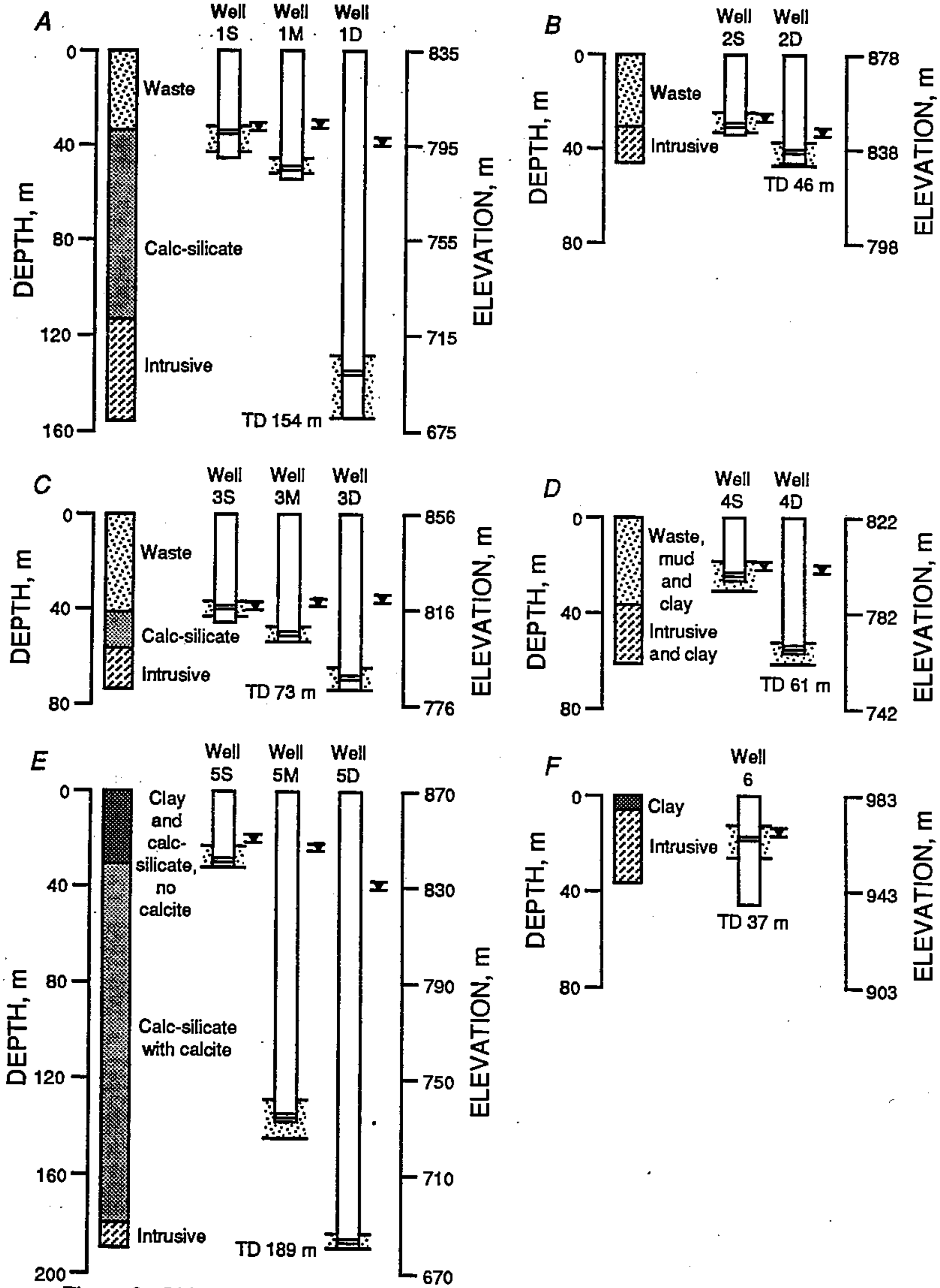

Figure 3. Lithologic logs and well construction of sampled intervals. Drilling locations are *A*, well 1; *B*, well 2; *C*, well 3; *D*, well 4; *E*, well 5; *F*, well 6; ....continued....

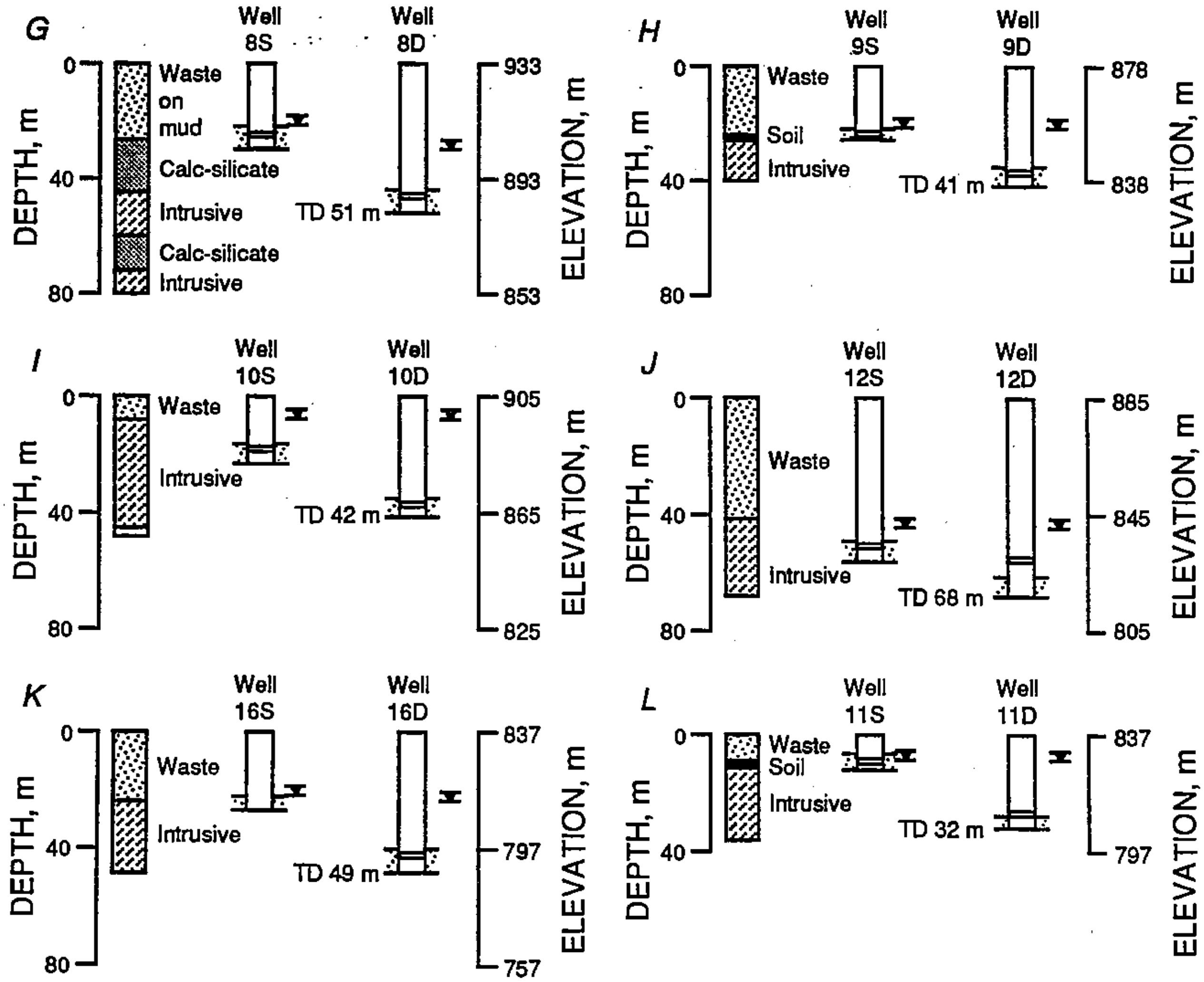

Figure 3. Continued.... *G*, well 8; *H*, well 9; *I*, well 10; *J*, well 12; *K*, well 16; and *L*, well 11.

Site Hydrology

The topography in the area of the Midnite Mine is steep, with an average gradient of 0.146 (14.6% grade) from north-northwest to the south. Groundwater flow approximately follows surface topography (figure 4). On what is roughly the western half of the site (see logs for wells 2, 6, 9, 10, 11, 12, and 16 in figure 3), alluvium or waste rock overly the intrusive. In most of these locations, these materials (consisting of alluvium, clays, metasediments, ore stockpiles, low-grade ore stockpiles, and waste rock) are saturated where they intersect the phreatic surface. The ground water in the surface materials, weathered intrusive, and the deeper intrusive appears to be unconfined. During drilling of the intrusive (by the BOM), significant water inflow was encountered only in fractured zones within the unweathered intrusive; however, the resulting water levels usually were very close to those of overlying units, indicating hydraulic interconnection. At these locations, either no vertical gradient or a downward vertical gradient exists, indicating that this ridge-top site is a groundwater recharge area. At fewer locations (represented by well 10, figure 3), the surface materials are above the phreatic surface.

Well 8 (figure 3) is on the contact between the calc-silicate and the intrusive. Three drill holes (1, 3, and 5) have completions wholly isolated within the calc-silicate. Two of these

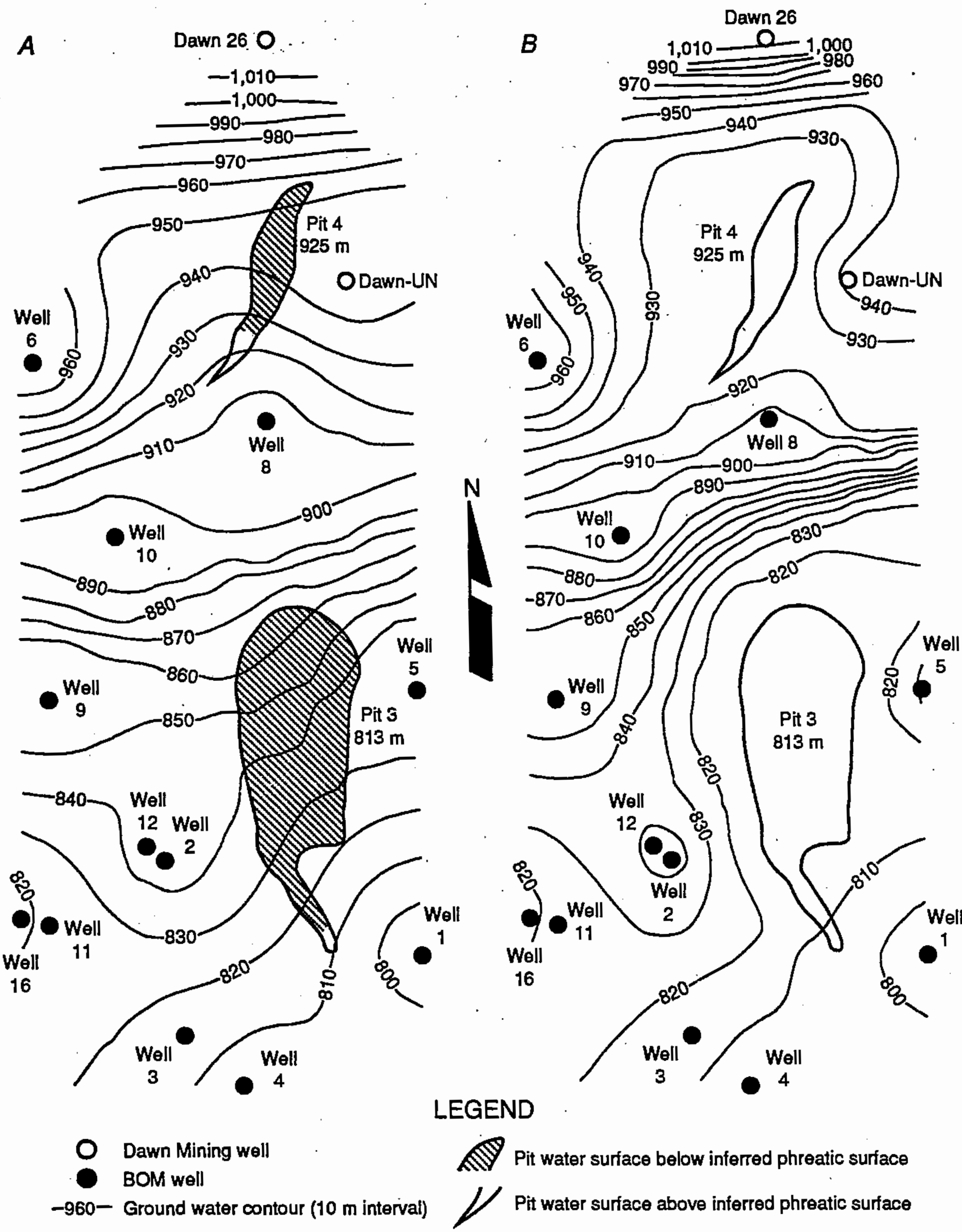

Figure 4. Groundwater elevation contours as interpolated among water elevations of the indicated wells. *A*, Contours using only water elevations in wells, and ignoring water elevations in pits; *B*, Contours assuming the phreatic surface is equal to the elevation of the water surface of the pits at the perimeters of the pits.

(wells 1 and 3) have vertical upward gradients between their middle and shallow completions. An upward gradient exists at well 3 between the intrusive and the overlying calc-silicate. These anomalous gradients, associated with the calc-silicate, are the only upward gradients that have been identified at this site.

Water elevation data from wells completed in the intrusive have been interpolated to form potentiometric maps. Figure 3 shows that heads in the intrusive tend to be closely related to those in overlying units in most cases. Two maps are shown (figure 4); the first is a contour map using only water elevations from wells, the second assumes the groundwater elevation to be equal to the surface elevation of the water in the pits at the pit perimeters. These two maps were generated to interpret the likely interaction between each pit and the ground water. Generally, the groundwater flow at the site is from north to south, regardless of localized pit-groundwater interactions. A detailed discussion of these interactions follows.

Groundwater Influences on the Hydraulics of Pit 4

Problem

The question of whether pit 4 would refill if it were dewatered is critically important. Pit 4 has been proposed as a permanent disposal site for reactive rock, including low-grade ore and spoils. Evaluation of this proposal must be based on a prediction of whether pit 4 would remain dry after being pumped out. If the backfilled pit 4 did refill with ground water, and a phreatic surface were established within the backfilled reactive wastes, a reactive "aquifer" would be created with the potential to adversely impact downgradient surface and ground waters.

Existing Data and Alternative Interpretations

The conceptual model proposed by some assumes that pit 4 would remain dry if it were dewatered. This assumption is held because pit 4 was purported not to have flooding problems during its excavation (Shepherd Miller, Inc., 1991). No records are likely to have been kept concerning minor, localized seepage unless it interfered with mining. By comparison, pit 3 did require pumping during mining (Shepherd Miller, Inc., 1991). The water in pit 4 is assumed (Shepherd Miller, Inc., 1991) to have come mainly from (1) pumpage from pit 3 and (2) subsequent precipitation and surface recharge to pit 4.

An alternative conceptual model assumes that pit 4 is in dynamic equilibrium with the local groundwater flow system. That is, the amount of water recharging the pit from is equal to the sum of evaporation and groundwater discharge. Head data for wells in the vicinity of pit 4 support this model. Wells to the north, east, and west of pit 4 have higher heads (table 2) than the surface of pit 4. The difference in head between each of these wells and the pit suggests that if there are no groundwater barriers, there is a gradient from the wells toward the pit and groundwater flow into the pit.

Table 2.--Water elevations in the vicinity of pit 4, November 1992.

Sample ID	Location	Water elevation, m
Well Dawn-26	N of pit 4	1,017
Well 6	W of pit 4	967
Well Dawn-UN[1] ..	E of pit 4	945
Pit 4	Water surface	925
Well 8S	S of pit 4	912
Well 8D	S of pit 4	908

[1]This well is unnamed.

Figure 4*A* indicates that there probably is some interaction between pit 4 and the ground water. The interpolations of water elevations between wells in the vicinity of pit 4 defines a phreatic surface that is higher than the true surface of pit 4 for the northern three-quarters of its extent (see shading, figure 4*A*). This indicates that ground water probably recharges pit 4 over most of its extent, and that figure 4*B* is probably a better representation of the phreatic surface. The head data of pit 4 and well 8 imply that pit 4 discharges ground water downgradient through its floor or via a buried alluvial channel. Both the shallow and deep completions of well 8, which is to the south of pit 4, have lower heads than pit 4 and are therefore downgradient of the pit. The downward gradient between well 8S and well 8M (figure 3) suggests downward motion of water consistent with leakage from the bottom of pit 4. This is also depicted by the downward-sloping phreatic surface between pit 4 and well 8 in figure 2. A possible flow path from pit 4 to pit 3 is evaluated geochemically in Marcy (1993) and is described as geochemically plausible.

A small problem with this model is explaining the lack of any records of inflow into pit 4 during mining. However, a lack of records regarding groundwater inflow to pit 4 means only that inflow did not interfere with mining. Minor groundwater inflow may have occurred which was not reported. The difference in inflow between the two pits may have occurred because pit 3 is a deeper excavation than pit 4 (approximately 130 m below original grade for pit 3, as opposed to approximately 52 m below original grade for pit 4). If the depth-to-phreatic surface were roughly the same in both locations, the headwall of pit 3 would have a steeper gradient than the headwall of pit 4, causing relatively less inflow into pit 4. The rock in the headwall of pit 4 may also have a lower hydraulic conductivity than pit 3), which would mean slower rates of recharge given the same gradient. Also, minor amounts of inflow to pit 4 might have been removed with excavated material.

Data Collection for Resolution

To further investigate the question of groundwater interaction with pit 4, BOM has proposed to perform a water balance calculation for the pit over some period of time during the drought between 1985 to 1991. Precipitation that fell directly into the excavated area during that time will be estimated on the basis of on-site precipitation data. Evaporation from the surface of the water body will be estimated on the basis of on-site and areal climatic data. The difference between these two quantities should provide an approximate measure of groundwater flow, if any, into or out of the pit.

As a second means of addressing this uncertainty, BOM employees have installed a continuous monitoring device to measure water elevation at well Dawn-UN, located approximately 60 m east of the east rim of pit 4. If fluctuations in water level can be correlated between this sampling location and pit 4, the hypothesis that pit 4 is hydraulically connected to the adjacent groundwater system will be supported.

A third hydraulic test would be to pump a significant portion of the water out of the pit during a low period of precipitation, such as July through August. Evaporation would lower the level of water in the pit only if it exceeded rate of inflow. If the pit responded to a significant drawdown by maintaining the prewithdrawal water level during the pump test or starting to refill after pumping, it would indicate that pit 4 is in hydraulic equilibrium with the ground water surrounding it. The rate of response would also provide a useful, although approximate, measure of the average hydraulic conductivity in the bedrock surrounding pit 4.

Groundwater Influences on the Future Water Quality of Pit 3

Problem

The water quality in pit 3 violates the National Pollution Discharge Elimination System (NPDES) standard for uranium (2 ppm daily average, or 4 ppm daily maximum), in part because of the poor quality of water pumped from the PCP that it (pit 3) has been receiving since 1983. The water level in pit 3 rose approximately 44 m until 1992, when Dawn Mining Co. started to pump and treat the water. The treated water is discharged from the site. Treatment is expected to continue until all the water has been removed and treated. The issue remains as to whether pit 3 will refill with good or poor quality water, assuming it no longer receives pumpage from the PCP.

Existing Data and Alternative Interpretations

There is general agreement that the water now in pit 3 is derived from three sources: precipitation, groundwater inflow, and pumpage from the contaminated PCP (see table 1 for PCP water quality). Some have assumed that when pit 3 refills, the water will be no worse than in 1982 because the water quality in pit 3 deteriorated after pumping from the PCP was initiated (1983). However, the water in pit 3 prior to pumping was marginally contaminated. Uranium levels in 1982 (before pumping) were approximately 6 ppm (Shepherd Miller, Inc., 1991), which exceeds the NPDES standard for dissolved uranium. There is no reason to expect that uranium concentrations in pit 3 will be lower than 6 ppm in the future, and they may be higher because of recharge flowpaths to the pit which flow through reactive material.

The groundwater recharging pit 3 is a mixture of water from several sources. To the west of pit 3 is a sequence of calc-silicate hornfels (represented by well 3M) and a lobe of the quartz monzonite intrusive (represented by well 3D). Large piles of waste rock and reactive protore overlie the lithologic sequence. The north headwall of pit 3 is composed of a phyllite-schist mineralized zone overlain by nonreactive waste rock and alluvium. The east headwall of pit 3 is composed of folded and fractured calc-silicate hornfels that is predominantly unmineralized.

Water elevations in each of the hydrologic units surrounding pit 3 are higher than the maximum water elevation ever recorded at pit 3 (813 m). This elevation difference provides the necessary gradient for these waters to recharge pit 3. In both completions of well 3 (west of pit 3), water elevations are approximately 5 m higher than pit 3 (although well 3 is too far west to have a linear flowpath to pit 3; see figure 4*B*). The elevation in well 5M (east of pit 3), is roughly 38 m higher than pit 3. The elevations of water in the deep (D) and middle (M) completions at well 3 are shown in table 3. A slight upward gradient has been consistent at this location over 3 years of measurement. (Most other locations at the mine exhibit a downward gradient into the intrusive [see figure 3].) This upward gradient at well 3 indicates that the calc-silicate may act to confine the intrusive at this location. Overall, the water elevations in both formations at well 3 have remained relatively constant over the 3-year period of record but show minor seasonal fluctuations.

Table 3.—Water elevations in the vicinity of pit 3, November 1992.

Sample ID	Location	Water elevation, m
Well 3M ...	W of pit 3	817.5
Well 3D....	W of pit 3	817.9
Well 5M ...	E of pit 3	851
Pit 3	Surface	813

Poor-quality water exists in several of the flow paths that surround pit 3. Well 3M water from a calc-silicate hornfels is representative of acidic water that has been partially neutralized from contact with carbonate rocks. Even though the pH is no longer extremely low, concentrations of dissolved constituents, such as sulfate and uranium, remain high. Small, contaminated seeps that discharge along the western edge of the ramp at the south end pit 3 may be fed by the formation that hosts well 3M. Chemical precipitation occurs where these seeps enter pit 3 and also along the edge of the ramp. Although 3M does not have an apparent linear flowpath to pit 3 on the basis of the inferred groundwater contours (figure 4), the water quality in well 3M is likely to be representative of these seeps because of well 3M's proximity to pit 3, depending upon the extent of the reactive calc-silicate hornfels unit.

The north headwall of pit 3 is predominately mineralized phyllite schist. Large areas around seeps part way down the headwall are covered with secondary mineral precipitates, which indicates pyrite oxidation and resulting acid production (Robertson, 1992). These mineralized seeps probably did not have time to develop during active mining, because the face was being advanced regularly. Faults can provide zones of increased hydraulic conductivity (Levens, 1990), and north-trending faults in the headwall are probably preferential flow paths that facilitate the migration of poor-quality water from ore-bearing phyllite schist into pit 3. No samples of the mineralized seeps were taken because of the physical danger involved in reaching the seeps. Nonetheless, these seeps represent another source of mineralized recharge to pit 3.

Water samples and flow measurements have been taken regularly from the pit 3 seep, also in the north headwall of pit 3. It issues along the interface between a channel buried by overburden and the bedrock. The overburden material is not believed to be highly reactive, but the bedrock is mineralized calc-silicate. This seep is higher on the face than the mineralized seeps mentioned above. The water quality of pit 3 seep is marginal. Although most parameters are within an acceptable range (table 1), the average total dissolved uranium is exactly the NPDES daily average limit (2 ppm). Over the 25 months that this seep was sampled, the total dissolved uranium concentrations exceeded the daily average limit 12 times and the daily maximum limit (4 ppm) 3 times. Discharge from pit 3 seep represents 1.8% of the total quantity of water filling pit 3 and 2.9% of the estimated non-pumped amount. Geochemical verification of possible sources of groundwater flow contributing to pit 3 seep are discussed in Marcy, 1993.

Good-quality water with the potential to recharge pit 3 exists only in the calc-silicate east of the pit (represented by well 5M). Several groundwater seeps issue from the fractured calc-silicate on the eastern wall of pit 3, but there is no precipitation of secondary minerals. The lack of visible precipitates suggests that these seeps are of relatively good water quality, but they have not been sampled because of dangerous access. Water quality at well 5M is probably representative of these good-quality seeps. No seeps issue from the large blocks of the unfractured calc-silicate. Well 5 and the pit 3 seep represent water quality in nonmineralized material.

When pit 3 begins to refill, water quality will reflect a mixture from good- and poor-quality sources and hydraulic conductivities of the tributary systems. Poor-quality water is found in groundwater flow systems west (wells 3S and 3M) and north (pit 3 seep) of the pit, whereas good-quality water is found east (well 5M) of the pit. Groundwater recharge to pit 3 is probably fault- and fracture-controlled. Water that refills pit 3 will almost inevitably be worse now than water accumulated in the pit during mining because adjacent protore stockpiles and mineralized zones in the headwall have been oxidized and are producing acid. However, it is not possible to predict how much worse the water quality will be because of the variability of hydraulic conductivity and water quality among the recharge flow paths that surround pit 3.

Data Collection for Resolution

A procedure should be devised to sample some of the other mineralized seeps issuing from the phyllite schist on the north headwall of pit 3 safely. As pit 3 is dewatered, newly exposed springs along the perimeter walls should be recorded and monitored, by boat, if necessary. The head response of wells in the vicinity of pit 3 should also be monitored as the pit is dewatered.

Summary

- The inactive Midnite uranium mine produces acid because sulfide minerals have been exposed to oxidation.

- The BOM has been conducting research on metal ion migration at the site since 1989. This work is now focused on hydrologic issues critical to reclamation.

- Head data from wells in the vicinity of pit 4 indicate that if pit 4 were dewatered, it would refill with ground water and would continue to discharge water to the groundwater flow system.

- Water quality data from pit 3 in the year before water from the PCP was pumped into it indicated that pit 3 will likely refill with water having uranium concentrations higher than the NPDES limit.

- Water quality data from wells in the calc-silicate in the vicinity of pit 3 indicate that groundwater recharge to pit 3 is a mixture of good and poor quality water. However, the quality of new recharge water to pit 3 will almost inevitably be worse now than it was during mining because protore piles and mineralized zones in the headwall have been exposed to weathering and acid production.

Recommendations

- Pit 4 should not be dewatered and backfilled with reactive material unless data are presented to demonstrate that it will not be refilled by groundwater recharge.

- Pit 3 should be expected to refill with water that does not meet NPDES discharge standards for uranium and possibly other constituents.

- Further data collection and interpretation of existing data should proceed to address the remaining uncertainties at the site.

References

Fleshman, B. R. and S. P. Dodd. 1982. National uranium resource evaluation. Ritzville Quadrangle, Washington, Bendix Field Engineering Corp., Grand Junction, CO, 62 pp.

Levens, R. L. 1990. Analysis of the hydrogeologic role of geologic structures with application to acid mine drainage abatement. M.S. thesis, Univ. of Idaho, Moscow, ID.

Ludwig, K. R., J. T. Nash and C. W. Naeser. 1981. U-Pb isotope systematics and age of uranium mineralization, Midnite Mine, Washington. Econ. Geol. v. 76, No. 1, pp. 89-110.
http://dx.doi.org/10.2113/gsecongeo.76.1.89

Marcy, A. D. 1993. Hydrochemistry of an inactive uranium mine. Proc., Annu. Mtg. of Am. Assoc. Surface Min. and Reclamation (Spokane, WA, May 16-19, 1993).
http://dx.doi.org/10.21000/JASMR93020467

Nash, J. T. 1977. Geology of the Midnite Uranium Mine, Stevens County, Washington -- A Preliminary Report. U.S. Geol. Surv. OFR 77-592, 38 pp.

Nash, J. T. and N. J. Lehrman. 1975. Geology of the Midnite Uranium Mine, Stevens County, Washington -- A Preliminary Report. U.S. Geol. Surv. OFR 75-402, 36 pp.

Robertson, A. M. 1992. Acid mine drainage - where are we now? Pres. at 98th Annu. Mtg. NW Min. Assoc. (Spokane, WA, Dec. 2-4, 1992).

Shepherd Miller, Inc. 1991. Midnite Mine Reclamation Plan prepared for Dawn Mining Company, Ford, Washington. 70 pp.

Sumioka, S. S. 1991. Quality of water in an inactive uranium mine and its effects on the quality of water in Blue Creek, Stevens County, Washington, 1984-85. U.S. Geol. Surv. Water-Resources Investigations Rep. 89-4110, 62 pp.