V7-22

Technical Memorandum

Golder Associates Ltd.
2390 Argentia Road
Mississauga, ON, Canada L5N 5Z7

Golder Associates
Telephone: 905-567-4444
Fax Access: 905-567-6561

TO:	Robin Johnstone De Beers Canada Mining Inc.	**DATE:**	April 16, 2003
FROM:	Ken DeVos and Don Chorley	**JOB NO:**	03-1322-017/5600
cc:	**Dawn Kelly, Rick Schryer, Lee Atkinson**		
RE:	**Snap Lake Diamond Project Mine Water Assessment - Diffusion**		

A telephone conference call with De Beers Canada Mining Inc. (DCMI) Don Chorley from Golder Associates, Lee Atkinson of HCI Consulting and Dr. Alexandre Desbarats and John Ramsey of Natural Resources Canada (NRCan) was held on 8 April 2003. In this call NRCan stated that their official position with respect to their outstanding concern about upward diffusion from the mine into Snap Lake. Molecular diffusion is the very slow process by which chemical mass can move from zones of higher concentrations to zones of lower concentrations. This upward diffusion is offset by downward flow of water. In the case of Snap Lake, NRCan are concerned that the downward flow at closure would not be sufficient to offset the upward diffusion of mass. This could be considered resolved if the satisfactory responses could be made to the following comments provided by Dr. Desbarats:

1. Prepare for each borehole of the 2001 Advanced Exploration Program (AEP), a table showing: test interval, test interval elevation datum (Z), pressure as measured (P in m H20), total head (H = gauge datum + P), and, apparent downward gradient J = (LL - H)/(LL - Z) where LL is lake level.

2. It has to be recognized that the downward gradients identified in 1) are the result of the natural, or background, gradient and an "artificial" gradient induced by mine dewatering during the AEP. Therefore, DCMI should provide a brief analysis of the results from 1) that gives an estimate of the actual background gradient which is of interest in post-closure scenarios.

3. Since these head gradients in the rock mass are quite low, would the gradients in the flooded drifts not be even lower given the lower resistance to flow? If so, upward diffusion from backfilled panels via flooded drifts could be an issue. I realize that estimating post-closure flow in flooded drifts is very difficult but I think that some sort of brief analysis is required to completely wrap up the upward diffusion issue.

Issues 1 and 2 are addressed primarily in the attached technical memorandum from HCI Consultants Inc. Additional discussion on the issue of regional hydraulic gradient and potential implications with respect to upward diffusion are provided below. As this document will be posted on the public record, this memorandum also provides a discussion of general hydrogeologic concepts that is not required by NRCAN.

Discussion of Mine Implications on Gradients at Post Closure and Regional Gradients

Groundwater flows from higher to lower hydraulic heads. The hydraulic gradient, which is the change in hydraulic head over a given distance, at any one location in this flow path, is a function of the overall hydraulic head difference and inversely related to the relative transmissivity of the material at that location. For example, should the transmissivity of the material be 2 times greater than a material located down gradient then the hydraulic gradient in the more transmissive layer will be half as much as that of the less transmissive layer.

At closure, the transmissivity of the flooded open workings of the mine will be very high, resulting in very low hydraulic gradients being established in these openings. However, because of this, higher downward hydraulic gradients will likely be established in the overlying less transmissive hanging wall rocks.

Based on the difference in lake water levels between Snap Lake and the Northeast lake (444.1m – 439.1m) and distance between Snap Lake and Northeast Lake (approximately 3000 m) yielding an average regional horizontal gradient of about 0.001.

Brief Analyses of Potential for Upward Diffusion

Diffusion from the backfill into the open mine workings will likely occur. However, it is expected that this diffusion would not extend much above the flooded mine workings because of the expected relatively high downward hydraulic gradients in the overlying hanging wall rocks. These downward gradients will create a dominant downward advection.

To investigate the potential implications of diffusion, a coupled flow and mass transport model (MODFLOW together with MT3D99) was developed assuming a 1 dimensional flow path between the mine and the lake, and assuming a regional gradient of 0.0001 (one tenth the gradient based on lake water levels and distance between Snap Lake and Northeast Lake).

Figure 1 provides a summary of the input parameters and results from the preliminary model runs. As can be observed in Figure 1, the high concentrations at the interface of the mine and overlying bedrock do not migrate a significant distance from the mine workings. The steady state solute concentration drops to approximately 5 mg/l (1% of the source concentration) within 5 m of the mine. At distances of 60 m and 120 m (the top of bedrock) from the mine the concentrations are essentially zero.

If we were to look at diffusive flux from the mine to the lake from a simplistic, worst case, perspective where we do not apply any advective movement of groundwater and use Ficks first law to calculate the amount of mass that would report to the lake we have:

$M_f = -D\theta\ dC/dx$

Where:

M_f = mass flux per unit area of rock ($kg/m^2/s$)
D = diffusion coefficient (assume $1 \times 10^{-9}\ m^2/s$)
θ = porosity (assume free diffusion through the open space in the rock 0.001)
dC = change in concentration between the mine and the lake (assume 500 mg/L [chloride] – 0 mg/L [chloride] = 500 mg/L [chloride] = 0.5 kg/m^3 [chloride])
dx = distance between the mine and lake (120 m)

Assuming an area of 2.5 km^2 that is underlain by the mine, the mass flux to the base of the sediments would be 0.0009 kg/d [chloride]. This is more than 4 orders of magnitude lower than the mass flux from the site runoff to Snap Lake.

The calculations were completed using rough approximations of effective parameters and using the concentrations associated with chloride as an example. Even with the very high difference in concentration between the mine and Snap Lake that was used in this analysis, the mass flux from diffusion is 10,000 times lower (0.01 %) than the mass flux expected from site runoff alone. For other parameters the mass flux will be much less, for example using a chromium concentration as assessed in the EA (313 ug/l) in the mine and zero in the lake yields a mass flux from Cr of 100,000 times lower (0.001 %) than for site runoff alone.

CLOSURE

Based on the calculations that have been undertaken, we are confident that upward diffusion from the mine workings will not be sufficient to affect surface water quality in Snap Lake. Further evidence that diffusion is not a significant source of mass to the waters of Snap Lake is evident in the surface water quality results from Snap Lake that show chloride concentrations near or below the detection limit of 1 mg/L.

We trust that the supplied information will be sufficient for NRCan to resolve their outstanding issue regarding upward diffusion. If there are any points in this submission that require further clarification please direct your questions to Robin Johnstone, Senior Environmental Manager, DBCMI.

Attachments:

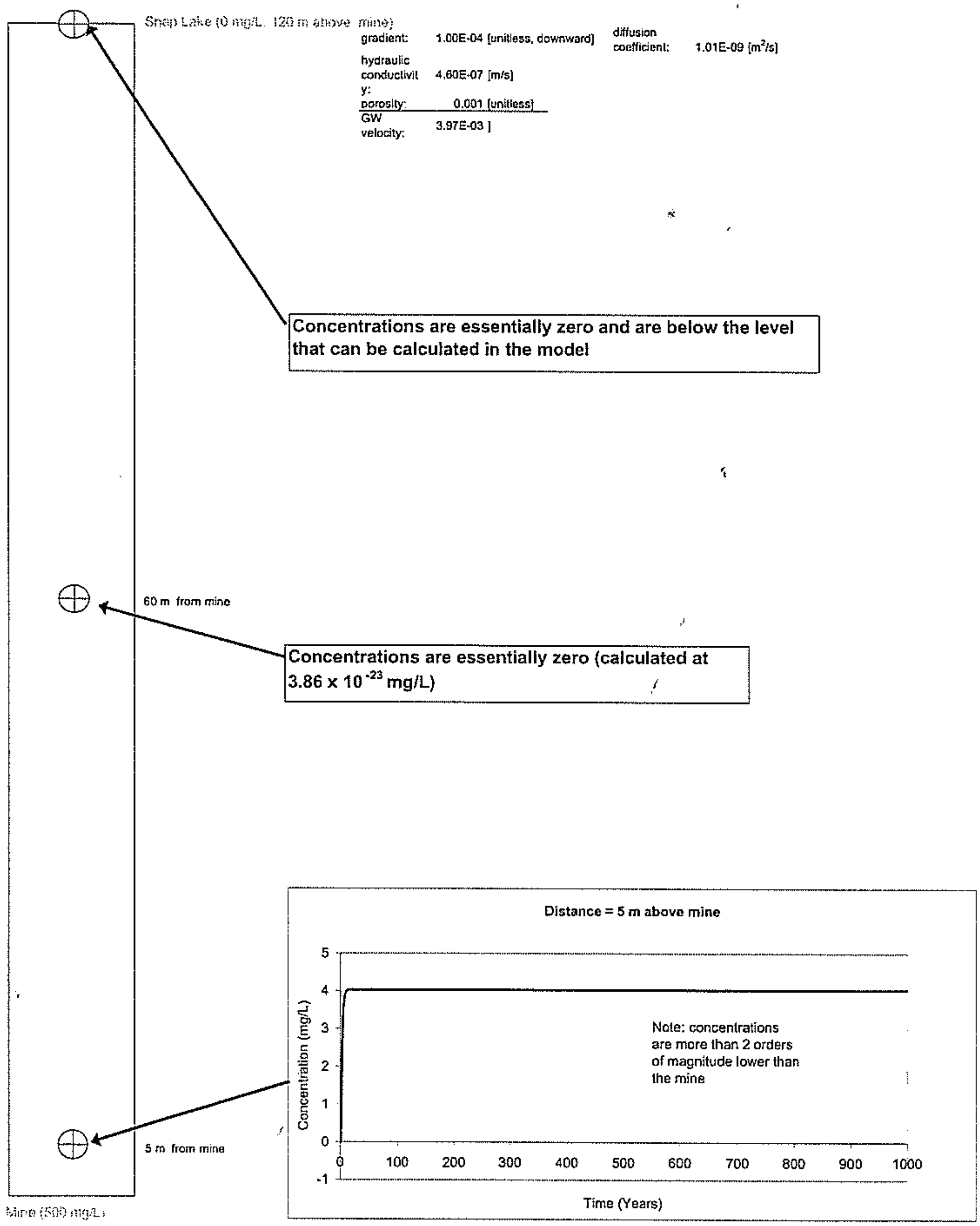
Figure 1 - Concentration Profiles in Bedrock Accounting for Diffusion and Regional Gradient of 0.001

Attachment 1 – Technical Memorandum from HCI entitled **"Vertical Hydraulic Gradients in Vicinity of Proposed Snap Lake Mine" Dated April 10, 2003**

Concentration Profiles in Bedrock
Accounting for Diffusion and Regional Gradient of 0.0001

Figure 1

Concentration Profile Beneath Snap Lake - Completed using MODFLOW together with MT3D



Note: Not to Scale

Date: April, 2003

Project: 03-1322-017

Drawn DH

Chkd KJD

Golder Associates

HCI HYDROLOGIC COLORADO CONSULTANTS, INC.
HCITASCA an company

Hydrologic Consultants, Inc. of Colorado
143 Union Blvd., Ste. 525
Lakewood, Colorado 80228 USA
telephone: 303-969-8033 fax: 303-969-8357
e-mail: hcico@hcico.com http://www.hcitasca.com

TECHNICAL MEMORANDUM

TO: Don Chorley - Golder Associates **HCI-1780**

FROM: Elfadil Azrag
Lee C. Atkinson

SUBJECT: Vertical Hydraulic Gradients in Vicinity of Proposed Snap Lake Mine

DATE: 10 April 2003

In follow-up to the telephone conference call with Dr. Alexandre Desbarats and John Ramsey of Natural Resources Canada (NRCan) on 8 April 2003, NRCan stated that their official position with respect to their outstanding concern about upward diffusion could be considered resolved if satisfactory responses could be made to the following issues:

1) Prepare, for each borehole of the 2001 AEP, a table showing

   a) test interval mid point elevation,
   b) pressure as measured in units of meters of a water column,
   c) total hydraulic head for each test interval, and
   d) apparent downward gradient with reference of the lake level.

2) It has to be recognized that the downward gradients identified in and estimated in the above item are the result of the natural, or background, gradient and an "artificial" gradient induced by mine dewatering during the AEP. Consequently, a brief discussion of the hydraulic gradient results should be included to estimate the actual background gradient which is of interest in post-closure scenarios.

3. Since the hydraulic gradients in the rock mass are quite low, would the gradients in the flooded drifts not be even lower given the lower resistance to flow?

The following Technical Memorandum summarizes data on shut-in hydraulic heads at various elevations in the eight hydrogeologic testholes that were completed during the 2001 Advanced Exploration Program (AEP) at the Snap Lake diamond project and addresses each of these issues.

HYDRAULIC DATA FROM TESTHOLES

The location and horizontal projections of the eight testholes that were drilled from the underground development during the AEP -- UG-45, UG-83, UG-84, UG-106, UG-173, UG-174, UG-175, and UG-176 -- are shown on Figure 1. All of the testholes were drilled within a few degrees of the horizontal with the exception of UG-176 which was drilled upward at 70 degrees from the horizontal. The midpoints of the various test intervals in each testhole are shown on the traces of the testholes. Also indicated in Figure 1 are the dates at which the various drifts were advanced and the testholes were completed.

Figure 2 is a schematic diagram of the methodology used to measure shut-in hydraulic heads at various points within the testholes and the definition of terms used in computing the relationship between elevation and hydraulic head. The elevation of the midpoint of any test interval is calculated from:

$$z_{mdpt} = z_c + L_l \sin\phi \quad (1)$$

where

z_{mdpt} = elevation of midpoint of test interval [mamsl],
z_c = surveyed elevation of drill collar [mamsl],
L_l = length of drillhole from collar to midpoint of test interval [m], and
ϕ = inclination of testhole (convention: +'ve if upward, -'ve if downward).

The hydraulic head at the midpoint of any test interval along a testhole is defined by:

$$h_{mdpt} = z_{gage} + P_{gage} \quad (2)$$

where

h_{mdpt} = hydraulic head at midpoint of test interval [mamsl],
z_{gage} = elevation of gage [mamsl], and
P_{gage} = gage pressure [m].

Equations 1 and 2 were used to generate the elevation (of the midpoint of the test interval) vs. hydraulic head data summarized in Table 1. This format follows the recommendations of Dr. Desbarats in Point 1 of his e-mail of 9 April 2003. The resulting data are plotted in Figure 3. The apparent gradient was computed based on Dr. Desbarats's formula.

CONCLUSIONS

Based on Figure 3, the following conclusions can be drawn:

1) All of the measured hydraulic heads are below the surface level of Snap Lake (444.1 mamsl)

2) The depressuring effects of passive inflow to the mine via either fractures, drainholes (e.g., DDH-8 which was used for water supply for the drill rigs), or bolt holes (shown on Figure 1) are clearly evident in the reduced hydraulic heads of testholes UG-173, UG-174, and UG-176. The measured heads in testhole UG-45, which was drilled downward, actually showed a local (and expected) upward gradient due to passive inflow to the mine. Such depressurizing was anticipated and recognized by Dr. Desbarats in Point 2 of his e-mail of 9 April 2003.

3) Hydraulic head data from testholes UG-83 and UG-84, which are the furthest from the mine, provide the best estimate of the "actual background gradient which is of interest in post-closure scenarios" (Point 2 of Dr. Desbarats' e-mail). The average vertical hydraulic gradient in these two testholes was in the range of 0.01 to 0.02 downward.

At mine closure, the "transmissivity" of the flooded open mine workings will be very high, resulting in very low lateral hydraulic gradients in this part of the regional ground-water flow system. This will actually result in a local increase, albeit quite small, in the downward vertical gradient. Dissolved constituents from the backfilled mine panels would likely move into the underlying open mine workings by both advective flow and diffusion. The downward advective flow, driven by the downward hydraulic gradient, would preclude upward movement by diffusion.

CLOSURE

We trust that the supplied information will be sufficient for NRCan to resolve their outstanding issue regarding upward diffusion. If there are any points in this submission that require further clarification please direct your questions to Robin Johnstone, Senior Environmental Manager, DBCMI.

We appreciate the input and suggestions by Dr. Alexandre Desbarats of NRCan which has lead us to more clearly define and illustrate the hydraulic heads and vertical hydraulic gradients in the vicinity of the Snap Lake diamond project prior to, during, and post mining.

Attachments: Figure 1 - Locations of Hydrogeologic Testholes Completed During 2001 AEP
Figure 2 - Method of Measuring Hydraulic Head
Figure 3 - Field-Measured Hydraulic Head vs. Elevation
Table 1 - Summary of Hydraulic Head vs. Elevation Data

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Table 1. Summary of Hydraulic Head vs. Elevation Data

Testhole	Distance of Test Interval from Collar (m)			Elevation of Midpoint (mamsl)	Shut-In Pressure (m)	Hydraulic Head (mamsl)	Apparent Downward Hydraulic Gradient
	Start	End	Midpoint				
UG-45	5.79	39.01	22.4	327.97	109.8	438.93	-
	39	58	48.5	326.79	113.3	442.43	-0.01
	58	83	70.5	325.79	113.4	442.53	-0.01
	83	109	96.0	324.64	113.7	442.83	-0.01
	109	132	120.5	323.52	113.5	442.63	-0.01
	132	158	145.0	322.41	113.5	442.63	-0.01
	152	167	159.5	321.75	113.9	443.03	-0.01
	167	191	179.0	320.87	113.8	442.93	-0.01
	173	198	185.5	320.58	114.0	443.13	-0.01
	198	208	203.0	319.78	114.1	443.23	-0.01
	208	213	210.5	319.44	114.4	443.53	0.00
	208	234	221.0	318.96	114.3	443.43	-0.01
	234	258	246.0	317.83	114.2	443.33	-0.01
	258	283	270.5	316.72	114.3	443.43	-0.01
	277	301	289.0	315.88	114.3	443.43	-0.01
UG-83	22.86	47.24	35.1	330.29	109.0	438.23	0.05
	47.26	71.63	59.4	330.97	111.5	440.73	0.03
	71.32	95.71	83.5	331.64	113.7	442.93	0.01
	91.44	103.63	97.5	332.03	113.8	443.03	0.01
	106.07	109.42	107.7	332.32	114.0	443.23	0.01
	103.63	120.4	112.0	332.44	114.3	443.53	0.01
	120.4	135.64	128.0	332.88	114.0	443.23	0.01
	135.64	148.74	142.2	333.28	114.4	443.63	0.00
	150.27	174.65	162.5	333.85	114.0	443.23	0.01
	174.65	199.64	187.1	334.54	115.1	444.33	0.00
	199.64	219.46	209.6	335.16	114.8	444.03	0.00
	219.46	243.84	231.7	335.78	114.3	443.53	0.01
	243.84	268.22	256.0	336.46	114.7	443.93	0.00
	268.22	294.13	281.2	337.16	113.9	443.13	0.01
	320.04	350.52	335.3	338.67	112.9	442.13	0.02

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Table 1. Summary of Hydraulic Head vs. Elevation Data
(continued)

Testhole	Distance of Test Interval from Collar (m)			Elevation of Midpoint (mamsl)	Shut-In Pressure (m)	Hydraulic Head (mamsl)	Apparent Downward Hydraulic Gradient
	Start	End	Midpoint				
UG-84	28.65	53.03	40.8	332.59	112.6	441.71	0.02
	53.34	71.62	62.5	334.32	112.6	441.71	0.02
	77.42	101.8	89.6	336.50	112.6	441.71	0.02
	101.8	123.14	112.5	338.33	112.6	441.71	0.02
	123.14	147.52	135.3	340.16	113.3	442.41	0.02
	147.52	173.43	160.5	342.18	114.4	443.47	0.01
	173.43	185.62	179.5	343.71	113.0	442.06	0.02
	185.62	211.53	198.6	345.24	114.5	443.54	0.01
	211.53	235.92	223.7	347.25	114.5	443.54	0.01
	235.92	254.2	245.1	348.96	114.5	443.61	0.01
	254.2	280.11	267.2	350.74	112.5	441.57	0.03
	280.11	304.5	292.3	352.75	114.1	443.19	0.01
	304.5	328.88	316.7	354.71	114.3	443.33	0.01
	327.36	351.74	339.6	356.54	114.0	443.05	0.01
	351.74	375.51	363.6	358.47	114.5	443.54	0.01
	375.51	395.94	385.7	360.24	114.5	443.54	0.01
UG-106	164	172	168.0	291.75	125.7	430.24	0.09
	184	209	196.5	289.62	125.9	430.45	0.09
	275.83	300.21	288.0	282.75	128.6	433.13	0.07
UG-173	3.05	36.88	20.0	282.56	139.4	420.51	0.15
	36.88	55.17	46.0	284.20	139.7	420.80	0.15
	55	80	67.5	285.55	139.7	420.80	0.15
	80	100	90.0	286.96	139.7	420.80	0.15
UG-174	0	24.4	12.2	282.00	139.7	420.24	0.15
	24.4	48.8	36.6	284.29	139.7	420.80	0.15
	48.8	73.2	61.0	286.59	139.7	420.80	0.15
	73.2	97.5	85.4	288.88	139.7	420.80	0.15

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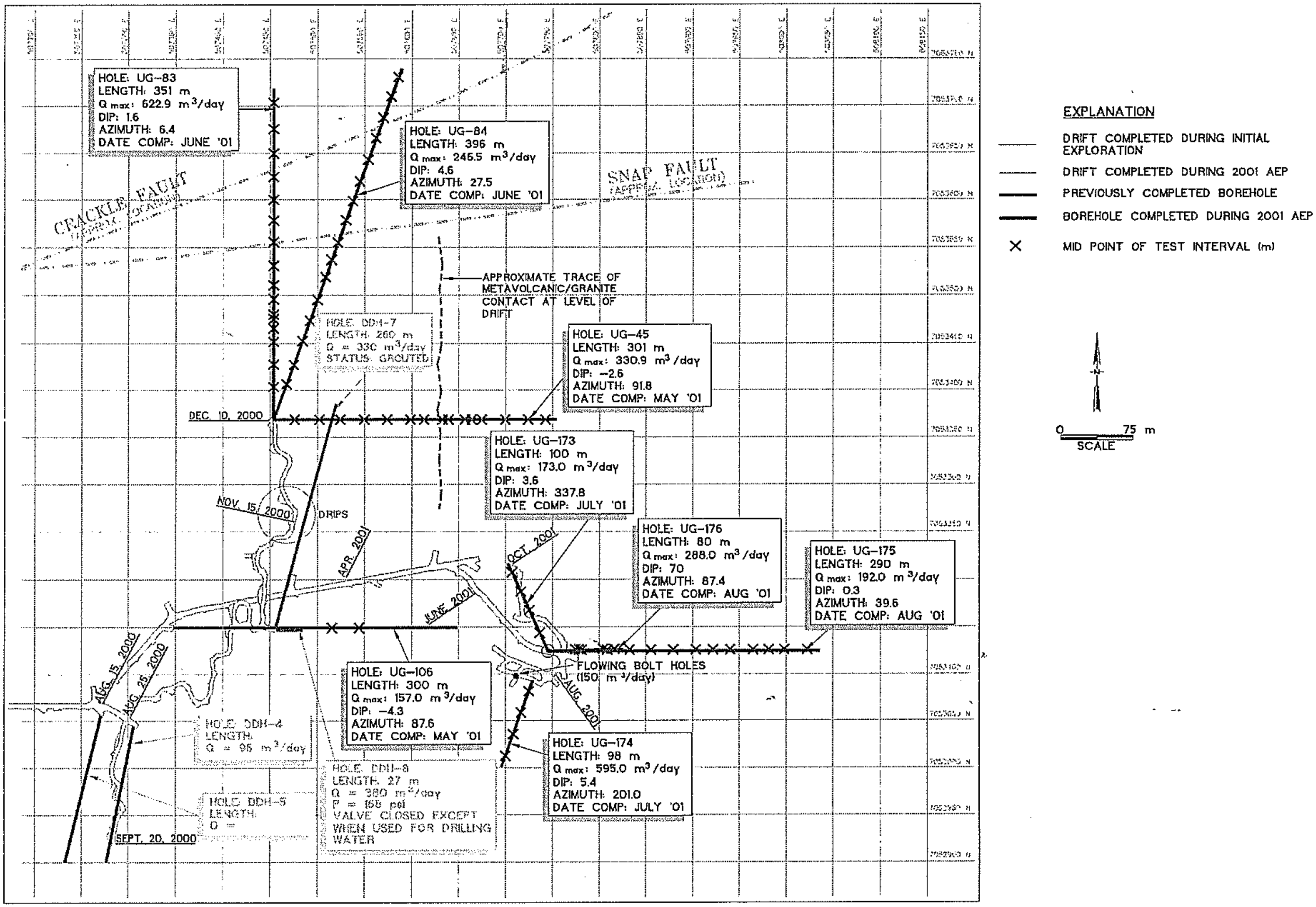
Table 1. Summary of Hydraulic Head vs. Elevation Data
(continued)

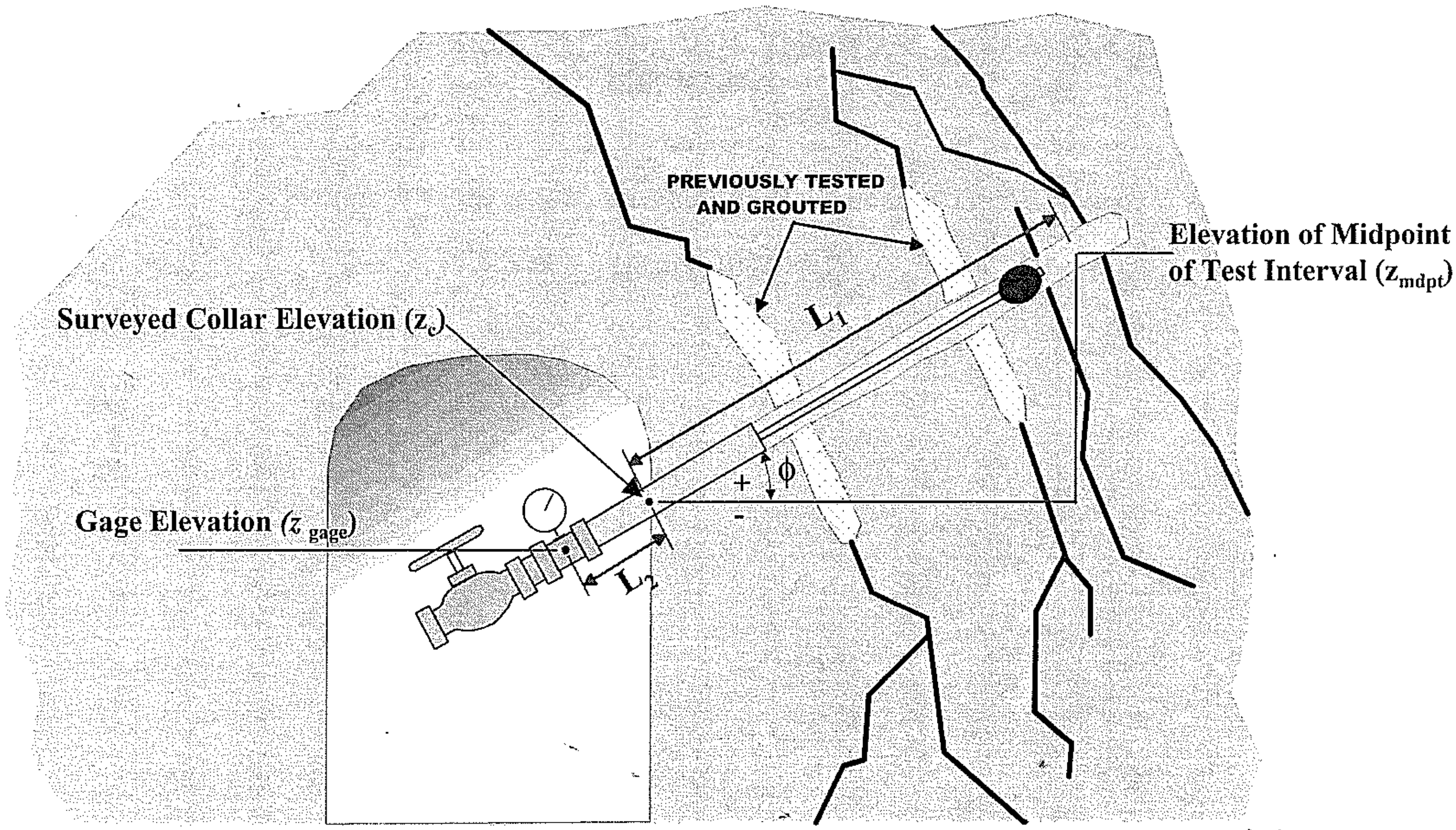
Testhole	Distance of Test Interval from Collar (m)			Elevation of Midpoint (mamsl)	Shut-In Pressure (m)	Hydraulic Head (mamsl)	Apparent Downward Hydraulic Gradient
	Start	End	Midpoint				
UG-175	52.1	75.9	64.0	281.66	161.9	443.22	0.01
	76.5	99.4	88.0	281.78	161.9	443.22	0.01
	99.4	122.2	110.8	281.90	161.9	443.22	0.01
	122.2	146.6	134.4	282.02	161.9	443.22	0.01
	146.6	171	158.8	282.15	161.9	443.22	0.01
	171	183.2	177.1	282.25	161.9	443.22	0.01
	183.2	207.6	195.4	282.34	158.4	439.70	0.03
	207.6	232	219.8	282.47	161.9	443.22	0.01
	232	241.1	236.6	282.56	161.9	443.22	0.01
	241.1	265.5	253.3	282.65	160.7	442.03	0.01
	265.5	289.9	277.7	282.77	160.9	442.24	0.01
UG-176	21.33	45.72	33.5	316.64	159.5	441.82	0.02
	3.05	56.31	29.7	313.03	159.6	441.92	0.02
	56.39	62.48	59.4	340.99	160.4	442.72	0.01
	60.96	82.29	71.6	352.45	161.7	444.02	0.00

Note: 1) Water surface elevation of Snap Lake is 444.1 mamsl.



Locations of Hydrologic Testholes Completed During 2001 AEP

Figure 1



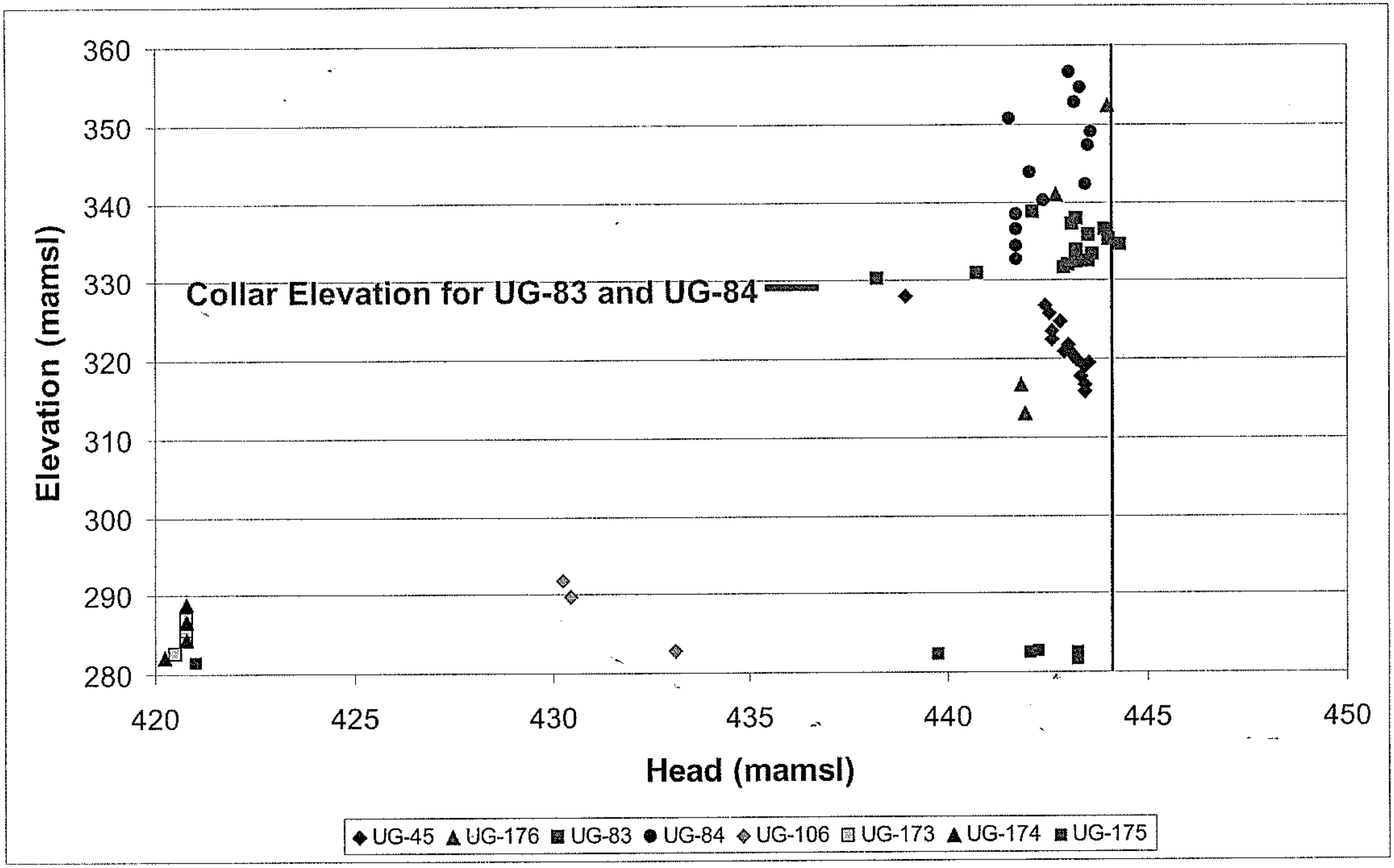
$$z_{mdpt} = z_c + L_1 \sin\phi$$

$$\text{hydraulic head } (h) = z_{gage} + P_{gage} \quad \textit{where: } z_{gage} = z_c - L_2 \sin\phi$$

(all elevations, lengths, and pressures to be expressed in metres)

Procedures for Measuring Hydraulic Heads at Snap Lake Project

Figure 2



Field-Measured Hydraulic Head vs. Elevation

Figure 3