APPENDIX M-3: Evaluation of Open Access Ramps and Ventilation Raises in Closure

Hydrometrics, Inc.
consulting scientists and engineers

TECHNICAL MEMORANDUM

DATE: March 8, 2017

TO: Jerry Zieg, Tintina Resources

FROM: Greg Bryce, Hydrometrics Inc.

SUBJECT: Evaluation of Open Access Ramps and Ventilation Raises in Closure

Hydrometrics, Inc. developed an analytical analyses to estimate the effects of open mine workings on the groundwater system during post-closure for the Black Butte Copper Project. This analysis is supplemental to the detailed numerical flow model (Hydrometrics, Revised 2016). The numerical model evaluated the impacts to water resources during all phases of the mining project. The Montana Department of Environmental Quality (DEQ) provided feedback (DEQ, 2017) from their review of the Mine Operating Permit Application (Revision 1) for the BBC Project (Tintina Resources, 2016); the feedback included comments on the groundwater modeling analysis. The DEQ requested in their review that the effects of open mine workings (e.g., access tunnels and ventilation raises) be evaluated during post-closure. The numerical modeling analysis did not include the open mine workings as it is not currently feasible to implement these complex three-dimensional features in the numerical flow model.

Hydrometrics developed multiple analytical models to demonstrate the potential mounding at the water table in the downgradient portion of access tunnels as well as change in seepage between hydro-stratigraphic units (HSU) in ventilation raises during post-closure. The post-closure analyses were conducted based on a fully recovered groundwater table in the three shallowest HSUs, which include the shallow Newland shales above the mineralized zone (YNL-A), the mineralized upper Newland (USZ/UCZ), and upper Newland below the mineralized zone (YNL-B). Based on results from the numerical groundwater flow model, this will occur approximately 20 years in the YNL-A and USZ/UCZ, but over 100 years in the YNL-B. Two analytical models were developed to evaluate post closure impacts of access ramps in different HSUs (USZ/UCZ and YNL-B). Another analytical model was developed to evaluate the effects of ventilation raises during post-closure. Below is a summary of the methodology and results of the analytical modeling analysis.

MODEL DESIGN

The analytical models for the access tunnels were designed to evaluate the effects where access ramps extend across an area with the greatest change in potentiometric head. As shown in Figure 1, the change in potentiometric head is greatest in the Lower Copper Zone (LCZ) decline (located in the YNL-B) and the main access tunnel (SW Access) to the southern portion of the Upper Copper Zone (UCZ). A third analytical analysis was conducted on the EVL ventilation raise and its interaction between the YNL-A, USZ/UCZ, and YNL-B. The location of the access ramps and EVL ventilation raise is shown on Figure 1.

Decline/Access Tunnel Analyses

The change in the current potentiometric head between the upgradient and downgradient ends of the Lower Decline and the SW Access is approximately 200 feet and 140 feet, respectively (Figure 1). The potentiometric head in the open mine workings will equilibrate to the average head across the workings; therefore, the head in the mine opening will drawdown by 100 feet in the lower decline and 70 feet in the SW Access in the upgradient portion of the tunnels and mound by an equal amount in the downgradient portion. However, this change in head only exists in the open tunnel themselves. The change in head in the bedrock immediately adjacent to the tunnel is dependent on the flow in or out of the access tunnel, which is highly dependent on the permeability of the HSU in which the mine workings are developed. The analysis looks at the mounding and associated flow to bedrock on the downgradient portion of the open workings. In the downgradient portion of the access tunnel, the mound at the top of the water table is dependent on how the flow from the tunnel dissipates through the different hydro-stratigraphic units.

The decline and access tunnel analytical models calculate the groundwater flux and associated mounding in the bedrock system directly adjacent to the access ramp and as the mound propagates to the overlying hydro-stratigraphic units. The groundwater flux is estimated based on Darcy's Law (Q=KAi), and the associated mound is evaluated based on the Hantush solution for growth and decay of groundwater mounds (Hantush, 1967) in the AQTESOLV 4.5 software package. The assumptions applied to the access ramp models are as follows:

- Water level elevation within the access ramp will equilibrate to the average head across the ramp;
- Each hydro-stratigraphic unit can be simulated as a homogeneous bulk permeability system;
- Vertical anisotropy (K_H/K_v) is equal to five (5);
- Gradient from ramp to bedrock is equal to one (1); and
- Access Ramp are 17 feet wide by 17 feet tall.

The general model layouts for the two access ramp analyses (Lower Decline and SW Access Tunnel) are shown in Figure 2. The analytical modeling steps for the SW Access Tunnel and the Lower Decline are as follows:

1. Estimate mound in decline or access ramp (1/2 change in head across mine working).

2. Use Darcy's Law to estimate flow from decline or access ramp to adjacent bedrock aquifer.

3. Estimate mound, using Hantush mounding solution in AQTESOLV, in bedrock adjacent to decline or access ramp based on flux calculated in Step 2. (Skip to step 6 for USZ/UCZ access ramp analysis.)

4. Estimate vertical flux (via Darcy's Law) from YNL-B to USZ/UCZ based on mounding calculated in Step 3. (LCZ Decline analysis only.)

5. Use Hantush mounding solution to estimate mound in USZ/UCZ based on vertical flux from YNL-B. (LCZ decline analysis only.)

6. Estimate vertical flux from USZ/UCZ to YNL-A using Darcy's Law based on mounding analysis in Step 3 for SW Access Tunnel analysis and Step 5 for LCZ Decline Analysis.

7. Estimate mound at top of water table based on vertical flux from USZ/UCZ (Step 6).

The aquifer characteristics used for each HSU were based on those used in the numerical groundwater model. Table 1 summarizes the aquifer characteristics used in this analytical analysis for each HSU.

TABLE 1. ANALYTICAL MODEL AQUIFER CHARACTERISTICS

Parameter	YNL-A	USZ/UCZ	YNL-B
Hydraulic Conductivity (ft/day)	1.3	0.16	0.03
Vertical Anisotropy (K_H/K_V)	5	5	5
Storativity	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-6}$

Ventilation Raise Analysis

The analytical analysis of open ventilation raises during post-closure was conducted on the EVL ventilation raise to estimate the flux from different HSUs that it encounters. The EVL ventilation raise was selected as it is located near wells MW-9, PW-9, and PW-10, which provide water level and hydraulic conductivities of the different HSUs the ventilation raise will encounter (YNL-A, USZ/UCZ, and YNL-B, respectively). It was assumed that the November 2016 water levels represent the steady-state post-closure water levels. The ventilation raise analysis assumes that the water level in the ventilation raise will equilibrate to the weighted average head of all the HSUs that the ventilation is completed through. The weighted average head was calculated based on the head within each HUS with each head being weighted based on the permeability of the HSU it is associated with. The ventilation analysis was conducted using a large diameter well in AQTESOLV v4.5 to estimate the flow between HSUs to create the change in head within the ventilation raise.

RESULTS

Access Tunnels and Decline Analytical Models

The lower decline is completed in the YNL-B, therefore, flow and mounding were evaluated through a flow path from the tunnel to the YNL-B then vertically to the USZ/UCZ and a final analysis in the YNL-A (Figure 3). The SW Access Tunnel is completed in the USZ/UCZ resulting in a flow path from the tunnel to the USZ/UCZ and then vertically to the YNL-A (Figure 4). The Darcy Law calculations for the SW Access Tunnel and Lower Decline analytical models are summarized in Table 2, and the AQTESOLV analyses are included as Attachment I. The mounding analysis results used in each step of the analytical models were based on near steady state mounding, which was determined to be 10 years into the mound simulation.

TABLE 2. SW ACCESS TUNNEL AND LOWER DECLINE ANALYTICAL MODEL RESULTS

Flow Path	K (ft/day)	Area (ft^2)	Gradient	Flow (gpm)	Mound (ft)
SW Access Tunnel					
SW Access to USZ/UCZ	0.16	289	1	0.23	15
USZ/UCZ to YNL-A	1.3	289	0.75	0.02	0.45
Lower Decline					
Lower Decline to YNL-B	0.03	289	1	0.04	14
YNL-B to USZ/UCZ	0.16	289	0.7	0.006	0.5
USZ/UCZ to YNL-A	1.3	289	0.025	<0.001	<0.01

The estimated flow from the open mine workings to bedrock is approximately 0.04 gpm for the lower decline and 0.23 gpm for the SW Access. The resultant mounding at the top of the water table is less than 0.01 feet from the lower decline and approximately 0.5 feet from the SW Access. The unsaturated zone is approximately 30 feet near the downgradient end of the lower decline and 50 feet at the downgradient end of the SW Access; therefore, the very small mound associated with the SW Access will not result in any seepage to the surface.

Ventilation Raise Post-Closure Analytical Model

A schematic of the ventilation raise analytical analysis is shown in Figure 5. The data used in the ventilation raise analysis and corresponding results are shown in Table 3. The weighted average head in the ventilation raise results in about 6.4 and 2.7 feet of drawdown in the USZ/UCZ and YNL-B, respectively, and a mound of 0.9 feet in the YNL-A. The resulting drawdown or mound and associated aquifer characteristics for each HSU were held as constants in the AQTESOLV analysis, and the flow rate was adjusted to match the drawdown/mound after 100 years. The AQTESOLV analysis used the Moench 1984 solution for fractured bedrock; this solution was used as it provided the best match to the observed drawdown from long-term pumping tests (Hydrometrics, 2015). The results of the AQTESOLV analysis for the ventilation raise for each HSU (YNL-B, USZ/UCZ, and YNL-A, respectively) are included in Attachment II. As shown in Table 3, the flux from the USZ/UCZ to the ventilation raise is 0.27 gpm, which is similar to the flux going from the ventilation raise to the YNL-A (0.27 gpm). The flux from the YNL-B to the ventilation raise is minimal (0.02 gpm).

TABLE 3. POST-CLOSURE VENTILATION RAISE SUMMARY

Parameter	YNL-A	USZ/UCZ	YNL-B
Hydraulic Conductivity (ft/day)	1.3	0.16	0.03
Ambient Head (feet)	5696.12	5703.39	5699.7
Permeability Multiplier*	2.62	0.32	0.06
Weighted Average Head in Vent Raise (feet)	5696.97	5696.97	5696.97
Head Difference (feet)	-0.85	6.42	2.73
Estimated Flux (gpm)	0.27	-0.27	-0.02

*Used in the weighted average calculations to determine the vent raise head.

MODEL LIMITATIONS

The assumptions used in the modeling analyses are based on available data. Variations in permeability and hydraulic head that are not identified by the current testing may affect the results. The analyses of the Lower Decline and SW Access use two conservative assumptions that likely cause the model to over predict the affects. One of the conservative assumptions is the assumed gradient between the mine workings and bedrock aquifer is 1. The gradient between the open mine workings and bedrock aquifer will be less than 1 as the mounding that occurs in the bedrock system is not accounted for. If the mounding was accounted for, the gradient would be lower resulting in a decreased flow from the open workings to the aquifer, which would affectively lower the mounding at the top of the water table. The second conservative assumption is that the models use an arbitrary thickness of 20 feet between the different HSUs. The thickness between the different HSUs is much greater than 20 feet in the majority of the mine area. If the larger thicknesses were applied to the modeling analysis, the vertical gradient between the different HSUs would be less resulting in lower vertical flow and decreased mounding at the water table.

This modeling analysis was conducted to illustrate the potential for open mine working to affect the groundwater system during post-closure. The modeling analysis does not account for the full three dimensional aspect and connectivity of the open mine workings during post closure. Since the analysis was conducted on the mine working that have the largest change and the analysis uses conservative assumptions, it is believed that the affects from the three dimensional aspect and connectivity of the different working will be minor. However, if necessary, the connectivity of the open workings could be limited by the placement of hydraulic plugs. Hydraulic plugs could be used to limit the length of which the access tunnels and declines extend across areas with large head changes and/or to limit the connectivity of ventilation raises to the access tunnels and declines.

SUMMARY AND DISCUSSION

The results of the post-closure analyses indicate that the open mine working will have very limited effects at the top of the water table. The largest change in water levels is predicted to occur in the SW access, with only 0.5 feet of mounding at the top of the water table. The result of the Lower Decline analysis indicate it will not have any measurable effect on the top of the water table. The results of the EVL ventilation raise analysis indicate there is a potential for approximately 0.3 gpm of groundwater from the USZ/UCZ to flow through the ventilation raise to the YNL-A. Although the ventilation raise provides a more direct path of water in the USZ/UCZ to the YNL-A, in the natural conditions (without any open accesses), water flowing through the USZ/UCZ co-mingles with the YNL-A as the USZ intersects the flow path of the YNL-A at the flanks of the Sheep Creek alluvial system. In general, this analysis shows that there is limited affects to the groundwater system and no effect on surface water resources due to the small amount of mine working being left open during post-closure.

REFERENCES

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Hantush, M.S., 1967. Growth and decay of groundwater mounds in response to uniform percolation, Water Resources Research, vol. 3, no. 1, pp. 227-234.

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Moench, A.F., 1984. Double-porosity models for a fissured groundwater reservoir with fracture skin, Water Resources Research, vol. 20, no. 7, pp. 831-846.

Tintina Montana, 2016. Mine Operating Permit Application, Black Butte Copper Project, Meagher County, MT, Revision 1. Originally submitted December 2015, revised September 2016.

FIGURES

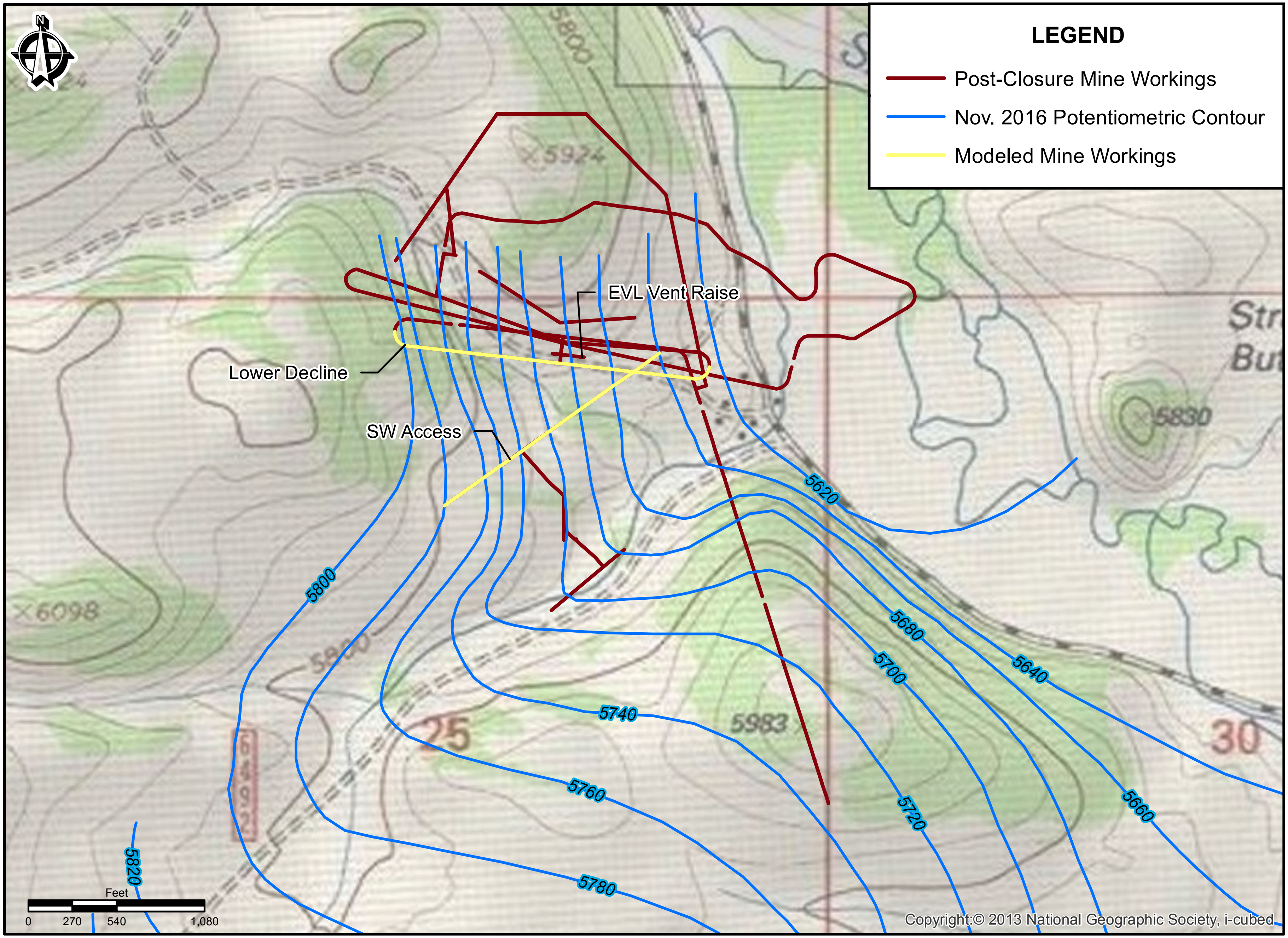

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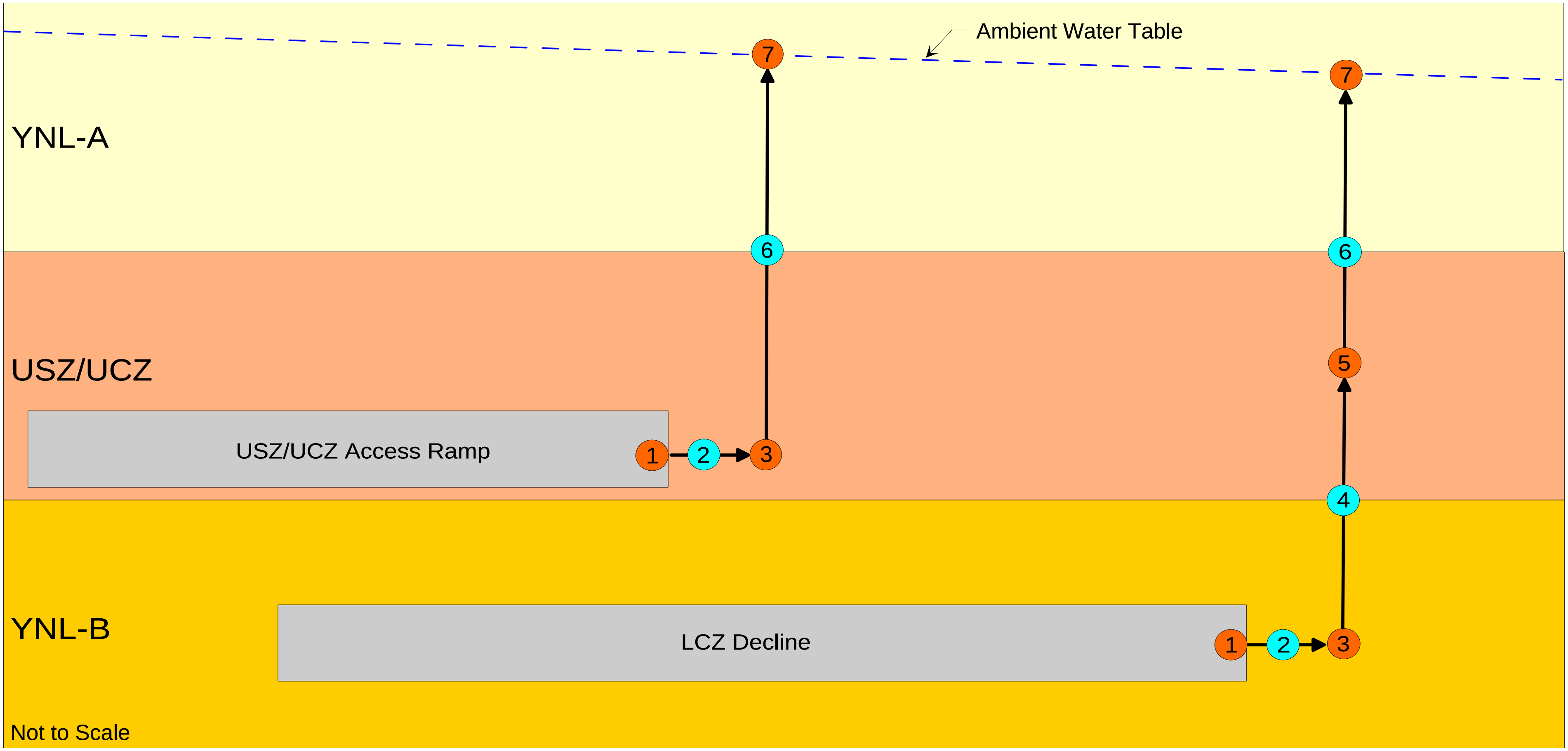
Figure 1
Post-Closure Mine Workings
Black Butte Copper Project
Meagher County, Montana



Analytical Model Steps

1) Calculate mound in decline or access ramp
2) Flux from decline or access ramp
3) Mounding analysis adjacent to decline or access ramp from flux calculated in Step 2 (skip to Step 6 for USZ/UCZ access ramp analysis)
4) Vertical flux to USZ/UCZ from mounding calculated in Step 3
5) Mounding analysis in USZ/UCZ from vertical flux calculated on Step 4
6) Vertical flux to YNL-A from mounding calculated in Step 5 (LCZ decline) or Step 3 (UCZ access ramp)
7) Mounding at top of water table from vertical flux calculated in Step 6.

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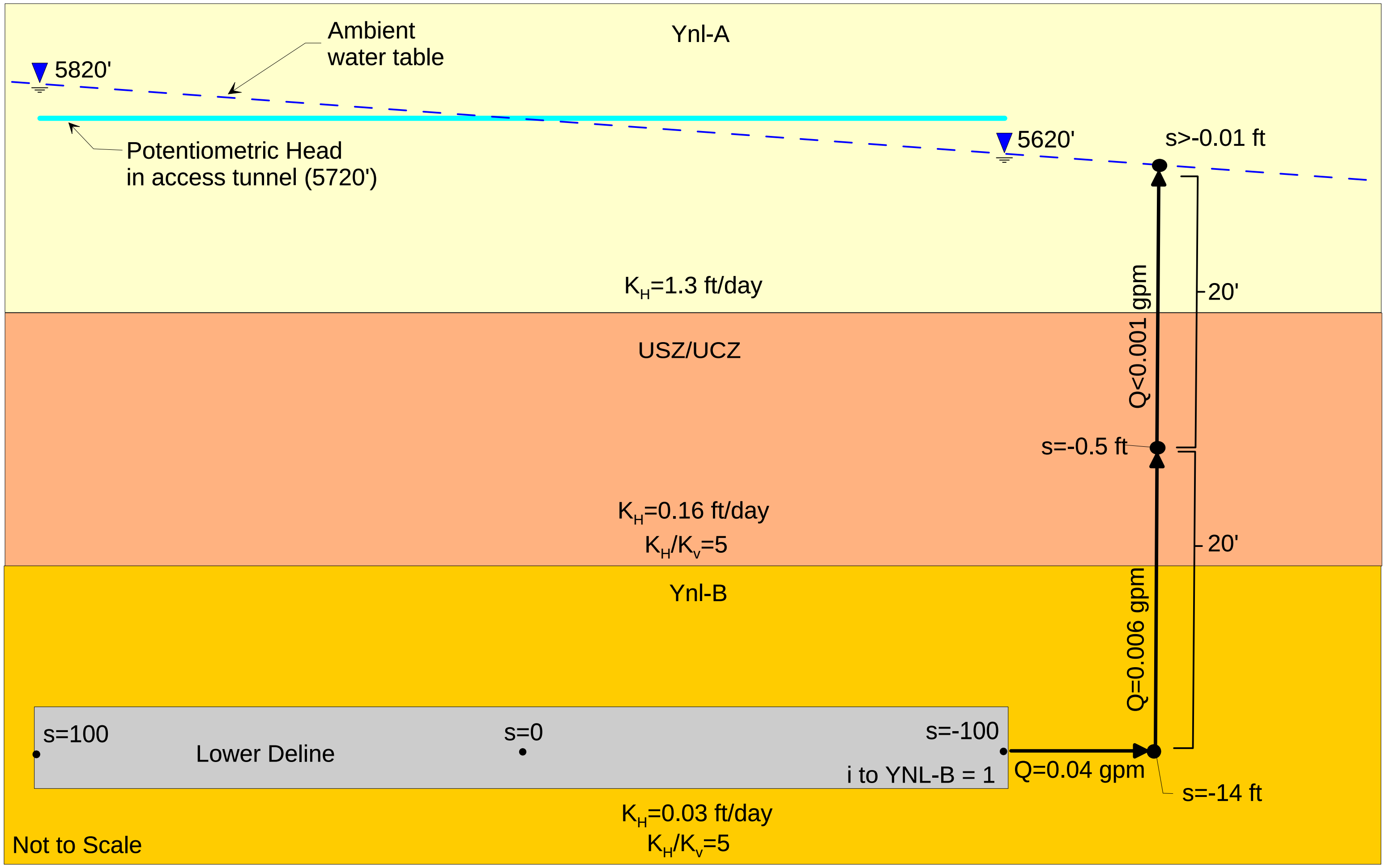
Figure 2
Post-Closure Analytical Model Steps
Black Butte Copper Project
Meagher County, Montana



Assumptions:
Q=Flux; s= drawdown (negative for mounding)
Area (A) of tunnel face 17' x 17'
Gradient (i) between tunnel and bedrock is 1
Mounding calculations based on flow across a 17' x 17' area where mounding causes flow to overlying HSU
Distance between center of HSUs is approximately 20 feet at downgradient end of tunnel
Unsaturated zone above access tunnel approximately 40 to 50 feet; based on PW-4 and PW-8 water level data

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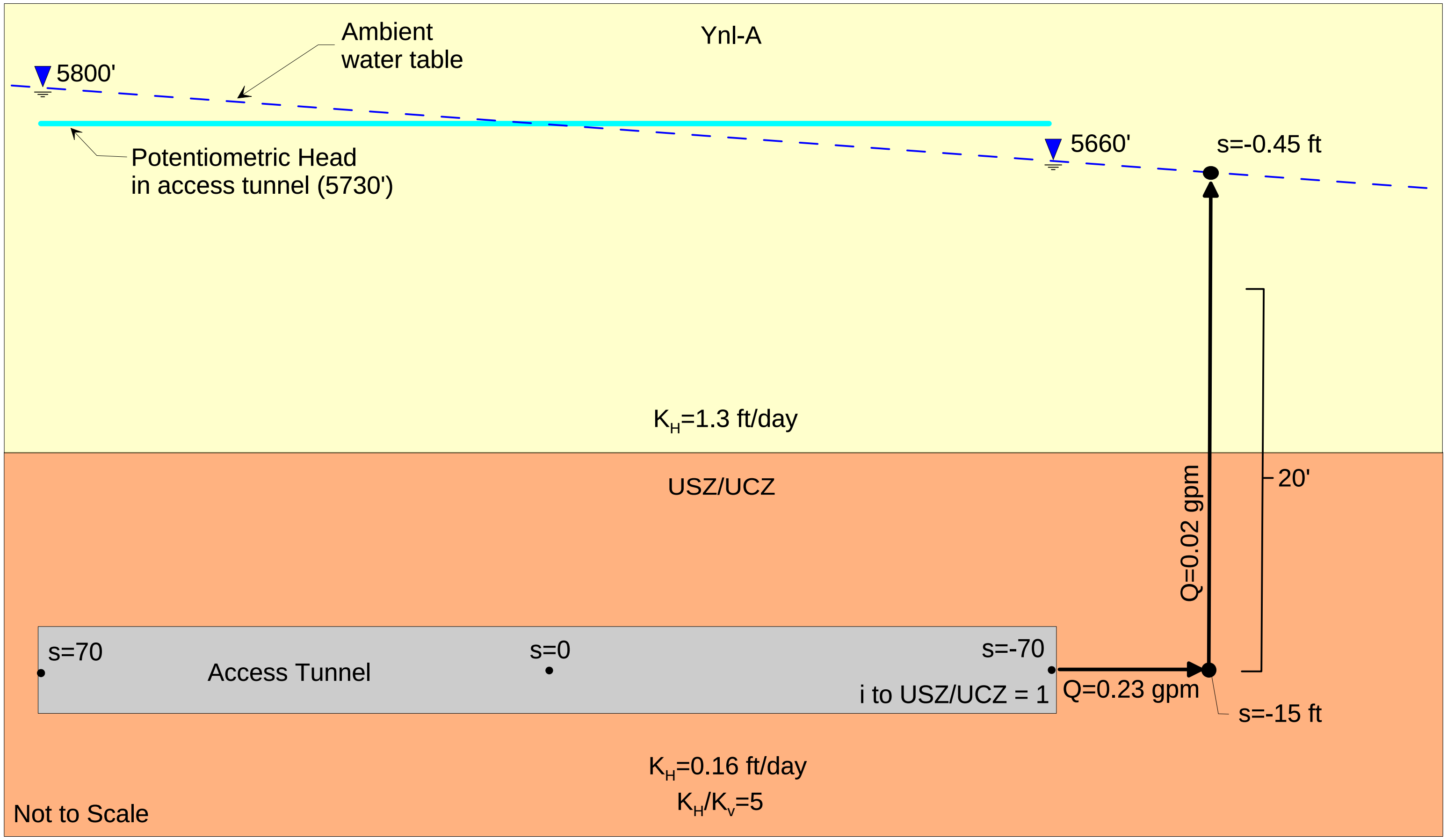
Figure 3
Lower Decline Analytical Model
Black Butte Copper Project
Meagher County, Montana



Assumptions:
Q=Flux; s= drawdown (negative for mounding)
Area (A) of tunnel face 17' x 17'
Gradient (i) between tunnel and bedrock is 1
Mounding calculations based on flow across a 17' x 17' area where mounding causes flow to overlying HSU
Distance between center of HSUs is approximately 20 feet at downgradient end of tunnel
Unsaturated zone above access tunnel approximately 40 to 50 feet; based on PW-4 and PW-8 water level data

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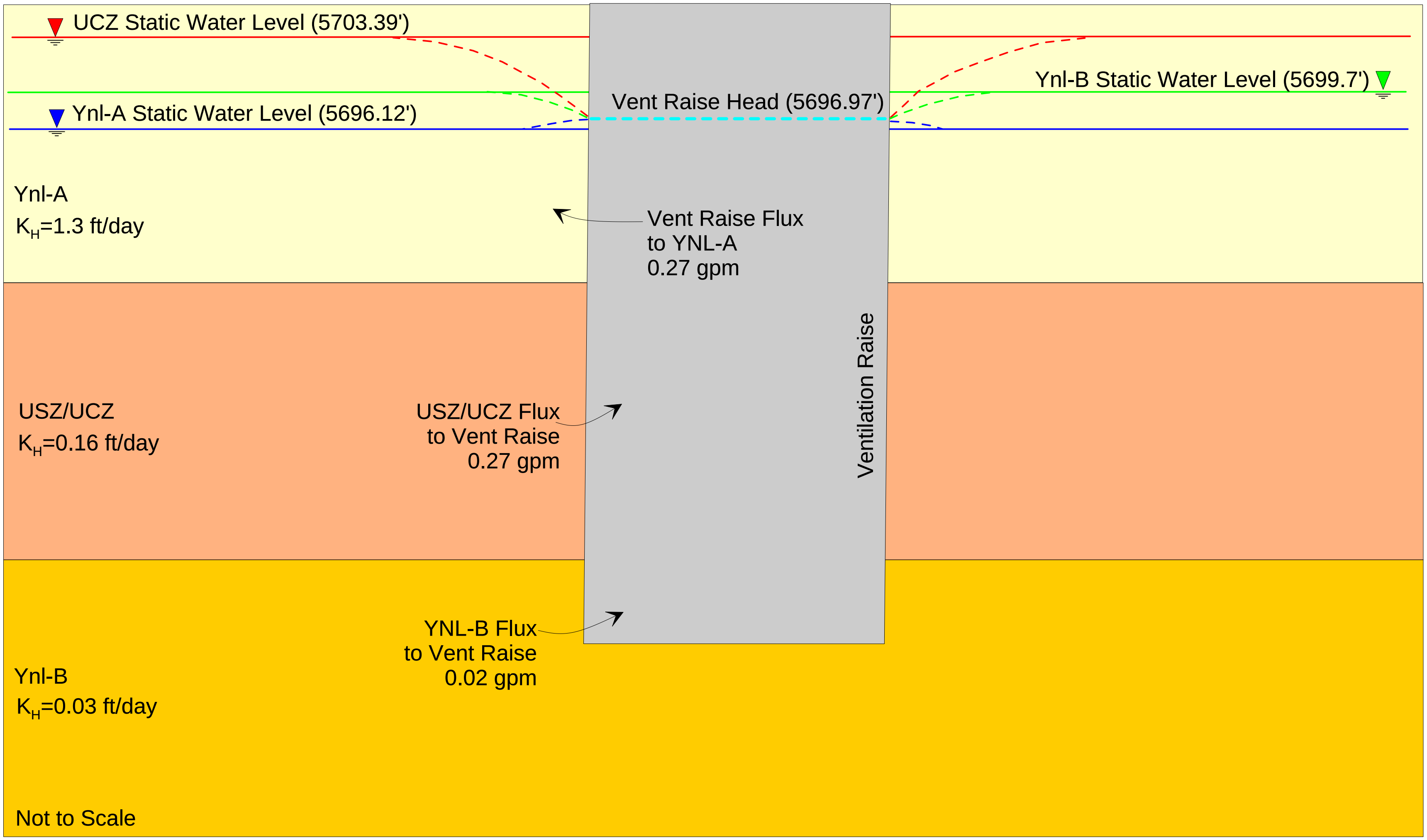
Figure 4
SW Access Tunnel Analytical Model
Black Butte Copper Project
Meagher County, Montana



Notes:
Water level (head) in each HSU are based on November 2016 water levels from MW-9 (YNL-A), PW-9 (USZ/UCZ), and PW-10 (YNL-B)
Ventilation raise head is based on weighted average head based on the head and permeability of each HSUs.
Flux in and out of ventilation raise is calculated based on AQTESOLV pumping/injection analysis for each HSU.

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Figure 5
Ventilation Raise Analytical Model
Black Butte Copper Project
Meagher County, Montana

ATTACHMENT I

Lower Decline Mounding Analysis
Flow from Lower Decline to YNL-B

Transient Water-Table Rise Beneath a Rectangular Recharge Area
Groundwater Mounding Solution by Hantush (1967)

Aquifer Properties:

Hydraulic conductivity, K = 0.03 ft/day
Specific yield, Sy = 3e-006
Initial saturated thickness, h(0) = 20 ft

Recharge Area Properties:

Recharge rate, w = 0.028 ft/day
Simulation time, t = 3650 day
Time when recharge stops, t(0) = 3650 day
X coordinate at center of recharge area, X = 0 ft
Y coordinate at center of recharge area, Y = 0 ft
Length in x direction, l = 17 ft
Length in y direction, a = 17 ft

Water-Table Rise at Center of Recharge Area:

t (day)	h (ft)
365	12.7374
730	13.1944
1095	13.4587
1460	13.645
1825	13.7888
2190	13.9058
2555	14.0044
2920	14.0895
3285	14.1645
3650	14.2314

Report generated by AQTESOLV v4.50.000 (www.aqtesolv.com) on 01/20/17 at 15:40:32.

Lower Decline Mounding Analysis
Flow from YNL-B to USZ/UCZ

Transient Water-Table Rise Beneath a Rectangular Recharge Area
Groundwater Mounding Solution by Hantush (1967)

Aquifer Properties:
 Hydraulic conductivity, K = 0.16 ft/day
 Specific yield, Sy = 3e-006
 Initial saturated thickness, h(0) = 20 ft

Recharge Area Properties:
 Recharge rate, w = 0.004 ft/day
 Simulation time, t = 3650 day
 Time when recharge stops, t(0) = 3650 day
 X coordinate at center of recharge area, X = 0 ft
 Y coordinate at center of recharge area, Y = 0 ft
 Length in x direction, l = 17 ft
 Length in y direction, a = 17 ft

Water-Table Rise at Center of Recharge Area:

t (day)	h (ft)
365	0.484479
730	0.503939
1095	0.515314
1460	0.52338
1825	0.529635
2190	0.534744
2555	0.539062
2920	0.542802
3285	0.546101
3650	0.549051

Report generated by AQTESOLV v4.50.000 (www.aqtesolv.com) on 01/20/17 at 15:46:38.

Lower Decline Mounding Analysis
Flow from USZ/UCZ to YNL-A

Transient Water-Table Rise Beneath a Rectangular Recharge Area
Groundwater Mounding Solution by Hantush (1967)

Aquifer Properties:
    Hydraulic conductivity, K = 1.3 ft/day
    Specific yield, Sy = 3e-006
    Initial saturated thickness, h(0) = 20 ft

Recharge Area Properties:
    Recharge rate, w = 2e-005 ft/day
    Simulation time, t = 3650 day
    Time when recharge stops, t(0) = 3650 day
    X coordinate at center of recharge area, X = 0 ft
    Y coordinate at center of recharge area, Y = 0 ft
    Length in x direction, l = 17 ft
    Length in y direction, a = 17 ft

Water-Table Rise at Center of Recharge Area:

t (day)	h (ft)
-------	------
365	0.000338598
730	0.00035086
1095	0.000358033
1460	0.000363122
1825	0.00036707
2190	0.000370295
2555	0.000373022
2920	0.000375384
3285	0.000187216
3650	0.000379332

Report generated by AQTESOLV v4.50.000 (www.aqtesolv.com) on 01/20/17 at 15:49:22.

SW Access Tunnel Mounding Analysis
Flow from SW Access Tunnel to USZ/UCZ

Transient Water-Table Rise Beneath a Rectangular Recharge Area
Groundwater Mounding Solution by Hantush (1967)

Aquifer Properties:
Hydraulic conductivity, K = 0.16 ft/day
Specific yield, Sy = 3e-006
Initial saturated thickness, h(0) = 20 ft

Recharge Area Properties:
Recharge rate, w = 0.15 ft/day
Simulation time, t = 3650 day
Time when recharge stops, t(0) = 3650 day
X coordinate at center of recharge area, X = 0 ft
Y coordinate at center of recharge area, Y = 0 ft
Length in x direction, l = 17 ft
Length in y direction, a = 17 ft

Water-Table Rise at Center of Recharge Area:

t (day)	h (ft)
365	13.8799
730	14.3233
1095	14.58
1460	14.761
1825	14.9007
2190	15.0144
2555	15.1103
2920	15.1931
3285	15.266
3650	15.3311

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SW Access Tunnel Mounding Analysis
Flow from USZ/UCZ to YNL-A

Transient Water-Table Rise Beneath a Rectangular Recharge Area
Groundwater Mounding Solution by Hantush (1967)

Aquifer Properties:
Hydraulic conductivity, K = 1.3 ft/day
Specific yield, Sy = 3e-006
Initial saturated thickness, h(0) = 20 ft

Recharge Area Properties:
Recharge rate, w = 0.024 ft/day
Simulation time, t = 3650 day
Time when recharge stops, t(0) = 3650 day
X coordinate at center of recharge area, X = 0 ft
Y coordinate at center of recharge area, Y = 0 ft
Length in x direction, l = 17 ft
Length in y direction, a = 17 ft

Water-Table Rise at Center of Recharge Area:

t (day)	h (ft)
365	0.402484
730	0.416911
1095	0.425345
1460	0.431327
1825	0.435966
2190	0.439756
2555	0.442959
2920	0.445734
3285	0.223413
3650	0.450369

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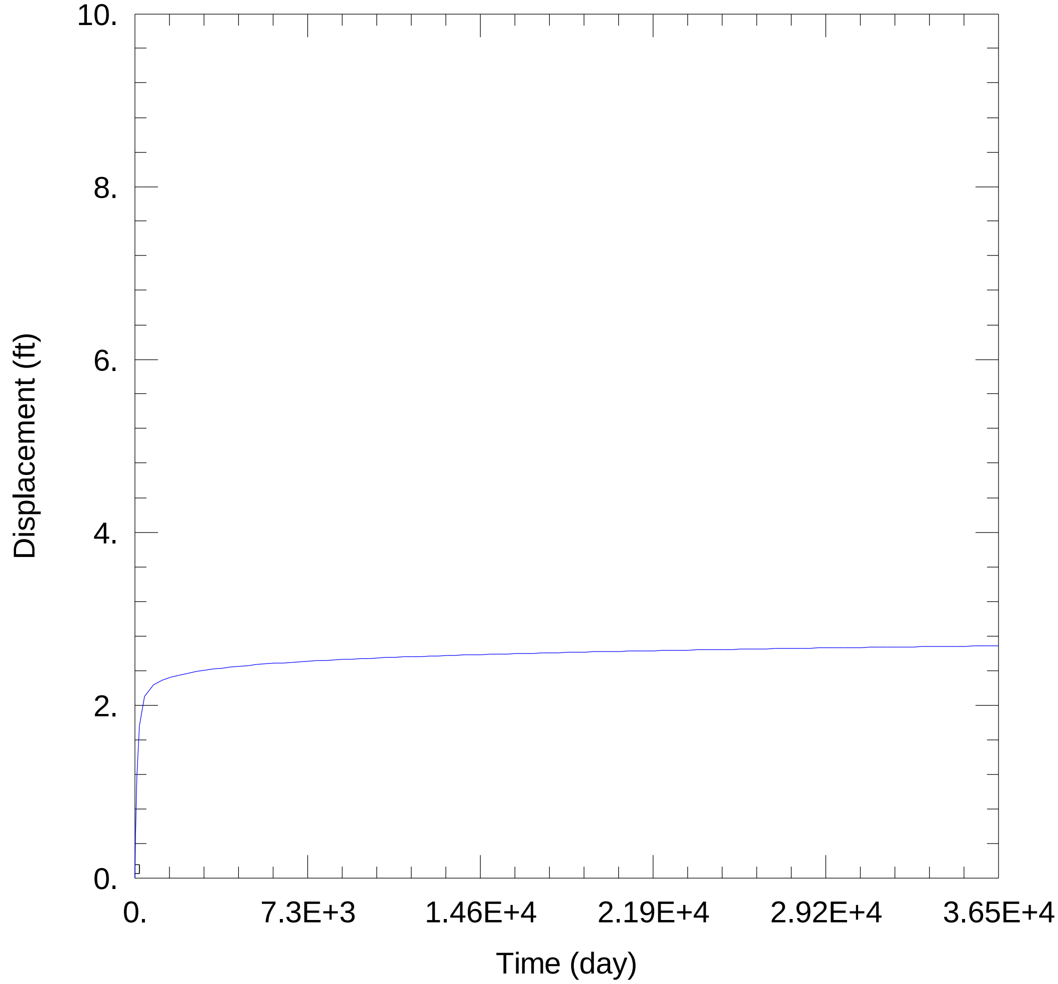
ATTACHMENT II



WELL TEST ANALYSIS

Data Set: K:\project\11048\GW Flow Model\AccessRamps_Analytical Model\YnlB_VentRaise_WeightedAvgHead.aqt
Date: 03/07/17 Time: 11:05:14

PROJECT INFORMATION

Company: Hydrometrics
Client: Tintina
Project: 11048
Test Well: YNL-B: Flow 0.02 gpm
Test Date: Forward

AQUIFER DATA

Saturated Thickness: 105. ft Slab Block Thickness: 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
YNL-B EVL	0	0

Observation Wells

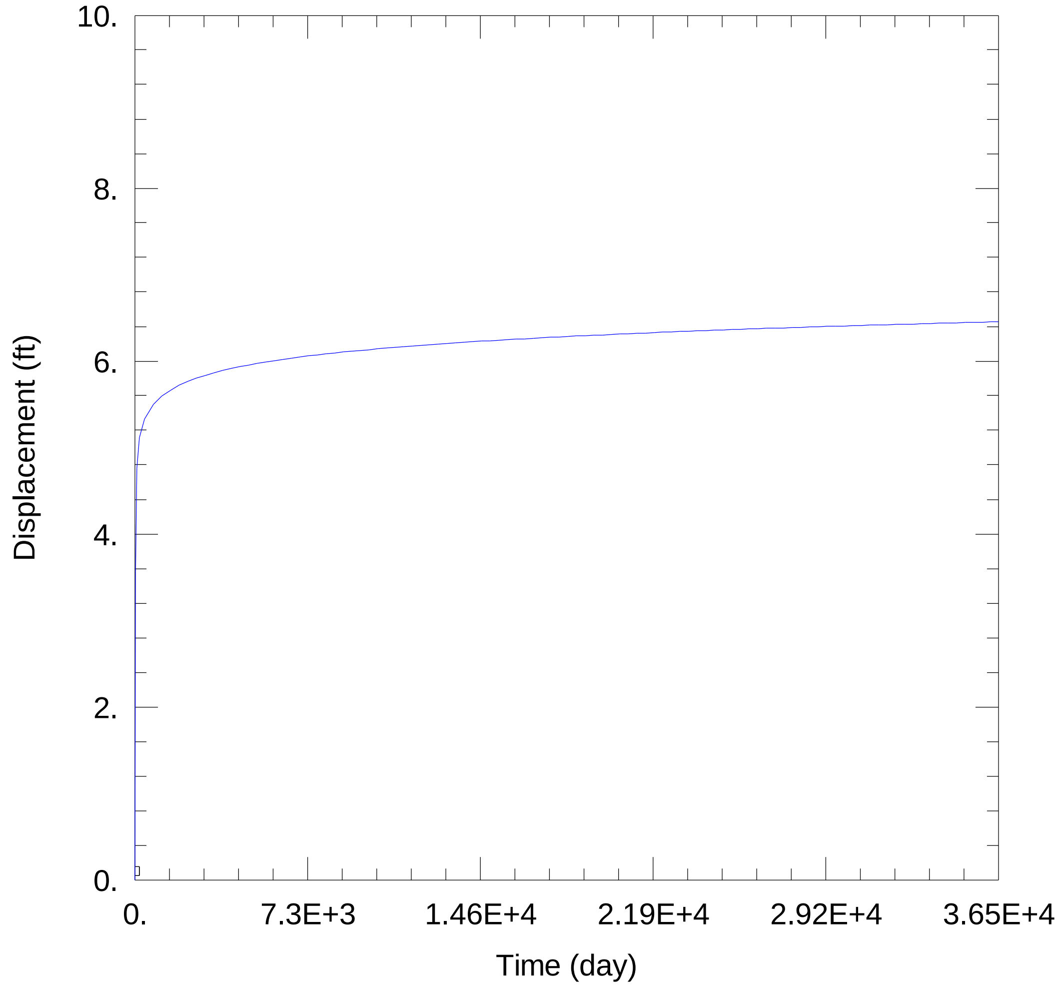
Well Name	X (ft)	Y (ft)
□ YNL-B EVL	0	0

SOLUTION

Aquifer Model: Fractured
Solution Method: Moench w/slab blocks

K = 0.03 ft/day
K' = 2.4E-9 ft/day
Sw = 3.6
r(w) = 8. ft

Ss = 1.1E-6 ft^{-1}
Ss' = 2.5E-8 ft^{-1}
Sf = 6.5
r(c) = 8. ft



WELL TEST ANALYSIS

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Date: 03/07/17 Time: 10:59:41

PROJECT INFORMATION

Company: Hydrometrics
Client: Tintina Resources
Project: 11048
Test Well: USZ/UCZ: Flow 0.27 gpm
Test Date: Forward

AQUIFER DATA

Saturated Thickness: 105. ft
Slab Block Thickness: 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
USZ/UCZ EVL	0	0

Observation Wells

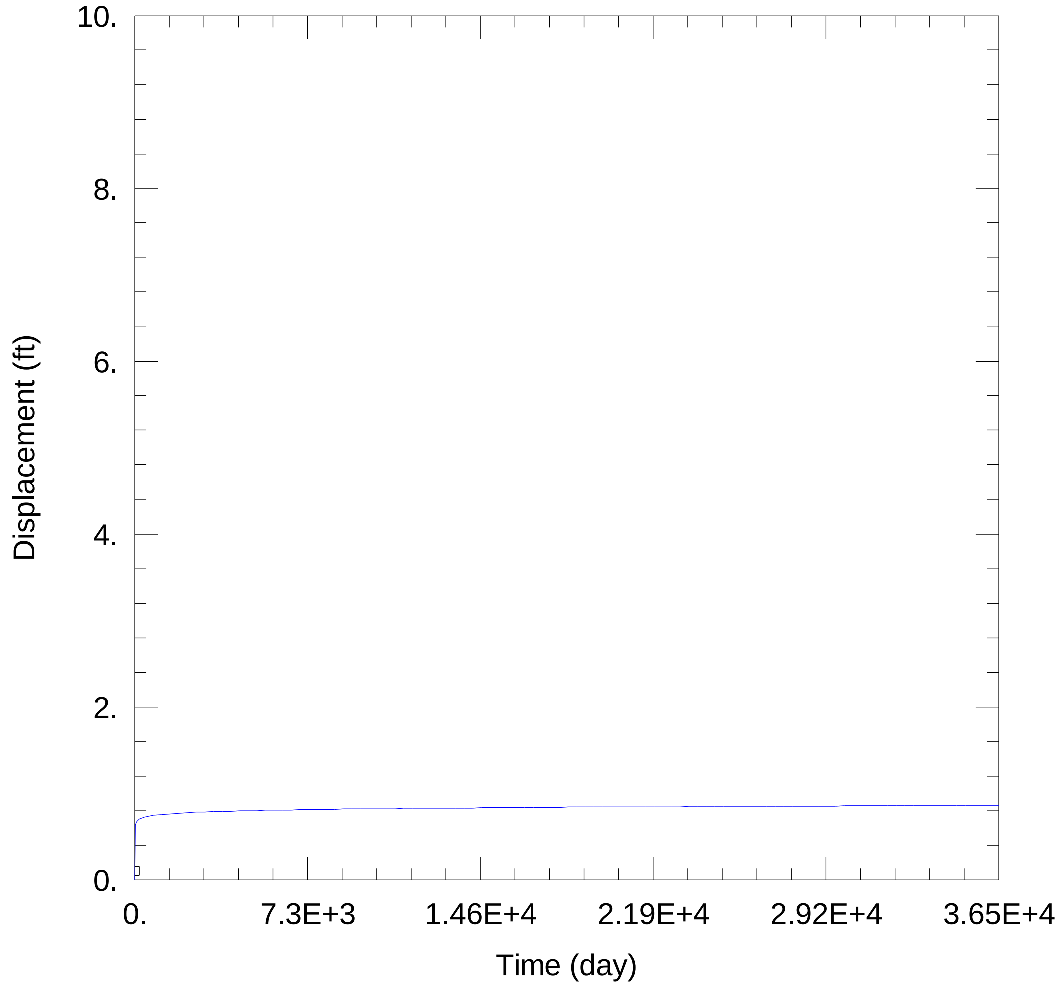
Well Name	X (ft)	Y (ft)
□ USZ/UCZ EVL	0	0

SOLUTION

Aquifer Model: Fractured
Solution Method: Moench w/slab blocks

K = 0.16 ft/day
K' = 2.4E-9 ft/day
Sw = 3.6
r(w) = 8. ft

Ss = 1.1E-6 ft^{-1}
Ss' = 2.5E-8 ft^{-1}
Sf = 6.5
r(c) = 8. ft



WELL TEST ANALYSIS

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Date: 03/07/17 Time: 11:04:52

PROJECT INFORMATION

Company: Hydrometrics
Client: Tintina
Project: 11048
Test Well: YNL-A: Flow -0.27 gpm
Test Date: Forward

AQUIFER DATA

Saturated Thickness: 105. ft Slab Block Thickness: 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
EVL YNL-A	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ EVL YNL-A	0	0

SOLUTION

Aquifer Model: Fractured Solution Method: Moench w/slab blocks

K = 1.3 ft/day
K' = 2.4E-9 ft/day
Sw = 3.6
r(w) = 8. ft

Ss = 1.1E-6 ft^{-1}
Ss' = 2.5E-8 ft^{-1}
Sf = 6.5
r(c) = 8. ft