GOLDER

Whale Tail Pit Project

MINE CONTACT WATER MODELLING COMMITMENTS

26 July 2018

AGENDA

Introduction

Modelling Results

- Whale Tail Pit Lake Hydrogeology, Arsenic Diffusion and Hydrodynamics
- Mammoth Lake Effluent Plume (near field) and Hydrodynamics (far field)
- WRSF Thermal Model

Discussion

Hydrogeological Model

Whale Tail Pit Lake Model

HYDROGEOLOGY

Term and Condition n. 6

Objectives of the hydrogeological model:

- Evaluate groundwater flow conditions into/out of the flooded open pit post-closure
- Assess effect of hydrogeological conditions on the potential for arsenic accumulation in the pit lake from release by diffusion from submerged pit walls

Whale Tail Pit Lake Model

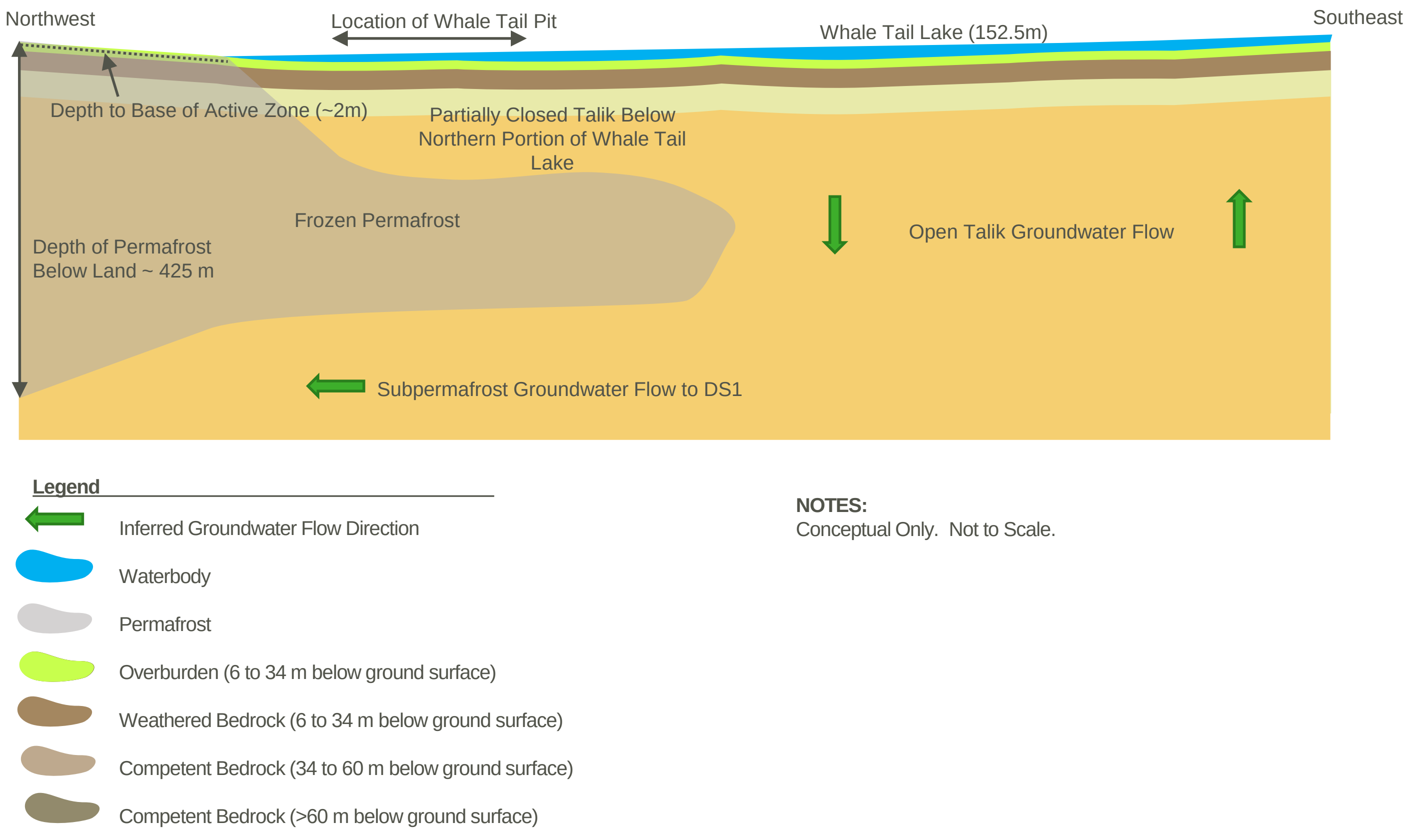
HYDROGEOLOGY

Pit Lake hydrogeological conceptual model:

- Open talik in Whale Tail Lake South Basin
- Permafrost present below the North Basin of Whale Tail Lake below the base of the pit. K of permafrost bedrock set at 1×10^{-12} m/s; very low flow zone.
- Limited inflow of water into the open pit during operations and closure since the pit will be mostly in a closed talik above a layer of permafrost
- Post-closure gradual thaw of permafrost below pit until fully open talik in the North Basin, modelled as 300 years after closure.
- Post-closure hydraulic gradients to pit are weak to absent, flow regime into/out of pit may be density driven: caused by lateral variations in fluid density due to differences in TDS between groundwater (from 650 mg/L TDS at Year 1 post-closure to 650 mg/L TDS 500 years post-closure) and pit Lake (TDS 77 mg/L in North Basin; 11 mg/L South Basin at closure)

Conceptual Model of Thermal-Hydrogeological Conditions

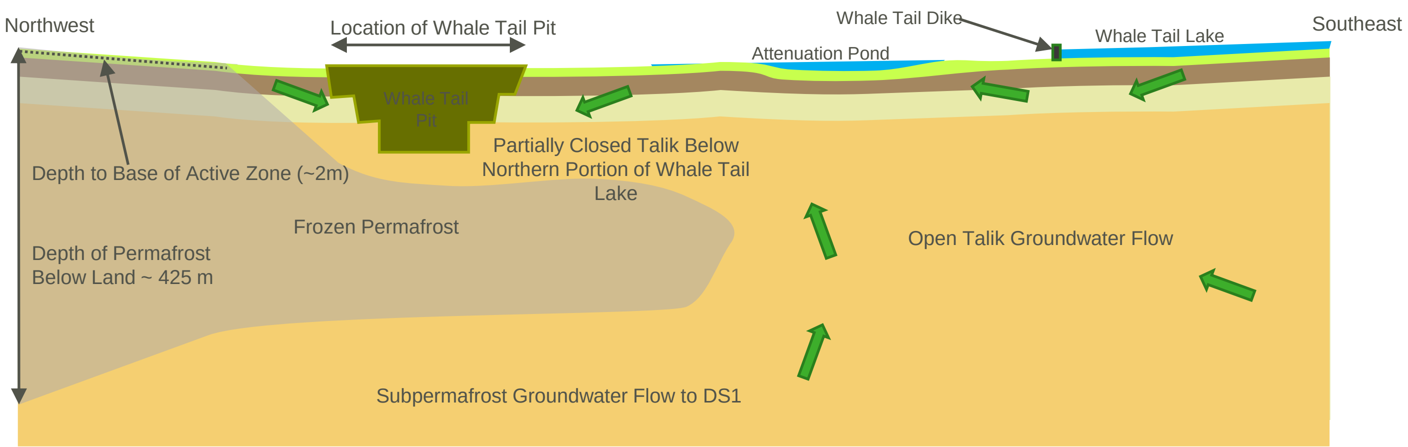
BASELINE



NOTES:
Conceptual Only. Not to Scale.

Conceptual Model of Thermal-Hydrogeological Conditions

OPERATIONS



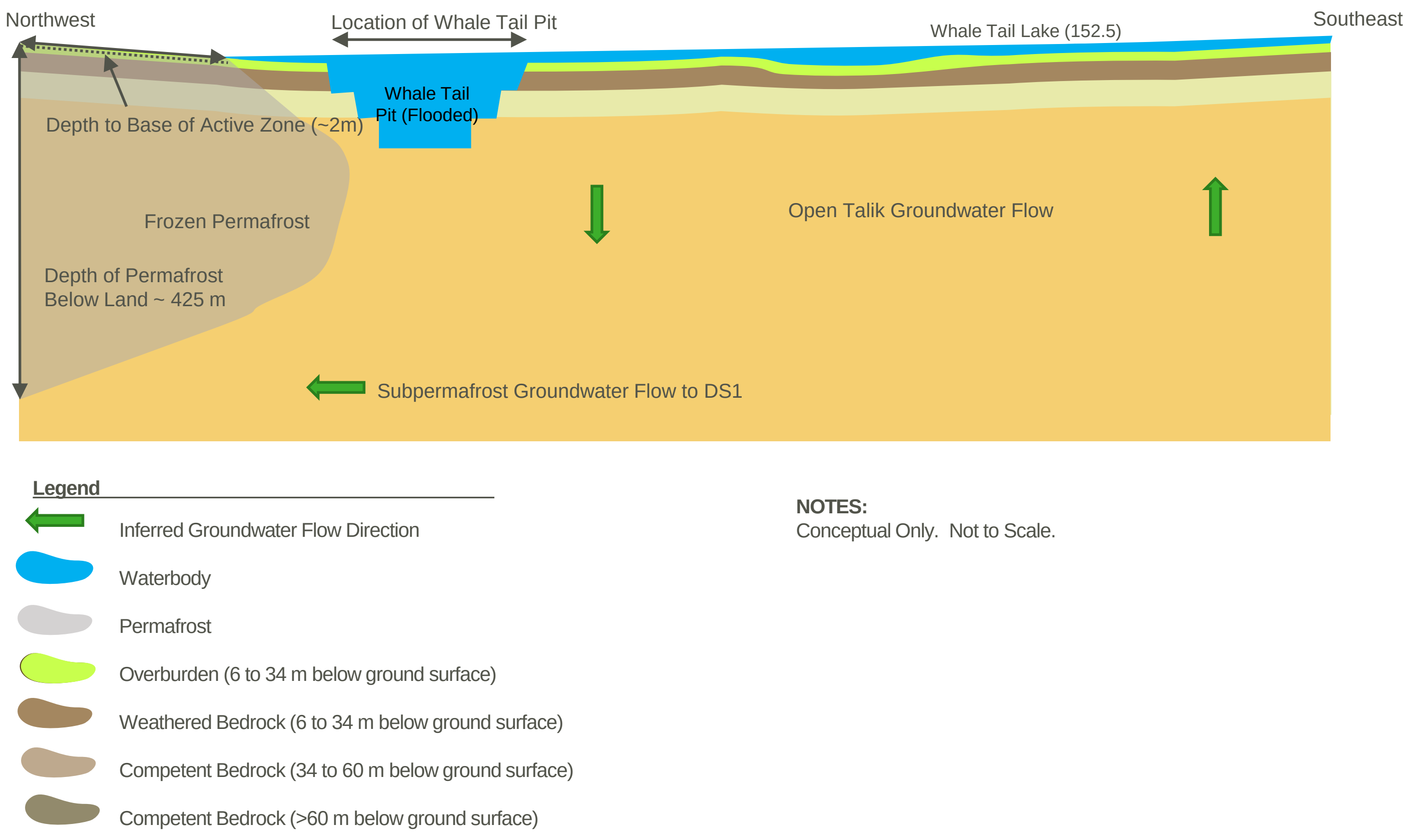
Legend

- Inferred Groundwater Flow Direction
- Waterbody
- Permafrost
- Overburden (6 to 34 m below ground surface)
- Weathered Bedrock (6 to 34 m below ground surface)
- Competent Bedrock (34 to 60 m below ground surface)
- Competent Bedrock (>60 m below ground surface)

NOTES:
Conceptual Only. Not to Scale.

Conceptual Model of Thermal-Hydrogeological Conditions

POST CLOSURE



NOTES:
Conceptual Only. Not to Scale.

Whale Tail Pit Lake Model

HYDROGEOLOGY

Simulation

- 2-dimension FEFLOW model over 500 years (300 with permafrost, 200 years for near steady-state conditions following melting
- Domain: 1,600 m NW x 2,800m SE from centre of pit
- Finite element mesh: 55,000 elements, node spacing of 5m near ground surface to 20 m near base of model

Whale Tail Pit Lake Model

HYDROGEOLOGY - RESULTS

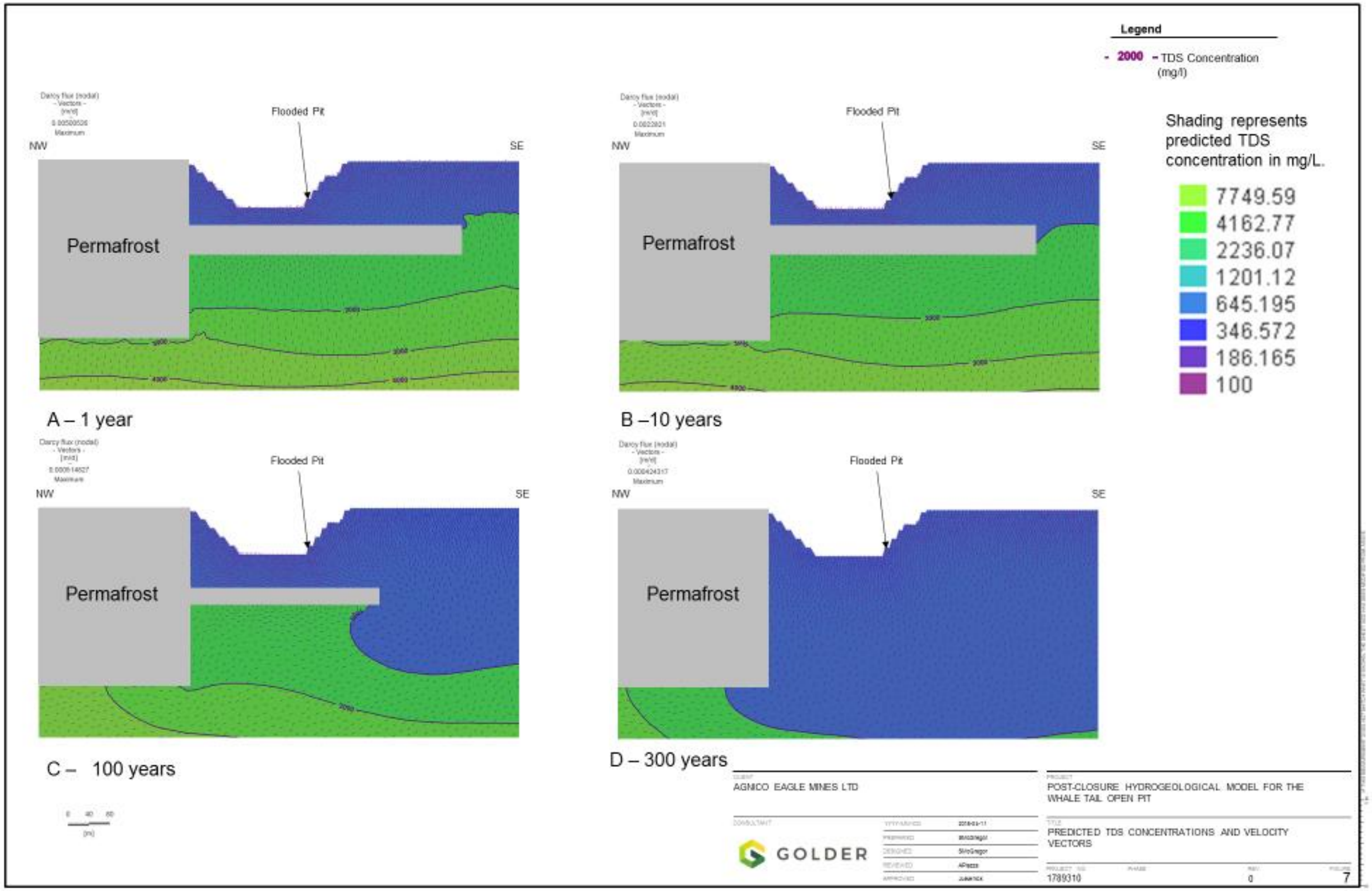
Pit Lake vs groundwater inflows and TDS concentrations

Predicted Fluxes per 1 m Width Section			
Years Following Closure	Groundwater Inflow to Pit Lake (m^3/day/m width)	Average TDS Concentration into pit (mg/l)	Pit Lake Outflow to Groundwater (m^3/day/m width)
1	0.008	650	0.004
10	0.004	540	0.003
100	0.0008	440	0.003
500	0.0005	77	0.006

Predicted Fluxes Up-scaled to Whale Tail Pit Lake		
Years Following Closure	Groundwater Inflow to Pit Lake (m^3/day)	Pit Lake Outflow to Groundwater (m^3/day)
1	2.2	1.1
10	1.1	0.8
100	0.2	0.8
500	0.1	1.7

Whale Tail Pit Lake Model

HYDROGEOLOGY – THAW OF PERMAFROST



Whale Tail Pit Lake Model

HYDROGEOLOGY

Conclusion

Short-term post closure (to approx. 10 years)

- groundwater inflow to pit > groundwater outflow to regional system

Medium and long term

- Pit Lake is a groundwater recharge even before permafrost not completely thawed

Arsenic Diffusion Assessment

from Submerged Pit Walls

Whale Tail Pit Lake Model

ARSENIC DIFFUSION

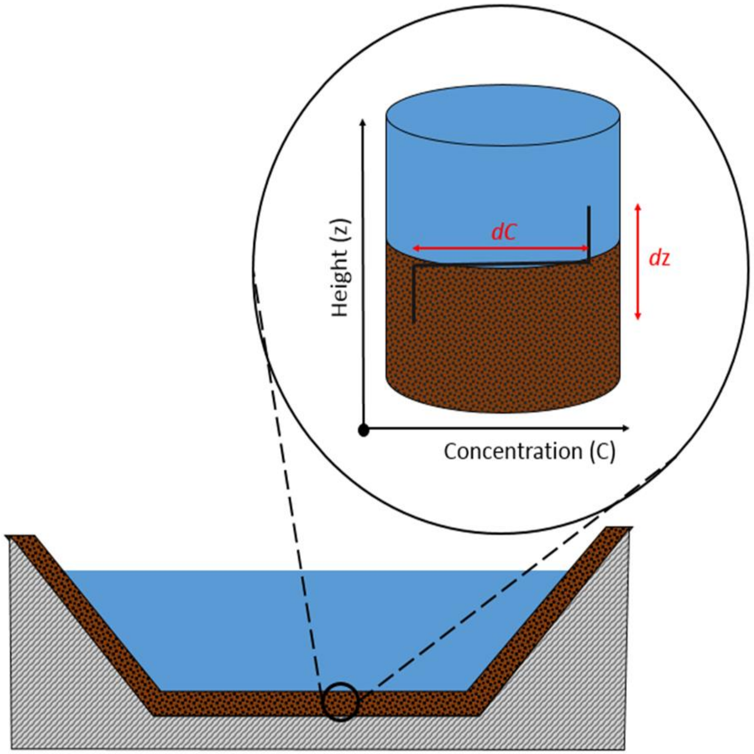
Method

Calculation of arsenic flux across the pit lake wall surface-water interface using Fick First Law of diffusion

$$J_z = \frac{D° J}{F} \phi \frac{dC}{dz}$$

$$Jz = \frac{8.2 X 10^{-6}}{1} \times 0.03 \times \frac{dC}{1}$$

Integration into the pit lake water quality model to evaluate additional arsenic load to pit lake from diffusion from pit walls for each lithology by proportion on the pit wall.



Whale Tail Pit Lake Model

ARSENIC DIFFUSION

Source data

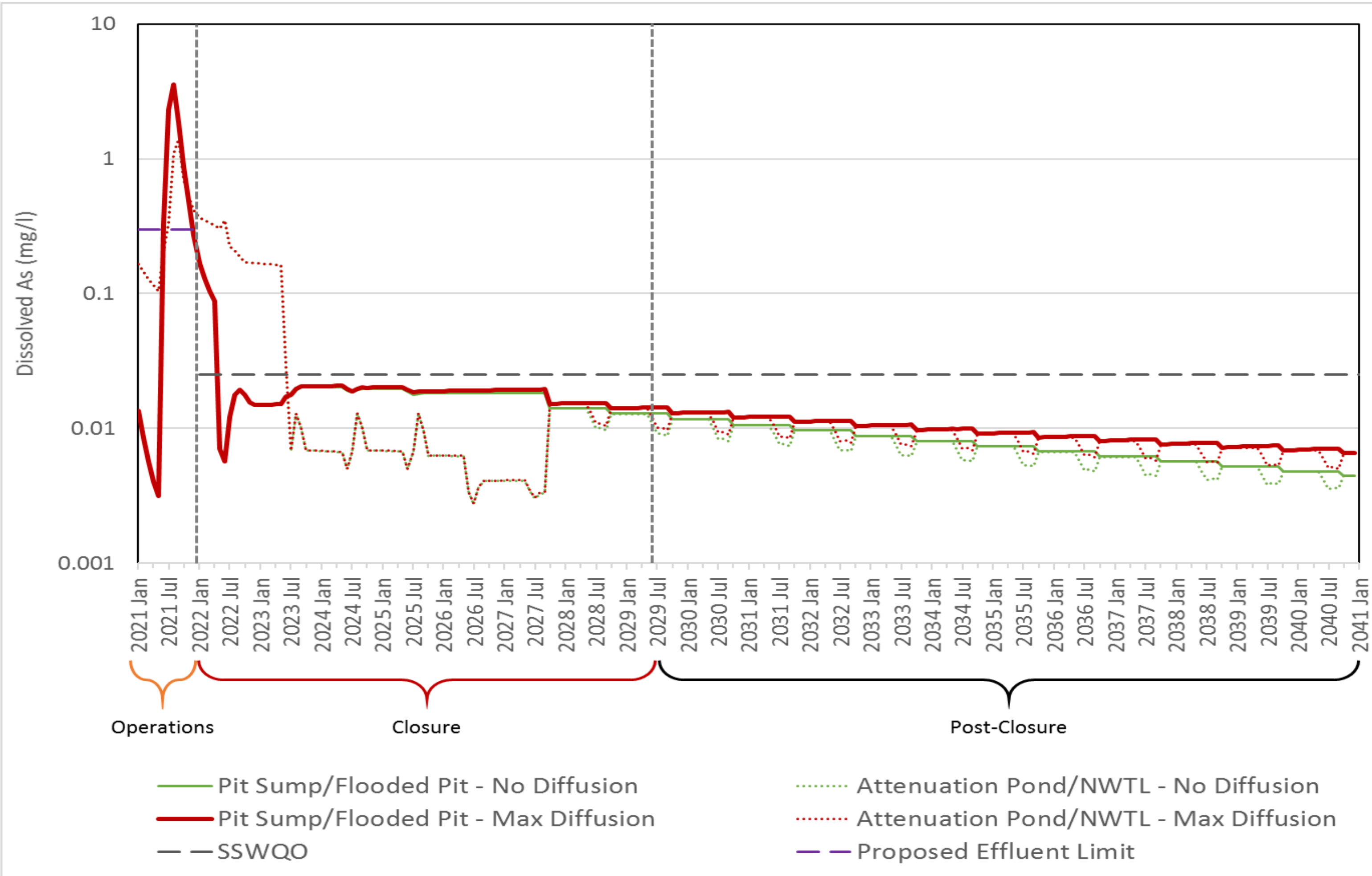
- arsenic concentrations in submerged leaching column: pore space vs above water column
- Leaching columns

Arsenic diffusive flux by lithology

Flux (Jz) ($mg\ cm^{-2}\ s^{-1}$)	Iron Formation Ultramafic Mixture ($x\ 10^{-10}$)	Ultramafic (North and South Wall) ($x\ 10^{-10}$)	Iron Formation ($x\ 10^{-10}$)	South and North Greywacke ($x\ 10^{-10}$)
Data Source	Submerged Column	Column Leach Tests (C1 and C5)	Column Leach Test (C2)	Column Leach Tests (C4)
Average	2.42	5.07	4.64	0.08

Whale Tail Pit Lake Model

ARSENIC DIFFUSION - RESULTS



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Whale Tail Pit Lake Model

ARSENIC DIFFUSION

Conclusion

Diffusion of arsenic from all pit walls has <u>no significant effect</u> on water quality in short and long-term.

Arsenic transfer to the open pit by diffusion from the submerged pit walls is not significantly affected by the hydrogeological regime around the flooded open pit.

Whale Tail Pit Lake

Hydrodynamic Model

Whale Tail Pit Lake Model

HYDRODYNAMICS

NIRB project certificate, Condition 16.

Objectives:

- Evaluate the potential for chemical stratification and the Pit Lake water quality profile post-closure

Whale Tail Pit Lake Model

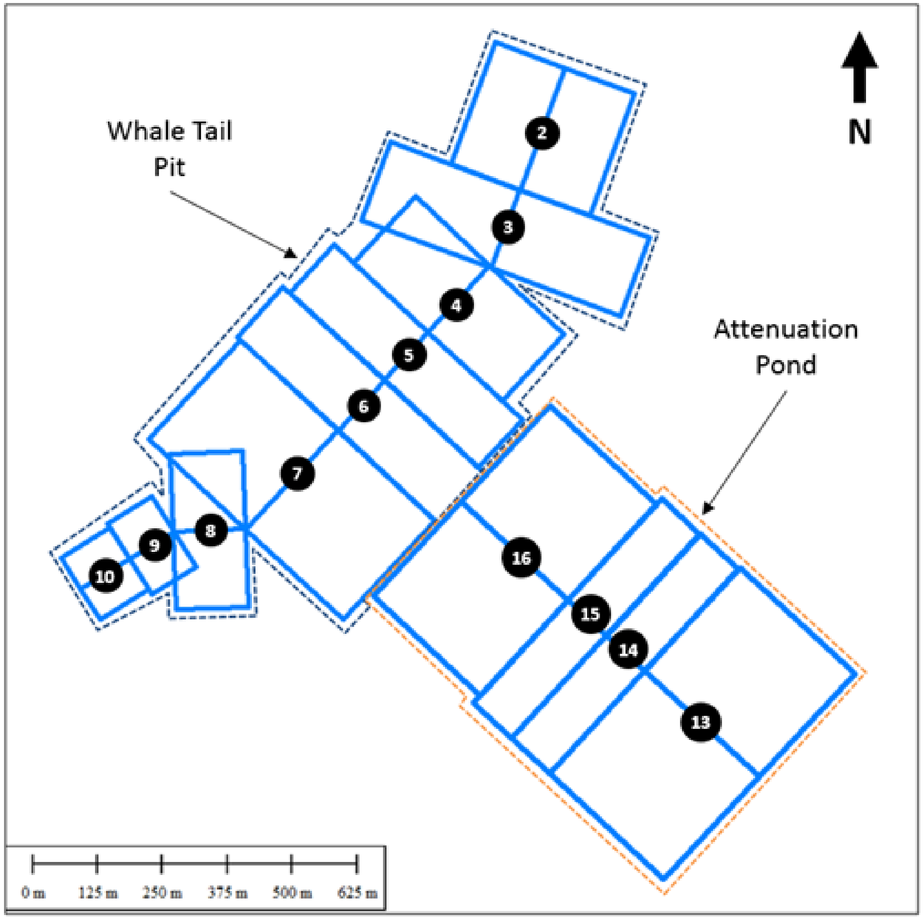
HYDRODYNAMICS - METHOD

- CE-QUAL-W2 software: fluid mechanics and water quality model to simulate distribution of heat, water momentum and mass transfer
- Model domain: 2-D grid of slices through the pit; horizontal grid spacing between 100 m and 260 m; vertical spacing.
- Model run for closure and 43 years post-closure: January 01, 2022 to December 31, 2070
- Input data: wind speed and direction, precipitation, run-off, pumped flows, groundwater flows, seepages, water temperature, outflow to Mammoth Lake

Whale Tail Pit Lake Model

HYDRODYNAMICS - METHOD

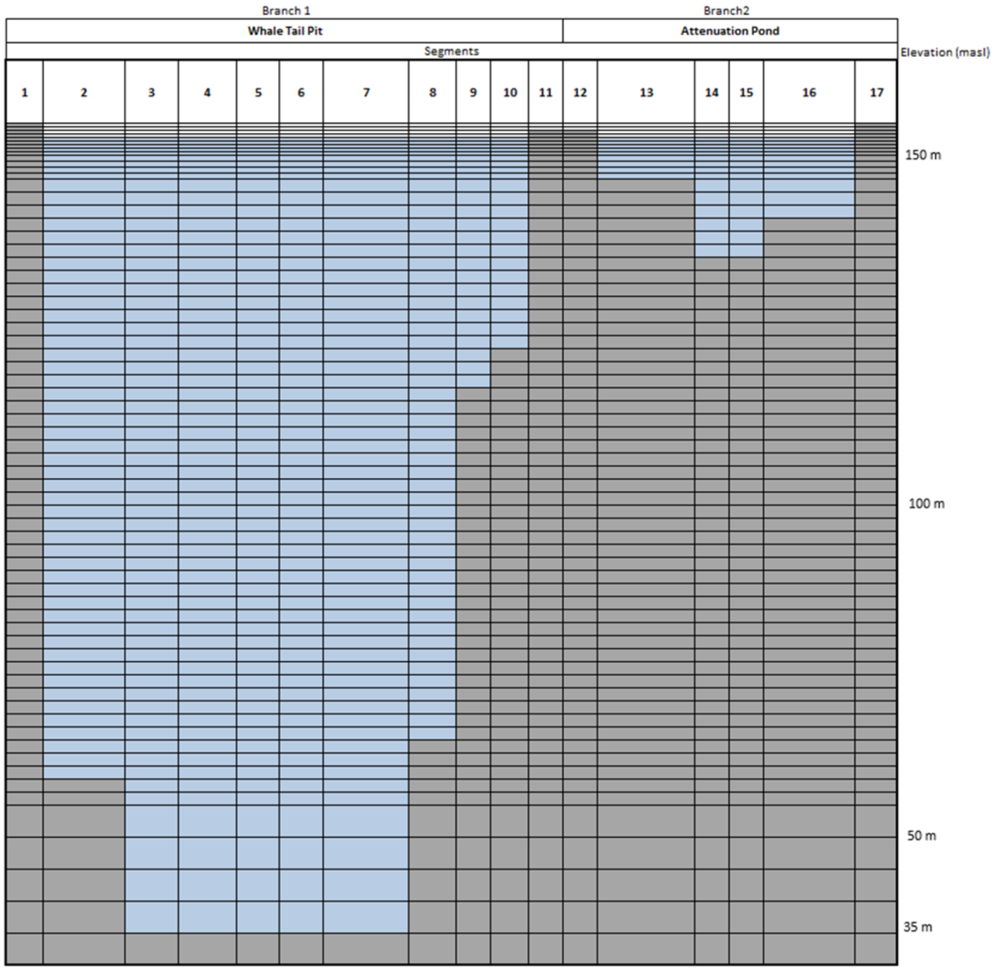
Plan view of segments representing the pit and attenuation pond



Whale Tail Pit Lake Model

HYDRODYNAMICS - METHOD

Profile of vertical layers and horizontal segmentation in the pit and attenuation pond

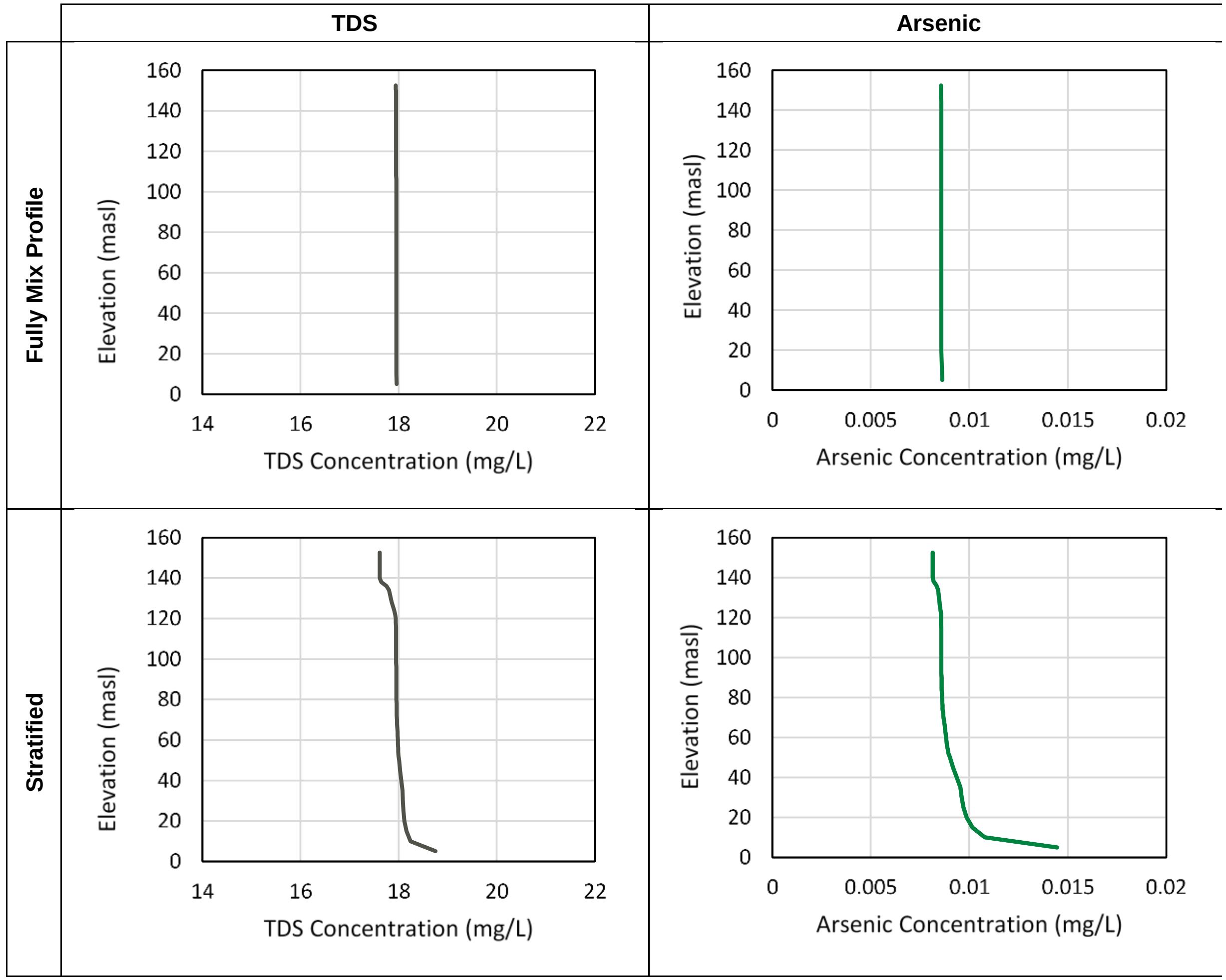


Whale Tail Pit Lake Model

HYDRODYNAMICS - RESULTS

2027 – 5 years post closure:

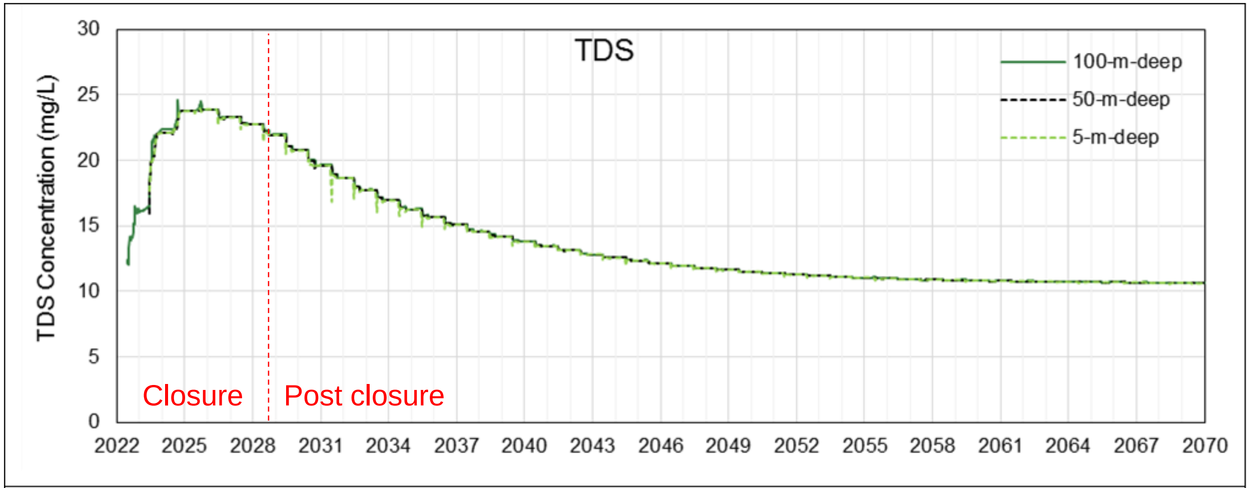
Fully mixed in spring and fall; weak stratification in winter and summer

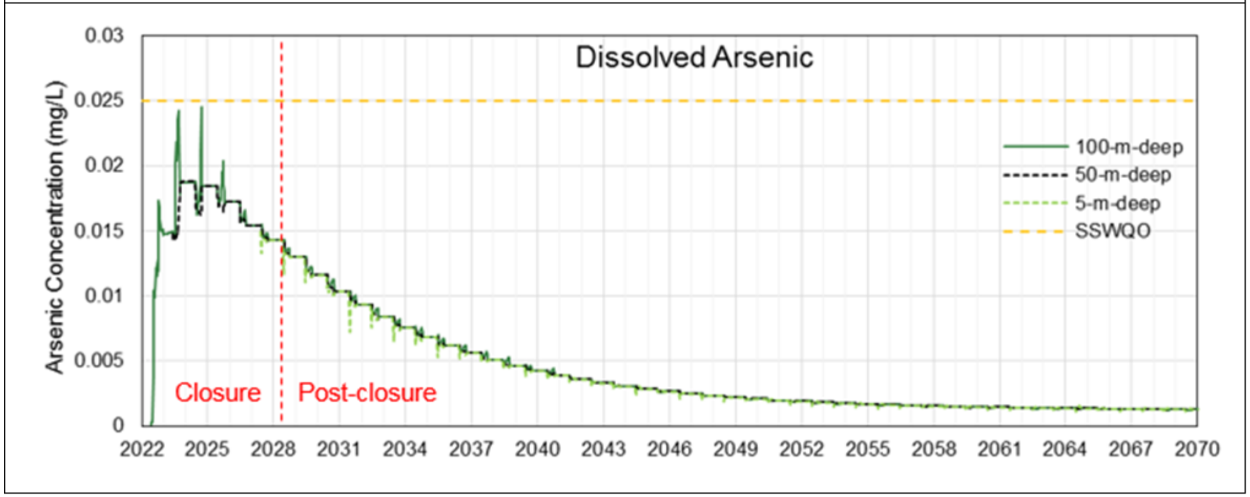


Whale Tail Pit Lake Model

HYDRODYNAMICS - RESULTS

Evolution in time of TDS and arsenic in pit lake, fully mixed conditions





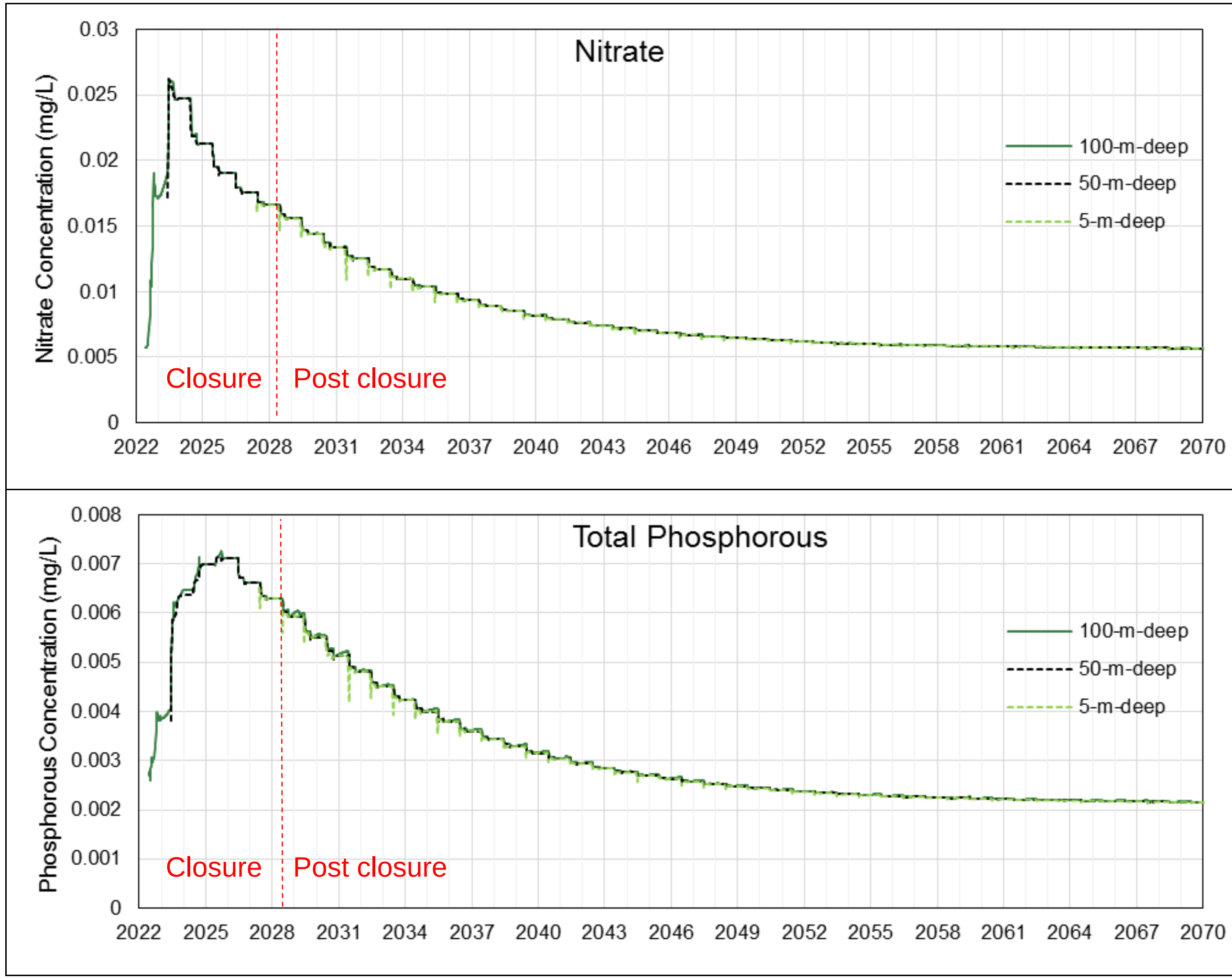
Recall: no significant effect on pit lake water quality by arsenic diffusion from submerged pit walls.

Whale Tail Pit Lake Model

HYDRODYNAMICS - RESULTS

Evolution of nitrate and phosphorous in fully mixed pit lake

Phosphorous is lower than the 0.01 mg/L threshold between oligotrophic and mesotrophic conditions



Whale Tail Pit Lake Model

HYDRODYNAMICS

Summary

- Pit lake to be fully flooded by 2028
- Lake water is predicted to completely mix bi-annually in spring and fall and exhibit weak chemical stratification in summer and winter.
- Pit lake water quality meets SSWQO for arsenic, oligotrophic level of 0.01 mg/L phosphorous and receiving water quality guideline for and nitrate in 2028 and post-closure, allowing breaching of dikes in 2028 to restore lake circulation

Mammoth Lake

Effluent Plume Model

Mammoth Lake Model

EFFLUENT PLUME

Objective:

Mammoth Lake Near-field water quality assessment at 1) WRSF seepage outlet post-closure and 2) mine discharge effluent

CORMIX model and the following design assumptions:

- WRSF seepage : surface flow and discharge through rock-fill weir into shallow bay of Mammoth Lake
- Effluent discharge: through engineered diffusor on Mammoth Lake Bed (1-meter above lake bottom)

Mammoth Lake Plume Model

WRSF SEEPAGE INPUT PARAMETERS

Required Dilution

Calculated as the dilution required for the predicted maximum effluent concentration to meet receiving environment quality guideline at the edge of the mixing zone.

Minimum required dilution is 16 for Phosphorus, this will also achieve the required dilution for all other constituents modelled

Month	Required C at edge of NFZ (mg/L) (CCME/SSWQO)		Arsenic Concentration (mg/L)		Phosphorus Concentration (mg/L)		Required Dilution	
	As	P	Diss.	Total	Diss.	Total	As	P
June	0.025	0.01	0.064	0.069	0.030	0.040	2.8	3.0
July	0.025	0.01	0.216	0.221	0.101	0.111	8.8	10.1
August	0.025	0.01	0.345	0.350	0.161	0.171	14.0	16.1
September	0.025	0.01	0.219	0.224	0.102	0.112	9.0	10.2

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Mammoth Lake Plume Model

WRSF SEEPAGE – INPUT PARAMETERS

Design Parameters – Ambient (Mammoth Lake)

Month	June	July	August	September	Note
Lake water depth at discharge (m)	0.5				Assumed
Lake bed slope (°)	10				Assumed
Temperature (°C)	2	8	10	6	Monthly temperature from June to September [1]
TDS concentration (mg/L)	15				Based on average of all monitoring data from 2014-2016
Water density (kg/m³)	999.9		999.7	999.98	Calculated
Calm condition: Assumed current speed (m/s)	0.001				wind velocity 0 (m/s) [2]
Median current condition: Assumed current speed (m/s)	0.11				wind velocity 5.56 (m/s) [2]
High current condition: Assumed current speed (m/s)	0.27				1% exceedance; wind velocity 0.28 (m/s) [2]

Note 1: Extracted from sheet "2013 Sample Year Temperatures" of file: "Sample year of temperature time series for Mammoth Lake inflows.xlsx"
Note 2: The hourly wind speed data were downloaded for Baker Lake A Station (2300500), Latitude of 64°17'56" and Longitude of 96°04'44"

Mammoth Lake Plum Model

WRSF SEEPAGE – INPUT PARAMETERS

Design Parameters - Effluent

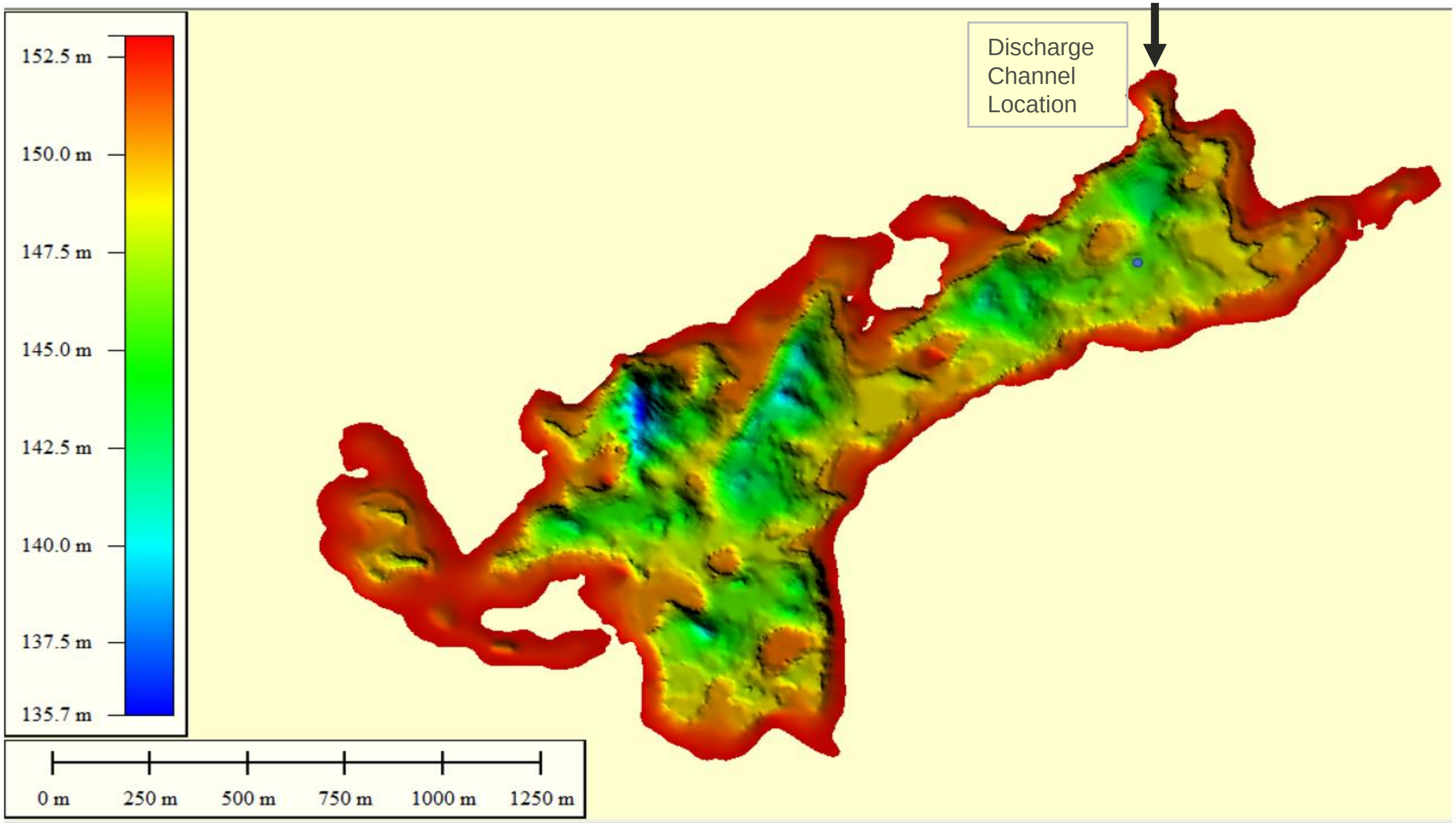
Month	June	July	August	September	Reference
Discharge (m^3/s)	0.045	0.004	0.006	0.014	modelled
Temperature (°C)	2	8	10	6	Assumed the same as Lake temperature
Maximum TDS concentration (mg/L)	416	1382	2209	1407	modelled
Density (kg/m^3)	1000.31	1000.97	1001.46	1001.09	calculated

Note 1: Extracted from sheet "2013 Sample Year Temperatures" of file: "Sample year of temperature time series for Mammoth Lake inflows.xlsx“

Mammoth Lake Plume Model

WRSF SEEPAGE

Discharge Channel Location



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Mammoth Lake Plume Model

WRSF SEEPAGE - RESULTS

CORMIX simulation results

Month	June	July	August	September
	Distance from Channel Mouth and along Plume Centre line (m) where Dilution =16			
Calm condition	20	5	7	10
Median Current	60	15	17	22
High Current	47	18	22	27

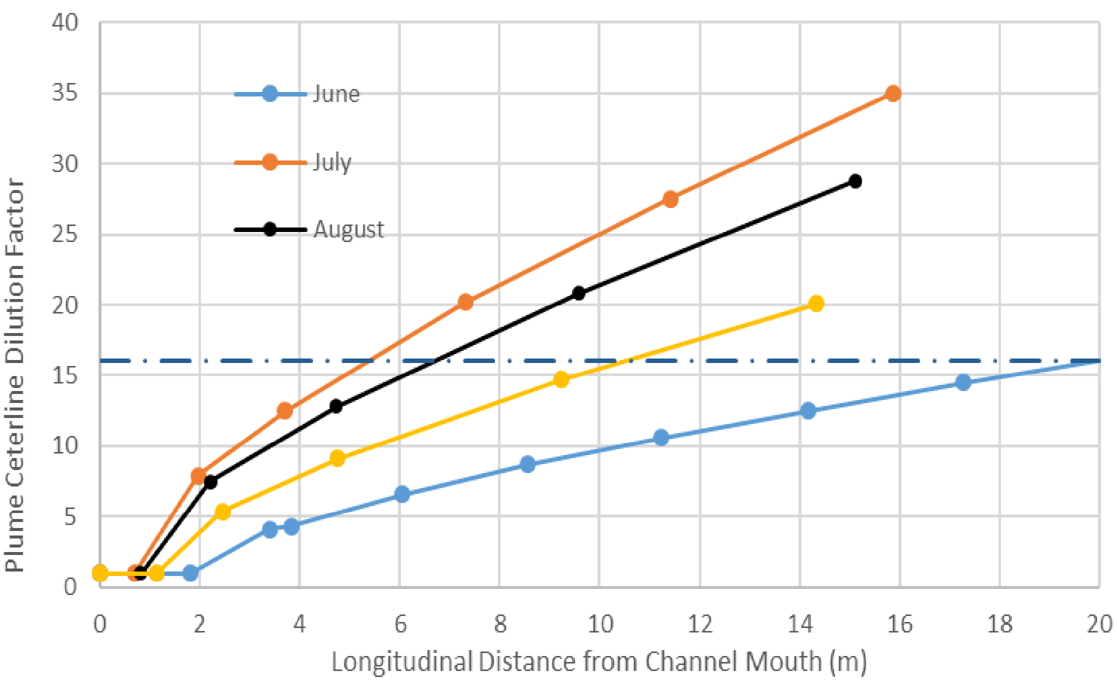
In all cased the minimum required dilution of 16 is provided within 60 m of the discharge location

Mammoth Lake Plume Model

WRSF SEEPAGE - RESULTS

Calm conditions require the shortest mixing zone distance to achieve required dilution:

5 to 20 meters

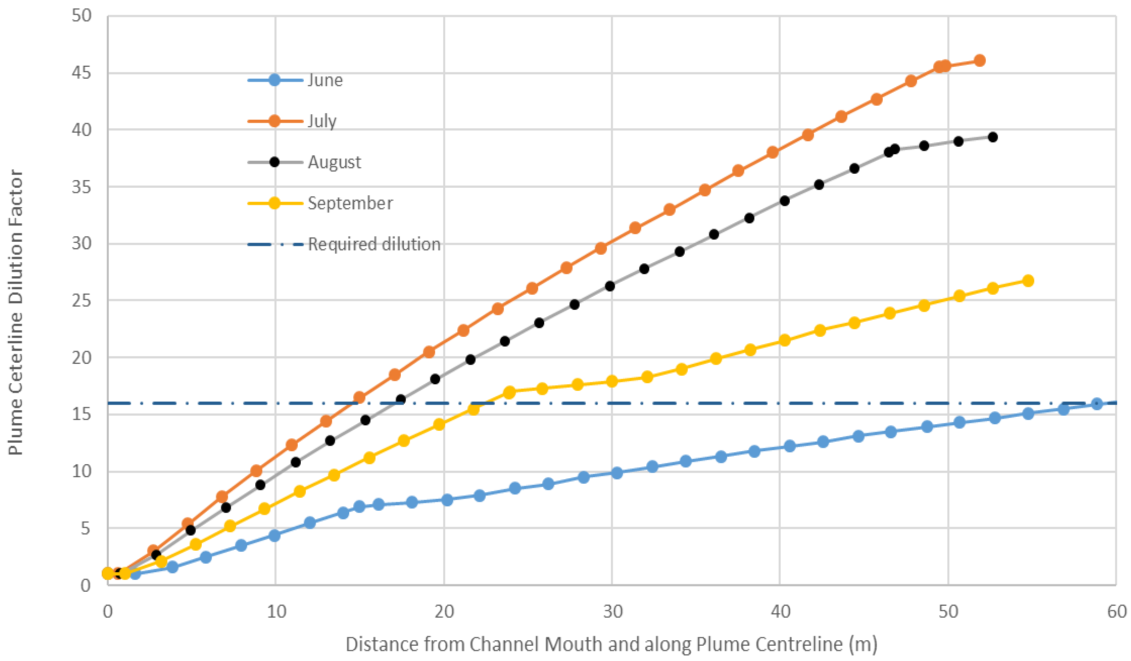


Mammoth Lake Plume Model

WRSF SEEPAGE - RESULTS

In median current, required dilution is achieved at longer distances

Up to 60 meters



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Mammoth Lake Plume Model

WRSF SEEPAGE

Conclusion

- A rock fill weir at outlet will channelize seepage outflow into Mammoth lake and facilitate dilution.
- Within Mammoth Lake, the required dilution of WRSF seepage is predicted to be met at 60 m from the discharge location in all scenarios

Mammoth Lake Model

EFFLUENT DISCHARGE PLUME – INPUT PARAMETERS

Required Effluent Dilution

For the predicted maximum effluent concentration to meet receiving environment quality guideline at the edge of the mixing zone.

Minimum required dilution is 27 for phosphorus; this will achieve the required dilution for all other constituents

Parameters	Units	CCME/SSWQO	Maximum Predicted Effluent Quality	Required Dilution
NH3	mg/L as N	2.9	0.23	0.1
P	mg/L	0.01	0.27	27
Al	mg/L	0.1	0.32	3.2
As	mg/L	0.025	0.11	4.4
Cd	mg/L	0.000012	0.000097	8.1
Cr	mg/L	0.001	0.019	19
Cu	mg/L	0.002	0.014	7.1
Fe	mg/L	0.3	1.1	4
Pb	mg/L	0.001	0.0037	3.7
Hg	mg/L	0.000026	0.000074	2.9
Ni	mg/L	0.038	0.059	1.6
Zn	mg/L	0.03	0.019	0.6

Mammoth Lake Model

EFFLUENT DISCHARGE PLUME – INPUT PARAMETERS

Design Parameters

Mammoth Lake

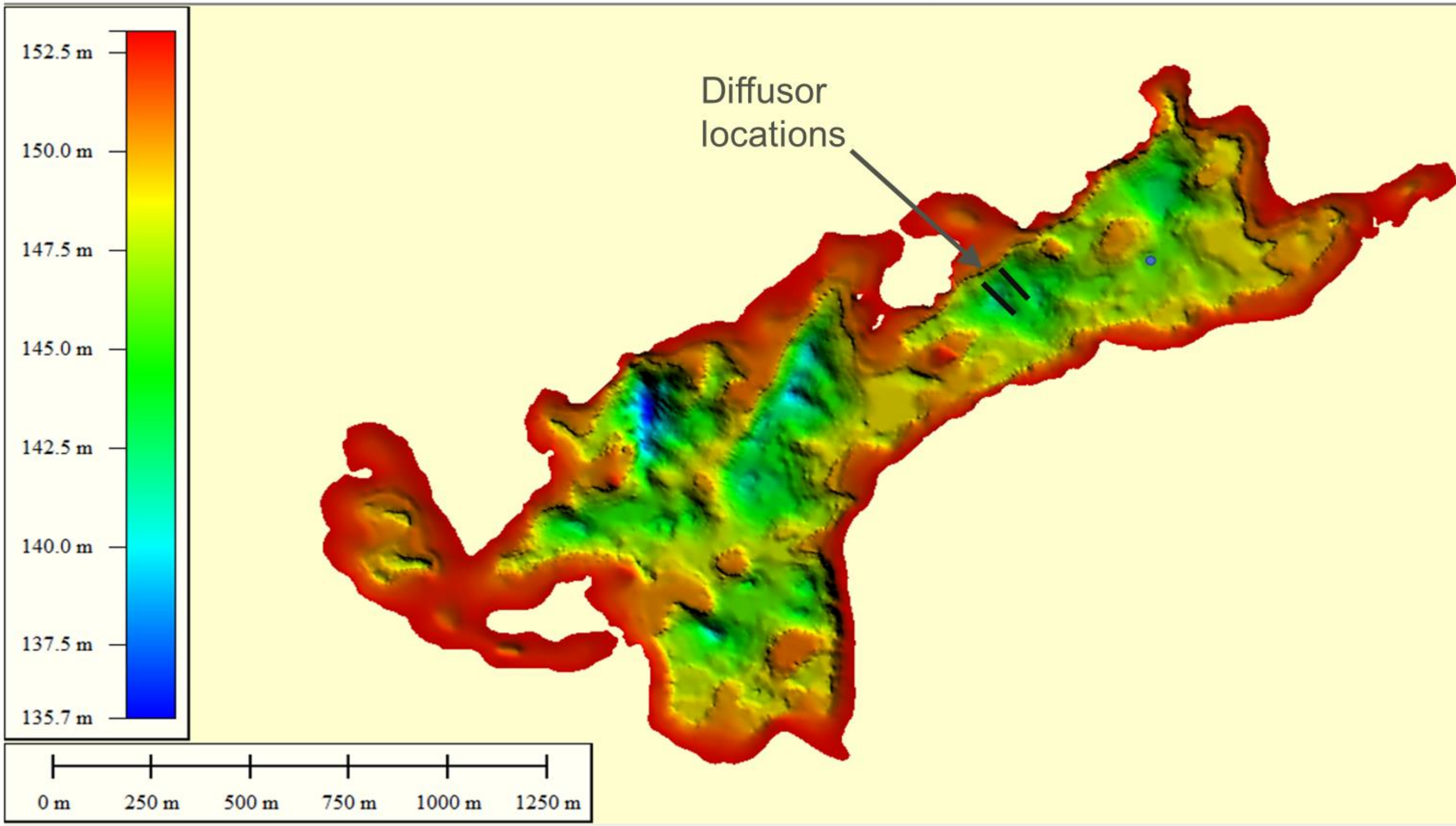
- Minimum Lake depth 7.9m; others same as for WRSF seepage analysis

Effluent

- 800 to 1600 m^3/hr discharge rate in two diffusor lines. This flow represents the maximum treatment capacity for high flow events

Mammoth Lake Model

EFFLUENT PLUME – INPUT PARAMETERS



Mammoth Lake Model

EFFLUENT PLUME

Outputs of CORMIX Simulations for Design Scenarios

Scenario	Open Water Season	
Discharge (m³/h)	800	400
Distance from near field mixing zone edge to diffuser (m)	59	44
Dilution factor at edge of near field zone	27	31

Mammoth Lake Model

DIFFUSOR DESIGN

Conclusions

- Proposed diffusor design: 10 ports at 12.6 m spacing and 75mm diameter diffusor ports
- Effluent mixing to receiving water quality targets are predicted to be achievable within 60 meters of the diffusor pipes. A mixing zone allowance of 100 metres is recommended.

Mammoth Lake

Hydrodynamic Model

Mammoth Lake Model

HYDRODYNAMICS

Objectives

Evaluate seasonal water circulation patterns in Mammoth Lake resulting from effluent discharge and to predict and evaluate the water quality within Mammoth lake during operations and post-closure

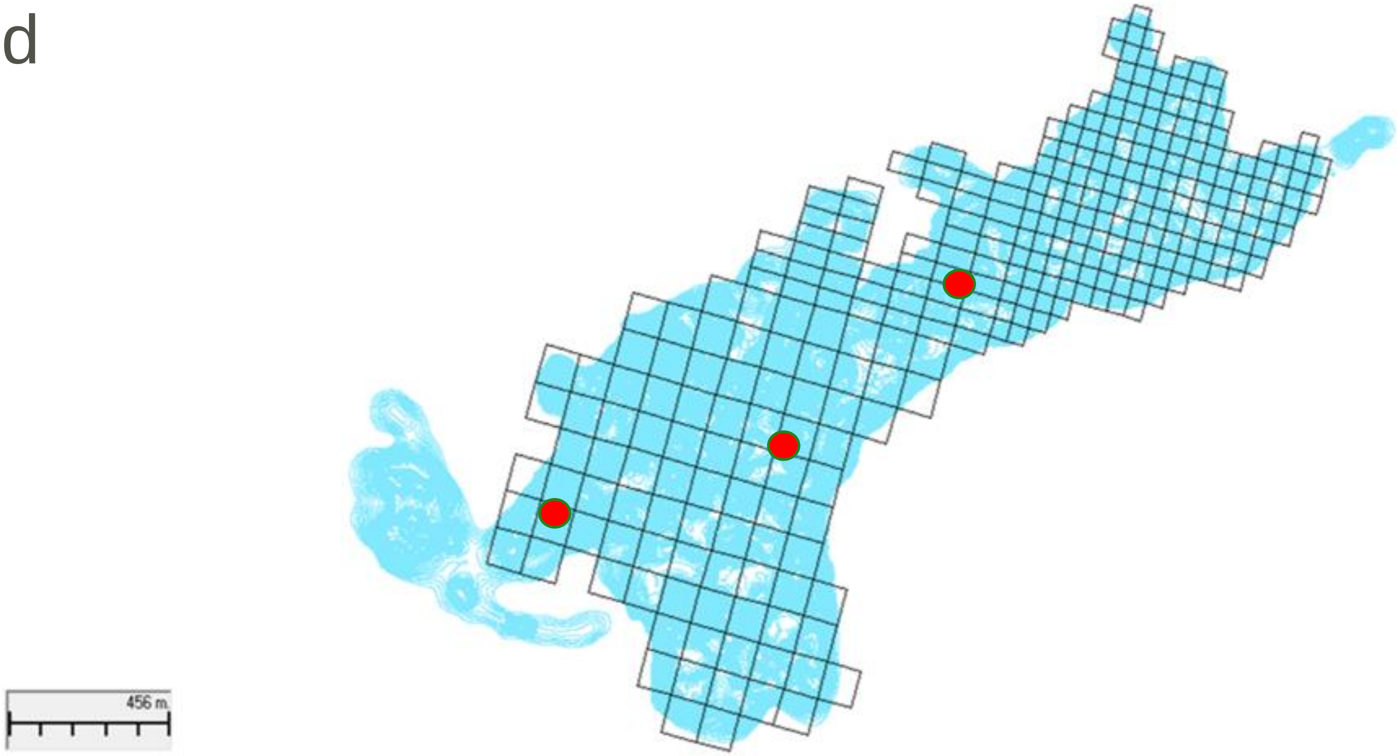
Use of Generalized Environmental Modelling System for Surface waters (GEMSS) 3-D modelling platform. A hydrodynamic and transport modules embedded in a geographic information and environmental data system

- Model domain: 3-D grid through Mammoth Lake grid size $50m^2$ in NE part of Lake (50m x 50m x 1m depth) near the diffusor and WRSF; $100m^2$ grid spacing in SW portion of Lake (100m x 100m x 1m).
- Model run from construction to 40 years post-closure: July 1, 2017 to January 1, 2067.
- Input data: wind speed and direction, precipitation, run-off, pumped flows, groundwater flows, seepages, water and lake bed sediment temperature, sediment heat exchange rate, outflow to Mammoth Lake
- Cryo-concentration effect from ice cover neglected given the low TDS of Mammoth Lake water quality, based on evidence in baseline water quality during ice cover and in open water season in Mammoth Lake

Mammoth Lake Model

HYDRODYNAMICS – INPUT PARAMETERS

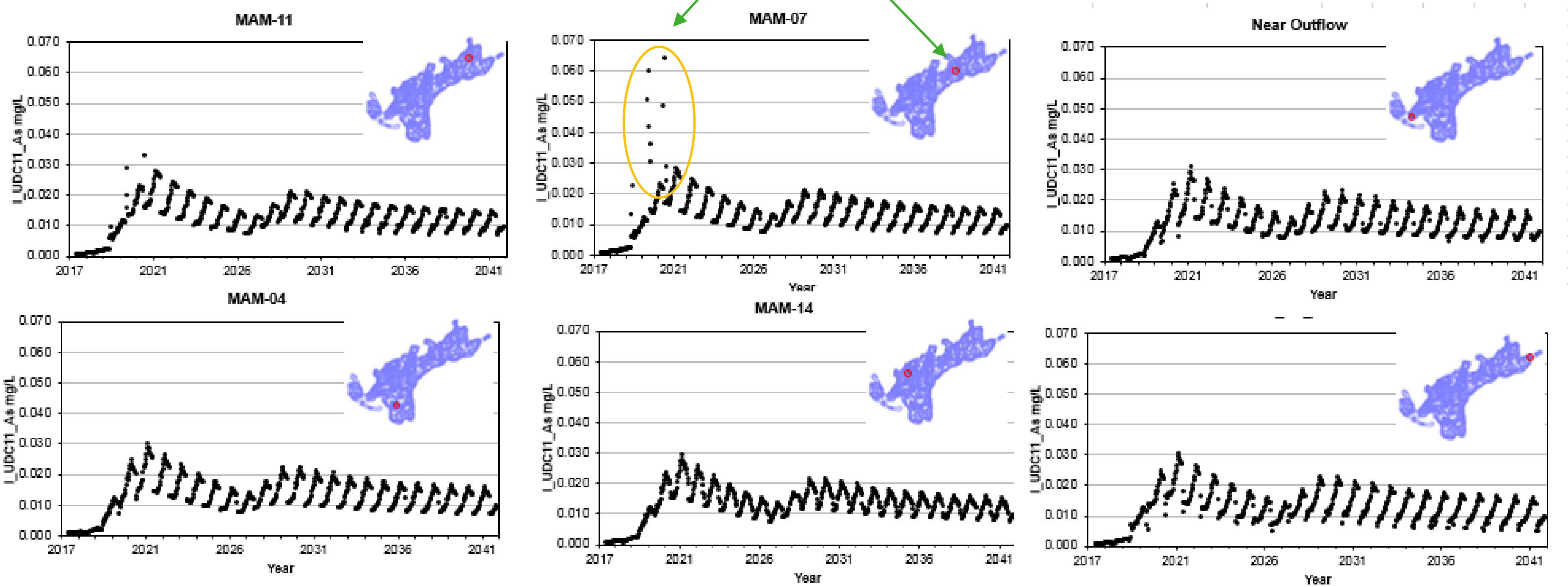
Model Segmentation and discharge locations evaluated



Mammoth Lake Model

HYDRODYNAMICS - RESULTS

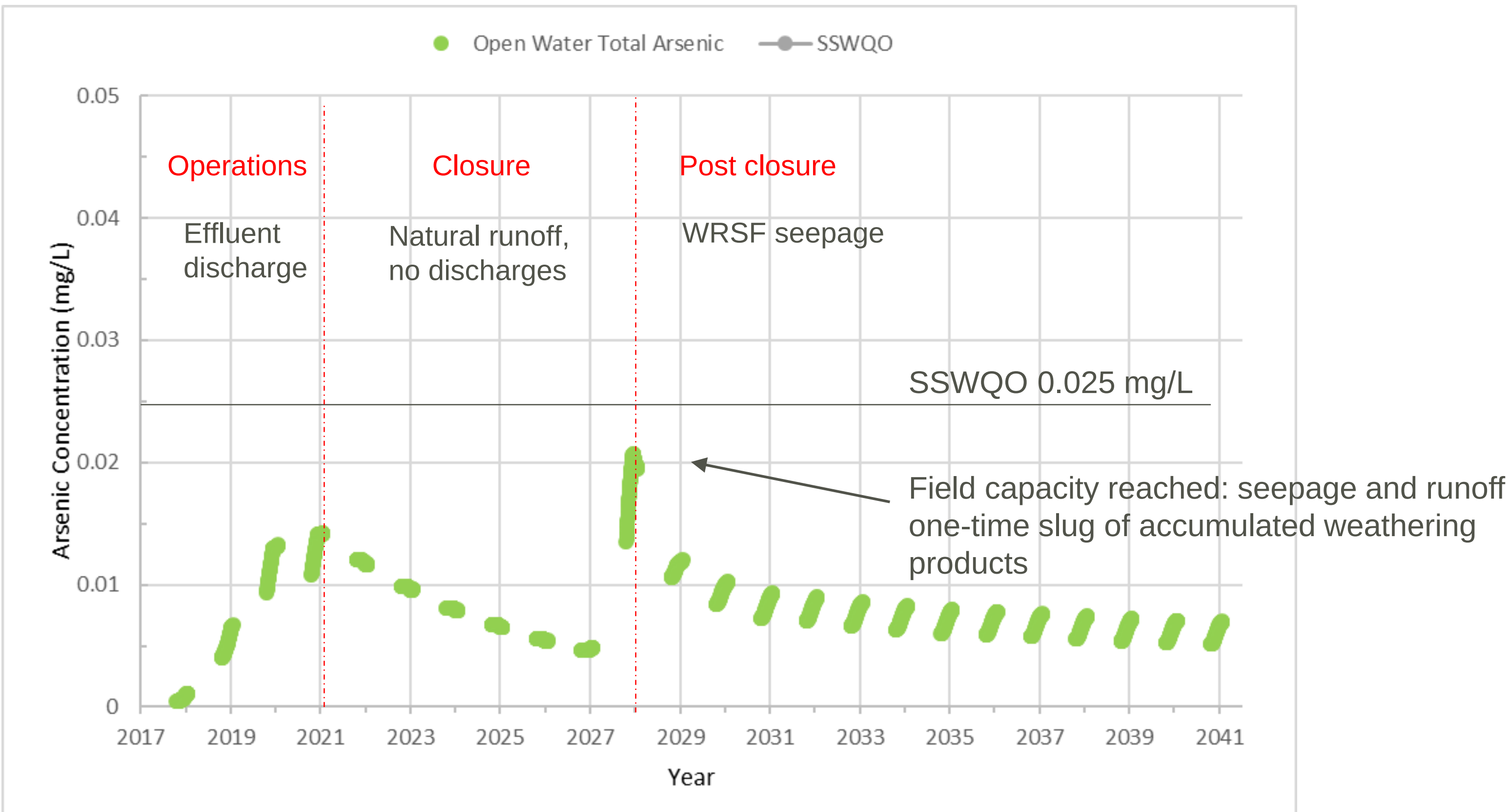
Similar results obtained for all discharge locations evaluated and at each result node (away from the diffusor mixing zone) = fully mixed conditions



Mammoth Lake Model

HYDRODYNAMICS - RESULTS

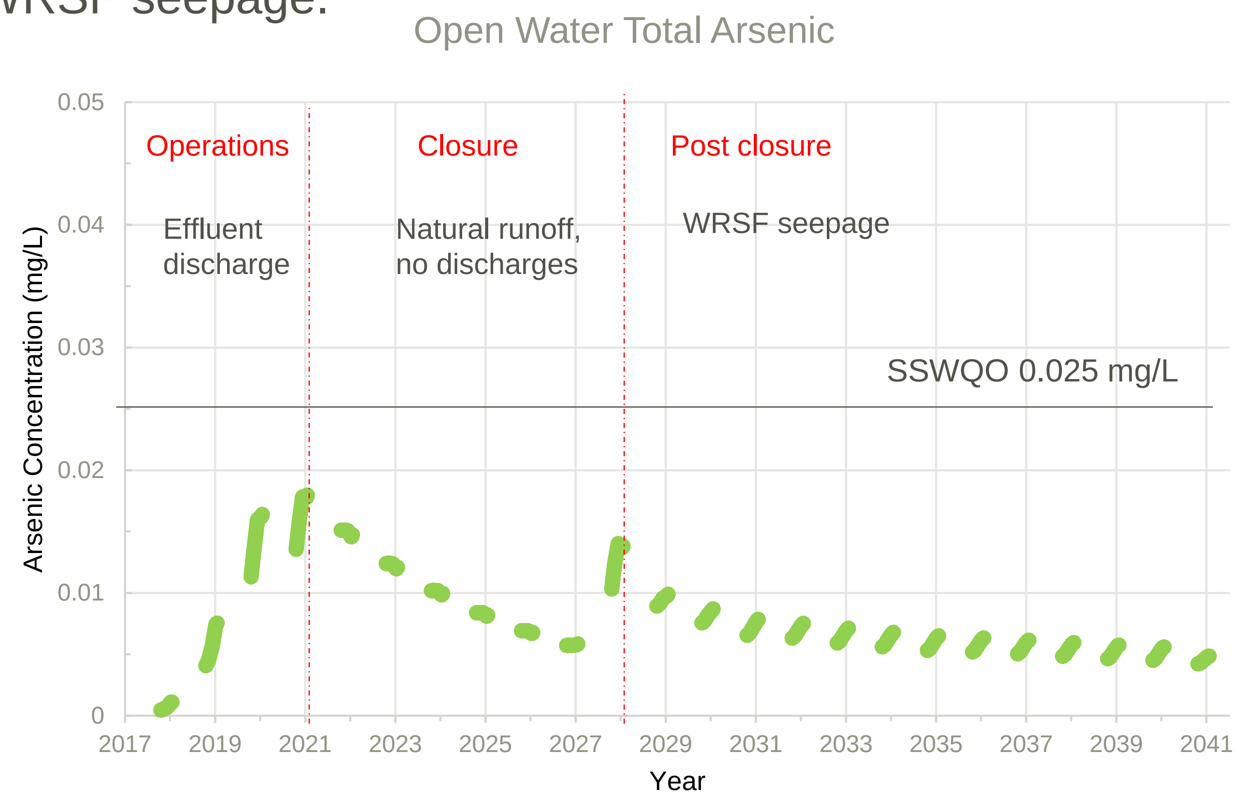
Arsenic in effluent discharge during operation and arsenic released from cover (4-meter active thaw depth cover with low leaching waste rock).



Mammoth Lake Model

HYDRODYNAMICS – RESULTS SENSITIVITY

Arsenic in effluent discharge during operation and arsenic released from cover (4-meter active thaw depth cover with low leaching waste rock) and 50% of predicted WRSF seepage.



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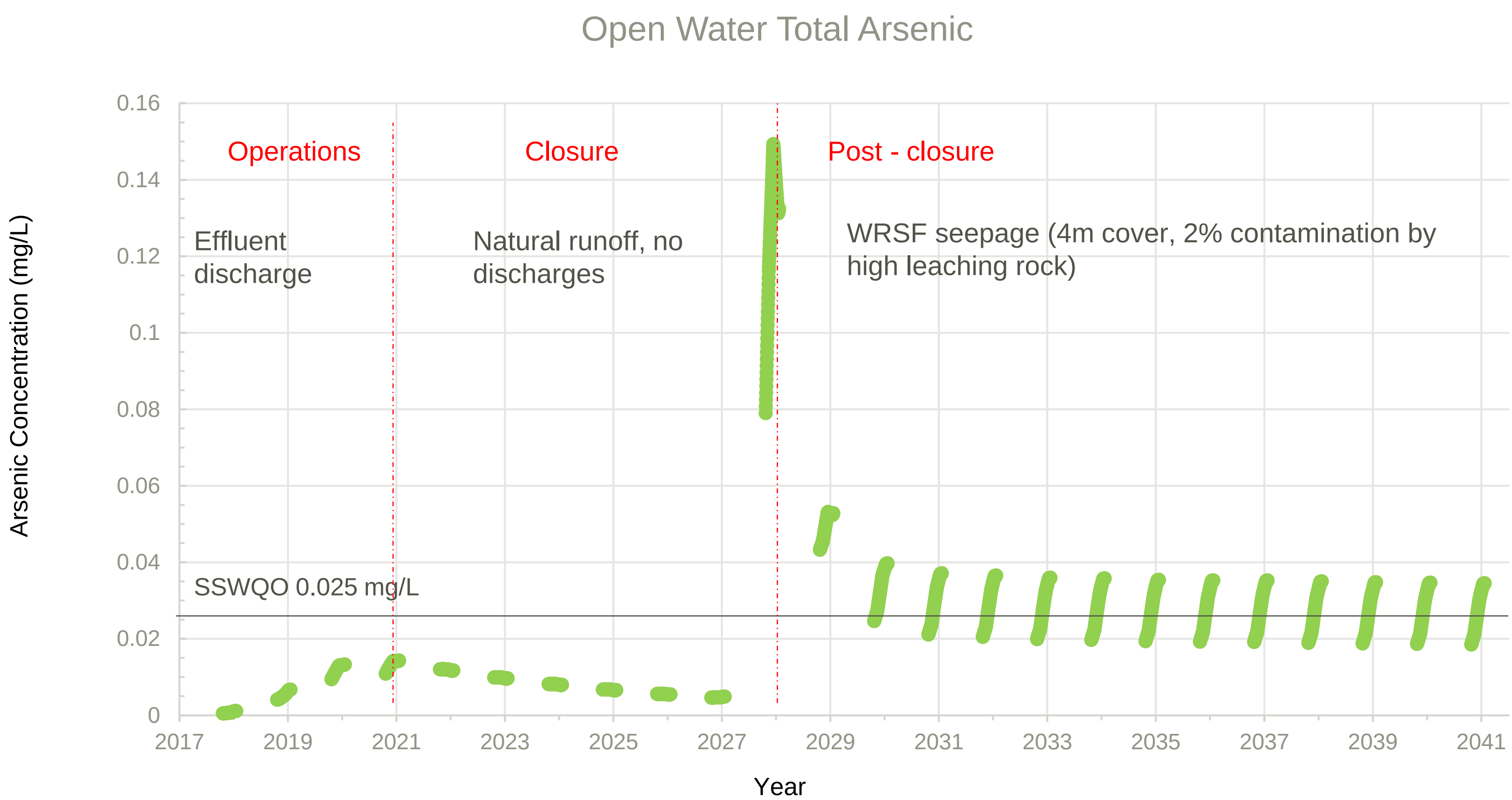
Mammoth Lake Model

HYDRODYNAMICS – RESULTS SENSITIVITY

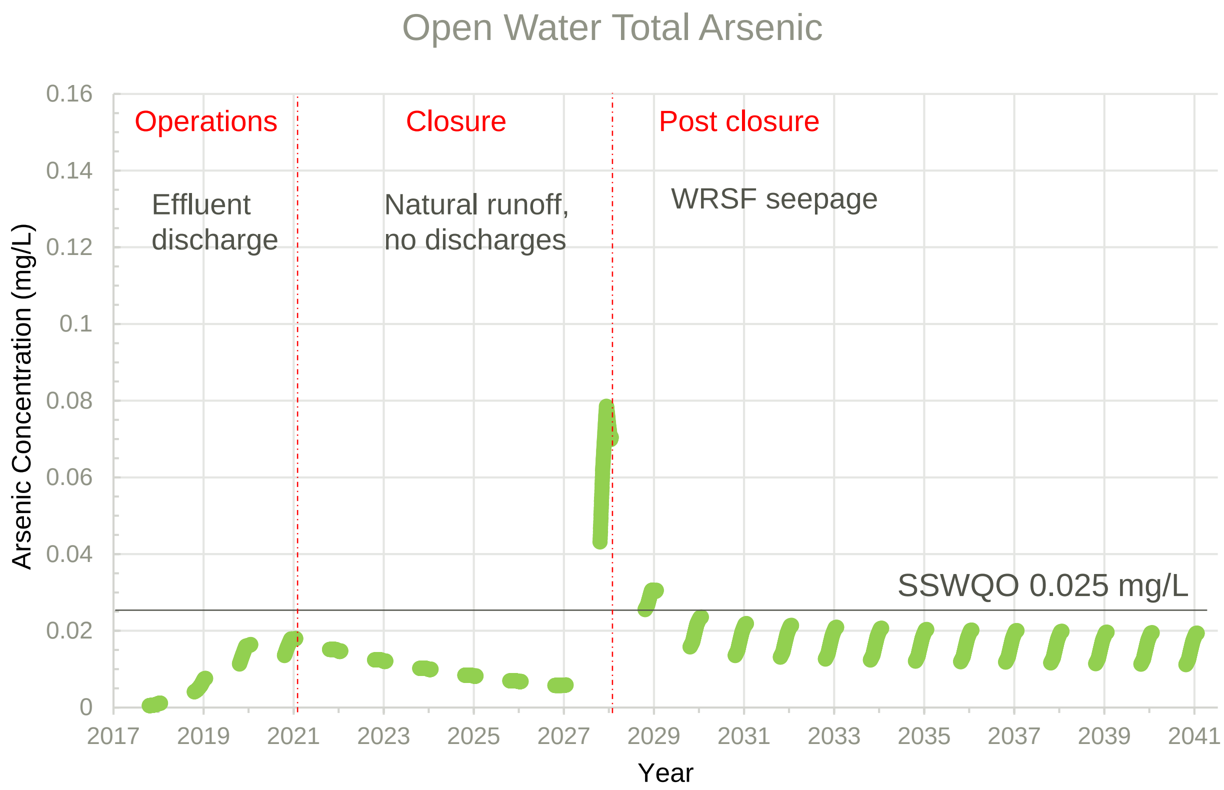
Arsenic release from 4-m cover with 2% contamination of high leaching waste rock



Mammoth Lake Model

HYDRODYNAMICS – RESULTS SENSITIVITY

Arsenic release from 4-m cover with 2% contamination of high leaching waste rock, 50% of WRSF seepage.



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Mammoth Lake Model

HYDRODYNAMICS

Conclusions

- Effluent discharge into Mammoth Lake will be well mixed
- Steady-state untreated WRSF contact water released is predicted to meet SSWQO for arsenic in the Lake in the long-term, under the anticipated cover performance scenario (from the 4-meter cover of low arsenic leaching waste rock)
- Mammoth Lake is sensitive to cover material seepage quality, in turn sensitive to cover composition and WRSF pile contact water volume. Observational data of Meadowbank's WRSF suggest that WRSF contact water volumes are substantially lower than originally predicted (Portage is 20 to 40% lower, Vault WRSF contact water is minimal compared to 178,000m^3 predicted at maximum footprint year) using similar modelling assumptions. Modelling results reflect a conservative chemical load estimate to Mammoth Lake in WRSF seepage that will be verified with monitoring.

➢ The Waste Rock Management Plan, the Water Quality and Flow Monitoring Plan and the ARD/ML Monitoring Plan are in place to verify and validate modelling assumptions and cover performance.

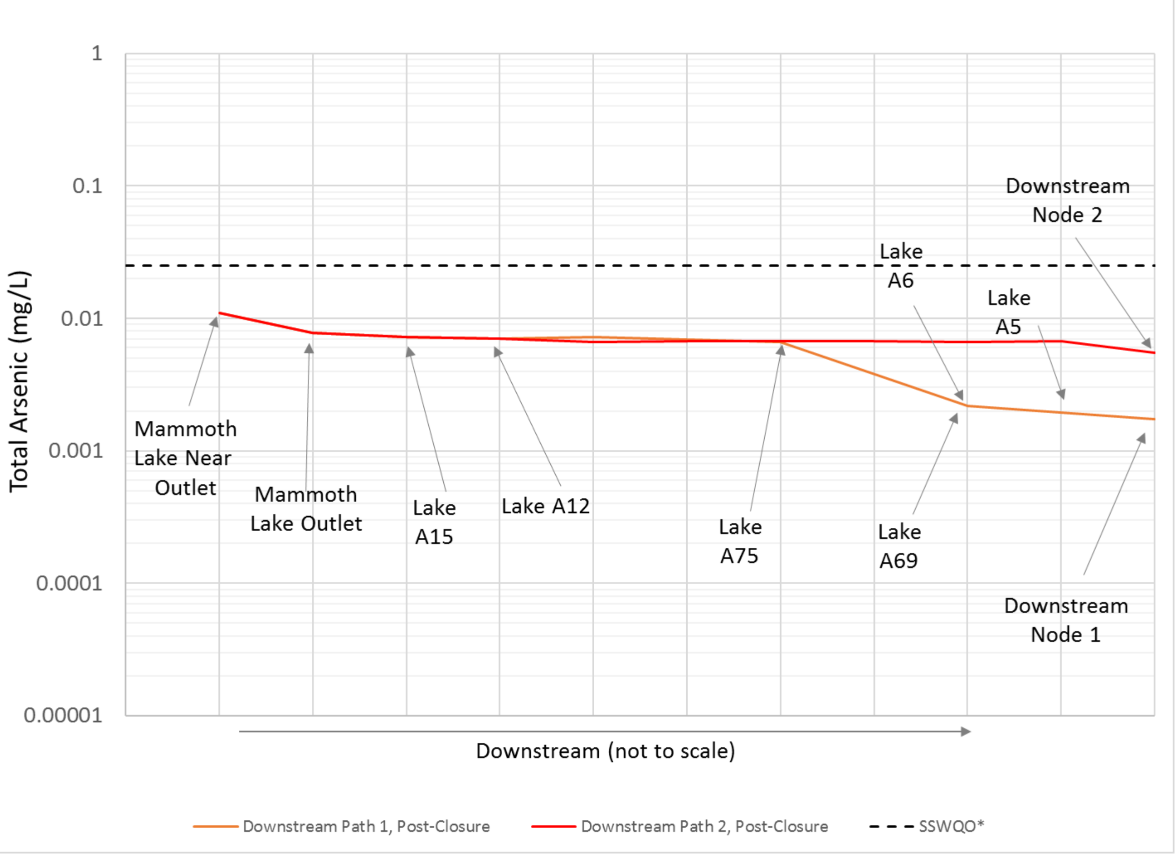
Downstream Lake Water Quality

Downstream Lakes

PREDICTED WATER QUALITY

Arsenic in downstream Lakes is predicted to meet SSWQO during operation and long term post-closure

Steady-state arsenic release rate, Year 2039



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Thermal Modelling of WRSF

WRSF Thermal Model

Objectives

- Validate or update anticipated thermal conditions in the Whale Tail WRSF using Meadowbank WRSF thermal data, namely, the active thaw depth.
- Adjust cover design as needed based on modelling results

WRSF Thermal Model

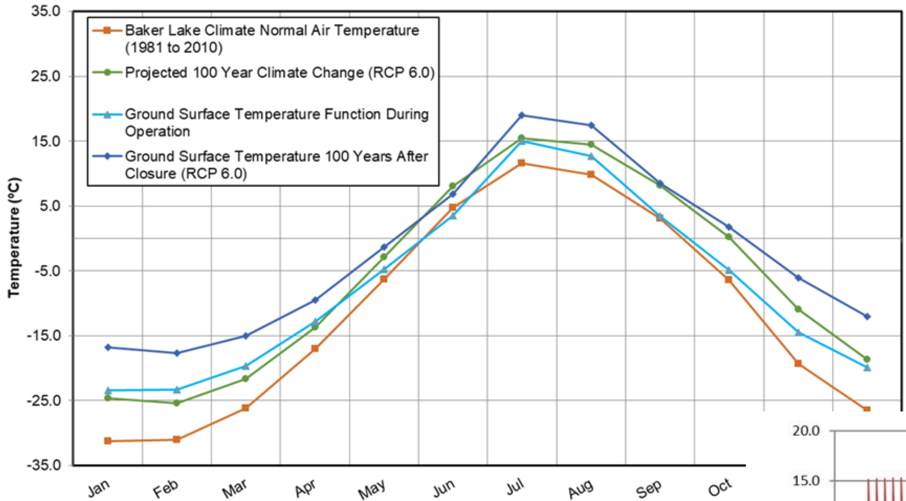
METHOD, INPUT PARAMETERS

- 1-D thermal model: TEMP/W software combined with Air/W and Seep/W
- Calibration using temperature profiles from thermistor data at Meadowbank (instrument RCP-6 which reflects the average active thaw depth of the entire pile)
- Assumed thermal properties of materials:

Material	In-situ Vol. Water Content (m^3/m^3)	Porosity	Saturation (%)	Thermal Conductivity (W/m-°C)		Volumetric Heat Capacity (MJ/m^3-°C)		Air Conductivity (m/s)
				Frozen	Unfrozen	Frozen	Unfrozen	
NAG Waste Rock (upper 5 m)	0.058	0.30	19.3	2.2	1.9	1.8	2.0	0.5
Waste Rock (5 to 25 m deep)	0.058	0.26	22.3	2.5	2.2	1.9	2.1	0.075

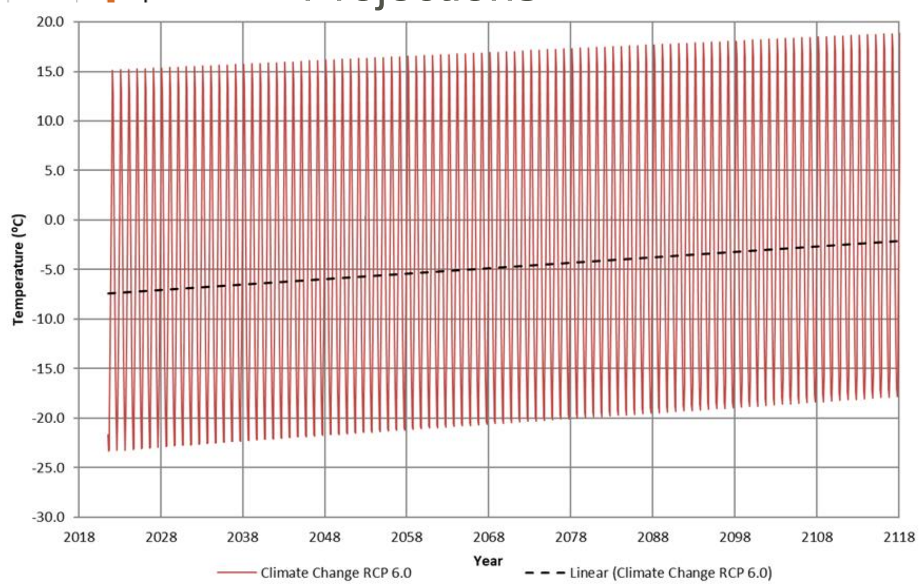
WRSF Thermal Model

CLIMATE CONDITIONS CONSIDERED



Ground Surface Temperature Function during Operations

Ground Surface Temperature 100 Year Climate Change Projections



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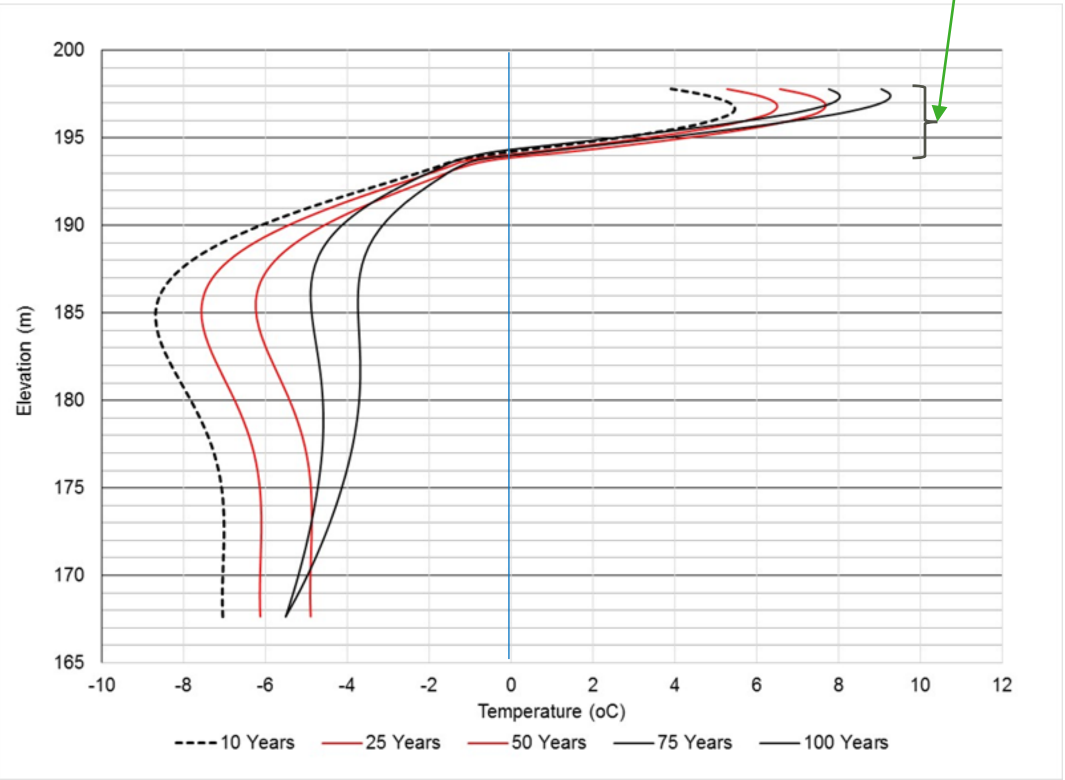
WRSF Thermal Model

PREDICTED ACTIVE THAW DEPTH

Long-term temperature profiles computed for model scenarios

Maximum active thaw depth



WRSF Thermal Model

Conclusions

- Based on results calibrated to the Meadowbank WRSF thermal data to date and climate change predictions, the maximum predicted thickness of the WRSF active layer is 4.24 meters ± 0.5 meters = 4.7 meter cover thickness (4.2 + 0.5 contingency).
- There is sufficient NPAG/NML material for this cover thickness if needed.
- Increased active thaw depth/rock cover from 4.0 to 4.7 is expected to have no effect on WRSF contact water quality during operations, and long-term post closure effects to water quality of a thicker active layer are expected to be within model accuracy where a clean (low leaching) waste rock cover present.
- The Thermal Monitoring Plan has measures to verify and validate the WRSF thermal model with operational data from site.

Modelling Conclusions

For the mine, water and waste management plans that describe the scenarios modelled, and per the interpretation of the modelling scenarios, no change to the overall water and waste management strategy is required for the operation and closure of the Whale Tail project since:

- Whale Tail flooded Pit Lake waters are predicted to fully mix twice per year
- Arsenic diffusion from submerged pit walls and the anticipated hydrogeological conditions around the Pit Lake post-closure are not expected to play a significant role on Pit Lake arsenic concentration
- Mammoth Lake is predicted to continue to be a fully mixed system during operation and post-closure with effluent and seepage discharge flowing into it
- Mammoth Lake water quality as well as downstream lakes are predicted to meet the project specific SSWQO for arsenic during operation and at closure according to the mine waste and water management plans proposed
- The average thickness of the WRSF active layer is within the range modelled. Should monitoring suggest the need for a thicker cover, material is available for this and the effect on contact water quality of a thicker, clean rock (NPAG and NML) cover is anticipated to fall within the model accuracy.
- The Mine Waste Management Plan, ARD/ML Monitoring Plan, Water Quality and Flow Monitoring Plan and the Thermal Monitoring Plan are in place to monitor and verify the performance of the cover material and systems and adapt as needed. Progressive covering of the WRSF and Meadowbank WRSF experience will assist in validating modelling predictions on the cover.

Open Discussion