TECHNICAL MEMORANDUM

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TO Michel Groleau Agnico Eagle Mines Limited

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AMARUQ MINE – HYDRODYNAMIC MODELLING OF MAMMOTH LAKE, WHALE TAIL APPROVED PROJECT

1.0 EXECUTIVE SUMMARY

Development of the Approved Whale Tail deposit will create a 150-m deep pit lake and a 20-m-deep water Attenuation Pond, within the North Basin of Whale Tail Lake. At the end of mine life, these areas will be flooded into a single water body again and re-joined with the South Basin of Whale Tail Lake. The mine and water management plans of the Approved Project were assessed in the Environmental Impact Assessment that was submitted to the Nunavut Water Board on November 25, 2016 and subsequently Approved.

Mammoth Lake has been considered as the discharge location for mine water from the Whale Tail Pit Lake (Golder 2018) and will also receive runoff from the Waste Rock Storage Area during the post-closure period of the Approved Project. To assess the effects of the Phase 1 mine plan on the water quality of Mammoth Lake, a hydrodynamic model was applied to simulate the circulation of lake water and resulting concentration of constituents within the waterbody over a 25-year period, from 2017 to 2042. Total Arsenic and total phosphorus concentrations in Mammoth lake were modelled using the three dimensional (3-D), hydrodynamic modelling program GEMSS (Generalized Environmental Modelling System for Surface waters, 2018). A 3-D model was selected over the 2-D model owing to the wide surface area and complex geometry of the lake relative to the specific inputs.

The model simulations indicated the following:

- Mammoth Lake is predicted to be well-mixed during operations, closure, and post-closure.
- Total arsenic concentrations in Mammoth Lake during operations, closure, and post-closure are predicted to meet Site-specific Water Quality Objectives (SSWQO) of 0.025 mg/L during open water seasons. A short-lived spike is predicted to occur when the WRSF cover reaches field capacity water content and releases stored mineral products modelled to accumulate over time. This is predicted to occur through a short-lived flushing event. After this, concentrations decrease to below the SSWQO into post-closure.
- Total phosphorus concentrations in Mammoth Lake show a temporary increase during operational discharge of treated effluent to slightly higher than the upper range for oligotrophic conditions, as was predicted in the Approved Project EA. These concentrations are predicted to decrease after discharge is stopped. A short-live spike is predicted to occur when the cover reaches field capacity; concentrations decrease to stay within the oligotrophic range after this flushing event.

- The formation of ice may not have a significant effect on lake water constituent concentration below the ice in winter given the low TDS of Mammoth Lake water during operations, closure and post-closure. As a conservative measure, this process was evaluated and shows that concentrations could periodically rise in winter below the ice if cryo-concentration becomes significant, if mine plans changed and/or if effluent salinity was elevated.

2.0 INTRODUCTION

The Whale Tail Project is located on Inuit-owned land, approximately 150 km north of the hamlet of Baker Lake, and approximately 50 km northwest of the Meadowbank Mine, in the Kivalliq region. In early 2013, the property was acquired by Agnico Eagle subject to a mineral exploration agreement with Nunavut Tunngavik Incorporated. The Kivalliq Inuit Association issued Agnico Eagle a land use permit, the Nunavut Impact Review Board issued a project certificate and the Nunavut Water Board issued a water licence allowing the project to move ahead to construction.

The Approved Project includes a single 150-m-deep open pit mine, called the Whale Tail Pit, located under the North Basin of the existing Whale Tail Lake. This basin will be dewatered for mining and the dewatered area will include a 20-m-deep Attenuation Pond. Mammoth Lake is located immediately downstream of Whale Tail (North Basin). It will receive North Basin dewatering water, mine contact waters (effluent and diverted clean flows) during operations and Whale Tail Waste Rock Storage Facility (WRSF) contact water post-closure (2027 to 2042).

The focus of this technical memo is the water quality of Mammoth Lake that is expected to result from receiving Approved Project discharge waters. The Approved Project includes three distinct time periods: operations, closure, and post-closure. At the start of the operations period (2020 to 2022), the Whale Tail Lake (North Basin) will be isolated from the remainder of the lake by the Mammoth dike (between Mammoth Lake and Whale Tail Lake (North Basin) and by the Whale Tail dike separating the Whale Tail North and South basins. Water from the North Basin will be pumped to Mammoth Lake to provide access to the Whale Tail deposit located beneath. During closure (2022 to 2027), Whale Tail Pit and the Attenuation Pond will be flooded to the original water level in Whale Tail (North Basin), forming the Whale Tail Pit Lake. Once the water quality in Whale Tail Pit Lake meets site surface water quality objectives (SSWQO), the dikes will be decommissioned re-establishing the original flow pattern and allowing Pit Lake water to flow naturally to Mammoth Lake. This will initiate the post-closure period (2025 to 2042). The Whale Tail Pit Lake will have similar surface dimensions, but different bathymetry, due to the original, pre-operations water body.

Mammoth Lake is located directly southwest of the Whale Tail Pit Lake and mine site. At a lake water surface elevation of 152.8 metres above sea level (masl), Mammoth Lake has a surface area of 1.6 square kilometres (km^2), a mean depth of 3.9 metres (m), and a maximum depth of 17 m (Golder, 2016). The north-eastern tip of Mammoth Lake is the inlet point that receives natural overland flow from Whale Tail Lake prior to mining. The outflow of Mammoth Lake to the downstream lake, designated as Lake A15, is located at the southwestern tip of Mammoth Lake (Figure 3).

Dewatering of Whale Tail Lake (North Basin) and the treated mine water during operations are predicted to be discharged into Mammoth Lake via submerged effluent diffusers. The purpose of the diffusers is to promote dilution of constituents in the water that is discharged into Mammoth Lake from mine discharge effluent during operations. Three potential diffuser locations were modelled to determine a suitable location for dilution of constituents released into Mammoth Lake from the mine site. During closure, no mine site water or waste rock water is predicted to be released into Mammoth Lake. During the post-closure time period, Mammoth Lake is predicted to receive runoff from the Whale Tail WRSF and to receive overflow discharge from the Whale Tail Pit Lake.

This technical memo provides the methods and results of hydrodynamic modelling performed on Mammoth Lake for the closure and post-closure periods. The goals of the model were:

- To predict and evaluate the water quality within Mammoth Lake over time – specifically, total arsenic and total phosphorus.
- To predict the dilution of constituents across Mammoth Lake after operations are complete.
- To assess how changing the diffuser discharge location in Mammoth Lake will affect constituent concentrations across Mammoth Lake and determine if Mammoth Lake will remain well-mixed.

The Mammoth Lake hydrodynamic model used results of the GoldSim water balance model of the mine site and the CE-QUAL-W2 hydrodynamic model of Whale Tail Pit Lake (Golder 2018). The water quality and discharge rates of the outflows predicted by these models were used as inputs in the Mammoth Lake model.

3.0 METHODS

3.1 Model Platforms

The Mammoth Lake model was developed in the GEMSS (Generalized Environmental Modeling System for Surfacewaters 2018) which is an integrated system of three-dimensional (3-D) hydrodynamic and transport modules embedded in a geographic information and environmental data system. GEMSS is in the public domain and has been used by Golder for similar studies in the North West Territories including the Snap Lake (De Beers Canada 2013), Lac du Sauvage (Dominion Diamond 2014), and Gahcho Kué (De Beers 2012) diamond mine projects, and other properties in North America and worldwide. GEMSS was developed in the mid-1980s as a hydrodynamic platform for transport and fate modelling. The hydrodynamic platform (“kernel”) provides 3-D flow fields from which the distribution of various constituents can be computed. The constituent transport and fate computations are grouped into modules. The modules used for the Mammoth Lake Model are the hydrodynamic and transport module and a user-defined constituent module.

The theoretical basis of the hydrodynamic kernel of the GEMSS is the 3-D generalized, longitudinal-lateral-vertical hydrodynamic and transport model (Edinger and Buchak 1980, 1985). This computation has been peer reviewed and published (Edinger and Buchak 1995; Edinger and Kolluru 1999; Edinger et al. 1994, 1997). The “kernel” is an extension of the longitudinal-vertical transport model written by Buchak and Edinger (1984) that forms the hydrodynamic and transport basis of the 2-D water quality model CE-QUAL-W2 (US Army Engineer Waterways Experiment Station 1986). Improvements to the transport scheme, construction of the constituent modules, incorporation of supporting software tools, Geographic Information System (GIS) interoperability, visualization tools, graphical user interface, and post-processors have been developed by Kolluru et al. (1998, 1999, 2003) and Kolluru and Fichera (2003).

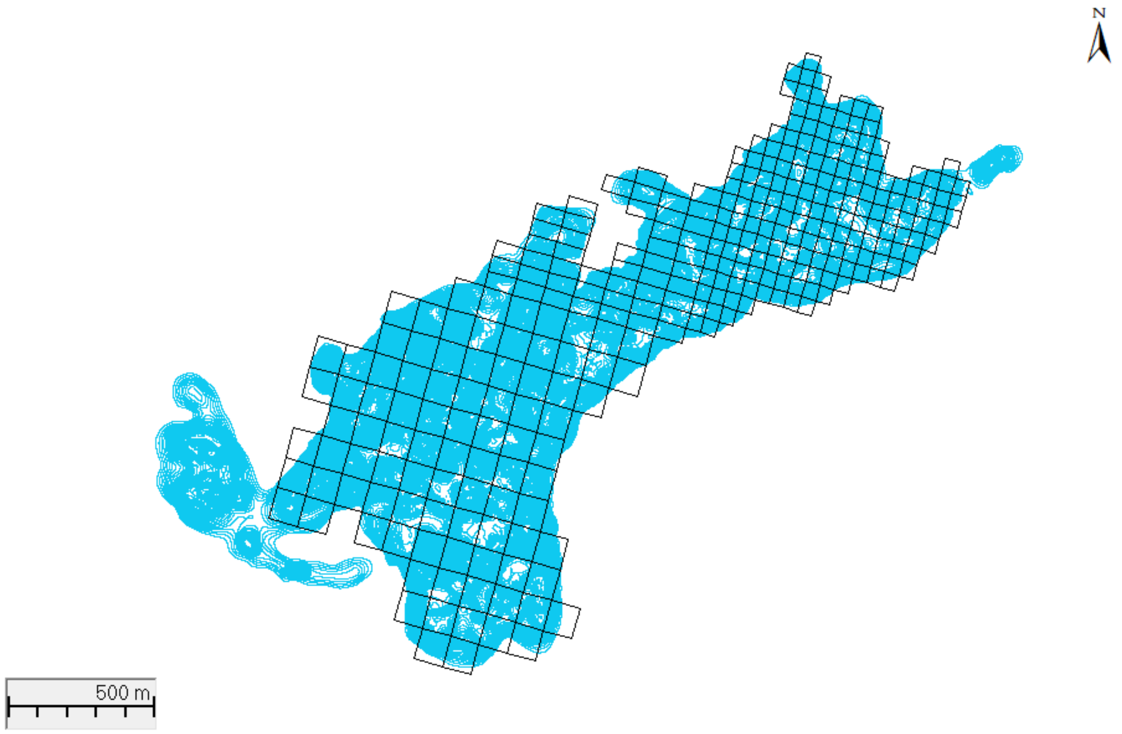
The GEMSS platform was used to evaluate circulation in Mammoth Lake, plus how changing the diffuser location affected the concentrations of constituents across Mammoth Lake at various sample locations. Three potential diffuser locations were modelled in GEMSS: Location A near the middle of Mammoth Lake, Location B in the north basin, and Location C in the south basin near the outflow (Figure 2). Initial modelling of the discharges showed full mixing throughout Mammoth Lake (Appendix A). This allowed for the development of a simplified and faster excel-based mass-balance model to predict future lake-wide concentrations for various management options. The mass-balance model produced similar water quality results as the GEMSS model indicating it is a reliable representation of the GEMSS-based model.

3.2 Model Segmentation

A 3-D grid was developed from the bathymetry of Mammoth Lake in the GEMSS program (Figure 1). The bathymetry scan was obtained in a baseline bathymetry study by Agnico Eagle in 2015 (Golder, 2016). The southwest portion of the lake was not included in this model because it is very shallow and can seasonably become completely dry. The GEMSS modelling system discards any cells that become completely dry and cannot return these cells to the simulation once discarded. To maintain a mass-balance and water-balance in the model throughout the simulation, this region was omitted.

The grid spacing varied between approximately 50 metres (m) and 100 m horizontally, and the vertical resolution was approximately 1 m (Figure 1). The highest horizontal resolution (50 m x 50 m) was used in the area of Mammoth Lake that received water from the WRSF and the preferred diffuser location (Location B).

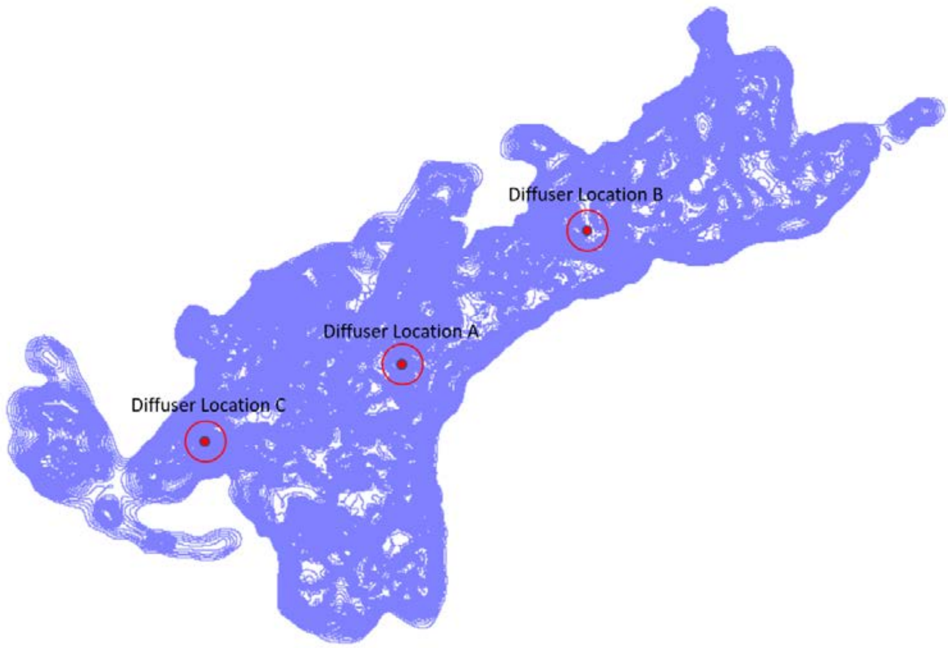
Figure 1: Mammoth Lake 3-D Grid for GEMSS Model



3.3 Potential Diffuser Locations

Three diffuser locations were assessed to determine if the location of the diffuser had a significant effect on water quality at different locations in Mammoth Lake and to determine if the lake is well-mixed. Locations are shown in Figure 2.

Figure 2: Mammoth Lake Diffuser Locations Evaluated



3.4 Model Inputs

The model was run for a period of 9,285 days, representing the 25-year period from July 1, 2017 to December 1, 2042. This time period covered all of operations and closure, and approximately 15 years of post-closure of the Approved Project.

Inflows and outflows were included in the model. Inputs to the model included meteorological, hydrologic, and water quality data, as described in the following sections. The temperature, volume, and concentration of each input were specified in the model in daily timesteps.

3.4.1 Meteorological Inputs

Meteorological input data required for this hydrodynamic model include: air temperature, dew point temperature, wind speed and direction, and solar radiation. An hourly time-series was constructed for each of these inputs during the modelling time period based on observed data from the nearest Environment Canada Meteorological Station, Baker Lake A (Station ID 2300500), located approximately 125 km southeast from the Whale Tail Lake. The Baker Lake A station is at a lower elevation (18.6 masl) compared to Mammoth Lake which has an elevation 152.8 masl (Golder 2016). The record air temperature was adjusted to compensate for the distance and elevation differences between the Baker Lake A station and the site using the following equation (AMEC 2003):

*Mean Daily Air Temperature (Local) = 1.01 * Mean Daily Temperature (Baker Lake) – 0.63*

This equation indicates that air temperatures at Mammoth Lake are about 0.6 degrees cooler that Baker Lake temperatures. The dew point temperature was calculated using the air temperature, relative humidity and air pressure. Solar radiation was calculated from the horizontal irradiance. Observations from 1998 to 2017 were repeated for the modelling time period, except for solar radiation, where the record from 1998 to 2012 was repeated. Where data gaps existed, these were either filled by interpolation (for time gaps < 24 hours) or filled using the previous day or next day's values (for time gaps > 24 hours).

Precipitation inputs were provided as monthly values representative of an average year (Agnico Eagle 2016).

Cumulative rainfall landing during frozen periods (e.g., between October to May) was applied as rainfall during the month of June of the same year if fallen between the months of January and May, or during the month of June of the following year if fallen between the months of October and December. Snowfall landing outside of frozen conditions, was applied as rainfall during the same month.

3.4.2 Hydrologic Inputs

Figures 3, 4, 5, and 6 show conceptual diagrams of the planned inflows and outflow locations in Mammoth Lake during the pre-operations, operations, closure, and post-closure periods, respectively. Descriptions of the inflow locations in the 3D model, plus the assigned temperature and water quality for each input, are presented in Table 1.

Figure 3: Conceptual diagram of inflow and outflow locations into Mammoth Lake during the Pre-Operations period (2018 and 2019)

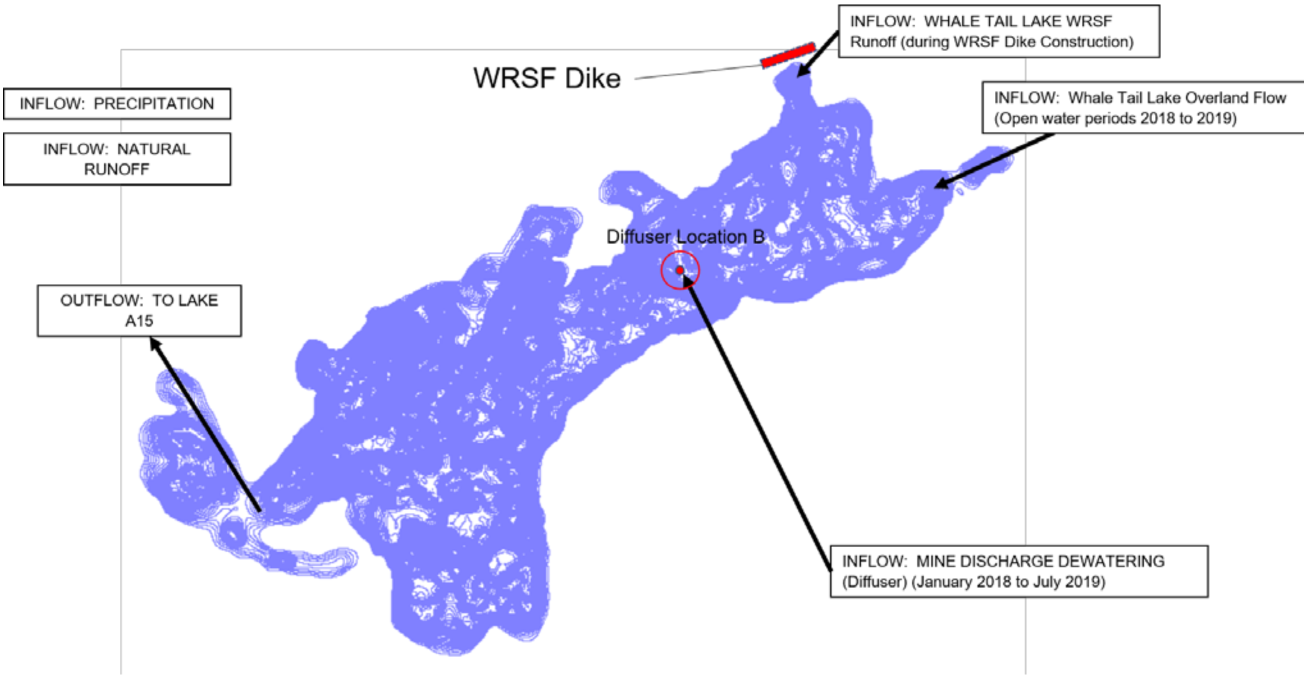


Figure 4: Conceptual diagram of inflow and outflow locations into Mammoth Lake during operations (June 2019 to 2021)

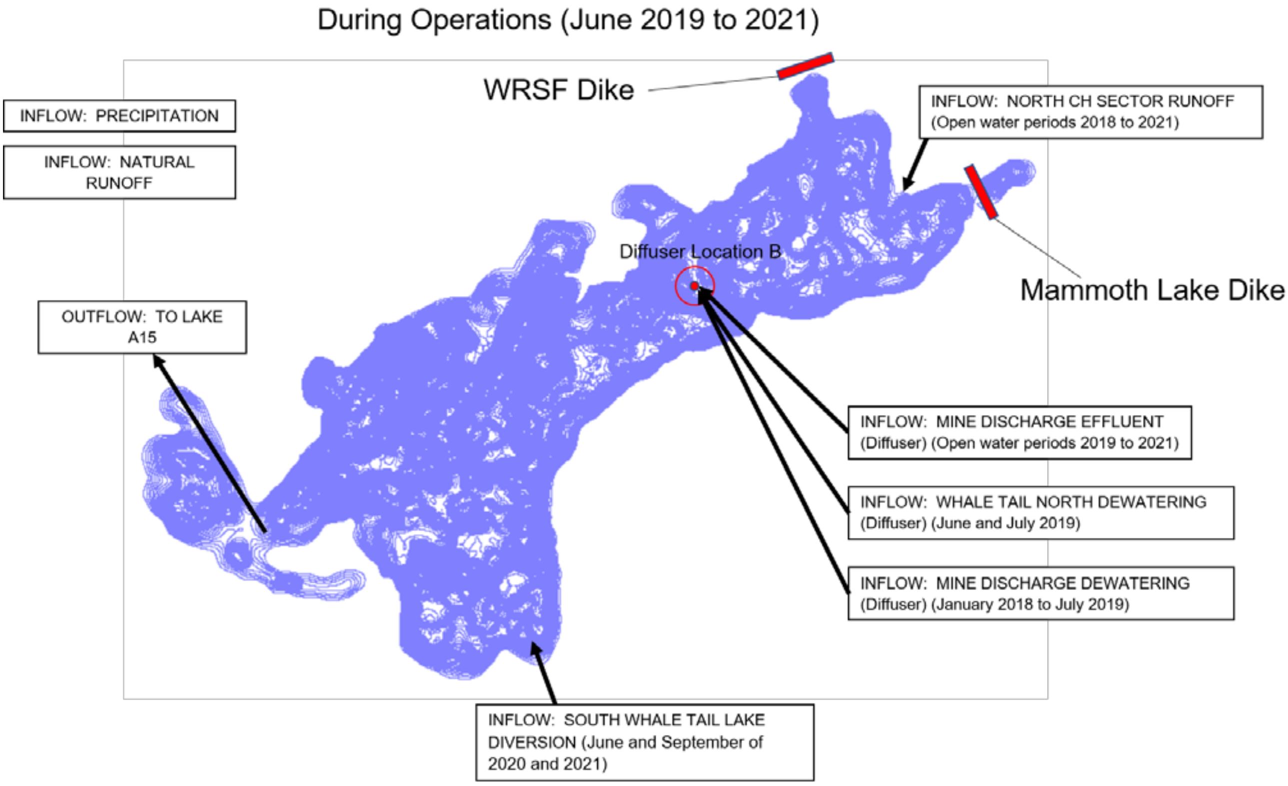


Figure 5: Conceptual diagram of inflow and outflow locations into Mammoth Lake during closure (2022 to 2027)

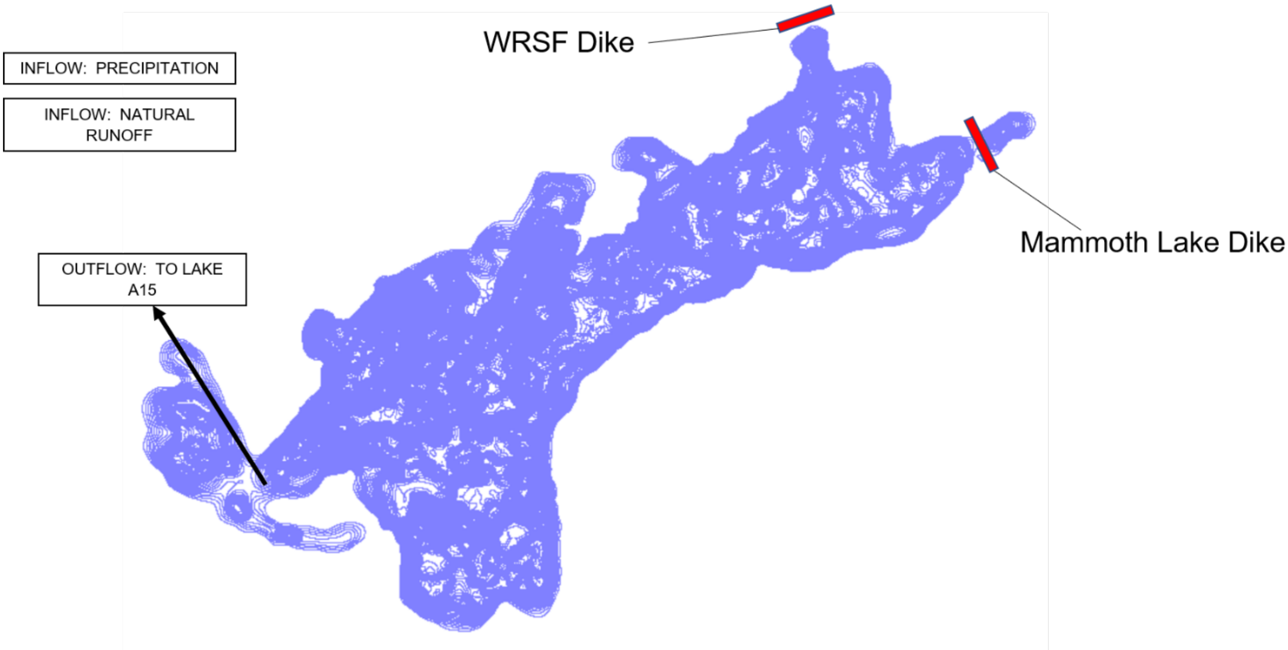
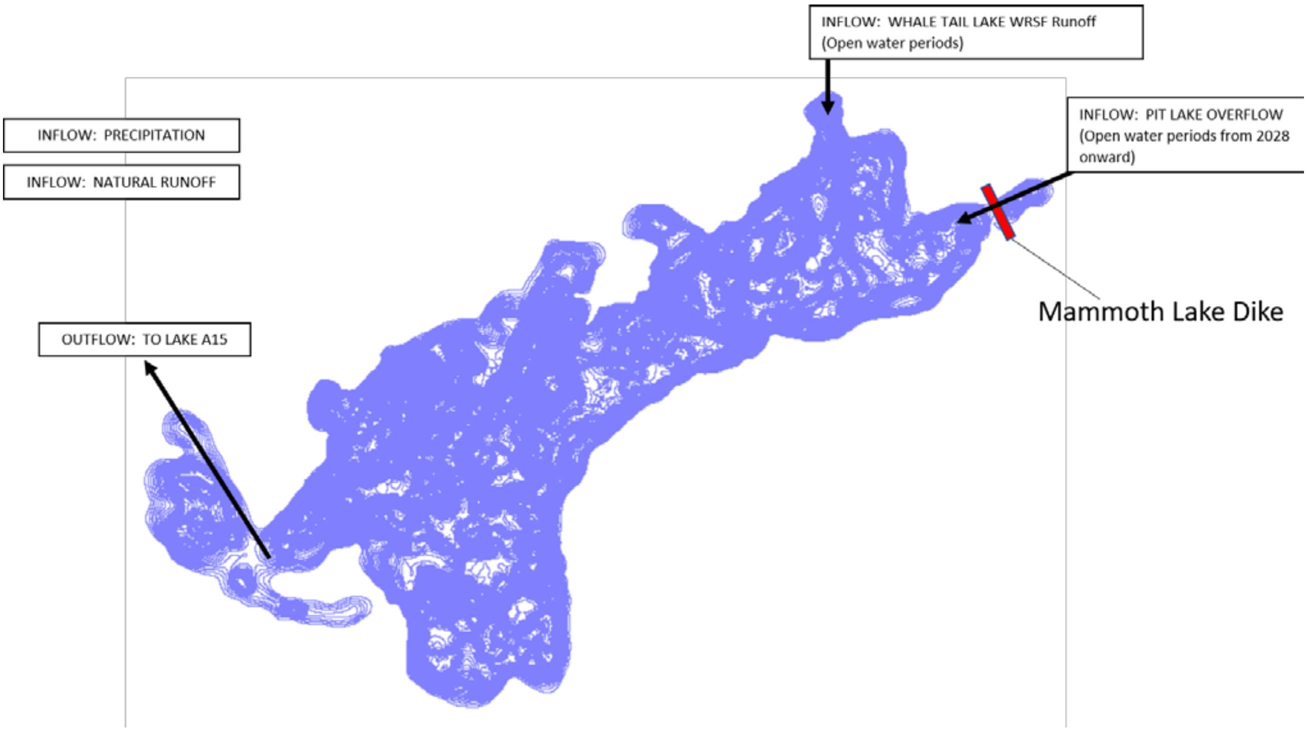


Figure 6: Conceptual diagram of inflow and outflow locations into Mammoth Lake post-closure (2027-onward)



3.4.3 Water Quality inputs

The inflows into Mammoth Lake were given an assigned water quality that included constituent concentrations and water temperatures (Table 1). For assigned water temperatures, a daily time series was developed using linear interpolation of average water temperatures from monitoring data of water bodies including Mammoth Lake, Whale Tail Lake, and Nemo Lake. This time series was assigned to all inflows into Mammoth Lake (except for the pit lake flows) and was repeated yearly over the duration of the simulation. Flows from the pit lake into Mammoth Lake were assigned water temperatures from the CE-QUAL-W2 model (Golder 2018).

Table 1: Inflows to Mammoth Lake, location of application, and specifications

Flow description	Max Flow (m^3/day)	Flow applied to	Temperature	Max Water Quality Input (mg/L)	
				TP	As
Pumped flow from water treatment plant (WTP)	10,709	Diffuser Location	Daily average time series of Mammoth Lake, Whale Tail Lake, and Nemo Lake temperatures	0.16	0.11
Runoff from WRSF pond	3,888	Location nearest to WRSF pond		1.4	2.9
North sector runoff	1,280	Diffuser Location		0.004	0.00027
Dewatering from Whale Tail Lake	24,000	Diffuser Location		0.020	0.013
Whale Tail South (WTS) diversion flow	61,538	Location where the WTS diversion channel meets Mammoth Lake		0.0024	0.00017
Whale Tail Pit Lake overflow runoff	99,026	Location closest to the Mammoth dike	CE-QUAL-W2 model (Golder, 2018)	0.006	0.0011
Natural Runoff	20,487	Runoff applied to edge of lake to cell locations where sub-watersheds meet Mammoth Lake	Daily average time series of Mammoth Lake, Whale Tail Lake, and Nemo Lake temperatures	0.0022	0.00039

Max = Maximum; mg/L = milligrams per litre; m^3/day = cubic metres per day; WTP = Water Treatment Plant; WRSF = Waste Rock Storage Facility

3.5 Model Assumptions

Hydrodynamic modelling of Mammoth lake required the use of certain assumptions and limitations that include:

- Cryo-concentration: As ice forms on lakes, dissolved constituents are excluded from the ice and remain in the free water; a process referred to as 'cryo-concentration'. The effects of this can be measured in water quality as an increase constituent concentration under ice where the open water quality (TDS) is sufficiently high (above 100 to 150 mg/L at Snap Lake; De Beers 2013). This phenomenon may not be measurable when the lake water has a low TDS such as in current conditions at Mammoth Lake (Azimuth 2018). Hydrodynamic models in general currently do not accurately model salt exclusion during ice formation. Nonetheless, the Mammoth Lake hydrodynamic model was built using a conservative approach to constituent exclusion during ice formation whereby 100% of total dissolved solids are extracted from the entire volume of ice. Ice-up is assumed to occur at the same rate and at the same thickness (2 m) each year from 2013 to 2042. It is acknowledged that this is an overly conservative assumption because ice can store saline inclusions and the degree to which this happens has not been quantified in present study. Changes in ice thickness and volume of free water below the ice from modelled values could affect predicted concentrations presented. This conservative modeling approach results in predicted cryo-concentration during winter conditions. This was not observed to the degree modelled in Mammoth lake or Snap Lake under the ice.

- Water chemistry data used as inputs to the Mammoth Lake GEMSS model were assumed to be representative of their respective sources. The Mammoth Lake model relied on predicted water quality concentrations and hydrology from the mine site hydrodynamic model, the Whale Tail Pit Lake model, and the water quality calculated from average concentrations of constituents in Mammoth Lake from 2014 to 2016. As a result, the accuracy of the predicted concentrations in the Mammoth Lake GEMSS model is dependent on the accuracy of these other models and the accuracy of the monitoring data for Mammoth Lake.
- All constituents were modelled conservatively (i.e. no reactions were predicted to take place between the constituents and biological uptake nor sedimentation of precipitated solids were modelled) except for total phosphorus which was assigned a settling rate of 0.003 m/day which has been used in hydrodynamic modelling of other northern lakes including Snap Lake (Golder, 2016).

4.0 MODEL CALIBRATION

The GEMSS model was calibrated using monitoring data collected in Mammoth Lake between 2014 and 2017. Time series and profile figures (Figure 8 to 11) were created to compare model results to measured data at different locations in the lake. Sample locations in Mammoth Lake are presented in Figure 7. The monitored data included samples analysed for temperature, TDS, major ions, nutrients, and total metals and metalloids. A visual comparison of model calibration results and monitored data was used to evaluate the performance of the model. All constituents were modelled conservatively except for total phosphorus which was modelled with a settling rate of 0.003 m/day. Monitoring data in Mammoth Lake was limited during the calibration period (2013 to 2017). Most locations were only sampled once during this time period. Due to the limited number of samples at each location, time series of average modelled TDS and temperatures were compared to monitoring data at multiple sample locations for the calibration (Figures 8 and 9).

The hydrodynamic component of the model was calibrated to match measured thermal and transport behaviour in Mammoth Lake. As the goal of calibration is to apply the formulae and constants that most closely approximate the behaviour of the system under study, an adjustment of parameters is standard practice during calibration (Cole and Wells 2008). Default model parameters were used for the thermal variables [e.g., the fraction of incident solar radiation absorbed by ice (0.6) and the radiation extinction coefficient through ice (0.1)], with the following exceptions:

- Sediment heat exchange was added to the Mammoth Lake Model. Based on the Mammoth Lake calibrations, the sediment temperature was set at a constant value of 4 degree Celsius (°C). This sediment temperature was used in GEMSS modelling of other northern lakes such as Snap Lake (Golder Associates 2016).
- A sediment-water heat exchange coefficient of $8x10^{-7}$ metres per second (m/s) was used in the model. This sediment heat-exchange coefficient was used in GEMSS modelling of other northern lakes such as Snap Lake (Golder Associates 2016).
- A negative heat load of 2 degrees Celsius per cubic metre per second (°C/m^3/s) was added to the surface of the lake to simulate an ice-water heat exchange. This represents the rate at which heat is lost from the water to the ice at the surface. The negative surface heat load under ice was adjusted to 2°C/m^3/s in order to match model profile temperatures to temperature profiles from monitoring data (Figure 10).

Time series plots of surface water temperatures at stations throughout Mammoth Lake showed that the model matched the surface water temperatures reasonably well (Figure 7). The modelled thermal profiles also fit the measured profiles well during both the ice-covered and open-water periods for Mammoth Lake (Figures 10). Modelled thermal profiles were considered a strong match to monitoring data if they followed the same vertical pattern and were within 3°C of monitoring data.

The transport calibration considered horizontal and vertical distribution of TDS in Mammoth Lake. Monitored TDS and chloride, barium, calcium, and strontium showed increasing trends over time in Mammoth Lake. The model used averaged concentrations of these constituents for the inflows during the calibration time period, so the model does not reproduce this increasing trend. The model matched well with the TDS monitoring data from 2013 to 2016 but underpredicted TDS concentrations in the final year of the calibration (Figure 9).

Profile monitoring data did not include TDS measurements at multiple depths at most locations. For the vertical component of the transport calibration, measured specific conductivity profile data were compared to predicted TDS profiles (Figure 11). The calibration was considered adequate if the observed specific conductivity profiles and the predicted TDS profiles followed the same vertical pattern, while recognizing that the absolute values would not be expected to match. Modelled TDS profiles throughout Mammoth Lake generally matched the observed conductivity profiles reasonably well during both open water and under-ice periods. Overall, the transport calibration indicates that the model tracks the movement of water and dissolved constituents well throughout the vertical and lateral dimensions of the lake.

Figure 7: Mammoth Lake Water Quality Sampling Locations

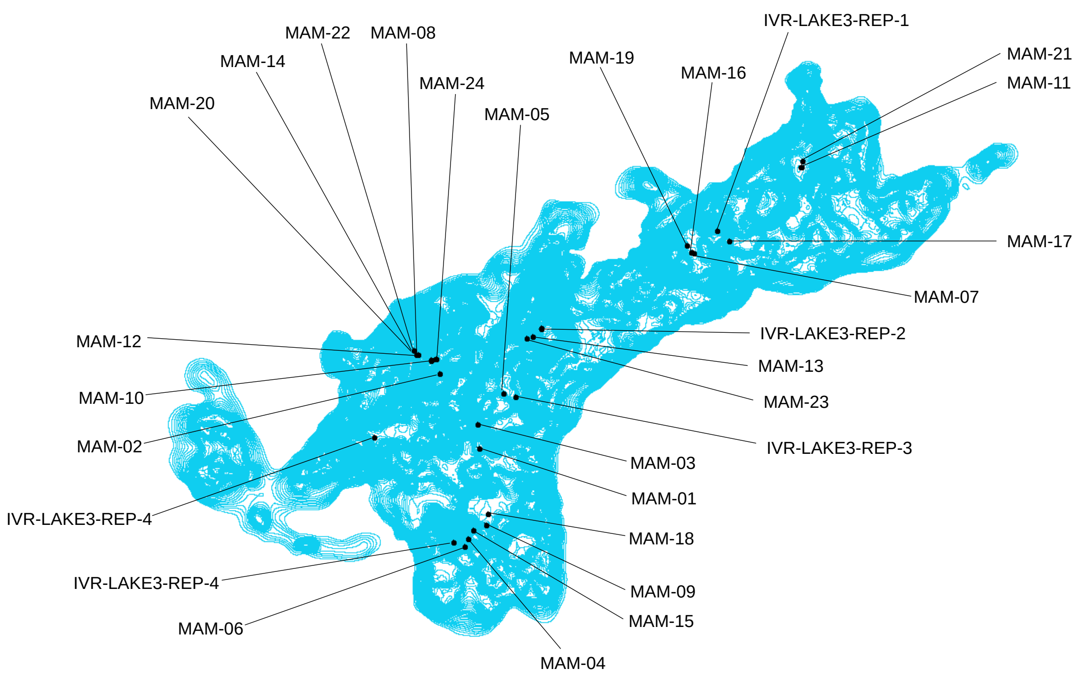
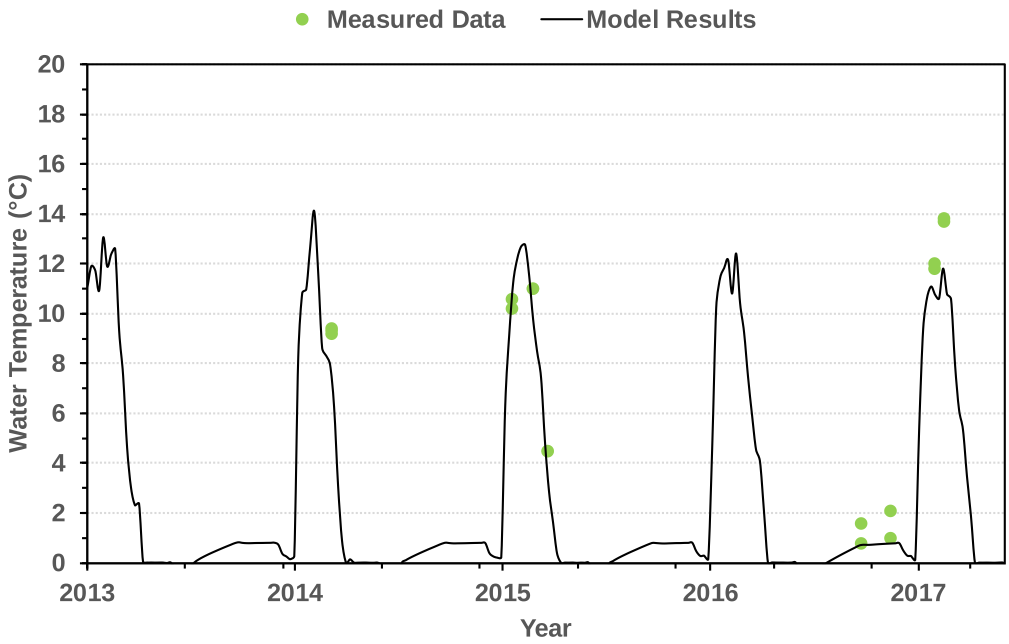


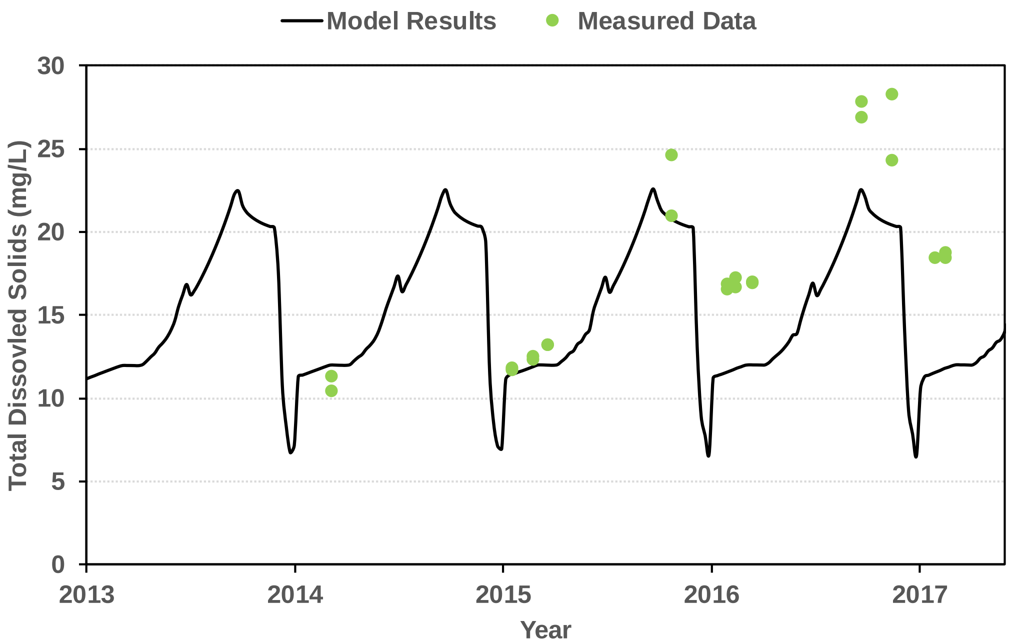
Figure 8: Average Simulated Surface Water Temperatures and Monitored Surface Water Temperatures in Mammoth Lake, 2013 to 2017



Note: Measured data from locations IVR-LAKE3-REP-1, IVR-LAKE3-REP-3, IVR-LAKE3-REP-5, MAM-01, MAM-02, MAM-03, MAM-04, MAM-05, MAM-06, MAM-17, MAM-18, MAM-19, MAM-20, MAM-21, MAM-22, MAM-23, and MAM-24.

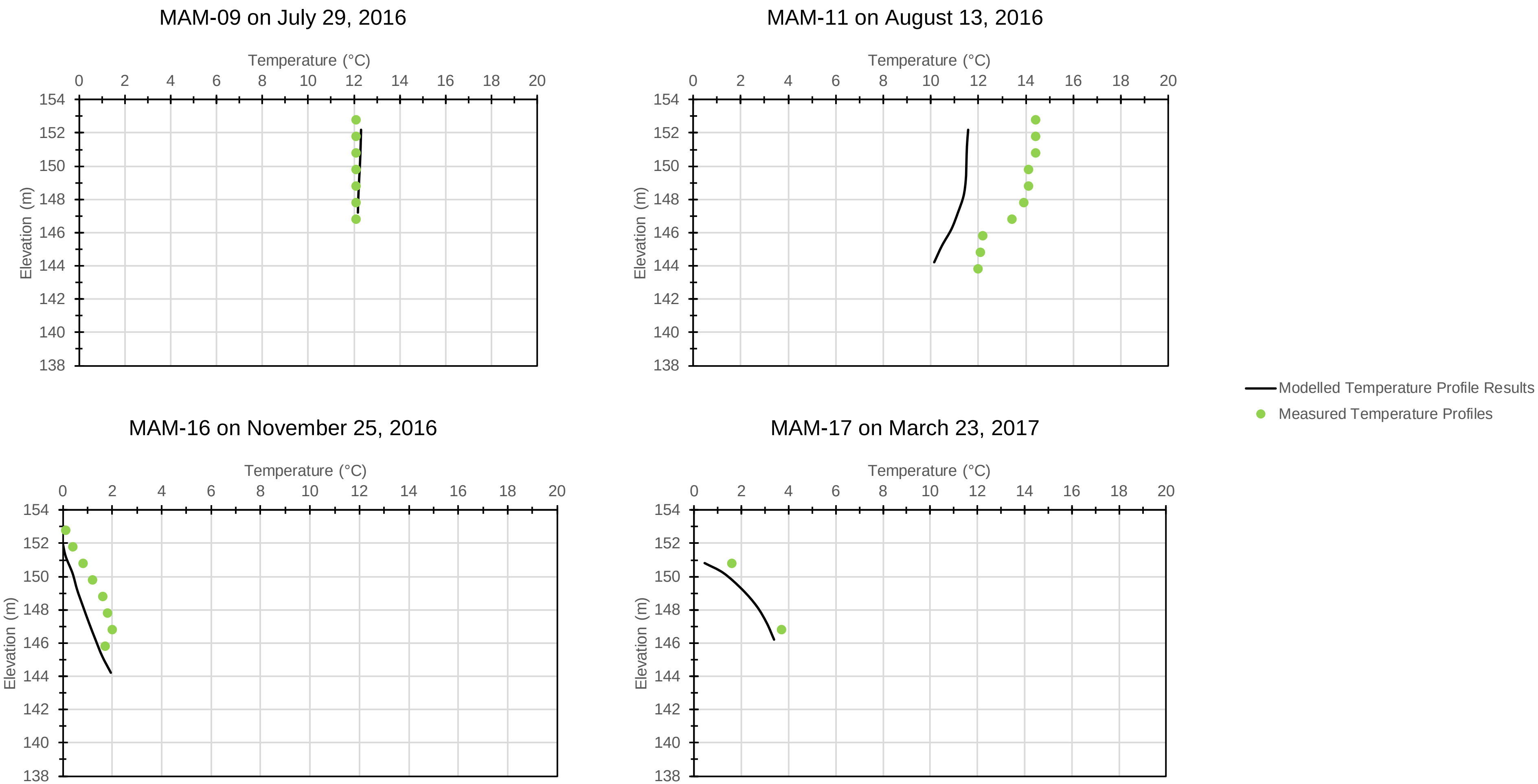
°C = degrees Celsius

Figure 9: Average Simulated Surface Total Dissolved Solids and Monitored Total Dissolved Solids Concentrations in Mammoth Lake, 2013 to 2017



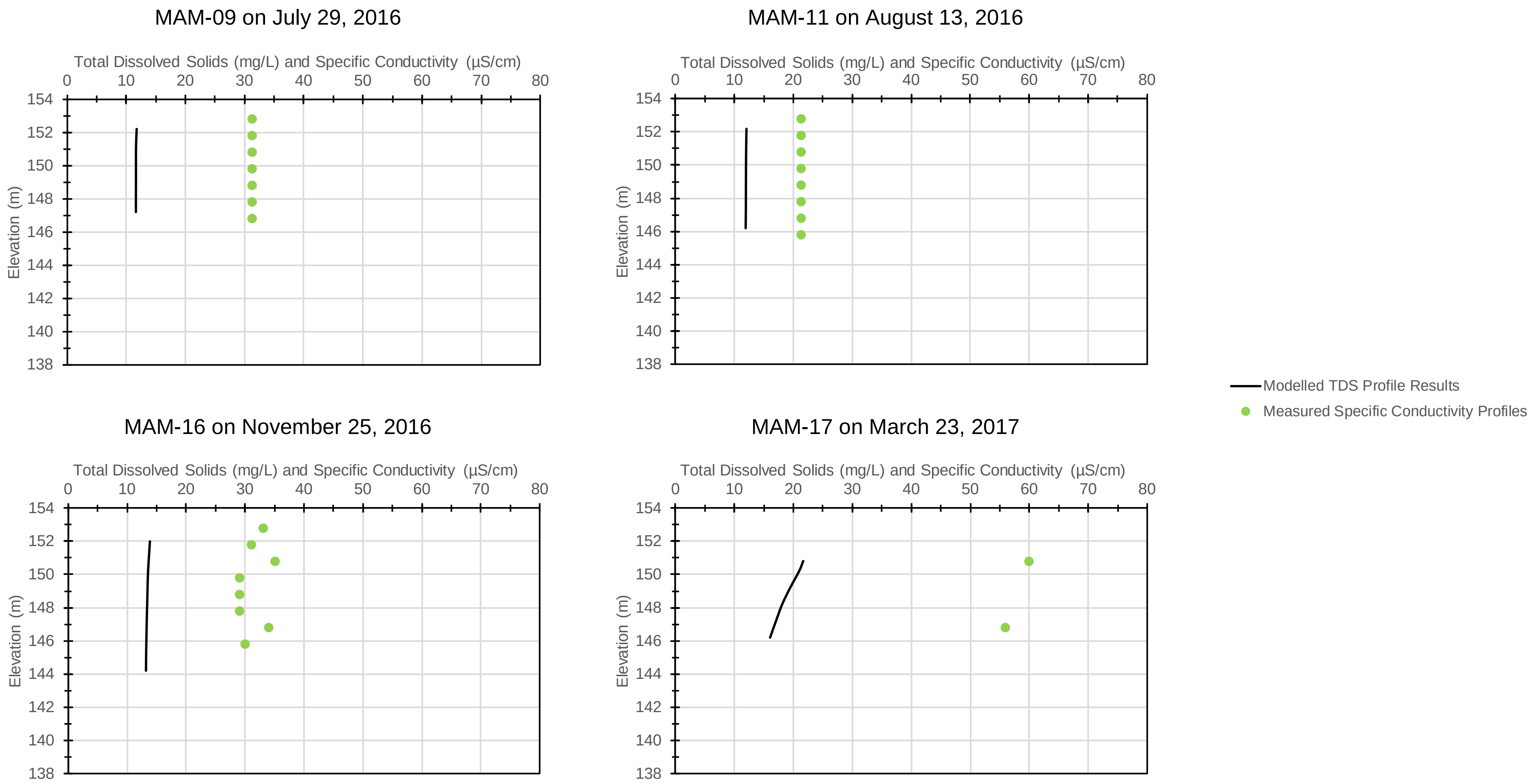
mg/L = milligrams per litre

Figure 10: Simulated Temperature Profiles and Monitored Temperature Profiles at four locations in Mammoth Lake during open water and under-ice conditions



°C = degrees Celsius; m = metres above sea level

Figure 11: Simulated TDS Profiles and Monitored Specific Conductivity Profiles at four locations in Mammoth Lake during open water and under-ice conditions



m = metres above sea level; mg/L = milligrams per litre; µS/cm = micro Siemens per centimetre

5.0 RESULTS

5.1 Lake Circulation

Seasonal circulation was evaluated in Mammoth Lake using predicted profiles of TDS at the end of operations, the end of closure, and during post-closure (Figures 12, 13, and 14).

Mammoth Lake is predicted to exhibit winter thermal and chemical stratification with complete mixing occurring each summer in mid-July. Winter stratification occurs during January to July. During the month of June, just before ice loss, concentrations of constituents are conservatively predicted to increase with depth below the ice surface due to inflows and the absence of wind mixing during ice-cover. Concentration profiles then homogenize each July as a product of complete mixing during spring turnover (Figures 12, 13, and 14).

Figure 12: Simulated Profiles of Total Dissolved Solids in Mammoth Lake at MAM-07 Location at the End of the Operations Period (2021)

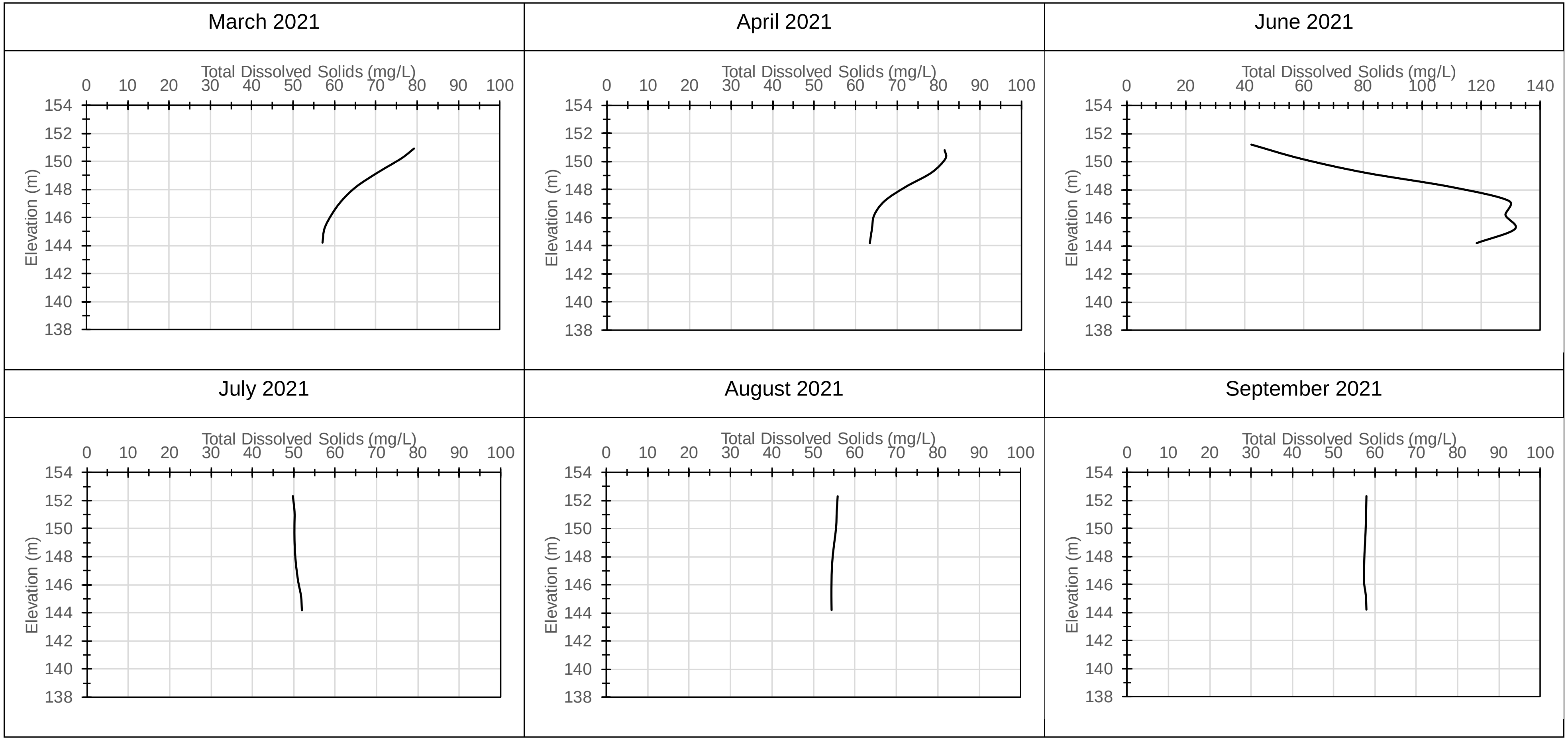
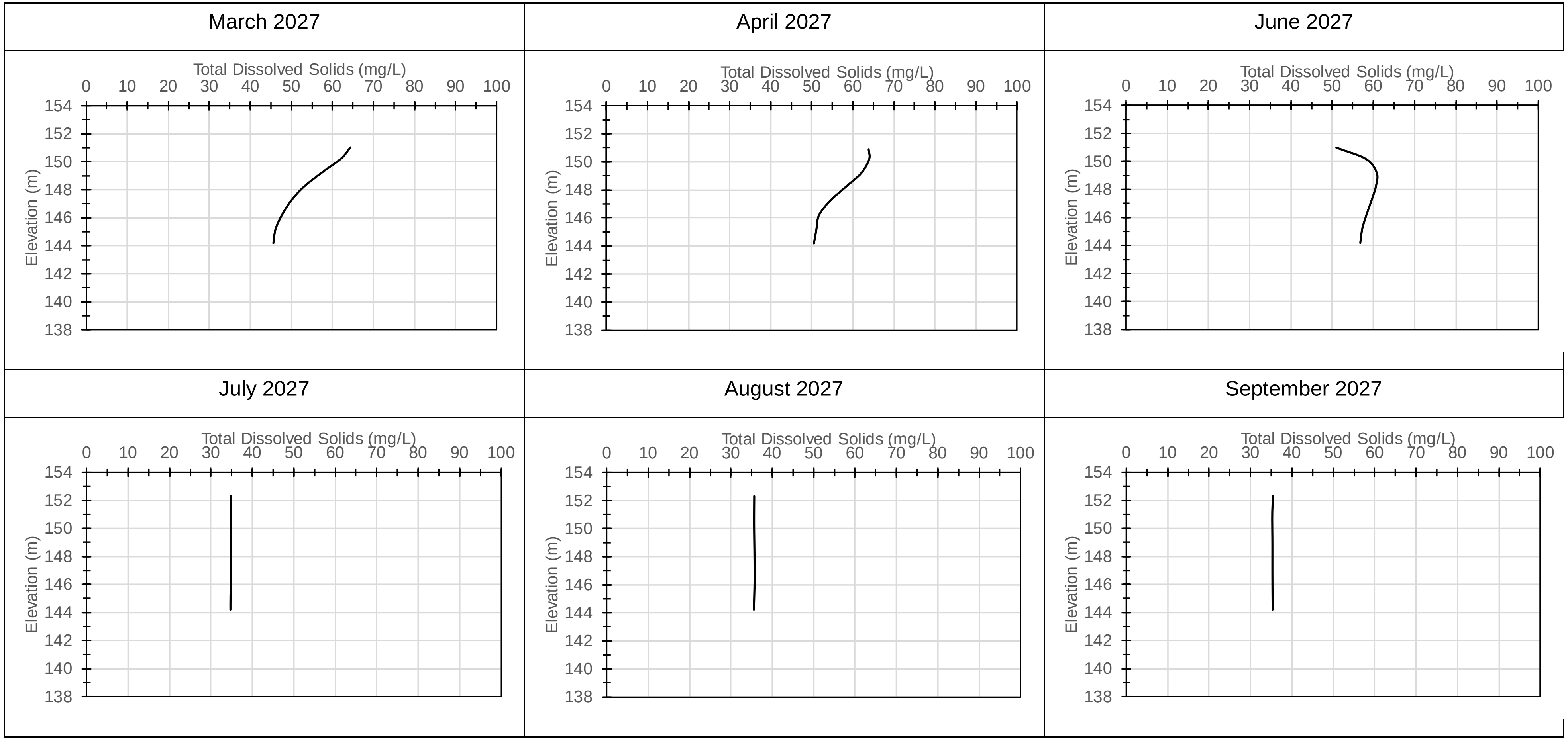
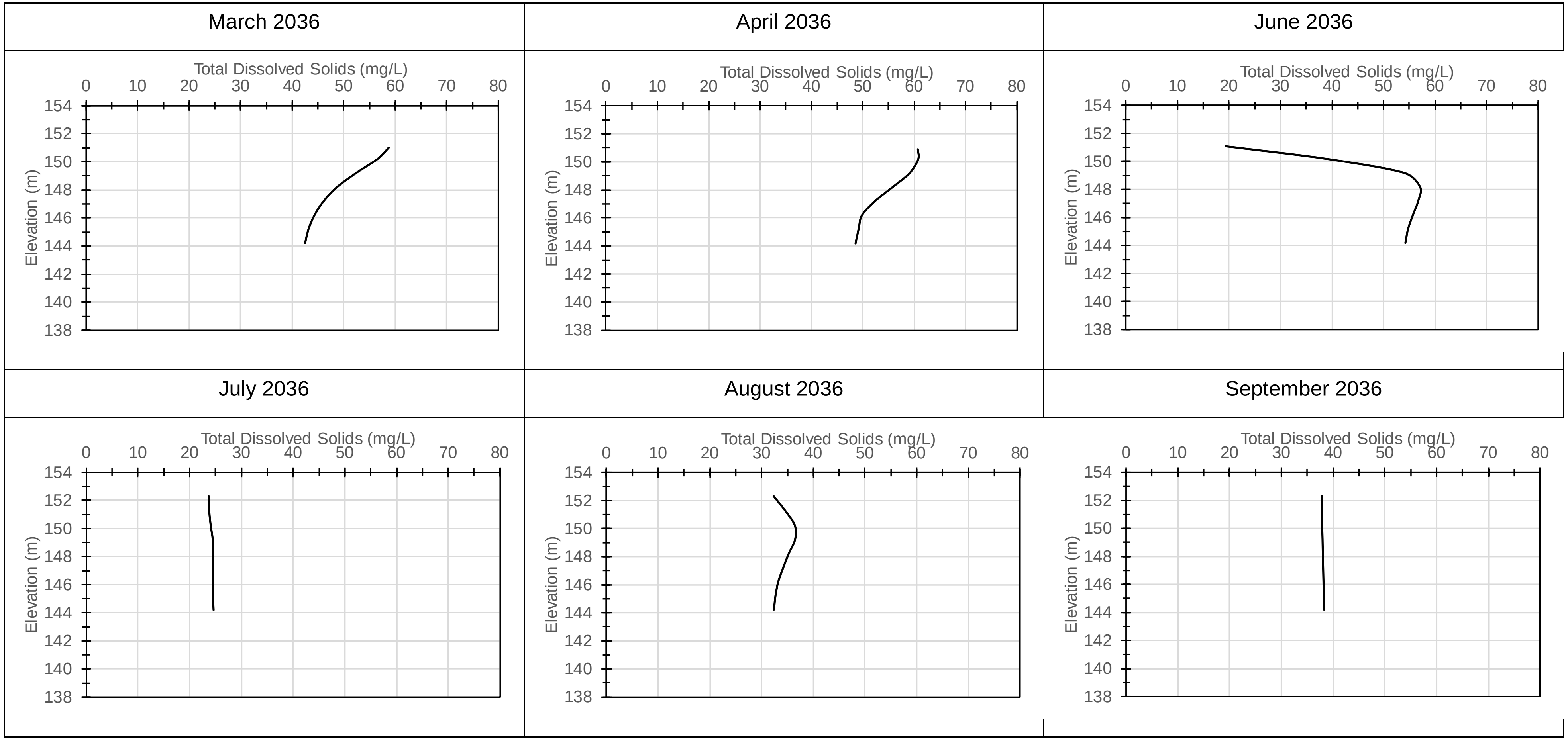


Figure 13: Simulated Profiles of Total Dissolved Solids in Mammoth Lake at MAM-07 Location at the End of the Closure Period (2027)



mg/L = milligrams per litre; m = metres above sea level

Figure 14: Simulated Profiles of Total Dissolved Solids in Mammoth Lake at MAM-07 Location in 2036, in Post-closure



mg/L = milligrams per litre; m = metres above sea level

5.2 Diffuser Locations

Three potential diffuser locations (Locations A, B, and C) were modelled to assess how different discharge locations could affect constituent concentrations across the lake (Figure 2).

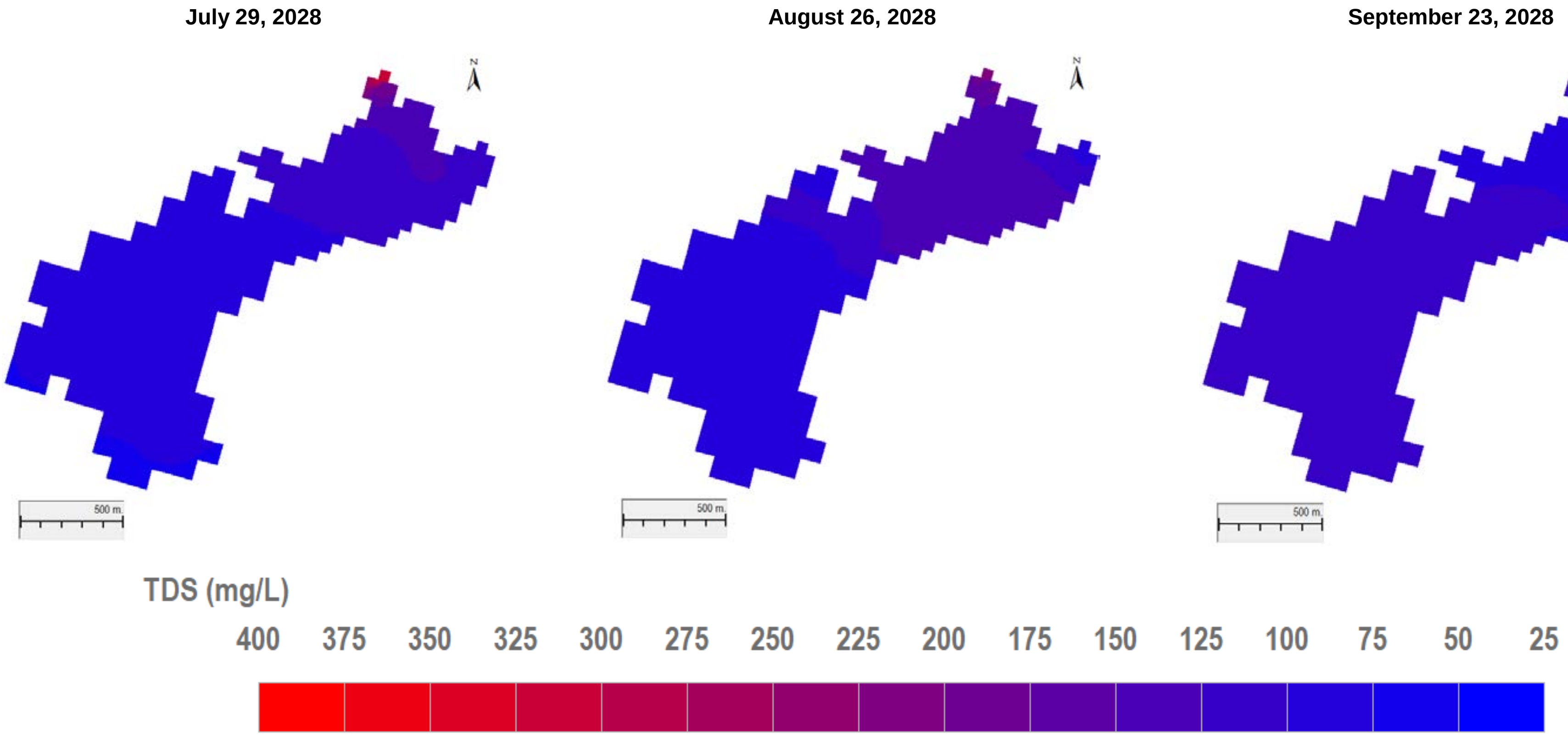
Diffuser inflows were adjusted to determine if decreasing or offsetting flow could decrease predicted Mammoth Lake constituent concentrations. Results are included in Appendix A. They show that predicted concentrations of total phosphorus and total arsenic at various locations in Mammoth Lake over the simulation period were similar in each discharge location scenario (Figure A-2 and A-3 respectively). That concentration patterns are similar at all locations suggests that Mammoth Lake is well-mixed and that changing the diffuser location would not significantly affect the dispersion of effluent-derived constituents in the lake. The seasonal (winter) peaks are an artefact of the conservative assumption of full cryo-concentration in winter, unlikely to occur at that level given the low overall TDS of Mammoth Lake throughout mine life and post-closure (maximum TDS values shown in Table 2).

Diffuser Location B was selected as the most favourable discharge point being the closest to the mine (shorter effluent pipe) and furthest from the Mammoth Lake outlet (Figure 2), providing the adequate potential for mixing of constituents throughout the lake before flowing downstream. Diffusor location B scenario was retained for this study.

5.3 Lake Mixing and WRSF Seepage Inflow Post-Closure

Predicted surface concentration plots of TDS were used to assess mixing of WRSF contact water in Mammoth Lake starting in Post-Closure (2028). These plots showed that the lake is well-mixed throughout the simulation period. Peaks in Mammoth Lake TDS concentrations are observed at the immediate location where WRSF seepage enters Mammoth Lake starting in July of 2028. The predicted concentration plots show that peaks in TDS between 350 mg/L and 400 mg/L are localized to the region within 100 metres of the inflow point of WRSF seepage (the red-coloured area in Figure 15). Outside of this area, predicted Mammoth Lake TDS concentrations are mostly uniformly-mixed, showing a range of between 75 mg/L to 125 mg/L across the lake (the blue areas in Figure 15). Mixing in the lake also causes the localized higher-concentration region near the WRSF inflow to disperse throughout Mammoth Lake over the summer as WRSF runoff stops.

Figure 15: Surface Total Dissolved Solids Maps of Mammoth Lake at the onset of post-closure (2028)



TDS = Total Dissolved Solids; mg/L = milligrams per litre

5.4 Water Quality

Time series plots showing maximum concentrations of total phosphorus and arsenic were generated to illustrate changes in predicted water quality in Mammoth Lake from the start of operations to post-closure (Figures 16 and 17). Predicted constituent concentrations in Mammoth Lake from 2017 to 2042 showed the following:

- Effluent discharge to Mammoth Lake is predicted to result in a progressive increase in total arsenic concentration during operation, from 2019 to 2021 (Figure 16) because discharge has a higher predicted total arsenic concentration (maximum of 0.1 mg/L) than Mammoth Lake (Golder, 2018).
- A temporary increase in predicted arsenic concentration occurs at the beginning of post-closure (Figure 16) from inflow of WRSF seepage. In that event, the WRSF seepage is conservatively predicted to suddenly flush mineral salts accumulated in time (Golder, 2018). The concentration of arsenic in the seepage improves thereafter, improving Mammoth Lake concentrations in time.
- A temporary increase in total phosphorus concentration is predicted to occur during operation, from 2019 to 2021 (Figure 17) because of mine discharges into Mammoth Lake. At that time, effluent phosphorus concentrations are predicted to be higher than in Mammoth Lake and slightly higher than the oligotrophic range, as stated in the Approved Project EA. The highest predicted total phosphorus concentration of the effluent is 0.16 mg/L (Golder, 2018).
- A second temporary increase in predicted total phosphorus concentrations occurs from inflow of WRSF seepage at the beginning of the post-closure (Figure 17). The WRSF runoff is predicted to have higher concentrations of total phosphorus than Mammoth Lake when the runoff begins at the start of the post-closure. The highest predicted total phosphorus concentration of the WRSF runoff during post-closure is 1.4 mg/L (Golder, 2018).
- The evaluation of the effect of cryo-concentration (conservatively assuming 100% exclusion of constituents in ice) results in increases in the concentrations of the constituents in winter. The model was designed so that the same volume of water lost to ice formation in the winter is regained in the spring when the ice melts during June of each year. This causes the sudden decrease in constituent concentrations during this spring freshet as ice melts and is added to the lake as pure water. The amount of increase (approximately 50%) reflects the proportion of ice (2 meters thick) to free water in Mammoth Lake (average depth of 4 m). This represents a hypothetical case that could occur if mine activities are such that effluent TDS concentrations are higher than predicted in the site wide water quality model (Golder 2018). Cryo-concentration may not result in significant changes in concentrations in water under the ice given the low TDS concentrations of Mammoth Lake throughout mine life and in post-closure (shown in Table 2). Should effluent TDS concentrations increase or ice be thicker, constituent concentrations could be higher under the ice.

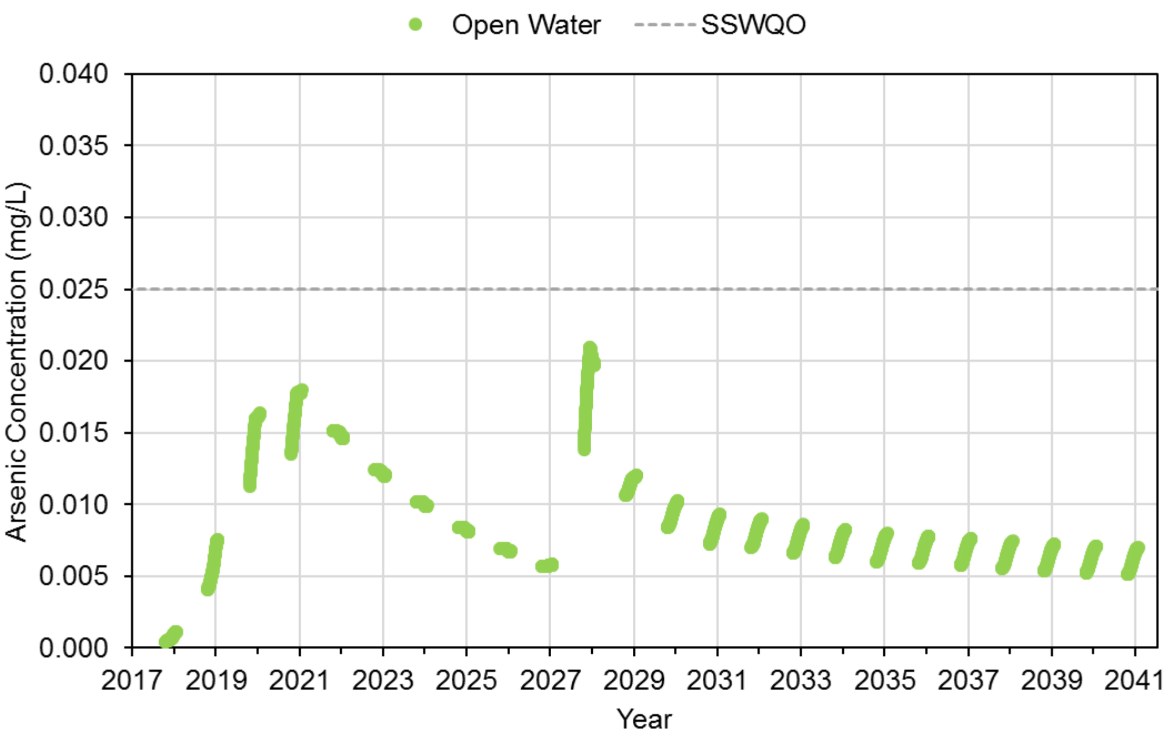
The highest open water TDS concentrations in the middle of Mammoth Lake are expected to occur during the first year of WRSF seepage into Mammoth Lake, decreasing thereafter. TDS concentrations are predicted to be low for the rest of the simulation period open water season.

Table 2: Maximum Predicted Total Dissolved Solids in the middle of Mammoth Lake during Operations, Closure, and Post-Closure

Period	Maximum Predicted TDS in Mammoth Lake (mg/L)	
	Open Water	Under-ice
Operations	114	178
Closure	85	107
Post-Closure	163	191

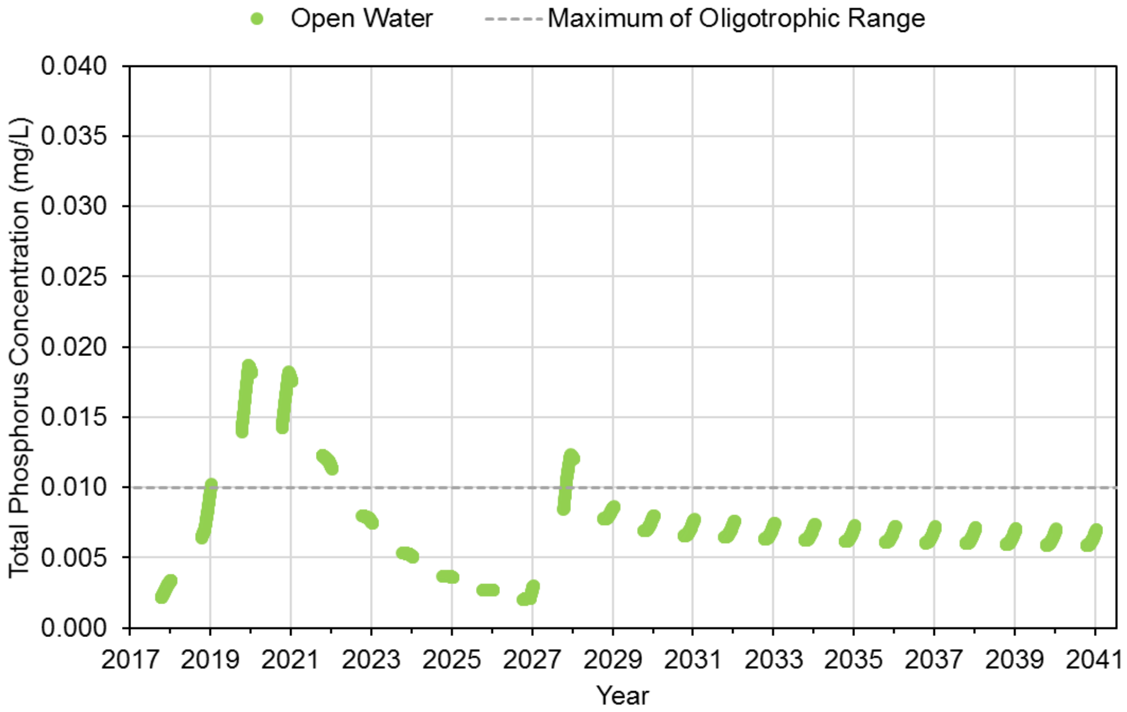
Note: Open water included July, August, and September; Under-ice included October to June.
TDS = Total Dissolved Solids; mg/L = milligrams per litre

Figure 16: Predicted Open Water Total Arsenic concentrations in Mammoth Lake



mg/L = milligrams per litre

Figure 17: Predicted Open Water Total Phosphorus concentrations in Mammoth Lake



mg/L = milligrams per litre

6.0 CONCLUSIONS

Hydrodynamic modelling of arsenic and total phosphorus in Mammoth Lake using the GEMSS program showed that the lake is well-mixed over time, and that permanent stratification does not develop.

Three different diffuser locations were considered for mine discharge into Mammoth Lake. The diffusor design considered is described elsewhere (Golder 2018). Each of these locations were modelled and the simulated concentrations at several sample locations in Mammoth Lake were compared across the three diffuser location scenarios. The simulation results showed that changing the diffuser location did not greatly affect concentrations of parameters across the lake. This indicates that Mammoth Lake is well-mixed.

Location B (in the northern basin of Mammoth Lake) was selected as the most favourable diffuser location because of its distance from the lake outlet and its relative proximity to the mine site. This location allows for the mixing of the effluent across the lake before flowing downstream and is an economically-favourable location since water from the mine site will not have to be pumped as far as the other potential diffuser locations.

The inflow of WRSF contact water to Mammoth Lake at post-closure is predicted to resulted in a short-lived, temporary increase of total phosphorus and total arsenic concentrations above the comparative criteria for arsenic and phosphorous, after which concentrations decrease to below the criteria later in post-closure.

Cryo-concentration (concentration of constituents in water from icing up of lake water surface) may not result in significant changes in concentrations in water under the ice given the low TDS concentrations of Mammoth Lake throughout mine life and in post-closure (shown in Table 2). Should effluent TDS load be higher or ice thicker, this may result in higher concentrations below the ice.

7.0 RECOMMENDATIONS

The following constants used in the model are known to be sensitive to climate change:

- The volume of stored snowpack contributing to spring freshet;
- The duration of the ice-covered period; and
- The thickness of lake ice.

Consideration should be given to assessing the effects of climate change on these variables in the GEMMS prediction to capture possible future climate conditions.

8.0 CLOSING

The reader is referred to the Study Limitations, which follows the text and forms an integral part of this memorandum.

We trust that the content of this technical memorandum meets your expectations. Please do not hesitate to contact the undersigned should you have any questions or comments.

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Date 25 March 2019
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NT/NU Association of Professional Engineers and Geoscientists

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10.0 STUDY LIMITATIONS

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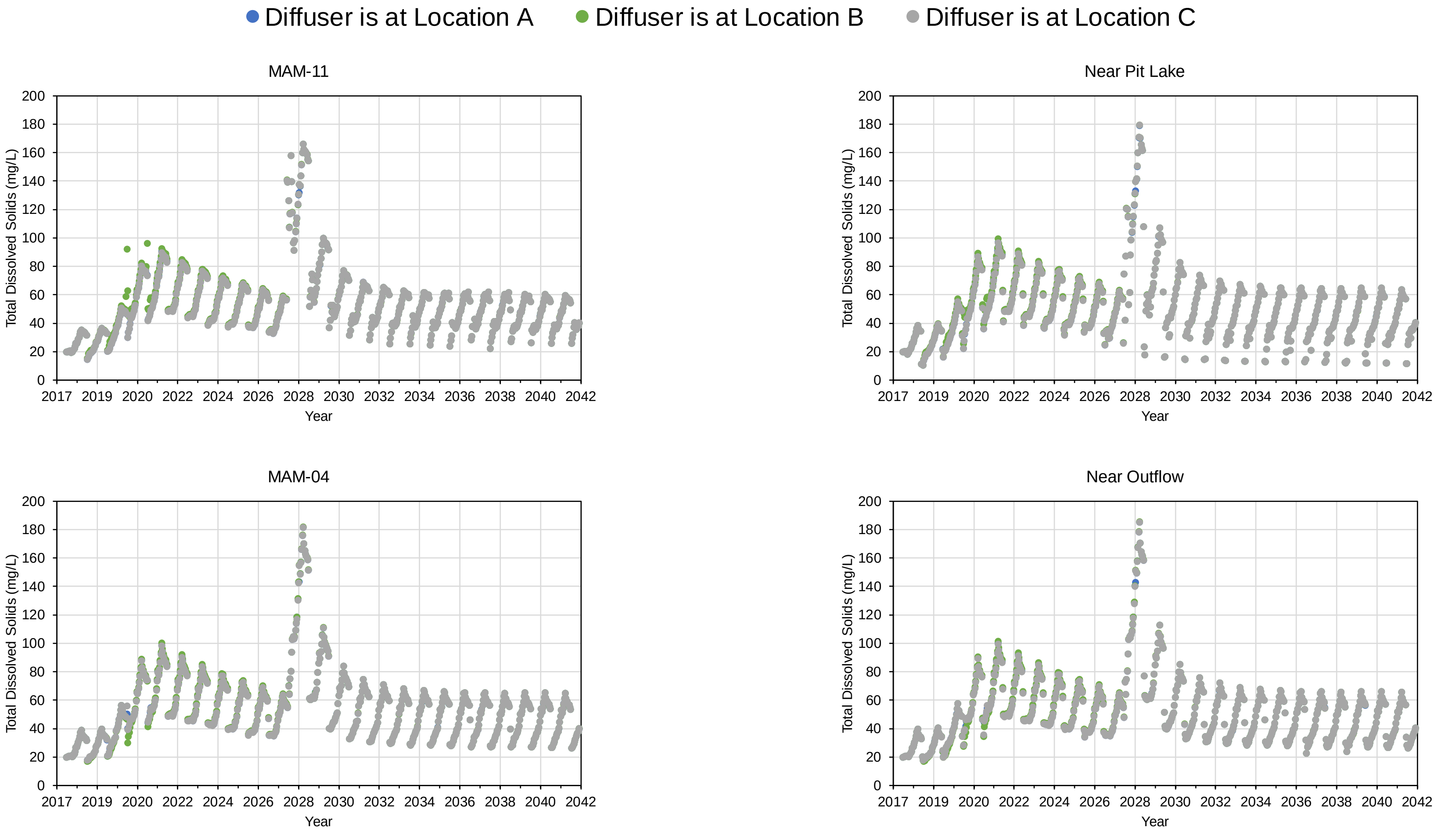
APPENDIX A – SIMULATED TOTAL DISSOLVED SOLIDS, TOTAL ARSENIC AND TOTAL PHOSPHORUS IN MAMMOTH LAKE

Figures A-1 to A-3 present the predicted TDS, total arsenic, and total phosphorus concentrations in Mammoth Lake at four different sample locations when discharging from 3 potential diffuser locations. The four sample locations shown are:

1) MAM-04 (See Figure 7 for location in Mammoth Lake)
2) MAM-11 (See Figure 7 for location in Mammoth Lake)
3) The outflow point for Mammoth Lake to downstream lakes
4) The region nearest to the pit lake in the northeast tip of Mammoth Lake

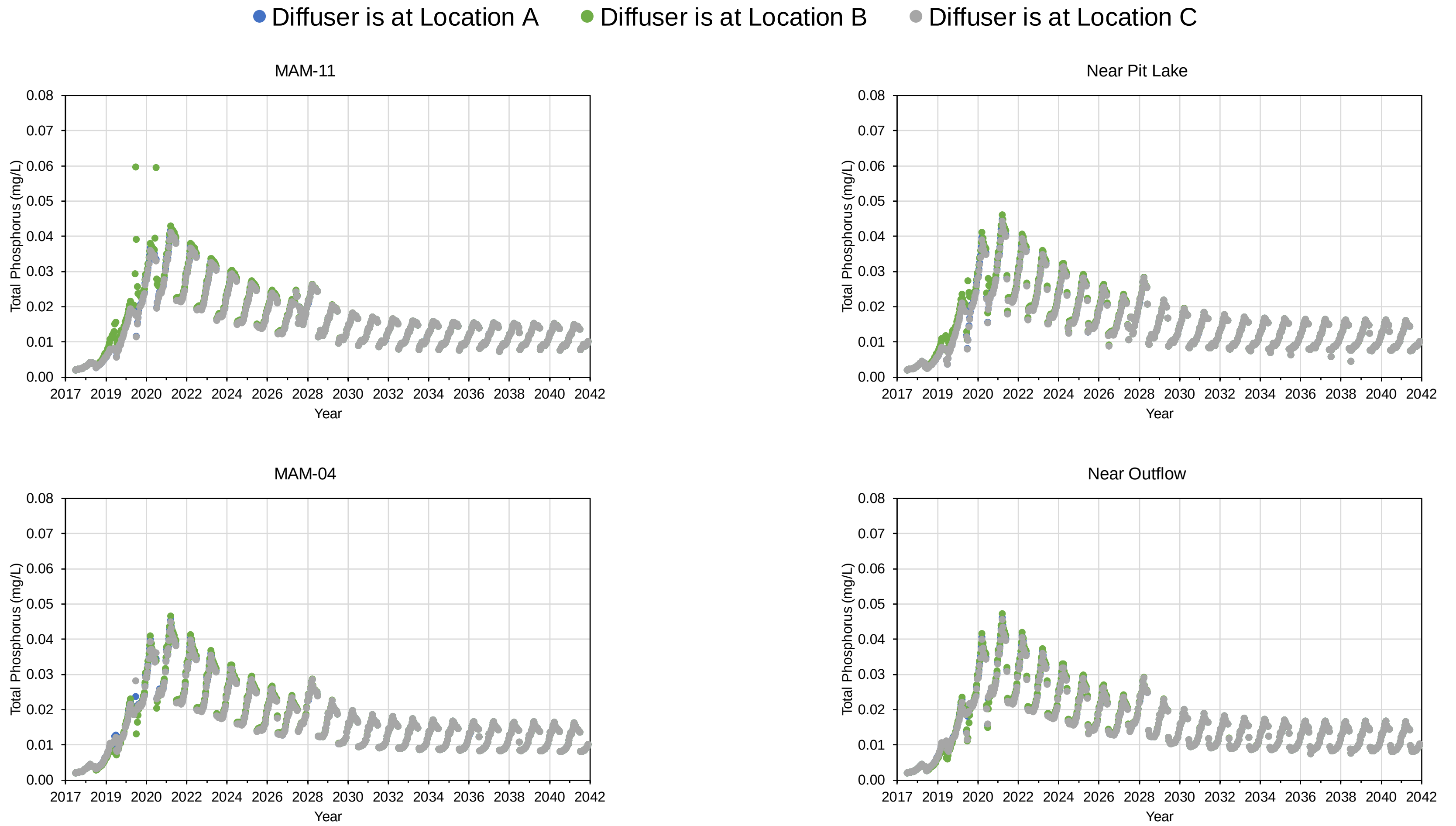
The results show that changing the diffuser location had little effect on parameter concentrations throughout Mammoth Lake since all three scenarios resulted in similar concentrations at each location. Furthermore, each sample location shows similar concentrations of parameters over time which demonstrates that the model predicts Mammoth Lake to be well-mixed.

Figure A-1: Maximum Total Dissolved Solids concentrations (across all depths) at four different locations in Mammoth Lake when diffuser is at Location A, B, and C



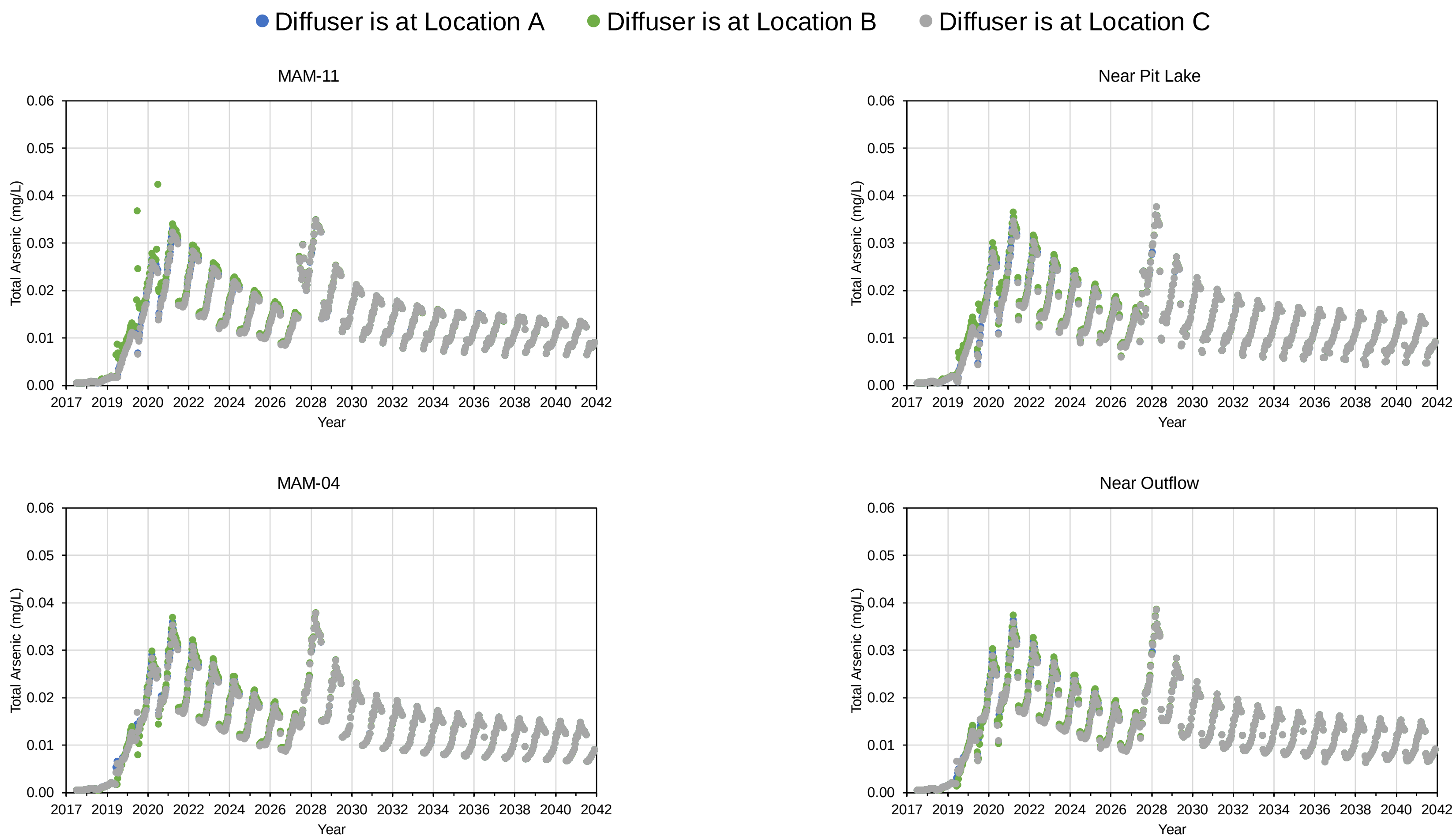
mg/L = milligrams per litre

Figure A-2: Maximum Total Phosphorus concentrations (across all depths) at four different locations in Mammoth Lake when diffuser is at Location A, B, and C.



mg/L = milligrams per litre

Figure A-3: Maximum Total Arsenic concentrations (across all depths) at four different locations in Mammoth Lake when diffuser is at Location A, B, and C.



mg/L = milligrams per litre