Docket No. _____
Exh. TDI-WHB-2

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Temperature Gradients in the Vicinity of NECPL Cables and Potential Effects on Water Quality, Bioavailability of Mercury, and Macroinvertebrates

Temperature Gradients in the Vicinity of NECPL Cables and Potential Effects on Water Quality, Bioavailability of Mercury, and Macroinvertebrates

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December 1, 2014

Contents

List of Figures

List of Tables

Executive Summary

Exponent was retained by TDI-NE to perform an engineering and scientific analysis of the thermal effects of the New England Clean Power Link project on the environment around the cables in Lake Champlain, Vermont. The potential increase in temperatures in water and sediment around the cables was evaluated for three cases that describe the proposed installation of the cables in Lake Champlain.

The heat transfer and fluid dynamics of the underwater cable environment were simulated with a model developed using the multi-physics simulation software package STAR-CCM+, Version 9. Using conservative assumptions, this modeling predicted temperature gradients for three specific configurations: cables installed in a trench, cables self-buried, and cables sitting on bedrock.

The cables are installed in a trench below the lakebed for approximately 53 miles or 54% of the route of the cables in Lake Champlain. In this configuration the temperature increase in the entire water region will be less than 1 degree F (°F**),** including at the sediment/water interface above the cables.

At depths greater than 150 feet, the cables would be laid on the lakebed and expected to self-bury about 1 foot beneath the sediment due to their weight. Self-burial is expected for approximately 42 miles or 43% of the lake route and produces a very limited region where the temperature increases are greater than 1°F. The extent of that region is less than 0.3 inches in thickness and a few feet in length.

For approximately 2 miles or 2% of the lake route the cables are expected to lay on bedrock or other obstacles. The area where the temperature increases are greater than 1°F extends 0.2 inches above the cables and a total of 1.4 inches to the upstream and downstream sides of the cables. In an even smaller 1% fraction of the route, concrete mattresses may be placed over the cables to protect the cables from physical damage and limit heat transfer from the cables to lake water.

The infinitesimal thermal contribution of the cables to Lake Champlain can be appreciated by considering that the combined water volume of the warm zones for self-buried and unburied cables is less than 1.9 millionth of a percent of the volume of Lake Champlain. Even when compared to a smaller volume such as a hypothetical mixing zone encompassed by a semi-circle of 200 feet in radius running along the cables, the combined volume of the warm zones still remains infinitesimal at less than 0.12 thousandth of a percent of this mixing zone's volume.

Research on the response of bacteria in lake sediments and non-mobile macroinvertebrate populations to the simulated increased temperatures around the cables was evaluated with reference to Lake Champlain. The analysis focused on the effect of temperature on the rate at which mercury is methylated by bacteria in sediments. The temperature rise in the upper layer of sediment where methylation of mercury is greatest was found to be too small to expect a significant increase methylmercury production. Mercury methylation should not be impacted by the presence of unburied cables, due to low biological activity of areas with bedrock. Similarly, the temperature rise in this same sediment zone was judged not sufficient to cause the range of temperatures to exceed that tolerated by major immobile species in Lake Champlain including zebra mussels (an invasive species), Chironomid larvae (the aquatic stage of non-biting midges), or pea clams at locations where these species would reside around the cables. Thus, little or no effect on the community structure of these macroinvertebrate populations is expected. Since the temperature zone around the cables is so limited, other species that are mobile would not encounter higher temperatures for any significant periods.

Introduction

Champlain VT, LLC, d/b/a TDI-New England (TDI-NE) is proposing the New England Clean Power Link project (NECPL project). The NECPL is a high-voltage direct current electric transmission line that will provide electricity generated by renewable energy sources in Canada to the New England electric grid. The line will run from the Canadian border at Alburgh, Vermont, along underwater and underground routes to Ludlow, Vermont.

The transmission line will be comprised of two approximately 5-inch diameter cables—one positively charged and the other negatively charged—and will be insulated with solid-state dielectric material and thus contain no fluids or gases. The nominal operating voltage of the line will be ±320 kilovolts, and the system will be capable of delivering 1,000 megawatts of electricity.

The proposed underwater portion of the transmission line will be approximately 98 miles in length. In shallow water, the cables will be buried in a trench at a target depth of at least 3 feet in the bed of Lake Champlain. In deep water, the cables will be placed on the lakebed where self-burial of the cables in sediment is expected to occur. In deep water where there are obstacles to self-burial (e.g., over pre-existing infrastructure or bedrock), the cables will be in direct contact with water.

Methodology for Thermal Modeling

Exponent was retained by TDI-NE to perform an engineering and scientific analysis of the thermal effects of the proposed NECPL project on the environment around the cables in Lake Champlain, Vermont. Exponent's work is summarized in this report and focused on three specific analyses:

- Temperature gradient modeling;
- The impact of temperature increases on bacterial metabolism of mercury; and,
- An assessment of potential temperature impacts on the marine environment.

Exponent first developed a conservative model of the temperature gradients around the cables when operating at a maximum load. For the thermal modeling, various scenarios that would maximize thermal exposures were considered in terms of cable configuration, water depth, ambient temperature, water flow velocity and direction, and cable burial depth, in order to yield conservative estimates of the temperature increase in the vicinity of the cables.

The thermal model calculated temperature gradients in water as well as in sediment. The water temperature gradients were subsequently assessed against the Vermont Water Quality Standards (VWQS), while the sediment temperature gradients were used in the assessment of the bioavailability of methylmercury and effects on macroinvertebrates.

Cable Configurations

There are many parameters to be taken into account in the thermal models. Some of them, such as the water flow velocity and angle, have a dynamic character and can change according to location, season, and depth, among other factors. Other parameters, such as heat load, are common to all configurations. Exponent considered a large number of parameters and data provided by TDI-NE and selected conservative scenarios to bound the problem; this narrowed the analyses to three very specific configurations of the cables in the cases described below:

- **Case T (Trench):** The cables are installed in a trench via shear plow or jet plow in a vertical or stacked profile (one cable above the other). Trench installation is expected to occur for approximately 53 miles or 54% of the route of the cables in Lake Champlain.

- **Case S (Self-Burial):** Where the route is in depths greater than 150 feet, the cables are proposed to be laid on the bottom of Lake Champlain. The cables are expected to self-bury in a horizontal (or side-by-side) profile in the sediment due to their weight. Self-burial is expected for approximately 42 miles or 43% of the lake route.

- **Case B (Bedrock):** In depths greater than 150 feet where bedrock or other obstacles to self-burial (such as pre-existing infrastructure) are encountered, the cables may lay in a horizontal profile on top of the bedrock. The bedrock configuration is expected for approximately 2 miles or 2% of the lake route. In shallow waters or in certain special situations in deep waters, concrete mattresses may be placed over the cables. This scenario, however, was not modeled in this report because the thermal impact in the water outside of the concrete mats over the cables will likely be smaller than Case B based on the 1-foot thickness of the concrete mat and because the cables will have little or no direct contact with water.

Figure 1 shows cross sections of each configuration. Table 1 provides an overview of the key assumptions relied on for each configuration. Table 2 summarizes the parameters and assumptions that are common to all configurations.

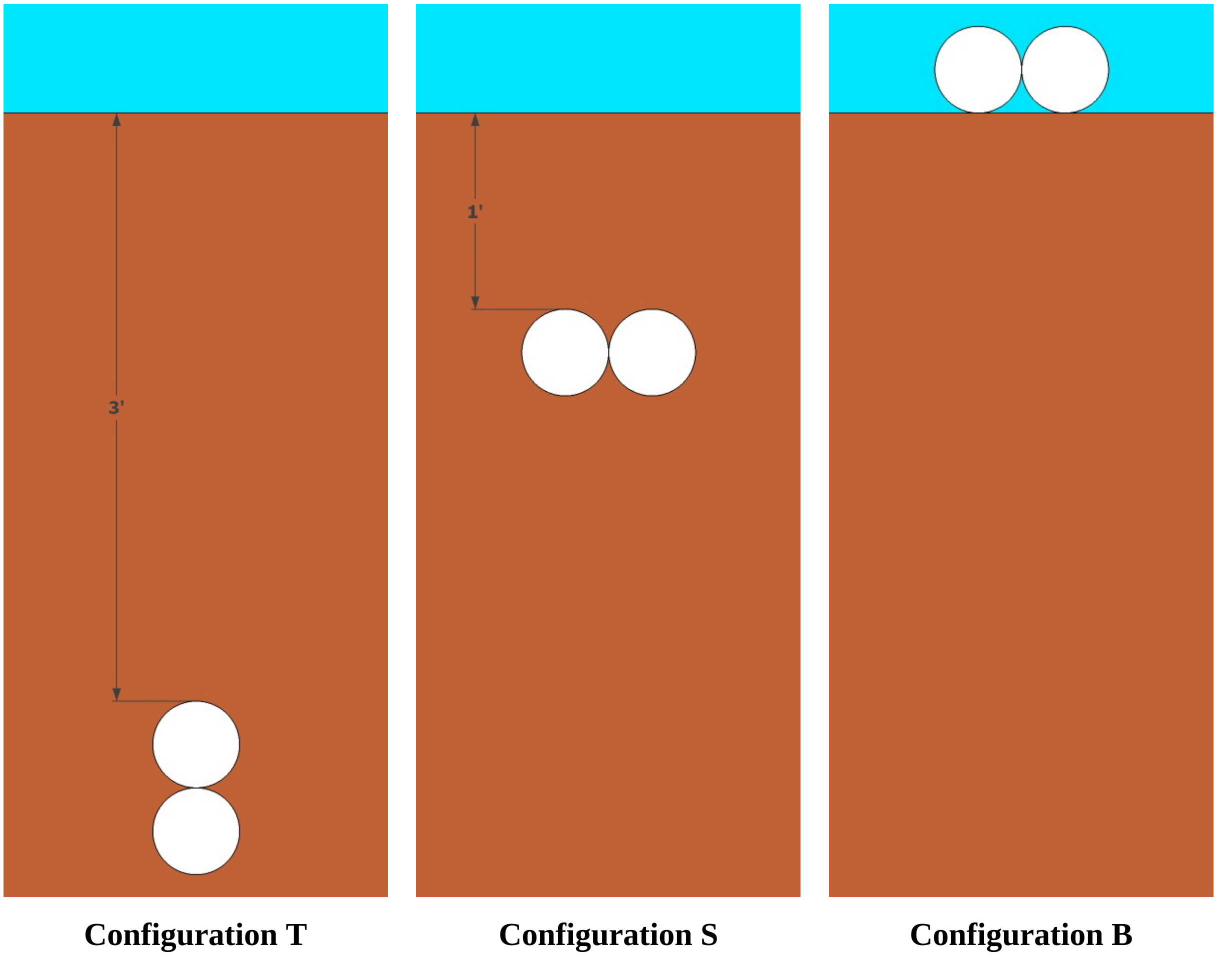

Figure 1.	Three analyzed configurations.

Table 1. Cable configurations

Configuration	Case T (Trench)	Case S (Self-burial)	Case B (On Bedrock)
Burial depth*	3 feet	1 foot	0 feet
% of route†	54%	43%	2%
Sediment type	Clay/Silt	Clay/Silt	Bedrock
Cable orientation	Stacked	Side-by-side	Side-by-side
Ambient temperature	68.7°F	46.4°F	46.4°F
Water depth	10 feet	150 feet	150 feet

* Burial depths are measured from the lakebed to the top of the cables. Data provided by TDI-NE.
† Data provided by TDI-NE. Note that 1% of the route is expected to be under concrete mats.

Table 2. Parameters common to all configurations

Parameter	Value
Cable diameter	135 mm
Heat load	23.3 Watts/meter/cable
Flow velocity	1 cm/second
Flow angle with respect to cable centerline	7 degrees
VWQS threshold for temperature increases*	1°F†

*VWQS, Vermont Code R 12 004 052, Section 3-01.B.1, pp. 18-19.
†This 1°F temperature rise threshold corresponds to the VWQS *"Cold Water Fish Habitat."* Temperature increase above 1°F may be permitted under the conditions outlined in Section 3-01.B.1.d. *"Assimilation of Thermal Wastes."*

The flow characteristics in terms of velocity and direction were analyzed from a statistically large number of data points by Dr. Tom Manley, Professor of Geology at Vermont's Middlebury College.[1] The values in Table 2 correspond to a conservative set of parameters representing a flow at low velocity and encountering the cables at a shallow angle. This scenario minimizes heat dissipation through the water's convective heat transfer and thus predicts conservatively high values of temperature rise. In reality, the velocities and flow angles are expected to vary, and are usually higher than the assumed values, resulting in more efficient convective heat transfer in the water and subsequently lower maximum water temperature rises.

All the above data were provided directly by TDI-NE except when specifically noted otherwise.

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[1] Manley T. Email communications and Technical Memorandum on Bottom Velocities Encountered in Lake Champlain during Summertime and Wintertime Conditions. November, 2014.

Simulation Model for the Thermal Analysis

The heat transfer and fluid dynamics of the underwater cable environment were simulated with a model developed using the multi-physics simulation software package STAR-CCM+, Version 9. The effect of buoyant gravity forces were neglected in order to yield conservative maximum expected thermal exposures.

Geometry Setup

As noted above, the model uses the conservative assumption that water will flow over cables at a fixed 7-degree angle, even though the angle of the flow will likely be higher and regularly changing. In the conservative scenario of a water flow making an angle of only 7 degrees with the centerline of the cables, the flow will have a small velocity component perpendicular to the cables as well as a large velocity component parallel to the cables. The component parallel to the cables captures the cumulative heat transfer as water moves from one region above the cable to the next. Given that the water flow is not perpendicular to the cables, the analysis cannot be done using a simple 2-dimensional (2D) plane perpendicular to the cables as shown in Figure 1.

Therefore, a model was developed to evaluate a section plane parallel to the direction of the flow (i.e., a cross section of the cables at an angle of 7 degrees) as shown in Figure 2 and Figure 3 below. The advantage of this approach is that it allows a simulation of the water's full convective heat transfer effects in the direction of the flow using a quasi-3-dimensional (3D) simulation along a relatively small repeatable section of the cable instead of a full 3D simulation along a very long section of the cable. The quasi-3D simulation is significantly more efficient and the results can be evaluated on a 2D plane. Using this approach, in the 2D plane parallel to the direction of the flow, the cables' cross-sections appear as ellipses instead of circles as shown in Figure 4 through Figure 6. The quasi-3D domain of Case T is shown in Figure 7 as an example. It is a prismatic domain with a trapezoidal base that is 100 feet long, 50 feet deep into the ground, 10 feet deep into the water, and 3.3 feet wide. This configuration provides the same results as a full 3D model and reliably accounts for the full convective heat transfer in the direction of the flow. For Cases B and S, a 50-foot layer of water above the lakebed is included in the model from a depth of 150 feet to a depth of 100 feet.

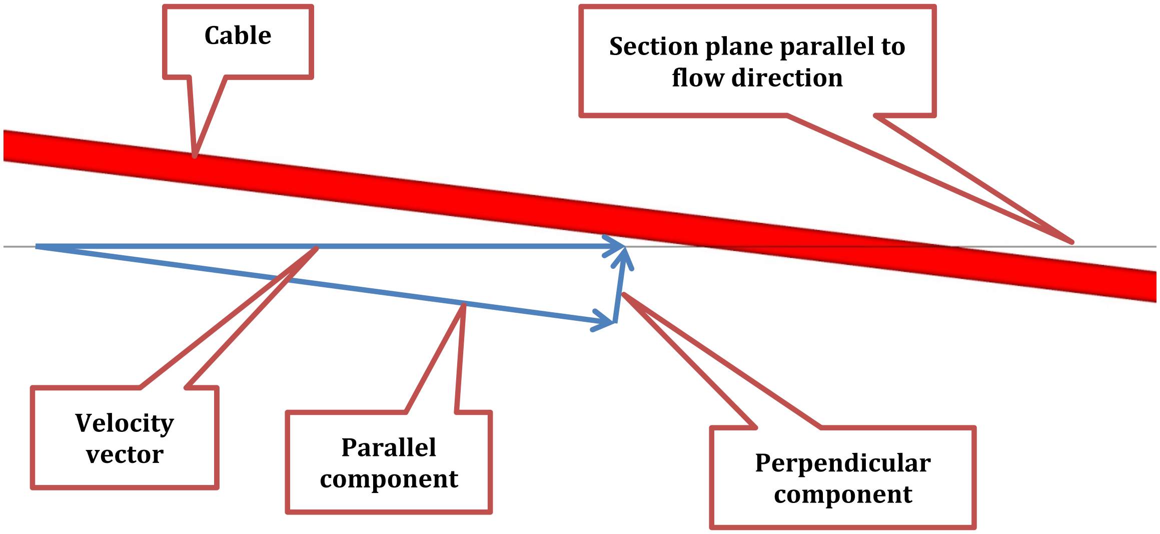

Figure 2. Top view of section plane at 7 degrees with respect to the cable.

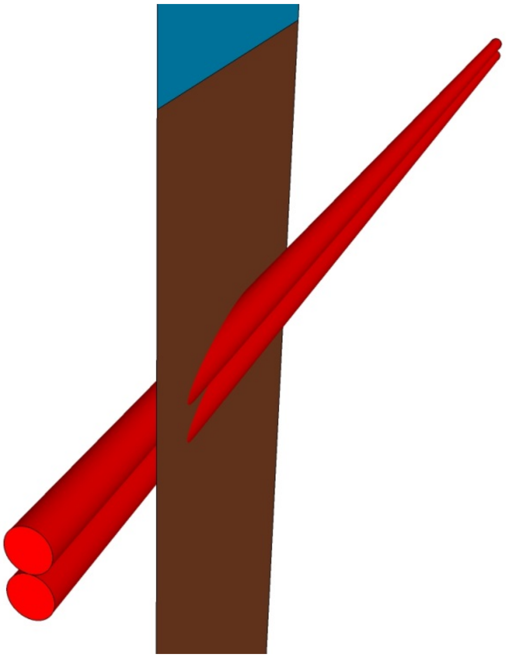

Figure 3. Perspective view of section plane at 7 degrees for Case T.

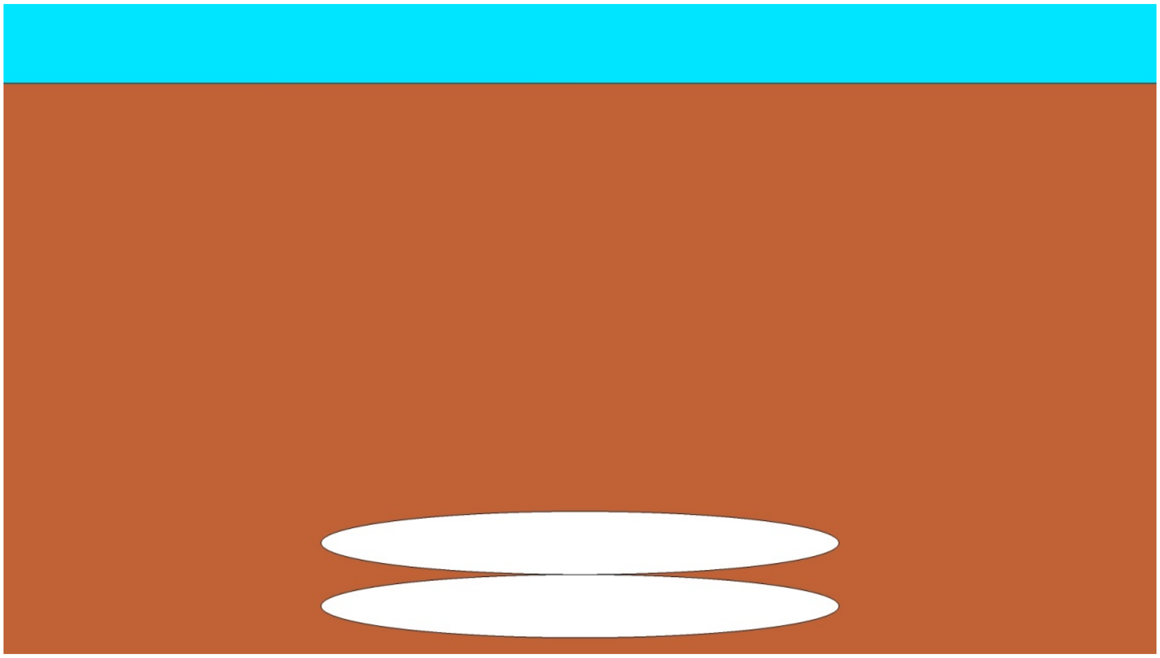

Figure 4. Cross section of Case T at 7 degrees.

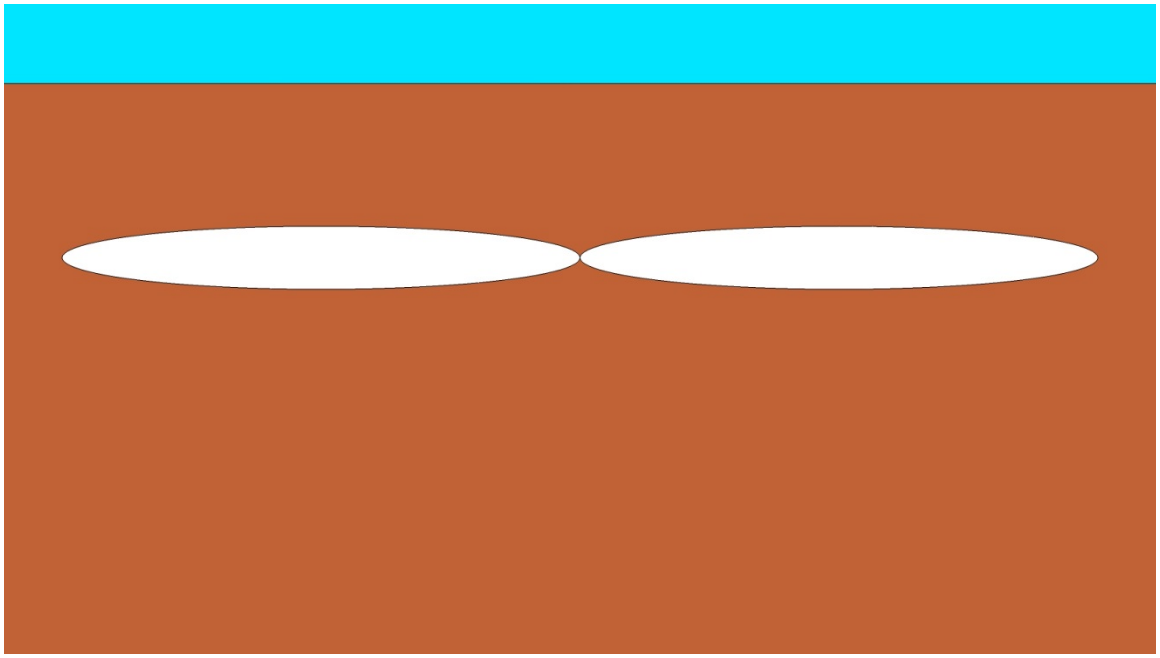

Figure 5. Cross section of Case S at 7 degrees.

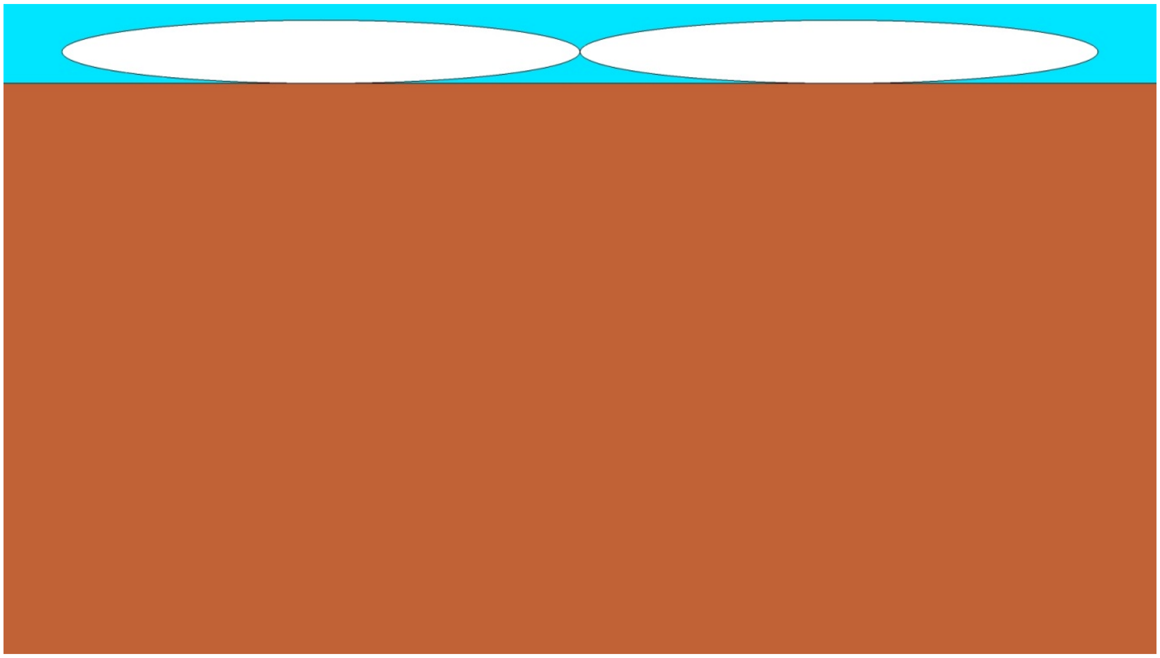

Figure 6. Cross section of Case B at 7 degrees.

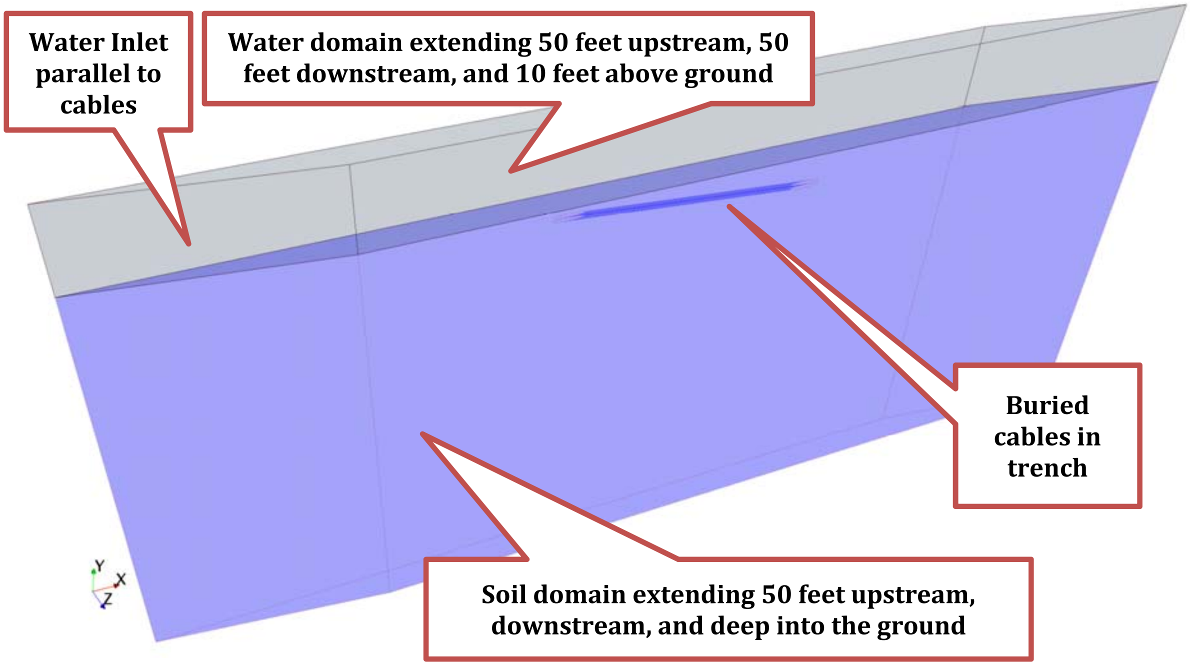

Figure 7. Quasi-3D computational domain for Case T.

Computational Mesh

Exponent ran STAR-CCM+ in the Reynolds-Averaged Navier-Stokes mode using the k-ε turbulence model. The computational mesh is a polyhedral mesh using a prism layer to properly resolve the boundary layer at the bottom of the lake. As an example, the mesh of Case S is shown in Figure 8 and Figure 9. Figure 8 shows an overview of the mesh while Figure 9 is a zoom onto the vicinity of the cables. A finer mesh resolution is chosen in the vicinity of the cables to capture the temperature gradients more accurately. The cell count varied depending on the configuration from approximately 618,000 to 1,077,000 cells. The transition from sediment to water at the lakebed is illustrated by the layer of prismatic cells.

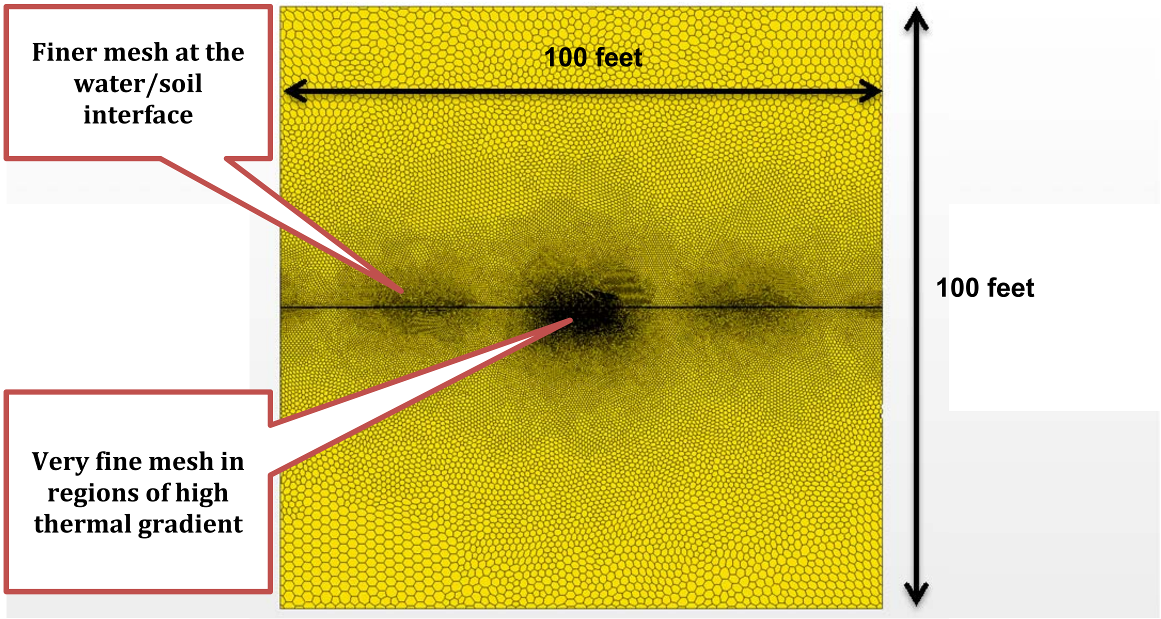

Figure 8. Computational mesh for Case S.

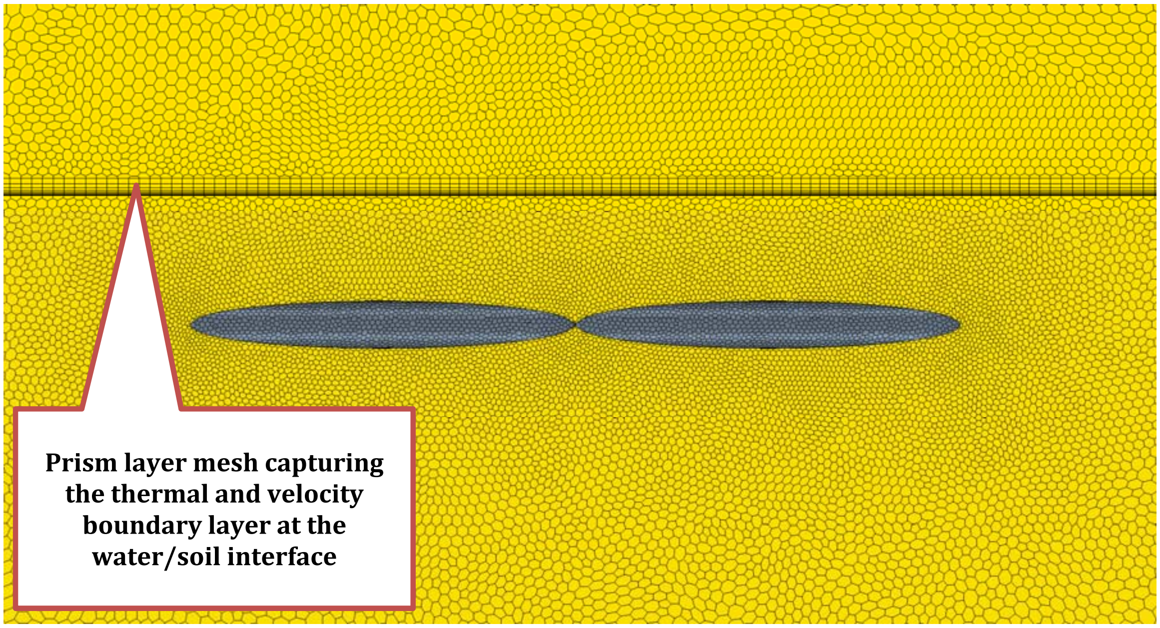

Figure 9. Zoom onto the finer mesh in the vicinity of the cables of Case S.

Water Temperature Results

Although the problem was set up in an oblique plane parallel to the direction of the flow, the temperature rise results can be viewed in any chosen direction. The plane section perpendicular to the cables was chosen to display these results for better clarity as seen in the figures in this section.

Case T: Trench Configuration in Shallow Waters

For the cables buried 3 feet below the water/sediment interface, the water temperature rise is negligible and remains below the 1 degree Fahrenheit (ºF) threshold of the VWQS.[2]

Figure 10 shows the water temperature rise in the vicinity of the cables. The maximum temperature increase is approximately 0.9ºF and occurs at the water/sediment interface immediately above the cables. The warmest region is confined to an extremely thin layer of water as shown by the color gradient.

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[2] VWQS, Vermont Code R 12 004 052, Section 3-01.B.1, pp. 18-19.

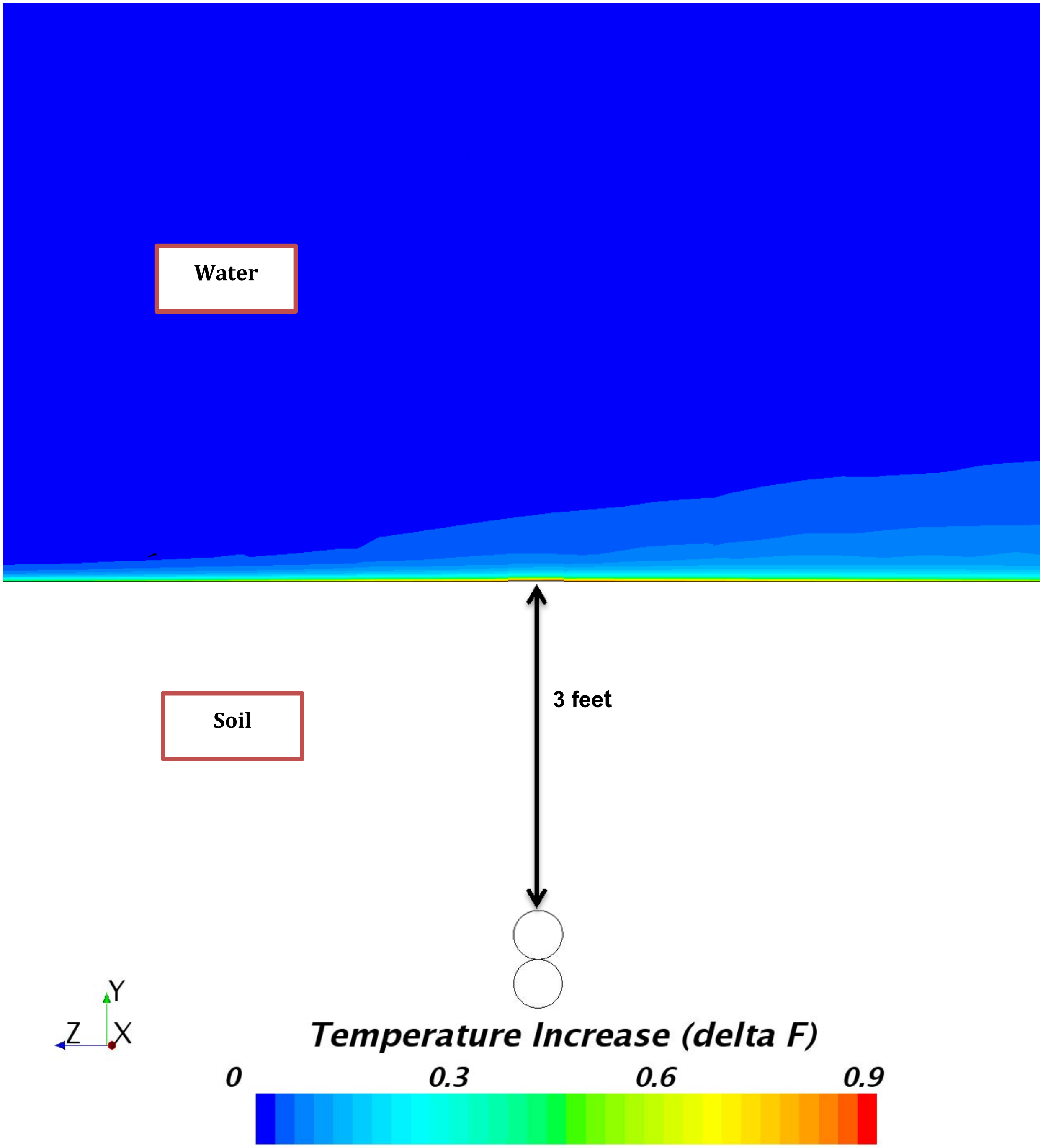

Figure 10. Water temperature rise for Case T in the vicinity of the cables.

Case S: Self-Burial Configuration in Deep Water

For this case, the maximum water temperature increase is slightly above the 1ºF threshold at approximately 1.8ºF, but only in an extremely thin layer of water of less than approximately 0.3 inches above the sediment/water interface as shown in Figure 11 and Figure 12:

- Figure 11 shows the temperature rise in the vicinity of the cables from 0ºF to a maximum of 1ºF. The warm zone between 1ºF and 1.8ºF is shown in white between the red boundary and the water/sediment interface. It is so thin that it is practically indistinguishable at this zoom level;
- Figure 12 zooms onto the warm zone between 1ºF and 1.8ºF and shows it as a convex region shaped like a very thin airfoil that extends 2.8 feet horizontally and only 0.3 inches vertically.

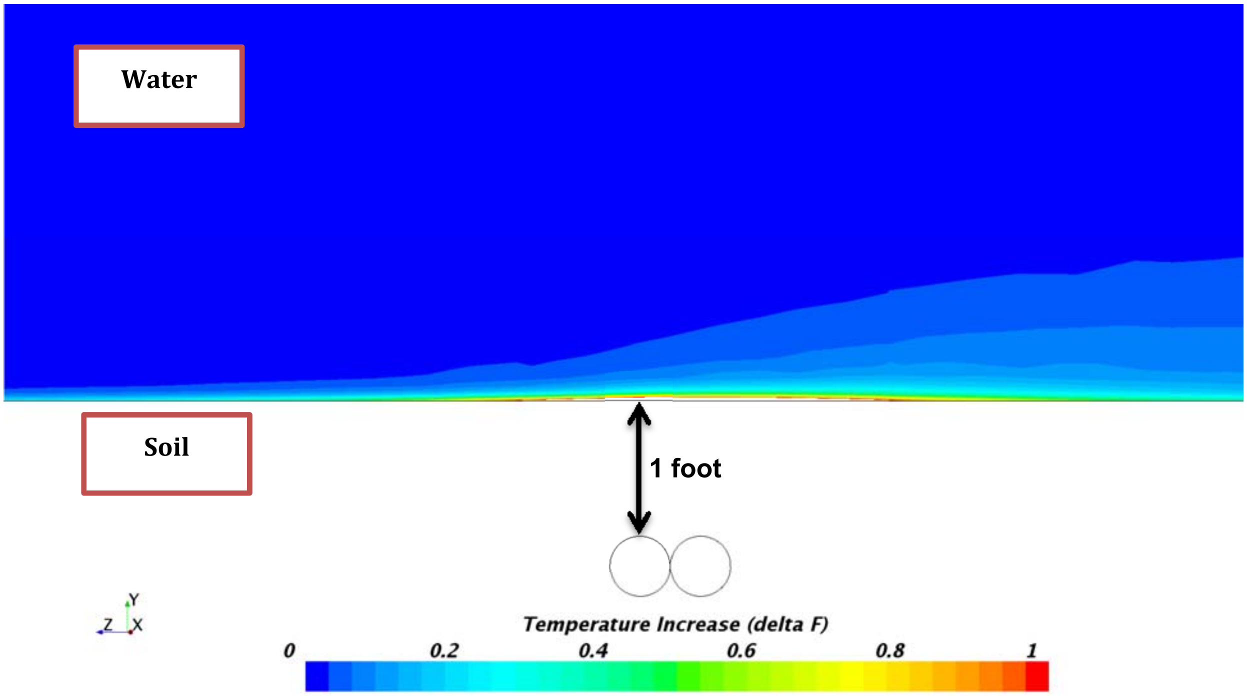

Figure 11. Water temperature rise for Case S.

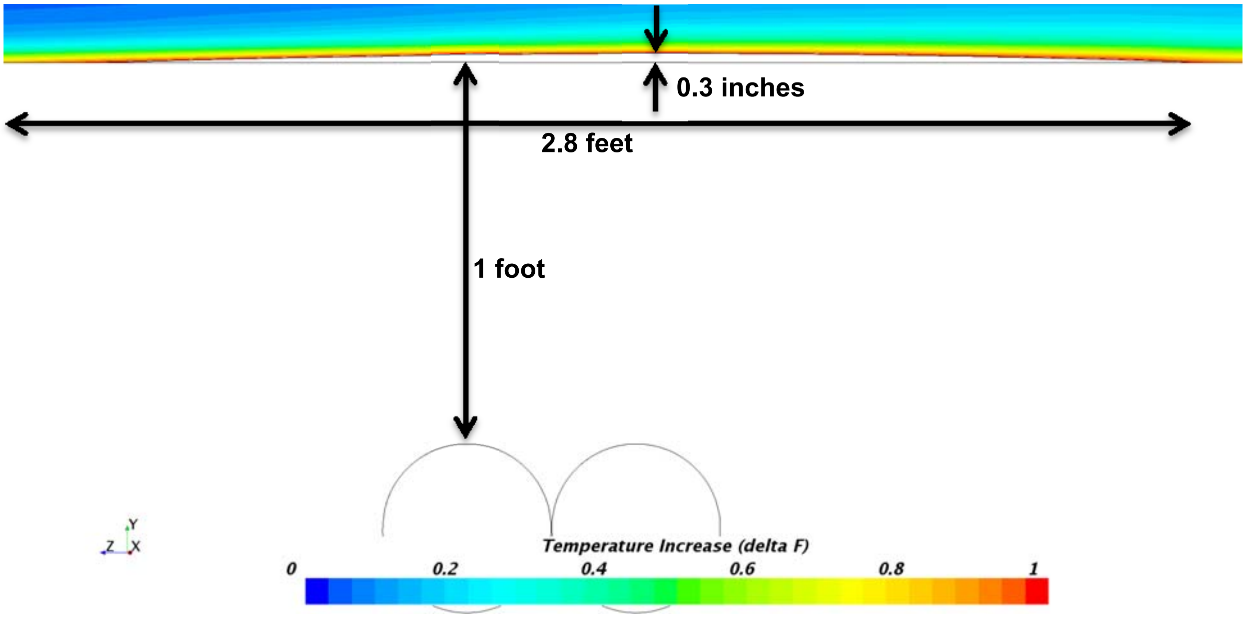

Figure 12. Zoom into water temperature rise for Case T displaying the extent of the warm region.

Case B: Bedrock Configuration in Deep Waters

In this case the cables are in direct contact with water and therefore the warm region is easier to distinguish. For this case, the cold zone is illustrated with color shades from blue to red for water temperature rises between 0ºF and 1ºF. The warm zone is shown in white to make its extent more easily visible. Figure 13 shows that the warm zone is confined to the immediate vicinity of the cables. A zoom into the cables on Figure 14 shows that this zone has a horizontal extent of 1.0 foot and a vertical extent of 5.5 inches. The warm zone barely extends beyond the periphery of the cables in either direction. The horizontal extent of the warm zone in Case B (1.0 foot) is less than that of Case S (2.8 feet). In Case S water flows perfectly parallel to the lakebed over a flat undisturbed terrain, while in Case B the cables lying on the lakebed disrupt the water flow and force the flow to go over the barrier formed by the cables.

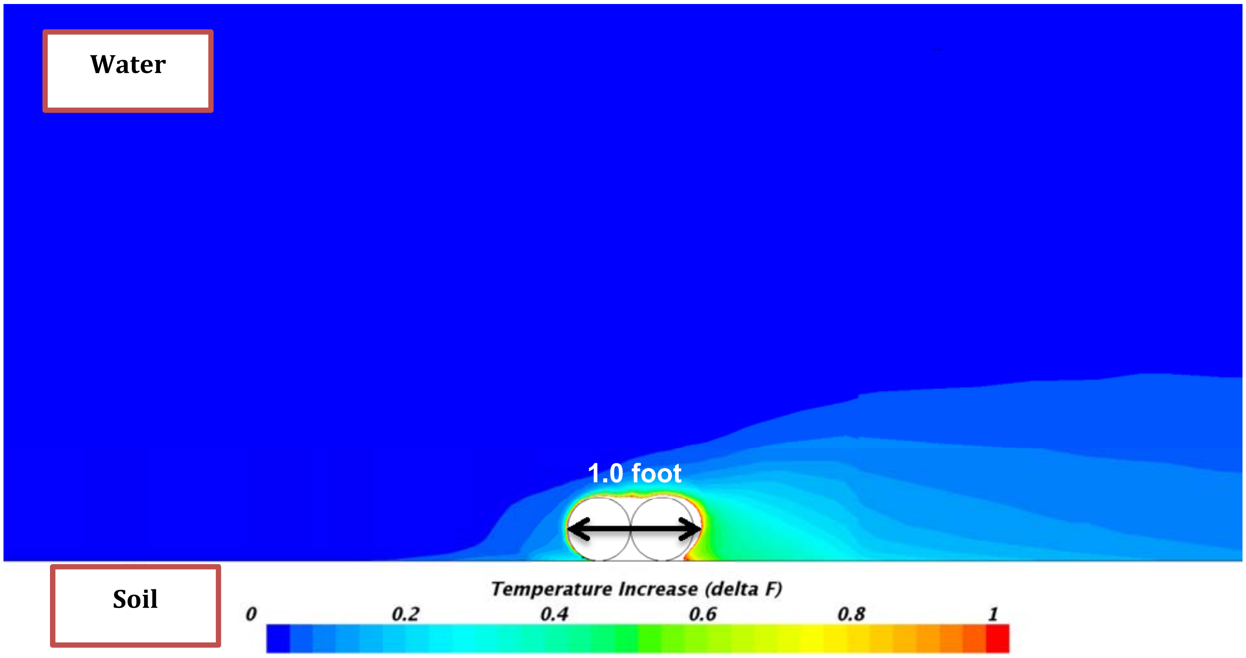

Figure 13. Water temperature rise for Case B displaying the horizontal extent of the warm region.

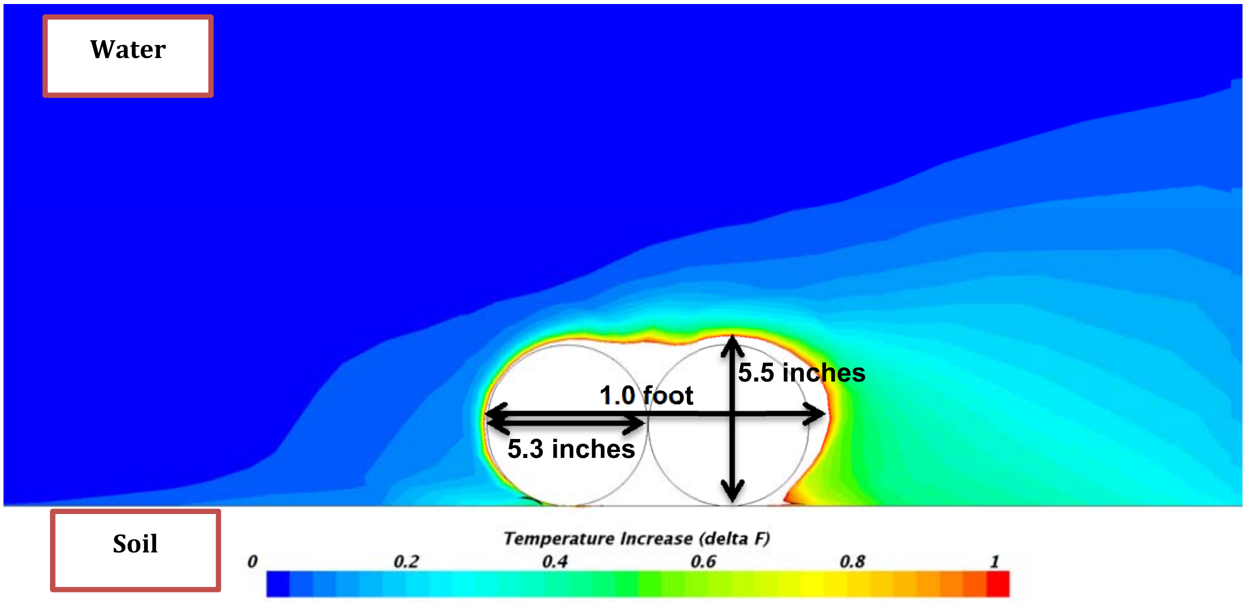

Figure 14. Zoom into water temperature rise for Case B displaying the horizontal and vertical extents of the warm region compared to the 5.3-inch diameter of the cables.

Thermal Analysis Summary

- Case T: water temperature increases remain below 1°F in the entire water domain.
- Cases S and B: there are limited regions where water temperature increases above 1°F:
    - In Case S, this region is extremely thin with a very low temperature rise;
    - In Case B, this region is limited to the immediate vicinity of the region where the water comes into direct contact with the cables.

Table 3 summarizes the above findings.

Table 3. Physical extent of domain where ΔT >1°F

Case	Region where ΔT >1°F	Horizontal extent (feet)	Vertical extent (inches)
T (Trench)	No	No warm zone present	No warm zone present
S (Self-burial)	Yes, but limited	2.8	0.3
B (Bedrock)	Yes, but limited	1.0	5.5

To place the above numbers in context, conservative estimates for the volumes of the warm zones are:

- For Case S: 2.8 feet × 0.3 inches × 42.1 miles = 1.2×10^5 gallons.
- For Case B: [1.0 feet × 5.5 inches - $2\pi \times (5.3/2 \text{ inches})^2$] × 2.0 miles = 1.2×10^4 gallons.

In comparison, the volume of the lake is 6.8×10^{12} gallons.[3] The combined warm zones would represent less than 0.0000019% (i.e., 1.9 millionth of a percent) of the volume of the lake.

Another useful comparison can be done if one considers the volume of a hypothetical mixing zone encompassed by a semi-circle of 200 feet[4] in radius running along the cables for Case S and Case B. This volume would be $(200 \text{ feet})^2 \times \pi/2 \times (42.1 \text{ miles} + 2.0 \text{ miles}) = 1.1 \times 10^{11}$

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[3] Lake Champlain Basin Program website http://plan.lcbp.org/quick-basin-facts

[4] The VWQS discusses the adequacy of a mixing zone of 200 feet in length under section *"Assimilation of Thermal Wastes,"* Vermont Code R 12 004 052, Section 3-01.B.1.d, p. 19.

gallons. The combined warm zones would represent less than 0.00012% (i.e., 0.12 thousandth of a percent) of the volume of such a mixing zone.

Effect of Temperature on Mercury Methylation in Lake Champlain Sediment

This section of the report summarizes Exponent's evaluation on the effect of possible increase in lake sediment temperature associated with each scenario described above (Case T, Case S, and Case B) on the net mercury methylation and macroinvertebrate populations.

Methodology

Mercury chemistry of the Lake Champlain sediment was investigated by reviewing reports and peer-reviewed journal articles to assess current conditions. Exponent further evaluated the impact of simulated temperature increases for Case T, Case S, and Case B relative to the current condition of Lake Champlain using published trend data. For a baseline sediment temperature, we have chosen 68.7ºF (i.e., 20.4 degrees Celsius [ºC]) for the shallower sediment (Case T), and 46.4ºF (i.e., 8ºC) for the deeper sediment (Case S). Hereafter, ºC is used as a unit for temperature, which the unit used in chemical and biological scientific discussion. We have selected these temperatures in order to predict the change in methyl mercury production using conservative baseline temperatures, although temperatures are expected to vary between locations and seasons. For example, at the Valcour Island monitoring station, in 1991 and 1992, the average temperature of the hypolimnetic layer was 6.4ºC (standard deviation 1.2ºC) during warmer months (i.e., June through October 1991), and 3.9ºC (standard deviation 2.6ºC) in colder months (i.e., November 1991 through May 1992) (Manley et al., 1999).

Overview of Mercury Chemistry in Lake Champlain

Mercury is one of the most widespread contaminants of concern in Lake Champlain, similar to many other inland lakes across the world (Gao et al., 2006; Lake Champlain Basin Program, 2012). Mercury enters into Lake Champlain due to both natural and anthropogenic activities (Burke et al., 1995; Gao et al., 2006; Lake Champlain Basin Program, 2012). A sediment survey conducted by the U.S. Geological Survey revealed that low-level contamination by total mercury (the sum of inorganic and organic, or methylmercury) was widespread in Lake Champlain with higher total mercury concentrations in selected areas such as Inner Burlington

Harbor (McIntosh, 1994). As McIntosh (1994) indicated in his report, however, it is the methylated form of mercury that is of concern (which was not provided in this US Geological Survey report by McIntosh).

The percentage of methylmercury in sediment is typically less than a few percent of total mercury (Krabbenhoft et al., 2003). Methylmercury is of concern, because unlike other forms of mercury, methylmercury bioaccumulates in aquatic food webs and increases in concentration (i.e., it is biomagnified) in organisms at the top of the food web. A portion of inorganic mercury in lake sediment is converted to methylmercury by naturally occurring bacteria. These bacteria are anaerobic, meaning they require alternative electron acceptors instead of oxygen, and are active in locations where oxygen is limited.

In general, the rate at which mercury is methylated depends largely on two factors: (1) the metabolic rate of the methylating bacteria, and (2) the supply of bioavailable mercury in the sediment pore water. The activity of mercury methylating bacteria is dependent on environmental conditions, including the availability of simple organic carbon compounds; the presence of sulfate and iron, which act as electron acceptors (the equivalent of oxygen for respiration); and sediment temperature (Bigham et al., 2006). Mercury exists in a variety of chemical forms in the environment; however, only a fraction of total mercury in the form of dissolved inorganic mercury (II) is available to methylating bacteria (Hsu-Kim et al., 2013). The amount of bioavailable mercury is controlled by the total amount of mercury present, but also by the surfaces and compounds to which the inorganic mercury may bind. The combination of all these factors will impact the rate and extent of mercury methylating at Lake Champlain.

Mercury methylation does not occur throughout the sediment column; rather, it typically occurs within the top 6 centimeters (cm) of lake sediment, where conditions are generally optimal for metabolism of the sulfate and iron-reducing bacteria (bacteria known to methylate mercury).

For example, Figure 15 shows typical methylmercury concentrations in lake sediment pore water as a function of depth. Pore-water methylmercury concentrations closely reflect the rate of bacterial mercury methylation; therefore, high concentrations of methylmercury in the top

6 cm of lake sediment indicate that this zone is where methylation takes place to the greatest extent.

Since there is very limited data available for the concentration of methylmercury, methylmercury production rates, and individual geochemical factors impacting methylation in Lake Champlain, we assume the basic principles and typical conditions for mercury methylation apply to Lake Champlain sediment as has been demonstrated in other lakes with low methylmercury concentrations.

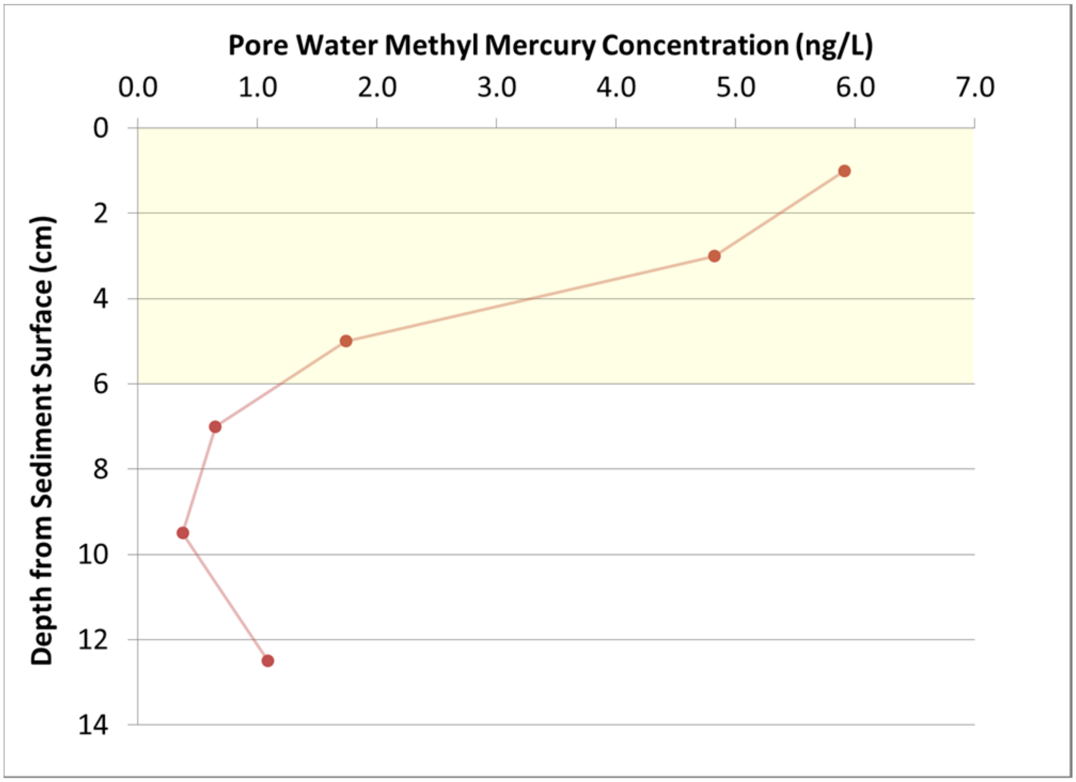

Figure 15. Pore-water methylmercury concentrations of sediment in a mercury-contaminated lake (Onondaga Lake, New York, as an example).

Source: Bigham, 2014

Effect of Temperature: Overview

As with most geochemical and biochemical processes, the rate of mercury methylation increases with increasing temperature due to an increase in biological activity. A laboratory study in which Wisconsin lake sediments were incubated at controlled temperatures showed the maximum rate of mercury methylation at 35ºC (Callister and Winfrey, 1986). In this study, the methylation rate increased three-fold when the temperature increased from 20ºC to 35ºC (Figure 16). Other researchers studying lake sediments from Canada also report a 50 – 70% increase in mercury methylation for temperature increases of 4ºC to 20ºC (Wright and Hamilton, 1982). As summarized by Ullrich et al. (2001), the rate of mercury methylation in aquatic systems typically peaks during the summer months, indicating the strong influence of temperature on overall mercury methylation.

The predicted increases in temperature for the scenarios investigated in this report were much smaller than those reported in the literature and are discussed specifically below.

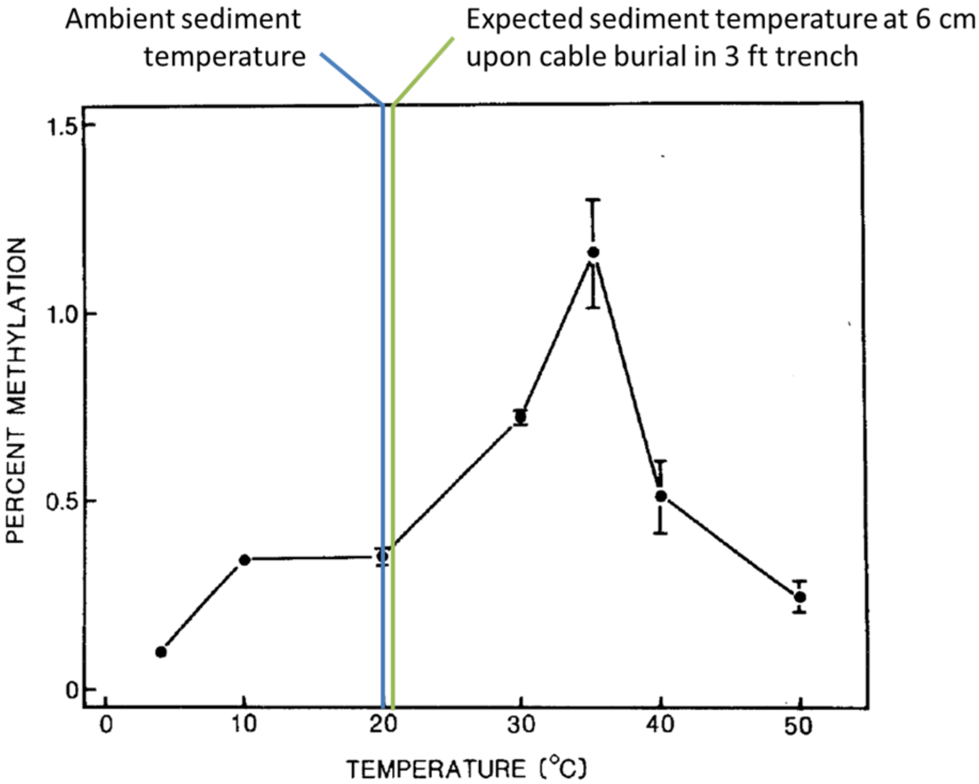

Figure 16. Effect of temperature on mercury methylation measured by Callister and Winfrey (1986).

Baseline ambient sediment temperature in Lake Champlain of shallower sediment (blue) and expected temperature at 6 cm (green) are shown as references for Case T.

Case T: Trench Configuration in Shallow Waters

Where the cable is buried in a trench at a depth of 3 feet, the thermal model simulation shows a small increase in sediment temperature in the zone of mercury methylation (Figure 17). In the top 6 cm of sediment, where mercury-methylating bacteria are most active, our simulation indicates that the expected temperature increase will range from 0.6ºC at the top of the sediment to 1.2ºC at 6 cm in depth below the sediment surface. The resulting change in temperature is small, and should not impact the activity of methylating bacteria as depicted in Figure 16.

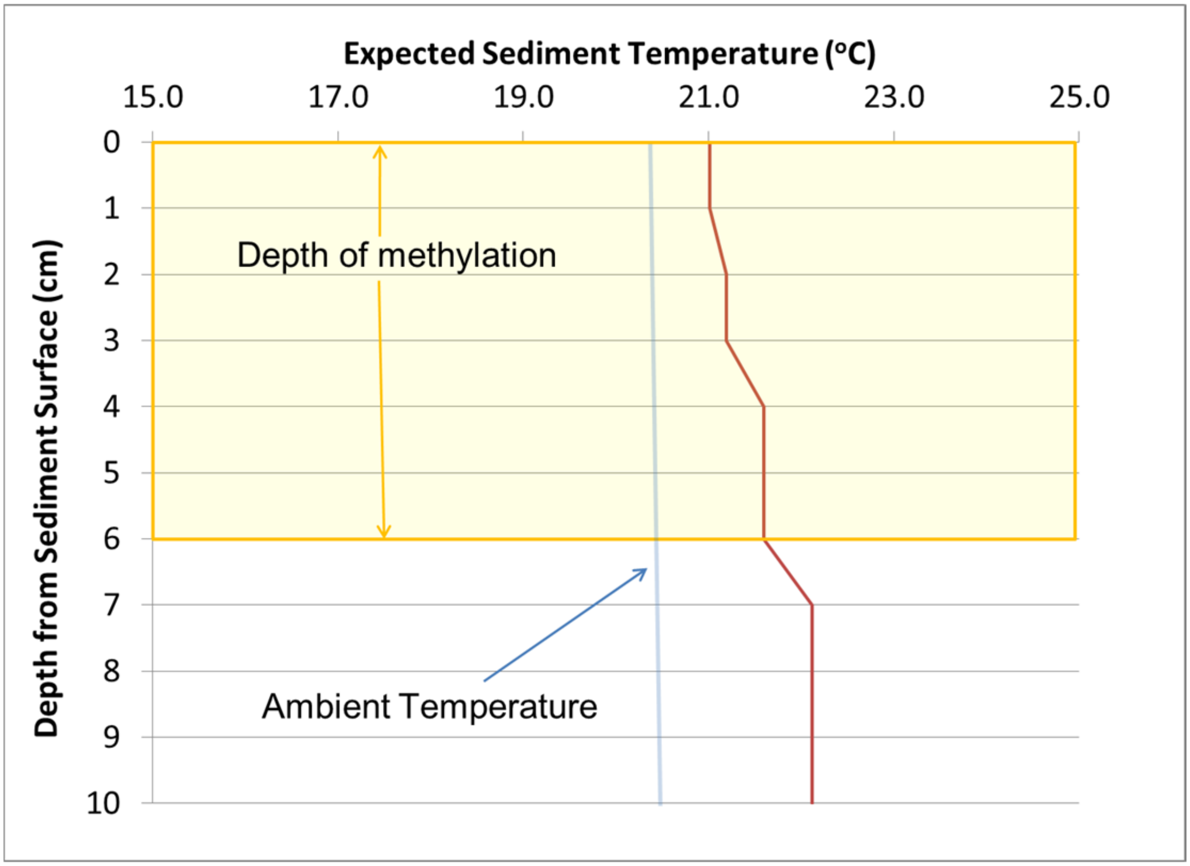

Figure 17. Expected sediment temperature on burial of cable in a 3 foot trench (Case T).

Case S: Self-Burial Configuration in Deep Waters

When the cable is subjected to self-burial, a small increase in sediment temperature and negligible impacts on net mercury methylation are expected (Figure 18). In the top 6 cm of sediment, where mercury-methylating bacteria are most active, our simulation indicates that the temperature will range from 8.9ºC at the top of the sediment to 10.6ºC at a depth of 6 cm below the sediment surface, assuming that the ambient sediment temperature is 8ºC. Similar to the scenario in Case T, this level of temperature increase is not expected to have a significant impact on mercury methylation (Figure 16).

Geochemical conditions of sediment such as sulfate concentrations, the form of organic matter available for mercury methylating bacteria, and distribution of various mercury species used in the study by Callister and Winfrey (1986) likely vary from Lake Champlain sediment; therefore, the results of this study should be extrapolated with caution. Nevertheless, it is the same biological process that is controlling mercury methylation, and we have not found a geochemical parameter that will change the biological mercury methylation potential as a function of temperature in Lake Champlain from the trend observed by Callister and Winfrey (1986). Therefore, the temperature dependence is expected to be similar for the microbial populations in Lake Champlain, compared to the ones observed by Callister and Winfrey (1986). In addition, because the expected temperature increase on cable self-burial is small (Figure 16), we expect any increase in the rate of mercury methylation in sediment along the project route to be negligible. In fact, the predicted increase in temperature is within the standard deviation of the temperature measurement provided by Manley et al. (1999). The possibility of an increase of methylmercury in the aquatic food web of Lake Champlain is further reduced due to the small footprint of the project area compared to the whole lake and our conservative selection of the baseline sediment temperature.

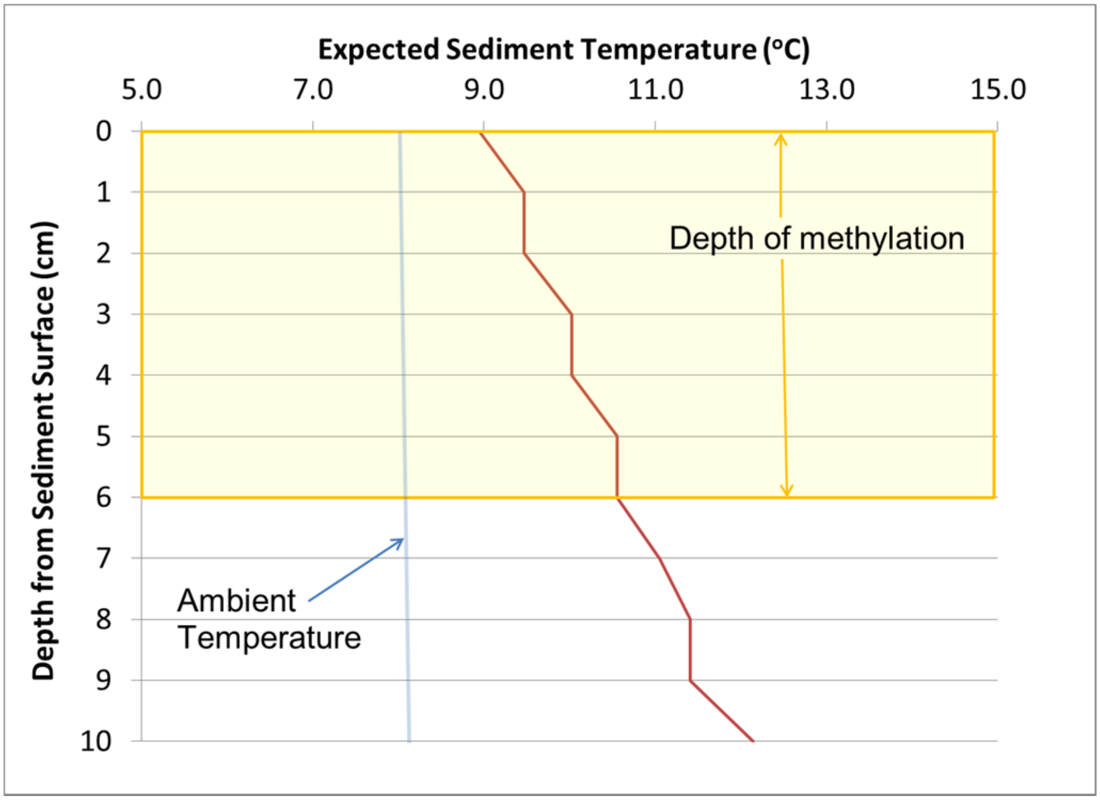

Figure 18. Expected sediment temperature on self-burial of cable at 1 foot (Case S).

Case B: Bedrock Configuration in Deep Waters

Under the Case B scenario, no effect on sediment temperature is expected. The presence of cable on bedrock or on infrastructure (likely with a protective layer) will not affect the propensity of mercury to be methylated due to inherently low microbial activity in these zones due to the relative absence of sediment substrate, as sediment is the major habitat providing organic carbon and nutrients required for microbial growth and function .

Effect of Temperature on Sediment Summary

Mercury is a contaminant of concern in Lake Champlain, similarly to many inland lakes across the globe. A small portion of inorganic mercury (generally less than few percent of total mercury) in lake sediment is converted to methylmercury by naturally occurring bacteria. Methylmercury is the form of mercury that bioaccumulates in aquatic food webs; therefore, it is critical to evaluate conditions impacting methylation process by bacteria. Although there is limited data available for methylmercury of sediment in Lake Champlain, Exponent has evaluated published reports and peer reviewed publications to assess the potential impacts of increase in sediment temperature by the cables under three conditions as simulated in the previous section: Trench Configuration in Shallow Waters (Case T), Self-Burial Configuration in Deep Water (Case S), and Bedrock Configuration in Deep Waters (Case B). For Cases T and S, expected increase in temperature in the zone of mercury methylation (i.e., the top 6 cm of sediment) is not large enough to significantly impact mercury methylation in Lake Champlain. Furthermore, due to low biological activity of the area with bedrock or where there is a protective layer over existing infrastructure, mercury methylation should not be impacted by the presence of cable.

Effect of Temperature on Benthic Macroinvertebrate Community Structure in Lake Champlain Sediment

The proposed project may cause thermal changes to a small area of sediment. Published literature has shown changes to community structure when thermal changes occurred throughout the entire stretch of a stream or when the temperature of an entire lake increased (Lessard and Hayes, 2003; Lamberti and Resh, 1985; Poff and Mathews, 1986). Under the proposed project, any potential changes in community structure in Lake Champlain would be localized to areas directly adjacent to the submerged cable. This would eliminate any potential effects to mobile benthic organisms (e.g., fish, crayfish, and snails). Furthermore, to the extent the Lake Champlain community structure already favors temperature-tolerant species, changes in water temperature on the scale predicted for the NECPL project may have little to no impact on community structure.

The temperature range of Lake Champlain is dependent on both depth and season. Warmer seasonal temperatures (June through October) range from 12ºC to 22ºC in shallow waters (10-12 meters [m]) and 6ºC to 10ºC in deeper water waters (55-57 m) (Manley et al 1999). Colder seasonal temperatures (November through May) range from 0ºC to 10ºC in shallow waters (10-12 m) and 0ºC to 8ºC in deeper waters (55-57 m) (Manley et al 1999). The benthic macroinvertebrate community of Lake Champlain is likely to be tolerant to a wide range of temperatures due to these seasonal temperature changes.

Lake Champlain Benthic Macroinvertebrate Community Structure

In the spring of 2010, a marine route survey was conducted on the proposed route for the Champlain Hudson Power Express project. As part of this survey, samples were collected to determine benthic community structure along the proposed route. This benthic survey can be considered representative of the entire lake, as samples were taken along the length of the lake in deep water, in shallow embayments, and in shoreline areas, which represent the available benthic habitats in Lake Champlain. Sample analysis determined that the dominate taxa were zebra mussels (*Dreissena polymorpha*), Chironomid species (dominantly from the genus *Tanytarsus*) (none-biting midge larvae), and pea clams (*Pisidium sp.*) (HDR, 2010).

Zebra mussels are an invasive species in North America. They can spread rapidly and have caused a great deal of economic damage by clogging intake pipes of water treatment plants and other submerged structures (Great Lakes Commission, 2011). Zebra mussels also pose a threat to local species: they can out-compete native species for resources because of their ability to filter large volumes of water, and they can smother native bivalve species by attaching to them in large numbers (Great Lakes Commission, 2011). There have been many attempts to reduce the populations of zebra mussels due to these issues. Since adverse effects to this invasive species is not a concern and zebra mussels are not expected to be affected in any way by the change in temperature due to this project, they are not discussed further in this report.

Chironomid larvae are the aquatic stage of non-biting midges. Chironomids, including the genus *Tanytarsus*, are ubiquitous in many freshwater systems because they can tolerate a wide range of water conditions, including temperature changes (Schultz-Benker and Mathis, 1985; Poff and Mathews, 1986; Pamplin et al., 2007; Živić et al., 2013). Some species of genus *Tanytarsus* have been shown to successfully emerge at temperatures up to 46ºC (Barbara and Kondratieff 1989), but optimum temperature for genus *Tanytarsus* is 8ºC to 26ºC (Brandt 2001, Rassaro, 1991).

Pea clams (*Pisidium sp.*) are small bivalves (8-11 millimeters in length) that are found in many freshwater lakes and slow-moving rivers with fine sediments (Kipp et al., 2014). They have a high tolerance for temperature ranges living in water from 1ºC to 21ºC (Kipp et al., 2014).

Case T: Trench Configuration in Shallow Waters

Where the cable is buried in a trench at a depth of 3 feet, our simulation shows that temperature will increase to 21ºC at the sediment surface to 22.1ºC at 10 cm below the sediment surface. This is still well within the acceptable range for *Tanytarsus sp.* and is not expected to cause any changes to community structure. Although 22.1ºC is above the optimum range for the pea clams, as filter feeders they are not expected to be present below the sediment surface (Kipp et al., 2014).

Case S: Self-Burial Configuration in Deep Waters

When the cable is subjected to self-burial, a modest increase in sediment temperature is expected due to the water depth at which the cable will rest. In the top 10 cm of sediment, our simulation indicates that the temperature will range from 8.9ºC at the surface of the sediment to 12.1ºC at 10 cm, assuming that the ambient sediment temperature is 8ºC. This temperature range is still suitable for *Tanytarsus sp*. and the pea clam species (Barbara and Kondratieff, 1989; Brandt, 2001; Kipp et al., 2014); therefore effects on the macroinvertebrate community structure are not expected.

Case B: Bedrock Configuration in Deep Waters

Under the Case B scenario, no effect on sediment temperature is expected. Chironomid species and pea clam species live on, and in, fine sediments and are not expected to be on areas of bedrock, therefore there is no expected impact on macroinvertebrate community structure.

Benthic Macroinvertebrate Community Structure Summary

Temperature increases can have significant impacts on benthic macroinvertebrate community structure. They can reduce taxa diversity by eliminating temperature-sensitive taxa within a community. In communities already dominated by temperature-tolerant species, however, increasing water temperatures are not expected to have significant effects on community composition. The proposed project could cause temperature changes to small areas of Lake Champlain sediment. Any temperature changes would be limited to areas directly adjacent to the submerged cable and potentially would only affect sessile organisms. Mobile benthic organisms (e.g., fish, crayfish, snails) would be able to move a short distance to avoid any unfavorable temperature conditions. Seasonal temperatures naturally range from 0ºC to 10ºC for deeper waters and 10ºC to 22ºC for shallow waters. These temperature changes would favor temperature tolerant macroinvertebrate taxa. This was confirmed by a benthic survey conducted in 2010 for the Champlain Hudson Power Express project, which showed that the dominant taxa in Lake Champlain are Chironomids (*Tanytarsus sp.*), pea clams (*Pisidium sp.*), and zebra mussels. Both *Tanytarsus* and *Pisidium* are tolerant to a wide range of temperatures. More mobile organisms are not expected to experience any possible adverse effects due to potential temperature increases only to highly localized areas of the benthic ecosystem. In Case T, where the cable is buried in a trench at a depth of 3 feet, our simulation shows that the temperature will increase to a maximum of 22ºC at a depth of 10 cm below the sediment surface. This temperature change is still within acceptable range for Chironomids and pea clam species. Case S, where the cable is subjected to self-burial in deep water, would result in temperature ranges that are again still suitable for Chironomid and pea clam species (8.9ºC to 12.1ºC). Under Case B, the cable is on bedrock or some other submerged structure, so there is no expected impact to macroinvertebrate communities because Lake Champlain Chironomid and pea clam species reside in soft sediments not on exposed structures.

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Limitations

At the request of TDI-NE, Exponent calculated temperature gradients around segments of the NECPL cables to be installed in Lake Champlain when operating at maximum capacity and assessed potential effects of temperature rise on water quality criteria, rate of methylation of mercury in sediment, and on macroinvertebrate populations in sediments. This report summarizes work performed to date and presents the findings resulting from that work. In the analysis, we have relied on information provided to us by staff of TDI-NE and its consultants with respect to parameters and configurations of the transmission line and site-specific data. The relevance of these results to methylation of mercury in sediment and invertebrates life was evaluated by reference to published research and technical reports. The findings presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this analysis may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented here are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.