STATE OF VERMONT
PUBLIC SERVICE BOARD

Petition of Champlain VT, LLC d/b/a TDI New England for a Certificate of Public Good, pursuant to 30 V.S.A. §248, authorizing the installation and operation of a high voltage direct current (HVDC) underwater and underground electric transmission line with a capacity of 1,000 MW, a converter station, and other associated facilities, to be located in Lake Champlain and in the Counties of Grand Isle, Chittenden, Addison, Rutland, and Windsor, Vermont, and to be known as the New England Clean Power Link Project ("NECPL")	)	Docket No. _____

PREFILED DIRECT TESTIMONY OF WILLIAM BAILEY, PH.D.

ON BEHALF OF CHAMPLAIN VT, LLC

December 8, 2014

Summary:

Dr. Bailey provides testimony regarding 30 V.S.A. § 248(b)(5), impacts on the Natural Environment from the Project's thermal and magnetic properties, including potential effects on water purity and water pollution for Lake Champlain. Dr. Bailey also provides testimony regarding 30 V.S.A § 248(b)(5) Public Health and Safety, with particular emphasis on magnetic fields.

Exhibit Number	Name of Exhibit
TDI-WHB-1.	Resume
TDI-WHB-2	Temperature Gradients in the Vicinity of NECPL Cables and Potential Effects on Water Quality, Bioavailability of Mercury, and Macroinvertebrates
TDI-WHB-3	Submarine Cable DC Magnetic Field in Lake Champlain and Marine Assessment
TDI-WHB-4	Overland Magnetic Field Report for the New England Clean Power Link Project

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General Background

Q1. Please state your name and position relative to this project.

A1. Response: My name is William H. Bailey, Ph.D. I am a Principal Scientist in the Center for Exposure Assessment and Dose Reconstruction of Exponent, Inc. Exponent is a scientific research and engineering firm engaged in a broad spectrum of activities in science and technology. In this project, I head a team of scientists and engineers that serve as a technical resource to TDI New England ("TDI-NE") on the proposed New England Clean Power Link Project ("NECPL" or "Project") concerning the potential effects of temperature and magnetic field gradients around the proposed cables on the environment of the aquatic portion of the route including water and sediment heating, magnetic field effects on compasses, potential effects on fish, and potential health and safety effects of the proposed cables when installed on the overland portion of the route.

Q2. Please describe your qualifications and expertise.

A2. Response: I earned a Ph.D. in neuropsychology from the City University of New York. I received two additional years of postdoctoral training in neurochemistry at The Rockefeller University in New York City under a fellowship from the National Institutes of Health. My education includes a BA from Dartmouth College received in 1966 and an MBA from the University of Chicago awarded in 1969.

I am a scientist and researcher focusing on environmental health sciences. My work involves reviewing, analyzing, and conducting health research. Much of my work over the past 30 years in bioelectromagnetics relates to the exposures and potential biological, environmental, and health effects associated with electrical facilities and devices, including electric utility facilities, electrified railroad lines, industrial equipment, appliances, and medical devices that produce electromagnetic fields across a wide range of frequencies. Since 1986, I have been a visiting research scientist at the Cornell University Weill Medical College. I also have been a visiting lecturer at Rutgers University, the University of Texas (San Antonio), and the Harvard School of Public Health in the field of bioelectromagnetics. From 1983 through 1987, I was head of the Laboratory of Neuropharmacology and Environmental Toxicology at the New York State Institute for Basic Research. For the seven previous years, I was an Assistant Professor in Neurochemistry at The Rockefeller University.

I have reviewed research for the National Institutes of Health, the National Science Foundation, and other government agencies. Specifically regarding transmission lines, I served on a Scientific Advisory Panel convened by the Minnesota Environmental Quality Board to review the health and safety aspects of a high-voltage transmission line. In addition, I served as a consultant on transmission line health and safety and environmental issues to the Vermont Department of Public Service, the New York State Department of Environmental Conservation, and the staffs of the Maryland Public Service Commission and the Maryland Department of Natural Resources.

I have worked with the National Institute of Occupational Safety and Health, the Oak Ridge National Laboratories, the U.S. Department of Energy, and the Federal Railroad Administration to review and evaluate health and environmental issues related to electric and magnetic fields (EMF) from power lines and other sources. I also assisted the U.S. EMF Research and Policy Information Dissemination program to evaluate biological and exposure research as part of its overall risk assessment process.

I worked with scientists from 10 countries to evaluate possible hazards from exposures to static electric and magnetic fields and extremely low frequency EMF for the International Agency for Research in Cancer, a division of the World Health Organization located in Lyon, France. I also was an invited participant in the workshop convened by the International Committee on Non-Ionizing Radiation Protection ("ICNIRP") to update guidelines for human exposures to alternating current ("AC") electric and magnetic fields ("EMF"). I have reviewed ICNIRP's draft guidelines for direct current ("DC") and AC magnetic fields on behalf of the International Committee on Electromagnetic Safety as well.

Most recently, I have served as an advisor to the U.S. Department of Energy, and several government agencies in Canada and the Netherlands on topics relating to scientific research on EMF health and safety. Regarding submarine power cables I have performed exposure assessments of proposed cable projects, compared post-construction measurements to pre-construction modeling, assessed potential neurobiological effects of magnetic and electric fields on marine life, and served as an advisor to the Connecticut Academy of Science and Engineering and the U.S. Bureau of Ocean Energy Management.

I have published or presented more than 50 scientific papers on this and on related subjects. These publications and presentations are listed in my curriculum vitae, attached as ***Exhibit (Exh.) TDI-WHB-1***.

Q3. On whose behalf are you offering this testimony?

A3. Response: I am offering this testimony on behalf of TDI-NE related to the proposed NECPL.

Q4. Have you previously testified before the Public Service Board or in other judicial or administrative proceedings?

A4. Response: Yes, as outlined in my resume, I have testified in a proceeding before the Public Service Board in Vermont and before similar regulatory bodies in other states including Connecticut, Maine, Maryland, Massachusetts, New York, and Virginia.

Q5. What is the purpose of your testimony?

A5. Response: The purpose of my testimony is to introduce and describe the modeling used to characterize the temperature gradients around the NECPL cables and potential effects on water quality, mercury methylation rates, and macroinvertebrates in Lake Champlain during operation. I also testify regarding the expected change to the earth's geomagnetic field around the cables by the magnetic field created by the flow of DC electricity in the cables and the potential implications for fish whose sensory capabilities may permit detection and responses to such stimuli. Finally, I summarize our analysis of any potential public health and safety issues related to magnetic fields for both the aquatic and overland segments of the Project, including any impact on navigational issues in Lake Champlain. My testimony relates to criteria 30 V.S.A. § 248(b)(5), specifically regarding water purity, the natural environment, and public health and safety.

Q6. Have you relied on the work of any other experts concerning this Project?

A6. Response: Yes. TDI-NE and consultants to TDI-NE provided information to Exponent regarding the proposed cables, DC power flow and direction, aquatic and overland installation, water temperature, current flows, lakebed characteristics, and self-burial depths of the cables, which were considered in the development of models for the temperature and magnetic field gradients around the cables.

Q7. Have you provided project information to other experts in support of their section 248 testimony and if so, what?

A7. Response: No, we furnished no project data to other experts except for the results of our analyses attached as exhibits to my testimony.

Aquatic Route

30 V.S.A. § 248(b)(5) – Aquatic Natural Environment and

10 V.S.A. § 6068(a)(1) – Water Purity and Water Pollution

Q8. Can you please briefly summarize the nature of the exposures from the Project to the water resources of Lake Champlain and natural and human environment that you have evaluated?

A8. Response: With respect to Lake Champlain, our work focused on two primary types of exposure associated with operation of a HVDC cable: thermal exposures and DC magnetic field exposures. The passage of electricity through the cables creates heat that dissipates into the surrounding environment. The flow of DC electricity through the cables also produces a DC magnetic field, commonly referred to as a static field because the magnitude and direction of the current flow and hence the field are unchanging for long periods of time. This DC magnetic field is to be contrasted to the magnetic fields produced by the passage of AC with a frequency of 60 Hertz ("Hz"), which means the intensity and direction of the fields oscillate in direction and intensity 60 times each second. The magnitude and spatial variation in the temperature and DC magnetic field gradients around the cables were modeled to evaluate potential environmental effects.

Evaluation of Aquatic Thermal Effects

Q9. Let's start with the temperature modeling that you conducted. Can you please describe the nature of the Project's thermal properties and the basic methodology that you used for this analysis?

A9. Response: At ambient temperatures all conductors have some resistance to current flow. This results in the conversion of electrical energy to heat. The steady-state temperature rise in the surrounding materials is primarily a function of their thermal conductivities and their coefficients of heat transfer. To determine the temperature rise in the Lake Champlain environment, we modeled the dissipation of heat energy from the two cables taking into account the thermal properties of the elements of the surrounding environment, namely water and sediment (clay/silt). We did not model the heat dissipation from the cables when installed on land as the magnitude of temperature increases associated with the Project in the soil pose no undue threat to the environment.

The cables produce a constant amount of heat per unit cable length (23.3 W/m/cable) which in turn translates into heat flux per unit of cable surface. The primary heat transfer modes are conduction and forced convection. Part of the heat is transported away through the water's convective heat transfer (which is primarily a function of water velocity), while the rest is dissipated deep into the ground through conduction.

Q10. Can you please identify the specific modeling methodology you used to analyze the Project's potential thermal effects?

A10. Response: Increased temperatures around the cables were analyzed using a model developed using the multi-physics simulation software package STAR-CCM+, Version 9, which allows us to simulate the heat transfer and fluid dynamics of the underwater cable environment. This methodology for modeling thermal impacts is a standard, well-accepted, and commonly used approach for analyzing thermal impacts similar to the ones under consideration here. At its core, the model simulates the behavior of actual thermal quantities in water and soil by dividing any given volume of solid or liquid into a large number of smaller discrete finite volumes called a computational mesh and then solves highly accurate mathematical models of the equations that govern fluid dynamics and heat transfer in these media. The model methodology and the results of our analyses are described in our report "Temperature Gradients in the Vicinity of NECPL Cables and Potential Effects on Water Quality, Bioavailability of Mercury, and Macroinvertebrates" (***Exh. TDI-WHB-2***), hereafter Thermal Report.

Q11. What general and project specific inputs are necessary to run your model, and how did you obtain these inputs?

A11. <u>Response:</u> The inputs to our thermal model were the heat load from each cable, cable diameter, position and burial depth, sediment type, water depth, ambient temperature, water velocity, and flow angle with respect to the cable centerline over the lakebed. These inputs were all provided by TDI-NE or their experts.

Q12. How specifically did you model the temperatures around the DC cables for the Project?

A12. <u>Response</u>: As identified above, Exponent considered a large number of parameters and data provided by TDI-NE and its other consultants, including HDR and Professors Tom Manley and Pat Manley. We selected conservative parameters to bound the problem and narrow it to three very specific cases, as follows:

- 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).
- Case S (Self-Burial): In depths greater than 150 feet, the cables are proposed to be laid on the bottom of Lake Champlain. They are expected to self-bury to a depth of about 1 foot in a horizontal (or side-by-side) profile in the sediment due to their weight.
- Case B (Bedrock): In depths greater than 150 feet where bedrock or other obstacles to self-burial (such as pre-existing infrastructure) is encountered, the cables may lay in a horizontal profile on top of the bedrock or other obstacle.

In these installations the two 5.3 inch cables occupy 10.6 inches in a vertical or horizontal direction. The heat transfer and fluid dynamics of the submarine cable environment were modeled using the multi-physics simulation software package STAR-CCM+, Version 9. We neglected the effect of buoyant gravity forces to yield conservative maximum expected temperatures. We used a quasi-3D approach by considering a thin 3D slice of cable parallel to the direction of the flow. The prismatic slice takes an oblique section of the cables with a trapezoidal base to account for the angle of flow over the cables. Exponent ran STAR-CCM+ in the Reynolds-Averaged Navier-Stokes mode using the k-ε turbulence model. The computational mesh was a polyhedral mesh using a prism layer to properly resolve the boundary layer at the bottom of the lake. A finer mesh resolution was 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.

Q13. Let's turn to the results of your analysis. Can you please explain the results for each of the three cases you modeled for the Project in Lake Champlain?

A13. <u>Response:</u> As described above, we modeled the change in the temperature of the sediment and the water over the cables during the maximum power transfer of 1,000 Megawatts ("MW") for the three cases just described. We assumed very conservative flow characteristics for all three cases: a slow water velocity of 1 cm/s and a shallow flow angle of 7 degrees with respect to the cable centerline. The results for each case are described in more detail in our Thermal Report (***Exh. TDI-WHB-2***), and are summarized below:

- Case T (Trench Case): When buried a minimum of 3 feet below the lakebed, the maximum temperature increase at the sediment/water interface over the lakebed was calculated to be 0.9°F for the Trench Case (Case T). See Figure 10 in ***Exh. TDI-WHB-2.*** For higher velocities and/or angles, the water's convective heat transfer dissipates heat faster and the maximum temperature increase will be even lower than 0.9°F. Case T is expected to represent approximately 54% of the total distance of the cable in the lake, where either a jet plow or a shear plow will be used to bury the cables into the lakebed.
- Case S (Self-Burial): Where the cables are self-buried about 1 foot below the lakebed at depths greater than 150 feet (Case S), a temperature rise above 1°F is found only within a vertical thickness of 0.3 inches above the sediment/water interface. In the horizontal direction, this zone spans 2.8 feet. See Figures 11 and 12 in ***Exh. TDI-WHB-2***. For higher velocities and/or angles, the water's convective heat transfer dissipates heat faster and the extents of this zone are expected to shrink both horizontally and vertically. This case represents an expected 43% of the total distance of the cable route in the lake, where in areas deeper than 150 feet, the cables will be laid on the bottom of the lake without trenching and allowed to self-bury into the sediment.
- Case B (Bedrock): In the event that some few short segments of the cables rest on bedrock or some similar obstruction and cannot be buried, the heat transfer will occur directly from the cable walls to the water and will therefore be greatest. This was modeled in Case B (or Bedrock), and

temperatures above 1°F are encountered within a thin layer around the cables. The layer extends 0.2 inches above the top of the cables and a total of 1.4 inches to the front and rear of the cables for a total of 1 foot horizontal extent. See Figures 13 and 14 in ***Exh. TDI-WHB-2***. Once again, for higher velocities and/or angles, the water's convective heat transfer dissipates heat faster and the thickness of this layer is expected to shrink both horizontally and vertically. This case is expected to represent 2% of the project route in the lake.

- The remaining 1% is assumed to be located under concrete mats where the temperature rise over the mats is expected to be less than over the cables in Case B.

At times when less than full load (i.e., less than 1,000 MW) is carried on the cables, the temperature gradient around the cables will be lower than modeled. The above results and methods are described in greater detail in our Thermal Report (***Exh. TDI-WHB-2***).

Q14. Based on these results, what general conclusions can you draw regarding the Project's potential thermal effects on water quality?

A14. <u>Response:</u> Based on our analysis, the Project's thermal effects are not expected to have an undue adverse impact on water quality under the applicable criteria found in the Vermont Water Quality Standards ("VWQS"). In cold water fish habitat, such as the majority of locations where the Project is proposed, VWQS Section 3-01(B)(1)(b) establishes a 1°F threshold for temperature changes above ambient temperature. VWQS

Section 2-04(A) provides for the ability to establish mixing zones of a limited size (200') where temperature increases are otherwise minor, and Section 3-01(B)(1)(d) provides greater flexibility to permit assimilation of thermal effects in zones larger than 200', where thermal effects will otherwise still allow for the full support of existing aquatic uses . For the majority of the cable route in the lake, the maximum temperature increases associated with the Project will be below the 1°F threshold, and for the remainder of the cable route the areas of temperature increases above 1°F are extremely limited, as described further below:

- Trench Configuration (Case T): water temperature increases remain below 1°F in the entire water domain.
- Self-Bury and Bedrock Configurations: there are very limited regions of temperature increase above 1°F:
  - In the Self-Bury Configuration (Case S) this region is extremely thin with a very low temperature rise (0.3 inches above x 2.8 feet wide)
  - In the Bedrock Configuration (Case B), this region is limited to the immediate vicinity of where water comes into direct contact with the cables (0.2 inches above and a total of 1.4 inches to the upstream and downstream sides of cables).

Taking all of this information into account, the overall thermal contribution of the cables to Lake Champlain waters is infinitesimal. Combined, the total water volume of the warm zones for Case S and Case B, where temperatures may be above 1°F, represents less than 1.9 millionth of a percent (0.00019%) of the volume of Lake Champlain. Given the limited temperature increases, and the extremely limited area in which the temperature increases are expected, it is our opinion that the Project's temperature-related impacts will not result in an undue adverse impact on water quality.

Q15. In your opinion, will the Project comply with applicable water quality standards for heat in Lake Champlain?

A15. Response: Yes. As noted above, the portion of the submarine route where the cables are buried will remain within the 1°F temperature change criterion. In those very small areas around partially buried or unburied cables on the remainder of the aquatic route where a temperature increase above 1°F meets the standards for establishment of a mixing zone under VWQS Section 2-04(A), and Section 3-01(B)(1)(d) for "Assimilation of Thermal Wastes," the extent of increased temperatures is very small, and will not impact the existing aquatic uses, as described further below.

Q16. In your opinion, will the heating of the cables from the Project have an undue adverse effect on water quality in Lake Champlain?

A16. Response: No.

Evalaution of Aquatic Magnetic Effects

Q17. Let's turn to your magnetic analysis. Please describe the magnetic properties associated with submerged transmission cables such as the one proposed in this Project?

A17. Response: As described earlier, the DC electricity carried on the cables is comprised of moving electric charges and is a source of a DC magnetic field. This magnetic field is not shielded much by the coverings on the conductors or by most materials in the environment including sediment and water. In contrast, the electric field associated with the voltage (±320 kilovolts ["kV"]) applied to the cables is contained within the grounded metallic sheathing of the cables.

The DC magnetic field from the cables is the same as the geomagnetic field of the earth. Since magnetic fields are vectors with a magnitude and direction, the magnetic field from both the cables and the earth must be evaluated together as they may add to or cancel one another at any particular location.

The DC magnetic field from the earth or the cables is not the same as the AC magnetic field associated with the transport of 60-Hz electricity on power lines and devices connected to the AC electric grid. The properties and effects of electromagnetic fields differ greatly with frequency and so have to be evaluated separately. For example, electric fields will not be induced in stationary objects in a DC magnetic field whilst a 60-Hz magnetic field will induce 60-Hz electric fields in both stationary and moving objects. For such reasons, both the scientific research evaluated and safety standards for exposure to DC and AC magnetic fields differ.

Q18. What kind of modeling did you conduct to evaluate the magnetic fields of this Project in Lake Champlain? Please describe the methodology of the study and any environmental or Project-specific inputs you used.

A18. Response: The DC magnetic field from the submarine cables was calculated by the application of the Biot-Savart Law to two cable configurations or cases. The Biot-Savart Law is derived from fundamental laws of physics and is used to compute the magnitude of magnetic fields created by the flow of electric current through conductors. These calculations took into account the size and configuration of the cables when buried 3 feet under the lakebed (Case T) and lying on top of the lakebed (Case B), and were performed at the rated maximum cable capacity of 1,000 MW. At times when less than full load is carried on the cables the magnetic field from the cables will be lower than modeled. All calculations were reported as deviations from the ambient geomagnetic field in Lake Champlain, which is approximately 535 milligauss ("mG").

When water currents or fish swim in the geomagnetic field of the earth a very weak electric field is induced. This electric field was calculated for a typical high water flow velocity in Lake Champlain to yield a conservative estimate of potential exposure. This calculation was performed by applying the Lorentz's Force Law to calculate the force on a moving charge and accounting for the angle between the magnetic field and water velocity vectors.

Our magnetic field modeling can be found in our Report "Submarine Cable DC Magnetic Field in Lake Champlain and Marine Assessment," hereafter Lake Magnetic Report (***Exh. TDI-WHB-3***).

Q19. Please summarize the results of the magnetic field modeling you conducted.

A19. <u>Response:</u> The effect of the NECPL cables on changes in the ambient geomagnetic field level will be limited to the area immediately surrounding the cables. The change in the calculated magnetic field is greatest over the cables and the calculated DC magnetic field deviations and compass deflections fall off rapidly with distance from the cables. At 10 feet from the cables these deviations are less than 10% of the ambient geomagnetic field level. Only slightly further away, at 25 feet from the cables, the magnetic field deviation is approximately 1% of the ambient geomagnetic field level. See Figures 1 and 2 in our Lake Magnetic Report (***Exh. TDI-WHB-3***).

Where the cables are buried, the change in the horizontal component of the geomagnetic field (the magnetic field component affecting compass readings) is very small: a calculated compass deviation of 8.0 degrees at 10 feet above the lakebed and 2.9 degrees at 19 feet above the lakebed. At ±10 feet to the sides of the cables at these depths the projected compass deviation is 1.6 degrees. See Figure 3 and Figure 4 in our Lake Magnetic Report (***Exh. TDI-WHB-3***). At the locations where the lake is more than 150 feet deep, the cables would not be buried and the calculated compass deflection would be less than 1 degree at the water's surface.

The methods and results pertaining to the DC magnetic field in Lake Champlain are provided in greater detail in the Lake Magnetic Report (***Exh. TDI-WB-3***).

Q20. Based on these results, what general conclusions can you draw regarding the impacts on the water quality in Lake Champlain due to the Project's magnetic field properties?

A20. <u>Response:</u> The magnetic field from the NECPL cables would not affect the water quality of Lake Champlain. Other investigations evaluated the potential effect of changes in the magnetic field on fish and invertebrate species as discussed below.

<u>Evalaution of Thermal and Magnetic Effects on Natural Environment</u>

Q21. Turning specifically to the Project's potential effects on the natural environment in Lake Champlain, what kind of investigations were conducted into the potential effects of the Project's temperature and magnetic exposures on aquatic plant and animal life?

A21. <u>Response:</u> Exponent first investigated the effect of increased lake sediment temperature from the cables in Case T, Case S, and Case B described above on the rate of conversion of inorganic mercury in lake sediment to methylmercury by naturally occurring bacteria. Next, the potential effects of increased temperature around the cables on the three dominant benthic macroinvertebrate community populations in Lake Champlain were assessed.

Finally, aquatic organisms with known ability to detect electric and magnetic fields are uncommon in Lake Champlain; however, both the American eel and the lake sturgeon are able to detect such fields. Because of the presence of such fish in the lake, we also reviewed the aquatic and neurobiological literature to assess their capability and that of fish with similar capabilities to detect magnetic or electric alterations in the aquatic environment around the NECPL cables.

Q22. You mentioned mercury methylation as one area of investigation. Can you please describe why mercury methylation is a concern, and what if anything you concluded regarding the Project's potential impact on mercury methylation?

A22. <u>Response</u>: Methylmercury is a toxic form of this widespread environmental contaminant and can accumulate in the tissues of fish and other organisms. Some methylmercury in lakes arises from the metabolism of mercury by certain bacteria in sediments; at higher temperatures the metabolic activity of bacteria is increased and supports increased production of methylmercury. Other factors in lakes that are reported to increase concentrations of methyl mercury in fish are the acidity of the water and organic matter. To evaluate the effect of cable heating on the methylation of mercury by such bacteria we investigated the temperatures in the zone of where mercury methylation occurs (i.e., the top 6 cm of the sediment). For Cases T and S, expected increase in temperature is not large enough to impact the rate of mercury methylation in Lake Champlain. Furthermore, due to low biological activity of the area with bedrock, mercury methylation should not be impacted by the presence of cables in Case B. This analysis is described further in our Thermal Report (***Exh. TDI-WHB-2***).

Q23. You mentioned that Exponent also analyzed the potential impact of temperature increases on aquatic species using the Lake. Can you please summarize the results of that study?

A23. Response: As described further in our Thermal Report (***Exh. TDI-WHB-2***), the temperature increases in Cases T, S and B are not sufficient to cause the range of temperatures to exceed the natural ranges of temperatures 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. Because the temperature zone around the cables is so limited, other species that are mobile would not encounter higher temperatures for any significant periods.

Q24. Finally, you also mentioned that Exponent analyzed the potential impact of DC magnetic fields on aquatic organisms. Can you please summarize the results of that study?

A24. Response: Yes, as noted briefly above, and described further in our Lake Magnetic Report (***Exh. TDI-WHB-3***), we conducted a review of neurobiological and aquatic research regarding the potential impact of DC magnetic fields on aquatic organisms. Our review indicated that changes in the DC magnetic field by the cables and to the associated induced electric fields in moving water currents or fish are likely to be detected by some species with specialized sensory receptors for static magnetic fields, and low frequency electric fields, e.g., sturgeon. The literature did not suggest the likelihood of any toxic effects on fish even at magnetic field levels far above the levels calculated over the cables, but the geomagnetic field of the earth by itself or as modified by the magnetic field from the cables is likely to be detected by some species. The very limited area around the cables where these fields would be increased is tiny relative to the habitat used by the species, and the total area of Lake Champlain through which the cables will traverse is small. This suggests that the probability of resident aquatic species encountering areas with significantly altered magnetic fields associated with the buried cable is very low, and that impacts will not be adverse. The results and methods pertaining to potential temperature and magnetic field effects in Lake Champlain are described in greater detail in our Lake Magnetic Report (***Exh. TDI-WHB-3***).

Q25. Are there any electric field changes associated with the aquatic segment of this Project, and if so will those changes have an impact on aquatic species?

A25. <u>Response:</u> There will be minor changes in the induced electric fields around the cables, but these minor changes are not expected to have any significant impacts on aquatic species, as discussed further in our Lake Magnetic Report (***Exh. TDI-WHB-3***). The movement of electric charges (in water or in fish) through the ambient environmental DC magnetic field of the earth, or as altered by the presence of a DC submarine cable, gives rise to an induced electric field, which will depend on the speed and direction the water passes over the cable. As noted above, this is different from the magnetic field from an AC cable which creates electric fields in both stationary and mobile objects.

At present in the Lake, the calculated electric field induced by movement of charges at 4.8 centimeters per second (which represents a high typical velocity of current in Lake Champlain), is 2.6 microvolts per meter ("μV/m") due just to the geomagnetic field. In comparison, with the addition of the proposed cables,the water current flow will increase the induced electric field to 3.7 μV/m at 1 foot over the lakebed for buried cables and 23.5 μV/m over unburied cables. At 10 feet from the cables the induced electric field falls below 2.6 μV/m. These values are within the range of ambient background values reported in the literature. These levels of electric field are, nonetheless, within the range of detection reported for electrosensitive marine species such as elasmobranch fishes and sturgeon and upon detection may elicit temporary investigatory behavior as has been seen in anecdotal observations of sharks or far weaker feeding approach responses reported in experimental studies of sturgeon. However, such limited changes are not expected to have adverse effects on lake species. For comparison, the small scale of anticipated change in the, the induced electric field resulting from water current flow over the cable may be analogous to the galvanic electric fields produced by the corrosion potentials from virtually any sunk or constructed metal infrastructure.

Q26. In your opinion, will the cable temperature and magnetic field from the Project's cables have an undue adverse effect on the natural environment in Lake Champlain?

A26. Response: No. Comprehensive modeling of the exposures to the natural environment from the cables, the continuity of these physical stimuli with ambient temperature and magnetic field gradients, and assessments of likely biological responses, support the conclusion that no undue adverse impacts would be created by the operation of the NECPL cables. As a result, it is our conclusion that the thermal and magnetic effects of the Project will allow for full support of aquatic biota, wildlife, and aquatic habitat uses in Lake Champlain.

Q27. Are there measures that have been taken in the Project's design to minimize the Project's temperature or magnetic field exposures on the natural environment and water resources in Lake Champlain? If so, please describe.

A27. Response: The Project's design incorporates several important features that minimize the magnitude of the temperature gradient and magnetic field level around the cables and their spatial extent. These include grounded metallic sheaths on the cables to shield the electric field of the conductors; strapping the two cables together and horizontal directional drill ("HDD") entry/exit from the lake to enhance cancellation of the magnetic field from the cables; and burial beneath the lakebed in shallower depths to minimize exposures to higher temperatures and magnetic fields at the lakebed surface sediment and water above. Concrete mattress in very small sections would provide insulation for unburied cables and prevent close approach to the area around unburied cables where the magnetic field is highest.

<u>30 V.S.A. § 248(b)(5) – Public Health and Safety</u>

Q28. Can you please describe the scope of your analysis of the aquatic segment of the route with respect to potential public health and safety issues?

A28. <u>Response:</u> We assessed the likelihood and magnitude of potential human exposure to the magnetic field from the NECPL cables in Lake Champlain and potential interference to navigational use of compasses by boaters.

Q29. Are you aware of any state, federal, or international health organizations or regulatory bodies that have adopted or issued recommended guidelines for exposure to static magnetic fields?

A29. <u>Response:</u> Neither the State of Vermont nor the federal government has a standard for static magnetic fields, such as those associated with the DC cables proposed here. The relevant standards published by scientific agencies are those for human exposure and for implanted medical devices. ICNIRP has recommended a general public exposure limit of 4,000,000 mG. For persons with implantable medical devices the limit for exposure to static magnetic fields published by the Association for the Advancement of Medical Instrumentation in PC69:2007 specifies that no changes in the function of the pacemaker or the implantable cardioverter defibrillator should occur up to 1 millitesla (i.e., 10,000 mG).

Q30. How do the results from the magnetic modeling you conducted for this Project in Lake Champlain relate to those standards or guidelines?

A30. Response: In the unlikely event that a person approached within 1 foot of buried or unburied DC cables, the magnetic field encountered is calculated to be no higher than 5,075 mG. This magnetic field level is just 0.1% of the ICNIRP limit and is well below recommended limits on exposure for implanted cardiac devices.

Q31. What if any impacts will the magnetic fields associated with the Project have on navigational issues in Lake Champlain?

A31. Response: The effect of the cables on navigational compass readings is small. In water depths of just 10 feet, the maximum compass deviation would be 8 degrees directly over the cable and would decrease to 1.3 degrees at a distance of 10 feet or more from the cable centerline. See ***Exh. TDI-WHB-3***. The small compass deviation and narrow width of area affected would not be a problem for boaters and the location of the cables will be indicated on nautical charts of Lake Champlain. Compass readings and locations obtained from global positioning system (GPS) receivers would not be affected by the magnetic field from the Project's cables.

Q32. In your opinion, will the magnetic fields associated with the aquatic portion of the Project have an undue adverse effect on public health and safety?

A32. Response: No.

Overland Route

30 V.S.A. § 248(b)(5) – Public Health and Safety

Q33. Let's turn to the overland segments of the Project. Can you describe the work that has been conducted to evaluate any potential public health and safety impacts related to the magnetic fields associated with the overland portion of the Project?

A33. Response: The evaluation of the magnetic fields from the cables along this overland route to address potential health and safety issues associated with exposure to magnetic fields is similar to that for the aquatic portion of the route summarized above. Exponent modeled the DC magnetic field from the cables for configurations: (1) proposed to be trenched about 4 feet beneath road/railroad rights-of-way (~55 miles); (2) installed in an underground duct bank (0.7 miles); or (3) attached to bridges or culverts within metal conduits (150 feet) at two locations of the overland cable route in Ludlow. In addition, the AC magnetic field from a 0.3 mile underground interconnection between the Converter Station and VELCO's 345 kV Coolidge Substation in Cavendish, Vermont, was modeled. No electric fields from the cables above ground will be produced because of metallic shielding around each of the cables. The results are summarized in our "Overland Magnetic Field Report for the New England Clean Power Link Project", hereafter Overland Magnetic Report (***Exh. TDI-WHB-4***) attached to this testimony.

Q34. What methodology and data inputs did you use for the overland magnetic field modeling? Please describe.

A34. Response: The same methods and types of data used to model the total DC magnetic field resulting from the cables and the earth in the aquatic portion of the Project in Lake Champlain were used to model the magnetic field from the buried DC cables in underground trenches and duct banks. Computation of the DC magnetic field around the cables contained in steel conduits and of the AC magnetic field from AC cables in an underground duct bank required the application of a finite element analysis model. As for the modeling of DC magnetic fields in Lake Champlain, the models of DC and AC magnetic fields for overland sections of the route assumed a power flow of 1,000 MW on the conductors. All model results are shown as deviations from the ambient geomagnetic field for the overland portion of the route, which is approximately 531 mG.

Q35. Please summarize the results of the overland magnetic field modeling.

A35. Response: The DC magnetic field deviations from the geomagnetic field above cables buried under road rights-of-way extended a greater distance from the cables because, unlike the aquatic portion of the Project, the buried cables in most configurations were separated by 1.5 to 6 feet, which reduced the degree of cancellation achieved by cables when touching. The calculated DC magnetic field deviations fall off rapidly with distance and calculated maximum magnetic field deviation at 25 feet to either side of the circuit centerline (for the trench where the cables are separated at the beginning and end of HDD segments), from the ambient geomagnetic field will be less than 18%. For the remaining trench configurations (and 25 feet to either side of the cables) the change will be less than 10%.

In the duct bank configurations at a distance of 25 feet to either side of the circuit centerline, the maximum deviation from the ambient geomagnetic field will be less than 5%.

Slightly higher deviations from the geomagnetic field were seen in modeling results for cables installed on bridge or culvert attachments than for typical trench installations. The permeability of the steel conduit proposed to contain the cables attached to bridges or culverts had a small effect on the DC magnetic field, with high permeability steel yielding higher values outside the conduit than for stainless steel. Such differences due to cable configuration and covering were not, however, apparent at a distance of 25 feet from the cables. This case represents less than about 0.02% of the overland route (150 feet). Modeling of the short underground interconnection between the Converter Station and the Ludlow Substation showed maximum AC magnetic field of 57.2 mG over the interconnection that diminished to 12.6 mG or less within 25 feet.

The methods and results of the study of the magnetic fields along the overland route of the Project are outlined in our Overland Magnetic Report (***Exh.TDI-WHB-4***).

Q36. Turning to the Converter Station, please describe the potential for public exposure to electric or magnetic fields from this facility.

A36. Response: The potential for public exposure to electric and magnetic fields from the Converter Station is extremely limited. The Converter Station is proposed to be constructed far from any residence and at least 400 feet from the closest public road on a site large enough such that the dominant sources of fields at the perimeter will be the underground DC line entering the Converter Station and the underground AC line that connects to the Ludlow Substation. Furthermore, TDI-NE anticipates that the Converter Station will be housed within a metal building, which will block electric fields. The fields from other equipment outside the Converter Station proper will diminish quickly with distance as is typical of utility substations.

Q37. Are there any electric fields associated with the overland portion of the Project?

A37. Response: The shielding around the DC and AC cables on the overland portion of the route, like the aquatic portion of the route, will prevent the voltage applied to the cables from producing an electric field outside the cables. Any electric field induced by movement of persons in the static field of the earth and cables at levels of μV/m is too weak to be a health or safety issue for humans and would not be detectible (ICNIRP, 2009).

Q38. What international health organizations or regulatory bodies have adopted or recommended guidelines for exposure to static magnetic fields standards and guidelines relevant to overland DC cable installations? Are similar guidelines recommended for exposure to AC magnetic fields from the underground interconnection?

A38. Response: The most relevant and current exposure guideline for static (i.e. , DC), magnetic field exposure is the 4,000,000 mG level for general public exposure (ICNIRP, 2009), and 10,000 mG PC69:2007 Standard of the Association for the Advancement of

Medical Instrumentation for implanted medical devices (which is the same as for the aquatic portion of the route).

For exposure to 60-Hz AC magnetic fields, different but analogous guidelines for public exposure have been recommended by ICNIRP (2010) at 2,000 mG and by the International Committee for Electromagnetic Safety (2007) at 9,040 mG. General standards for implanted medical devices, such as the European Committee for Electrotechnical Standardization's ("CENELEC") EN 50527-1 Standard, specify that the function of implanted medical devices should not be impaired at AC magnetic-field levels below 100 μT (1,000 mG). As for DC magnetic fields, neither the State of Vermont nor the federal government has a standard for AC magnetic fields.

Q39. How do the results from the magnetic field modeling you conducted for this overland section of Project relate to the relevant standards or guidelines you identified?

A39. <u>Response:</u> The maximum magnetic field level at 1 m above ground level from the underground DC cables or the DC cables attached to a bridge is quite small, approximately 0.04% of ICNIRP's general public exposure limit for static magnetic fields and below limits set to prevent interference by static magnetic fields to implanted medical devices. The levels of AC magnetic fields are well below the reference level recommended by ICNIRP for exposure of the public to 60-Hz magnetic fields (2,000 mG) or for the CENELEC guideline for AC magnetic field exposure to implanted medical devices.

Q40. In your opinion, will the magnetic fields associated with the overland portion of the Project have an undue adverse effect on public health and safety?

A40. Response: No. The exposures to static magnetic fields from DC cables in the overland portion of the Project are far below health-based ICNIRP guidelines for public exposure and below the PC69:2007 Standard for implanted medical devices. As for the AC magnetic field from the 0.3-mile underground interconnection, that level too is below the relevant ICNIRP exposure guideline for 60-Hz magnetic fields and CENELEC's recommendation for implanted medical devices.

Q41. Does this conclude your testimony at this time?

A41. Response: Yes.