STATE OF NEW HAMPSHIRE
SITE EVALUATION COMMITTEE

DOCKET NO. 2015-06

JOINT APPLICATION OF NORTHERN PASS TRANSMISSION, LLC AND PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE D/B/A EVERSOURCE ENERGY FOR A CERTIFICATE OF SITE AND FACILITY

PREFILED DIRECT TESTIMONY OF

EARLE C. (RUSTY) BASCOM, III

ON BEHALF OF
COUNSEL FOR THE PUBLIC

December 30, 2016

Qualifications and Purpose of Testimony

Q. Please state your name, position and your employer.

A. My name is Earle Clarke Bascom, III, but I am also known as "Rusty Bascom." I am the President and a Principal Engineer of Electrical Consulting Engineers, P.C. ("ECE"). ECE is an engineering consulting firm that provides consulting services to the electric power industry focused on underground transmission and distribution cable systems.

Q. Please summarize your education background and work experience.

A. I have a B.S. degree and M.E. degree in Electric Power Engineering from Rensselaer Polytechnic Institute, an A.S. in Engineering Science from Hudson Valley Community College, and an M.B.A. from the State University of New York. I am a registered Professional Engineer in New York, Florida, Texas, Maryland, Delaware, Arizona and the District of Columbia.

I have 26 years of experience focusing on underground cable systems. I have authored numerous technical papers, reports and reference manuals. I have been active in technical organizations such as the Institute of Electrical and Electronics Engineers ("IEEE") and the International Council on Large Electronic Systems ("CIGRÉ"). I have instructed short courses for CPD International (Australia), Amabhubesi (South Africa), the University of Pennsylvania and others involving AC and DC power cable systems, uprating, analytical techniques, and hybrid (underground and overhead) line design.

Prior to co-founding ECE, I worked for nine years with Power Technologies, Inc. (PTI, now part of Siemens) focusing on underground cable systems. I also worked for 11 years for Power Delivery Consultants, Inc., focusing on providing engineering services for underground transmission and distribution systems. See my resume attached as Exhibit A.

Q. Have you testified previously before the New Hampshire Site Evaluation Committee?

A. I have not testified before the New Hampshire Site Evaluation Committee.

Q. What is the purpose of your testimony?

A. My report and testimony discusses the design of the underground sections of the proposed Northern Pass transmission line project (the "Project"), including the trenchless methods to install the transmission line underneath rivers, bridges and other areas along the route. See report by ECE dated December 30, 2015 attached as Exhibit B.

Design of the HVDC Underground Cable

Q. Please describe generally the design of the HVDC cable?

A. The HVDC cable consists of the conductor which carries the DC current; concentrically stranded copper or aluminum wires; the conductor and insulation shield, the insulation to support the rated conductor-to-ground voltage; bedding and water-swellable tapes, which allows the cable core to expand and limit moisture effects; a metallic radial moisture barrier (sheath) to prevent moisture from entering the cable; and an insulating jacket.

Q. Have you evaluated the cable size and electrical design for the Project?

A. Yes, based upon a review of the information available since the design is not complete. The Applicants indicated that the required power transfer capacity of the proposed Project is 1,090 MW. ECE evaluated cable ratings for assumed parameters that were considered to be representative of the range of installation conditions that would be encountered along various portions of the Applicants' proposed route including areas that could consist of open-cut trenching (shallow installation depths) and civil construction methods using trenchless technologies (horizontal directional drilling, pipe jacking). ECE did not attempt to assess details of the installation conditions for every conceivable set of conditions along the Applicants' proposed route. However, ECE made some assumptions about possible installation conditions to determine the rating with two selected conductor sizes that were considered possible sizes to achieve the Applicants' stated power transfer requirements.

Q. Please summarize your assessment.

A. From an electrical engineering standpoint, underground power cables using a single circuit (two cables in a symmetrical monopole HVDC circuit with no separate return conductor and no assumed ground return path) would provide a viable option for the proposed HVDC underground transmission segments, with generally available route options using combinations of open cut trenching, horizontal directional drilling and pipe-jacking.

Route Considerations and Constraints

Q. Did you inspect the three underground sections of the Project?

A. Yes. I drove each of the underground sections, and I inspected on foot many of the areas of trenchless construction.

Q. Are there route constraints for the HVDC underground sections?

A. Yes, there are many. As identified in my report, there are several areas where narrow roads will pose challenges to construction and to maintaining traffic during construction. Also, throughout the three underground sections, much of the HDD construction will be difficult, given factors such as limited off-road areas given the expectation that work will remain within public rights-of-way, the length and depth of drilling, the close proximity of buildings and bridges and apparent constraints on available work space.

Q. Please describe the main challenges to constructing the Project.

A. The main challenges to constructing the Project are civil construction constraints on available workspace throughout the underground route. Factors that could be further evaluated from a civil construction perspective include:

- Unrealistic rates of construction for open cut trenching given possible constraints on subsurface ground material potentially containing large areas of rock shelf that would require blasting or rock saws to form the trench.
- Possibly unrealistic rates of construction due to constraints of effective traffic control plans and the ability to maintain access for residential, tourist, commercial and emergency service vehicles given that the majority of the route is in rural settings with few roads offering travel alternatives.
- Potential impacts to businesses and residents in areas with limited parking or alternative road access.
- Some routing options appear to offer limited ability to remain in the public rights-of-way and still perform the civil work. For example, areas where a sharp turn in the route is immediately adjacent to a trenchless installation section.

Q. What specific observations can you make about the Applicants planned use of the horizontal directional drilling construction method?

A. From descriptions provided by the Applicants, potentially unrealistic expectations for areas requiring the use of horizontal directional drilling (HDD) from the standpoint of both laydown area (limits of disturbance) and time of construction; both appear underreported in Applicants' stated plans with specifics for the time required at each location. For example, from other projects where I have supported the cable design, the footprint for the horizontal directional drilling equipment is on the order of 150ft by 250ft, while the Applicants have suggested that much of this work at each HDD site can be constrained to the width of one normal traffic lane. Also, the extent to which difficulties can emerge with horizontal directional drilling are not detailed, specifically as relates to the impact on work activities and time at a given location also appear to be underreported. Given the proposed number of locations where the Applicant has proposed to utilize the HDD method, the likelihood that all such locations will not experience difficulties is underreported.

Q. Are there impacts that the Applicants' design that need further evaluation or more detail?

A. Yes. Based on materials provided for review, it appears that the Applicants have not yet fully evaluated the details of the many underground project work areas, so the viability of construction in some areas is uncertain. Aspects of the Applicants' proposed construction plan are not well defined, particularly with respect to the duration of work in some areas that would require temporary road closures and in areas with more significant limits of disturbance such as near locations to be installed by horizontal directional drilling. Also, Applicants' drawings show conceptual traffic control plans for only some areas, some of which include completely closing portions of the road. Given the complexity and longer duration construction activities associated with horizontal directional drilling, the traffic control plans for each of these areas should be defined and explained to fully assess the impact. Letters to various stakeholders suggest that despite these closures, access to individual driveways and for emergency service vehicles will be retained; a clarification on how these will be maintained is unclear.

Q. Does this conclude your testimony?

A. Yes.

<u>Exhibits</u>

A. Resume of Earle C. (Rusty) Bascom, III

B. *Technical Report Regarding the Assessment of HVDC Underground Cable Segments Proposed for the Northern Pass HVDC Project* submitted by Electrical Consulting Engineers, PC

EARLE C. (RUSTY) BASCOM, III – PRINCIPAL ENGINEER

Rusty Bascom holds B.S. (1989) and M.E. (1990) degrees in Electric Power Engineering from Rensselaer Polytechnic Institute, an A.S. in Engineering Science (1987) from Hudson Valley Community College, and an M.B.A. (1993) from the State University of New York.

While completing studies for his Master of Engineering degree, Mr. Bascom worked in the Software Products Department of Power Technologies, Inc. to develop time over-current and distance relay software for PSS/E. He joined PTI's Underground Cable Systems group in 1990 as an Analytical Engineer where he spent nine years gaining experience in the T&D Technology and System Planning & Operations departments while focusing on underground and submarine cable applications and technologies. Mr. Bascom was with Power Delivery Consultants from 1999 to 2010 where he continued specializing in underground cable systems, providing support to utility and research projects, and coordinating all of PDC's short courses and educational accreditation with IACET and the Florida Board of Professional Engineers.

Mr. Bascom co-founded Electrical Consulting Engineers in 2010. As company President and Principal Engineer, he specializes in cable system studies that include the following areas:

- *Feasibility studies, budgetary costing, design, specification preparation, bid review, and procurement support of new underground transmission circuits up to 500kV, including consideration of hybrid overhead-underground lines and horizontal directional drilled (HDD) projects*
- *Quality Assurance services during factory acceptance testing, field installation and commissioning*
- *Analytical studies including ampacity audits, magnetic field analysis/mitigation, pulling tension, and circulation and forced cooling evaluations (pipe-type cables)*
- *Research projects involving underground cables*
- *Studies of operational issues, condition assessment and failure investigation of cable systems*
- *Expert witness for utility outreach, public forums and hearings relating to underground cable systems*

Mr. Bascom has developed analytical methods used for the analysis and design of power equipment, some of which were incorporated in tools such as cable ampacity software for General Electric, pulling-tension software for Con Edison of New York, and circuit breaker coordination, costing and fault study software for a joint venture by Alcan and Square D. He has also developed some of ECE's in-house analytical tools to calculate ampacity, pulling tension, magnetic fields, induced voltage and hydraulic forced cooling.

Mr. Bascom has been principal investigator for several research studies for the Electric Power Research Institute including as a reviewer of the 1992 edition and author of the ampacity chapter in the 2006 edition of EPRI's *Underground Transmission Systems Reference Book*, and principal author of two editions of an underground cable fault location reference manual. He provided engineering development for EPRI software including the EPRIGEMS® Cable Ampacity Tutorial, Alternative Cable Evaluation (ACE) program, Power Transformer Analysis (PTLOAD) system, and the insulated cable models in the Dynamic Thermal Circuit Rating (DTCR) system. He has been Principal Investigator for development of UTWorkstation since 1991.

Mr. Bascom has instructed short courses for CPD International (Australia), Amabhubesi (South Africa), the University of Pennsylvania, Power Delivery Consultants, Siemens and Pterra Consulting involving AC and DC power cable systems, uprating, analytical techniques, and hybrid (underground and overhead) line design. He is a Senior Member of the IEEE, its Power & Energy Society and Standards Association, and a voting member of the IEEE Insulated Conductors Committee (ICC); he was selected as Vice Chair/Treasurer Elect in 2014 and remains active in several ICC working groups by contributing to the development of IEEE guides and standards including as past chair of ICC C8W to develop a cable standard for AC cable systems above 161kV and as past co-chair of ICC WG 7-41, Transmission Cable Operations Report. He is a member of CIGRÉ, its Joint Task Force CIGRÉ-ICC, TAG (Tutorial Advisory Group) and the U.S. representative for Working Groups B1.35, B1.50 and B1.56, and a past member of the National Association of Corrosion Engineers (NACE). Mr. Bascom authored the cable systems chapter in the 14th, 15th and 16th editions of the McGraw-Hill *Standard Handbook for Electrical Engineers*. Mr. Bascom is a registered Professional Engineer in New York, Florida, Texas, Maryland, Delaware, Arizona and the District of Columbia, is a member of the NCEES International Registry, and he is the author of 60 technical papers and publications. He holds 1 patent.

January 2016

Pre-Filed Technical Report Regarding the Assessment of HVDC Underground Cable Segments Proposed for the Northern Pass HVDC Project

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Pre-Filed Technical Report Regarding the Assessment of HVDC Underground Cable Segments Proposed for the Northern Pass HVDC Project

30-December-2016

1.0 INTRODUCTION AND BACKGROUND

Counsel for the Public, Office of New Hampshire's Attorney General is assessing a proposed high-voltage direct current (HVDC) transmission project that transfers power between the Canadian border in Pittsburg, New Hampshire along 192 miles to the southern part of the state and planned to carry 1090MW of electric power predominantly using hydroelectric generation in Canada through New Hampshire to southern New England. The proposed project is being developed by Northern Pass Transmission, LLC and Public Service Company of New Hampshire d/b/a Eversource Energy and will be operated by Northern Pass Transmission, LLC. Approximately a third of the HVDC transmission circuit is planned to be constructed underground using insulated power cables. Figure 1 shows an illustration of underground portions of the line.

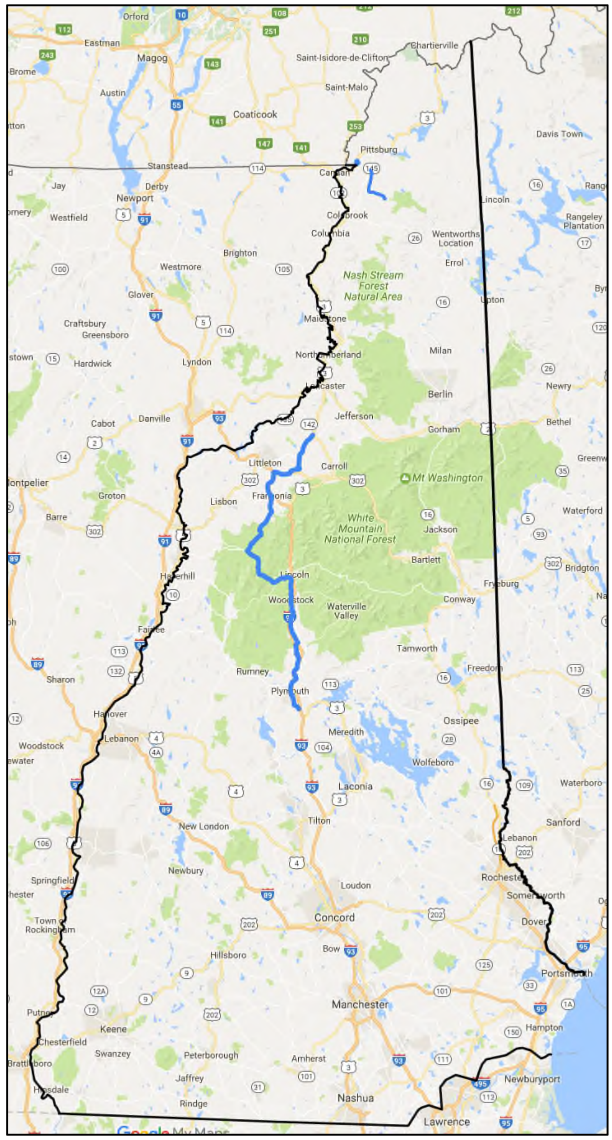

Figure 1 – Areas of Underground Cable for the HVDC Northern Pass Project

In an effort to assess aspects of the HVDC underground cable portion of the project, Counsel for the Public retained Electrical Consulting Engineers, P.C. (ECE) to work with Counsel for the Public to provide a technical review and background. This report summarizes aspects of the cable system.

2.0 BACKGROUND OF ECE

ECE is an engineering consulting company formed in February 2010 to provide engineering consulting services to the electric power industry focused on underground transmission and distribution cable systems. ECE works directly for utilities and developers or as a subcontractor to architect-engineering firms to analyze and design cable systems, prepare material and installation specifications, assist with procurement activities, and provide quality assurance during manufacturing, construction and installation of underground cable systems. ECE also provides assistance with operational issues related to underground cable systems, provides courses and training, and performs engineering research.

For the work for Counsel for the Public, ECE provided the engineering expertise of **Earle C. (Rusty) Bascom, III**. Mr. Bascom is a Principal Engineer and President of ECE. He holds an Associate's of Science in Engineering Science from Hudson Valley Community College (Troy, New York, 1987), a Bachelor's of Science (1989) and Master of Engineering (1990) from Rensselaer Polytechnic Institute (Troy, New York) and an MBA from the State University of New York (Albany). Mr. Bascom has 26 years of experience focusing on underground cable systems, has authored numerous technical papers and reports and has been active in technical organizations such as the Institute of Electrical and Electronics Engineers (IEEE), its Power and Energy Society and Insulated Conductors Committee, where he is current vice-chair and treasurer, and with CIGRÉ (International Council on Large Electric Systems).

Prior to founding ECE, Mr. Bascom worked for nine years with Power Technologies, Inc. (PTI, now part of Siemens, located in Schenectady, New York) focusing on underground cable systems within the Transmission & Distribution Department. During his tenure at PTI, that company provided transmission and distribution engineering consulting services for overhead, underground, substation and generation equipment as well as being a supplier of power system analysis (load flow, etc.) software. In 1999, Mr. Bascom left PTI and joined Power Delivery Consultants, Inc. (PDC, based on Ballston Lake, New York); at the time, PDC was focused on providing engineering consulting services for underground transmission and distribution systems, but also offered limited services for overhead line and power transformer ratings. Mr. Bascom was with PDC for 11 years before founding ECE.

***Notes on Report Content**: Underground power cable projects require a mix of engineering disciplines including electrical, mechanical and civil engineering. Mr. Bascom's training and engineering background is focused on electric power engineering. Through experience on multiple projects, Mr. Bascom has gained an understanding of related engineering fields but does not represent himself to be an expert in civil construction, environmental or mechanical engineering fields.*

3.0 POWER SYSTEMS AND UNDERGROUND POWER CABLES

3.1 Basic Electric Power System Types

Electric power may be generated and transmitted using "alternating current" ("AC") or "direct current" ("DC"). The history of these electric system types dates back to the late 1800s when George Westinghouse and Thomas Edison proposed competing technologies.

- "AC" uses a cyclic change ("alternating") in polarity at a specified frequency; the polarity on most electric power systems in North America occurs sixty (60) times per second or "60 Hertz" (60Hz). Most of the electric power systems throughout the world use some form of AC power.

  Advantages to AC for power generation, transmission and distribution include the ability to easily change voltage (via power transformers) for transmission (generally above 69,000 Volts) to utilization voltages (e.g., 120 Volts used in homes) common for appliances and lights used in homes and manufacturing equipment used in commercial businesses.

Disadvantages of AC power systems include energy loss (inefficiency) associated with the changing alternating current, special consideration and equipment to compensate or adjust for these losses, and the requirement that the electric systems on opposite ends of long AC lines operate at exactly the same power frequency (e.g., to be synchronous).

- "DC" uses a constant polarity (positive and negative) to transfer electric power; some commonly-encountered machines or equipment that use "DC" include the electric power sources in automobiles, flashlights, cell phones and generally any device using some form of battery.

  Advantages of DC are lower electrical loss, especially for longer transmission distances,[1] generally smaller number of conductors for the equivalent AC energy transmission, and the ability to connect two asynchronous power systems.

  Disadvantage of DC for power transmission is the need to convert the DC to AC for connection to the electric systems common to the power system, and due to the required conversion process, the inability to easily make intermediate power system connections to the DC system. The required converter station equipment is elaborate and expensive, so to justify using HVDC, generally, a long distance connection is necessary.

Given the distance of the power transmission in the Northern Pass Project, the developers have selected DC for the purposes of transferring the power over most of the 192-mile project length, and it is the HVDC portion that includes underground cables.

Electric power transmission is more efficient at higher voltages because electric losses are lower. "Transmission" is therefore generally associated with electric equipment that is 69,000 Volts or higher (69 thousand Volts or 69 kilo-Volts, which may be expressed as "69kV"). "High Voltage" is expressed as "HV", so a "high voltage direct current" power system would be noted as "HVDC"). The HVDC portion of the Northern Pass Project is planned to operate at a voltage of positive and negative (+/-) 320,000 Volts (or sometimes noted as +/-320kV).

3.2 HVDC Transmission

HVDC transmission is done using "conductors" over which power is transferred. The conductors may be installed in air; the air provides the electrical insulation to avoid an electrical breakdown between conductors and between each conductor and ground. As the voltage increases, the separation – sometimes called "clearance" – between adjoining conductors or between individual conductors and ground also increases. The overhead portion of the Northern Pass Project is being assessed by other consultants assisting Counsel for the Public.

The conductors for HVDC transmission may also be installed underground. A special material called "insulation" is applied around the conductor to support the voltage. Because of the location below ground where the environment may be wet or insect or agents within the soil could negatively impact the cable, additional layers of material are applied to the cable to

[1] For this reason, high-voltage direct current cables are often used for submarine installations across wide expanses of water, so submarine cable applications are the predominant application of high-voltage direct current cable throughout the world.

protect the performance of the insulation. The general construction of a HVDC cable consists of the following components:

- **Conductor** – This component carries the DC current and is usually constructed of concentrically stranded copper or aluminum wires. The power carried by each cable, in Watts, is the current times the voltage. A larger conductor can carry more current because it has lower resistance.
- **Conductor Shield, Insulation Shield** – These help reduce electrical stress in the insulation by providing a smooth interface to the insulation. Generally, the conductor shield, insulation and insulation shield are applied during one process in the cable factory.
- **Insulation** – Supports the conductor-to-ground voltage; in the case of the Northern Pass cables, this would be 320kV.
- **Bedding and Water-Swellable Tape(s)** – This is a layer of one or more tapes that permit the cable core (conductor, conductor shield, insulation, insulation shield) to expand radially.

  The water-swellable tapes expand when exposed to moisture or water, creating a blockage to longitudinal water movement under the metallic moisture barrier. This limits the extent of damage if the external layers of the cable are mechanically damaged (e.g., a “dig in”).
- **Metallic Radial Moisture Barrier (Sheath)** – This layer prevents moisture from entering the cable. The electrical insulating properties of most insulation materials degrade when exposed to moisture.
- **Insulating Jacket** – This layer provides mechanical protection, corrosion protection and electrical insulation to the radial moisture barrier. The jacket is insulating so that a test may be performed on the metallic radial moisture barrier at the factory, after shipping and after installation as an integrity check of the overall cable. Sometimes a partially-conductive coating (semi-conductive extrusion) or material (graphite) is applied over the insulating jacket to enhance the jacket test.

Figure 2 shows a detailed cross section of a single HVDC cable, and Figure 3 shows an actual cable. Two such cables would be needed for the Northern Pass Project.

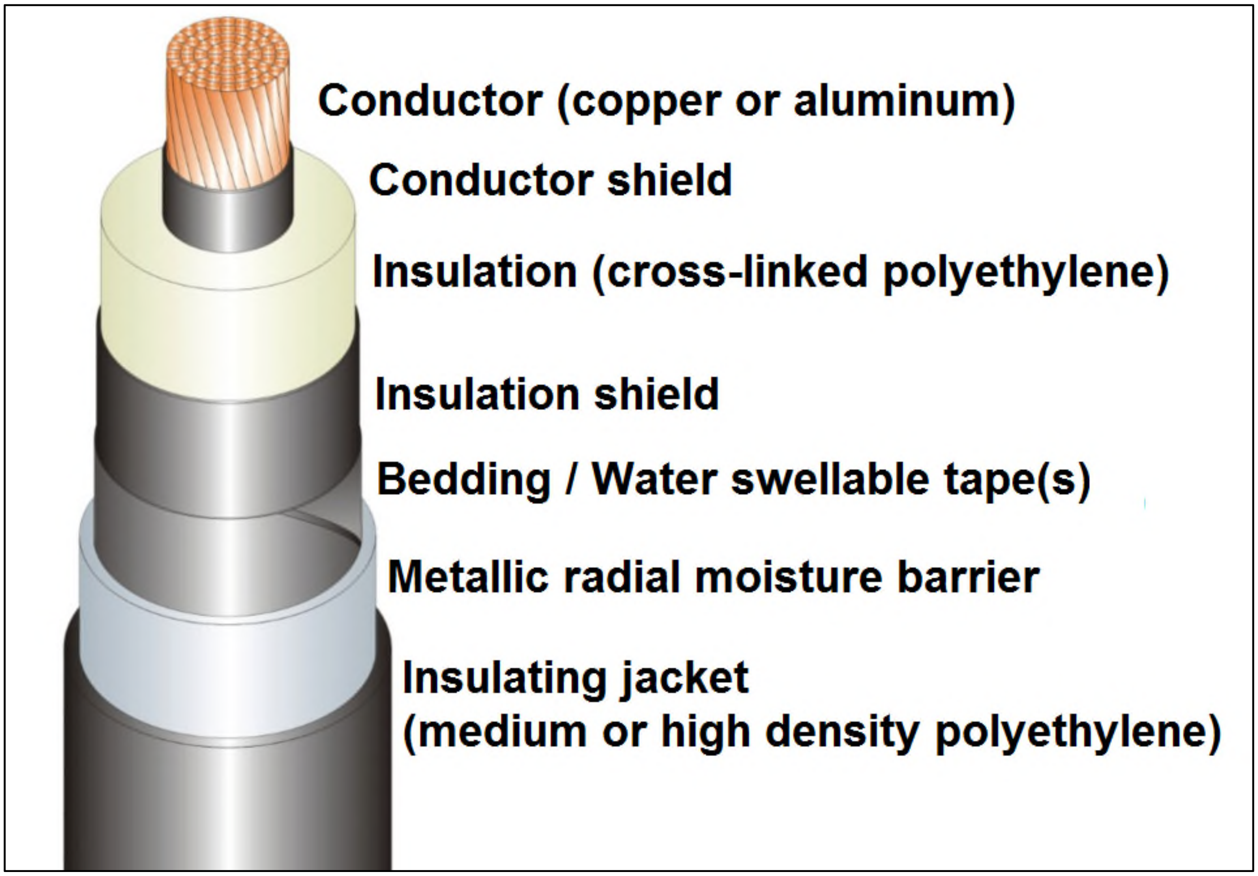

Figure 2 – Detail of a HVDC underground cable

Figure 3 – Example HVDC Cable Cross Section

3.3 Underground Cable Civil Construction Methods

Underground cables are installed along the selected route primarily using "open cut" trenching where some form of excavator is used to create a trench in which the cables may be installed. The cables may be placed directly in the ground (i.e., "direct buried") or pulled into conduits that are installed in the ground. Other methods of construction categorized as "trenchless" use driven casings to install conduits that can later be used for cable installation. Combinations of these methods may be used. This section summarizes the characteristics of each method as relates to the proposed Northern Pass Project. A high-level summary of the likely construction methods is provided below. Further detail is provided in the remainder of this section.

	Construction Method		
	Open Cut	**HDD**	**Pipe-Jacking**
Major Equipment	• Back hoe or track hoe excavator • Dump truck to haul away spoils • Concrete truck to deliver backfill	• Drill rig • Mud processing truck • Control House • Truck trailer for drill stem • Crane or excavator to add/remove drill stem on drilling rig • Roll-off type dumpsters for spoils	• Jacking equipment • Crane to lower in casing sections • Trailer to deliver casing sections
Footprint	• Typically a traffic lane wide enough to accommodate excavators and trucks	• Typically 250 ft. x 150 ft. for area around drill rig • Long, straight area opposite end from drill rig for laydown of casing pipe and conduit bundles equal in length to HDD drill path	• Minimum is 10x20 ft. pit on either side of crossing; larger pits are common
Rate of Construction	• Varies depending on ground conditions. Rock may require blasting or rock saw.	• Varies depending on ground conditions.	• Varies depending on ground conditions.
Allowance for Interruption During Construction Activity	• Many open cut operations can be temporarily paused or shut down on relatively short notice (minutes to hours) using steel plates or temporary bridging over the trench or construction site allowing for temporary access, especially for normal duct-bank construction.	• Due to the complexity of the equipment layout and general risk to interrupted operations with the HDD process, a temporary (few hours or days) shut down of HDD operations is not easily implemented. Therefore, the construction site is treated as permanent for the duration period.	• The excavated pits and equipment placed within are not easily relocated on short notice, so these areas of the construction site are effectively permanent during construction. However, the construction process can generally be interrupted without risking the drilling operation. Equipment may be relocated during the interruption and may be accomplished over a period of hours.

For open cut methods or those requiring pits (i.e., pipe-jacking) the excavation areas generally must be kept dry. "Geotechnical Engineering Report – Transition Station #1 Project" dated December 16, 2016 suggests that ground water levels were encountered in the range of depth below the surface of 0 ft. to 9.7ft. This indicates that de-watering would be required for portions of the route any place where excavations would be this deep; this would be consistent with any place an open-cut excavation or pit is created for the project and would hamper productivity during construction.

3.3.1 Direct Burial

Direct buried cable installations are less costly because they avoid the expense of materials and expenses associated with the duct bank and the higher cost concrete backfill. However, direct buried installations require that the entire trench for each installation section be open at one time. Direct burial is a method usually selected for rural areas not under roadways due to the disruption to traffic flow and the cost of restoring pavement; there is the potential added cost of future excavation of the roadway to make repairs if the cable fails.

The trench is excavated, with spoils left on site or hauled away. A layer of thermal backfill (fluidized thermal backfill or thermal sand) may be placed in the bottom of the trench prior to cable installation. Depending on the weight of the cable, the reel of cable may be moved along the trench to lay the cable or, more likely due to the weight, rollers are placed in the trench every 4-10 feet on which the cables are pulled with the reel of cable at one end and a winch at the other. After the cable has been pulled, the cable is removed from the rollers, and additional thermal backfill is placed around the cables before surface conditions are restored.

Figure 4 – Direct Burial of HVDC Cable (Murray Link, Australia)

3.3.2 Conduits and Duct Banks

An advantage to installing power cables in conduits over direct burial is that the civil work and electrical contractor work can be separated. This generally reduces the amount of continuous time for the cable trench to be kept open in a given area. By virtue of installing the duct bank, construction is generally limited to 50-100 ft. of open trench at a time; the length of the trench to be kept open is usually kept to a minimum although multiple crews may be working in different sections of the route at the same time.

Civil work for underground cable circuits is similar to those for water lines, sewer lines, etc. Once the final route is selected, a geotechnical survey is performed to assess conditions along the route,[2] drawings are obtained and reviewed to determine the presence of other utilities, a physical inspection is made along the route, and a specific corridor is selected. In selecting a route, care should be taken to avoid damage to existing underground utilities and carefully managing traffic control. Route selection generally should consider the lowest impact to stakeholders and sensitive areas (parklands, lake or other protected regions, etc.) in an effort to minimize project cost and challenges to permitting.

The number of conduits used in a duct bank depends on the project requirements. Generally for a single HVDC bi-pole, two 6 inch or 8 inch conduits are installed for the power cables, and then additional smaller conduits are used for communication, other utilities and, in some cases, a metallic return conductor.[3]

For duct banks after excavation is completed, spacers hold the conduits in place (<u>see</u> Figure 5) while the concrete envelope is poured around the ducts (<u>see</u> Figure 6). The characteristics of the concrete are usually determined by specifying a mix design to the aggregate supplier; these characteristics are important for sufficient heat transfer away from the buried cables. The mechanical properties of the backfill are also important, especially when installed below roadways that must support vehicular loads. The material usually has a compression strength of 2500-4000 psi. Prior to delivery, samples of the mix design from the aggregate supplier should be sent to a qualified testing laboratory to verify thermal properties, and testing is often done periodically during construction to verify consistency for quality control purposes.

[2] Route selection may involve limited geotechnical borings to obtain a preliminary assessment of conditions during the route evaluation phase.
[3] A return conductor is not incorporated into the proposed Northern Pass cable system due to the specific configuration (symmetrical monopole) that would not permit single-phase operation.

Figure 5 –Duct bank installation

Figure 6 – An engineered flowable concrete backfill being installed

The street is open at any one location at a time, usually for a work shift, and is generally plated-over as needed until complete surface restoration and repaving can be completed. Splice vaults are placed at the selected locations – requiring a much larger opening than the trench itself. The trench is backfilled. Temporary pavement is placed until work activities in a given area are complete and placement of permanent pavement may be installed.

Once conduit is installed from vault to vault, cables can be pulled and splicing can begin in the vaults. Power cables are pulled into the conduits and spliced in manholes that are typically spaced 1500-3000 ft. along the trench. The range of installation section length is determined based on factors such as the number of bends in a given installation section, the pulling tensions, and ability to transport cable reels to a given area.

Open cut trenching operations can usually be temporarily halted on short notice due to the minimal equipment involved (excavator, dump truck, concrete truck) which remains mobile. Temporary bridging or steel plates may be placed over the trench to allow vehicle or pedestrian traffic during breaks in work shifts or to allow property owners access to their properties.

3.3.3 Trenchless Methods

There are two principal trenchless methods used for underground power cables; horizontal directional drilling (HDD) and/or pipe-jacking. The distinguishing features of the two methods are length and ability to steer during the boring operation. Conduits are used with either method and incorporated into installation sections similar to open-cut trenching using a duct bank.

Details of each method are described below.

Horizontal Directionally-Drilled Installation

Horizontal directional drilling (HDD) is a method of civil construction derived from the oil and gas industry where borings may extend thousands of feet vertically below ground. The same technology is used with HDD with some modifications to the tracking methods and adaption for the types of soils or rock encountered.

Installation of a pipeline or conduit by HDD is generally accomplished in three stages as illustrated in Figure 7. The first stage consists of directionally drilling a small diameter pilot hole along a designed directional path. The second stage involves enlarging this pilot hole to a diameter suitable for installation of the casing with conduits. The third stage consists of pulling the assembled casing/conduits back into the enlarged hole.

Each end of the directionally-drilled installation requires a work space of 150 feet by 250 feet for large drilling rigs although a smaller foot print may be possible if the installation conditions allow for smaller equipment based on factors such as the type of material (soil, rock, etc.) through which the drilling will be done, the length, and the diameter of the bore hole and casing.

The directional drilling process requires the basic steps:

- **Mobilization** - Equipment is mobilized, primarily at the location where the drill rig will be placed. This includes a rig that is approximately the size of 50 ft. truck trailer, a trailer to hold drill stem (sections of pipe that is attached to the drill rig), a mud handling plant (another truck), dumpsters or other containers to collect cuttings from the drilling process, water tankers (if a local source of fresh water is not readily available), drill rig control house and tracking system, and a crane to manipulate drill stem sections on to the drill rig. Figure 8 below shows a photo of a drill rig site. Estimated time: 1 week.

- **Pilot Hold Drilling** - Drilling is commenced, pumping drilling mud through the drill stem at high pressure while the drill stem is rotated and advanced with sufficient force to push it through the ground; the leading end of the drill stem has a drill head appropriate for the type of ground material (soil, rock, etc.). The pressurized mud powers the drill head, cakes the bore hole to hopefully keep it open, and returns along the drill stem to the drill rig. The mud is then processed by removing cuttings (soil, rock, etc.) suspended from the bore hole; the mud is then re-used. Estimated time: 1-2 weeks.

Drilling mud consists of a mixture of water and bentonite clay with other additives. The drilling process is done at high pressure, so any cracks or fractures in the ground can allow drilling mud to reach the surface above the drill path; this is called inadvertent returns (or “frac out”).

Cuttings from the processed drilling mud are put in dumpsters or other holding containers and disposed of during the drilling operation as necessary.

- **Reaming** – After the pilot hold is established for the entire drill path, the hole may be enlarged by a process called reaming. Progressively larger reamers are passed forward and backwards through the bore hole removing cuttings using drilling mud until the hole is approximately 1.5x the diameter of the product pipe (casing) that will be pulled in. The number of reaming passes is determined by the civil engineering design firm. Estimated time: 1-3 weeks (depends on length).

- **Casing Assembly** – Usually in parallel to the pilot hole and reaming processes, the casing pipe to be installed is assembled in an area nearby the drill hole and usually at the opposite end of the bore hole from the drill rig (or the drill rig will have to be moved). Ideally, the casing is completely assembled for the entire length of the boring, which essentially doubles the length of the work space for the actual boring. Plastic or steel casing pipe is used; steel requires adjacent sections be welded while plastic requires that adjacent sections be fused (melted). Estimated time: 1-3 weeks (parallel to other operations).

  Inner conduits for the power cables are also assembled and pulled into the casing. The inner conduits are installed in a separate pull back process that can also be done in parallel with other operations or, depending on available lay down area, might be done sequentially. Estimated time: 1-3 weeks.

- **Pull Back** – During the final reaming pass, the assembled casing is pulled back into the bore hole. Estimated time: 2-4 days.

- **Demobilization** – Equipment is removed from the ends of the HDD boring and conditions are restored. This may include transitioning to conventional open-cut trench sections including possibly setting manholes at the ends of the HDD section. Estimated time: 1 week.

Surface monitoring equipment is used to track the position of the drilling head during drilling of the pilot hole. Pre-reaming (back reaming) is done in front of the product pipe and possibly additional times to enlarge the pilot for the size of the product pipe being installed.

One concern about HDD installations is the possibility of inadvertent returns (sometimes called “frac out”) of the pressurized drilling mud that may migrate through fractures in the ground and leak to the surface (or through the water bottom when being installed under bodies of water. A detailed geotechnical survey, including borings and evaluations of local geology, is done for each crossing to best understand the installation parameters so that the likelihood of inadvertent returns is minimized. General construction practices are to avoid drilling under foundations or bridge abutments for fear of disturbing the structural integrity of the overlying facilities.

The length of an HDD can be up to a few thousand feet. The entry and exit angles of the drill are on the order of 10-25° from horizontal; this means that the entry and exit points must be backed up an appropriate distance from the lowest point of the obstacle to be crossed (bottom of a foundation, safe distance below a water way, etc.) and is determined based upon the geology determined from geotechnical borings.

With HDD, the casing is prefabricated prior to pull back and must be placed in series with the entry point of the bore hole. This means, for example, if there is a 500 ft. HDD, sufficient lay-down space for 500 ft. of casing pipe must be available and aligned with the bore hole.

One concern with horizontal directional drilling is an interruption to activities, especially during reaming and prior to pull-back. Depending on the characteristics of the ground medium (type of soil or rock) through which the drilling takes place, the hole may collapse which inhibits the reaming process and pull-back processes. Therefore, once drilling is initiated, the contractor will generally want to proceed through to completion without any interruptions making the construction sites on either end of the drill path permanent for the duration of the work.

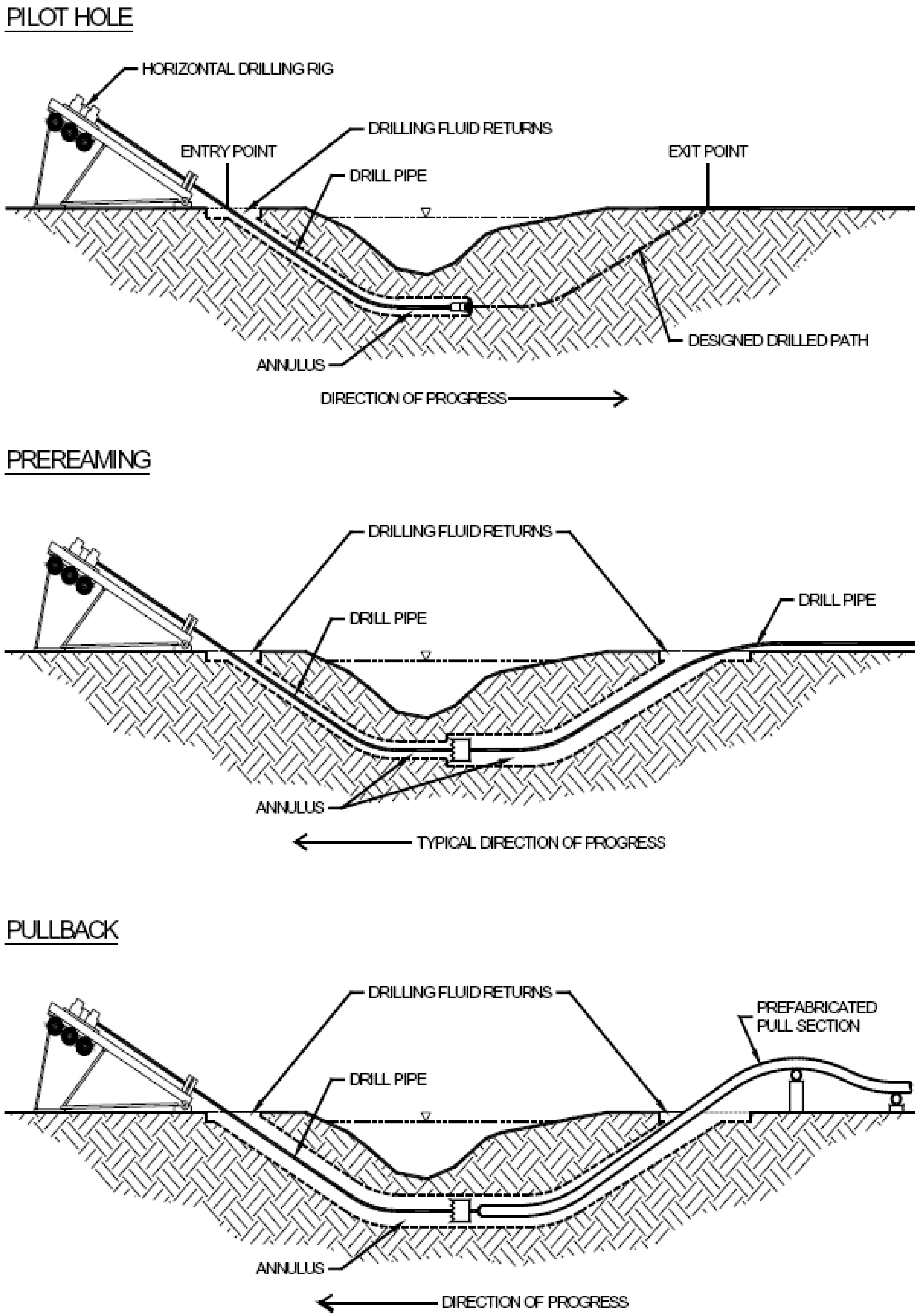

Figure 7 – General detail of major stages of horizontal directional drilling

The typically 150 ft. by 250 ft. laydown area for a horizontal directional drilling project typically requires a week or more for mobilization, days to weeks to complete the pilot hole and pull back the casing pipe, and a week or two for demobilization. Figure 8 shows a laydown area for a 24in casing installation using HDD. For the proposed Northern Pass Project, the underground sections of the route will be within the right of way of public roads, sometimes at the edge of the road and sometimes under the road. The Applicants have indicated that up to 51 locations might use some manner of trenchless technology for installation. Given the footprint of equipment involved and the typical laydown area, directional drilling could be a challenge to confine to one lane of traffic as proposed by the Northern Pass Project Applicants.

Figure 8 – Horizontal directional drilling laydown area

Pipe Jacking

With pipe-jacking, pits are excavated on either side of the obstacle to be crossed (roadway, etc.). Excavations are then advanced from the "thrust pit" using a mechanical press as the leading end of casing pipe sections are excavated by hand digging or an auger to bring spoils back through the product pipe. As each section is advanced, the mechanical ram is retracted, a new section inserted, and the casing pipe further advanced. Figure 9 illustrates the general layout.

Pipe-jacking, and the similar method of microtunneling, are typically used for crossings less than 300 ft. in length. It is not possible to change the direction of the boring because steering is not possible although there may be a change in elevation. The casing pipe material may be steel, spun-fiberglass reinforced resin or reinforce concrete pipe (RCP). The size of the pits on either side of a pipe-jacking work site, in particularly the thrust pit, are determined by the size of the pipe sections, but are typically on the order of 10 ft. by 20 ft. as a minimum.

After the casing is driven, inner conduits may be installed and the annular space grouted. The conduits within the casing are generally transitioned to the conventional cable trench while accommodating minimum cable bending radii and following the defined cable route.

The pits excavated for pipe-jacking must remain in place during construction, but other equipment may temporarily be relocated if necessary, and the bore hole and casing are generally not sensitive to interruptions of work.

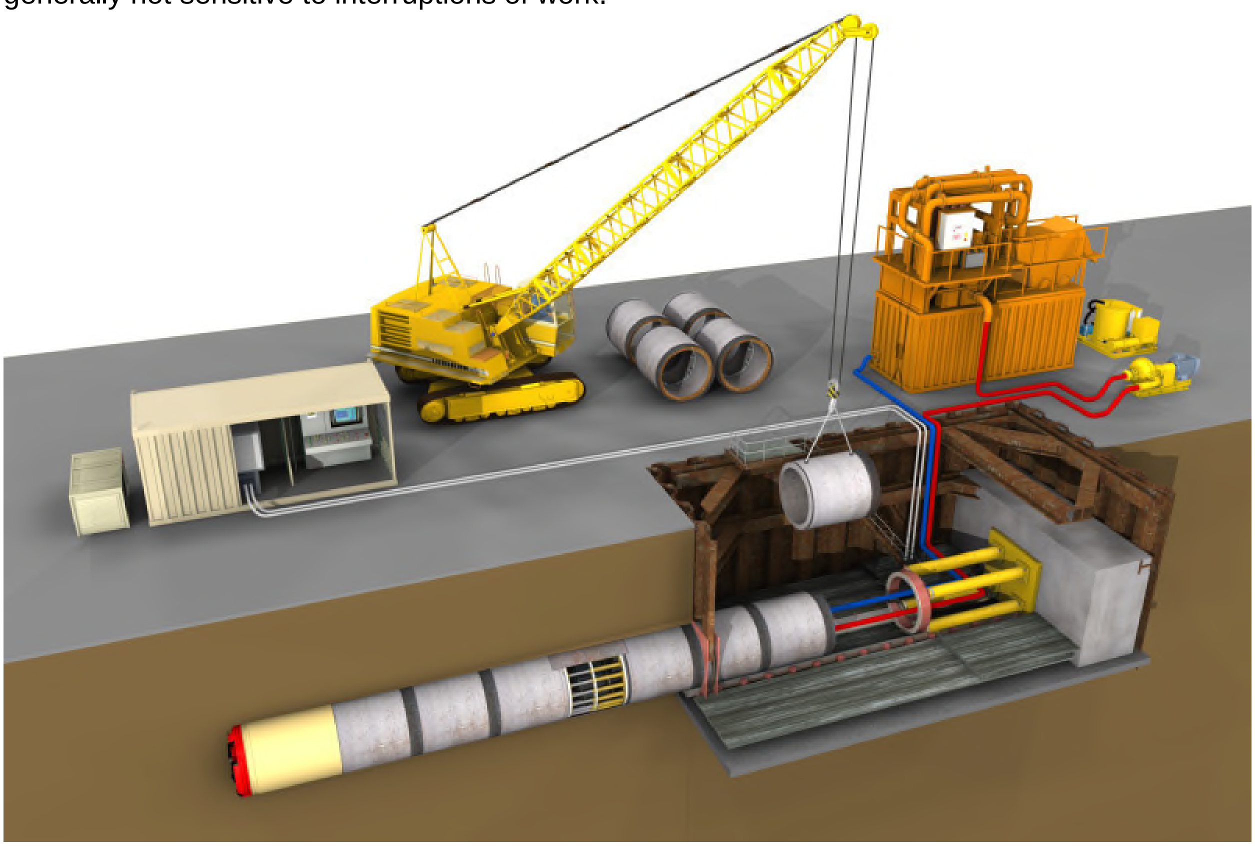

Figure 9 – Illustration of pipe-jacking

Figure 10 – Example sending pit for pipe-jacking with rail / ram system

3.3.4 Splice Vaults

Underground cable splices would be made in concrete vaults. Vaults are normally set in place and then the duct bank is constructed up to the vault. The type of conduit used for trenchless installations often differs from that used in conventional open-cut trenching, so vaults may be used as transitions between trenchless and open-cut trenched installation sections.

Cable conduits would terminate at the end walls of a splice vault through which cable ends would pass. One splice for each pole of cable would likely be mounted on opposite walls within the splice vault to join the ends of the cables together. The estimated size for a splice vault would be approximately 7 ft. wide, 8 ft. tall and 33 ft. long (inside dimensions). Figure 11 shows the lower halves of two adjacent 345kV splice vaults that would be approximately the same size as used for a 330kV HVDC cable circuit (note that only one vault would be needed for each splice location on the Northern Pass Project).

Figure 11 – Example underground splice vaults, approximately 7 ft. wide x 8 ft. tall (top and bottom) x 33 ft. long (this photo is from a 345kV AC cable system)

3.4 Cable Electrical Installation

Cable Installation

Cable is placed in the (direct buried) cable trench or pulled into conduits after the duct bank is completed; with conduit installations, direct buried sections near the terminal locations are sometimes used to provide greater flexibility during installation.

Figure 12 – Pulling cable into a conduit run

Splice (Joints)

The assembly of splices for the bipole cables will generally take 5-8 days for each set at 320kVDC. In some cases, the vaults may be lined with plastic to help keep the vault clean and dry. A temporary splice house or specialized vehicle resembling a bread truck is placed over the manhole openings to provide a clean, controlled-atmosphere and safe and comfortable working environment. Because of the critical attention to detail needed to make a successful high-voltage splice, the cable manufacturer would probably provide splicers to install the joints and terminations, or the installation contractor would use factory-trained splicers. Splices would be placed along one wall within the splice vault or on opposite walls depending on the manhole design.

Terminations

Like joints, 5-8 days would be required to construct a pair of terminations at transition stations (see Figure 13). Scaffolding or other work platforms may be required to perform the work; the scaffolding for high voltage cables on elevated structures can be elaborate and time consuming to setup and break down. The structure to support the terminations would be erected in advance, along with other elements of the substation (communications systems, station building, etc.).

Figure 13 – Example HVDC underground-to-overhead transition station

4.0 ASSESSMENT OF NORTHERN PASS CABLE SYSTEM

As part of ECE's assessment of the Northern Pass Project, materials made available from the Northern Pass Project application documents, selected materials provided to the Site Evaluation Committee, and selected materials provided as a result of public expert-assisted and other data requested was reviewed. In addition, the underground route was explored by driving along the route and walking areas where trenchless technology and drilling will occur.

4.1 Cable Size and Electrical Design

The Applicants for the Northern Pass Project indicated that the required power transfer capacity ("rating") of the proposed project is 1090MW. ECE evaluated cable ratings for assumed parameters that were considered to be representative of the range of installation conditions that would be encountered along various portions of the Applicants' proposed route including areas that could consist of open-cut trenching (shallow installation depths) and civil construction methods using trenchless technologies (horizontal directional drilling, pipe jacking).

ECE did not attempt to assess details of the installation conditions for every conceivable set of conditions along the Applicants' proposed route. However, ECE made some assumptions about possible installation conditions to determine the rating with two selected conductor sizes that were considered possible sizes to achieve the Applicants' stated power transfer requirements.

Assumptions included in ECE's evaluation are listed in the following list and table along with calculated power transfer capacities for the stated conditions:

- Conduit Size: 8in, Schedule 40 PVC
- Maximum Conductor Temperature: 70°C

These results are for information purposes only:

Calculated Ratings for Various Configurations and Conductor Sizes

Installation Depth, Native Soil Thermal Resistivity	3500kcmil Copper Conductor	5000kcmil Copper Conductor
4 ft. Burial, 12in Duct Spacing, 1.0 C°-m/Watt, 25°C ambient	1016 MW	1232 MW
30 ft. Burial (e.g., Pipe-Jacking), Ducts Touching 0.8 C°-m/Watt, 15°C ambient	990 MW	1200 MW
50 ft. Burial (e.g., HDD), Ducts Touching 0.8 C°-m/Watt, 15°C ambient	960 MW	1160 MW

The ratings listed in the table above were determined to evaluate the viability of the Applicants' proposed use of one cable to meet the ratings. They were not intended to be representative of all design parameters for all portions of the underground route as ECE was not tasked to design the entire route, and at the time this report was prepared, the Applicants' detailed design for the entire route was not available. Based on this evaluation, there appears to be viable cable sizes available to meet, in general, the stated power transfer requirements listed in documents provided by the Applicants.

In terms of physical cable installation criteria, the Applicants have indicated that on average, manholes (splice points) will be separated by approximately 1800ft. The general alignments illustrated on Applicants' drawing packages from November 30, 2016, suggest general conduit alignment consistent with normal design layouts including limiting the total number of bends in an individual conduit run to no more than 270° of bends. The number of bends is limited to manage the sidewall bearing pressure forces, which are forces exerted on the sides of the cable as it is pulled around bends of conduit. Assuming that the Applicants select a cable size in the range (3500kcmil to 5000kcmil) listed in the table above, the maximum allowable pulling force on the cable would be on the order of 28,000lbs to 40,000lbs. The anticipated pulling forces for cable pull sections of 1800-2500ft and with no more than 270 degrees of bends would be below this pulling tension threshold assuming the installation contractor uses an appropriate type and quantity of pulling lubricant consistent with usual high-voltage power cable installation practice. Therefore, no damage to the cable would be anticipated based on the Applicant's drawings.

The Applicants' drawings show the selection of an 8in conduit for the installation of the high-voltage power cables. This conduit size is anticipated to be of adequate size to accommodate the expected size of the power cables listed in the table above provided that due diligence is used during the installation of the conduit system with appropriate connections of conduit joints, compliance with minimum cable bending radii and successful certification of the conduits by passing a suitable mandrel.

The Applicants do not specifically call out details of the proposed manhole design in the information provided. ECE anticipates that the Applicants would be required by state and local laws to use manholes with suitable highway traffic (HT) rating as required by the New Hampshire Department of Transportation. The manhole size shown on Applicants' drawing package from November 30, 2016, appears to be consistent with the size required for a set of 330kV HVDC cable splices.

The details of the transition towers were not provided for assessment. Such an assessment is necessary to determine that they will be suitable for the wind, seismic and mechanical loads anticipated for the cables and terminations to be used for this project.

4.2 Route Considerations and Specific Route Constraints

The underground segments of the proposed Northern Pass Project were inspected by ECE. From a general constructability perspective, there are challenges to construction given the constraints of the Applicants building the circuit within the public rights-of-way, impacts on traffic flow, and general construction particularly in areas of bridge crossings. For example, the shoulder areas of many roads are narrow, and the Applicants have indicated that up to 750 ft. of trench could be open at a time. Figure 14 illustrates how a lane closure – assuming all construction work could be constrained to a single lane – impacts traffic flow for a small work site. The more substantial and lengthy construction required for the proposed project would be disruptive in many of these areas; selective areas of construction that would be impacted are described and detailed in the remainder of this section.

Electrically, there do not appear to be any technical issues that would prohibit the installation of the cable system. The balance of this section discusses specific considerations for locations along the underground route that could pose challenges.

Figure 14 – Example "short" lane closure on Route 3 just south of North Woodstock

The Applicants have identified in their November 30, 2016 drawing package locations where the road would be completely blocked as illustrated in Figure 14A. The extent or duration of such closures was not clearly identified. Given the remoteness of several of the areas where construction is proposed, this could represent a significant inconvenience to normal vehicular traffic for the purposes of daily activities including commuting to and from work locations as well as providing access for emergency services vehicles.

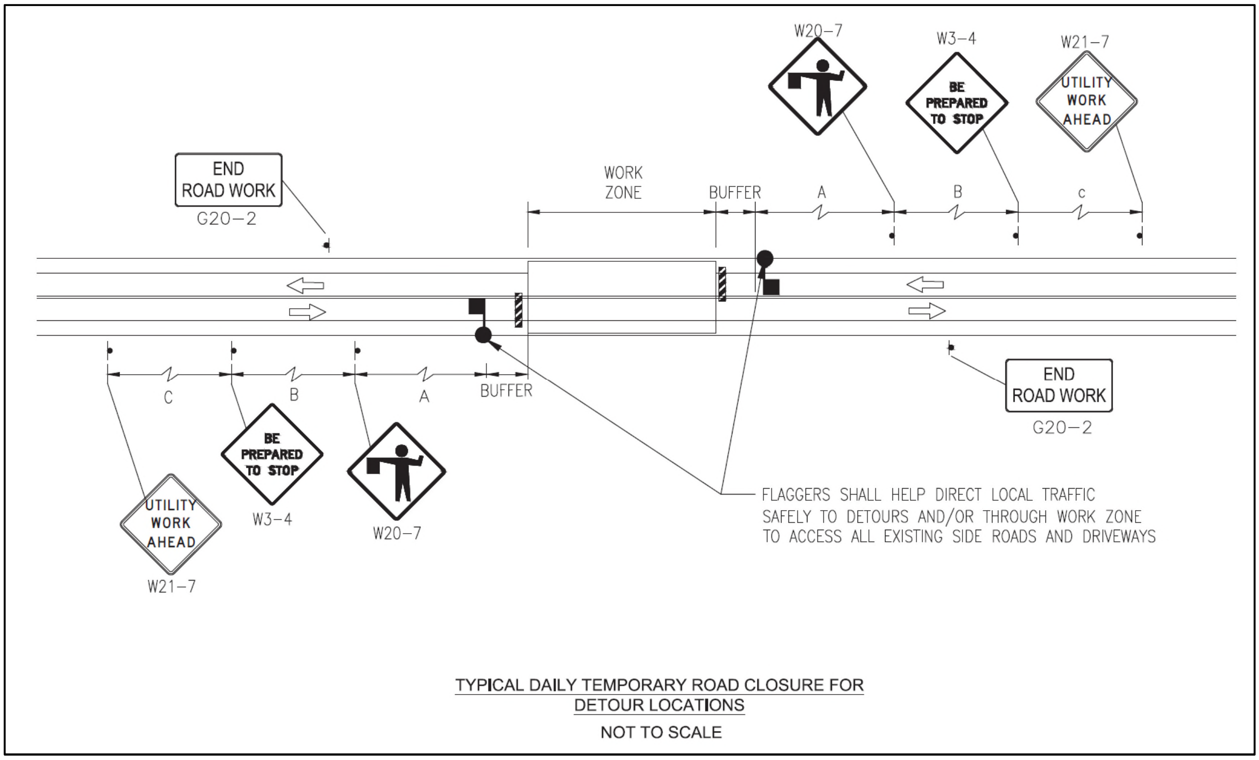

Figure 14A – Applicant's representation of a road closure during construction.

4.2.1 Clarkesville (Near Canadian Border / Old Canaan Road & HDD)

At the northern end of the project (US Rt. 3 and Beeches Falls Road), there is a segment of underground cable planned. A portion of the route requires construction along a sharp bend in the road (i.e., a "U-turn"); conduit layout and manhole placement in the area will need to be considered carefully.

Figure 15 – Cable route to sweep around bend and then cross bridge (distant, left)

In the same area, there is a bridge over the Connecticut River (Figure 16) on US Rt.-3; use of horizontal directional drilling adjacent to the bridge is the proposed construction method. US Rt.-3 is the principal route connecting Pittsburgh and points south and is heavily traveled by tourist, commercial carriers and local residents.

Work space restricted to the public right-of-way (i.e., the road) would be a challenge. Working within a single-lane road to keep the road open in one direction would be a challenge given the required footprint for typical medium- to large-scale horizontal directional drilling operations. This particular HDD location also has to follow the sweeping curvature of the road would mean that an HDD installation would need to consider a compound bend to the alignment.

From a cable standpoint, manholes (approximately 8 ft. x 30 ft.) would be placed on either side of the HDD to facilitate the transition from the conduits used in the HDD (fused HDPE or PVC) to those used in the open-cut trench (PVC with bell/spigot or couplings).

Figure 16 – Bridge over Connecticut in vicinity of proposed HDD

The Applicants' drawing package dated November 30, 2016, identifies a horizontal directional drill installation under the Connecticut River between Sta. 17+50 and Sta. 27+50. The HDD alignment appears to show a compound bend (drill path changing direction along more than one axis) and impacting the road on either side of the Connecticut River. The duration of the impact should be clarified to fully assess the viability of blocking Route 3. Example of roadway work closures are identified in the same drawing package, but a detailed traffic control plan was not included in this set of drawings.

In a letter dated December 2, 2016, the Applicants have identified the need to close roads, specifically Old County Road in Clarksville, during construction of the underground segment. This letter indicates that driveway access and emergency vehicle access will remain "regardless of any road closure"; ***the Applicant does not specifically indicate how driveway and emergency access will be maintained despite closure of roads or specifically affect response times for emergency services***. This appears to deviate from the expected plan discussed in the hearings of 12-14 September 2016 represented that only one travel lane would be blocked during construction.

4.2.2 Stewartstown (Old Country Road)

Old Country Road is a rural gravel and dirt road with minimal shoulder space. Construction in this area without widening the road while maintaining traffic would be a challenge. This area has limited alternative routes for public traffic. Figure 17 illustrates the area. Traffic in the area was observed to be relatively light during the site visit due to the rural setting.

Figure 17 – Road with limited shoulder space and few alternatives for local residents

4.2.3 Stewartstown (N. Hill Road)

Similar to Old Country Road, North Hill Road is a narrow gravel and dirt road with limited should area to the sides of the road. The limited alternative routes in this area would complicate construction activities while managing traffic. Figures 18 and 19 illustrate the general conditions along North Hill Road.

Figure 18 – Road with limited shoulder space and few alternatives for local residents

A portion of the route on the Applicants' November 30, 2016 drawing package for North Hill Road shows a pipe-jacking sections between Sta. 146+00 and Sta. 148+00 with excavations that are approximately 50ft deep on either side of a pipe-jacking section. The ability to construct the pipe-jacking section in this area should be clarified by the Applicants, including the expected duration for work in this area, as excavating pits of that depth would appear to be a lengthy process. Also, the open-cut trench areas adjacent to the pipe-jacking section show depths of cover up to 25ft to 35ft. This appears to be a very difficult construction area that would potentially require an extended work period (multiple weeks) during which the area would be inaccessible or effectively blocked to vehicular traffic, including emergency services. The trenchless methods are generally not easy to temporarily demobilize, so the blockage of access would be constant throughout the work window.

Figure 19 – Area on N. Hill Road just off Old Country Road
(narrow shoulder space, steep grades in some areas)

4.2.4 Stewartstown (N. Hill Road / North Hill Cemetery)

Along North Hill Road is the North Hill Cemetery. This history and extent of the cemetery, including the possibility that grave sites might extend beyond the existing fence would need to be evaluated for archaeological importance.

Figure 20 – North Hill Cemetery
(archaeological remains reported to possibly extend outside of fenced area)

4.2.5 Stewartstown (Bear Rock Road)

Bear Rock Road is a gravel and dirt road. The road appears to be generally wide (see Figure 21) in many areas, there are limited shoulder areas, and the road is the only route to residential homes along the road. Traffic control and construction activities will have to be managed.

Figure 21 – Road with limited shoulder space and few alternatives for local residents

In a December 6, 2016 information letter, Applicants have indicated that Bear Rock Road would be closed temporarily for the purposes of "avoiding impacts to wetlands and trees." The frequency or durations of these closures are not identified, so it is difficult to assess the extent of inconvenience to the general public or compromise of safety for emergency services that would result. This appears to deviate from the expected plan that only one travel lane would be blocked during construction as was stated during technical sessions in September 2016.

Furthermore, the Applicants show in their November 30, 2016 drawing package submitted to the NHDOT between Sta. 241+00 and Sta. 248+00 a section to be installed by horizontal directional drilling. The lay-down area and limits of disturbance are identified, but the duration of the activities is not specifically called out for each location. Similarly, there are horizontal directional drill sections identified between Sta. 251+00 and Sta. 269+00, between Sta. 313+00 and Sta. 319+00, and between Sta. 384+50 and Sta. 390+50, where similar concerns on the physical extent and time duration of disturbance are not detailed.

4.2.6 Heath Road (Transition Station Area)

An underground to overhead transition station is planned for an area off of Heath Road. The area has exposed bedrock that could be a challenge for underground construction. The rate of construction in rock is substantially slower than in soils.

Figure 22 – Bedrock in vicinity of planned transition station (potential for blasting)

4.2.7 Franconia (Bridge, HDD)

The proposed route for the underground cable includes an area near the intersection of Route 116 and Route 18 in Franconia. Near the intersection is the Gale River, and the cables must pass below the river. Due to the length and probably depth, HDD it proposed to be used. The close proximity of the bridge to the intersection would complicate getting down to the required burial depth while making the turn and staying within the right-of-way. Typical radii for installing cable conduits in roads are 30-50 ft. for the sweeps around the intersection. The space near the intersection seems like achieving the required burial depth to cross under the river while connecting to the prevailing duct bank would be difficult.

Traffic control in the area will also be a challenge considering the proximity to the intersection and the I-93 exit and entrance ramps where at least some of the construction activity would take place. The depth of the required excavation adjacent to the bridge crossing and close proximity to the river might require extensive de-watering and management of erosion.

Figure 23 – Intersection of Wallace Hill Road (Route 116) and Main Street (Route 18)

4.2.8 White Mountain National Forest (Narrow Working Space)

This area is a scenic area of pristine wilderness, views and a lake. Construction through the White Mountain National Forest would include work along the road where there is steep ledge and a narrow shoulder on one side and drop-off and lake to the other. Construction in the road would impede traffic, and careful control of sediments and run-off from entering the nearby lake will require careful planning. If construction is to take place on the side (shoulder) of the road, some trees in close proximity to the road might be affected or require removal.

Figure 24 – Road with limited shoulder space, close proximity to Beaver Pond

4.2.9 North Woodstock (Route 3, Gordon Pond Brook Crossing near Woodstock Firehouse, HDD)

Along Route 3 in North Woodstock, there is an area where the route must pass the Gordon Pond Brook. HDD is the proposed method to be use in this area. Construction in one lane of traffic would be a challenge while maintaining and managing traffic flow. There is also a curve to the road in this area that would result in the HDD being a “compound” alignment that is often more risky and challenging for the construction contractor. Open cut trenching near the fire house would interfere with access to emergency vehicles entering and leaving the Woodstock Firehouse. As indicated earlier in the report, HDD activities in this area would likely require 3-5 weeks of time as a minimum and could take longer.

The depth of the Gordon Pond Brook relative to the prevailing road elevation would also mean a relatively deep HDD would be needed.

Figure 25 – Vicinity of Woodstock Fire Department
(road has some curvature – artificially distorted due to panoramic photo)

Figure 26 – Bridge crossing over Gordon Pond Brook

4.2.10 West Thornton (Route 3, Pemigewasset River Crossing, HDD)

In the vicinity of the Pemigewasset River will require a deep HDD installation due to the elevation of the river bed below the prevailing road elevation. There are curves to the road on either end, so construction using HDD would require a compound bend. Pipe-jacking might be used, but the depth of the pits and length could be challenges.

Figure 27 – Bridge crossing over Pemigewasset River

4.2.11 Thornton (West Branch Brook Crossing, HDD – Narrow Roads)

In the vicinity of the West Branch Brook, the cable route would cross the road, and there are residences and other structures built up to the edge of the road. This limits the available work area. The contractors would also need to carefully manage and maintain access for the residents in the area.

Figure 28 – Example area with minimal shoulder work space (road is generally straight – apparent curvature is due to panoramic photo)

Figure 29 – Bridge crossing over West Branch Brook (bridge above is visible in Figure 25 on the right)

4.2.12 Plymouth (Route 3, Baker River / Bridge Crossing, HDD)

The bridge over the Baker River and adjacent roadway present a challenge for the application HDD due to the curvature of the road in the area and the deep elevation difference of the river bottom relative to the prevailing Route 3 road adjacent to the bridge/river.

Figure 30 – Baker River Bridge

Figure 31 – Baker River Bridge and area likely to be constructed using HDD

4.2.13 Plymouth (Downtown)

Construction activities through downtown Plymouth will require closing at least one lane of traffic and displacing parking spaces for the duration of construction in the area. The road is wide, but travel lanes or parking will temporarily be unavailable. Steel plating may be used to temporarily restore access. Subsurface conditions including possible rock or other dense material could slow construction progress.

Construction activities in this area are likely to be difficult in terms of siting the cable duct bank due to the likely existence of multiple existing utilities. Construction would block access to multiple commercial businesses and disrupt limited parking. Given that manholes would be needed every 1500-3000 ft., typically 8 ft. x 30 ft. manholes would need to be sited at each splice location.

Figure 32 – Downtown Plymouth

Figure 33 – Downtown Plymouth

4.2.14 Italian Farmhouse (Route 3, Rock Excavation)

Based on observed geology (rock ledge) near portions of the route, there appears to be significant quantities of bedrock through which the cable trench will be excavated or trenchless borings will be constructed. There are also existing constraints (railroad tracks) in the vicinity that could make construction difficult off of the main roadway. With the road falling away sharply on one side, construction and controlling erosion and sediments disturbed during construction would be a challenge. These constraints appear to present challenges for the rate of construction.

In addition, for portions of the route (Figure 34), there is minimal shoulder, which drops down from the roadway grade, in which to work during construction.

Figure 34 – Area near the historic Italian Farmhouse

4.2.15 Other Locations

Other locations along the route were observed to provide potential construction challenges requiring careful construction management and traffic control plans. However, from a cable system civil construction and electrical installation perspective, these areas would allow construction of the cable system and do not appear to offer material challenges to the construction of the project aside from managing traffic, construction equipment access and laydown, and delivery of materials to the respective areas. These include the following:

- Dan Web Road / Daniel Webster Highway (Route 3), Campton – Stream crossing near intersection of NH Route 49
- Daniel Webster Highway – Stream Crossing (west of Pemigewasset River, Alpha Car Service)
- Thornton (Bagley Brook Crossing)
- North Woodstock (Route 112, HDD, Maple Haven Campground)
- Northumberland (Route 3)

5.0 SUMMARY ASSESSMENT

From an electrical engineering standpoint, underground power cables would provide a viable option for the proposed HVDC underground transmission segments, with generally available route options using combinations of open cut trenching, horizontal directional drilling and pip-jacking.

The main challenges to executing the project are civil construction constraints on available workspace throughout the underground route. Factors that could be further evaluated from a civil construction perspective include:

- Unrealistic rates of construction for open cut trenching given possible constraints on subsurface ground material potentially containing large areas of rock shelf that would require blasting or rock saws to form the trench.

- Possibly unrealistic rates of construction due to constraints of effective traffic control plans and the ability to maintain access for residential, tourist, commercial and emergency service vehicles given that the majority of the route is in rural settings with few roads offering travel alternatives.

- From descriptions provided by the Applicants, potentially unrealistic expectations for areas requiring the use of horizontal directional drilling from the standpoint of both laydown area (limits of disturbance) and time of construction; both appear underreported in Applicants' stated plans with specifics for the time required at each location.

- Some routing options appear to offer limited ability to remain in the public rights-of-way and still perform the civil work. For example, areas where a sharp turn in the route is immediately adjacent to a trenchless installation section.

- Applicants' drawings show conceptual traffic control plans, some of which include completely closing portions of the road. Letters to various stakeholders suggest that despite these closures, access to individual driveways and for emergency service vehicles will be retained; a clarification on how these will be maintained is unclear.

Aspects of the Applicants' proposed construction plan are not well defined, particularly with respect to the duration of work in some areas that would require temporary road closures and in areas with more significant limits of disturbance such as near locations to be installed by horizontal directional drilling.