December 2017

RHODE ISLAND ENERGY FACILITY SITING BOARD ENVIRONMENTAL REPORT

Providence River 115 kV Cable Relocation Project
Providence, Rhode Island

Prepared For:
The Narragansett Electric Company d/b/a National Grid
280 Melrose Street
Providence, RI 02907

For Submittal to:
State of Rhode Island Energy Facility Siting Board
89 Jefferson Boulevard
Warwick, RI 02888

Prepared By:
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This document has been reviewed for Critical Energy Infrastructure Information (CEII). [November 2017]

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GLOSSARY OF TERMS

A	amps
ACI	American Concrete Institute
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
BMPs	Best Management Practices
Cable	A fully insulated conductor usually installed underground, but in some circumstances can be installed overhead.
Circuit	A system of conductors (three conductors or three bundles of conductors) through which an electric current is intended to flow and which may be supported above ground by transmission structures or placed underground.
Conductor	A metallic wire which serves as a path for electric current to flow.
Conduit	Pipes, usually PVC plastic, typically encased in concrete to house and protect underground power cables or other subsurface utilities.
dB	A decibel is a logarithmic unit of measurement that expresses the magnitude of a sound.
dBA	Decibel, on the A-weighted scale. A-weighting is used to emphasize the range of frequencies where human hearing is most sensitive.
Demand	The total amount of electric power required at any given time by an electric supplier's customers.
Dielectric Fluid	Liquid used as an electrical insulator in high voltage applications, e.g. transformers, capacitors, high voltage cables, and switchgear.
Distribution Line or System	Power lines that operate under 69 kV
DPW	Department of Public Works
Duct Bank	A group of ducts or conduit usually encased in concrete in a trench.
Duct	Pipe for underground power cables (see also Conduit).
EFSB	Rhode Island Energy Facility Siting Board
EFSB Rules	State of Rhode Island and Providence Plantations Energy Facility Siting Board Rules of Practice and Procedure, effective April 11, 1996.
Electric Field	A field produced as a result of voltages applied to electrical conductors and equipment; usually measured in units of kilovolts per meter.
Electric Transmission	Facilities (≥ 69 kV) that transmit electrical energy from generating plants to substations.
ELUR	Environmental Land Use Restriction
EMF	Electric and magnetic fields
Environmental Monitor	Inspects environmental conditions within the construction site, reviews the contractors' compliance with environmental permit conditions during the construction phase of a project, and makes recommendations

	for corrective actions to protect sensitive environmental resources proximate to a construction site.
EPR	Ethylene Propylene Rubber, type of electric cable insulation
ER	Environmental Report
Fault	A failure or interruption in an electrical circuit (a.k.a. short-circuit)
FRE XHW	Fiberglass Reinforced Epoxy Extra Heavy Wall, a type of conduit
HASP	Health and Safety Plan
HDD	Horizontal Directional Drilling
HVED	High Voltage Extruded Dielectric
Hz	Hertz, a measure of the frequency of alternating current; expressed in units of cycles per second.
IEEE	Institute of Electrical and Electronic Engineers
I-195	Interstate Route 195
ISO-NE	ISO New England, Inc., the independent system operator of the New England electric transmission system
kcmil	One thousand circular mils, approximately 0.0008 square inches, a measure of conductor cross-sectional area.
kV	Kilovolt - one kV equals 1,000 volts
Load	Amount of power delivered upon demand at any point or points in the electric system; load is created by the power demands of customers' equipment (residential, commercial and industrial).
M	million
Megavolt Ampere	Measure of electrical capacity equal to the product of the line-to-line voltage, the current and the square root of 3 for three-phase systems; electrical equipment capacities are sometimes stated in MVA.
MW	Megawatt - a megawatt equals 1.0 million watts
NAAQS	National Ambient Air Quality Standards
National Grid	National Grid USA Service Company
NERC	North American Electric Reliability Corporation
NESC	National Electrical Safety Code. The NESC is an ANSI standard that covers basic provisions for safeguarding of persons from hazards arising from the installation, operation, or maintenance of 1) conductors and equipment in electrical supply stations, and 2) overhead and underground electric supply and communication lines. It also includes work rules for the construction, maintenance, and operation of electric supply and communication lines and equipment.
NOI	Notice of Intent
NPCC	Northeast Power Coordinating Council
NRCS	Natural Resource Conservation Service

NRHP	National Register of Historic Places
OSHA	Occupational Safety and Health Administration
Phase	Transmission and distribution AC circuits are comprised of three conductors or bundles of conductors that have voltage and angle differences between them; each of these conductors (or bundles) is referred to as a phase.
POWER	POWER Engineers, Inc.
Project	The Providence River 115 kV Cable Relocation Project
Project Area	The area immediately adjacent to the project route between Franklin Square Substation and Dollar Street.
PVC	Polyvinyl Chloride, a type of plastic.
Q-143 Line	Q-143 115 kV underground electrical transmission cable
R-144 Line	R-144 115 kV underground electrical transmission cable
RAWP	Remedial Action Work Plan
Reactive Power	A component of power associated with capacitive or inductive circuit elements; its unit of measurement is the VAR (Volt-Ampere, Reactive).
Reconductor	Replacement of existing conductors with new conductors, and any necessary structure reinforcements or replacements.
RICRMC	Rhode Island Coastal Resources Management Council
RIDEM	Rhode Island Department of Environmental Management
RIDFW	Rhode Island Division of Fish and Wildlife
RIDOT	Rhode Island Department of Transportation
R.I.G.L.	Rhode Island General Laws
RIHPHC	Rhode Island Historical Preservation & Heritage Commission
ROW	Right-of-Way. Corridor of land within which a utility company holds legal rights necessary to build, operate, and maintain power lines.
Rules	Rhode Island Fresh Water Wetlands Act and Rules
SCFF	Self-Contained Fluid Filled, a type of underground transmission cable.
SESC	Soil Erosion and Sediment Control
SHPO	State Historic Preservation Office
Study Area	A 1,000-foot-wide corridor measured 500 feet on either side of the subject underground cables.
Substation	A fenced-in yard containing switches, circuit breakers, power transformers, line terminal structures, and other equipment enclosures and structures; voltage changes, adjustments of voltage, monitoring of circuits and other service functions take place in the substation.
Switching Station	Same as Substation except with no power transformers; switching of circuits and other service functions take place in a switching station.

TNEC	The Narragansett Electric Company
Transmission Line	An electric power line operating at 69,000 volts or more.
Tribes	Federally-recognized Indian tribes
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United Stated Geological Survey
VAR	Volt Ampere, Reactive, a measure of reactive power flow.
Voltage	Electric potential difference between any two conductors or between a conductor and ground, typically measured in kilovolts (thousands of volts) for utility project.
Watercourses	Rivers, streams, brooks, waterways, lakes, ponds, swamps, bogs and all other bodies of water, natural or artificial, public or private.
XLPE	Cross Linked Polyethylene, a type of underground cable insulation.

1.0 INTRODUCTION

1.1 Project Overview

This Environmental Report (ER) has been prepared in accordance with Rule 1.6 (f) of the *Rhode Island Energy Facility Siting Board* (*EFSB) Rules of Practice and Procedure* to support a Notice of Intent (NOI) for the relocation of a portion of the existing Q-143 and R-144 115-kilovolt (kV) underground electric transmission lines (the "Q-143 and R-144 Lines" or "Lines"), owned and operated by The Narragansett Electric Company d/b/a National Grid (TNEC) (the "Project"). These Lines are located in Providence, Rhode Island. The Q-143 and R-144 Lines were installed in 1939 and 1946, respectively, and connect the Franklin Square Substation to the Admiral Street Cable Terminal, both in Providence. Each line consists of three single phase self-contained fluid-filled (SCFF) cables and share 2.3 miles of land based common duct bank and manhole system. The existing Lines include a 700 foot section of direct buried armored submarine cables installed beneath the Providence River north of the Point Street Bridge.

The Q-143 and R-144 Lines have experienced failures of various components, over the life of the cable system, with increasing frequency in recent years. TNEC is currently developing a separate project to reconductor the balance of the Q-143 and R-144 cable system. That project will be the subject of a future EFSB filing.

This Project involves the relocation of 1,650 feet of the Q-143 and R-144 Lines from Franklin Square Substation to Dollar Street which includes the submarine cable portion of the Lines. The relocated route is approximately 1,930 feet. The Project is a priority for TNEC because the R-144 Line is out of service following a 2017 submarine cable failure. There are no remaining spare submarine cables to put the R-144 Line back in service. The extended loss of the R-144 Line puts the reliability of electric service to portions of Providence at risk. TNEC also has reliability concerns for the submarine portion of the Q-143 Line as a result of a 2016 failure on this Line. The submarine portion of the Q-143 Line remains similarly vulnerable to additional failure, further increasing the reliability risk. Relocation of the Q-143 Line is included in the Project scope for these reasons.

The Purpose and Need for the Project is detailed in Section 2.0 of this ER. Section 3.0 provides a detailed description of each of the components of the Project, and also discusses construction practices, right-of-way (ROW) maintenance practices, Electric and Magnetic Fields (EMF), safety and public health considerations, estimated costs for the Project, and anticipated Project schedule. An analysis of alternatives to the Project, together with reasons for the rejection of each alternative, is presented in Section 4.0 of this report. Detailed descriptions of the characteristics of the natural and social environment within and immediately surrounding the Project location are included as Sections 5.0 and 6.0, respectively. Section 7.0 of this report identifies the potential impacts of the Project on the natural and social environments. Finally, Section 8.0 summarizes proposed mitigation measures which are intended to offset or eliminate the potential impacts associated with the Project.

Section 4 of the Energy Facility Siting Act states that, "No person shall site, construct, or alter a major energy facility within the state without first obtaining a license from the siting board pursuant to this chapter." Transmission lines with a design rating equal to or greater than 69 kV are classified as major energy facilities. This ER is being submitted to satisfy the applicable requirements of Rhode Island General Laws (R.I.G.L.) 42-98-1 et seq., the Energy Facility Siting Act, and Rule 1.6(f) of the EFSB Rules. Rule 1.6(f) permits the filing of a Notice of Intent at least 90 days before commencement of construction of a new transmission line that is more than 1,000 feet and less than 6,000 feet in length. Pursuant to Rule 1.6(f) of the EFSB Rules, the Board must make a determination as to whether the Project "may have a significant impact on the environment or the public health, safety and welfare" and, therefore, constitutes an alteration of a major energy facility. If the Board determines that the Project will not have such an impact, the Project may proceed without further review.

1.2 Project Team

This ER has been prepared by TNEC with contributions from numerous employees and consultants retained by TNEC, including planners, engineers, and legal personnel. The description of the affected natural and social environments, and impact analyses were prepared by POWER Engineers, Inc. (POWER) and Exponent prepared the analysis of the health effects of EMF and EMF modeling and calculations. POWER is preparing the Project engineering and design documents.

1.3 Compliance with EFSB Requirements

Compliance with the EFSB Rules is addressed in the application which is filed under separate cover with the EFSB.

2.0 PROJECT NEED

2.1 Introduction

TNEC strives to provide its customers with high quality and reliable electric service at the lowest possible cost, while minimizing environmental and social impacts. Reliability is measured in terms of frequency and duration of power outages lasting one minute or more. The quality of electric service refers to voltage levels, variations in voltage frequency, harmonics, and outages lasting less than one minute.

The extended loss of the R-144 Line puts the reliability of electric service to portions of Providence at risk. TNEC believes that the Q-143 submarine cable remains similarly vulnerable to failure, further increasing the reliability risk. As a result of the recent submarine cable failures, there is an urgent need to return the R-144 Line to service and to reduce the risk of failure of the Q-143 submarine cable.

Under current conditions, with one of the two existing cables out of service, overloads on the transmission cables under contingency ("outage") conditions result in the transmission system not meeting the performance requirements set by North American Electric Reliability Corporation (NERC), Independent System Operator – New England (ISO-NE), Northeast Power Coordinating Council Inc. (NPCC) planning standards and TNEC transmission guidelines. The Project is needed to maintain firm and reliable electric supply to TNEC customers in Providence.

2.2 Project Background

The Q-143 and R-144 Lines have been experiencing an increasing trend in cable failures due to the gradual deterioration of both the cable and hydraulic system. In November of 2016, the Q-143 submarine cable experienced a failure and the only remaining spare submarine cable was used to address that failure. In April of 2017, a failure occurred on the R-144 submarine cable leaving the R-144 Line out of service with no expeditious method to return the R-144 Line to service. The R-144 Line remains out of service.

2.3 Need

The Project need is driven by the outage of the R-144 Line and the reliability concerns with the submarine portion of the Q-143 Line. The relocation of the submarine cables is the most effective way to restore the R-144 Line into service and address the reliability concerns with the submarine portion of the Q-143 Line. As further explained in Section 4 of this ER, the Project is the preferred option for resolving the reliability issues.

2.4 Conclusion

If the Project does not proceed, the supply to the Providence area load will continue to be at risk. The Project is needed for TNEC to continue to provide reliable electric service to its Providence area customers.

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3.0 PROJECT DESCRIPTION AND PROPOSED ACTION

3.1 Introduction

In this section of the ER, the overall scope of the Project is identified and the individual components and facilities comprising the Project are described. This section of the ER also details TNEC's construction and ROW maintenance practices, safety and public health considerations, traffic patterns, estimated costs, the anticipated construction schedule and community outreach for the Project.

The Project is needed to restore the R-144 Line, which has experienced a submarine cable failure and is currently out of service. The Project will also address ongoing reliability concerns with the Q-143 Line, as described in Section 2. The recent submarine cable failures have created a need to relocate a portion of the Q-143 and R-144 Lines on an expedited basis.

3.2 Description of the Existing Transmission Cables

The Q-143 and R-144 Lines feed areas of Providence, including commercial, residential, and industrial customers. The existing Q-143 and R-144 Lines were installed in 1939 and 1946, respectively, and connect the Franklin Square Substation to the Admiral Street Cable Terminal, both located in Providence. The Franklin Square Substation is located at 469 Eddy Street, at the corner of Eddy Street and Point Street. The Admiral Street Cable Terminal is located at the intersection of Admiral Street and Clarkson Street. The Lines include the following configuration:

- The land-based sections of these two Lines share a common duct bank of four-inch fiber conduits, with short sections of duct bank exchanged with five-inch and six-inch polyvinyl chloride (PVC) conduit from past relocations.
- The common duct bank includes an active fiber optic cable and a single ground continuity conductor that is shared between the two Lines.
- The linear route length between the substation and terminal station is 2.3 miles.
- The route includes a 700-foot section of direct buried armored submarine cables installed beneath the Providence River adjacent to the north side of the Point Street Bridge.
- The existing cables are single core self-contained fluid-filled 500 kcmil hollow-core copper conductor with several sections of 1,000 kcmil conductor.

The original Q-143 and R-144 Providence River crossing included eight (8) submarine cables with six (6) active and two (2) spare submarine cables. The cables were originally buried approximately 6 to 10 feet under the river bed. Over time, sediment has accumulated to a depth of approximately 25 feet over the cables. In 1982 one of the spare submarine cables was used for the R-144 Line as result of a submarine cable failure. In November of 2016, one of the Q-143 submarine cables experienced a failure and the only remaining spare submarine cable was used to address that failure. These events left TNEC with no spare submarine cables. In April of 2017, a failure occurred on one of the R-144 submarine cables leaving the R-144 Line out of service with no expeditious method to return the line to service. As a result of the submarine cable failures, the Project is to relocate the portion of the Q-143 and R-144 Lines between the Franklin Square Substation and manhole # 31 on Dollar Street.

The portion of the Q-143 and R-144 Lines to be relocated under the Project is approximately 1,650 feet long with approximately 950 feet of cable in duct bank on land and 700 feet of direct buried submarine cable crossing the Providence River. This section includes six (6) outdoor cable terminations at Franklin Square Substation and six (6) pairs of manholes, including manhole # 31 on Dollar Street. Manhole #31 consists of a pair of manholes that are known as manhole 31-B for the Q-143 Line and manhole 31-A for the R-144 Line.

3.3 Scope of the Project

The components of the Project are described below.

Duct Bank

- Install approximately 1,410 feet of new duct bank via open cut trenching from Franklin Square Substation to the west side of the Point Street Bridge and from the east side of the Point Street Bridge to existing manhole #31. The new duct bank will consist of six (6) five inch (5”) Schedule 40 PVC conduits, two (2) three inch (3”) PVC conduits and one (1) four inch (4”) Schedule 40 PVC conduits. The five inch (5”) conduits are for the power cables. The three-inch (3”) conduits are for the ground continuity conductors. The four-inch (4”) conduit is for the communication cable. The PVC conduits will be encased in a common concrete envelope.

Bridge Crossing

- Install approximately 520 feet of a conduit system consisting of eight (8) fiberglass reinforced epoxy (FRE) conduits under the northern sidewalk of the Point Street Bridge to carry the Q-143 and R-144 Lines over the Providence River. The new conduit system will consist of six (6) five inch (5”) FRE conduits, and two (2) three inch (3”) FRE conduits. The five inch (5”) conduits are for the power cables. The three-inch (3”) conduits are for the ground continuity conductors. An existing four inch (4”) galvanized steel conduit on the side of the bridge will be used for the communication cable. Installation of conduit hangers and any necessary modifications to the bridge structural steel will be performed in accordance with RIDOT and Providence Department of Public Works (DPW) requirements.
- A standard work barge or jack-up barge/ spud barge equipped with a scissor lift will likely be used to access the underside of the Point Street Bridge for the conduit installation. The installation of the cables will be performed from a work barge in the river and assisted by support vessels. The bridge work may also be performed utilizing articulated bridge inspection man lifts from the road surface rather than from a barge.

Manholes

- Install two (2) manholes (approximately 8 feet wide × 8 feet high × 20 feet long) on the east-side of the Point Street Bridge. Consistent with the existing line design and modern practice, the Lines will be spliced in separate manholes.
- Modify existing manholes 31-A and 31-B on Dollar Street, enlarging them to approximately 20 feet long to accommodate transition splices from SCFF to High Voltage Extruded Dielectric (HVED) cable.

Cable and Accessories

- Install approximately 1,930 feet of 1,500 kcmil copper 115 kV HVED cables and 500 kcmil copper ground continuity conductors (per Line) in the new Q-143 and R-144 duct bank between the Franklin Square Substation and manhole #31 on Dollar Street.

Substation Modifications

- Replace the termination structures within the Franklin Square Substation.
- Install three (3) outdoor terminations and three (3) surge arresters per Line within Franklin Square Substation.

3.3.1 Project Benefits

Completing the Project will result in measurable benefits, including the following:

- Restore and improve reliability to the 115 kV transmission system serving TNEC's Providence customers, by returning the R-144 Line to service and eliminating Q-143 submarine cable vulnerability.
- Reduce exposure to long term submarine cable outages by installing the Q-143 and R-144 Lines in conduit.
- Install solid dielectric cables which typically require less maintenance compared to the existing fluid-filled cables.

3.3.2 Underground Route

The proposed cable route is located entirely within a developed urban area, including city streets, sidewalks and roadway ROW. The bridge structure of the Point Street Bridge will be used to cross the Providence River. A new duct bank and manhole system will be constructed along the proposed route from Franklin Square Substation to the existing manhole #31 on Dollar Street.

The Project route is approximately 1,930 feet long (see Figure 1) extending from the existing TNEC Franklin Square Substation to the existing manhole #31 on Dollar Street. The detailed cable route is as follows:

- Approximately 430 feet through the TNEC fee-owned property occupied by the Franklin Square Substation.
- Approximately 200 feet on Point Street from TNEC fee-owned property occupied by the Franklin Square Substation to the western end of the Point Street Bridge.
- Approximately 520 feet on the underside of the Point Street Bridge.
- Approximately 240 feet on Point Street / Wickenden Street from the eastern end of the Point Street Bridge to South Water Street.
- Approximately 400 feet on South Water Street from Wickenden Street to Dollar Street.
- Approximately 140 feet on Dollar Street from South Water Street to the existing manhole #31 on Dollar Street near the intersection with South Main Street.

3.3.3 Cable Rating

TNEC's Transmission Planning group reviewed the future capacity needs of the cables. Upon completion of the future reconductoring project on the balance of the cable route (manhole # 31 on Dollar Street to Admiral Street Cable Terminal), each of the Q-143 and R-144 Lines must meet the requirements of 130 Megavolt Ampere or 653 amps (A) summer normal. An ampacity study for the two Lines in the proposed land and bridge duct bank configurations determined that 1,500 kcmil copper 115 kV solid dielectric cable will satisfy this future requirement. The cable size selected for the Project is consistent with the requirements of the future project.

3.4 Construction Practices

3.4.1 Introduction

The Project is located within an urban environment, including paved roadways, sidewalks, the Point Street Bridge, and adjacent to open green space/ landscaped areas along the Providence River. Project construction will be sequenced in a series of construction phases. Each of these steps is described in more detail below. The construction steps will be conducted in sequence at each location so that several phases of construction will be ongoing simultaneously in different sections of the route. After in-street construction is completed, the pavement will be temporarily patched. Subsequently the pavement will be repaired or replaced.

Manhole installation, trenching, conduit installation and backfilling will proceed progressively along the route such that relatively short sections of trench (typically 200 feet per work crew) will be open at any given time and location. During non-work hours, temporary cover (steel plates) will be installed over the trench and manhole locations within paved roads to maintain traffic flow over the work area. After backfilling, the trench area will be repaved using a temporary asphalt patch or equivalent. Final paving will be completed in coordination with the City of Providence and the RIDOT.

3.4.2 Installation of Environmental Controls

Prior to starting underground construction, the contractor will install appropriate soil erosion and sediment controls (e.g., catch basin inlet protection, straw wattles, silt fence) at locations where the disturbance of pavement or soils have the potential to impact a resource. All storm water control measures will be installed in accordance with National Grid's standards and all applicable requirements, including applicable design and manufacturer specifications. Installation techniques and maintenance requirements are detailed in National Grid's *EG-303NE* and the *RI Soil Erosion and Sediment Control (SESC) Handbook*.

Excess sediment that is observed within the roadway will be removed. The contractor will sweep streets daily to minimize accumulation of sediment or dust within the construction work zone.

A barge will likely be used to install the conduit on the underside of the Point Street Bridge. Appropriate measures will be implemented on the barge to contain construction materials and debris within the confines of the barge. The barge will be equipped with an emergency spill control kit, including surface booms, to respond to any inadvertent release.

Sediment barriers will be installed along the perimeter areas of the Project that will receive storm water from disturbed areas. Installation and maintenance of sediment barriers must be completed in accordance with National Grid's *EG-303NE* and the maintenance requirements specified by the product manufacturer or the *RI SESC Handbook*. National Grid's *EG-303NE* approved perimeter sediment control barriers (e.g., straw wattles, silt fence or other TNEC approved sediment controls) will be installed around the limits of ground disturbance. The sediment control barriers will be included in the SESC Plan.

3.4.3 Manhole Installation and Modifications

Manholes are typically spaced every 1,500 to 2,500 feet along the cable route. For the Project, two precast manholes will be installed within Point Street on the east side of the Point Street Bridge. It will also be necessary to enlarge existing manholes 31-A and 31-B on Dollar Street.

The location of the manholes will be excavated and shored to the required dimensions for the setting of the manhole. Precast manholes will be manufactured at a remote location in two or more parts and delivered to the site on a tractor trailer. A crane is then used to set the manhole into the pit. The area around the manhole is then backfilled and compacted. The manhole #31 enlargements will be field cast. Field cast manholes are constructed on site in a similar excavation.

For safety purposes, the manhole excavation will be shored and barricaded. Manhole sites also may be protected by concrete (Jersey) barriers during construction. Manhole installation within roadways may require the temporary closure of a travel lane in the immediate vicinity of the manhole construction.

3.4.4 Trenching and Installation of Duct Bank

The basic method for constructing an underground duct bank is by open-cut trenching. In open-cut trenching, the width of the trench is marked on the street, dig-safe is contacted, the location of existing utilities is marked, and the pavement is saw cut. The saw cutting provides a clean break in the pavement and defines the trench for the next activity. Saw cutting is a relatively fast operation and is not performed every day so as not to proceed too far ahead of the construction crew that follows.

Following saw cutting, the existing pavement is removed by pneumatic hammers and loaded into a dump truck with a backhoe. Pavement is handled separately from the soil because the pavement is recycled at an asphalt batching plant.

The trench is then excavated to the required depth by a backhoe. In pre-determined areas, some of the excavation will be done by hand so as to avoid disturbing existing utility lines and/or service connections. Within a public way, a "clean trench" method will be used where soil is loaded directly into a dump truck for temporary staging, off-site recycling or disposal. Removal of the soil, rather than stockpiling, reduces the size of the required work area and reduces the potential for sedimentation and nuisance dust. Any rock encountered during excavation will be removed by mechanical means.

The conduits will be encased in 3,000 pounds per square inch strength concrete to protect the conduits and cables from mechanical damage. In general, the duct banks will be installed at a minimum depth of 30 inches to the top of the concrete. Overlapping steel plates will be installed over the two trench arrangements in shallow burial areas such as at both approaches to the Point Street Bridge to provide additional mechanical protection against third-party damage to the cables.

The trench is shored as required by soil conditions and Occupational Safety and Health Administration (OSHA) safety rules. The shoring is designed to permit the passage of traffic adjacent to the trench and will allow for the trench to be covered with a steel plate to permit traffic over the trench during non-working hours. Under typical conditions, a crew can excavate and shore approximately 100 to 200 feet of trench per day.

The conduit will be installed in sections. After installation in the trench, the conduits will be encased with high-strength concrete. The duct bank will then be backfilled with native soil, select gravel backfill, or fluidized thermal backfill with sufficient thermal characteristics to dissipate the heat generated by the cables.

If groundwater is encountered, dewatering will be performed in accordance with applicable regulatory requirements and in accordance with National Grid's *EG-303*.

Temporary paving will restore the roadway to use once the section of duct line is completed. Permanent restoration is discussed in the restoration section below.

3.4.5 Bridge Attachment and Conduit Installation

Attaching the cables to the Point Street Bridge will require installation of a new conduit system on the underside of the bridge. There is an existing electric distribution conduit system installed beneath the southern sidewalk of the bridge. The proposed conduit system will be installed under the northern sidewalk of the bridge.

The new conduit system will consist of six (6) five inch (5") FRE conduits, and two (2) three inch (3") FRE conduits. The five inch (5") conduits are for the power cables. The three inch (3") conduits are for the ground continuity conductors. An existing four inch (4") galvanized steel conduit on the north side of the bridge will be used for the communication cable. The weight of the proposed conduit and cable system under the bridge is approximately 220 pounds per foot.

A structural loading analysis of the bridge has been performed and confirmed that the loading capacity of the bridge structure will remain unchanged after addition of the new facilities (see report entitled, "Load Rating Analysis With Additional Utility Loads" by CDR Maguire, Inc. dated September 2017 in Appendix B of this report). The addition of the new cable and conduit system will not result in a reduction in vertical clearance under the bridge nor create an adverse impact to navigation within the Providence River. TNEC reviewed the report and proposed configuration with RIDOT and the City of Providence DPW, and both parties have agreed to the proposed configuration (see letters from RIDOT and Providence Department of Public Works contained in Appendix C).

Installation of conduit hangers and any necessary modifications to the bridge structural steel, in accordance with RIDOT and Providence DPW requirements, will be performed under this activity.

Construction of the new conduit system will include the following activities:

- Modification of existing submarine cable protection structures and cables underneath the Point Street Bridge.

- Modification of the bridge structural steel as required to support the new cable and conduit system. Any lead paint removal will be performed in accordance with regulatory requirements.

- Installation of conduit supports and hangers underneath the bridge.
- Modification of bridge backwalls and approach slabs to allow transition between the land conduits and the bridge conduits.
- Installation of the conduits under the bridge.
- Restoration of the underside of the bridge, backwalls, approach slabs, and other bridge structures as required.

Work activities will likely be performed from a standard work barge or jack-up/ spud barge in the river assisted by support vessels. A jack-up or spud barge is a self-elevating barge that elevates the work platform above the level of the water supported by jacks resting on the riverbed. Some bridge work may be performed utilizing articulated bridge inspection man-lifts from the road surface.

3.4.6 Installation and Testing of New Cable

After the manholes and duct bank are in place, the conduits will be swabbed and tested (proofed), using a cylindrical mandrel to check for defects. The mandrel is a testing procedure to verify that the conduit has not been crushed, damaged, or installed improperly. After successful proofing, the transmission cables and ground-continuity conductors will be installed and spliced. Cable reels will be delivered by tractor trailers to the manholes, where the cable will be pulled into the conduit using a truck-mounted winch and cable handling equipment.

After the transmission cables and ground-continuity conductors are pulled into the conduits, they will be spliced together in the manholes. It takes approximately one to two weeks to complete the transmission cable splices in each vault. A splicing van will be parked over or next to the manholes during this time.

Once the complete cable system has been installed, the cable system is tested. At the completion of successful testing, the circuits are energized.

3.4.7 Restoration of Project Route

After construction activities are completed, disturbed areas will be restored and environmental controls will be removed. Some environmental controls may need to remain until the area is stabilized.

Work areas in the paved surface will be restored per the city ordinances. Temporary pavement placed during the in-street construction will be repaved in collaboration with the City of Providence to restore the street surface.

3.4.8 Environmental Compliance Monitoring

TNEC will retain the services of an environmental monitor to oversee construction activities including the installation and maintenance of soil erosion and sediment controls on a routine basis to ensure compliance with all federal, state, and local permit commitments.

3.4.9 Construction Work Hours

Proposed construction work hours for the Project will be between 7:00 a.m. and 7:00 p.m. Monday through Friday when daylight permits and between 7:00 a.m. and 5:00 p.m. on Saturday. Night construction, if needed, may require a special permit from the DPW. This will also require lighting and may result in temporary and localized noise impacts.

3.4.10 Construction Traffic Management

Construction-related traffic will occur over the approximately eight to twelve month construction period. TNEC will coordinate closely with the City of Providence and the RIDOT to develop acceptable traffic management plans for work within the city and state roadway layouts. Appropriate safety measures will be implemented to allow safe traffic patterns for vehicles, bicyclists and pedestrians.

3.4.11 Safety and Public Health Considerations

TNEC will design, install, and maintain the transmission cables so that the health and safety of the public are protected. This will be accomplished through adherence to all applicable regulations, and industry standards and guidelines established for the protection of the public. Specifically, the Project will be designed, built, and maintained in accordance with the National Electrical Safety Code (NESC). The facilities will be designed in accordance with sound engineering practices using established design codes and guidelines published by, among others, the Institute of Electrical and Electronic Engineers (IEEE), the American Society of Civil Engineers (ASCE), the American Concrete Institute (ACI), and the American National Standards Institute (ANSI). Practices that will be used to protect the public during construction will include, but not be limited to, establishing traffic control plans for construction traffic on busy streets to maintain safe driving conditions, restricting public access to potentially hazardous work areas, noise and dust control management, and coordination with the City of Providence and the RIDOT during installation.

The barge used to access the underside of the Point Street Bridge will be a U.S. Coast Guard (USCG) approved work vessel equipped with the necessary spill control and containment devices. The captain operating the barge will be responsible for providing a USCG Local Notice to Mariners and notification to the City of Providence Harbor Master.

A discussion of the current status of the health research relevant to exposure to EMF is attached as Appendix A. This report was prepared by Exponent.

3.4.12 Estimated Project Costs

TNEC has prepared conceptual level estimates (-25%/+50%) for the relocation of the Q-143 and R-144 Lines between the Franklin Square Substation and manhole #31 in Dollar Street utilizing the Point Street Bridge (Table 1). At the current level of design, the Project is anticipated to cost a total of approximately $16.3 M.

TABLE 1 ESTIMATED PROJECT COSTS

PROJECT COMPONENTS	ESTIMATED COST ($M)
Transmission Cable Facilities	$14.0
Franklin Square Substation Termination Structures	$ 2.3
Total	$16.3

3.4.13 Project Schedule

Due to the critical need to restore the R-144 Line and address the reliability risk of the Q-143 Line, this Project is being designed and planned by TNEC on an expedited schedule to address these issues. Preliminary design for the Lines between Franklin Square Substation and manhole #31 on Dollar Street has been completed and final engineering is currently underway. Due to the long lead time required to manufacture and purchase transmission cable, the procurement process has been initiated by TNEC for the cable and cable terminations. It is expected that the licensing and permitting process will continue through the winter of 2017/18 with final engineering completed in early spring of 2018. Construction is anticipated to begin in the summer of 2018 with completion in summer 2019.

TNEC has developed a preliminary schedule based on time estimates for planning and engineering, permitting and licensing, and construction (Table 2). The Project is expected to be completed and in-service by the summer 2019.

TABLE 2 PROJECT SCHEDULE

ACTIVITY	ESTIMATED START DATE	ESTIMATED COMPLETION DATE
Planning and Engineering	Spring 2017	Spring 2018
Permitting and Licensing	Summer 2017	Spring 2018
Construction	Summer 2018	Summer 2019
Facilities In-Service	Summer 2019	
Final Restoration	Summer/Fall 2019	

3.4.14 Public Outreach

TNEC has reached out to RIDOT, Providence officials and major employers in the immediate vicinity to describe the Project. Because the Project is an underground project, the outreach effort was more limited than for a typical overhead transmission line project. Prior to construction, TNEC will provide the details of planned construction including the normal work hours and any extended work hours.

3.4.15 ISO-NE Approval of Project

The Q-143 and R-144 Line relocations are not defined as Pool Transmission Facilities by New England's Independent System Operator, ISO-NE. A Level I Proposed Plan Application will be filed by TNEC with the ISO-NE to ensure the proposed changes and upgrades to the transmission system will not have a significant impact on the bulk power system.

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4.0 PROJECT ALTERNATIVES

4.1 Introduction

This section describes the alternatives to the Project that were considered to address the need to restore service to the R-144 Line and enhance the reliability of the Q-143 Line. TNEC's goal is to select the alternative that best meets the Project need, with a minimum impact on the natural and social environments, at the lowest possible cost. Alternatives to the Project have been evaluated to ensure that these objectives are met. Section 4.2 describes the no-action alternative. Section 4.3 describes the Point Street Bridge crossing alternative (preferred), Section 4.4 describes the buried submarine cable alternative and Section 4.5 describes an alternative using Horizontal Directional Drilling (HDD) technology, respectively. Figure 5 illustrates the Alternative Options.

4.2 No-Action Alternative

The Q-143 and R-144 Lines have experienced submarine cable failures. The R-144 Line is presently out of service, as there are no remaining spares. The No-Action Alternative would leave the R-144 Line out of service, exposing the Providence area to increased contingency risk. The potential for extended loss of the Q-143 Line further increases the risk to electric reliability. The potential for thermal overloads and the increased possibility of loss of load due to the long term loss of Q-143 and R-144 Lines is not an acceptable alternative for maintaining a firm and reliable electric supply for TNEC's Providence customers.

This alternative was dismissed as it would not address the need to restore the R-144 Line to service; it would leave the Q-143 Line vulnerable to failure, and would expose Providence customers to unacceptable degradation of electric reliability. The No Action alternative is not acceptable from either an operational or reliability perspective.

4.3 Point Street Bridge Crossing Alternative (Preferred)

TNEC examined an underground route that utilizes conduit installed on the underside of the Point Street Bridge to cross the Providence River, similar to the distribution conduits located on the underside of the southern side of the bridge. A benefit of this route is that it minimizes disturbance to the Providence River. The cost of the bridge attachment alternative (line work and substation modifications) is estimated at $16.3M. In addition, permitting and implementation schedules would be shorter for the bridge alternative. This alternative is the preferred option because it will resolve the asset and reliability concerns for this section of the Q-143 and R-144 Lines at the lowest cost, with the fewest environmental impacts, and with the shortest Project schedule.

4.4 Submarine Cable Alternative

TNEC examined a submarine cable alternative that would involve the installation of a series of direct buried cables in the riverbed of the Providence River. The existing Q-143 and R-144 Lines cross the Providence River as buried submarine cables within the same corridor. Installing a new submarine cable would require two circuit (i.e., Q-143 and R-144 Lines) outages for an extended (e.g., 12+ months) duration to complete the new submarine cable installations.

Installing a submarine cable involves laying the cable on the riverbed with or without supplemental protection/armoring, or trenching the riverbed sediments and lowering the cable within the trench. Laying a submarine cable on the bed of the Providence River presents risk from third party damage to the cable, since the river channel is shallow and narrow in the vicinity of the Point Street Bridge. Trenching and lowering the cable using an alternative technology such as jet-plowing is not feasible because there is not sufficient work space for a vessel to tow a jet-plow and simultaneously trench, lay and bury the cable.

Installation of a submarine cable would therefore require a direct burial technique such as open trenching/ excavation/ dredging of the riverbed, and either side-casting the sediment or live-loading the sediment onto a barge. The new submarine cables would be entrenched a minimum of 10 feet below the elevation of the riverbed. Use of a barge or other marine-operated vessel may be hindered due to the size constraints imposed by the presence of the Fox Point Hurricane Barrier. Trenching/ dredging of the riverbed may need to be accomplished from the landward sides of the river.

Over time, development within the city and construction of the Fox Point Hurricane Barrier has caused accumulation of sediment within the Providence River upstream of the hurricane barrier, including deposition of contaminated sediments. To contain the known contaminated sediments, shoring and temporary cofferdams would need to be installed. These installations would have a temporary impact on navigation and recreational use of the Providence River. Work in the Providence River may be limited by seasonal restrictions on in-water activities to minimize impacts on fisheries migration. Soil handling and management would be a major effort in attempts to minimize resuspension of sediments back into the water column, and managing and disposing of historically contaminated sediments. Modifications to the Point Street Bridge abutments would likely still be required to make a transition from the submarine cable to adjacent landfalls located on either side of the river banks. The cost of a submarine cable installation (line work and substation modifications) is estimated at $23.8M, which is approximately 1.5 times the cost of the bridge attachment alternative. Repair of a submarine cable would require dredging to expose the cable, splicing on a barge, and reburial to the 10+ feet depth.

The schedule would be significantly affected and lengthened by the need to obtain the necessary environmental licenses, permits and approvals, and the construction duration would be longer to complete the submarine cable installation. TNEC's preference is to install a cable system within a series of conduits for ease of operation and maintenance, and a submarine cable alternative does not provide this advantage. After consideration of these substantial constraints and potential project delays, TNEC rejected the submarine cable alternative.

4.5 Horizontal Directional Drilling Alternative

TNEC examined a Horizontal Directional Drilling (HDD) installation alternative which would involve the use of trenchless technology to install a series of conduits and cables beneath the riverbed of the Providence River. This alternative would require the excavation of an HDD entry site on the east side of the river, an HDD underneath the Providence River, and excavation of an HDD exit site in the Franklin Square Substation parking lot. This option would most likely not disturb the existing marine sediment because it would be installed at a targeted depth of approximately 60 feet below the elevation of the riverbed. The depth of the HDD is determined based upon several factors including: the elevations of the adjacent landfalls and bottom elevation of the river, cable pulling radii, depth of the navigation channel within the river, geotechnical characteristics of the sediments and soils below the riverbed, and depth of anticipated river sediment contamination.

Temporary construction work space would need to be acquired on either sides of the river for the purposes of excavating entry and exits pits for the HDD operations. Property acquisition would be required on the landfall sides of the river to install new below-ground structures to serve as tie-in points for the underground cables. The HDD would require significant excavation and shoring at both landfall locations, which would also require a soil management plan for handling and managing potentially impacted soil. An HDD contingency plan would need to be developed, in the event that the HDD failed. If the HDD encountered an obstacle that prevented the HDD from being completed, an alternate cable installation method would need to be at the ready. The cost of an HDD (line work and substation modifications) is estimated at $17.9M, which is greater than the cost of the bridge attachment alternative. This is fairly close to the cost of the preferred plan. However, HDD conduit installations are considered to be higher risk construction than the preferred plan.

The schedule would be significantly affected and lengthened by the need to secure real estate rights, obtain the necessary environmental licenses, permits and approvals, and construction would require a longer duration to complete the HDD cable installation. After evaluation of these significant constraints, TNEC rejected the HDD alternative.

4.6 Summary of Alternatives and Conclusions

In the development of the Project, evaluation of feasible alternatives and selection of the preferred alternative, TNEC evaluated a number of alternative routes and cable installation methods. Following an evaluation of the relative merits and disadvantages of the various alternatives, TNEC concluded that the preferred alternative of installing underground cables to include attachment to the Point Street Bridge is superior to the other routing alternatives.

For the reasons summarized in the above sections, the installation of new conduits and cables on the underside of the Point Street Bridge is significantly preferred to the No Action, Submarine Cable, and HDD alternatives. An attachment to the existing bridge structure offers the more constructible alternative. The Point Street Bridge alternative costs and environmental impacts would be considerably less than the other alternatives. Permitting and construction schedules would be shorter for the Point Street Bridge alternative in comparison to the other alternatives and the No Action alternative is not acceptable from either an operational or reliability perspective.

The preferred alternative will resolve the reliability concerns for this section of the Q-143 and R-144 Lines meeting the need for the Project; be installed at the lowest cost; constructed with the fewest environmental impacts; and completed in the shortest timeframe. The preferred alternative also offers the advantage of improved access for inspection, operation and maintenance of the new facilities.

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5.0 DESCRIPTION OF AFFECTED NATURAL ENVIRONMENT

5.1 Introduction

The Project Area is the area immediately adjacent to the project route between the Franklin Square Substation and Dollar Street (Figure 1). According to the EFSB Rules, a detailed description of the environmental characteristics of the "Study Area" is required. As shown in Figure 2, the Study Area is the area within 500 feet on either side of the Project. As permitted by EFSB Rule 1.6(f)(3), several natural and environmental descriptions (climate and weather, wetlands, wildlife and geology) have not been addressed in this report because the Project is located within a highly developed area and will not have impacts on them.

5.2 Soils

Soils along the proposed routes primarily consist of urban fill materials. According to the Natural Resources Conservation Service (NRCS) web soil survey, the entire upland route from the Franklin Square Substation to manhole #31 on Dollar Street is identified as urban land. Based on previous investigations at the Franklin Square Substation, soils generally consist of 1 to 2 inches of topsoil in unpaved portions underlain by granular urban fill (as characterized by the presence of brick, concrete debris, etc.). Most of the proposed land cable route to manhole #31 on Dollar Street consists of asphalt pavement.

The Franklin Square Substation and adjacent properties have been identified as State-listed sites regulated by the Rhode Island Department of Environmental Management (RIDEM) Office of Waste Management due to certain impacts to soils and groundwater from historical operations. As a result, the sites are subject to Environmental Land Use Restriction (ELUR).

5.3 Groundwater

The RIDEM classifies all of the state's groundwater resources and establishes groundwater quality standards for each class. The four classes are designated GAA, GA, GB, and GC. Groundwater classified as GAA and GA is to be protected to maintain drinking water quality, whereas groundwater classified as GB and GC is known or presumed to be unsuitable for drinking water use without treatment. The Study Area falls within a RIDEM designated GB groundwater resource area (81.3 percent of the Study Area). The remaining portion of the Study Area consists of the Providence River crossing.

Businesses and residences in the area are connected to the Providence municipal water supply. There are no known well head protection areas within the Study Area.

Groundwater may be encountered during excavation activities conducted as part of the Project and construction dewatering is anticipated to be necessary. If dewatering occurs, the pumpate encountered may require treatment prior to discharge.

5.4 Surface Water

The Project crosses the tidally influenced Providence River (waterbody identification No.RI0007020E-01B) on the Point Street Bridge. The RIDEM List of Impaired Waters developed in response to the requirements of Section 303(d) of the federal Clean Water Act lists the Providence River as Category 5 Waters, which are waters that are impaired or threatened for one or more designated uses by a pollutant(s), and requires a Total Maximum Daily Load (TMDL). TMDL refers to the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. The term also refers to the waterbody specific studies completed to determine the allowable pollutant levels and the pollution control activities needed to restore water quality. The Providence River is listed by RIDEM as a SB1{a} water body that is impaired due to fecal coliform, total nitrogen, and dissolved oxygen. The primary use of the Providence River is limited because of poor water quality. Due to the condition of the river, it is not considered a viable drinking water resource.

The Providence River does support populations of marine fisheries, such as Atlantic menhaden (*Brevoortia tyrannus*). The river also supports populations of crustaceans, such as blue crab (*Callinectes sapidus*). RIDEM has monitored hypoxic (low oxygen levels) conditions in the Providence River which has led to reported fish kills within the river.

The Providence River in the area is classified by the Rhode Island Coastal Resources Management Council (RICRMC) as Type 5 Waters, Recreational and Commercial Harbor. Type 5 waters are defined as waters that are adjacent to waterfront areas that support a variety of tourist, recreational, and commercial activities. There are no other surface water resources (streams, ponds) on or adjacent to the Project Area.

5.5 Vegetation

The existing pervious areas are predominantly vegetated with grass with some areas of shrubbery and trees. Point Street Landing Park is located on the west bank of the Providence River at Point Street surrounding the entrance to the bridge. An Urban Coastal Greenway creates a vegetated green space along the waterfront north of Point Street. This area is currently a public access/boardwalk that consists of both a timber and brick boardwalk area with several bench and gazebo structures.

5.6 Air Quality

The Project Area is subject to the National Ambient Air Quality Standards (NAAQS). These standards were established by the federal Clean Air Act Amendments and are designed to protect public health and welfare. Air quality analyses for projects that may impact motor vehicle traffic are required to evaluate their impact on atmospheric ozone and carbon monoxide levels downwind of the Project Area. After considerable analysis and review, Rhode Island was able to demonstrate to the United States Environmental Protection Agency that Rhode Island sources do not significantly contribute to downwind ozone attainment and will not prevent downwind areas from attaining the NAAQS by required attainment dates. This Project will not require further evaluation of atmospheric emissions from vehicular sources.

6.0 DESCRIPTION OF AFFECTED SOCIAL ENVIRONMENT

6.1 Introduction

According to the EFSB Rules, a detailed description of the social environmental characteristics of the Study Area is required. The Study Area is wholly within the City of Providence and is subject to the City of Providence Comprehensive Land Use Plan. Based on the nature of the Project (relocating of existing underground facilities) and the limited scope of the proposed work, information is not being provided on regional population trends, or employment conditions as permitted by EFSB Rule 1.6(f)(3), since the Project will not impact these resources.

6.2 Land Use

Land use near the Franklin Square Substation and along the proposed cable route includes primarily industrial and commercial uses as well as properties developed as part of the Interstate 195 (I-195) relocation project (see Figure 6 for Land Use/Zoning). There are also residential properties within the vicinity of the Project limits.

The Franklin Square Substation property is within the Downtown District (D1-100), General Industrial District (M-2), Educational Institutional and Healthcare Institutional Overlay Districts. The cable route west of the Point Street Bridge crossing is part of the Downtown District (D1-100) and is within the Educational Institutional and Healthcare Institutional Overlay Districts. The proposed cable section just to the east of the bridge is an Open Space (OS) District while the land that was formally the I-195 corridor is a General Commercial (C-2) District. The Study Area to the east of the Providence River also includes Residential Districts (R-2 and R-4) and a Mixed-Use Waterfront District. These sections are also included as part of the East Side Overlay District. Additionally, there is a portion of the Historic District-Providence Landmark District, included within the Study Area. There are several monuments and memorials within the Study Area.

The entire cable route is proposed along either existing roadway ROW under state and local jurisdiction or land under the control of TNEC.

6.3 Historic and Cultural Resources

There is one known archaeological resource on file at the Rhode Island Historical Preservation and Heritage Commission (RIHPHC) within 1,000 feet of the Project. The site dates to the historic period. RI-1213, the Central Wharf site, was excavated in 2004 in advance of reconstruction of I-195; archaeologists identified the remains of the Fuller-McLaughlin House, Central Wharf Warehouse, and Central Wharf during this investigation. This site informs about the commercial and residential history of the area immediately adjacent to the Point Street Bridge.

The Point Street Bridge is itself described in the document Historic Highway Bridges of Rhode Island (RIDOT 1990), in the section on metal-truss bridges. It was built during 1926 and 1927 to provide a means of crossing the Providence River south of the downtown area and the Dyer Street docks. Designed by City engineers, it was the third swing bridge constructed in the state. The Bridge is now fixed - it last moved in 1959. It is not listed on the National Register of Historic Places (NRHP). There are two NRHP listed above-ground properties or districts within 1,000 feet of the Bridge. These listings are the Davol Rubber Company (1880) and South Street Station (1912).

6.4 Visual Resources

The area is characterized by the Providence River and a mix of commercial, industrial, residential and mixed-use waterfront uses.

6.5 Transportation

The Project route is located along city and state roads and the transportation needs of the Project Area are served by a network of federal, state and local streets and highways.

6.6 Electric and Magnetic Fields

EMF is a term used to describe electric and magnetic fields that are created by voltage (electric field) and electric current (magnetic field). TNEC, like all North American electric utilities, supplies electricity at 60 Hertz (Hz). Therefore, the electric utility system and the equipment connected to it, produce 60-Hz (power-frequency) EMF. These fields can be measured using instruments and can be calculated using computer models.

Power frequency EMFs are present wherever electricity is used. Sources of these fields include utility transmission lines, distribution lines, substations, building wiring in homes, offices, and schools, and the appliances and machinery used in these locations.

Electric fields are present whenever voltage exists on a wire, and do not depend on the magnitude of the current flow. The magnitude of the electric field is primarily a function of the configuration and operating voltage of the line and decreases with the distance from the source (i.e., the transmission line). Electric fields are shielded (i.e., the strength is reduced) by conducting surfaces, including trees, fences, walls, buildings, and most types of structures. The strength of an electric field is measured in volts per meter (V/m) or kilovolts per meter (kV/m). In this project, neither the existing lines nor the rebuilt lines produce an electric field above ground because of the shielding provided by the cable sheaths and the earth.

Magnetic fields are present whenever current flows in a conductor and are not dependent on the voltage present on the conductor. The magnetic field strength from a transmission line is a function of both the current flow on the conductor and the configuration of the transmission line. The strength of these fields also decreases with distance from the source. However, unlike electric fields, most common materials have little shielding effect on magnetic fields.

Magnetic fields are measured in units called Gauss. However, for the low levels normally encountered during daily activities, the field strength is expressed in a much smaller unit, the milligauss (mG), which is one thousandth of a Gauss.

Magnetic fields from the transmission lines in the existing duct bank were calculated by Exponent® using projected annual average and annual peak load levels for the year 2019. Calculations were performed at average loading to best predict the magnetic field that might occur on any randomly-selected day of the year for projected loadings on the transmission lines. Calculations also were performed for peak loading on the existing lines to estimate the highest magnetic fields but which are expected to occur at most during a few hours on a few days of the year. The magnetic fields from two configurations: As Built and As Operating were calculated to describe the historical normal operation of both lines in service (As Built) and the current operating condition where only the Q-143 Line is in service (As Operating). Tables 3 and 4 show the magnetic field (Root Mean Square [RMS] Resultant) levels produced by the transmission lines in the existing duct bank under average and peak loads, respectively.

TABLE 3 CALCULATED MAGNETIC FIELD LEVELS (MG) (ANNUAL AVERAGE LOAD) UNDER EXISTING CONDITIONS (2019 PRE-CONSTRUCTION)

DISTANCE FROM DUCT BANK CENTERLINE						
Configuration	Loading (Year)	**−50 ft**	**−25 ft**	Max	+ 25 ft	+50 ft
As-Built	Existing (2019)	0.5	1.1	12.5	1.2	0.5
As-Operating	Existing (2019)	0.8	2.4	30	2.2	0.8

TABLE 4 CALCULATED MAGNETIC FIELD LEVELS (MG) (ANNUAL PEAK LOAD) UNDER EXISTING CONDITIONS (2019 PRE-CONSTRUCTION)

DISTANCE FROM DUCT BANK CENTERLINE						
Configuration	Loading (Year)	**−50 ft**	**−25 ft**	Max	+ 25 ft	+50 ft
As-Built	Existing (2019)	0.8	2.2	24	2.0	0.8
As-Operating	Existing (2019)	0.9	2.8	36	2.7	0.9

At average loading the highest magnetic-field level for the As-Operating configuration is approximately 2.5 times higher than for the As-Built configuration (30 milligauss [mG] compared to 12.5 mG). This occurs because the close proximity of the Q-143 and R-144 Lines in the As-Built configuration allow for mutual cancellation of magnetic fields with an optimal phasing configuration. With the R-144 Line out of service this cancellation does not occur.

The magnetic fields from the As-Built and As-Operating configurations both decrease rapidly with distance. At ±25 feet from the duct bank, the magnetic-field level at average loading is 2.4 mG or less for both the As-Built and As-Operating configurations. At peak loading, the magnetic-field levels for both As-Built and As-Operating configurations are higher than for average loading directly over the duct bank, but are similar to the magnetic field levels under average loading at distances of ±25 feet from the duct bank centerline.

A discussion of the current status of the health research relevant to exposure to electric and magnetic fields is included in Appendix A. This report was prepared by Exponent, Inc®.

6.7 Noise

Noise in the vicinity of the Project Area is typical of a busy urban area with city traffic being the predominant source of noise.

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7.0 IMPACT ANALYSIS

This section presents an analysis of the potential impacts of the Project on the existing environmental and social surroundings within the Study Area. As with any projects requiring construction, potential adverse impacts can be associated with the construction, operation and maintenance of an underground utility project.

The Project will be constructed in a manner that minimizes the potential for adverse environmental impacts. The option to utilize the existing Point Street Bridge along with the installation of a new duct bank on the underside of the northern bridge sidewalk will minimize the impacts to environmental resources and social background. Any anticipated minor impacts are addressed within the following sections. No impacts to climate and weather, wetlands, wildlife or geology are expected.

A monitoring program will be conducted by TNEC to verify that the Project is constructed in compliance with all relevant licenses and permits and all applicable federal, state and local laws and regulations. Design and construction mitigation measures will be implemented so that construction-related environmental impacts are minimized.

7.1 Soils

Project excavation activities may encounter contaminants from former land uses in the vicinity of the Franklin Square Substation and along the preferred route. Appropriate soil management procedures will be used for handling, managing and disposing or reusing of potentially impacted soil and groundwater. Additionally, excavation activities will be performed in accordance with existing ELURs and subject to RIDEM regulations.

During construction related activities, portions of the Project Area will be exposed to wind and precipitation that have the potential to increase erosion and sedimentation. As part of the permitting process, a SESC Plan will be developed and implemented during the construction phase of the Project. Additionally, to minimize impacts, TNEC will adhere to its ROW Access, Maintenance, and Construction Best Management Practices (*EG-303*). Typical BMPs include straw wattles, siltation fencing, water bars, diversion channels, the reestablishment of vegetation and dust control measures, as well as other erosion and sedimentation control measures. These devices will be inspected by TNEC’s environmental monitor during construction and repaired or replaced if necessary. Soil erosion and sediment control measures will be selected to minimize the potential for soil erosion and sedimentation in areas where soils are disturbed.

In the vicinity of active construction sites within the road ROW, catch basins will have inserts of geotextile fabric or other equivalent controls. The SESC Plan will be maintained on-site and updated throughout the Project to reflect environmental inspection reporting and BMPs.

The Project construction contractors will be responsible for maintaining appropriate setback distances between the watercourses and work areas. Signs alerting the construction crews of sensitive resources will be installed, if necessary.

During the course of periodic post-construction inspections, TNEC will determine the appropriate time frame for removing these temporary soil erosion controls. This determination will be made based on the effectiveness of restoration measures, such as percent vegetative cover achieved, and in accordance with applicable permit and certificate requirements.

7.2 Surface Water Resources

Any impact of the Project on surface waters will be minor and temporary. Construction activities increase risks for soil erosion and sedimentation that may temporarily degrade existing water quality; however, appropriate BMPs will be implemented and maintained to effectively control sediment. In addition, appropriate measures will be implemented to ensure that materials used by equipment during the Point Street Bridge cable installation will be contained to the construction area and will not be disposed of in the Providence River. Sedimentation and turbidity within the river will be minimized through the implementation of BMPs prior to construction activities. The Providence River is the only surface water feature within the Study Area.

The implementation and maintenance of stringent soil erosion and sediment control BMPs will limit the levels of Project related sedimentation and will minimize adverse impacts to the river.

The Project will not adversely impact recreational and commercial activities along the waterfront during construction.

7.3 Groundwater Resources

RIDEM designated the groundwater for the Study Area as GB, or water not suitable for human consumption without treatment. Project construction and operation is not expected to impact the groundwater quality.

Since the Franklin Square Substation site is listed with the RIDEM Office of Waste Management and some historical impacts to groundwater were previously noted, proper management of impacted groundwater for construction purposes will be required.

7.4 Vegetation

The Project Area is an urban area that does not currently contain any significant vegetation. If vegetated areas along the underground cable route are damaged as a result of construction related activities, they will be returned to their pre-existing conditions.

7.5 Air Quality

There are two potential sources of air quality impacts associated with the Project – dust and vehicle emissions – neither of which are expected to be significant. During earth disturbing activities, the contractor will deploy dust mitigation measures as described in National Grid's *EG-303* guidelines. Exposed soils will be wetted and stabilized as necessary to suppress dust generation. These measures will be designed to keep fugitive dust emissions low.

Emissions generated by the operation of construction machinery (carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter) are short in duration and generally not considered significant. TNEC requires the use of ultra-low sulfur diesel fuel exclusively in its contractor's diesel-powered construction equipment. Vehicle idling is to be minimized during the construction phase of the Project, in compliance with the Rhode Island Diesel Engine Anti-Idling Program, Air Pollution Control Regulation No. 45, authorized pursuant to RIGLs § 31-16.1 and § 23-23-29. Vehicle idling for diesel and non-diesel powered vehicles is limited to five minutes except for powering auxiliary equipment, for heating/defrosting purposes in cold weather, and for cooling purposes in hot weather.

The contractor is responsible for complying with the state regulatory requirements along with the TNEC Environmental Guidance (*EG-802RI*) Vehicle Idling – Rhode Island.

Upon completion of the installation of the proposed underground cables, the Project will not generate air emissions. Daily vehicle traffic patterns, characteristics, and volumes will not be permanently affected; therefore, no additional vehicular air emissions will be generated.

7.6 Land Use and Recreation

The Project will be constructed underground and in public streets; therefore, it will not displace any existing land uses, nor will it affect any future development proposals that meet local zoning requirements. Short-term land use impacts may occur during the construction phase of the Project. The pedestrian walkway located on the north side of the Point Street Bridge may be temporarily closed and pedestrians would be detoured to the pedestrian walkway on the south side of the bridge. Temporary disruption to pedestrian sidewalks may occur on Point Street and South Water Street. Detours and other accommodations will be made to provide alternative access around the construction work site. Dollar Street may be temporarily closed to facilitate the work required within the two existing manholes. Detours are available on adjacent streets to allow for vehicular access around the construction zone. Impacts associated with the construction phase of the Project will be temporary, and present land uses within the Study Area can continue during and following construction. TNEC will provide notification of the intended construction plan and schedule to affected businesses and other land owners so that the effect of any temporary disruptions may be minimized.

No existing recreational uses will be displaced long-term by the Project. Impacts to the open space areas adjacent to the cable route on the western side of the bridge from the construction of the Project will be minimal and short-term. Since the Project is located within existing public streets, potential long-term impacts will be avoided.

7.7 Visual Resources

The only aboveground facilities associated with the Project will be upgrades at the Franklin Square Substation. Visual and aesthetic impacts from installation of new equipment and/or upgrades of existing equipment will not substantially alter the overall visual impact of the existing Substation. The new cable installation will be completed using new duct bank in public roadways and conduit installed under the Point Street Bridge and will not show additional visual changes.

7.8 Historic and Cultural Resources

No impacts are expected as there are no known archaeological areas of significance in the Project Area and there are no known tribal activities or resources in the Project Area.

Potential impacts, if any, to both known and unknown historic and archaeological resources will be addressed through consultation with the RIHPHC. The Point Street Bridge is not listed on the NRHP. Potential effects to adjacent architectural and above-ground resources are expected to be indirect and limited to temporary construction impacts (i.e., noise, traffic, possible dust). Direct effects to unknown archaeological sites may potentially occur as a result of ground disturbing activities, however, the probability of encountering unknown archaeological resources is considered low due to the heavy commercial and industrial land uses along the project corridor. Therefore, no direct effects to archaeological sites are anticipated.

7.9 Noise

The Project is located entirely within urban portions of the City of Providence, where ambient sound levels are influenced by diverse factors including vehicular noise, commercial and industrial activities, and outdoor activities. Temporary, minor construction noise may be generated by the Project. Proper mufflers will be required to control noise levels generated by construction equipment.

7.10 Transportation

The construction-related traffic increase will be small relative to total traffic volume on public streets in the area. In addition, it will be intermittent and temporary, and construction related traffic will cease once the Project is completed. However, work on the underground transmission cables will involve temporary lane restrictions to Dollar Street, South Water Street, Point Street, possibly Wickenden Street and the Point Street Bridge during certain times of the construction. TNEC will coordinate closely with the City and RIDOT to develop acceptable Traffic Management Plans for work within the City and state streets and highways. No long-term impacts to traffic flow or roadways are expected.

7.11 Safety and Public Health

Because the proposed electrical facilities will be designed, built and maintained in accordance with the standards and codes as discussed in Section 3.4.11, public health and safety will be protected.

7.12 Electric and Magnetic Fields

The magnetic fields produced by the existing transmission lines in 2019 are compared here to the magnetic field levels after completion of the Project in 2019 and five years later.

For projects involving construction of new or reconfigured transmission lines, it is TNEC’s standard practice to evaluate low cost/no cost options for reducing magnetic field levels through optimization of phase configurations (Ref. Transmission Line Engineering Document GL.06.01.101), a practice consistent with recommendations of the World Health Organization (WHO, 2007). Consistent with this practice, based upon Exponent’s phasing analysis, TNEC has selected a phasing of the lines that will minimize magnetic fields.

The magnetic fields were calculated for the proposed configurations (Proposed Duct Bank and Proposed Bridge Crossing). The results are summarized in Tables 5 and 6 and compared to the magnetic fields from the existing configurations.

TABLE 5 CALCULATED MAGNETIC FIELDS (MG) PRE-CONSTRUCTION AND POST-CONSTRUCTION (ANNUAL AVERAGE LOAD)

		DISTANCE FROM DUCT BANK CENTERLINE				
Configuration	Loading (Year)	**−50 ft**	**−25 ft**	Max	+ 25 ft	+50 ft
As-Built	Existing (2019)	0.5	1.1	12.5	1.2	0.5
As-Operating	Existing (2019)	0.8	2.4	30	2.2	0.8
Proposed Duct Bank	Proposed (2019)	0.5	1.1	12.5	1.2	0.5
	Proposed (2024)	0.4	1.0	10.7	0.9	0.4
Proposed Bridge Crossing	Proposed (2019)	0.3	0.7	39	1.7	0.6
	Proposed (2024)	0.4	0.8	42	1.1	0.5

TABLE 6 CALCULATED MAGNETIC FIELDS (MG) PRE-CONSTRUCTION AND POST-CONSTRUCTION (ANNUAL PEAK LOAD)

		DISTANCE FROM DUCT BANK CENTERLINE				
Configuration	Loading (Year)	**−50 ft**	**−25 ft**	Max	+ 25 ft	+50 ft
As-Built	Existing (2019)	0.8	2.2	24	2.0	0.8
As-Operating	Existing (2019)	0.9	2.8	36	2.7	0.9
Proposed Duct Bank	Proposed (2019)	0.9	2.4	26	2.2	0.9
	Proposed (2024)	1.0	2.3	24	2.0	0.9
Proposed Bridge Crossing	Proposed (2019)	0.5	1.3	77	2.9	1.2
	Proposed (2024)	0.7	1.7	89	2.6	1.1

Calculated magnetic-field levels at average loading of the transmission lines in the proposed underground duct bank in both 2019 and 2024 are shown in Table 5. These calculations indicate that the magnetic-field levels will be very similar to those from the original As-Built duct bank configuration. The highest magnetic-field level is calculated to be approximately 12.5 mG, decreasing to 1.2 mG or less at a distance of ±25 feet from the duct bank centerline. In 2024, the loading of the transmission lines is projected to increase overall, but loading on the two transmission lines is more balanced so that the mutual cancellation of magnetic fields is higher in 2024, leading to lower overall magnetic-field levels. The maximum calculated magnetic-field level in 2024 is 10.7 mG, decreasing to 1.0 mG or less at a distance of ±25 feet from the duct bank centerline. At peak loading, the magnetic-field levels in both 2019 and 2024 are higher than for average loading directly over the duct bank, but are similar to average loading at distances of ±25 feet from the duct bank centerline.

Where the transmission lines are proposed to be installed in closely-spaced fiberglass conduits beneath the sidewalk on the north side of the Point Street Bridge, the magnetic-field levels are calculated to be higher than for the Proposed Duct Bank configuration. As shown in Table 5, magnetic-field levels at average loading in both 2019 and 2024 will be similar with a maximum of 42 mG over the duct bank. Magnetic-field levels are higher above the transmission lines, due primarily to the configuration of the transmission lines and installation ~1-foot beneath the sidewalk. As shown in Figure 3, the conductors of both transmission lines are laid out in a single horizontal line. The location and arrangement of the conduits under the bridge sidewalk were constrained by the available space within the bridge structure. While the small spacing between the conductors leads to some mutual cancellation of magnetic fields from the two transmission lines, the cancellation is less than in the side-by-side configuration of the underground duct bank. At a distance of ±25 feet from the duct bank, however, magnetic-field levels from the Proposed Bridge Crossing configuration will decrease to 1.7 mG or less, similar to the magnetic-field level ±25 feet from the centerline of the underground duct bank. At peak loading, the magnetic-field levels in both 2019 and 2024 are higher than for average loading, but at distances of ±25 feet from the duct bank, are similar to those of the underground duct bank.

As described above, National Grid has selected the phasing of the lines to maximize the cancellation of the magnetic fields from the phase conductors.

The magnetic-field levels from all existing and proposed configurations are similar to the magnetic-field levels experienced on a right-of-way from distribution or sub-transmission lines and to more common intermittent exposure from appliances (Savitz, et al., 1989; NIEHS, 2002). At peak loading, expected to occur for a few hours on a few days per year, magnetic-field levels would be higher, but still similar to those within the right-of-way of typical distribution or sub-transmission lines (Savitz, et al., 1989).

The magnetic field levels produced by the existing and proposed facilities are well below guidelines for public exposure recommended by the International Committee on Electromagnetic Safety and the International Committee on Nonionizing Radiation Protection. No national scientific or public health agency has determined that exposure to field levels below these guideline levels poses any health hazard. A discussion of the current state of the health research relevant to exposure to electric and magnetic fields is included in Appendix A. This report was prepared by Exponent, Inc.

8.0 MITIGATION MEASURES

The Project is not anticipated to have any long-term impacts to the natural or social environment of the Study Area. Mitigation measures for this Project will be used to reduce the impacts of the work on the natural and social environment. There are no long-term impacts to mitigate as a result of this Project; therefore, mitigation efforts are focused on the construction phase.

Overview of the extent of construction work performed in each area along the cable route will be determined during the final Project design after the existing conditions are fully evaluated, and the location of the duct bank and manholes can be optimized to avoid potential impacts.

8.1 Natural Environment

8.1.1 Soil Erosion and Sediment Controls

Soil erosion and sediment controls will be used during construction activities involving disturbance of soils. These will be installed and maintained to mitigate migration of sediment into the Providence River, catch basins along the roadway, and at the Franklin Square Substation. A SESC Plan will be developed and implemented for the construction activities. Sediment control measures will include the installation and maintenance of silt fencing, straw bales, straw wattles, and silt sacks for dewatering. These measures will be inspected regularly during construction and maintained as necessary in accordance with the Rhode Island Pollutant Discharge Elimination System General Permit for Storm Water Discharge Associated with Construction Activity. Upon completion of construction activities, pervious areas will be stabilized, revegetated and replanted, as necessary.

Construction crews will be responsible for conducting daily inspections and identifying erosion controls that must be maintained or replaced as necessary.

8.1.2 Soil Management

Site specific handling and management of materials will be developed and implemented, as appropriate. The Project will comply with the Soil Management Plans for areas designated as ELUR sites.

8.1.3 Dewatering

Where excavations along the Project ROW require the need for dewatering of groundwater or accumulated storm water, BMPs shall be implemented to treat pumpate prior to discharge.

Alternatively, groundwater or accumulated storm water may be containerized for proper off-site disposal. Dewatering discharge water shall never be directed into wetlands, streams/rivers, other sensitive resource areas, catch basins, other storm water devices, or substation *Trenwa* trenches. If it is determined that the chosen controls are not appropriately filtering the fine sediment from the dewatering pumpate then the controls shall be revised or supplemented.

8.1.4 Dust and Odor

All reasonable precautions will be taken to prevent the excessive generation of dust and/or nuisance odor during soil excavation, stockpiling, loading, and other soil handling activities for the underground cable and Franklin Square Substation upgrade. Dust control measures will be implemented, as required, to prevent airborne particulate matter from leaving the Project site at all times. Methods of stabilization consisting of sprinkling, mulching, or similar methods will be employed as soil conditions warrant (i.e., visual evidence of dust). Odor controls such as sprinkling, covering of piles and/or disturbed areas, and use of foams or other techniques shall also be employed as necessary to control odors.

Work at the Project will comply with all applicable federal, state, and local regulations, including the RIDEM's Air Pollution Control Regulations, and specifically Regulation No.5 regarding control of fugitive dust.

8.2 Social Environment

8.2.1 Traffic

TNEC will develop a Traffic Management Plan, based on consultations with the City of Providence and RIDOT, which will serve to minimize potential traffic congestion and access restrictions during the construction period. The Traffic Management Plan will be submitted to the City of Providence, DPW and RIDOT (as applicable) as part of the utility permit process. TNEC will also inform affected businesses and other landowners in the area of the underground cable route of the construction schedule.

8.2.2 Supervision and Monitoring

Throughout the entire construction process, TNEC will retain the services of an environmental monitor. The primary responsibility of the monitor will be to oversee construction activities including the installation and maintenance of erosion and sedimentation controls. Environmental monitoring will be conducted on a routine basis to ensure compliance with all federal and state permit requirements, TNEC company policies, and other commitments. The environmental monitor will be a trained environmental scientist responsible for supervising construction activities relative to environmental issues. The environmental monitor will be experienced in the erosion and sedimentation control techniques described in this report and will have an understanding of watercourse resources to be protected.

During periods of prolonged precipitation, the monitor will inspect all locations to confirm that the environmental controls are functioning properly. In addition to retaining the services of an environmental monitor, TNEC will require the contractor to designate an individual to be responsible for the daily inspection and upkeep of environmental controls. This person will also be responsible for providing direction to the other members of the construction crew regarding matters of wetland access and appropriate work methods. Additionally, all construction personnel will be briefed on Project environmental compliance issues and obligations prior to the start of construction. Regular construction progress meetings will provide the opportunity to reinforce the contractor's awareness of these issues.

8.2.3 Safety and Public Health

Practices to be used to protect the public during construction will include, but not be limited to, establishing Traffic Management Plans for construction traffic on busy streets to maintain safe driving conditions, and restricting public access to potentially hazardous work areas. Following construction, all cable infrastructures and the substation facility will be clearly marked with warning signs to alert the public of potential hazards if entered.

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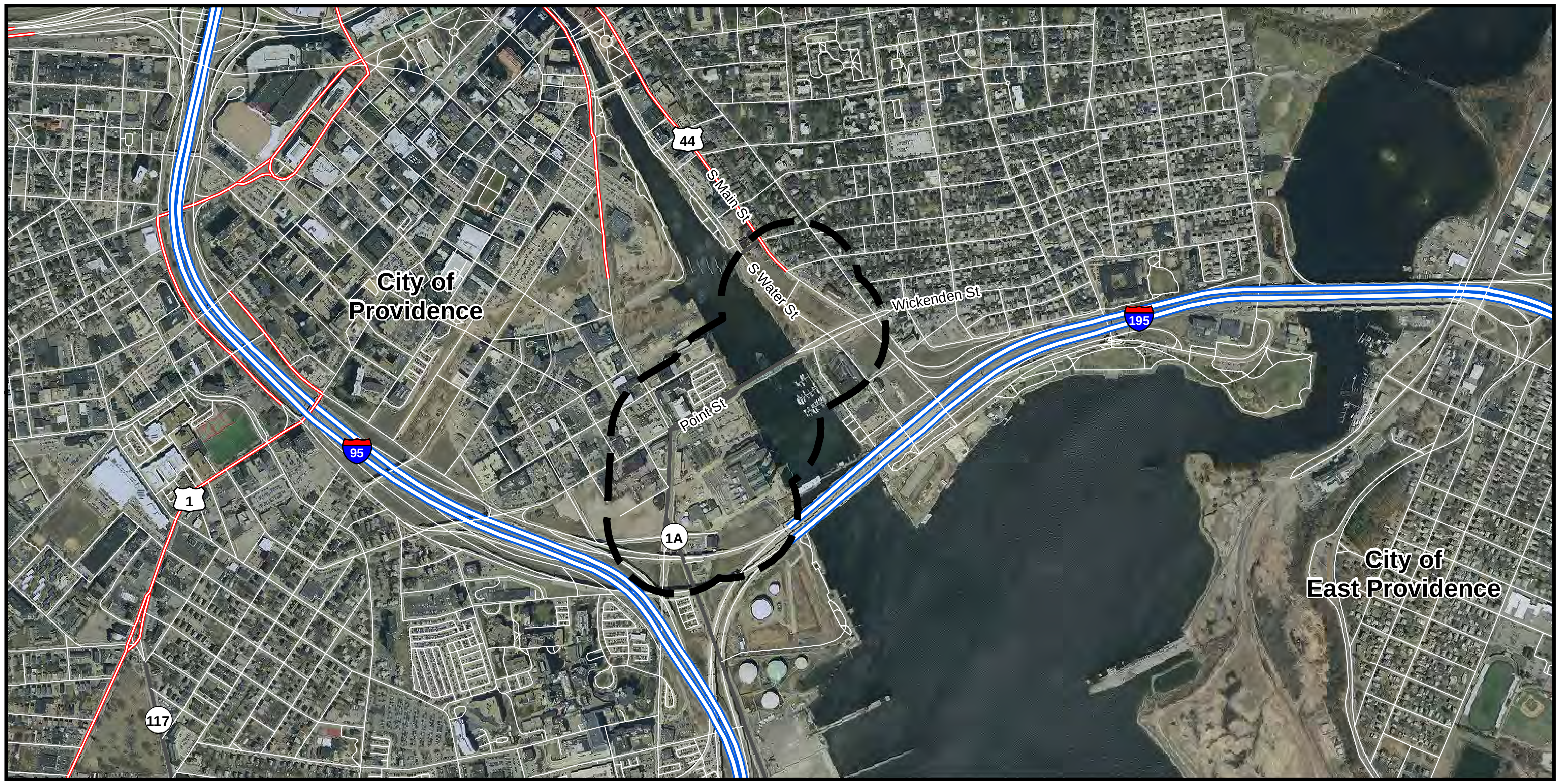
Providence River 115kV Cable Relocation Project

Providence, Rhode Island

Figures

NOT FOR CONSTRUCTION



1 " = 1,000 '

Prepared For:

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280 Melrose Street
Providence, RI 02907

Compiled By:

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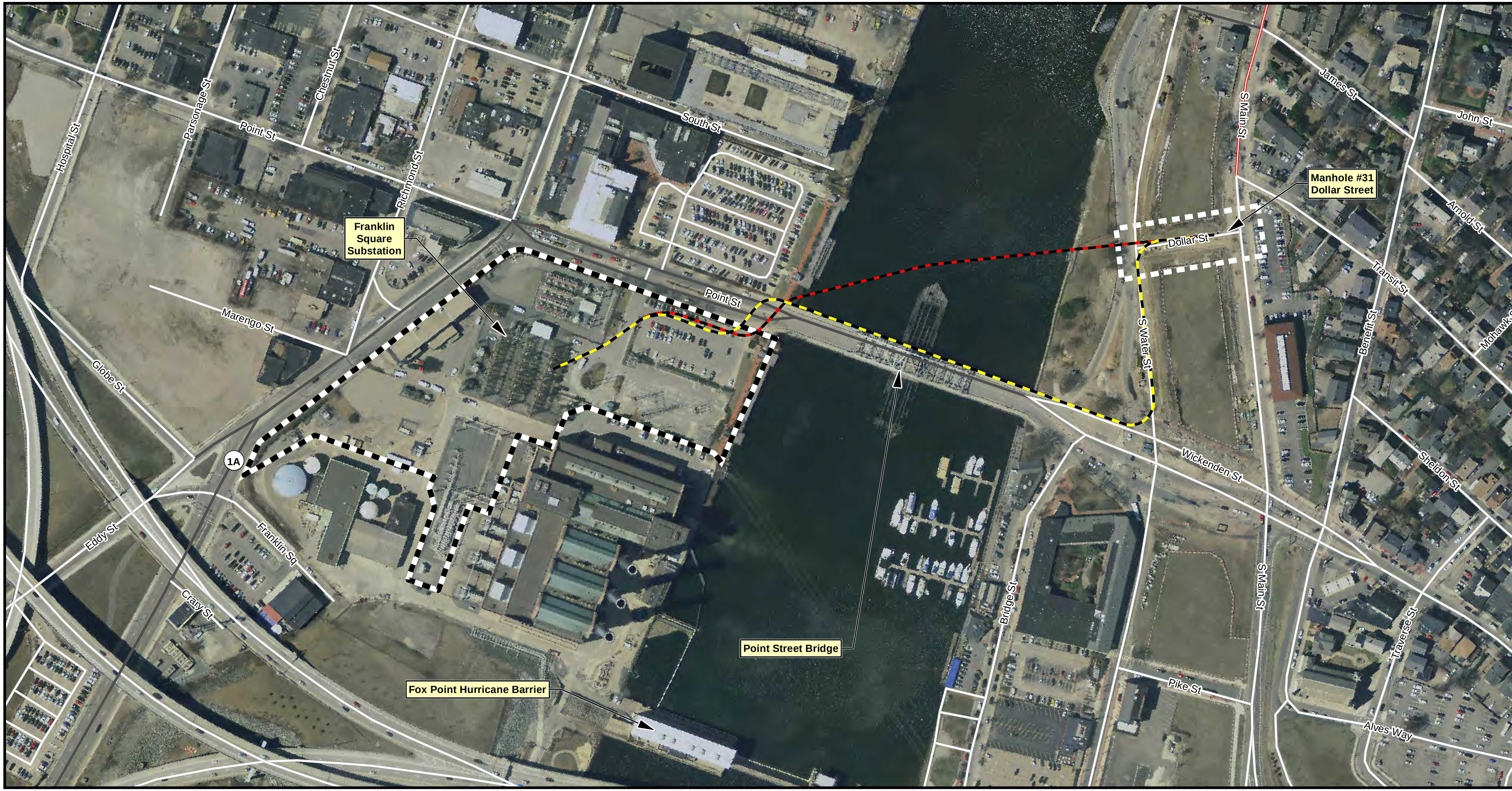
North Attleboro, MA 02763

December 2017

Providence River 115kV Cable Relocation Project

Providence, Rhode Island

List of Figures



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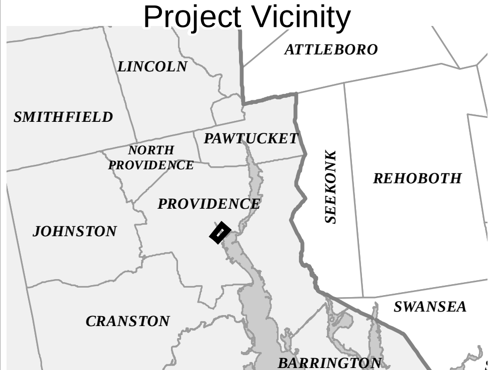

Legend

- Point Street Bridge Route (Proposed)
- Existing Cable Route
- The Narragansett Electric Company Substation Parcel
- Dollar Street Highlight (White Dash)

Providence River 115kV Cable Relocation Project

Figure 1 Proposed Route

State of Rhode Island

Providence County:
City of Providence

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nationalgrid

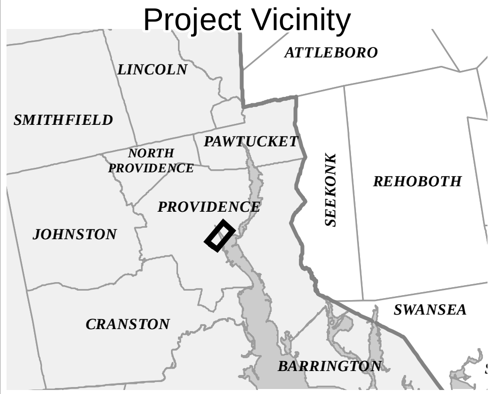
NAD 1983 UTM Zone 18N USFt

0 200 400 Feet

1 " = 200 '

Date: 12/8/2017

Author: TDH



Legend

- Point Street Bridge Route (Proposed)
- Existing Cable Route
- Study Area (500' Buffer of all cable alternatives)
- Narragansett Electric Company Substation Parcel
- Dollar Street Highlight (White Dash)
- Interstate Highway
- US Highway
- State Highway
- Local Road

Providence River 115kV Cable Relocation Project

Figure 2 Study Area

State of Rhode Island

Providence County:
City of Providence

POWER ENGINEERS

nationalgrid

NAD 1983 UTM Zone 18N USFt

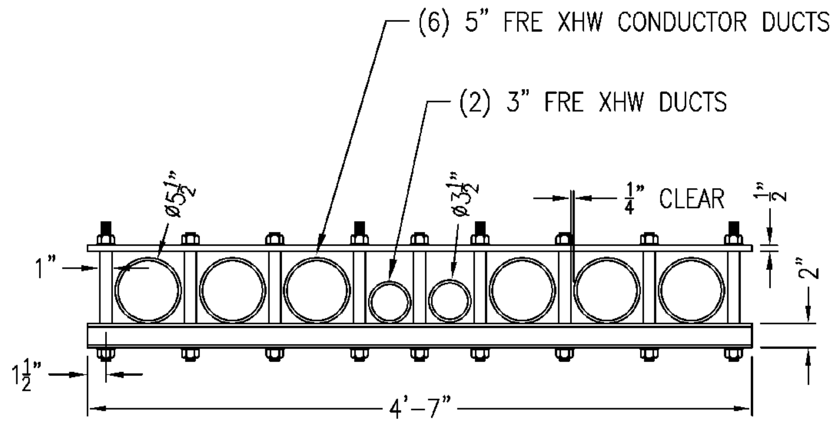
NOT FOR CONSTRUCTION

0 300 600 Feet

1 " = 333 '

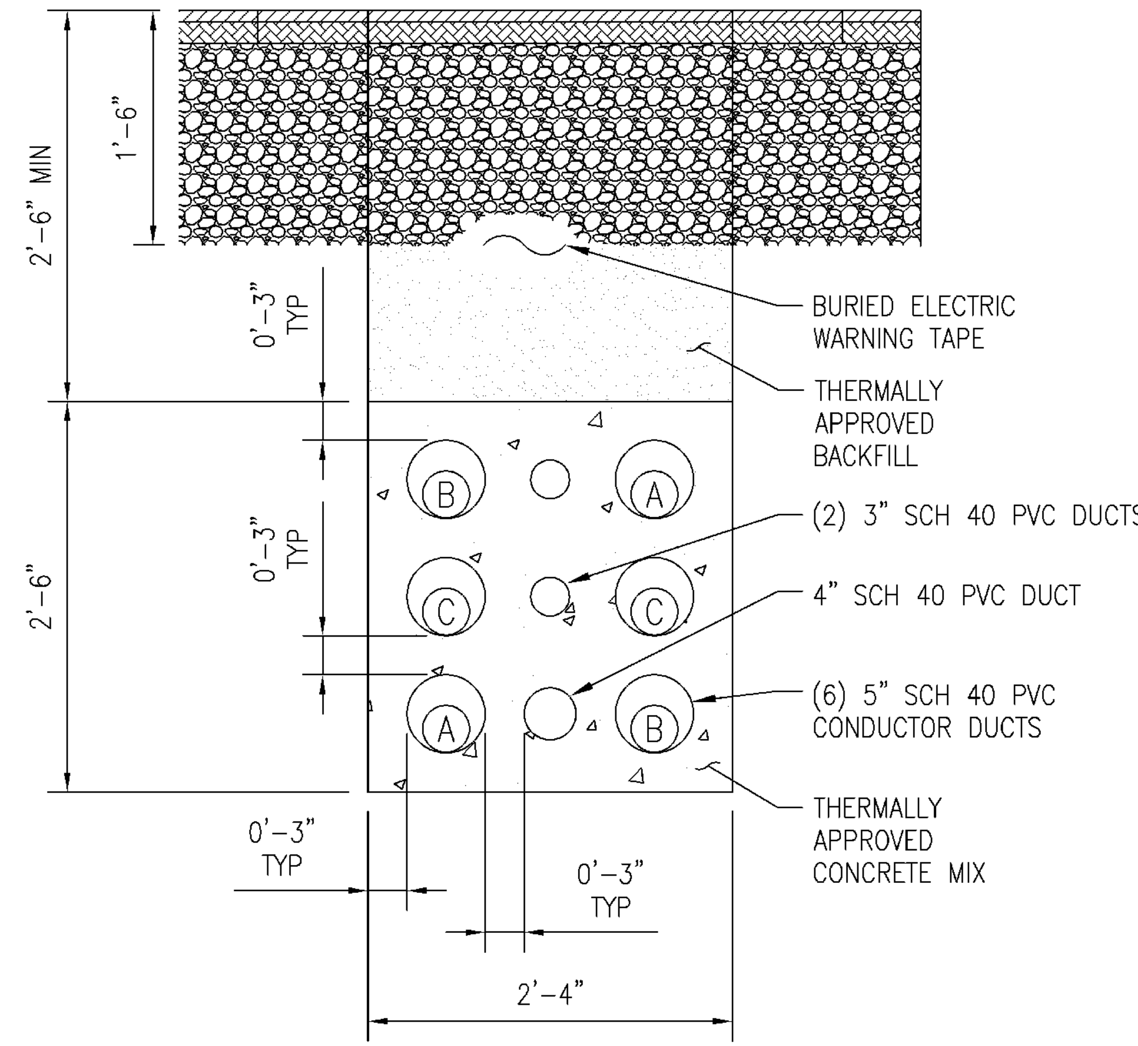
Date: 12/8/2017

Author: TDH



SECTION 2
SCALE: NTS

BRIDGE DUCT BANK CROSS SECTION (TYP)



SECTION 1
SCALE: NTS

LAND DUCT BANK CROSS SECTION (TYP)

Providence River 115kV Cable Relocation Project

Figure 3 Engineering Detail Sheet

State of Rhode Island

Providence County:
City of Providence

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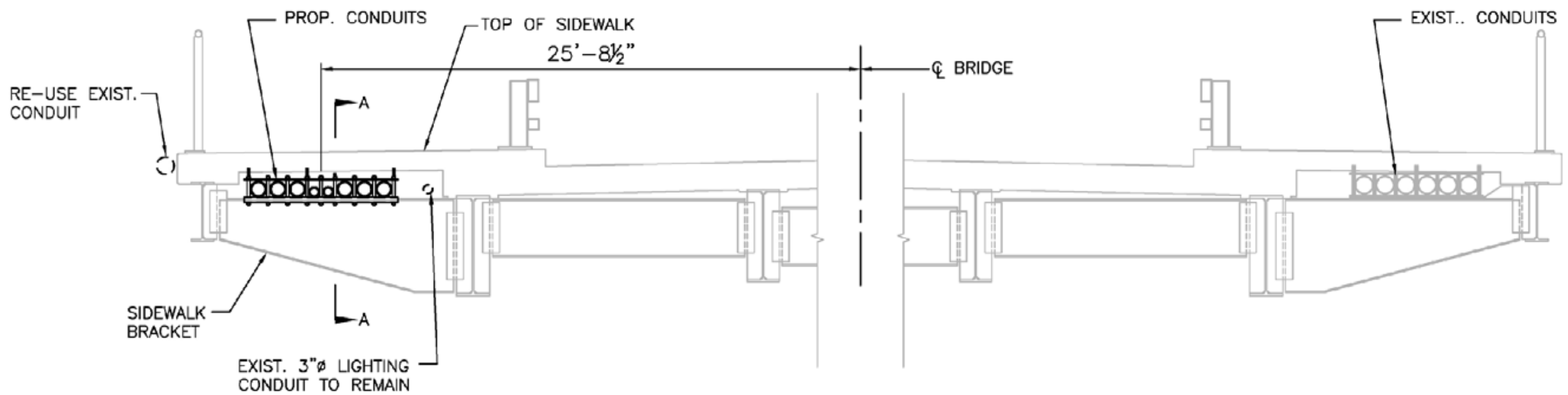
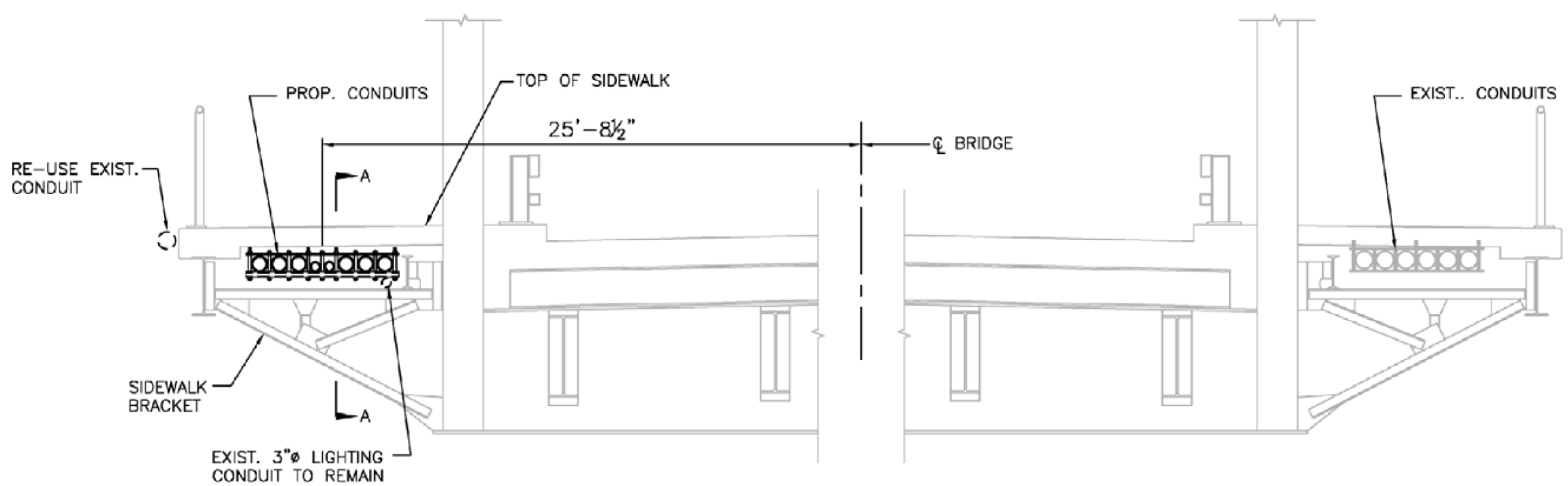
NAD 1983 UTM Zone 18N USFt

Date: 12/8/2017

Author: TDH



TYPICAL APPROACH SPAN SECTION
SCALE: ⅜" = 1'-0"



TYPICAL MAIN SPAN SECTION
SCALE: ⅜" = 1'-0"

Providence River 115kV Cable Relocation Project

Figure 4 Point Street Bridge Attachment

State of Rhode Island

Providence County:
City of Providence

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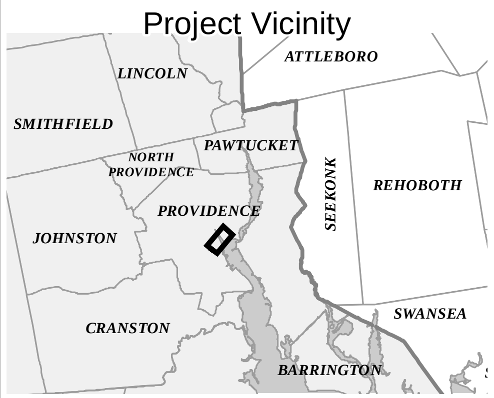
Author: TDH



Legend

- Point Street Bridge Route (Proposed)
- Submarine Cable using Existing Route
- Horizontal Directional Drill (HDD)
- R144 HDD Pit
- Study Area (500' Buffer of all cable alternatives)
- Narragansett Electric Company Substation Parcel
- Dollar Street Highlight (White Dash)
- Interstate Highway
- US Highway
- State Highway
- Local Road

Providence River 115kV Cable Relocation Project

Figure 5 Underground Transmission Line Alternative Routes

State of Rhode Island

Providence County:
City of Providence

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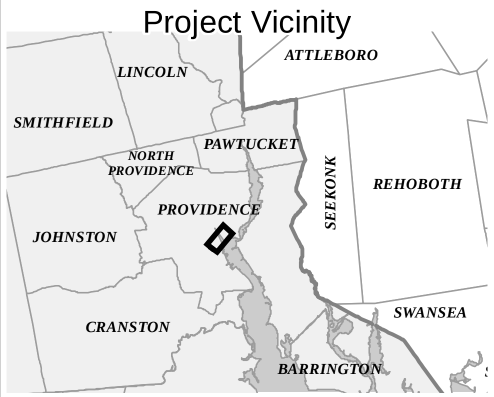
NAD 1983 UTM Zone 18N USFt

0 300 600 Feet

1 " = 333 '

Date: 12/13/2017

Author: TDH



Legend

- Point Street Bridge Route (Proposed)
- Existing Cable Route
- Study Area (500' Buffer of all cable alternatives)
- Narragansett Electric Company Substation Parcel
- Dollar Street Highlight (White Dash)
- Interstate Highway
- US Highway
- State Highway
- Local Road

Land Use / Zoning

- Downcity Overlay District
- East Side I-195 Overlay District
- Educational or Healthcare Institutional Overlay District
- Historic Overlay District
- A Streets
- B Streets
- Historic District - Providence Landmark District
- Downtown District
- Educational Institutional District
- General Commercial District
- General Industrial District
- Healthcare Institutional District
- Mixed-Use Industrial District
- Mixed-Use Waterfront District
- Open Space District
- Port/Maritime Industrial Waterfront District
- Public Space District
- Residential District

Providence River 115kV Cable Relocation Project

Figure 6 Land Use / Zoning

State of Rhode Island

Providence County:
City of Providence

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NAD 1983 UTM Zone 18N USFt

0 300 600 Feet

1 " = 333 '

Date: 12/8/2017

Author: TDH

APPENDIX A CURRENT STATUS OF RESEARCH ON EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS AND HEALTH: RHODE ISLAND TRANSMISSION LINE PROJECTS – THE NARRAGANSETT ELECTRIC COMPANY D/B/A NATIONAL GRID (MARCH 9, 2015)

Health Sciences Practice

Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health:

Rhode Island Transmission Projects – The Narragansett Electric Company d/b/a/ National Grid

Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health:

Rhode Island Transmission Projects – The Narragansett Electric Company d/b/a National Grid

Prepared for:

Rhode Island
Energy Facility Siting Board
and
The Narragansett Electric Company d/b/a
National Grid

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March 9, 2015

1408726.000 - 5450

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Acronyms and Abbreviations

AC	Alternating current
ALL	Acute lymphoblastic leukemia
ALS	Amyotrophic lateral sclerosis
AMI	Acute myocardial infarction
CI	Confidence interval
DMBA	7,12-dimethylbenz[a]anthracene
ELF	Extremely low frequency
EMF	Electric and magnetic fields (or electromagnetic fields)
G	Gauss
HCN	Health Council of the Netherlands
Hz	Hertz
IARC	International Agency for Research on Cancer
ICES	International Commission on Electromagnetic Safety
ICNIRP	International Committee on Non-Ionizing Radiation Protection
JEM	Job exposure matrix
kV	Kilovolt
kV/m	Kilovolts per meter
mG	Milligauss
OR	Odds ratio
RR	Relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
TWA	Time weighted average
V/m	Volts per meter
WHO	World Health Organization

Limitations

At the request of Narragansett Electric Company d/b/a National Grid, Exponent prepared this summary report on the status of research related to extremely low-frequency electric- and magnetic-field exposure and health. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

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

1 Executive Summary

This report was prepared to address the topic of health and extremely low frequency (ELF) electric and magnetic fields (EMF) for the Rhode Island Energy Facility Siting Board at the request of The Narragansett Electric Company d/b/a National Grid as part of its Applications for the 2015 Rhode Island Transmission Projects.

ELF EMF are invisible fields surrounding all objects that generate, use, or transmit electricity. There are also natural sources of ELF EMF, including the electric fields associated with the normal functioning of our circulatory and nervous systems. People living in developed countries are constantly exposed to ELF EMF in their environments, since electricity is fundamental part of technologically-advanced societies. Sources of man-made ELF EMF include appliances, wiring, and motors, as well as distribution and transmission lines. Section 3 of this report provides information on the nature and sources of ELF EMF, as well as typical exposure levels.

Research on ELF EMF and health began with the goal of finding therapeutic application and understanding biological electricity, i.e., the role of electrical potentials across cell membranes and current flows between cells in our bodies. Over the past 35 years, researchers have examined whether ELF EMF from man-made sources can cause short- or long-term health effects in humans using a variety of study designs and techniques. Research on ELF EMF and long-term human health effects was prompted by an epidemiology study conducted in 1979 of children in Denver, Colorado, which studied the relationship of their cancers with the potential for ELF EMF exposure from nearby distribution and transmission lines. The results of that study prompted further research on childhood leukemia and other cancers. Childhood leukemia has remained the focus of EMF and health research, although many other diseases have been studied, including other cancers in children and adults, neurodegenerative diseases, reproductive effects, and cardiovascular disease, among others.

Guidance on the possible health risks of all types of exposures comes from health risk assessments, or systematic weight-of-evidence evaluations of the cumulative literature, on a particular topic conducted by expert panels organized by scientific organizations. The public and policy makers should look to the conclusions of these reviews, since the reviews are conducted using set scientific standards by scientists representing the various disciplines required to understand the topic at hand. In a health risk assessment of any exposure, it is essential to consider the type and strength of research studies available for evaluation. Human health studies vary in methodological rigor and, therefore, in their capacity to extrapolate findings to the population at large. Furthermore, relevant studies in three areas of research (epidemiologic, *in vivo,* and *in vitro* research) must be evaluated to understand possible health risks. Section 4 of this report provides a summary of the methods used to conduct a health risk assessment.

The World Health Organization (WHO) published a health risk assessment of ELF EMF in 2007 that critically reviewed the cumulative epidemiologic and laboratory research to date, taking into account the strength and quality of the individual research studies. Section 5 provides a summary of the WHO's conclusions with regard to the major outcomes they evaluate. The WHO report provided the following overall conclusions:

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (WHO, 2007, p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (WHO, 2007, p. 355).

This report provides a systematic literature review and a critical evaluation of relevant epidemiology and *in vivo* studies published from July 2013 to November 2014, and it updates the report submitted as part of the Application for the G-185S 115-kilovolt Transmission Line Project.[1] These recent studies did not provide sufficient evidence to alter the basic conclusion of the WHO: the research does not suggest that electric fields or magnetic fields are a cause of cancer or any other disease at the levels we encounter in our everyday environment.

There are no national recommendations, guidelines, or standards in the United States to regulate ELF EMF or to reduce public exposures, although the WHO recommends adherence to the International Commission on Non-Ionizing Radiation Protection's or the International Committee for Electromagnetic Safety's exposure limits for the prevention of acute health effects at high exposure levels and low-cost measures to minimize exposures. In light of the epidemiologic data on childhood leukemia, scientific organizations are still in agreement that only low-cost interventions to reduce ELF EMF exposure are appropriate. This approach is mirrored by the Rhode Island Energy Facility Siting Board that has approved transmission projects that have proposed effective no-cost and low-cost technologies to reduce magnetic-field exposure to the public. While the large body of existing research does not indicate any harm associated with ELF EMF, research on this topic will continue to reduce remaining uncertainty.

---

[1] Exponent, Inc. *Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: G-185S 115-kV Transmission Line*. Prepared for the Rhode Island Energy Facility Siting Board. October 31, 2013.

Note that this Executive Summary provides only an outline of the material discussed in this report. Exponent's technical evaluations, analyses, conclusions, and recommendations are included in the main body of this report, which at all times the controlling document.

2 Introduction

Questions about electric and magnetic fields (EMF) and health are commonly raised during the permitting of transmission lines. Numerous national and international scientific and health agencies have reviewed the research and evaluated potential health risks of exposure to extremely low frequency (ELF) EMF. The most comprehensive of these reviews of ELF EMF research was published by the World Health Organization (WHO) in 2007. The WHO's Task Group critically reviewed the cumulative epidemiologic and laboratory research through 2005, taking into account the strength and quality of the individual research studies.

The Narragansett Electric Company d/b/a National Grid requested that Exponent provide an easily-referenced document that supplements a report previously prepared for the Rhode Island Energy Facility Siting Board to bring the WHO report's conclusions up to date.[2] The G-185S 115-kilovolt (kV) Transmission Line Project report systematically evaluated peer-reviewed research and reviews by scientific panels published up to July 2013. This current report systematically evaluates peer-reviewed research and reviews by scientific panels published between July 2013 and November 2014 and also describes if and how these recent results affect conclusions reached by the WHO in 2007.

[2] Exponent, Inc. *Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: G-185S 115-kV Transmission Line*. Prepared for the Rhode Island Energy Facility Siting Board. October 31, 2013.

3 Extremely Low Frequency Electric and Magnetic Fields: Nature, Sources, Exposure, and Known Effects

Nature of ELF EMF

Electricity is transmitted as current from generating sources to high-voltage transmission lines, substations, distribution lines, and then finally to our homes and workplaces for consumption. The vast majority of electricity in North America is transmitted as alternating current (AC), which changes direction 60 times per second (i.e., a frequency of 60 Hertz [Hz]).

Everything that is connected to our electrical system (i.e., power lines, wiring, appliances, and electronics) produces ELF EMF (Figure 1). Both electric fields and magnetic fields are properties of the space near these electrical sources. Forces are experienced by objects capable of interacting with these fields; electric charges are subject to a force in an electric field, and moving charges experience a force in a magnetic field.

- **Electric fields** are the result of voltages applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m); one kV/m is equal to 1,000 V/m. Conducting objects including fences, buildings, and our own skin and muscle easily block electric fields. Therefore, certain appliances within homes and workplaces are the major source of electric fields indoors, while transmission and distribution lines are the major source of electric fields outdoors.

- **Magnetic fields** are produced by the flow of electric currents; however, unlike electric fields, most materials do not readily block magnetic fields. The strength of a magnetic field is expressed as magnetic flux density in units called gauss (G), or in milligauss (mG), where 1 G = 1,000 mG.[3] The strength of the magnetic field at any point depends on characteristics of the source; in the case of power lines, strength is dependent on the arrangement of conductors, the amount of current flow, and distance from the conductors.

[3] Scientists also refer to magnetic flux density at these levels in units of microtesla. Magnetic flux density in units of mG can be converted to microtesla by dividing by 10, i.e., 1 mG = 0.1 microtesla.

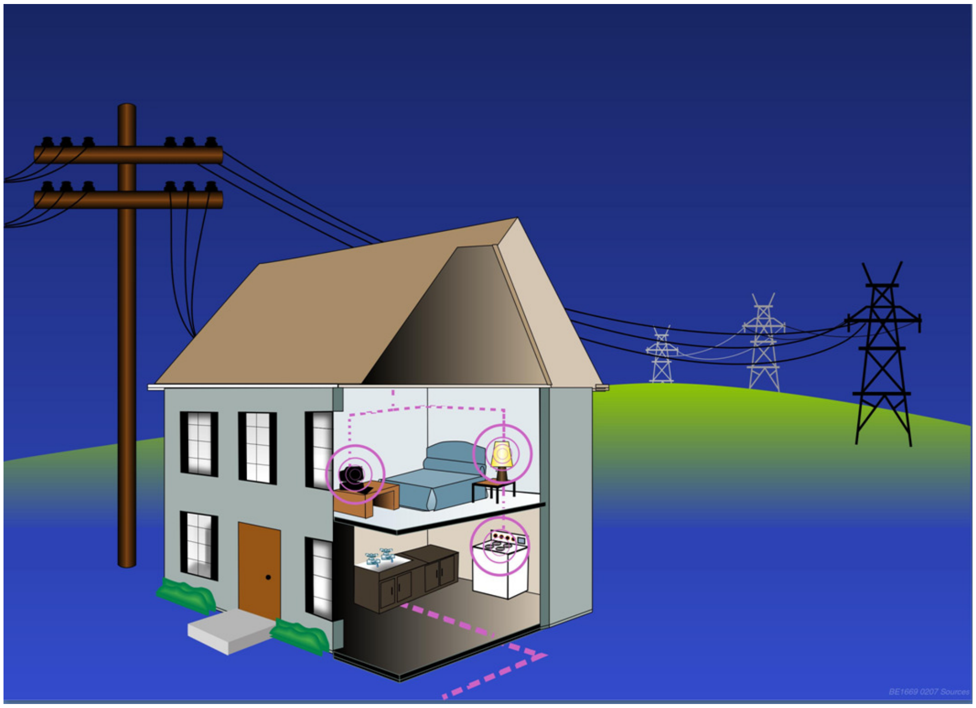

Figure 1. Numerous sources of ELF EMF in our homes (appliances, wiring, currents running on water pipes, and nearby distribution and transmission lines).

Sources and exposure

The intensity of both electric fields and magnetic fields diminishes with increasing distance from the source. Electric and magnetic fields from transmission lines generally decrease with distance from the conductors in proportion to the square of the distance, described as creating a bell-shaped curve of field strength around the lines.

Since electricity is such an integral part of our infrastructure (e.g., transportation systems, homes, and businesses), people living in modern communities literally are surrounded by these fields. Figure 2 describes typical EMF levels measured in residential and occupational environments, compared to levels measured on or at the edge of transmission-line rights-of-way. While EMF levels decrease with distance from the source, any home, school, or office tends to have a "background" EMF level as a result of the combined effect of the numerous EMF sources. In general, the background magnetic-field level in a house away from appliances is typically less than 20 mG, while levels can be hundreds of mG in close proximity to appliances. Background levels of electric fields range from 10-20 V/m, while appliances produce levels up to several tens of V/m (WHO, 2007).

Experiments have yet to show which aspect of ELF EMF exposure, if any, may be relevant to biological systems. The current standard of EMF exposure for health research is long-term, average personal exposure, which is the average of all exposures to the varied electrical sources encountered in the many places we live, work, eat, and shop. As expected, this exposure is difficult to approximate, and exposure assessment is a major source of uncertainty in studies of ELF EMF and health (WHO, 2007).

Little research has been done to characterize the general public's exposure to magnetic fields, although some basic conclusions are available from the literature:

- *Personal magnetic-field exposure:*
    - The vast majority of persons in the United States have a *time-weighted average* (TWA) exposure to magnetic fields less than 2 mG (Zaffanella and Kalton, 1998).[4]
    - In general, personal magnetic-field exposure is greatest at work and during travel (Zaffanella and Kalton, 1998).
- *Residential magnetic-field exposure:*
    - The highest magnetic-field levels are typically found directly next to appliances (Zaffanella, 1993). For example, Gauger (1985) reported the maximum AC magnetic field at 3 centimeters from a sampling of appliances as 3,000 mG (can opener), 2,000 mG (hair dryer), 5 mG (oven), and 0.7 mG (refrigerator).
    - The following parameters affect the distribution of personal magnetic-field exposures at home: residence type, residence size, type of water line, and proximity to overhead power lines. Persons living in small homes, apartments, homes with metallic piping, and homes close to three-phase electric power distribution and transmission lines tended to have higher at-home magnetic-field levels (Zaffanella and Kalton, 1998).
    - Residential magnetic-field levels are caused by currents from nearby transmission and distribution systems, pipes or other conductive paths, and electrical appliances (Zaffanella, 1993).
- *Workplace magnetic-field exposure*
    - Some occupations (e.g., electric utility workers, sewing machine operators, telecommunication workers) have higher exposures due to work near equipment with high magnetic-field levels.[5]

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[4] TWA is the average exposure over a given specified time period (i.e., an 8-hour workday or a 24-hour day) of a person's exposure to a chemical or physical agent. The average is determined by sampling the exposure of interest throughout the time period.

[5] http://www.niehs.nih.gov/health/assets/docs_p_z/emf-02.pdf

- *Power line magnetic-field exposure*
    - The magnetic-field levels associated with transmission and distribution lines vary substantially depending on their configuration, amount of current flow (load), and distance from conductors, among other parameters. At distances of approximately 300 feet from overhead transmission lines and during average electricity demand, the magnetic-field levels from many transmission lines are often similar to the background levels found in most homes (Figure 2).

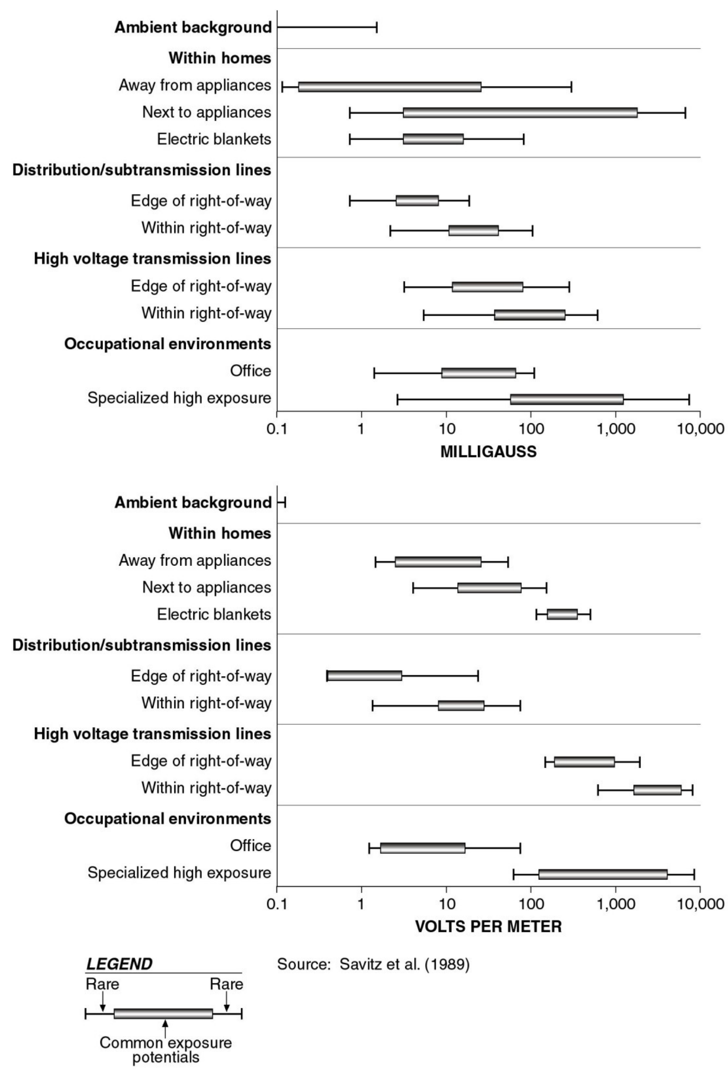


Figure 2. Electric- and magnetic-field strengths in the environment.

Known effects

Similar to virtually any exposure, adverse effects can be expected from exposure to very high levels of ELF EMF. If the current density or electric field induced by an extremely strong magnetic field exceeds a certain threshold, excitation of muscles and nerves is possible. Also, strong electric fields can induce charges on the surface of the body that can lead to small shocks, i.e., micro shocks. These are acute and shock-like effects that cause no long-term damage or health consequences. Limits for the general public and workplace have been set to prevent these effects, but real-life situations where these levels would be exceeded are rare. Standards and guidelines are discussed in more detail in Section 8.

4 Methods for Evaluating Scientific Research

Science is more than a collection of facts. It is a method of obtaining information and of reasoning to ensure that the information and conclusions are accurate and correctly describe physical and biological phenomena. Many misconceptions in human reasoning occur when people casually interpret their observations and experience. Therefore, scientists use systematic methods to conduct and evaluate scientific research and assess the potential impact of a specific agent on human health. This process is designed to ensure that more weight is given to those studies of better quality and studies with a given result are not selected out from all of the studies available to advocate or suppress a preconceived idea of an adverse effect. Scientists and scientific agencies and organizations use these standard methods to draw conclusions about the many exposures in our environment.

Weight-of-evidence reviews

The scientific process entails looking at *all* the evidence on a particular issue in a systematic and thorough manner to evaluate if the overall data presents a logically coherent and consistent picture. This is often referred to as a weight-of-evidence review, in which all studies are considered together, giving more weight to studies of higher quality and using an established analytic framework to arrive at a conclusion about a possible causal relationship. Weight-of-evidence reviews are typically conducted within the larger framework of health risk assessments or evaluations of particular exposures or exposure circumstances that qualitatively and quantitatively define health risks. Weight-of-evidence and health risk assessment methods have been described by several agencies, including the International Agency for Research on Cancer (IARC), which routinely evaluates substances such as drugs, chemicals, and physical agents for their ability to cause cancer; the WHO International Programme for Chemical Safety; and the US Environmental Protection Agency, which set guidance for public exposures (WHO, 1994; USEPA, 1993; USEPA, 1996). Two steps precede a weight-of-evidence evaluation: a systematic review to identify the relevant literature and an evaluation of each relevant study to determine its strengths and weaknesses.

The following sections discuss important considerations in the evaluation of human health studies of EMF in a weight-of-evidence review, including exposure considerations, study design, methods for estimating risk, bias, and the process of causal inference. The purpose of discussing these considerations here is to provide context for the later weight-of-evidence evaluations.

Exposure considerations

Exposure methods range widely in studies of ELF EMF, including: the classification of residences based on the relative capacity of nearby power lines to produce magnetic fields (i.e., wire code categories); occupational titles; calculated magnetic-field levels based on job histories (i.e., a job-exposure matrix [JEM]); residential distance from nearby power lines; spot measurements of magnetic-field levels inside or outside residences; 24-hour and 48-hour measurements of magnetic fields in a particular location in the house (e.g., a child's bedroom); calculated magnetic-field levels based on the characteristics of nearby power installations; and, finally, personal 24-hour and 48-hour magnetic-field measurements.

Each of these methods has strengths and limitations (Kheifets and Oksuzyan, 2008). Since magnetic-field exposures are ubiquitous and vary over a lifetime as the places we frequent and the sources of ELF EMF in those places change, making valid estimates of personal magnetic-field exposure challenging. Furthermore, without a biological basis to define a relevant exposure metric (average exposure or peak exposure) and a defined critical period for exposure (e.g., *in utero*, shortly before diagnosis), relevant and valid assessments of exposure are problematic. Exposure misclassification is one of the most significant concerns in studies of ELF EMF.

In general, long-term personal measurements are the metrics selected by epidemiologists. Other methods are generally weaker because they may not be strong predictors of long-term exposure and do not take into account all magnetic-field sources. ELF EMF can be estimated indirectly by assigning an estimated amount of exposure to an individual based on calculations considering nearby power installations or a person's job title. For instance, a relative estimate of exposure could be assigned to all machine operators based on historical information on the magnitude of the magnetic field produced by the machine. Indirect measurements are not as accurate as direct measurements because they do not contain information specific to that person or the exposure situation. In the example of machine operators, the indirect measurement may not account for how much time any one individual spends working at that machine or any potential variability in magnetic fields produced by the machines over time. In addition, such occupational measurements do not take into account the worker's residential magnetic-field exposures.

While JEMs are an advancement over earlier methods, they still have some important limitations, as highlighted in a review by Kheifets et al. (2009) summarizing an expert panel's findings.[6] A person's occupation provides some relative indication of the overall magnitude of their occupational magnetic-field exposure, but it does not take into account the possible variation in exposure due to different job tasks within occupational titles, the frequency and intensity of contact to relevant exposure sources, or variation by calendar time. This was highlighted by a recent study of 48-hour magnetic-field measurements of 543 workers in Italy in a variety of occupational settings, including: ceramics, mechanical engineering, textiles, graphics, retail, food, wood, and biomedical industries (Gobba et al., 2011). In this study, there was significant variation in measured TWA magnetic-field levels for workers in many of the International Standard Classification of Occupations' job categories, which the authors attributed to variations within these task-defined categories in some of the industries.

Types of health research studies

Research studies can be broadly classified into two groups: 1) epidemiologic observations of people and 2) experimental studies on animals, humans, cells, and tissues conducted in laboratory settings. Epidemiology studies investigate how disease is distributed in populations

[6] Kheifets et al. (2009) reports on the conclusions of an independent panel organized by the Energy Networks Association in the United Kingdom in 2006 to review the current status of the science on occupational EMF exposure and identify the highest priority research needs.

and what factors influence or determine this disease distribution (Gordis, 2000). Epidemiology studies attempt to identify potential causes for human disease while observing people as they go about their normal, daily lives. Such studies are designed to quantify and evaluate the associations between disease and reported exposures to environmental factors.

The most common types of epidemiology studies in the ELF EMF literature are case-control and cohort studies. In case-control studies, people with and without the disease of interest are identified and the exposures of interest are evaluated. Often, people are interviewed or their personal records (e.g., medical records or employment records) are reviewed in order to establish the exposure history for each individual. The exposure histories are then compared between the diseased and non-diseased populations to determine whether any statistically significant differences in exposure histories exist. In cohort studies, on the other hand, individuals within a defined cohort of people (e.g., all persons working at a utility company) are classified as exposed or non-exposed and followed over time for the incidence of disease. Researchers then compare disease incidence in the exposed and non-exposed groups.

Experimental studies are designed to test specific hypotheses under controlled conditions and are vital to assessing cause-and-effect relationships. An example of a human experimental study relevant to this area of research would be studies that measure the impact of magnetic-field exposure on acute biological responses in humans, such as hormone levels. These studies are conducted in laboratories under controlled conditions. *In vivo* and *in vitro* experimental studies are also conducted under controlled conditions in laboratories. *In vivo* studies expose laboratory animals to very high levels of a chemical or physical agent to determine whether exposed animals develop cancer or other effects at higher rates than unexposed animals, while attempting to control other factors that could possibly affect disease rates (e.g., diet, genetics). *In vitro* studies of isolated cells and tissues are important because they can help scientists understand biological mechanisms as they relate to the same exposure in intact humans and animals. In the case of *in vitro* studies, the responses of cells and tissues outside the body may not reflect the response of those same cells if maintained in a living system, so their relevance cannot be assumed. Therefore, it is both necessary and desirable that agents that could present a potential health threat be explored by both epidemiology and experimental studies.

Both of these approaches—epidemiology and experimental laboratory studies—have been used to evaluate whether exposure to ELF EMF has any adverse effects on human health. Epidemiology studies are valuable because they are conducted in human populations, but they are limited by their non-experimental design and typical retrospective nature. In epidemiology studies of magnetic fields, for example, researchers cannot control the amount of individual exposure, how exposure occurs over time, the contribution of different field sources, or individual behaviors other than exposure that may affect disease risk, such as diet. In valid risk assessments of ELF EMF, epidemiology studies are considered alongside experimental studies of laboratory animals, while studies of isolated tissues and cells are generally considered supplementary.

Estimating risk

Epidemiologists measure the statistical association between exposures and disease in order to estimate risk. This brief summary of risk is included to provide a foundation for understanding and interpreting statistical associations in epidemiology studies as risk estimates.

Two common types of risk estimates are absolute risk and relative risk (RR). Absolute risk, also known as incidence, is the amount of new disease that occurs in a given period of time. For example, the absolute risk of invasive childhood cancer in children ages 0 to 19 years for 2004 was 14.8 per 100,000 children (Reis et al., 2007). RRs are calculated to evaluate whether a particular exposure or inherent quality (e.g., EMF, diet, genetics, race) is associated with a disease outcome. This is calculated by looking at the absolute risk in one group relative to a comparison group. For example, white children in the 0 to 19 year age range had an estimated absolute risk of childhood cancer of 15.4 per 100,000 in 2004, and African American children had an estimated absolute risk of 13.3 per 100,000 in the same year. By dividing the absolute risk of white children by the absolute risk of African American children, we obtain a RR of 1.16. This RR estimate can be interpreted to mean that white children have a risk of childhood cancer that is 16% greater than the risk of African American children. Additional statistical analysis is needed to evaluate whether this association is statistically significant, as defined in the following sub-section.

It is important to understand that risk is estimated differently in cohort and case-control studies because of the way the studies are designed. Traditional cohort studies provide a direct estimate of RR, while case-control studies only provide indirect estimates of RR, called odds ratios (OR). For this reason, among others, cohort studies usually provide more reliable estimates of the risk associated with a particular exposure. Case-control studies are more common than cohort studies, however, because they are less costly and more time efficient.

Thus, the association between a particular disease and exposure is measured quantitatively in an epidemiology study as either the RR (cohort studies) or OR (case-control studies) estimate. The general interpretation of a risk estimate equal to 1.0 is that the exposure is not associated with an increased incidence of the disease. If the risk estimate is greater than 1.0, the inference is that the exposure is associated with an increased incidence of the disease. On the other hand, if the risk estimate is less than 1.0, the inference is that the exposure is associated with a reduced incidence of the disease. The magnitude of the risk estimate is often referred to as its strength (i.e., strong vs. weak). Stronger associations are given more weight because they are less susceptible to the effects of bias.

Statistical significance

Statistical significance testing provides an idea of whether or not a statistical association is a chance occurrence or whether the association is likely to be observed upon repeated testing. The terms "statistically significant" or "statistically significant association" are used in epidemiology studies to describe the tendency of the level of exposure and the occurrence of disease to be linked, with chance as an unlikely explanation. Statistically significant associations, however, are not necessarily an indication of cause-and-effect, because the interpretation of statistically significant associations depends on many other factors associated with the design and conduct of the study, including how the data were collected and the number of study participants.

Confidence intervals (CI) reported along with RR and OR values, indicate a range of values for an estimate of effect that has a specified probability (e.g., 95%) that the sample of data examined includes the "true" estimate of effect; CIs evaluate statistical significance, but do not address the role of bias, as described further below. A 95% CI indicates that, if the study were conducted a very large number of times, 95% of the measured estimates would be within the upper and lower confidence limits based on sampling of a normal statistical distribution.

The range of the CI is also important for interpreting estimated associations, including the precision and statistical significance of the association. A very wide CI indicates great uncertainty in the value of the "true" risk estimate. This is usually due to a small number of observations. A narrow CI provides more certainty about where the "true" RR estimate lies. If the 95% CI does not include 1.0, the probability of an association being due to chance alone is 5% or lower and the result is considered statistically significant, as discussed above.

While a 95% CI is commonly applied, it provides marginal protection against falsely rejecting a hypothesis of no effect, so acceptance of a 99% CI level is recommended (e.g., Goodman, 1999).

Meta-analysis and pooled analysis

In scientific research, the results of smaller studies may be difficult to distinguish from normal, random variation. This is also the case for sub-group analyses where few cases are estimated to have high exposure levels, e.g., in case-control studies of childhood leukemia and TWA magnetic-field exposure greater than 3-4 mG. Meta-analysis is an analytic technique that combines the published results from a group of studies into one summary result. A pooled analysis, on the other hand, combines the raw, individual-level data from the original studies and analyzes the data from the studies altogether. These methods are valuable because they increase the number of individuals in the analysis, which allows for a more robust and stable estimate of association. Meta- and pooled analyses are an important tool for qualitatively synthesizing the results of a large group of studies.

The disadvantage of meta- and pooled analyses is that they can convey a false sense of consistency across studies if *only* the combined estimate of effect is considered (Rothman and Greenland, 1998). These analyses typically combine data from studies with different study populations, methods for measuring and defining exposure, and disease definitions. This is particularly true for analyses that combine data from case-control studies, which often use very different methods for the selection of cases and controls and exposure assessment. Therefore, in addition to the synthesis or combining of data, meta- and pooled analyses should be used to understand what factors cause the results of the studies to vary (i.e., publication date, study design, possibility of selection bias), and how these factors affect the associations calculated from the data of all the studies combined (Rothman and Greenland, 1998).

Meta- and pooled analyses are a valuable technique in epidemiology; however, in addition to calculating a summary RR, they should follow standard techniques (Stroup et al., 2001) and analyze the factors that contribute to any heterogeneity between the studies.

Bias in epidemiology studies

One key reason that the results of epidemiology studies cannot directly provide evidence for cause-and-effect is the presence of bias. Bias is defined as “any systematic error in the design, conduct or analysis of a study that results in a mistaken estimate of an exposure’s effect on the risk of disease” (Gordis, 2000, p. 204). In other words, sources of bias are factors or research situations that can mask a true association or cause an association that does not truly exist. As a result, the extent of bias, as well as its types and sources, is one of the most important considerations in the interpretation of epidemiology studies. Since it is not possible to fully control human populations, perfectly measure their exposures, or control for the effects of all other risk factors, bias will exist in some form in all epidemiology studies of human health. Laboratory studies, on the other hand, more effectively manage bias because of the tight control the researchers have over most study variables.

One important source of bias occurs in epidemiology studies when a third variable confuses the relationship between the exposure and disease of interest because of its relationship to both. Consider an example of a researcher whose study finds that people who exercise have a lower risk of diabetes compared to people who do not exercise. It is known that people who exercise more tend to also consume healthier diets and healthier diets may lower the risk of diabetes. If the researcher does not control for the impact of diet, it is not possible to say with certainty that the lower risk of diabetes is due to exercise and not to a healthier diet. In this example, diet is the confounding variable.

Cause vs. association and evaluating evidence regarding causal associations

Epidemiology studies can help suggest factors that may contribute to the risk of disease, but they are not used as the sole basis for drawing inferences about cause-and-effect relationships. Since epidemiologists do not have control over the many other factors to which people in are exposed in their studies, and diseases can be caused by a complex interaction of many factors, the results of epidemiology studies must be interpreted with caution. A single epidemiology study is rarely unequivocally supportive or non-supportive of causation; rather, a weight is assigned to the study based on the validity of its methods and all relevant studies (epidemiology, *in vivo*, and *in vitro*) must be considered together in a weight-of-evidence review to arrive at a conclusion about possible causality between an exposure and disease.

In 1964, the Surgeon General of the United States published a landmark report on smoking-related diseases (HEW, 1964). As part of this report, nine criteria for evaluating epidemiology studies (along with experimental data) for causality were outlined. In a more recent version of this report, these criteria have been reorganized into seven criteria. In the earlier version, which was based on the commonly referenced Hill criteria (Hill, 1965), coherence, plausibility, and analogy were considered as distinct items, but are now summarized together because they have been treated in practice as essentially reflecting one concept (HHS, 2004). Table 1 provides a listing and brief description of each criterion.

Table 1. Criteria for evaluating whether an association is causal

Criteria	Description
Consistency	Repeated observation of an association between exposure and disease in multiple studies of adequate statistical power, in different populations, and at different times.
Strength of the association	The larger (stronger) the magnitude and statistical strength of an association is between exposure and disease, the less likely such an effect is the result of chance or unmeasured confounding.
Specificity	The exposure is the single (or one of a few) cause of disease.
Temporality	The exposure occurs prior to the onset of disease.
Coherence, plausibility, and analogy	The association cannot violate known scientific principles and the association must be consistent with experimentally demonstrated biologic mechanisms.
Biologic gradient	This is also known as a dose-response relationship, i.e., the observation that the stronger or greater the exposure is, the stronger or greater the effect.
Experiment	Observations that result from situations in which natural conditions imitate experimental conditions. Also stated as a change in disease outcome in response to a non-experimental change in exposure patterns in population.

Source: Department of Health and Human Services, 2004

The criteria were meant to be applied to statistically significant associations that have been observed in the cumulative epidemiologic literature (i.e., if no statistically significant association has been observed for an exposure then the criteria are not relevant). It is important to note that these criteria were not intended to serve as a checklist but as guide to evaluate associations for causal inference. Theoretically, it is possible for an exposure to meet all seven criteria, but still not be deemed a causal factor. Also, no one criterion can provide indisputable evidence for causation, nor can any single criterion, aside from temporality, rule out causation.

In summary, the judicious consideration of these criteria is useful in evaluating epidemiology studies, but they cannot be used as the sole basis for drawing inferences about cause-and-effect relationships. In line with the criteria of "coherence, plausibility, and analogy," epidemiology studies are considered along with *in vivo* and *in vitro* studies in a comprehensive weight-of-evidence review. Epidemiologic support for causality is usually based on high-quality studies reporting consistent results across many different populations and study designs that are supported by the experimental data collected from *in vivo* and *in vitro* studies.

Biological response vs. disease in human health

When interpreting research studies, it is important to distinguish between a reported biological response and an indicator of disease. This is relevant because exposure to ELF EMF may elicit a biological response that is simply a normal response to environmental conditions. This response, however, may not be a disease, cause a disease, or be otherwise harmful. There are many exposures or factors encountered in day-to-day life that elicit a biological response, but the response is neither harmful nor a cause of disease. For example, when an individual walks from a dark room indoors to a sunny day outdoors, the pupils of the eye naturally constrict to limit the amount of light passing into the eye. This constriction of the pupil is considered a biological response to the change in light conditions. Pupil constriction, however, is neither a disease itself, nor is it known to cause disease.

5 The WHO 2007 Report: Methods and Conclusions

The WHO is a scientific organization within the United Nations system whose mandate includes providing leadership on global health matters, shaping health research agendas, and setting norms and standards. The WHO established the International EMF Project in 1996, in response to public concern about exposure to ELF EMF and possible adverse health outcomes. The project's membership includes 8 international organizations, 8 collaborating institutions, and over 54 national authorities. The overall purpose of the Project is to assess health and environmental effects of exposure to static and time varying fields in the frequency range of 0 Hz to 300 gigahertz. A key objective of the Project is to evaluate the scientific literature and make periodic status reports on health effects to be used as the basis for a coherent international response, including the identification of important research gaps and the development of internationally acceptable standards for ELF EMF exposure.

In 2007, the WHO published their Environmental Health Criteria (EHC) 238 on EMF summarizing health research in the ELF range. The EHC used standard scientific procedures, as outlined in its Preamble and described above in Section 4, to conduct the review. The Task Group responsible for the report's overall conclusions consisted of 21 scientists from around the world with expertise in a wide range of scientific disciplines. They relied on the conclusions of previous weight-of-evidence reviews,[7] where possible, and mainly focused on evaluating studies published after an IARC review of ELF EMF and cancer in 2002.

The WHO Task Group and IARC use specific terms to describe the strength of the evidence in support of causality between specific agents and cancer. These categories are described here because, while they are meaningful to scientists who are familiar with the IARC process, they can create an undue level of concern with the general public. *Sufficient evidence of carcinogenicity* is assigned to a body of epidemiologic research if a positive association has been observed in studies in which chance, bias, and confounding can be ruled out with reasonable confidence. *Limited evidence of carcinogenicity* describes a body of epidemiologic research where the findings are inconsistent or there are outstanding questions about study design or other methodological issues that preclude making a conclusion. *Inadequate evidence of carcinogenicity* describes a body of epidemiologic research where it is unclear whether the data is supportive or unsupportive of causation because there is a lack of data or there are major quantitative or qualitative issues. A similar classification system is used for evaluating *in vivo* studies and mechanistic data for carcinogenicity.

Summary categories are assigned by considering the conclusions of each body of evidence (epidemiologic, *in vivo,* and *in vitro*) together (see Figure 3). *In vitro* research is not described in Figure 3 because it provides ancillary information and, therefore, is used to a lesser degree in evaluating carcinogenicity and is classified simply as strong, moderate, or weak. Categories

[7] The term "weight-of-evidence review" is used in this report to denote a systematic review process by a multidisciplinary, scientific panel involving experimental and epidemiologic research to arrive at conclusions about possible health risks. The WHO EHC on EMF does not specifically describe their report as a weight-of-evidence review. Rather, they describe conducting a health risk assessment. A health risk assessment differs from a weight-of-evidence review in that it also incorporates an exposure and exposure-response assessment.

include (from highest to lowest risk): carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, unclassifiable, and probably not carcinogenic to humans. These categories are intentionally meant to err on the side of caution, giving more weight to the possibility that the exposure is truly carcinogenic and less weight to the possibility that the exposure is not carcinogenic. The category "possibly carcinogenic to humans" denotes exposures for which there is limited evidence of carcinogenicity in epidemiology studies and less than sufficient evidence of carcinogenicity in studies of experimental animals.

	Epidemiology Studies				Animal Studies			
	Sufficient evidence	Limited evidence	Inadequate evidence	Evidence suggesting lack of carcinogenicity	Sufficient evidence	Limited evidence	Inadequate evidence	Evidence suggesting lack of carcinogenicity
Known Carcinogen	✓							
Probable Carcinogen		✓			✓			
Possible Carcinogen		✓				✓	✓	
Not Classifiable			✓			✓	✓	
Probably not a Carcinogen				✓				✓

Sufficient evidence in epidemiology studies—A positive association is observed between the exposure and cancer in studies, in which chance, bias and confounding were ruled out with "reasonable confidence."

Limited evidence in epidemiology studies—A positive association has been observed between the exposure and cancer for which a causal interpretation is considered to be credible, but chance, bias or confounding could not be ruled out with "reasonable confidence."

Inadequate evidence in epidemiology studies—The available studies are of insufficient quality, consistency or statistical power to permit a conclusion regarding the presence or absence of a causal association between exposure and cancer, or no data on cancer in humans are available.

Evidence suggesting a lack of carcinogenicity in epidemiology studies—There are several adequate studies covering the full range of levels of exposure that humans are known to encounter, which are mutually consistent in not showing a positive association between exposure to the agent and any studied cancer at any observed level of exposure. The results from these studies alone or combined should have narrow confidence intervals with an upper limit close to the null value (e.g. a relative risk of 1.0). Bias and confounding should be ruled out with reasonable confidence, and the studies should have an adequate length of follow-up.

Sufficient evidence in animal studies—An increased incidence of malignant neoplasms is observed in (a) two or more species of animals or (b) two or more independent studies in one species carried out at different times or indifferent laboratories or under different protocols. An increased incidence of tumors in both sexes of a single species in a well-conducted study, ideally conducted under Good Laboratory Practices, can also provide sufficient evidence.

Limited evidence in animal studies—The data suggest a carcinogenic effect but are limited for making a definitive evaluation, e.g. (a) the evidence of carcinogenicity is restricted to a single experiment; (b) there are unresolved questions regarding the adequacy of the design, conduct or interpretation of the studies; etc.

Inadequate evidence in animal studies—The studies cannot be interpreted as showing either the presence or absence of a carcinogenic effect because of major qualitative or quantitative limitations, or no data on cancer in experimental animals are available

Evidence suggesting a lack of carcinogenicity in animal studies—Adequate studies involving at least two species are available which show that, within the limits of the tests used, the agent is not carcinogenic.

Figure 3. Basic IARC method for classifying exposures based on potential carcinogenicity.

The IARC has reviewed close to 1,000 substances and exposure circumstances to evaluate their potential carcinogenicity. Over 80% of exposures fall in the categories possible carcinogen

(29%) or non-classifiable (52%). This occurs because, as described above, it is nearly impossible to prove that something is completely safe, and few exposures show a clear-cut or probable risk, so most agents will end up in either of these two categories. Throughout the history of the IARC, only one agent has been classified as probably not a carcinogen, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

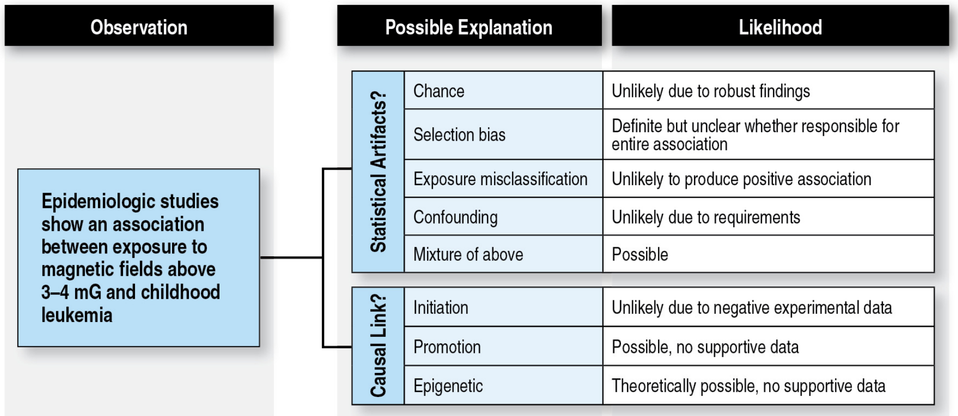
The WHO report provided the following overall conclusions with regard to ELF EMF:

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (p. 355, WHO, 2007).

With regard to specific diseases, the WHO concluded the following:

Childhood cancers. The WHO report paid particular attention to childhood leukemia because the most consistent epidemiologic association in the area of ELF EMF and health research has been reported between this disease and TWA exposure to high, magnetic-field levels. Two pooled analyses reported an association between childhood leukemia and TWA magnetic-field exposure >3-4 mG (Ahlbom et al., 2000; Greenland et al., 2000); it is these data, categorized as limited epidemiologic evidence, that resulted in the classification of magnetic fields as possibly carcinogenic by the IARC in 2002.

The WHO report systematically evaluated several factors that might be partially, or fully, responsible for the consistent association, including: chance, misclassification of magnetic-field exposure, confounding from hypothesized or unknown risk factors, and selection bias. The authors concluded that chance is an unlikely explanation since the pooled analyses had a larger sample size and decreased variability; control selection bias probably occurs to some extent in these studies and would result in an overestimate of the true association, but would not explain the entire observed association; it is less likely that confounding occurs, although the possibility that some yet-to-be identified confounder is responsible for the association cannot be fully excluded; and, finally, exposure misclassification would likely result in an underestimate of the true association, although it is not entirely clear (see Figure 4 below). The WHO concluded that reconciling the epidemiologic data on childhood leukemia and the negative (i.e., no hazard or risk observed) experimental findings through innovative research is currently the highest priority in the field of ELF EMF research. Given that few children are expected to have long-term *average* magnetic-field exposures greater than 3-4 mG, however, the WHO stated that the public health impact of magnetic fields on childhood leukemia would likely be minimal, if the association was determined to be causal.



Source: Adapted from Schüz and Ahlbom (2008)

Figure 4. Possible explanations for the observed association between magnetic fields and childhood leukemia.

Fewer studies have been published on magnetic fields and childhood brain cancer compared to studies of childhood leukemia. The WHO Task Group described the results of these studies as inconsistent and limited by small sample sizes and recommended a meta-analysis to clarify the research findings.

Breast cancer. The WHO concluded that the more recent studies they reviewed on breast cancer and ELF EMF exposure were higher in quality compared with earlier studies, and for that reason, they provide strong support to previous consensus statements that magnetic-field exposure does not influence the risk of breast cancer. In summary, the WHO stated "[w]ith these [more recent] studies, the evidence for an association between ELF magnetic-field exposure and the risk of female breast cancer is weakened considerably and does not support an association of this kind" (WHO, 2007, p. 9). The WHO recommended no further research with respect to breast cancer and magnetic-field exposure.

Adult leukemia and brain cancer. The WHO concluded, "In the case of adult brain cancer and leukaemia, the new studies published after the IARC monograph do not change the conclusion that the overall evidence for an association between ELF [EMF] and the risk of these disease remains inadequate" (WHO, 2007, p. 307). The WHO panel recommended updating the existing European cohorts of occupationally-exposed individuals and pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

In vivo research on carcinogenesis. The WHO concluded the following with respect to *in vivo* research, "[t]here is no evidence that ELF [EMF] exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate" (WHO, 2007, p. 10). Recommendations for future research included the development of a rodent model for childhood acute lymphoblastic leukemia (ALL) and the continued investigation of whether magnetic fields can act as a co-carcinogen.

Reproductive and developmental effects. The WHO concluded that, overall, the body of research does not suggest that maternal or paternal exposures to ELF EMF cause adverse reproductive or developmental outcomes. The evidence from epidemiology studies on miscarriage was described as inadequate and further research on this possible association was recommended, although low priority was given to this recommendation.

Neurodegenerative diseases. The WHO reported that the majority of epidemiology studies have reported associations between occupational magnetic-field exposure and mortality from Alzheimer's disease and amyotrophic lateral sclerosis (ALS), although the design and methods of these studies were relatively weak (e.g., disease status was based on death certificate data, exposure was based on incomplete occupational information from census data, and there was no control for confounding factors). The WHO concluded that there is inadequate data in support of an association between magnetic-field exposure and Alzheimer's disease or ALS. The panel highly recommended that further studies be conducted in this area, particularly studies where the association between magnetic fields and ALS is estimated while controlling for the possible confounding effect of electric shocks.

Cardiovascular disease. It has been hypothesized that magnetic-field exposure reduces heart rate variability, which in turn increases the risk for acute myocardial infarction (AMI). With one exception (Savitz et al., 1999), however, none of the studies of cardiovascular disease morbidity and mortality that were reviewed show an association with exposure. Whether a specific association exists between exposure and altered autonomic control of the heart remains speculative and overall the evidence does not support an association. Experimental studies of both short- and long-term exposure indicate that, while electric shock is an obvious health hazard, other hazardous cardiovascular effects associated with ELF EMF are unlikely to occur at exposure levels commonly encountered environmentally or occupationally.

6 Current Scientific Consensus

The following sections identify and describe epidemiology and *in vivo* studies related to ELF EMF and health published between July 2013 and November 2014. The purpose of this section is to evaluate whether the findings of these recent studies alter the conclusions published by the WHO in their 2007 report, as described in Section 5. The previous Exponent report that summarized the literature up to July 2013[8] concluded that recent results did not provide sufficient evidence to alter the basic conclusion of the WHO EHC published in 2007.

A structured literature search was conducted using PubMed, a search engine provided by the National Library of Medicine and the National Institutes of Health that includes over 15 million up-to-date citations from MEDLINE and other life science journals for biomedical articles (http://www.pubmed.gov). A well-defined search strategy was used to identify literature indexed between July 2013 and November 2014.[9] All fields (e.g., title, abstract, keywords) were searched with various search strings that referenced the exposure and disease of interest.[10] A researcher with experience in this area reviewed the titles and abstracts of these publications for inclusion in this evaluation. Only peer-reviewed, epidemiology studies, meta-analyses, and human experimental studies of 50/60-Hz AC ELF EMF and recognized disease entities, along with whole animal *in vivo* studies of carcinogenesis, were included. The following specific inclusion criteria were applied:

1. **Outcome**. Included studies evaluated one of the following diseases: cancer; reproductive effects; neurodegenerative diseases; or cardiovascular disease. Research on other outcomes was not included (e.g., psychological effects, behavioral effects, hypersensitivity). Few studies are available in these research areas and, as such, research evolves more slowly.

2. **Exposure**. The study must have evaluated 50/60-Hz AC ELF EMF.

3. **Exposure assessment methods**. Exposure must have been evaluated beyond self-report of an activity or occupation. Included studies estimated exposure through various methods including calculated EMF levels using distance from power lines; time-weighted average EMF exposures; and average exposure estimated from JEMs.

4. **Study design**. Epidemiology studies, meta-analyses, human experimental studies, and *in*

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[8] Exponent, Inc. *Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: G-185S 115-kV Transmission Line*. Prepared for the Rhode Island Energy Facility Siting Board. October 31, 2013.

[9] Since there is sometimes a delay between the publication date of a study and the date it is indexed in PubMed, it is possible that some studies not yet indexed, but published prior to November 2014, are not included in this update.

[10] EMF OR magnetic fields OR electric fields OR electromagnetic OR power frequency OR transmission line AND cancer (cancer OR leukemia OR lymphoma OR carcinogenesis) OR neurodegenerative disease (neurodegenerative disease OR Alzheimer's disease OR amyotrophic lateral sclerosis OR Lou Gehrig's disease) OR cardiovascular effects (cardiovascular OR heart rate) OR reproductive outcomes (miscarriage OR reproduction OR developmental effects).

vivo studies were included. Only *in vivo* studies of carcinogenicity were evaluated in this review; the review relies on the conclusions of the WHO with regard to *in vivo* studies in the areas of reproduction, development, neurology, and cardiology. Further, this report relies on the conclusions of the WHO report (as described in Section 5) with regard to mechanistic data from *in vitro* studies since this field of study is less informative to the risk assessment process (IARC, 2002).

5. **Peer-review**. The study must have been peer-reviewed and published. Therefore, no conference proceedings, abstracts, or on-line material were included.

Epidemiology studies are evaluated below first by outcome (childhood cancer; adult cancer; reproductive or developmental effects; neurodegenerative disease; and cardiovascular effects), followed by an evaluation of *in vivo* research on carcinogenesis. Tables 3 through 9 list the relevant studies that were published between July 2013 and November 2014 in these areas.

Childhood health outcomes

Childhood leukemia

In 2002, the IARC assembled and reviewed research related to ELF EMF to evaluate the strength of the evidence in support of carcinogenicity. The IARC expert panel noted that, when studies with the relevant information were combined in a pooled analysis, a statistically significant two-fold association was observed between childhood leukemia and estimated exposure to high, average levels of magnetic fields (i.e., greater than 3-4 mG of average 24- and 48-hour exposure). This evidence was classified as "limited evidence" in support of carcinogenicity, falling short of "sufficient evidence" because chance, bias, and confounding could not be ruled out with "reasonable confidence." Largely as a result of the findings related to childhood leukemia, the IARC classified magnetic fields as "possibly carcinogenic," a category that describes exposures with limited epidemiologic evidence and inadequate evidence from *in vivo* studies. The classification of "possibly carcinogenic" was confirmed by the WHO in June 2007.

Recent studies (July 2013 to November 2014)

Childhood leukemia remains one of the most studied health outcomes in ELF EMF epidemiologic research. Three large case-control studies from France, Denmark, and the United Kingdom have assessed the risk of childhood leukemia in relation to residential proximity to high-voltage power lines (Sermage-Faure et al., 2013; Bunch et al., 2014; Pedersen et al., 2014). The French study, which was discussed in the previous update, included 2,779 cases of childhood leukemia diagnosed between 2002 and 2007 and 30,000 control children (Sermage-Faure et al., 2013). The authors used geocoded information on residential address at the time of diagnosis for cases and at time of selection for controls. They reported no statistically significant increase in leukemia risk with distance to power lines. The authors, however, noted a statistically non-significant risk increase in a sub-analysis within 50 meters of 225-400 kV lines, but this was based on a small number of cases (n=9). The ensuing scientific correspondence following the publication of the study focused on the magnitude of inaccuracies in distance assessment with geocoding as a main limitation of the study, and its implication on the inference that can be drawn from the study. The correspondence also addressed the statistical uncertainties of the results that are based on small numbers (Bonnet-Belfais et al. 2013; Magana Torres and Garcia, 2013).

A similar study from Denmark identified 1,698 cases of childhood leukemia from the Danish Cancer Registry and 3,396 individually matched healthy control children from the Danish Central Population Registry (Pedersen et al., 2014). The investigators used geographical information systems to determine the distance between birth addresses and the 132-400 kV overhead transmission lines of the seven Danish transmission companies. The authors reported no risk increases for childhood leukemia with residential distance to power lines; the reported ORs were 0.76 (95 % CI 0.40–1.45) and 0.92 (95% CI 0.67–1.25) for children who lived 0–199 meters and for those who lived 200–599 meters from the nearest power line compared to children who lived more than 600 meters away.

The third study by Bunch et al. (2014) provided an update and extension of the 2005 study conducted by Draper et al. (2005) in the United Kingdom. The update included 13 additional years of data, included Scotland in addition to England and Wales, and included 132-kV lines in addition to 275-kV and 400-kV transmission lines. Bunch et al. included over 53,000 childhood cancer cases, diagnosed between 1962 and 2008, and over 66,000 healthy children as controls, representing the largest study to date in this field of study. The authors reported no overall association with residential proximity to power lines with any of the voltage categories. The statistical association that was reported in the earlier study (Draper et al., 2005) was no longer apparent in the updated and extended study. An analysis by calendar time revealed that the association was apparent only in the earlier decades (1960s and 1970s) but not in the later decades starting from the 1980s (Bunch et al., 2014). This observation does not support the hypothesis that the associations observed earlier were due to the effects of magnetic-fields.

These three studies had a large sample size and they were population-based studies requiring no subject participation, which minimizes the potential for selection bias. The main limitation of all of these studies was the reliance on distance to power lines as the main exposure metric. Estimated distance to power lines is known to be a poor predictor of actual residential magnetic field exposure. Chang et al. (2014) recently provided a detailed discussion on exposure assessment methods based on geographical information systems and their potential to result in severe bias. Using data from the UK study, Swanson et al. (2014a) also showed that geocoding data may not be sufficiently reliable to accurately predict actual magnetic-field exposures due to inaccuracies in distance assessment, especially when the exact address is not available.

The meta-analysis conducted by Zhao et al. (2014a) included nine case-control studies of EMF exposure and childhood leukemia published between 1997 and 2013. Zhao et al. reported a statistically significant association between average exposure above 4 mG and all types of childhood leukemia (OR 1.57; 95% CI 1.03-2.4). The meta-analysis relied on published results from some of the same studies included in previous pooled analyses, and thus, provided little new insight.

Swanson et al. (2014b) investigated the potential role of corona ions from power lines in childhood cancer development in the largest-to-date epidemiologic study of childhood cancer conducted in the United Kingdom. The authors used an improved model to predict exposure to corona ions using meteorological data on wind conditions, power line characteristics and proximity to residential address. Swanson et al. concluded that their results provided no empirical support for the corona ion hypothesis

Methodological studies have also examined the potential role of alternative, non-causal explanations for the reported epidemiologic associations. Swanson (2013) examined differences in residential mobility among residents who lived at varying distances from power lines. Swanson attempted to assess if these differences in mobility may explain the statistical association of leukemia with residential proximity to power lines. Although some variations in residential mobility were observed, these were "only small ones, and not such as to support the hypothesis." Scientists in California evaluated whether selection bias may influence the association in an epidemiologic study of childhood leukemia and residential magnetic-field exposure (Slusky et al., 2014). Wire code categories were used to assess exposure among participant and nonparticipant subjects in the Northern California Childhood Leukemia Study. The authors reported systematic differences between participant and nonparticipant subjects in both wire code categories and socioeconomic status and concluded that these differences did not appear to explain the lack of an association between childhood leukemia and exposure estimates in this study. The main limitation of the study is the use of wire code categories for exposure assessment; wire code categories are known to be poor predictors for actual magnetic-field exposure.

In a recent review, Grellier et al. (2014) estimated that, if the association was causal, ~1.5% to 2% of leukemia cases might be attributable to ELF EMF in Europe. They conclude that "this contribution is small and is characterized by considerable uncertainty."

Assessment

While some of the recently published large and methodologically advanced studies showed no association (e.g., Bunch et al., 2014; Pedersen et al., 2014), and one showed weak associations in selected subgroups (Sermage-Faure et al., 2013), the previously observed association between childhood leukemia and magnetic fields reported in some studies (e.g., Ahlbom et al., 2000; Greenland et al., 2000; Kheifets et al., 2010) remains unexplained. Overall, the results of recent studies do not change the classification of the epidemiologic data as limited, which is consistent with the most recent assessment conducted by the Scientific Committee on Newly-Identified Health Risks (SCENIHR) in 2015.

One of the major limitations of recent work remains the limited validity of the exposure assessment methods. Magnetic-field estimates have largely been based on calculated levels from nearby power lines, distance from nearby power lines, and measured, short-term residential levels. Recent analyses (e.g., Swanson et al., 2014a) have further demonstrated the limitations of distance assessment in childhood cancer epidemiologic studies basing the exposure assessment on distance from power lines. Scientists have continued to examine the role of selection bias in the childhood leukemia association, but no conclusive evidence has emerged that could attribute the entire observed association to bias (e.g., Swanson, 2013; Slusky et al., 2014). Some scientists have opined that epidemiology has reached its limits in this area and any future research must demonstrate a significant methodological advancement (e.g., an improved exposure metric or a large sample size in high exposure categories) to be justified (Savitz, 2010; Schmiedel and Blettner, 2010).

The findings from the recent literature do not alter previous conclusions of the WHO and other reviews, including ours, that the epidemiologic evidence on magnetic fields and childhood leukemia is "limited" from the perspective of the IARC classification. Chance, confounding, and several sources of bias still cannot be ruled out. Conclusions from several published reviews (Kheifets and Oksuzyan, 2008; Pelissari et al., 2009; Schüz and Ahlbom, 2008; Calvente et al., 2010; Eden, 2010; Schüz, 2011) and scientific organizations (SSI, 2007; SSI, 2008; HCN, 2009a; SCENIHR, 2015; EFHRAN, 2012; SSM, 2013) support this conclusion.

Researchers will continue to investigate the association between exposure to magnetic fields and childhood leukemia. In recent assessments of the epidemiologic evidence of magnetic-field exposure and childhood leukemia, it has been concluded that only 1% to 3% of all childhood leukemia cases in Europe and North America could be due to magnetic-field exposure, should a causal relationship exist (Schüz, 2011; Grellier et al., 2014).

It is important to note that magnetic fields are just one area of study in the extensive body of research on the possible causes of childhood leukemia. There are several other hypotheses under investigation that point to possible genetic, environmental, and infectious explanations for childhood leukemia (e.g., McNally and Parker, 2006; Belson et al., 2007; Rossig and Juergens, 2008; Urayama et al., 2010; Bartley et al., 2010 [diagnostic x-rays]; Amigou et al., 2011 [road traffic]; Swanson, 2013).

Table 2. Relevant studies of childhood leukemia

Author	Year	Study Title
Bunch et al.	2014	Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962-2008.
Grellier et al.	2014	Potential health impacts of residential exposures to extremely low frequency magnetic fields in Europe
Pedersen et al.	2014	Distance from residence to power line and risk of childhood leukemia: a population-based case-control study in Denmark
Sermage-Faure et al.*	2013	Childhood leukaemia close to high-voltage power lines – the Geocap study, 2002–2007
Slusky et al.	2014	Potential role of selection bias in the association between childhood leukemia and residential magnetic fields exposure: a population-based assessment
Swanson	2013	Residential mobility of populations near UK power lines and implications for childhood leukaemia
Swanson et al.	2014a	Relative accuracy of grid references derived from postcode and address in UK epidemiological studies of overhead power lines

Author	Year	Study Title
Swanson et al.	2014b	Childhood cancer and exposure to corona ions from power lines: an epidemiological test
Zhao et al.	2014a	Magnetic fields exposure and childhood leukemia risk: a meta-analysis based on 11,699 cases and 13,194 controls
*Comments and Replies on Sermage-Faure et al.:		
Bonnet-Belfais et al.	2013	Comment: childhood leukaemia and power lines--the Geocap study: is proximity an appropriate MF exposure surrogate?
Magana Torres and Garcia	2013	Comment on 'Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007'--odds ratio and confidence interval.
Clavel and Hemon	2013	Reply: Comment on 'Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007'--odds ratio and confidence interval
Clavel et al.	2013	Reply: Comment on 'Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007'--is proximity an appropriate MF exposure surrogate?

Childhood brain cancer

Compared to the research on magnetic fields and childhood leukemia, there have been fewer studies of childhood brain cancer. The data are less consistent and limited by even smaller numbers of exposed cases compared with studies of childhood leukemia. The WHO review recommended the following:

> As with childhood leukaemia, a pooled analysis of childhood brain cancer studies should be very informative and is therefore recommended. A pooled analysis of this kind can inexpensively provide a greater and improved insight into the existing data, including the possibility of selection bias and, if the studies are sufficiently homogeneous, can offer the best estimate of risk (WHO 2007, p. 18).

Recent studies (July 2013 to November 2014)

There has been one new publication that specifically examined the potential relationship between residential proximity to transmission lines and childhood brain cancer among other childhood cancers. The Bunch et al. (2014) study, described above, also included cases of brain cancer (n=11,968) and other solid tumors (n=21,985) among children in the United Kingdom between 1962 and 2008. No association was reported by the authors for either brain cancer or for other cancers.

The results of the methodological study that investigated the accuracy of distance assessment in childhood cancer studies (Swanson et al., 2014a) are also relevant for childhood brain cancer. The study that investigated the role of corona ions in childhood cancer development, similarly to childhood leukemia, reported no consistent associations for childhood brain cancer (Swanson et al., 2014b).

Assessment

Overall, the weight-of-evidence does not support an association between magnetic-field exposures and the development of childhood brain cancer. The results of recent studies do not alter the classification of the epidemiologic data in this field as "inadequate."

Table 3. Relevant studies of childhood brain cancer

Authors	Year	Study
Bunch et al.	2014	Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962-2008.
Swanson et al.	2014a	Relative accuracy of grid references derived from postcode and address in UK epidemiological studies of overhead power lines
Swanson et al.	2014b	Childhood cancer and exposure to corona ions from power lines: an epidemiological test

Adult health outcomes

Breast cancer

The WHO reviewed studies of breast cancer and residential magnetic-field exposure, electric blanket usage, and occupational magnetic-field exposure. These studies did not report consistent associations between magnetic-field exposure and breast cancer. The WHO concluded that the recent body of research on this topic was less susceptible to bias compared with previous studies, and, as a result, it provided strong support to previous consensus statements that magnetic-field exposure does not influence the risk of breast cancer. Specifically, the WHO stated:

> Subsequent to the IARC monograph a number of reports have been published concerning the risk of female breast cancer in adults associated with ELF magnetic field exposure. These studies are larger than the previous ones and less susceptible to bias, and overall are negative. With these studies, the evidence for an association between ELF exposure and the risk of breast cancer is weakened considerably and does not support an association of this kind (WHO 2007, p. 307).

The WHO recommended no specific research with respect to breast cancer and magnetic-field exposure.

Recent studies (July 2013 to November 2014)

A Dutch study, that included a cohort of about 120,000 men and women in the Netherlands Cohort, investigated occupational exposure to ELF magnetic fields and cancer development (Koeman et al., 2014). The study was a case-cohort analysis of 2,077 breast cancer cases among women (no breast cancer was identified among men in the cohort). Job titles were used to assign estimates of ELF magnetic field exposures using a JEM. No association was reported for breast cancer with the level of estimated ELF magnetic-field exposure, the length of employment, or cumulative exposure in the exposed jobs.

A nested case-cohort analysis of breast cancer incidence was conducted in a large cohort of more than 267,000 female textile workers in Shanghai (Li et al., 2013). A total of 1,687 incident breast cancer cases were identified in the cohort between 1989 and 2000; their estimated exposure was compared with the estimated exposure of 4,702 non-cases. Exposure was assigned based on complete work history and a JEM specifically developed for the cohort. No association was reported between cumulative exposure and risk of breast cancer regardless of age, histological type, and whether a lag period was used or not. An accompanying editorial opined that this well-designed study further adds to the already large pool of data not supporting an association between ELF EMF and breast cancer (Feychting, 2013). The editorial suggests that further studies in breast cancer “have little new knowledge to add,” following the considerable improvement in study quality over time in breast cancer epidemiologic studies, and with the evidence being “consistently negative.”

Zhao et al. (2014b) reported the results of their meta-analysis of 16 case-control epidemiologic studies of ELF EMF and breast cancer published between 2000 and 2007. They reported a weak but statistically significant association, which appeared to be stronger among non-menopausal women. The conclusion of the authors that ELF magnetic fields might be related to breast cancer is contrary to the conclusion of the WHO and other risk assessment panels. This may be due to the inclusion of earlier and methodologically less advanced studies in the meta-analysis.

Assessment

The two large recently published studies (Li et al., 2013; Koeman et al., 2014) support the growing body of scientific evidence against a causal role for magnetic fields in breast cancer. The meta-analyses by Zhao et al. (2014b) include numerous limitations and therefore should be interpreted with great caution due to flaws within the individual studies and the crude pooling of data with a vast range of exposure definitions and cut-points. Several review papers (Feychting and Forssén 2006; Hulka and Moorman, 2008) and expert groups (SCENIHR, 2009) support the previous WHO (2007) conclusion that magnetic-field exposure does not influence the risk of breast cancer.

Table 4. Relevant studies of breast cancer

Authors	Year	Study
Koeman et al.	2014	Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort
Feytching	2013	Invited commentary: extremely low-frequency magnetic fields and breast cancer--now it is enough!
Li et al	2013	Occupational exposure to magnetic fields and breast cancer among women textile workers in Shanghai, China
Zhao et al.	2014b	Relationship between exposure to extremely low-frequency electromagnetic fields and breast cancer risk: a meta-analysis.

Adult brain cancer

Brain cancer was studied along with leukemia in many of the occupational studies of ELF EMF. The findings were inconsistent, and there was no pattern of stronger findings in studies with more advanced methods, although a small association could not be ruled out. The WHO classified the epidemiologic data on adult brain cancer as inadequate and recommended (1) updating the existing cohorts of occupationally-exposed individuals in Europe and (2) pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

The WHO stated the following:

> In the case of adult brain cancer and leukaemia, the new studies published after the IARC monograph do not change the conclusion that the overall evidence for an association between ELF [EMF] and the risk of these disease remains inadequate (WHO 2007, p. 307).

Recent studies (July 2013 to November 2014)

Epidemiology studies published since our last review on adult brain cancer and ELF EMF exposure are listed in Table 5 and include two cohort studies and one case-control study.

The large cohort study of occupational ELF EMF exposure in the Netherlands (Koeman et al., 2014) also investigated adult brain cancer development. The authors reported no association with adult brain cancer for any of the exposure metrics investigated for EMF exposure for either men or women.

Sorahan (2014a) reported the analysis of brain cancer incidence between 1973 and 2010 among more than 70,000 British electricity supply workers in a cohort analysis. The study reported no consistent association between brain cancer risk (glioma and meningioma) and estimated cumulative, recent and distant occupational exposure to ELF EMF.

Turner et al. (2014) investigated the association between occupational exposure to ELF EMF and brain cancer in a large international case-control epidemiologic study. While the authors reported both an increase (with exposure 1-4 years prior to diagnosis) and a decrease (with the highest maximum exposure) in associations with brain cancer in some of the sub-analyses, overall there was no association with lifetime cumulative or average exposure for either main type of brain cancer (glioma or meningioma).

Assessment

Findings from the recent literature predominantly support no association between exposure to ELF EMF and brain cancer in adults, but remain limited due to the exposure assessment methods and insufficient data available on specific brain cancer subtypes. Currently, the literature provides very weak evidence of an association in some studies, if any, between magnetic fields and brain cancer.[11] The overall evidence for brain cancer has not materially changed and remains inadequate as classified by the WHO in 2007.

Table 5. Relevant studies of adult brain cancer

Authors	Year	Study
Koeman et al.	2014	Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort
Sorahan	2014a	Magnetic fields and brain tumour risks in UK electricity supply workers.
Turner et al	2014	Occupational exposure to extremely low frequency magnetic fields and brain tumour risks in the INTEROCC study

Adult leukemia

There is a vast amount of literature on adult leukemia and ELF EMF, most of which is related to occupational exposure. Overall, the findings of these studies are inconsistent—with some studies reporting a positive association between measures of ELF EMF and leukemia and other studies showing no association. No pattern has been identified whereby studies of higher quality or design are more likely to produce positive or negative associations. The WHO subsequently classified the epidemiologic evidence for adult leukemia as "inadequate." They recommended updating the existing European occupation cohorts and updating a meta-analysis on occupational magnetic-field exposure.

Recent studies (July 2013 to November 2014)

The Dutch cohort study previously discussed (Koeman et al., 2014) identified 761 and 467 malignancies of the hematopoietic system among men and women, respectively. Overall, no increases in risk or trends were observed in association with cumulative exposure to ELF magnetic fields or duration of exposure among either men or women. In some sub-analyses by subtype, however, statistically significant associations were noted for acute myeloid leukemia and follicular lymphoma among men.

Sorahan also completed detailed analyses for leukemia incidence in the cohort of over 70,000 British electricity supply employees (Sorahan, 2014b). For all leukemias overall, there was no indication for risk increases with cumulative, recent or distant occupational exposure to magnetic fields. In some sub-analyses, however, the authors reported a statistically significant association for adult ALL.

Assessment

Recent studies of adult leukemia have not provided new evidence to support an association of magnetic field exposure with adult leukemia overall or with any leukemia sub-type. Thus, there

[11] A consensus statement by the National Cancer Institute's Brain Tumor Epidemiology Consortium confirms this statement. They classified residential power frequency EMF in the category "probably not risk factors" and described the epidemiologic data as "unresolved" (Bondy et al., 2008, p. 1958).

is no new evidence to alter the overall conclusion and the evidence remains inadequate for adult leukemia.

Table 6. Relevant studies of adult leukemia

Authors	Year	Study
Koeman et al.	2014	Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort
Sorahan	2014b	Magnetic fields and leukaemia risks in UK electricity supply workers.

Reproductive and developmental effects

Two studies in the past have received considerable attention because of a reported association between peak magnetic-field exposure greater than approximately 16 mG and miscarriage—a prospective cohort study of women in early pregnancy (Li et al., 2002) and a nested case-control study of women who miscarried compared to their late-pregnancy counterparts (Lee et al., 2002).

These two studies improved on the existing body of literature because average exposure was assessed using 24-hour personal magnetic-field measurements (early studies on miscarriage were limited because they used surrogate measures of exposure, including visual display terminal use, electric blanket use, or wire code data). Following the publication of these two studies, however, a hypothesis was put forth that the observed association may be the result of behavioral differences between women with "healthy" pregnancies that went to term (less physically active) and women who miscarried (more physically active) (Savitz, 2002). It was proposed that physical activity is associated with an increased opportunity for peak magnetic-field exposures, and the nausea experienced in early, healthy pregnancies and the cumbersomeness of late, healthy pregnancies would reduce physical activity levels, thereby decreasing the opportunity for exposure to peak magnetic fields. Furthermore, nearly half of women who had miscarriages reported in the cohort by Li et al. (2002) had magnetic-field measurements taken after miscarriage occurred, when changes in physical activity may have already occurred, and all measurements in Lee et al. (2002) occurred post-miscarriage.

The scientific panels that have considered these two studies concluded that the possibility of this bias precludes making any conclusions about the effect of magnetic fields on miscarriage (NRPB, 2004; FPTRPC, 2005; WHO, 2007). The WHO concluded, "There is some evidence for increased risk of miscarriage associated with measured maternal magnetic-field exposure, but this evidence is inadequate" (WHO 2007, p. 254). The WHO stated that, given the potentially high public health impact of such an association, further epidemiologic research is recommended.

Recent studies (July 2013 to November 2014)

Two epidemiologic studies investigated the potential association between ELF EMF exposure and miscarriage or stillbirth. A hospital-based case-control study from Iran included 58 women with spontaneous abortion and 58 pregnant women (Shamsi Mahmoudabadi et al., 2013). The authors reported that measured magnetic-field levels were statistically significantly higher among the cases than among controls. The study was small and provided little information on subject recruitment, exposure assessment, type of metric used to summarize exposure, and potential confounders; thus, it contributes little weight to an overall assessment.

A Chinese study identified 413 pregnant women at 8 weeks of gestation between 2010 and 2012 (Wang et al., 2013). Magnetic-field levels were measured at the front door and the alley in front of the participants' homes. No statistically significant association was seen with average exposure at the front door, but the authors reported an association with maximum magnetic-field values measured in the alleys in front of the homes. The study provides a fairly limited contribution to our current knowledge as magnetic-field levels measured at the front door or outside the home are very poor predictors of in-home and personal exposures.

Two studies examined various birth outcomes in relation to ELF EMF exposure. A study from the United Kingdom investigated birth outcomes in relation to residential proximity to power lines during pregnancy between 2004 and 2008 in Northwest England (de Vocht et al., 2014). The researchers examined hospital records of over 140,000 births, and distance to the nearest power lines were determined using geographical information systems. The authors reported moderately lower birth weight within 50 meters of power lines, but observed no statistically significant increase in risk of any adverse clinical birth outcomes (such as preterm birth, small for gestational age, or low birth weight). The limitations of the study include its reliance on distance for exposure assessment and the potential for confounding by socioeconomic status, as also discussed by the authors. A study from Iran reported no association between ELF EMF and pregnancy and developmental outcomes, such as duration of pregnancy, birth weight and length, head circumference, and congenital malformations (Mahram and Ghazavi, 2013). The study, however, provided little information on subject selection and recruitment; thus, it is difficult to assess its quality.

Su et al. (2014) conducted a cross-sectional study in Shanghai to examine correlations between magnetic-field exposure and embryonic development. The authors identified 149 pregnant women who were seeking induced termination of pregnancy during the first trimester. Personal 24-hour measurements were conducted for women within four weeks of the termination. Ultrasound was used to determine embryonic bud and embryonic sac length prior to the termination. The authors reported an association with maternal daily magnetic-field exposure and embryonic bud length. The study has a number of severe limitations, including the cross-sectional design, which cannot distinguish if exposure measured after termination describes that experienced during the first trimester; thus, it is impossible to assess causality. Additionally, the lack of careful consideration for gestational age, which is a major determinant of embryonic bud length, is an issue. Overall, the study provides little, if any, weight in a weight-of-evidence assessment.

Lewis et al. (2014) analyzed magnetic field exposure data over 7 consecutive days among 100 pregnant women from an earlier study. They reported that measures of central tendency (e.g., mean, median) were relatively well correlated day-to-day, and a measurement on one day could be used reasonably well to predict exposure on another day. Peak exposure measures (e.g., maximum value) showed poorer performance. The study did not examine the outcomes of the pregnancies, but these results have implications for earlier studies that reported association for spontaneous abortions with peak measures but not with measures of central tendency.

Assessment

The recent epidemiologic studies have not provided sufficient evidence to alter the conclusion that the evidence for reproductive or developmental effects is inadequate.

Table 7. Relevant studies of reproductive and developmental effects

Authors	Year	Study
de Vocht et al.	2014	Maternal residential proximity to sources of extremely low frequency electromagnetic fields and adverse birth outcomes in a UK cohort
Lewis et al.	2014	Temporal variability of daily personal magnetic field exposure metrics in pregnant women.
Mortazavi et al.	2013	The study of the effects of ionizing and non-ionizing radiations on birth weight of newborns to exposed mothers
Shamsi Mahmoudabadi et al.	2013	Exposure to Extremely Low Frequency Electromagnetic Fields during Pregnancy and the Risk of Spontaneous Abortion: A Case-Control Study
Su et al.	2014	Correlation between exposure to magnetic fields and embryonic development in the first trimester
Wang et al.	2013	Residential exposure to 50 Hz magnetic fields and the association with miscarriage risk: a 2-year prospective cohort study

Neurodegenerative diseases

Research into the possible effect of magnetic fields on the development of neurodegenerative diseases began in 1995, and the majority of research since then has focused on Alzheimer's disease and a specific type of motor neuron disease called amyotrophic lateral sclerosis (ALS), which is also known as Lou Gehrig's disease. Early studies on ALS, which had no obvious biases and were well conducted, reported an association between ALS mortality and estimated occupational magnetic-field exposure. The review panels, however, were hesitant to conclude that the associations provided strong support for a causal relationship. Rather, they felt that an alternative explanation (i.e., electric shocks received at work) may be the source of the observed association.

The majority of the more recent studies discussed by the WHO reported statistically significant associations between occupational magnetic-field exposure and mortality from Alzheimer's disease and ALS, although the design and methods of these studies were relatively weak (e.g., disease status was based on death certificate data, exposure was based on incomplete occupational information from census data, and there was no control for confounding factors). Furthermore, there were no biological data to support an association between magnetic fields and neurodegenerative diseases. The WHO panel concluded that there is "inadequate" data in support of an association between magnetic fields and Alzheimer's disease or ALS. The panel recommended more research in this area using better methods; in particular, studies that enrolled incident Alzheimer's disease cases (rather than ascertaining cases from death certificates) and studies that estimated electrical shock history in ALS cases were recommended. Specifically, the WHO concluded, "When evaluated across all the studies, there is only very limited evidence of an association between estimated ELF exposure and [Alzheimer's] disease risk" (WHO 2007, p. 194).

Recent studies (July 2013 to November 2014)

Davanipour et al. (2014) have reported on a study of severe cognitive dysfunction and occupational ELF magnetic-field exposure, in which "[t]he study population consisted of 3,050 Mexican Americans, aged 65+, enrolled in Phase I of the Hispanic Established Population for the Epidemiologic Study of the Elderly (H-EPESE) study." Occupational history, along with data on other socio-demographic information, was obtained via in-home personal interviews. Occupational exposure to magnetic fields was classified as low, medium, and high. Cognitive function was evaluated with the use of a mini-mental state exam and cognitive dysfunction was defined as an exam score below 10. While the authors describe their study as a population-based case-control study, based on the provided description in the paper, the study appears to be a cross-sectional study. Based on their analyses, the authors reported a statistically significant association between estimated occupational magnetic-field exposure and severe cognitive dysfunction. This study had a number of limitations, including the cross-sectional study design, the lack of clear clinical diagnosis for case-definition, and the crude assessment of occupational exposure.

Seelen et al. (2014) conducted a large population-based case-control study of ALS and residential proximity to high-voltage power lines in the Netherlands. The authors included 1,139 ALS cases diagnosed between 2006 and 2013 and 2,864 frequency-matched controls selected from general practitioners' rosters. Lifetime residential history was determined for all cases and controls using data from the Municipal Personal Records Database. Addresses were geocoded and the shortest distance to a high-voltage power was determined for each address. High-voltage power lines with voltages between 50 kV and 150 kV (high voltage) and between 220 kV and 380 kV were analyzed. No statistically significant association was reported for ALS with residential proximity to power lines with any of the voltages included. The authors also conducted a meta-analysis including their own results along with those of two previously published studies (Marcilio et al., 2011; Frei et al., 2013) and reported an overall OR of 0.9 (95% CI 0.7-1.1) for living within 200 meters of a high voltage power line. Similar to the previous power-line studies, the main limitation of the current study is the use of distance to power lines as a surrogate for magnetic-field exposure. The authors, however, reconstructed lifetime residential history, which represents a methodological improvement.

The role of electric shocks in development of neurodegenerative diseases has been examined in three recent studies. Electric shocks have been hypothesized to be a potential etiologic agent, primarily for ALS, based on the observation that linked "electric occupations," but not estimates of magnetic-field exposure to ALS (Vergara et al., 2013). Researchers in the Netherlands conducted a hospital-based case-control study of Parkinson's disease and occupational exposure to electric shocks and ELF magnetic fields (van der Mark et al., 2014). The study included 444 cases of Parkinson's disease and 876 matched controls. Occupational history was determined based on telephone interviews. JEMs were used to categorize jobs for exposure to both electric shocks and magnetic fields. The authors reported no risk increases with any of the two investigated exposures and concluded that their results suggest no association with Parkinson's disease.

A mortality case-control study using death certificates between 1991 and 1999 was conducted in the United States (Vergara et al., 2014). The study analyzed 5,886 ALS deaths and 10-times as many matched control deaths. Exposure to electric shocks and ELF magnetic fields was classified based on job titles reported on the death certificates and using corresponding JEMs. While a statistically significant association was reported for "electrical occupations," no consistent associations were observed for either magnetic field or electric shock exposures. The main limitation of the study is its reliance on death certificates that may result in disease and exposure misclassifications.

Huss et al. (2014) reported results of their analysis of ALS mortality in the Swiss National Cohort between 2000 and 2008. The cohort included about 2.2 million workers with high, medium, or low exposure to ELF magnetic fields and electric shocks. For exposure classification, JEMs for magnetic-field exposure and electric shocks were applied to occupations reported by the subjects at the 1990 and 2000 censuses. The authors reported a statistically significant association of ALS mortality with estimated medium or high occupational magnetic-field exposure based at both censuses, but not with estimates of electric shock exposure. The main limitations of the study include the reliance on mortality data, which may result in disease misclassification, and the use of census data for exposure assessment, which may result in exposure misclassification.

Assessment

Overall, the recent literature does not alter the conclusion that there are "inadequate" data for a causal link between exposure to ELF magnetic fields and neurodegenerative diseases. Most of the recent studies provided no support for a potential association. Several recent studies have investigated the potential role of electric shocks in neurodegenerative disease development. None of these studies reported results that would support the hypothesis that electric shocks play an etiologic role.

With respect to Alzheimer's disease, the main limitations of the available literature remains: the difficulty in diagnosing Alzheimer's disease; the difficulty of identifying a relevant exposure window given the long and nebulous course of this disease; the difficulty of estimating magnetic-field exposure prior to the appearance of the disease; the under-reporting of Alzheimer's disease on death certificates; crude exposure evaluations that are often based on the recollection of occupational histories by friends and family given the cognitive impairment of the study participants; and the lack of consideration of both residential and occupational exposures or confounding variables.

Although the most-recently published studies on this topic in Table 8 below were not available for inclusion in the SCENIHR opinion (their cut-off date was June 2014), the authors concluded that "[a]lthough the new studies in some cases have methodological weaknesses, they do not provide support for the previous conclusion that ELF MF exposure increases the risk for Alzheimer´s disease" (SCENIHR, 2015, p. 166).

Table 8. Relevant studies of neurodegenerative disease

Authors	Year	Study
Davanipour et al.	2014	Severe cognitive dysfunction and occupational extremely low frequency magnetic field exposure among elderly Mexican Americans.
Huss et al.	2014	Occupational exposure to magnetic fields and electric shocks and risk of ALS: The Swiss National Cohort.
Seelen et al.	2014	Residential exposure to extremely low frequency electromagnetic fields and the risk of ALS
Van der Mark et al.	2014	Extremely low-frequency magnetic field exposure, electrical shocks and risk of Parkinson's disease
Vergara et al.	2014	Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991–1999

Cardiovascular disease

It has been hypothesized that magnetic-field exposure reduces heart rate variability, which in turn increases the risk for AMI. In a large cohort of utility workers, Savitz et al. (1999) reported an association with arrhythmia-related deaths and deaths due to AMI among workers with higher magnetic field exposure. Previous and subsequent studies did not report a statistically significant increase in cardiovascular disease mortality or incidence related to occupational magnetic-field exposure (WHO, 2007).

The WHO concluded:

> Experimental studies of both short- and long-term exposure indicate that, while electric shock is an obvious health hazard, other hazardous cardiovascular effects associated with ELF fields are unlikely to occur at exposure levels commonly encountered environmentally or occupationally. Although various cardiovascular changes have been reported in the literature, the majority of effects are small and the results have not been consistent within and between studies. With one exception [Savitz et al., 1999], none of the studies of cardiovascular disease morbidity and mortality has shown an association with exposure. Whether a specific association exists between exposure and altered autonomic control of the heart remains speculative. Overall, the evidence does not support an association between ELF exposure and cardiovascular disease." (WHO, 2007, p. 220)

Recent studies (July 2013 to November 2014)

Since our last review in July 2013, no newly published studies of ELF EMF and cardiovascular diseases have been identified by our literature search.

Assessment

The conclusion that there is no association between magnetic fields and cardiovascular diseases has not changed.

In vivo studies related to carcinogenesis

In the field of ELF EMF research, a number of research laboratories have exposed rodents, including those with a particular genetic susceptibility to cancer, to high levels of magnetic fields over the course of the animals' lifetime and performed tissue evaluations to assess the incidence of cancer in many organs. In these studies, magnetic-field exposure has been administered alone (to test for the ability of magnetic fields to act as a complete carcinogen), in combination with a known carcinogen (to test for a promotional or co-carcinogenetic effect), or in combination with a known carcinogen and a known promoter (to test for a co-promotional effect).

The WHO review described four large-scale, long-term studies of rodents exposed to magnetic fields over the course of their lifetime that did not report increases in any type of cancer (Mandeville et al., 1997; Yasui et al., 1997; Boorman et al., 1999a, 1999b; McCormick et al., 1999). No directly relevant animal model for childhood ALL existed at the time of the WHO report. Some animals, however, develop a type of lymphoma similar to childhood ALL and studies exposing predisposed transgenic mice to ELF magnetic fields did not report an increased incidence of this lymphoma type (Harris et al., 1998; McCormick et al., 1998; Sommer and Lerchel, 2004).

Studies investigating whether exposure to magnetic fields can promote cancer or act as a co-carcinogen used known cancer-causing agents, such as ionizing radiation, ultraviolet radiation, or other chemicals. No effects were observed for studies on chemically-induced preneoplastic liver lesions, leukemia or lymphoma, skin tumors, or brain tumors; however, the incidence of 7,12-dimethylbenz[a]anthracene (DMBA)-induced mammary tumors was increased with magnetic-field exposure in a series of experiments in Germany (Löscher et al., 1993, 1994, 1997; Mevissen et al., 1993a,1993b, 1996a, 1996b, 1998; Baum et al., 1995; Löscher and Mevissen, 1995), suggesting that magnetic-field exposure increased the proliferation of mammary tumor cells. These results were not replicated in a subsequent series of experiments in a laboratory in the United States (Anderson et al., 1999; Boorman et al.1999a, 1999b), possibly due to differences in experimental protocol and the species strain. In Fedrowitz et al. (2004), exposure enhanced mammary tumor development in one sub-strain (Fischer 344 rats), but not in another sub-strain that was obtained from the same breeder, which argues against a promotional effect of magnetic fields.[12]

Some studies have reported an increase in genotoxic effects among exposed animals (e.g., DNA strand breaks in the brains of mice [Lai and Singh, 2004]), although the results have not been replicated.

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[12] The WHO concluded with respect to the German studies of mammary carcinogenesis, "Inconsistent results were obtained that may be due in whole or in part to differences in experimental protocols, such as the use of specific substrains" (WHO 2007, p. 321).

In summary, the WHO concluded the following with respect to *in vivo* research: "There is no evidence that ELF [EMF] exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate" (WHO, 2007, p. 322). Recommendations for future research included the development of a rodent model for childhood ALL and the continued investigation of whether magnetic fields can act as a promoter or co-carcinogen.

Recent studies (July 2013 to November 2014)

No new animal bioassays of tumor development due to magnetic-field exposure alone or in combination with known cancer initiators have been conducted since the study by Bernard et al. (2008) that was the first study to use an animal model of ALL, the most common leukemia type in children, reviewed in the previous update. Instead, various *in vivo* studies examining potential mechanisms that could precipitate cancer development have been conducted. These studies are listed in Table 9.

Two recent animal studies examined the ability of magnetic-field exposure to cause DNA damage. Saha et al. (2014) exposed pregnant mice to one of three different magnetic field (50-Hz) exposure conditions: 1,000 mG for 2 hours on day 13.5 of gestation, 3,000 mG (continuous) for 15 hours on day 12.5 of gestation, or 3,000 mG (intermittent: 5 minutes on, 10 minutes off) for 15 hours on day 12.5 of gestation. Controls were either untreated or sham-exposed under these same conditions, but with the exposure equipment turned off. Additional animals were exposed to either 10 or 25 Gray of X-irradiation on day 13.5 of gestation; however, the amount of time for which these treatments were given is not known. Although X-irradiation was associated with increased DNA double strand breaks and cell apoptosis in the embryonic brain cells of the ventricular and subventricular zones, none of the magnetic field conditions had a significant effect on these parameters. These analyses were not conducted in a blinded manner; however, the potential influence of the animal litter was taken into account in the statistical analysis.

In a related study, Korr et al. (2014) continuously exposed mice for 8 weeks to either 1,000 mG or 10,000 mG, 50-Hz magnetic fields. Controls were not sham-exposed, but maintained in the same room as the magnetic-field-exposed animals. At the end of the exposure period, the animals were injected with radiolabeled thymidine to look for DNA single-strand breaks and unscheduled DNA synthesis in the liver, kidneys, and brain using an autoradiographic method. A slight reduction in mitochondrial DNA synthesis was observed in the epithelial cells of the kidney collecting ducts at 1,000 mG, but no increase in DNA single-strand breaks was observed. At 10,000 mG, a slight reduction in unscheduled DNA synthesis (likely related to reduced mitochondrial DNA synthesis) was observed in the epithelial cells of the choroid plexus of the brain's fourth ventricle and the kidney collecting duct, but again, there was no difference in the degree of DNA single-strand breaks observed between treated and control animals. These investigations were conducted in a blinded manner.

Oxidative stress is a condition in which oxygen free radical levels in the body are elevated and is one mechanism by which DNA damage, as well as other forms of cellular damage, may occur. Numerous recent *in vivo* studies have evaluated whether magnetic-field exposure may be associated with oxidative stress, with mixed results. Seifirad et al. (2014) examined the expression of various markers, including the lipid peroxidation markers malondialdehyde, conjugated dienes, and total antioxidant capacity, in the blood following exposure of rats to a 5,000 mG, 60-Hz magnetic fields for either 4 hours (acute) or 14 days (chronic). The acute exposure was associated with increased total antioxidant capacity, while the chronic exposure was associated with increased malondialdehyde levels and a reduced total antioxidant capacity. Although the controls were reportedly sham-exposed, it is not known if this was for the acute or chronic exposure condition, making interpretation difficult. Blinded analyses and control of environmental conditions also were not reported.

In another study, Glinka et al. (2013) examined the expression of various antioxidant markers in the blood and liver of male rats following 30 minutes of exposure to 100,000 mG, 40-Hz magnetic fields, for 6, 10, or 14 days. The purpose of this analysis was to examine the potential role of magnetic fields in the treatment of wounds; thus, the rats were first wounded surgically prior to exposure. Controls were sham exposed, but blinded analyses were not reported. Further, no details on the preparation of liver homogenates or the methods used to analyze the various samples were reported. Differences from control in the expression of the antioxidant markers superoxide dismutase, glutathione peroxidase, and malondialdehyde were reported in either the blood or the liver on various days, but no clear pattern of expression was apparent. No differences in the expression of glutathione S-transferase was observed. It should be noted, however, that control values varied considerably across the different study days, which may be related to a confounding effect associated with the wound healing process.

Hassan and Abdelkawi (2014) exposed male rats to 100,000 mG, 50-Hz magnetic fields for 1 hour per day for 30 days. Other groups of rats were treated with cadmium chloride or both cadmium chloride and magnetic-field exposure. Although it was reported that the controls were sham-exposed, based on the methods description, this does not appear to be the case; also, analyses were not conducted in a blinded manner. Both magnetic-field exposure and cadmium treatment were reported to increase the total oxidant status and protein carbonyls present in the blood; both exposures combined results in an increased response over either single condition alone. Deng et al. (2013) conducted a similar study in which mice were exposed to 20,000 mG, 50-Hz magnetic fields for 4 hours per day, 6 days per week for 8 weeks. In this case, other treatment groups were exposed to aluminum or both magnetic fields and aluminum. Control mice were not reported to have been sham-exposed and analyses were not reported to have been conducted in a blinded manner. Both brain and serum levels of superoxide dismutase were reported to be lower in all exposure conditions compared to controls. In contrast, malondialdehyde levels were increased in all exposure groups. Other analyses looking at behavior and brain pathology were also conducted in this study, but are not reported here.

Manikonda et al. (2014) looked at the effects in rats of continuous, 90-day exposure to much lower magnetic field strengths (500 mG and 1,000 mG, 50-Hz). Controls were sham exposed in a similar exposure apparatus, but with the equipment turned off. Analyses were not reported to have been conducted in a blinded manner. Reactive oxygen species, thiobarbituric acid reactive substances (a marker of lipid peroxidation), and glutathione peroxidase were significantly increased compared to control levels in the hippocampus and cerebellum with both exposure conditions; they were also increased in the cortex, but at 1,000 mG only. Superoxide dismutase levels were also increased in all three tissues at 1,000 mG, while the thiol status (GSH/GSSG) was reduced with exposure in these tissues. Generally, the cortex was less responsive than the other brain tissues examined. It should be noted, however, that the exposed rats showed significantly higher levels of physical activity than the controls, which may have confounded the study results. Finally, Akdag et al. (2013) examined the effects of more long-term magnetic-field exposure. Rats were continuously exposed to a 1,000 or 5,000 mG, 50-Hz magnetic field for 2 hours per day for 10 months. Control rats were sham exposed (with the exposure system turned off) and analyses were reported to have been conducted in a blinded manner. Neither exposure condition affected the expression of various oxidant/anti-oxidant markers in the testes, although expression of an apoptosis marker seemed to be increased in an exposure-related manner.

Overall, it is hard to draw any conclusions from these studies of oxidative stress markers because the numbers of animals per group were generally low, the exposure parameters and oxidative stress markers examined varied across the studies, reported effects were contradictory across studies in some cases, and none of the analyses (with the exception of that by Akdag et al., 2013) were reported to have been conducted in a blinded manner. The equivocal nature of these data is similar to that of earlier studies investigating the influence of magnetic-field exposure on the expression of oxidative stress markers. Independent replications of findings in studies with greater sample sizes and blinded analyses are needed as well as a better understanding of how such markers may be related to health and disease processes.

Assessment

As previously noted, no new animal bioassays of long-term magnetic-field exposure as a possible carcinogen or co-carcinogen have been conducted since the last update. Rather, more recent animal studies have investigated two potential mechanisms related to carcinogenesis: genotoxicity and oxidative stress. The studies of oxidative stress generally suffer from various methodological deficiencies, including small samples sizes, the absence of sham-exposure treatment groups, and analyses that were not conducted in a blinded manner. Further, the results are generally inconsistent across the body of studies, with some studies reporting effects and other studies showing no change. Even in the studies showing alterations, these changes are not necessarily consistent from one study to the next. While these dissimilarities could be a function of the differences in exposure conditions employed across the body of studies, the equivocal nature of the findings on oxidative stress is consistent with that of earlier studies.

One particularly well-conducted study on genotoxicity found no effect of magnetic-field exposure on DNA double strand breaks. This study employed positive control X-irradiation, sham exposure of negative controls, and blinded analyses. Further, the results are generally consistent with those of another recent investigation that found no influence of magnetic-field exposure on the induction of DNA single strand breaks in the brain, liver, or kidneys of exposed mice.

Overall, the *in vivo* studies published since the last update do not alter the previous conclusion of the WHO that there is inadequate evidence of carcinogenicity due to ELF EMF exposure. Further, the limited recent investigations suggest that DNA single and double strand breaks do not occur as a result of magnetic-field exposure.

Table 9. Relevant *in vivo* studies related to carcinogenesis

Authors	Year	Study
Akdag et al.	2013	Can safe and long-term exposure to extremely low frequency (50 Hz) magnetic fields affect apoptosis, reproduction, and oxidative stress?
Deng et al.	2013	Effects of aluminum and extremely low frequency electromagnetic radiation on oxidative stress and memory in brain of mice
Glinka et al.	2013	Influence of extremely low-frequency magnetic field on the activity of antioxidant enzymes during skin wound healing in rats
Hassan and Abdelkawi	2014	Assessing of plasma protein denaturation induced by exposure to cadmium, electromagnetic fields and their combined actions on rat
Korr et al.	2014	No evidence of persisting unrepaired nuclear DNA single strand breaks in distinct types of cells in the brain, kidney, and liver of adult mice after continuous eight-week 50 Hz magnetic field exposure with flux density of 0.1 mT or 1.0 mT
Manikonda et al.	2014	Extremely low frequency magnetic fields induce oxidative stress in rat brain
Saha et al.	2014	Increased apoptosis and DNA double-strand breaks in the embryonic mouse brain in response to very low-dose X-rays but not 50 Hz magnetic fields
Seifirad et al.	2014	Effects of extremely low frequency electromagnetic fields on paraoxonase serum activity and lipid peroxidation metabolites in rat

7 Reviews Published by Scientific Organizations

A number of national and international scientific organizations have published reports or scientific statements with regard to the possible health effects of ELF EMF since January 2006. Although none of these documents represents a cumulative weight-of-evidence review of the caliber of the WHO review published in June 2007, their conclusions are of relevance. In general, the conclusions of these reviews are consistent with the scientific consensus articulated in Section 6.

The following list indicates the scientific organization and a link to the online reports or statements.

- **The European Health Risk Assessment Network on Electromagnetic Fields Exposure**
    - http://efhran.polimi.it/docs/D2_Finalversion_oct2012.pdf (EFHRAN, 2012 [human exposure])
    - http://efhran.polimi.it/docs/IMS-EFHRAN_09072010.pdf (EFHRAN, 2010 [*in vitro* and *in vivo* studies])
- **The Health Council of Netherlands**
    - http://www.gezondheidsraad.nl/sites/default/files/200902.pdf (HCN, 2009a)
    - http://www.gezondheidsraad.nl/en/publications/advisory-letter-power-lines-and-alzheimer-s-disease (HCN, 2009b)
    - http://www.gezondheidsraad.nl/en/publications/bioinitiative-report-0 (HCN, 2008a)
    - http://www.gezondheidsraad.nl/en/publications/high-voltage-power-lines-0 (HCN, 2008b)
- **The Health Protection Agency (United Kingdom)**
    - http://www.hpa.org.uk/Publications/Radiation/DocumentsOfTheHPA/RCE01PowerFrequencyElectromagneticFieldsRCE1/ (HPA, 2006)
- **The International Commission on Non-Ionizing Radiation Protection**
    - http://www.icnirp.de/documents/LFgdl.pdf (ICNIRP, 2010)

- **The Scientific Committee on Emerging and Newly Identified Health Risks (European Union)**
    - http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_007.pdf (SCENIHR, 2007)
    - http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_022.pdf (SCENIHR, 2009)
    - http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf (SCENIHR, 2015)

  The Swedish Radiation Protection Authority
    - http://www.who.int/peh-emf/publications/reports/SWEDENssi_rapp_2006.pdf (SSI, 2007)
    - http://www.who.int/peh-emf/publications/reports/SWEDENssi_rapp_2007.pdf (SSI, 2008)
- **The Swedish Radiation Safety Authority**
    - http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2009/SSM-Rapport-2009-36.pdf (SSM, 2009)
    - http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2010/SSM-Rapport-2010-44.pdf (SSM, 2010)
    - http://www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2013/201319/ (SSM, 2013)

8 Standards and Guidelines

Following a thorough review of the research, scientific agencies develop exposure standards to protect against known health effects. The major purpose of a weight-of-evidence review is to identify the lowest exposure level below which no health hazards have been found (i.e., a threshold). Exposure limits are then set well below the threshold level to account for any individual variability or sensitivities that may exist.

Several scientific organizations have published guidelines for exposure to ELF EMF based on acute health effects that can occur at very high field levels.[13] The ICNIRP reviewed the epidemiologic and experimental evidence and concluded that there was insufficient evidence to warrant the development of standards or guidelines on the basis of hypothesized long-term adverse health effects such as cancer; rather, the guidelines put forth in their 2010 document set limits to protect against acute health effects (i.e., the stimulation of nerves and muscles) that occur at much higher field levels. The ICNIRP recommends a residential screening value of 2,000 mG and an occupational exposure screening value of 10,000 mG (ICNIRP, 2010). If exposure exceeds these screening values, then additional dosimetry evaluations are needed to determine whether basic restrictions on induced current densities are exceeded. For reference, in a national survey conducted by Zaffanella and Kalton (1998) for the National Institute for Environmental Health and Safety's EMF Research and Public Information Dissemination program, only about 1.6% of the general public in the United States experienced exposure to magnetic fields of at least 1,000 mG during a 24-hour period.

The ICES also recommends limiting magnetic field exposures at high levels because of the risk of acute effects, although their guidelines are higher than ICNIRP's guidelines; the ICES recommends a residential exposure limit of 9,040 mG and an occupational exposure limit of 27,100 mG (ICES, 2002). Both guidelines incorporate large safety factors.

The ICNIRP and ICES guidelines provide guidance to national agencies and only become legally binding if a country adopts them into legislation. The WHO strongly recommends that countries adopt the ICNIRP guidelines, or use a scientifically sound framework for formulating any new guidelines (WHO, 2006).

There are no national or state standards in the United States limiting exposures to ELF EMF based on health effects. Two states, Florida and New York, have enacted standards to limit magnetic fields at the edge of the right-of-way from transmission lines (NYPSC, 1978; FDER, 1989; NYPSC, 1990; FDEP, 1996), however, the basis for these limits was to maintain the "status quo" so that fields from new transmission lines would be no higher than those produced by existing transmission lines.

[13] Valberg et al. (2011) provides a listing of guidelines provided by health and safety organizations.

Neither Rhode Island nor Massachusetts has EMF standards for transmission lines but the Energy Facility Siting Boards have encouraged the use of practical and cost-effective designs to minimize magnetic field levels along the edges of transmission rights-of-way. This approach is consistent with recommendations of the WHO (2007) for addressing ELF EMF.

Table 10. Screening guidelines for EMF exposure

Organization	Exposure (60 Hz)	Magnetic field
ICNIRP	Occupational	10,000 mG
	General Public	2,000 mG
ICES	Occupational	27,100 mG
	General Public	9,040 mG

Sources: ICNIRP, 2010; ICES, 2002

9 Summary

A significant number of epidemiology and *in vivo* studies have been published on ELF EMF and health since the WHO 2007 report was released in June 2007. The weak statistical association between high, average magnetic fields and childhood leukemia has not been appreciably strengthened or substantially diminished by subsequent research, although the most recent studies tended to show no overall associations. The previously reported association remains unexplained and unsupported by the experimental data. The recent *in vivo* studies confirm the lack of experimental data supporting a leukemogenic risk associated with magnetic-field exposure. Recent publications on other cancer and non-cancer outcomes provided no substantial new information to alter the previous conclusion that the evidence is inadequate to link outcomes to ELF EMF exposure.

In conclusion, recent studies when considered in the context of previous research do not provide evidence to alter the conclusion that ELF EMF exposure is not a cause of cancer or any other disease process at the levels we encounter in our everyday environment.

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APPENDIX B LOAD RATING ANALYSIS WITH ADDITIONAL UTILITY LOADS

LOAD RATING ANALYSIS WITH ADDITIONAL UTILITY LOADS

PROVIDENCE

POINT STREET

OVER

PROVIDENCE RIVER

Bridge No. 098001

SEPTEMBER 2017

Submitted To:

POWER Engineers, Inc.
100 John L. Dietsch Square
North Attleboro, MA 02763

Prepared By:

CDR Maguire, Inc
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POINT STREET OVER PROVIDENCE RIVER

Table of Contents

Report Prepared By: Yihui Wu

Yihui Peter Wu, P.E. **Date: 9/07/2017**

1.0 Introduction

1.1 Existing Bridge Description

Point Street Bridge No. 980 carrying Point Street over the Providence River (Point Street Bridge), is located in Providence, Rhode Island and owned by the City of Providence. The bridge was originally built in 1927 and rehabilitated in 1999.

The Point Street Bridge is an eight (8) span steel bridge with a total length of approximately 524 feet. The first and last three (3) spans (1-3 and 6-8) consist of a steel multi-girder superstructure supporting a composite concrete deck. The main spans (spans 5-6) consist of a two-span continuous through Warren truss. The bridge has a 60 foot out to out width and a 39 foot roadway, curb to curb, width. There are 10.5 foot wide reinforced concrete sidewalks on both sides of the roadway. See Appendix 4.2 for the existing Bridge Plans.

1.2 Proposed Work

One of the underground electrical lines that pass beneath the Providence River has failed in the River and is not repairable. A new duct bank within the Point Street Bridge will be installed to replace the failed electrical line. The new duct bank will consist of nine fiberglass conduits beneath the North Sidewalk. The conduits will house six power conductors, two grounding cables and one communication cable. These added utilities will cause additional loads to the bridge. The calculated added load from the proposed new duct bank is 217 lbf/ft as shown in appendix 4.1.33. A load rating analysis is conducted on the existing structure with the added utility loads in order to determine the effects of the added utilities on the existing bridge structure. The current RIDOT load rating of the bridge shall be maintained.

2.0 Load Ratings

The bridge structure is scheduled for preservation in the year of 2025. It is not anticipated that significant rehab or preservation construction work will be required prior to 2025, based upon the current RIDOT bridge condition inspection and load rating report. The added utility to the existing structure shall maintain the current load rating level to avoid significant bridge structure modification. The following criteria was used for the evaluation:

1. The bridge load rating factors shall not be lowered due to the addition of the utility. If needed, bridge element rehabilitation or modification will be completed to maintain the bridge load rating. The Bridge capacity for live vehicle traffic or weight postings will not be affected.

2. The Bridge Elements governing the bridge load rating will be identified, among the Main Span truss bridge and approach span steel stringer bridge. The load group for the governing elements will be identified.
3. A loading analysis will be conducted for the governing bridge elements and load group. The load rating factors will be compared to the existing load rating to determine if the existing load rating is maintained.
4. The Bridge Elements directly impacted by the added utility will be analyzed. Load rating factors will be compared to the existing load rating results to determine the effects to the bridge.
5. In order to compare the load rating of the bridge against the load rating of the bridge with the proposed utility addition to the North Sidewalk, the governing load group limit state will be checked for the controlling bridge elements. It is assumed that if the proposed utility addition load rating of the controlling bridge elements, under the governing load group, remain unchanged, then the bridge structure's capacity for vehicle traffic and load rating will be maintained.
6. The sidewalk supporting diaphragm of the approach span and supporting bracket bracing of the main span are not rated for vehicle live load. No separate analysis will be conducted as they are adequate to support the utilities by inspection of the similar utility loading condition on the bridge south sidewalk.

2.1 RIDOT Load Rating of the Existing Bridge

The Load Rating (LR) of the existing bridge structure was performed by Michael Baker Engineering, Inc in 2012. This Load Rating was performed based on the existing conditions found in the routine inspection conducted on May 2nd, 2012. The Loading Rating was prepared in accordance with the AASHTO – Manual for Bridge Evaluation, AASHTO LRFD Bridge Design Specifications and RIDOT Guidelines for Load and Resistance Factor Rating of Highway Bridges. The bridge was rated for HL-93 Design loads (inventory and operating), the legal loads for H-20, Type 3, Type 3S2, Type 3-3, SU4, SU5, SU6, and SU7, and the permit vehicle loads of RI-BP1, RI-BP2, RI-BP3, RI-BP4, RI-OP1, RI-OP2, and RI-OP3. The Approach Spans and Main Truss spans were analyzed separately and the governing rating factor was used to rate the overall bridge. The Summary of the Bridge Rating, performed by Michael Baker in 2012, is given in Table 1 below; the governing Rating Factor (RF) of 0.62 is shaded. The bridge has ratings less than statutory but greater than 10 tons. Therefore, the Bridge Rating Report Cover is noted as Yellow. The RIDOT Load Rating report is attached in Appendix 4.3.

Table 1: Summary of Existing Bridge Load Rating

Vehicle Type		RF	RL (TONS)	POSTING
HL-93	INV	0.62	N/A	-
	OPER	0.81	N/A	-
H20		1.22	24.40	N/A
TYPE 3		1.32	33.00	N/A
TYPE 3S2		1.37	49.32	N/A
TYPE 3-3		1.64	65.60	N/A
SU 4		1.13	30.51	N/A
SU 5		1.09	33.79	N/A
SU 6		1.09	37.87	N/A
SU 7		1.09	42.23	N/A
RI-BP1		0.87	33.06	30
RI-BP2		0.99	37.12	36
RI-BP3		1.03	53.97	N/A
RI-BP4		0.77	50.05	43
RI-OP1		1.41	79.66	N/A
RI-OP2		1.52	121.60	N/A
RI-OP3		1.80	203.04	N/A

The governing load rating is for HL-93 design load, and permit vehicle of RI-BP1, RI-BP2 and RI-BP2.

2.1.1 Approach Spans

The approach spans consist of three 12’ wide lanes and two 1’-6” shoulders and 11’ wide sidewalks on both sides. Spans 1-3 and 6-8 each consists of three-span continuous structures. The West approach spans (1-3) have greater lengths than the East approach spans (6-8) and thus these lengths were used in the load rating analysis. The framing consists of two W36x150 fascia girders and four W33x118 interior girders, and W21x62 sidewalk stringers outside of the fascia girders. Welded cantilever brackets support the sidewalk stringers and carry loads back to the fascia girders. There are six 6 inch conduits under the south sidewalks, installed in 1999, and one 4 inch conduit on the north side fascia.

The typical fascia and interior girders were rated using BRASS GIRDER (LRFD). The following assumptions were used in the rating of the approach spans:

- The self-weight of the girders, deck and deck haunches were calculated by BRASS.
- The six 6 inch conduits utility load (largest utility load), pedestrian rail, sidewalk stringer, sidewalk and sidewalk bracket loads were applied entirely to the fascia girder
- The girders were rated using their “as-built” conditions as the inspection report stated that they had no section loss
- Vehicular live loads are not anticipated to be on the sidewalks, and thus the sidewalk supporting stringer and bracket were not rated.
- The bridge deck condition is rated as “very good” (rated as 8) and thus per RIDOT guidelines the deck was not rated.

From the 2012 Load Rating Report, the governing Rating Factors for the Interior and Exterior Girders, in the Approach Spans, are given in Table 2 and Table 3. The tables list the member, Point Of Interest (POI) and the limit state that governs. The X's mean the rating factors do not govern in this location/limit state. The governing interior girder RF is 1.74 (HL-93 inv.) and the governing fascia (exterior) girder RF is 2.33 (HL-93 inv.). Both governing factors are due to the Strength I limit state; which are shaded.

Table 2: Summary of Approach Span Rating Factors (Design and Legal)

Bridge Component	Design Load (HL-93)		Legal Load (TONS)							
	INV	OPER	H20	TYPE 3	TYPE 3S2	TYPE 3-3	SU4	SU5	SU6	SU7
Int. Girder Span 1-3 – As Built – Strength I – POI: 306 (Span 3 at 25.09')	1.74	2.26	X	X	X	X	X	X	X	X
Int. Girder Span 1-3 – As Built – Service II – POI: 210 (Span 2 at 41.56')	X	X	X	X	115.93	134.43	X	X	X	X
Int. Girder Span 1-3 –As Built – Service II – POI: 306 (Span 3 at 25.09')	X	X	59.47	74.22	X	X	69.07	73.71	75.58	80.01
Int. Girder Span 1-3 –As Built – Fatigue I – POI: 210 (Span 2 at 41.56')	2.83	X	X	X	X	X	X	X	X	X
Ext. Girder Span 1-3 –As Built – Strength I – POI: 306 (Span 3 at 25.09')	2.33	3.01	X	X	X	X	X	X	X	X
Ext. Girder Span 1-3 –As Built – Service II – POI: 210 (Span 2 at 41.56')	X	X	X	X	148.93	172.73	X	X	X	X
Ext. Girder Span 1-3 –As Built – Service II – POI: 306 (Span 3 at 25.09')	X	X	79.49	99.19	X	X	92.31	98.52	101.03	106.93
Ext. Girder Span 1-3 –As Built – Fatigue I – POI: 210 (Span 2 at 41.56')	4.02	X	X	X	X	X	X	X	X	X

Table 3: Summary of Approach Span Rating Factors (RI Permit)

Bridge Component	RI Permit Trucks (TONS)						
	RI-BP1	RI-BP2	RI-BP3	RI-BP4	RI-OP1	RI-OP2	RI-OP3
Int. Girder Span 1-3 – As Built – Strength II POI: 306 (Span 3 at 25.09')	X	X	X	X	177.46	302.55	423.54
Int. Girder Span 1-3 – As Built – Service II POI: 306 (Span 3 at 25.09')	89.52	92.18	127.40	139.69	141.91	241.95	338.70
Ext. Girder Span 1-3 – As Built – Strength II POI: 306 (Span 3 at 25.09')	X	X	X	X	224.49	382.74	535.91
Ext. Girder Span 1-3 – As Built – Service II POI: 306 (Span 3 at 25.09')	119.65	123.20	170.28	186.71	179.63	306.26	428.82

2.1.2 Main Span

The Main Spans of the bridge (4 and 5) consist of a two span continuous through Warren riveted truss. The truss is supported at the panel points L0, L6, L7 and L13. The members that make up the truss system are the truss members themselves, built up floorbeams, seven riveted stringers and cross beams. There are sidewalk stringers outside of the truss system that are connected to the truss by sidewalk bracket members. The sidewalk stringers were not rated as it is not anticipated that vehicular live load will act on them.

The truss system of floorbeams, truss members, stringers and cross beams were rated separately. The following methodology and assumptions were used, by Michael Baker, to rate the main span members.

- The truss was modeled in STAAD to obtain live load and dead load force effects. The truss members were then load rated, by hand, based on AASHTO LRFD 6.8 and 6.9 and RIDOT Guidelines. The sidewalk, sidewalk brackets, sidewalk stringers, and utility loads were applied to the panel points in STAAD. Table 4 and Table 5 list the governing truss member rating factors.
- The stringers and floorbeams were rated using BRASS GIRDER (LRFD). The members with significant section loss were rated by determining the reduced section areas and associated properties and inputting these into BRASS. The members with less than 2% section loss were rated based on as-built conditions. Table 6 and Table 7 list the governing Floorbeam rating factors. The governing overall floorbeam rating factor is shaded. Table 8 and Table 9 list the governing stringer rating factors.
- The reactions at the supports for the crossbeams were determined from SAP 2000. These reactions were applied to the crossbeams and rated by BRASS GIRDER (LRFD). Table 10 and Table 11 list the governing rating factors for the crossbeams.
- Gusset plates were analyzed by hand calculations based on AASHTO LRFD and FHWA.

The following tables list the governing rating factors for the various members of the truss system as determined by the 2012 Load Rating. Each summary table includes the governing bridge component, the condition it was rated in (as built or as inspected), the limit state, the Point of Interest (POI) and the rating factor (HL-93) or Loading (in TONS). If there is an X under the loading than at this location and/or limit state than this loading is not governing.

Based upon these load rating results, the truss members, stringers, cross beams and gusset plates all have rating factors above 1. The floorbeams have a couple of members that have rating factors below 1 and below statutory load levels due to deterioration. The governing main span bridge rating factor is due to HL-93 loading at floorbeam 13 for the Strength I limit state, it is shaded in Table 6. This rating factor is less than 1 due to the reduced shear resistance because of section loss within a critical stress region. The floorbeam was also found to rate below statutory load levels for R1-BP1, RI-BP2 and RI-BP4 vehicles. See Appendix 4.3 for complete RIDOT Load Rating Report.

Table 4: Summary of Truss Member Rating Factors (Design and Legal Load)

Bridge Component	Design Load (HL-93)		Legal Load (TONS)							
	INV	OPER	H20	TYPE3	TYPE 3S2	TYPE 3-3	SU 4	SU 5	SU 6	SU 7
L5U5 – As Built Strength I Tension Resistance	1.98	2.57	90.20	111.25	171.72	180.40	102.60	110.98	111.90	117.03

Table 5: Summary of Truss Member Rating Factors (RI Permit)

Bridge Component	RI Permit Trucks (TONS)						
	RI-BP1	RI-BP2	RI-BP3	RI-BP4	RI-OP1	RI-OP2	RI-OP3
L5U5 & L8U8 – As Built Strength II Tension Resistance	114.38	118.13	164.54	170.30	218.09	382.40	562.74

Table 6: Summary of Floorbeam Rating Factors (Design and Legal Load)

Bridge Component	Design Load (HL-93)		Legal Load (TONS							
	INV	OPER	H20	TYPE 3	TYPE 3S2	TYPE 3-3	SU 4	SU 5	SU 6	SU 7
End Floorbeam – As Built Strength I POI: 105 (FB 0&13 at 21.4’)	1.84	2.38	X	X	X	X	X	X	X	X
End Floorbeam – As Built Service II POI: 105 (FB 0&13 at 21.4’)	X	X	69.20	94.00	140.76	186.40	86.94	96.10	107.72	120.12
End Floorbeam 0 – As Insp. Strength I POI: 109.727 (FB 0 at 41.53’)	1.06	1.37	41.40	56.25	84.24	111.60	52.11	57.35	64.28	71.68
End Floorbeam 13 – As Insp. Strength I POI: 109.727 (FB13 at 41.62’)	0.62	0.81	24.40	33.00	49.32	65.60	30.51	33.79	37.87	42.23
Int. Floorbeam – As Built Strength I POI: 105 (FB 1-4 & 9-12 at 21.4’)	1.62	2.10	X	X	X	X	X	X	X	X
Int. Floorbeam – As Built Service II POI: 105 (FB 1-4 & 9-12 at 21.4’)	X	X	62.40	84.75	126.72	168.40	78.57	86.80	97.30	108.50
Int. Floorbeam 9 – As insp. Strength I POI: 109.593 (FB 9 at 41.05’)	0.85	1.10	33.20	45.25	67.68	89.60	41.85	46.19	51.77	57.73
Int. Floorbeam – As Built Strength I POI: 105 (FB 5 & 8 at 21.4’)	1.66	2.15	X	X	X	X	X	X	X	X
Int. Floorbeam – As Built Service II POI: 105 (FB 5 & 8 at 21.4’)	X	X	63.80	86.50	129.6	172.00	80.19	88.66	99.38	110.82
Int. Floorbeam 8 – As insp. Strength I POI: 109.726 (FB 8 at 41.62’)	1.39	1.80	54.60	74.00	110.52	146.80	68.58	75.64	84.79	94.55

Table 7: Summary of Floorbeam Rating Factors (RI Permit)

Bridge Component	RI Permit Trucks (TONS)						
	RI-BP1	RI-BP2	RI-BP3	RI-BP4	RI-OP1	RI-OP2	RI-OP3
End Floorbeam – As Built Strength II POI: 105 (FB 0&13 at 21.4’)	98.04	109.87	159.82	148.85	X	X	X
End Floorbeam – As Built Strength II POI: 110 (FB 0&13 at 42.79’)	X	X	X	X	242.38	370.40	620.37
End Floorbeam – As Built Service II POI: 105 (FB 0&13 at 21.4’)	X	X	X	X	235.60	360.80	602.29
End Floorbeam 0– As Insp. Strength II POI: 109.704 (FB 0 at 41.53’)	56.62	63.37	92.22	85.80	135.60	207.20	346.91
End Floorbeam 0– As Insp. Service II POI: 105 (FB 0 at 21.4’)	X	X	X	X	229.95	352.00	586.47
End Floorbeam 13– As Insp. Strength II POI: 109.727 (FB 13 at 41.62’)	33.06	37.12	53.97	50.05	79.66	121.60	203.40
End Floorbeam 13– As Insp. Service II POI: 105 (FB 13 at 21.4’)	X	X	X	X	231.08	353.60	589.86
Int. Floorbeam – As Built Strength II POI: 105 (FB 1-4 & 9-12 at 21.4’)	86.64	96.75	140.95	131.30	X	X	X
Int. Floorbeam – As Built Strength II POI: 110 (FB 1-4 & 9-12 at 42.79’)	X	X	X	X	215.26	328.80	551.44
Int. Floorbeam – As Built Service II POI: 105 (FB 1-4 & 9-12 at 21.4’)	X	X	X	X	212.44	325.60	543.53
Int. Floorbeam 9 – As Insp Strength II POI: 109.593 (FB 9 at 41.05’)	45.60	51.00	73.88	68.90	109.04	166.40	277.98
Int. Floorbeam 9 – As Insp Service II POI: 105 (FB 9 at 21.4’)	X	X	X	X	212.44	325.60	543.53
Int. Floorbeam – As Built Strength II POI: 105 (FB 5 & 8 at 21.4’)	88.54	99.00	144.62	133.90	220.91	337.60	565.00
Int. Floorbeam – As Built Service II POI: 105 (FB 5 & 8 at 21.4’)	X	X	X	X	216.96	332.80	554.83
Int. Floorbeam 8 – As Insp Strength II POI: 109.726 (FB 8 at 41.62’)	74.48	83.25	121.04	112.45	177.97	272.00	456.52
Int. Floorbeam 8 – As Insp. Service II POI: 105 (FB 8 at 21.4’)	X	X	X	X	216.96	332.80	554.83

Table 8: Summary of Stringer Rating Factors (Design and Legal)

Bridge Component	Design Load (HL-93)		Legal Load (TONS							
	INV	OPER	H20	TYPE 3	TYPE 3S2	TYPE 3-3	SU 4	SU 5	SU 6	SU 7
Int. Stringer – As Built Strength I POI: 105 (Panels 1-6 & 8-13 at 10.25’)	1.37	1.78	X	X	X	X	X	X	X	X
Int. Stringer – As Built Service II POI: 105 (Panels 1-6 & 8-13 at 10.25’)	X	X	43.57	63.05	99.57	122.49	58.05	63.26	67.24	74.98
Int. Stringer – As Built Fatigue I POI: 105 (Panels 1-6 & 8-13 at 10.25’)	1.84	X	X	X	X	X	X	X	X	X
Int. Stringer C – As insp Strength I POI: 105 (Panels 11 at 10.25’)	1.37	1.78	X	X	X	X	X	X	X	X
Int. Stringer C – As insp Service II POI: 105 (Panels 11 at 10.25’)	X	X	43.57	63.05	99.58	122.49	58.05	63.26	67.25	74.99
Int. Stringer C – As insp Fatigue I POI: 105 (Panels 11 at 10.25’)	1.84	X	X	X	X	X	X	X	X	X
Ext. Stringer – As Built Strength I POI: 105 (Panels 1-6 & 8-13 at 10.25’)	2.18	2.83	X	X	X	X	X	X	X	X
Ext. Stringer – As Built Service II POI: 105 (Panels 1-6 & 8-13 at 10.25’	X	X	69.60	100.28	158.37	194.82	92.33	100.61	106.95	119.26
Ext. Stringer – As Built Fatigue I POI: 105 (Panels 1-6 & 8-13 at 10.25’	2.55	X	X	X	X	X	X	X	X	X
Int. Stringer – As Built Strength I POI: 105 (Panels 7 at 10.25’)	1.40	1.81	X	X	X	X	X	X	X	X
Int. Stringer – As Built Service II POI: 104 (Panels 7 at 8.2’)	X	X	X	65.27	X	X	X	X	X	X
Int. Stringer – As Built Service II POI: 105 (Panels 7 at 10.25’)	X	X	48.69	X	95.51	X	58.18	62.46	63.62	67.71
Int. Stringer – As Built Service II POI: 106 (Panels 7 at 12.3’)	X	X	X	X	X	128.38	X	X	X	X
Int. Stringer – As Built Fatigue I POI: 105 (Panels 7 at 10.25’)	2.15	X	X	X	X	X	X	X	X	X
Ext. Stringer – As Built Strength I POI: 105 (Panels 7 at 10.25’)	2.24	2.91	X	X	X	X	X	X	X	X
Ext. Stringer – As Built	X	X	X	104.43	X	X	X	X	X	X

Service II POI: 104 (Panels 7 at 8.2’)										
Ext. Stringer – As Built Service II POI: 105 (Panels 7 at 10.25’)	X	X	78.02	X	153.03	X	93.22	100.08	101.94	108.48
Ext. Stringer – As Built Service II POI: 106 (Panels 7 at 12.3’)	X	X	X	X	X	205.40	X	X	X	X
Ext. Stringer – As Built Fatigue I POI: 105 (Panels 7 at 10.25’)	2.96	X	X	X	X	X	X	X	X	X
Ext. Stringer G – As Insp Strength I POI: 105 (Panels 7 at 10.25’)	2.05	2.66	X	X	X	X	X	X	X	X
Ext. Stringer G – As Insp Service II POI: 105 (Panels 7 at 10.25’)	X	X	69.48	93.46	136.29	185.52	82.03	89.13	90.79	96.62
Ext. Stringer G – As Insp Fatigue I POI: 105 (Panels 7 at 10.25’)	2.66	X	X	X	X	X	X	X	X	X

Table 9: Summary of Stringer Rating Factors (RI Permit)

Bridge Component	RI Permit Trucks (TONS)						
	RI-BP1	RI-BP2	RI-BP3	RI-BP4	RI-OP1	RI-OP2	RI-OP3
Int. Stringer – As Built Strength II POI: 105 (Panels 1-6 & 8-13 at 10.25’)	X	X	X	X	152.54	220.28	364.33
Int. Stringer – As Built Service II POI: 105 (Panels 1-6 & 8-13 at 10.25’)	95.70	82.60	121.67	110.45	124.28	182.00	294.74
Int. Stringer C – As Insp Strength II POI: 105 (Panels 11 at 10.25’)	X	X	X	X	152.55	220.29	364.34
Int. Stringer C – As Insp Service II POI: 105 (Panels 11 at 10.25’)	75.71	82.61	121.67	110.46	124.28	182.01	294.76
Ext. Stringer – As Built Strength II POI: 105 (Panels 1-6 & 8-13 at 10.25’)	X	X	X	X	215.75	311.74	515.13
Ext. Stringer – As Built Service II POI: 105 (Panels 1-6 & 8-13 at 10.25’)	120.41	131.38	193.51	175.68	175.70	257.31	416.70
Int. Stringer – As Built Strength II POI: 105 (Panels 7 at 10.25’)	X	X	X	X	126.85	203.88	344.92
Int. Stringer – As Built Service II POI: 105 (Panels 7 at 10.25’)	74.68	78.13	118.8	111.01	104.44	167.87	283.99
Ext. Stringer – As Built Strength II POI: 105 (Panels 7 at 10.25’)	X	X	X	X	180.82	290.63	491.67
Ext. Stringer – As Built Service II	119.65	125.18	190.34	177.85	148.74	239.07	404.45

POI: 105 (Panels 7 at 10.25’)							
Ext. Stringer G – As Insp Strength II POI: 105 (Panels 7 at 10.25’)	X	X	X	X	165.66	266.26	450.45
Ext. Stringer G – As Insp Service II POI: 105 (Panels 7 at 10.25’)	106.56	111.49	169.52	158.4	132.47	212.92	360.22

Table 10: Summary of Crossbeam Rating Factors (Design and Legal)

Bridge Component	Design Load (HL-93)		Legal Load (TONS)							
	INV	OPER	H20	TYPE3	TYPE 3S2	TYPE 3-3	SU 4	SU 5	SU 6	SU 7
Int. Crossbeam – As built Strength I POI: 310 (Span 3 at 6.33’)	1.49	1.94	62.80	81.25	127.80	156.80	78.30	89.28	94.17	105.01
Ext. Crossbeam – As built Strength I POI: 310 (Span 3 at 6.33’)	2.04	2.64	62.40	104.50	166.68	202.40	111.51	127.72	143.51	160.03

Table 11: Summary of Crossbeam Rating Factors (RI Permit)

Bridge Component	RI Permit Trucks (TONS)						
	RI-BP1	RI-BP2	RI-BP3	RI-BP4	RI-OP1	RI-OP2	RI-OP3
Int. Crossbeam – As built Strength II POI: 310 (Span 3 at 6.33’)	83.98	99.00	142.00	127.40	X	X	X
Int. Crossbeam – As built Strength II POI: 610 (Span 6 at 6.33’)	X	X	X	X	171.19	236.00	368.38
Int. Crossbeam – As built Service II POI: 310 (Span 6 at 6.33’)	X	X	X	X	374.59	516.00	805.69
Ext. Crossbeam – As built Strength II POI: 310 (Span 3 at 6.33’)	110.96	157.50	187.06	209.95	240.12	403.20	596.64
Ext. Crossbeam – As built Service II POI: 710 (Span 7 at 6.33’)	X	X	X	X	555.39	932.0	1379.73

Table 12: Summary of Gusset Plate Rating Factors (Design and Legal)

Bridge Component	Design Load (HL-93)		Legal Load (TONS)							
	INV	OPER	H20	TYPE3	TYPE 3S2	TYPE 3-3	SU 4	SU 5	SU 6	SU 7
L1 & L12 As Built Strength I Tension Resistance of GP at L1U1	X	X	58.40	72.00	X	X	66.42	71.92	72.62	75.56
U5 & U8 As Built Strength I Resistance of Fasteners at U5L6	1.34	1.74	X	X	82.80	111.60	X	X	X	X

Table 13: Summary of Gusset Plate Rating Factors (RI Permit)

Bridge Component	RI Permit Trucks (TONS)						
	RI-BP1	RI-BP2	RI-BP3	RI-BP4	RI-OP1	RI-OP2	RI-OP3
L1 & L12 As Built Strength I Tension Resistance of GP at L21U1	74.10	76.50	106.37	109.85	141.25	247.20	X
U5 & U8 As Built Strength I Resistance of Fasteners at U5L6	X	X	X	X	X	X	307.36

2.1.3 North Sidewalk

The structure elements to support the sidewalk were not rated for the pedestrian live load in accordance with RIDOT LRFD bridge Load rating Manual. Pedestrian live load is not included in the bridge load rating. The support bracket diaphragm plate (for the approach span) and bracing (for the main span), utility and other incidental dead weights were add to the joint load (for the main span truss) and the steel beam (for the approach span).

2.2 Load Rating Analysis – Additional Utilities

The proposed additional utility weight under the north side is 217 lbf/ft per POWER Engineers (see Appendix 4.1.3 for the calculation). For the Load Rating Analysis of the additional utility loads on the structure a total loading of 250lbf/ft was used to be conservative. This additional utility load will be added to the approach span structure and main span structure to check its effects on the existing load rating.

2.2.1 Approach Spans

In the RIDOT rating analysis performed by Michael Baker, the maximum utility dead load under south sidewalk was applied entirely on the exterior girder in the approach spans. The existing maximum utility load used was 28lbf/ft. This uniform load was applied to the exterior (fascia) beam and rated in BRASS GIRDER (LRFD). The governing existing load rating factor is 2.33 for the exterior girder. This load factor is due to the HL-93 loading, Strength I limit state. The BRASS GIRDER (LRFD) exterior beam rating was rerun using the 250lbf/ft value for utility loading instead of the 28lbf/ft. The load rating factor was reduced by approximately 3.6% and is 2.25. See Table 14 for the existing and new rating factor comparison for the exterior stringers. See Appendix 4.1.2.2 for the BRASS Output with the 250lbf/ft utility load.

Table 14: HL-93 Governing Rating Factor Comparison (Approach)

Member	Existing RF	New RF	RF Difference (%)	RF > 1 (OK/NG)
Typical Exterior Girder	2.33	2.25	-3.56	OK

The new rating factor is 2.25 for the approach span which is significantly greater than the bridge governing rating factor of 0.62. Therefore the added utility loads on the approach span will not alter the bridge load rating.

2.2.2 Main Spans

In the RIDOT rating analysis performed by Michael Baker, the maximum utility dead load of 28lbf/ft, under the south sidewalk, was multiplied by the panel lengths and applied at the panel points (L0, L1, etc.) in the STAAD model for the main span truss. STAAD output the tensile and compressive forces in the various truss members resulting from the self-weight, dead loads, live loads and DW (utility and wearing surface) load. The output forces from STAAD were used to calculate the Existing Rating Factor (RF). The governing loading was due to the Strength I HL-93 loads.

The overall governing bridge rating factor is at Floorbeam 13 for Strength I HL-93 loading due to the reduced shear resistance at the beam end. Since the floor beam has a pin connection with the main span truss at the panel joint, the added utility load at the joint has no loading path to the floor beam. Thus only the truss members connected to the panel joint need to be checked for the increased utility loads to ensure their rating factor is not lowered.

For the proposed added utility analysis, the new maximum utility load of 250lbf/ft was multiplied by the panel lengths and applied at the panel points in STAAD to replace the existing utility load. The STAAD Model was rerun with this new loading and the newly output DW forces were used to calculate the new RF. See Appendix 4.1.1.1 for the new Rating Factor calculations and Appendix 4.1.1.2 for the STAAD Output. The other existing loads remained the same and thus their tensile and compressive forces remained the same. The new load rating factors were calculated for the governing load case of HL-93. Table 15 compares the new RF to the Existing Rating factor for truss members connected to the panel joint. The Rating factor decreased approximately 2%, however it is still over 1 and will not adversely affect the bridge load rating. Thus, the utility loads acting on the truss members do not lower the bridge rating and will not reduce the posting.

Table 15: HL-93 Governing Rating Factor Comparison (Main)

Member	Tension/Compression	Existing RF	New RF	RF Difference (%)	RF > 1 (OK/NG)
L5U5	Tension	1.98	1.95	-1.79	OK
L0U1	Compression	2.35	2.30	-2.10	OK

3.0 Conclusions

The existing governing load rating factor of 0.62 is for the HL-93 design vehicle loading at the beam end of Floorbeam 13, for shear resistance due to the floor beam section loss. The bridge rating for Floorbeam 13 is below statutory. The purpose of the additional utility load rating analysis was to determine if the added loads would lower the bridge load rating. CDR Maguire analyzed the existing structure and RIDOT Load Rating Report in relation to the proposed added utility load of 250lbf/ft.

Due to the added utility loads the Approach Spans (Spans 1-3 and 6-8) fascia girder rating factor was reduced approximately 4%, from 2.33 to 2.25, but still much greater than 1.0. Furthermore, the approach span exterior stringer rating is not the critical bridge element for the bridge load rating. Thus, the added utility loads on the approach spans do not alter the Bridge Rating.

For main span truss structure, the additional utility loads will not alter the floor beam system, only the truss members. The governing rating factor for the truss members was decreased from 1.98 to 1.95, less than a 2% difference, but still much greater than 1.0. The truss members are not the bridge load rating controlling elements. Thus, the added utility loads on the Main span will not alter the Bridge Load Rating.

Based upon the analysis, it is concluded that the bridge load rating and live load capacity is not affected by the additional utility loads; the existing bridge load rating shall be maintained.

APPENDIX C AGENCY CORRESPONDENCE

Michael D. Borg
Director

Jorge O. Elorza
Mayor

DEPARTMENT OF PUBLIC WORKS

"Building Pride in Providence"

December 12, 2017

Marisa Albanese
Manager, Community & Customer, RI
National Grid
280 Melrose St.
Providence, RI 02907

Re: Point Street Bridge

Dear Ms. Albanese:

This communication shall serve as a formal notice that the City of Providence has reviewed the information submitted on December 6, 2017, regarding the attachment of electrical transmission cables to the Point Street Bridge, owned by the City, and has no objection with this project proceeding as outlined.

Permits will be required for excavating within the public right of way, as well as impacts to traffic, both vehicular and pedestrian.

If you have any further questions or comments on this matter, feel free to contact this office.

Very truly yours,

Michael D. Borg
Director

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RI dot
Driven to get you there

Department of Transportation
Two Capitol Hill
Providence, RI 02903

Office 401-222-2450
Fax 401-222-3905

November 3, 2017

Ms. Marisa Albanese
National Grid
280 Melrose Street
Providence, RI 02907

Dear Ms Albanese,

This letter is in response to the request of RIDOT to review a proposal to add conduit under the Point Street Bridge.

The Department's Bridge Engineers reviewed the Load Rating Results submitted by Maguire and find them to be acceptable. No decrease in the governing vehicular load rating factors were noted and we see no detrimental effects to the load capacity of this bridge by adding the weight of the conduit.

The Department appreciates the opportunity to provide feedback on the proposal. If I can be of further assistance, please do not hesitate to contact me.

Sincerely,

Lori A. Fisette

Lori A. Fisette
Manager of Project Management
Rhode Island Department of Transportation

Cc: David Fish