February 2021

THE NARRAGANSETT ELECTRIC COMPANY

d/b/a NATIONAL GRID

J16S 115 kV Transmission Line Thermal Upgrade Project

Cumberland, Rhode Island

Rhode Island Energy Facility Siting Board

PROJECT NUMBER:
154599

PROJECT CONTACT:
David Halliwell
EMAIL:
david.halliwell@powereng.com
PHONE:
774-643-1861

POWER ENGINEERS CONSULTING, PC

This page intentionally left blank.

Rhode Island Energy Facility Siting Board

Siting Report

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:
POWER Engineers, Inc.
2 Hampshire Street
Suite 301
Foxborough, MA 02035

This page intentionally left blank.

TABLE OF CONTENTS

TABLES:

APPENDICES:

ACRONYMS AND ABBREVIATIONS

ACCC	Aluminum Conductor Composite Core
ACGIH	American Conference of Governmental and Industrial Hygienists
APE	Area of Potential Effects (Cultural resources assessment)
ASF	Areas Subject to Flooding
ASSF	Areas Subject to Storm Flowage
BMP	Best Management Practices
Company	The Narragansett Electric Company d/b/a National Grid
EFSB	Energy Facility Siting Board
EMF	Electric and Magnetic Fields
ESA	Endangered Species Act
Hz	Hertz
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IPaC	Information for Planning and Conservation
ISO-NE	Independent System Operator - New England
kV	kilovolt
kV/M	kilovolts per meter
mG	milliGauss
NOI	Notice of Intent
NRCS	Natural Resource Conservation Service
PAL	Public Archaeology Laboratory
PDWS	public drinking water supply
POWER	POWER Engineers, Inc.
Project	Reconductoring of the J16S 115 kV transmission line, owned and operated by TNEC
Report	Siting Report
RIDEM	Rhode Island Department of Environmental Management
RIGIS	Rhode Island Geographic Information System
RIHPHC	Rhode Island Historic Preservation and Heritage Commission
ROW	right-of-way
SESC	Soil Erosion and Sediment Control
TMDL	Total Maximum Daily Load
TNEC	The Narragansett Electric Company d/b/a National Grid
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife
USGS	United States Geological Survey
V/m	volts per meter

1.0 INTRODUCTION

1.1 Project Overview

This Siting Report (Report) has been prepared by The Narragansett Electric Company d/b/a National Grid (TNEC or Company)[1] in accordance with Rule 1.6(F) of the Rhode Island Energy Facility Siting Board (EFSB) Rules of Practice and Procedure (the EFSB Rules) to support a Notice of Intent (NOI) for the thermal upgrade of the existing J16S 115 kilovolt (kV) transmission line (J16S Line) owned and operated by TNEC (Project).

The J16S electric transmission line is 1.7 miles long and originates at Staples Substation and terminates at the Highland Park Substation, both in Cumberland, Rhode Island (refer to Project Area on Figure 1.1. Project Overview Map in Appendix A). In Cumberland, the J16S is double circuited with the R9 115 kV overhead transmission line (R9 Line)[2] and the two lines share Structures 130 through 143A. TNEC is proposing to reconductor five spans between Structures 130 and 135 for a total of 3,242 feet (0.61 mile). For maintenance purposes, the R9 Line will also be reconductored with the Project between Structures 130 and 135. Additionally, the following structure upgrades will be required to support the proposed new Aluminum Conductor Composite Core (ACCC) conductor:

- Reinforcement of Structures 130 and 135.
- Replacement of tower hanger members at Structures 134 and 131.
- Replacement of Structure 133 with a galvanized steel pole structure.
- Replacement of insulator strands on Structures 130 through 135.
- Conversion of Structure 132 to a suspension structure and replacement of hanger members.
- Install conductor weights on Structure 136.

The need for this Project is driven by contingencies identified which could lead to thermal overloads on the J16S Line. The R9, which shares structures with the J16 along the Project, will also be reconductored because the replacement of structure 133 with a taller structure will require the introduction of splices into the conductor and it is the Company's standard that there shall be no splices in spans that cross ponds or are within 100 feet of dead-end clamps. The reconductoring of the R9 will not increase the normal carrying capacity of the R9 Line. While work on the R9 Line is

[1] The Narragansett Electric Company d/b/a National Grid, a subsidiary of National Grid USA, is an electric and gas distribution and transmission company serving approximately 465,000 customers in 38 Rhode Island communities. National Grid USA is a public utility holding company. Other subsidiaries of National Grid USA include operating companies such as New England Power Company, Massachusetts Electric Company, Nantucket Electric Company (in Massachusetts), and Niagara Mohawk Power Corporation (in New York), as well as National Grid USA Service Company, Inc., which provides services such as engineering, legal, facilities construction and accounting.

[2] The R9 transmission line (R9 Line) is 10.4 miles between the Riverside Substation in Woonsocket and the Valley Street Substation in Cumberland (refer to Figure 1-1 Project Overview Map in Appendix A, shows the portion of the R9 Line from Riverside Substation to Staples Substation).

not independently jurisdictional, it will occur simultaneously and, therefore, is included in this report. The need is further described in Section 2.0 below.

No significant environmental or social impacts will result from the Project described herein.

1.2 Project Team

This Report has been prepared by Company employees and consultants retained by the Company. The description of the affected natural and social environments and impact analyses were prepared by POWER Engineers, Inc. (POWER). Other consultants contributing to the Report include Public Archaeology Laboratory (PAL) for cultural resources, and Exponent for analysis of health effects, modeling and calculations of electric and magnetic fields (EMF). Vanderweil Power Group is responsible for Project engineering and design.

1.3 Compliance with EFSB Requirements

This Report is being submitted to satisfy the applicable requirements of Rhode Island General Laws §§ 42-98-1 et seq., the Energy Facility Siting Act. Section 4 of the Energy Facility Siting Act states that, "[n]o 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 of greater than or equal to 69 kV are classified as major energy facilities. The EFSB application filing requirements and associated procedures for alterations to major energy facilities are established in the EFSB Rules.

This Report has been prepared in accordance with Rule 1.6(F) of the EFSB Rules, which requires TNEC to file a NOI for the "…modification or relocation of a powerline with a capacity of 69 kV or more … at least 90 days prior to commencing construction."

1.4 Organization of the Report

This Report has been prepared in accordance with the EFSB Rules to provide information on the potential impacts of the electric transmission system improvements proposed by TNEC. The Purpose and Need for the Project is detailed in Section 2.0 of this Report. Section 3.0 provides a detailed description of the components of the Project, and discusses construction practices, right-of-way (ROW) maintenance practices, safety and public health considerations, estimated costs for the Project, and anticipated Project schedule. An analysis of the alternatives to the Project, together with reasons for the rejection of those alternatives, is presented in Section 4.0. Detailed descriptions of the characteristics of the natural and social environment within and immediately surrounding the Project location are included in 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. Section 8.0 summarizes proposed mitigation measures which are intended to offset or eliminate the potential impacts associated with the Project. This Report also contains supporting mapping, figures, reports and agency correspondence, as applicable.

2.0 PROJECT PURPOSE AND NEED

A considerable portion of the loads in eastern Rhode Island and southeastern Massachusetts are served by local generation located in Tiverton, RI, and Taunton, Dighton and Dartmouth, MA. When one or more of these generation units are unavailable, certain contingencies could lead to several thermal overloads on the transmission network including the J16S Line. Overloading conductors can lead to annealing, loss of tensile strength, excessive conductor sag, and possible loss of adequate clearances beneath the transmission line. This Project is needed to resolve these issues identified on the J16S.

The R9, which shares structures with the J16 along the Project, will also be reconductored because the replacement of structure 133 with a taller structure will require the introduction of splices into the conductor and it is the Company's standard that there shall be no splices in spans that cross ponds or are within 100 feet of dead-end clamps. The reconductoring of the R9 is not considered to be jurisdictional as it will not increase the normal carrying capacity for the R9 Line.

This page intentionally left blank.

3.0 PROJECT DESCRIPTION AND PROPOSED ACTION

3.1 Introduction

In this section of the Report the scope of the Project is identified, the proposed facilities and TNEC's construction practices are described, estimated Project costs are identified, and the anticipated Project schedule is discussed.

3.2 Description of the Existing Transmission Lines

3.2.1 J16S Line

The J16S Line is a 1.7-mile 115 kV transmission line in northern Rhode Island. This Project involves the portion of the line between Structures 130 and 136 in Cumberland, Rhode Island. The route of the J16S and R9 Lines is illustrated in the Project Alignment Drawings which can be found in Appendix A, Figure 3-1. This transmission line was originally built in the 1920s and has since undergone several upgrades over the years. The J16S Line consists of double-circuit square-base suspension and dead-end lattice towers which are shared with the R9 115 kV Line. A Photographic log showing existing structures can be found in Appendix A, Figure 3-2.

3.2.2 R9 Line

The R9 Line is a 115 kV transmission line primarily located in northern Rhode Island. The R9 Line runs between Riverside Substation in Woonsocket and Valley Street Substation in Cumberland for approximately 10.4 miles. The R9 Line runs through Woonsocket (RI), North Attleboro (MA), and Cumberland (RI). The R9 Line was originally installed in the 1920s. The R9 Line consists mainly of double-circuit steel lattice towers with intermittent double-circuit steel single-pole structures, and a section of four-circuit steel dead-end structures.

3.3 Scope of the Project

The J16S and R9 Lines will be reconductored from Structures 130 to 135 with ACCC conductors. The new conductors will mitigate the J16S clearance shortfalls to the ground and will alleviate potential line overloads on the J16S Line under the contingency conditions described in Section 2.0 of this Report. Existing lattice tower structure, number 133 will be replaced with a galvanized steel pole structure. A drawing of a typical monopole structure can be found in Appendix A, Figure 3-3 Typical Structure Detail.

Tree-trimming and removal of danger trees will be performed along the ROW in conjunction with the Project. The proposed modifications will not significantly change the appearance of the existing ROW.

3.4 Construction and Maintenance Practices

3.4.1 Construction Sequence

The Project will be constructed using conventional overhead electric transmission line construction techniques. TNEC and its consultants conducted detailed constructability field reviews to determine access and workspace requirements, and to evaluate measures to avoid or minimize environmental impacts. The Project will generally progress in the following sequence of activities:

1. Removal of vegetation and ROW mowing in advance of construction;
2. Installation of soil erosion and sediment controls;
3. Access road and work pad maintenance or construction;
4. Installation of replacement structure and transfer conductors;
5. Removal and disposal of existing transmission line components; and
6. Restoration of the ROW.

3.4.2 Construction Traffic and Mitigation

Construction equipment typically will access the ROW from two public roadways which cross the ROW: West Wrentham Road and Staples Road in Cumberland. Because each of the construction tasks will occur at different times and locations over the course of the construction, traffic impacts will be intermittent at these entry roadways. Traffic will consist of vehicles ranging from pick-up trucks to heavy construction equipment.

3.4.3 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. Some limited construction may occur outside of standard work hours when needed to complete certain activities. For example, some work tasks such as pulling in new conductor, once started, must be continued to completion, and may go beyond normal work hours.

In addition, the nature of transmission line construction requires line outages for certain procedures such as transmission line connections, equipment cutovers, or stringing under or over other transmission lines. Availability of these outages, which is dictated by the ISO-NE based on regional system load and weather conditions, can be limited. Such scheduled outages will have no effect on electric service to local customers. Work requiring scheduled outages and crossings of certain transportation and utility corridors may need to be performed on a limited basis outside of normal work hours, including on Sundays and holidays.

Prior to and during construction, TNEC will notify landowners, abutting property owners, municipal officials, the Departments of Public Works, and Police and Fire Chiefs of the details of planned construction including the normal work hours and any extended work hours.

3.4.4 Environmental Compliance Monitoring

Throughout the entire construction process, TNEC will retain the services of an environmental monitor who will verify and report on compliance with all federal, state, and local permit requirements and TNEC's policies and procedures. At regular intervals and during periods of prolonged precipitation, the environmental monitor will inspect all locations to determine whether the environmental controls are functioning properly. Prior to the start of construction, all Project personnel will be trained on Project environmental requirements and permit conditions, including rare species, storm water management, and cultural resources. Refresher training will be held as new crew members join the Project work force and as otherwise necessary. TNEC will conduct regular construction progress meetings to reinforce the construction team's awareness of these issues. Pre-construction "look-ahead meetings" will take place in the field with appropriate Project personnel. TNEC's environmental monitor will attend these meetings to provide feedback on environmental requirements and compliance to construction personnel.

In addition to retaining the services of an environmental monitor, TNEC will require the construction team to designate an individual to be responsible for the daily inspection and maintenance of environmental controls. This person will also be responsible for providing direction to the other members of the construction crew regarding matters such as wetland access, appropriate work methods, driving safety, and good house-keeping practices along the ROW.

3.5 Safety and Public Health Considerations

TNEC will design, build, and maintain the Project 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 Company's own standards as well as the National Electric Safety Code. The facilities will be designed in accordance with sound engineering practices using established design codes and guides published by, among others, the Institute of Electrical and Electronic Engineers, the American Society of Civil Engineers, the American Concrete Institute, and the American National Standards Institute (ANSI). Practices which 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 work areas, noise and dust control, and coordination with the Town of Cumberland during construction.

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

3.6 Public Outreach

TNEC has notified the Town of Cumberland of the Project. TNEC's outreach plan will include the mailing of Project factsheets to abutting landowners prior to the start of construction, and advanced notification to applicable town and state officials and agencies.

3.7 Estimated Project Costs

TNEC has prepared Project Grade level estimates for the reconductoring of the Project (Table 3-1). Project Grade estimates have an accuracy of +/- 10%.

TABLE 3-1 ESTIMATED PROJECT COSTS

PROJECT COMPONENTS	ESTIMATED COST ($M)
Transmission Line Facilities J16S and R9	2.189

3.8 Project Schedule

The overall construction of the Project is expected to take approximately four months to complete.

4.0 PROJECT ALTERNATIVES

4.1 Introduction

This section describes the alternatives to the Project that were considered to address the need for reconductoring the J16S Line. As described in Section 2.0, the Project is needed to prevent thermal overloads on the J16S Line.

Selecting a preferred design option involves evaluating project alternatives, analyzing potential alternative routes and configurations, general ranking of alternatives, and identifying initial recommendations in the selection of a preferred solution. TNEC's overriding goal has been to select the alternative that best meets the Project need, with a minimum impact on the environment, at the lowest possible cost.

Section 4.2 describes the no-action alternative, Section 4.3 to Section 4.5 describe the engineering alternatives, and Section 4.6 describes the Preferred Alternative (the Project).

4.2 No-Action Alternative

Under the "No-Action" alternative, a contingency condition would force the system operator to drop customers to avoid overloading conductors. Overloading conductors can lead to annealing, loss of tensile strength, excessive conductor sag, and possible loss of adequate clearances beneath the transmission line. Because of the potential for a thermal overload, continuing to operate the existing system without reconductoring the J16S Line is not an acceptable alternative for maintaining a reliable electric supply. The No-Action alternative was dismissed as it would not address the need to upgrade the existing electrical transmission system and continue to provide reliable service to customers.

4.3 Raising or Replacing Existing Structures with Existing Conductors

This alternative would be to keep the existing conductor type but raise or replace the existing dead-end structures on the J16S Line from Structures 130 to 135. This alternative would not address the potential for the overloading and annealing of the existing conductor. This alternative would also require a substantially greater amount of structure work, which would result in significant additional cost. Accordingly, this alternative was rejected.

4.4 Using Alternative Conductor Types

Engineering explored other conductor types that might meet the need to upgrade the J16S Line but that would not require any structure upgrades; however, no alternative conductors could be identified that would provide the necessary sag, tension, and ground clearance characteristics.

4.5 Tensioning New Conductor on the Existing Structures

This alternative would entail installing new conductor without performing a structure replacement and increasing the tension on the new conductors to achieve the desired ground clearance. This alternative was dismissed because increasing the tension of the conductors put too much structural load on the existing structures and would not meet design requirements.

4.6 J16S Reconductoring Alternative (Preferred)

TNEC concluded that the proposed Project is the preferred alternative to meet the need, which is:

- Reconductor J16S Line with ACCC conductor between Structures 130 and 135;
- Install conductor weights on Structure 136;
- Reinforce Structure 135;
- Replace tower hanger members at Structure 134;
- Replace Structure 133 with a galvanized steel pole structure;
- Convert Structure 132 to a suspension structure and replace hanger members;
- Replace hanger members at Structure 131; and
- Reinforce Structure 130.

The proposed Project was determined to be the most economical solution that met the identified need.

5.0 DESCRIPTION OF AFFECTED NATURAL ENVIRONMENT

A description of environmental characteristics that may be affected by the Project is provided below. This section describes the specific natural features that have been evaluated for potential impacts based upon published resource information, the Rhode Island Geographic Information System (RIGIS) database, various state and local agencies, and field investigations of the Project ROW.

The Project involves work activities on existing 115 kV transmission lines within an established and maintained ROW; therefore, the Project is anticipated to have no impacts on geology and farmlands. For these reasons, these environmental characteristics are not included in the below assessment.[3] The Project is anticipated to have only limited and temporary impacts on soils, vegetation, surface water, wetland and waterbodies, and wildlife.

5.1 Project Study Area

A Study Area was established to assess the existing environment both within and immediately adjacent to the existing ROW. This Study Area consists of a 5,000-foot-wide corridor, measured 2,500 feet on either side of the centerline of the ROW. The boundaries of this corridor were established to allow for a detailed desktop analysis of existing conditions within and adjacent to the Project ROW (Figure 5-1).

5.2 Soils

Because soils will be disturbed and graded for access roads, work pads and pull pads during Project construction, information concerning the physical properties, classification, agricultural suitability, and erodibility of soils near the Study Area (Figure 5-1) were obtained from the Natural Resource Conservation Service (NRCS). The Soil Survey delineated map units that may consist of one or more soil series and/or miscellaneous non-soil areas that are closely and continuously associated on the landscape. In addition to the named series, map units include specific phase information that describes the texture and stoniness of the soil surface and the slope class. The soil series within the Study Area were identified. Common soil types found within the Study Area include Canton and Charlton, Ridgebury, Sutton and Woodbridge fine sandy loams, and Freetown and Swansea muck. All soils found within the Study Area have greater than 60 inches depth to bedrock. Study Area hydric soil status is depicted on Figure 5-2.

5.2.1 Erosive Soils

The erodibility of soils is dependent upon the slope of the land and the texture of the soil. Soils are given an erodibility factor (K), which is a measure of the susceptibility of the soil to erosion by water. Soils having the highest K values are the most erodible. K values in Rhode Island range from 0.10 to 0.64 and vary throughout the depth of the soil profile with changes in soil texture. Very poorly drained soils and certain floodplain soils usually occupy areas with little or no slope. Therefore, these soils are not subject to erosion under normal conditions and are not given an erodibility factor. Soil map units described as strongly sloping or rolling may include areas with slopes greater than eight

[3] Per EFSB Rule 1.6(F)(3), which states to the extent the proposed project will have only negligible impact on any particular resource in the natural and social environment, the applicant may so state and need not provide a detailed analysis of the baseline conditions for that resource.

percent and soil map units with moderate or higher erosion hazard within in the Study Area include Canton and Charlton, Sutton and Woodbridge fine sandy loam, and Canton-Charlton-Rock outcrop complexes.

5.3 Water Resources

5.3.1 Major Surface Waters

The Study Area is drained by waterways in the Lower Blackstone River Watershed. Waterways generally flow to the south and east and ultimately empty into the Narragansett Bay. The Study Area is located within the Abbott Run sub-watershed. The major surface water resources and classifications within the Study Area are listed in Table 5-1. The waters of the state of Rhode Island (meaning all surface water and groundwater of the State) are assigned a Use Classification which is defined by the most sensitive uses which it is intended to protect. Waters are classified according to specific physical, chemical, and biological criteria which establish parameters of minimum water quality necessary to support the water Use Classification. The water quality classification of the major surface waters within the Study Area are identified in the descriptions of the water bodies that follow.

TABLE 5-1 MAJOR SURFACE WATER RESOURCES WITHIN THE STUDY AREA

WATER BODY NAME	TOWN	CLASSIFICATION/ USE	FISHERY DESIGNATION	WATER BODY CROSSED
Sneech Pond	Cumberland	AA	Unassessed	Yes
East Sneech Brook	Cumberland	AA	Warm	No

Notes: Class AA - These waters are designated as a source of public drinking water supply or as tributary waters within a public drinking water supply watershed, for primary and secondary contact recreational activities and for fish and wildlife habitat. These waters shall have excellent aesthetic value.

Pursuant to the requirements of Section 305(b) of the federal Clean Water Act, water bodies that are determined to be not supporting their designated uses in whole or in part are considered impaired and scheduled for restoration. The causes of impairment are those pollutants or other stressors that contribute to the actual chemical contaminants, physical parameters, and biological parameters. Sources of impairment are not determined until a total maximum daily load (TMDL) assessment is conducted on a water body. Table 5-2 lists the impaired surface water resources in the Study Area.

TABLE 5-2 IMPAIRED SURFACE WATER RESOURCES IN THE STUDY AREA

WATER BODY NAME	IMPAIRMENT	CATEGORY
Sneech Pond	Non-Native Aquatic Plants	4C
East Sneech Brook	Enterococcus Bacteria	4A

Notes: Category 4 - Impaired or threatened for one or more designated uses but does not require development of a TMDL.

A) TMDL has been completed. Waterbodies will be placed in this subcategory once all TMDLs for the waterbody have been developed and approved by the United States Environmental Protection Agency.

C) Impairment is not caused by a pollutant. Waterbodies will be placed in this subcategory if pollution (e.g., flow) rather than a pollutant causes the impairment.

5.3.2 Wetlands and Waterbodies

Federal- and State-regulated freshwater wetlands and/or streams were identified and delineated within the Project ROW in the winter of 2015 and in the summer of 2017. A total of three freshwater wetlands were identified and delineated on the Project ROW. Field methodology for the delineation of State-regulated resource areas within the ROW was based upon vegetative composition, presence of hydric soils, and evidence of wetland hydrology. The study methods included both on-site field investigations and off-site analysis to determine the wetland and watercourse resource areas on the Project ROW. Wetlands outside the ROW but within the Study Area were identified based on a desktop review of RIGIS wetlands data (RIGIS 1993). Figure 5-3 depicts wetland resources within the Study Area based on the results of this desktop analysis.

Wetlands are resources which have ecological functions and societal values. Wetlands are characterized by three criteria: (i) the presence of undrained hydric soil, (ii) a prevalence (>50 percent) of hydrophytic vegetation, and (iii) wetland hydrology, where soils are saturated near the surface or flooded by shallow water during at least a portion of the growing season.

In accordance with the provisions of the Rhode Island Fresh Water Wetlands Act and Rules, State-regulated freshwater wetlands include swamps, marshes, bogs, forested or shrub wetlands, emergent plant communities and other areas dominated by wetland vegetation and showing wetland hydrology. The Rules also regulate activities in and around streams and open water bodies which include rivers, streams, ponds, Areas Subject to Storm Flowage (ASSF), Areas Subject to Flooding (ASF) and floodplains.

Pond

The boundary of a pond is determined by the extent of water which is delineated and surveyed. A pond is an area of open standing or slow-moving water present for six or more months during the year and at least 0.25% of an acre in size. Ponds have a 50-foot perimeter wetland associated with their boundary. Sneech Pond is the only named pond within the Study Area and is also within the Project ROW. Sneech Pond is a surface water reservoir providing a drinking water source for the Town of Cumberland.

Swamp

Swamps are defined as areas at least three acres in size, dominated by woody vegetation, where groundwater is at or near the surface for a significant part of the growing season. A 50-foot Perimeter Wetland is applied to both forested and shrub swamps. Shrub swamps are areas dominated by broad-leaved deciduous shrubs and often have an emergent herbaceous layer. Typical species in shrub swamps include sweet pepperbush (*Clethra alnifolia*), highbush blueberry (*Vaccinium corymbosum*), winterberry (*Ilex verticillata*), swamp azalea (*Rhododendron viscosum*), and silky dogwood (*Cornus amomum*). Drier portions of shrub swamps are often densely overgrown with greenbrier (*Smilax* sp.) and blackberry (*Rubus allegheniensis*). Common species in the herbaceous layer include sensitive fern (*Onoclea sensibilis*), skunk cabbage (*Symplocarpus foetidus*), and cinnamon fern (*Osmundastrum cinnamomeum*). Shrub swamp generally occurs in areas where the wetland crosses the managed portion of the ROW.

Forested swamps mainly occur on the edges of the managed ROW where the shrub swamps are present, but where the tree cover is allowed to dominate. Vegetation in a forested swamp includes predominantly red maple, willow (*Salix* sp.), black gum (*Nyssa sylvatica*), alder (*Alnus* sp.), silky dogwood, sweet pepperbush, winterberry, swamp azalea, cinnamon fern, common reed (*Phragmites* sp.), and peat moss (*Sphagnum* spp.).

There are approximately 10 acres of swamp within the Study Area (RIGIS 1993).

Marsh/ Emergent Wetlands/ Wet Meadows

Marshes are wetlands at least one acre in size where water is generally above the surface of the substrate and where the vegetation is dominated by emergent herbaceous species. Marsh vegetation is typically dominated by broad-leaved cattail (*Typha latifolia*), tussock sedge (*Carex stricta*), and reed canary grass (*Phalaris arundinaceae*), with lesser amounts of common reed (*Phragmites australis*), sensitive fern, skunk cabbage, steeplebush (*Spiraea tomentosa*), marsh fern (*Thelypteris palustris*), and soft rush (*Juncus effusus*). Emergent wetlands and wet meadows are typically dominated by cattail, bulrush (*Scirpus pungens*), woolgrass (*Scirpus cyperinus*), soft rush, sensitive fern, and reed canary grass. Within the Study Area there are approximately 16 acres of wetland that are identified as marsh/ emergent wetlands or wet meadows (RIGIS 1993).

River/ Perennial Stream

A river is typically a named body of water designated as a perennial stream by United States Geological Survey (USGS). A perennial stream maintains flow year-round and is also designated as a solid blue line on a USGS topographic map. If a stream or river is less than 10 feet wide, the area within 100 feet of each bank is regulated as a 100-foot riverbank wetland. If the stream or river is greater than 10 feet wide, the area within 200 feet of each bank is regulated as a 200-foot riverbank wetland. No perennial streams were identified during wetland surveys on the ROW, but eight perennial streams were identified off the ROW in the Study Area (USGS 2007-2014).

Stream / Intermittent Stream

A stream is any flowing body of water or watercourse other than a river which flows during sufficient periods of the year to develop and maintain defined channels. Such watercourses carry groundwater discharge and/or surface water runoff. Such watercourses may not have flowing water during extended dry periods but may contain isolated pools of standing water. No intermittent streams were identified during wetland surveys on the ROW. Based on a GIS analysis, there are three mapped intermittent streams within the Study Area (USGS 2007-2014).

Shrub / Forested Wetland

Shrub / forested wetlands are characterized by the dominance of shrubs or trees. Shrub and forested wetlands have the same typical vegetation types as shrub and forested swamps. There are approximately 46 acres of forested wetland and approximately 53 acres of shrub wetland within the Study Area (RIGIS 1993).

Floodplain

A floodplain is the land area adjacent to a river, stream or other body of flowing water which is, on average, likely to be covered with flood waters resulting from a 100-year frequency storm event as mapped by Federal Emergency Management Agency (RIGIS 2015). Floodplain areas within the Study Area are shown on Figure 5-3.

Area Subject to Storm Flowage

ASSF are channel areas which carry storm, surface, groundwater discharge or drainage waters out of, into, and/or connect freshwater wetlands or coastal wetlands. ASSFs are recognized by evidence of scouring and/or other marked change in vegetative density and/or composition. No ASSFs were delineated on the ROW, and there are no mapped ASSFs within the Study Area.

Special Aquatic Site – Vernal Pools

A vernal pool is a type of special aquatic site that is generally defined as a contained basin that generally lacks a permanent above-ground outlet. It fills with water between late fall and spring from rising groundwater, or with the meltwater and runoff of winter and spring snow and rain (Rhode Island Department of Environmental Management [RIDEM] 2016). Many vernal pools are regulated by the RIDEM as special aquatic sites. A special aquatic site is defined in the RIDEM Freshwater Wetlands Rules and Regulations as a body of open standing water, either natural or artificial, which does not meet the definition of pond, but which is capable of supporting and providing habitat for aquatic life forms, as documented by the: 1) presence of standing water during most years, as documented on site or by aerial photographs; and 2) presence of habitat features necessary to support aquatic life forms of obligate wildlife species, or the presence of evidence of, or use by aquatic life forms of obligate wildlife species (excluding biting flies).

Most vernal pools contain water for a few months in the spring and early summer and are dry by mid-summer. Because they lack a permanent water source and dry periodically, vernal pools lack a permanent fish population. Vernal pools provide breeding habitat for species, particularly amphibians, which depend upon pool drying and the absence of fish for breeding success and survival (obligate vernal pool species). Some wetlands and water bodies may provide breeding habitat for amphibians, but lack the specific criteria to meet the definition of a vernal pool (e.g., provide habitat to facultative vernal pool species only, or contain evidence of breeding obligate vernal pool species occurring together with fish populations); these wetlands and water bodies have been designated as "amphibian breeding habitats."

Field investigations for potential vernal pools and amphibian breeding habitats were performed in the spring of 2016, 2017, and 2018. The wetlands on the ROW were investigated to confirm the presence/absence of amphibian breeding activity, and no vernal pools were identified.

5.3.3 Groundwater Resources

The RIDEM classifies all 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 presence and availability of groundwater resources is a direct function of geologic deposits in the vicinity of the Project.

Groundwater resources within the Study Area are depicted on Figure 5-4. All of the groundwater resources in the Study Area are classified by the RIDEM as GA (RIDEM designates approximately 71 percent of groundwater in Rhode Island as GA). Groundwater classified GA are groundwater resources, which are known or presumed to be suitable for drinking water use without treatment. There are approximately 131 acres of Non-Community Wellhead Protection Area within the Study Area.

The United States Environmental Protection Agency has designated Sole Source Aquifer status to aquifers that supply at least 50 percent of the drinking water for its service area and for which there are no reasonably available alternative drinking water sources should the aquifer become contaminated. There are no Sole Source Aquifers in the Study Area.

5.4 Vegetation

The Study Area contains a variety of vegetative cover typical of Southern New England (DeGraaf and Yamasaki 2001). These include oak/pine forest, old field, and managed lawn. This section of the report focuses on upland communities. Wetland communities are discussed in Section 5.3.2 of this report.

5.4.1 Oak/Pine Forest Community

Forested cover types within the Study Area are typically dominated by oaks (*Quercus* spp.) with or without a white pine (*Pinus strobus*) component. Although these woodlands may appear similar throughout the Study Area, differences in the structure and composition of species in these forests may occur between sites. Soil moisture holding capacity and slope aspect are important factors in determining the plant associations present at a particular site. Plant associations growing on hilltops and south facing slopes are likely to face moisture deficits during the summer. Sandy soils associated with glacial outwash deposits have lower moisture holding capacity in comparison with soils formed over deposits of glacial till. Forests established in these drier sites are often characterized by smaller and more widely spaced trees in comparison with more mesic sites.

Common associates of the hilltop oak/pine forests in the vicinity of the Project ROW include black (*Quercus velutina*), scarlet (Q. *coccinea*), and white oaks (Q. *alba*) as well as aspen (*Populus* sp.) and gray birch (*Betula populifolia*). The shrub/sapling understory includes such species as black cherry (*Prunus serotina*), lowbush blueberry (*Vaccinium angustifolium*) and greenbrier (*Smilax rotundifolia*). Sheep laurel (*Kalmia angustifolia*) and sweet fern (*Comptonia peregrina*) occasionally occur in openings between oak stands with canopy openings and on rocky slopes. Herbaceous species include bracken fern (*Pteridium aquilinum*), tree clubmoss (*Lycopodium obscurum*) and hayscented fern (*Dennstaedtia punctilobula*). These hilltop communities occur where excessively drained soils predominate, and on hilltops throughout the Study Area.

There is an increase in the diversity within plant communities on midslopes compared with dry hilltops. The increase in soil moisture produces this greater diversity in trees, shrubs and herbs. Midslope tree species in addition to oaks include black birch (*Betula lenta*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*) and several species of hickory (*Carya* spp.). Shrubs include witch hazel (*Hamamelis virginiana*), sassafras (*Sassafras albidum*) and ironwood (*Carpinus caroliniana*). Greenbrier and poison ivy (*Toxicodendron radicans*) are also common in this community. Common groundcover species include tree clubmoss and wintergreen (*Gaultheria procumbens*). Midslope oak/pine communities occur on mesic mid-slope and lower slope positions and adjacent to forested wetlands on the uncleared portion of the Study Area.

5.4.2 Shrub/ Old Field Community

Vegetation within the cleared portions of the ROW is typically representative of an old field successional community. Old field communities are established through the process of natural succession from cleared land to mature forest. Within the cleared ROW, periodic vegetation management has favored the establishment and persistence of grasses and herbs. Over time, pioneer woody plant species including gray birch, black cherry, sumac (*Rhus* sp.) and eastern red cedar

(*Juniperus virginiana*) have become established. Within the cleared portions of the ROW, vegetation varies considerably. On dry hilltops, little bluestem (*Schizachyrium scoparium*), round-head bushclover (*Lespedeza capitata*), staghorn sumac (*Rhus typhina*) and eastern red cedar are common. On the mid-slope, greenbrier and blackberry (*Rubus* sp.) form dense, impenetrable thickets. Numerous herbs including goldenrod (*Solidago* sp.), aster (*Aster* sp.), pokeweed (*Phytolacca americana*), and mullein (*Verbascum thapsus*) are also common.

The ROW has been managed to selectively remove trees so they do not interfere with the operation of the existing transmission lines. Low shrub lands dominate portions of the ROW where succession of old field has occurred and where ROW management has resulted in tree sapling removal. Sweet fern (*Comptonia peregrina*), bayberry (*Myrica pensylvanica*), and northern arrowwood (*Viburnum recognitum*) are shrub species that are commonly found within the ROW.

Forest vegetation abuts the area of managed ROW in many places along the corridor. This forested edge contains species of trees and the ROW contains saplings that require more sunlight, such as black cherry (*Prunus serotina*), grey birch (*Betula populifolia*) and eastern red cedar. Mature forest containing northern red oak and red maple (*Acer rubrum*) are also present along the corridor, and saplings of these species are occasionally found in the ROW.

5.4.3 Managed Lawn/Grass

Portions of the Study Area contain managed residential lawn. Typically, these areas consist of a continuous grass cover which may include Kentucky bluegrass (*Poa pratensis*), red fescue (*Festuca rubra*), clover (*Trifolium* sp.), and plantains (*Plantago* sp.). Ornamental shrubs may also occur within these areas.

5.5 Wildlife

As previously described, the Study Area includes a variety of aquatic and terrestrial habitats. The wildlife assemblages present within the Study Area vary according to habitat characteristics. Typical wildlife species found commonly in the habitat types within the Study Area may include the following:

- Mammals such as white-tailed deer, foxes, raccoons, weasels and bats.
- A variety of birds such as songbirds, woodpeckers, owls, hawks and turkeys.
- Amphibians and reptiles such as salamanders, turtles, frogs, toads and snakes.
- Many different species of invertebrates.

5.5.1 Fisheries

There are no Designated Trout Waters within the Study Area. Refer to Table 5-1 for the fishery designations associated with the surface water bodies within the Study Area.

5.5.2 Rare and Endangered Species

Correspondence regarding federally- and Rhode Island state-listed species is included in Appendix C, Agency Correspondence.

Federally-listed Species

The current United States Fish and Wildlife (USFWS) Endangered Species Consultation Procedure makes use of the online Information for Planning and Conservation (IPaC) Form (https://ecos.fws.gov/ipac/) which streamlines the USFWS environmental review process. POWER completed and submitted the IPaC Form on September 7, 2018 and again on November 19, 2020, and results indicated that one federally-listed species, the northern long-eared bat (*Myotis septentrionalis*), may occur in Providence County which is where the Project ROW is located. No federally-designated Critical Habitat occurs in the Project ROW or Study Area. Species descriptions and habitat requirements for the northern long-eared bat are further described below.

Northern Long-eared Bat

The northern long-eared bat is a medium-sized bat in the Family Vespertilionidae with distinguishing long ears. Their body lengths range from 3.0 to 3.7 inches with a wingspan of 9.0 to 10 inches. Fur color ranges from medium to dark brown on the back and tawny to pale-brown on the underside. The northern long-eared bat has both a winter and summer habitat. During winter, these bats hibernate in natural caves and abandoned mines (known as hibernacula) which have high humidity, constant temperatures, and no air currents (Massachusetts Division of Wildlife 2015). Northern long-eared bats will share caves and mines with other wildlife species but hibernate singly or in small groups within deep crevices or cracks of the caves and mines. Rhode Island does not have any natural caves or abandoned mines so most bats that spend the summer in Rhode Island must leave the state and travel elsewhere to hibernate (Rhode Island Department of Environmental Management 2018).

During the summer, northern long-eared bats prefer forests where the bats roost in colonies or singly in cavities of both live and dead trees, as well as underneath tree bark. Females give birth to a single pup each season. The estimated maximum lifespan of the northern long-eared bat is up to 18.5 years. Northern long-eared bats feed at dusk and eat a variety of insects such as flies, leafhoppers, caddisflies, beetles, and moths. The greatest threat to the northern long-eared bat is white-nose syndrome, which is spreading from the Northeast to the Midwest and Southeast United States. The northern long-eared bat is federally-listed as a threatened species under the Endangered Species Act (ESA) (USFWS 2015).

According to the final 4(d) Rule for the northern long-eared bat, the Project ROW is considered exempt from ESA prohibitions for removal of “danger” trees. Danger trees are those which present the risk of falling and causing personal injury or property damage. Where possible, if danger trees are required to be removed, that work will be done outside of the time-of-year restrictions set forth by the USFWS New England Field Office (June 1st – July 31st).

Additionally, since northern long-eared bat may occur throughout the Project Area and the Project involves minor tree cutting, NEP must comply with the 4(d) rule under the Endangered Species Act which became effective February 16, 2016. The 4(d) rule states that “incidental take resulting from tree removal is prohibited if it: 1) occurs within 0.25 mile radius of known northern long-eared bat hibernacula or 2) cuts or destroys known occupied maternity roost trees, or any other trees within a 150-foot radius from the known maternity tree during the pup season (June 1 through July 31).” USFWS guidance also directs Project proponents to contact state natural resources agencies to obtain additional information on the location of known northern long-eared bat hibernacula and maternity roost trees. POWER contacted RIDEM and it was confirmed that there are no known NLEB maternity roosts or hibernaculum within 5 miles of the Project. The Determination Key for the NLEB Consultation and 4(d) Rule Consistency resulted in a “May Effect” and was submitted to the USFWS on November 19, 2020.

State-Listed Species

Based on correspondence with the RIDEM, the following state-listed species have been documented on or near the Project ROW (Table 5-3):

TABLE 5-3 STATE LISTED SPECIES DOCUMENTED ON OR WITHIN 500 FEET OF THE PROJECT ROW

COMMON NAME	SCIENTIFIC NAME	REFERENCES FOR IDENTIFICATION
Large-spiked Beak Rush, Horned-rush	*Rhynchospora macrostachya*	Canada Species at Risk Public Registry. *Rhynchospora macrostachya*. http://www.registrelep-sararegistry.gc.ca/document/default_e.cfm?documentID=2762. Accessed November 19, 2020.
Rusty Woodsia, Rusty Cliff-fern	*Woodsia ilvensis*	Connecticut Botanical Society. *Woodsia ilvensis*. https://www.ct-botanical-society.org/Plants/view/2707. Accessed June 25, 2018.

Note: All state listed species on the Project ROW are subject to the Project-specific Rare Species Avoidance Plan.

6.0 DESCRIPTION OF AFFECTED SOCIAL ENVIRONMENT

This section provides a detailed description of the physical and social environment on and off site. As required by the EFSB Rules, a description of social characteristics that may be affected by the Project is provided below. The Project involves the work activities on the existing 115 kV transmission lines within an established and maintained ROW, therefore the Project is anticipated to have no impacts on the current land use, population trends, employment and visual resources of the Study Area. Therefore, in accordance with EFSB Rule 1.6(F)(3), TNEC will not provide a detailed analysis of the baseline conditions for those resources.

6.1 Future Land Use

To assess future land use, an analysis of current zoning was undertaken. Typically, towns and cities manage future growth through zoning regulations and comprehensive planning. The Study Area is zoned commercial, residential, open space and agricultural. The Comprehensive Plan approved by the Cumberland Planning Board May 26, 2016, adopted by Cumberland Town Council on June 15, 2016, and adopted by the Division of Statewide Planning April 19, 2017 discusses infrastructure, specifically water transmission facilities, but makes no mention of electric transmission facilities.

6.2 Visual Resources

The Study Area for visual resources was assessed by TNEC's cultural resource consultant, PAL, as part of the Cultural and Historic Resources assessment (see Section 6.4 below).

6.3 Noise

Ambient sound levels are influenced by diverse factors such as vehicular traffic, commercial and industrial activities, and outdoor activities typical of both rural and developed environments. Sensitive noise receptors include residences, and institutional areas. For the most part, the Study Area is characterized by forestland, suburban, and commercial land uses.

6.4 Cultural and Historic Resources

TNEC's cultural resource consultant, PAL, conducted a cultural resource due diligence for the proposed Project, identifying historic architectural properties, archaeological sites, previous cultural resource surveys, and other cultural resources within the vicinity of the Project. PAL identified such properties through a search of the RIHPHC's archaeological, architectural and National Register of Historic Places files and through consultation with interested stakeholders during previous Projects.

For archaeological resources, the due diligence review area encompassed 0.5 mile on either side of the Project centerline for a total width of 1.0 mile. For historic architectural properties, the due diligence review area was established at 0.25 mile on either side of the Project centerline. The area of potential effects (APE) for archaeological sites is defined as any areas of ground disturbances that may occur as a result of implementing planned improvements, including the relocation or replacement of existing structures, access roads, and staging areas. The APE for historic architectural properties includes the construction area and areas adjacent to the ROW where visual impacts may occur.

The ROW is not proximate to any scenic areas and is not part of any protected vistas or view-sheds. In addition, as discussed below, PAL surveyed historic architectural properties within the Study Area and prepared an effects assessment to evaluate potential indirect impacts to aboveground resources.

PAL submitted the cultural resource due diligence and a cultural resource assessment to the RIHPHC and the Narragansett Indian Tribal Historic Preservation Office (NITHPO) on July 28, 2020, recommending that the proposed Project would not affect historic properties; the due diligence referenced Phase I archaeological and historic architectural properties reconnaissance surveys that were conducted for previous Projects along the ROW that correspond with the proposed Project impact areas. No significant archaeological resources or historic architectural properties were identified within the relevant Study Areas during the surveys that were conducted in 2018. On August 21, 2020, the RIHPHC responded, concurring with PAL's recommendation that the proposed Project will not affect historic properties (included within Agency Correspondence).

On August 17, 2020, the USACE initiated Section 106 consultation with the NITHPO, providing the PAL correspondence to RIHPHC from July 28, 2020 (included within Agency Correspondence). The NITHPO did not respond to the USACE's correspondence.

6.5 Transportation

The Study Area is served by a limited network of state and local roads and highways. No state highways are crossed by the ROW near the Project.

6.6 Electric and Magnetic Fields (EMF)

Electric fields are created by the voltage on electric conductors, whereas magnetic fields are created by the current on electric conductors. TNEC, like all North American electric utilities, supplies electricity at 60 Hertz (Hz). Therefore, the electric utility system and the equipment and conductors connected to it produce 60 Hz (power-frequency) EMF. These fields can be either measured using instruments or calculated using an electromagnetic model.

EMFs are present wherever electricity is used. This includes not only utility transmission lines, distribution lines, and substations, but also electrical wiring in homes, offices, and schools and electrical appliances and machinery.

Electric fields exist whenever voltages are present on transmission conductors; they are not dependent on the magnitude of 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. The electric field may be shielded (i.e., the strength may be reduced) by any conducting surface, such as 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), where 1 kV/m = 1,000 V/m.

Magnetic fields are present whenever current flows in a conductor; they are not dependent on the voltage present on the conductor. The magnetic field strength is a function of both the current flow on the conductor and the configuration of the transmission line. The strength of magnetic fields also decreases with distance from the source. Since the flow of electricity or load on a transmission line varies with time of day based on the need for electric power in the region, the magnetic field associated with electric transmission lines also varies throughout the day and with seasonal changes in electric demand. Unlike electric fields, however, most common materials have little shielding effect on magnetic fields.

Magnetic fields are measured in units called Gauss. 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. Table 6-1 lists common household devices and typical magnetic field levels measured at the distances indicated from the source.

TABLE 6-1 COMMON SOURCES OF MAGNETIC FIELDS

SOURCES*	DISTANCE FROM SOURCE	
	6 inches (mG)	24 inches (mG)
Microwave Ovens	100-300	1-30
Dishwashers	10-100	2-7
Refrigerators	Ambient - 40	Ambient – 10
Fluorescent Lights	20-100	Ambient – 8
Copy Machines	4-200	1-13
Drills	100-200	3-6
Power Saws	50-1,000	1-40

Note: * Different makes and models of appliances, tools, or fixtures will produce different levels of magnetic fields. These are generally-accepted ranges.
Source: Public Service Commission of Wisconsin 2013.

Table 6-2 is provided to illustrate guidelines suggested by various national and international health organizations for exposure to both electric and magnetic fields.

TABLE 6-2 60 HZ EMF GUIDELINES ESTABLISHED BY HEALTH AND SAFETY ORGANIZATIONS

ORGANIZATION	MAGNETIC FIELD	ELECTRIC FIELD
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	10,000 mG[a] 1,000 mG[b]	25 kV/m[a] 1.0 kV/m[b]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public, continuous exposure)	2,000 mG	4.2 kV/m
Non-Ionizing Radiation Committee of the American Industrial Hygiene Assoc. endorsed (in 2003) ICNIRP's occupational EMF levels for workers	4,170 mG	8.3 kV/m
International Committee on Electromagnetic Safety	9,040 mG	5.0 kV/m
U.K., National Radiological Protection Board [now Health Protection Agency]	2,000 mG	4.2 kV/m
Australian Radiation Protection and Nuclear Safety Agency, Draft Standard, Dec. 2006[c]	3,000 mG	4.2 kV/m

Notes:
[a] ACGIH guidelines for the general worker.
[b] ACGIH guideline for workers with cardiac pacemakers.
[c] http://www.arpansa.gov.au/pubs/comment/dr_elfstd.pdf; and http://www.arpansa.gov.au/News/events/elf.cfm.

This page intentionally left blank.

7.0 IMPACT ANALYSIS

This section analyzes potential impacts of the Project on the existing natural and social environments within the Study Area and the APE. As with any construction Project, potential adverse impacts can be associated with the construction, operation, or maintenance of an electric transmission line. These impacts have been minimized to the greatest extent feasible through thoughtful design, construction, operation, and maintenance practices.

Potential impacts to the natural and social environments associated with the Project can be categorized based on construction-related (temporary) impacts and operation-related (permanent) impacts. Examples of potential temporary construction-related impacts include wetlands impacts due to construction mats, traffic impacts, and construction noise associated with the operation of heavy equipment. This Project will not require permanent impacts to wetlands. The old structure located adjacent to the new structure will be removed and the area will be restored.

The Project will be constructed in a manner that minimizes the potential for adverse environmental impacts. 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 along with BMPs. Design and construction mitigation measures will be implemented so that construction-related environmental impacts are minimized.

7.1 Summary of Environmental Effects and Mitigation

The Project will occur within an existing ROW and will use existing access roads, thereby largely avoiding and minimizing adverse environmental impacts. No long-term impacts to soil, bedrock, vegetation, surface water, groundwater, wetland resources or air quality will occur. Any potential sedimentation impacts, and other short-term construction impacts to wetlands and surface waters will be mitigated using soil erosion and sediment control Best Management Practice (BMPs) and construction mats to protect wetland soils, vegetation root stock, and streams. Minor, temporary disturbances of wildlife may result from equipment travel and construction crews working in the Project corridor. Any wildlife displacement will be negligible and temporary, since no permanent alteration of the existing habitat is proposed. An environmental monitor will be part of the Project team to ensure compliance with all regulatory programs and permit conditions, and to oversee the proper installation and maintenance of the soil erosion and sediment control BMPs.

7.2 Summary of Social Effects and Mitigation

The Project involves existing transmission lines within existing ROWs. No long-term impacts to residential, commercial or industrial land uses will occur as a result of the Project. Any construction noise impacts are expected to be brief and localized. No visual impacts will result from the Project. Traffic control plans will be employed as necessary at the ROW access points off local and state roads, and for the installation of conductors across roadways. The Project will not adversely impact the social and economic conditions in the Project area. To the contrary, the Project will ensure the continued reliability of the electric system.

7.3 Soils

Construction activities which expose unprotected soils have the potential to increase natural soil erosion and sedimentation rates. Soil compaction and decreased infiltration rates may result from equipment operations. Standard construction techniques and BMPs will be employed to minimize any short-term impacts due to construction activity. These include the installation of straw bales, siltation fencing, water bars, diversion channels, the reestablishment of vegetation and dust control measures as appropriate. These devices will be inspected by TNEC's environmental monitor frequently during construction and repaired or replaced if necessary. TNEC will develop and implement a Soil Erosion and Sediment Control Plan, which will detail BMPs and inspection protocols.

Soil erosion and sediment control measures will be selected to minimize the potential for soil erosion and sedimentation in areas where soils are impacted. TNEC will adhere to its ROW Access, Maintenance, and Construction Best Management Practices document (EG-303). The Company will pay particular attention to the highly erodible soils that are encountered within the Study Area. On all slopes greater than eight percent which are above sensitive areas, impacted soils will be stabilized with straw or chipped brush mulch to prevent the migration of sediments.

Temporary soil erosion controls may be placed in the following types of areas, in accordance with site-specific field determinations:

- Across or along portions of cleared ROW, at intervals dictated by slope, soil erodibility, amount of vegetative cover remaining, and down-slope environmental resources;
- Along access ways within the transmission line ROW;
- Across areas of impacted soils on slopes leading to streams and wetlands; and
- Around portions of construction work sites that must unavoidably be located in wetlands.

The temporary soil erosion controls will be maintained, as necessary, throughout the period of active construction until restoration has been deemed successful, as determined by standard criteria for storm water pollution control/prevention and soil erosion control. In addition to silt fence or straw bales, temporary soil erosion controls may include the use of mulch, jute netting (or equivalent), soil erosion control blankets, reseeding to establish a temporary vegetative cover, temporary or permanent diversion berms (if warranted), and/or other equivalent structural or vegetative measures. After the completion of construction activities in any area, permanent stabilization measures (e.g., seeding and/or mulching) will be performed as necessary.

During the 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 re-vegetative cover achieved, in accordance with applicable permit and certificate requirements.

7.4 Water Resources

7.4.1 Major Surface Waters

There are two major surface water features within the Study Area – Sneech Pond and East Sneech Brook. Potential impacts to surface waters if sediment transport is not controlled include temporary increased turbidity and sedimentation (locally and downstream) and subsequent alterations of benthic substrates, decreases in primary production and dissolved oxygen concentrations, releases of toxic substances and/or nutrients from sediments, and destruction of benthic invertebrates. For this Project, however, any impact of the Project upon major surface waters will be minor and temporary. Construction activities temporarily 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. Temporary construction mats will be used to access structure locations within or adjacent to surface water features as conditions warrant. Sedimentation and turbidity within these watercourses will be minimized through the implementation and installation of BMPs prior to construction activities.

7.4.2 Wetlands and Waterbodies

Construction of the Project will result in temporary impacts to wetland resources. No permanent impacts to wetlands will be required. The temporary impacts associated with construction of the Project are limited to the use of matting for access and work space in wetlands within the ROW. Table 7-1 summarizes the matting proposed for each wetland location on the Project based on preliminary design data.

TABLE 7-1 SUMMARY OF POTENTIAL TEMPORARY IMPACTS ON WETLANDS AND WATERBODIES IN RHODE ISLAND

WETLAND ID	APPROXIMATE IMPACT (SQUARE FEET)
J2	35,025
Total Temporary Wetland Impacts from Matting	35,025 (0.8 acre)

Water Quality

The primary potential impact to water quality from any construction project is the increase in turbidity of surface waters in the vicinity of construction resulting from soil erosion and sedimentation from the impacted site. The use of existing access roads will effectively minimize impacts to previously undisturbed areas on the ROW.

A second potential impact is the spillage of petroleum, hydraulic fluid, or other products near waterways. The Company will avoid such impacts by requiring that equipment (with exceptions for equipment that is not readily mobile) will not be refueled or maintained near wetland or surface water resources. The construction team will respond to an inadvertent release or spill of soil or other hazardous materials in accordance with Rhode Island State requirements. Pre-construction environmental training of the construction team will reinforce this obligation. Therefore, no permanent or temporary impacts to water quality, surface wetlands, or waterbodies are anticipated.

Hydrology

Some minor, temporary impacts to surface drainage can be expected during Project construction. These impacts will be associated with access road and workspace improvements. Following construction, temporarily disturbed areas will be restored to pre-construction conditions to the extent practicable. Features that are to permanently remain on the Project ROW (such as improved access roads) will be stabilized.

No stream crossings are required for the construction of the Project. No permanent impacts to hydrology are anticipated.

Floodplain

The Project is not located within the 100-year floodplain.

7.4.3 Groundwater Resources

The only potential impact to groundwater resources would result from inadvertent spillage or release of petroleum, hydraulic fluid, or other products. Potential impacts to groundwater resources within the Project ROW as a result of construction activity on the transmission line facilities will be negligible or nonexistent. Equipment used for construction will be properly inspected, maintained and operated to reduce the chances of spill occurrences of petroleum products. Construction equipment will be required to carry spill containment and prevention devices (i.e., absorbent pads, clean up rags, five-gallon containers, and absorbent material) and fueling of equipment will occur in upland areas where practicable. In addition, maintenance equipment and replacement parts for construction equipment will be on hand to repair failures and stop a spill in the event of equipment malfunction. Following construction, the normal operation and maintenance of the transmission line facilities will have no impact on groundwater resources.

7.5 Vegetation

Along most of the ROW and at structure sites, vegetation mowing will be required prior to construction of the Project. These activities will be limited to those areas necessary to provide access to existing and proposed Project structure locations, to facilitate safe equipment passage, to provide safe work sites for personnel within the ROW, and to maintain safe clearances between vegetation and transmission line conductors for reliable operation of the transmission facilities. Pruning and individual tree removal may be required in certain locations along the ROW to ensure adequate safety and operational clearances for the new transmission line. During and following the construction, danger trees that have been determined to present a potential hazard to the integrity of the line will be marked and pruned or removed. Limited tree removal and trimming may be required for use of approved off-ROW access routes. No long-term change in the vegetation on the ROW will be required for the Project since all the work will be within existing and maintained transmission line ROW.

TNEC has developed a Rare Plant Avoidance Plan which will be adhered to during vegetation removal for the Project. All rare plants will be avoided and fenced off with orange safety fencing prior to the work crews arriving on the site.

After completion of work on the transmission facilities, TNEC will stabilize, seed and mulch impacted areas with appropriate grass-type mixes and straw mulch. Vegetative species compatible with the use of the ROW for transmission line purposes are expected to regenerate naturally, over time. TNEC will promote the re-growth of desirable species by implementing vegetative maintenance practices to control tall-growing trees and undesirable invasive species that conflict with line clearances, thereby enabling native plants to dominate.

7.6 Wildlife

Minor, temporary disturbances of wildlife may result from equipment travel and construction crews working in the Project corridor. During construction, displacement of wildlife may occur due to disturbance associated with ROW mowing and the operation of construction equipment. Wildlife currently utilizing the forested edge of the cleared ROW may be affected by the construction of the Project.

Larger, more mobile species, such as eastern white-tailed deer or red fox, will temporarily leave the construction area. Individuals of some bird species will also be temporarily displaced. Depending on the time of year of these operations, this displacement could impact breeding and nesting activities. Smaller and less mobile animals such as small mammals, reptiles, and amphibians may be affected during vegetation mowing and the transmission line construction. The species impacted during the reconductoring of the transmission line are expected to be limited in number. Effects will be localized to the immediate area of construction around structure locations and along existing access roads. However, this is anticipated to be a temporary effect as it is expected that existing wildlife utilization patterns will resume, and population sizes will recover once work activities are completed. Any wildlife displacement will be negligible and temporary, since no permanent alteration of the existing habitat is proposed. Only minor tree cutting or trimming is required for the Project; therefore, no impacts to northern long-eared bats are anticipated. No long-term impacts to general wildlife are expected to result from the Project.

7.7 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. Due to the transitory nature of the construction, air quality in the Project ROW will not be significantly affected by construction along the ROW. Emissions produced by the operation of construction machinery (nitrogen oxides, sulfur oxides, carbon monoxide, and particulate matter) are short-term and not generally considered significant.

7.8 Social and Economic

The Project will not adversely impact the overall social and economic condition of the Project area. The Project does not require, nor will it lead to long-term residential or business disruption. Temporary construction impacts, primarily related to construction traffic and equipment operation, are expected to be minor. As described in Section 6.0, the proposed work will be located entirely within an existing 115 kV transmission Line ROW. By providing continued reliable supply of electricity, the Project will support economic growth and development.

7.8.1 Land Use

The Project is compatible with various land uses along the proposed route. Because the Project will only affect an existing line located within existing ROWs, it will not displace any existing residential, agricultural, institutional, or recreational 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. TNEC will provide notification of the intended construction plan and schedule to affected landowners and abutters so that the effect of any temporary disruptions may be minimized. The installation or construction of buildings, pools or other non-transmission related facilities is not allowed within the transmission line easement.

7.8.2 Consistency with Cumberland Comprehensive Plan

Because the Project will occur entirely within an existing cleared transmission line ROW, it will not alter existing land use patterns and will not adversely impact future planned development. The Project will provide a continued reliable supply of electricity for the growth and development envisioned by the Comprehensive Plan of the Town of Cumberland.

7.9 Visual Resources

The Project involves replacing conductors and upgrades to existing structures, with the exception of one proposed structure to be replaced. The structure will be replaced generally along the same alignment and in roughly the same location. Structure 133 will be replaced with a new structure that is approximately 32 feet higher than the existing. Because the Project will not materially change the existing appearance of the ROW, no significant impacts to visual resources are anticipated as a result of the Project.

7.10 Cultural and Historic Resources

TNEC's cultural resource consultant, PAL, completed a cultural resource due diligence and cultural resource assessment, referencing Phase I archaeological and historic architectural properties reconnaissance surveys conducted in 2018 for a previous Project, and corresponded with the currently proposed Project impact areas.

On July 28, 2020, PAL submitted the cultural resource due diligence and assessment to the RIHPHC and the NITHPO. On August 21, 2020, the RIHPHC concurred with PAL's recommendations that the proposed Project will not affect any historic properties. On August 17, 2020, the USACE initiated consultation with the NITHPO, providing the PAL cultural resource due diligence and assessment to the NITHPO. The NITHPO did not respond to the USACE's correspondence.

7.11 Noise

Noise impacts are expected to be negligible. Temporary construction noise may be generated by the Project that will occur during normal daytime working hours. Proper mufflers will be required to control noise levels generated by construction equipment. Some work tasks such as concrete pours and transmission line stringing, once started, must be continued through to completion and may go beyond normal work hours. Work requiring scheduled outages and crossings of certain transportation and utility corridors may need to be performed on a limited basis outside of normal work hours, including on Sundays and holidays. Prior to and during construction, TNEC will notify landowners, abutting property owners, municipal officials, and local Police and Fire Chiefs of the details of planned construction including the normal work hours and any extended work hours.

7.12 Transportation

The construction related traffic increase will be small relative to total traffic volume on public roads in the area. In addition, it will be intermittent and temporary, and construction related traffic will cease once the Project is completed. The addition of this traffic for the limited periods of time is not expected to result in any additional congestion or change in operating conditions along any of the roadways along the ROW. Where access to the ROW intersects a public way, the construction team will follow a pre-approved work zone traffic control plan. Although traffic entering and exiting the ROW at these locations is expected to be small, vehicles entering and exiting the site will do so safely and with minimal disruption to traffic along the public way. Following construction, traffic activity will be minimal and will occur only when the ROW or transmission lines must be maintained. As a result, no long-term impacts to traffic flow or roadways are expected.

7.13 Safety and Public Health

Following construction of the facilities, all transmission line structures will be clearly marked with warning signs to alert the public to potential hazards if climbed. Trespassing on the ROW will be discouraged by using existing gates and/or barriers at entrances from public roads.

7.13.1 Electric and Magnetic Fields

Exponent has calculated 60 Hz EMF levels for existing and proposed future conditions at projected average and peak loading in year 2022.[4]

Calculations indicate that the magnetic field levels after the reconductoring of the Project will either not change or will increase slightly along the route under both average and peak line loadings. The magnetic field level at the ROW edge under average loading conditions is calculated to increase by between 0.8 and 3.8 mG. The magnetic field level changes at peak line loadings are similar (refer to Tables 7-2 and 7-3). These levels are well below the guidelines presented in Table 6-3 *60 HZ EMF Guidelines Established by Health and Safety Organizations*.

TABLE 7-2 J16S LINE MAGNETIC FIELD LEVEL (mG) AT AVERAGE LOADING

	EDGE OF ROW MAGNETIC FIELD LEVELS	
Configuration	Northern ROW edge	Southern ROW edge
Existing	2.3	12
Proposed	2.3	12

[4] Typically, projections showing levels post construction and 5 years after construction to reflect projected growth. However, this Project addresses present conditions so the projected levels at 5 years after construction were not provided. In addition, with active and passive demand response, energy efficiency, and inclusion of distributed photovoltaic generation the total New England load is not expected to be appreciably different. Furthermore, there are no additional planned projects in the area that would significantly increase the loading on the subject lines.

TABLE 7-3 J16S LINE MAGNETIC FIELD LEVEL (mG) AT PEAK LOADING

	EDGE OF ROW MAGNETIC FIELD LEVELS	
Configuration	Northern ROW edge	Southern ROW edge
Existing	3.2	18
Proposed	3.2	18

Electric field levels do not directly depend on loading and, thus, are calculated to not change as a result of the Project (refer to Table 7-4).

TABLE 7-4 J16S LINE ELECTRIC- FIELD LEVELS (KV/M)

	EDGE OF ROW ELECTRIC FIELD LEVELS	
Configuration	Northern ROW edge	Southern ROW edge
Existing	< 0.1	0.4
Proposed	< 0.1	0.4

8.0 MITIGATION MEASURES

The Project consists of the reconductoring of 0.61 mile of an existing transmission line in existing ROW. As described in Section 7.0, there are no long-term impacts to mitigate as a result of this Project. Therefore, mitigation efforts are focused on the construction phase.

8.1 Construction Phase

The construction phase of the Project will include the replacement of one structure and reconductoring the J16S and R9 Lines. This work will require only minor disturbances to the surrounding natural environment.

TNEC will implement several measures during construction which will minimize impacts to the environment. These include the use of existing access roads and structure pads where possible, installation of erosion and sedimentation controls, supervision and inspection of construction activities within resource areas by an environmental monitor and minimization of disturbed areas. Stabilization of soil will occur when areas are disturbed. The following section details various mitigation measures which will be implemented to minimize construction related impacts.

8.1.1 Mitigation of Natural Resource Impacts

When the existing transmission lines were originally constructed, and as the lines have been maintained over the years, access roads were established within most portions of the ROW. During construction of the Project, vehicles will utilize these existing access roads where practical to minimize disturbance within the ROW. Access through wetlands will be provided by using construction mats from the existing maintained portion of the ROW. Excavated soils will be stockpiled and spread in approved upland areas outside all biological wetland areas in such a manner that general drainage patterns will not be affected. Construction access will be limited to the existing structure locations, work pads, and proposed access routes, and will be lined with erosion and sedimentation control BMPs where needed. Each area will be restored following erection of the structures and installation of the new conductors.

Where possible, if danger trees are required to be removed, they will be removed outside of the time-of-year restrictions set forth by the USFWS New England Field Office (June 1st – July 31st) for northern long-eared bat. Any other tree removal that will be required for approved, new access roads, or off-ROW access roads, will occur outside of the time-of-year restrictions set forth by the USFWS New England Field Office. Additionally, TNEC will adhere to a Rare Species Avoidance Plan for all state-listed species identified on the ROW. All state-listed species will be avoided through the placement of protection and avoidance measures such as orange safety exclusion fencing, temporary matting, or working outside of the growing season.

To maintain a visual buffer into the ROW, existing vegetation will be retained at all road crossings and areas subject to public view, where possible. TNEC will adhere to a site-specific invasive species control plan which will require that all equipment and temporary matting brought on site will be certified as clean. Temporary matting will be removed upon completion of the Project and the area will be restored back to pre-existing conditions and contours to the extent practicable.

8.1.2 Erosion and Sedimentation Control

Erosion and sediment control devices will be installed along the perimeter of identified wetland resource areas prior to the onset of soil disturbance activities to ensure that soil stockpiles and other disturbed soil areas are confined and do not result in downslope sedimentation of sensitive areas. Low growing tree species, shrubs and grasses will only be mowed along access roads and at pole locations. Construction crews will be responsible for conducting daily inspections and identifying erosion controls that must be maintained or replaced as necessary.

8.1.3 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, 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 control techniques described in this report and will have an understanding of wetland 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 construction team 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 construction team's awareness of these issues.

8.1.4 Air Quality

During earth disturbing activities, the construction team will deploy dust mitigation measures as described in National Grid's EG-303. Exposed soils will be wetted and stabilized as necessary to suppress dust generation, and crushed stone aprons will be used at all access road entrances to public roadways. Consequently, fugitive dust emissions are anticipated to be low.

TNEC requires the use of ultra-low sulfur diesel fuel exclusively in the construction team'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 Rhode Island General Laws § 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 construction team is responsible for complying with the state regulatory requirements along with the National Grid Environmental Guidance (EG-802RI) Vehicle Idling – Rhode Island.

8.1.5 Mitigation of Social Resource Impacts

TNEC will minimize social resource impacts during construction by incorporating several standard mitigation measures. By use of an established transmission line ROW rather than creating a new ROW, the potential for disruption due to construction activities will be limited to an area already dedicated to transmission line uses. Construction generated noise will be limited by the use of mufflers on all construction equipment and by limiting construction activities to the hours specified in the local ordinances. Dust will be controlled by wetting and stabilizing access road surfaces, as necessary, and by maintaining crushed stone aprons at the intersections of access roads with paved roads. TNEC will minimize the potential for disturbance from the construction by notifying abutters of planned construction activities before and during construction of the line. Some short-term impacts are unavoidable, even though they have been minimized. By carrying out the reconductoring of the transmission lines in a timely fashion, TNEC will keep these impacts to a minimum. TNEC will prepare a traffic management plan which will minimize impacts associated with increased construction traffic on local roadways.

As noted in Section 7.0, Project construction will avoid impacts to cultural and historic resources. Therefore, there is no mitigation required.

8.2 Post-Construction Phase

Following the completion of construction, TNEC uses standard mitigation measures on all transmission line construction projects to minimize the impacts of projects on the natural and social environment. These measures include revegetation and stabilization of disturbed soils, ROW vegetation management practices and vegetation screening maintenance at road crossings and in sensitive areas. Other measures are used on a site-specific basis. TNEC will implement the following standard and site-specific mitigation measures for the Project.

8.2.1 Restoration of Natural Resource Impacts

Restoration efforts, including final grading and installation of permanent erosion control devices, and seeding of disturbed areas, will be completed following construction. Construction debris will be removed from the Project site and disposed of at an appropriate landfill. Pre-existing drainage patterns, ditches, roads, fences, and stone walls will be restored to their former condition, where appropriate. Permanent slope breakers and erosion control devices will be installed in areas where the disturbed soil has the potential to impact wetland resource areas.

Vegetation maintenance of the ROW will be accomplished with methods identical to those currently used in maintaining the existing ROW. TNEC's ROW vegetation maintenance practices encourage the growth of low-growing shrubs and other vegetation which provides a degree of natural vegetation control. In addition to reducing the need to remove tall growing tree species from the ROW, the vegetation maintained on the ROW inhibits erosion.

8.2.2 Mitigation of Social Resource Impacts

Upon completion of the Project, electric field levels will not change and magnetic field levels at the edges of the ROW will not significantly change from the existing condition. Because all EMFs will be well below established exposure guidelines, no mitigation is proposed. Where possible, TNEC will limit access to the ROW by installing permanent gates and barriers where access roads enter the ROW from public ways. Select areas may be visually screened with landscaping and/or grading.

9.0 BIBLIOGRAPHY

Canada Species at Risk Public Registry. 2018. Rhynchospora macrostachya. http://www.registrelep-sararegistry.gc.ca/document/default_e.cfm?documentID=2762. Accessed November 19, 2020.

Connecticut Botanical Society. 2018. Woodsia ilvensis. https://www.ct-botanical-society.org/Plants/view/2707. Accessed June 25, 2018.

DeGraaf, R.M. and M. Yamasaki. 2001. New England Wildlife: Habitat, Natural History, and Distribution. 2nd edition. Hanover, NH: University Press of New England. 482 p.

Hermes, O.D., Gromet, L.P., Murray, D.P., Hamidzada, N.A. 1994. Geologic Map of Rhode Island, file name = bedrock_shp.zip (870kb) obtained from Rhode Island Geographic Information System, http://www.rigis.org/datasets?q=geology, shapefile or interchange file, scale 1/100,000. Accessed November 19, 2020.

Massachusetts Division of Fisheries and Wildlife. 2015. Natural Heritage Endangered Species Program. Northern Long-eared Bat. Myotis septentrionalis. http://www.mass.gov/eea/docs/dfg/nhesp/species-and-conservation/nhfacts/myotis-septentrionalis-2015.pdf. Accessed November 19, 2020.

Murray, C.D. 1982: Geomorphology of New England, USGS Professional Paper 1208, 18 Pages w/14 Figures.

Natural Resource Conservation Service (NRCS) United States Department of Agriculture (USDA). 2016. Web Soil Survey. http://websoilsurvey.nrcs.usda.gov/. Accessed June 25, 2018.

_____. 2018. USDA Erodibility Values (K) and Texture of the B and C Horizons of Soils in Rhode Island. https://efotg.sc.egov.usda.gov/references/public/RI/section7(USLE).pdf. Accessed June 25, 2018.

Rhode Island Department of Administration. Division of Planning. 2013. Rhode Island Population Projections 2010-2040. http://www.planning.ri.gov/documents/census/tp162.pdf. Accessed June 25, 2018.

Rhode Island Department of Environmental Management (RIDEM). 2016. Vernal Pools. Retrieved June 25, 2018 from: http://www.dem.ri.gov/programs/water/wetlands/vernal-pools.php

_____. Environmental Resource Map. 2018. http://ridemgis.maps.arcgis.com/apps/webappviewer/index.html. Accessed June 25, 2018

_____. 2018. What You Should Know About Bats. http://rhodeislandwoods.uri.edu/files/bats.pdf . Accessed June 26, 2018.

Rhode Island Department of Labor and Training. 2016. State of the State, Labor Market Information. http://www.dlt.ri.gov/lmi/pdf/stateofstate.pdf. Accessed June 25, 2018.

_____. 2018. Rhode Island City, Town, and Sub-State Labor Force Statistics. http://www.dlt.ri.gov/lmi/laus/town/town.htm. Accessed June 25, 2018

Rhode Island Emergency Management Agency. 2016. State of Rhode Island Hazard Identification and Risk Assessment (draft). August 2016. http://www.riema.ri.gov/planning/hazardmitigation/Documents/Final_Draft_Rhode%20Island%20Hazard%20Identification%20and%20Risk%20Assessment_29AUG16.pdf. Accessed June 25, 2018.

Rhode Island Geographic Information System (RIGIS). 1993. Wetlands; s44wwt93. RIGIS Data Distribution System, URL: http://www.rigis.org, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 30 September 2014).

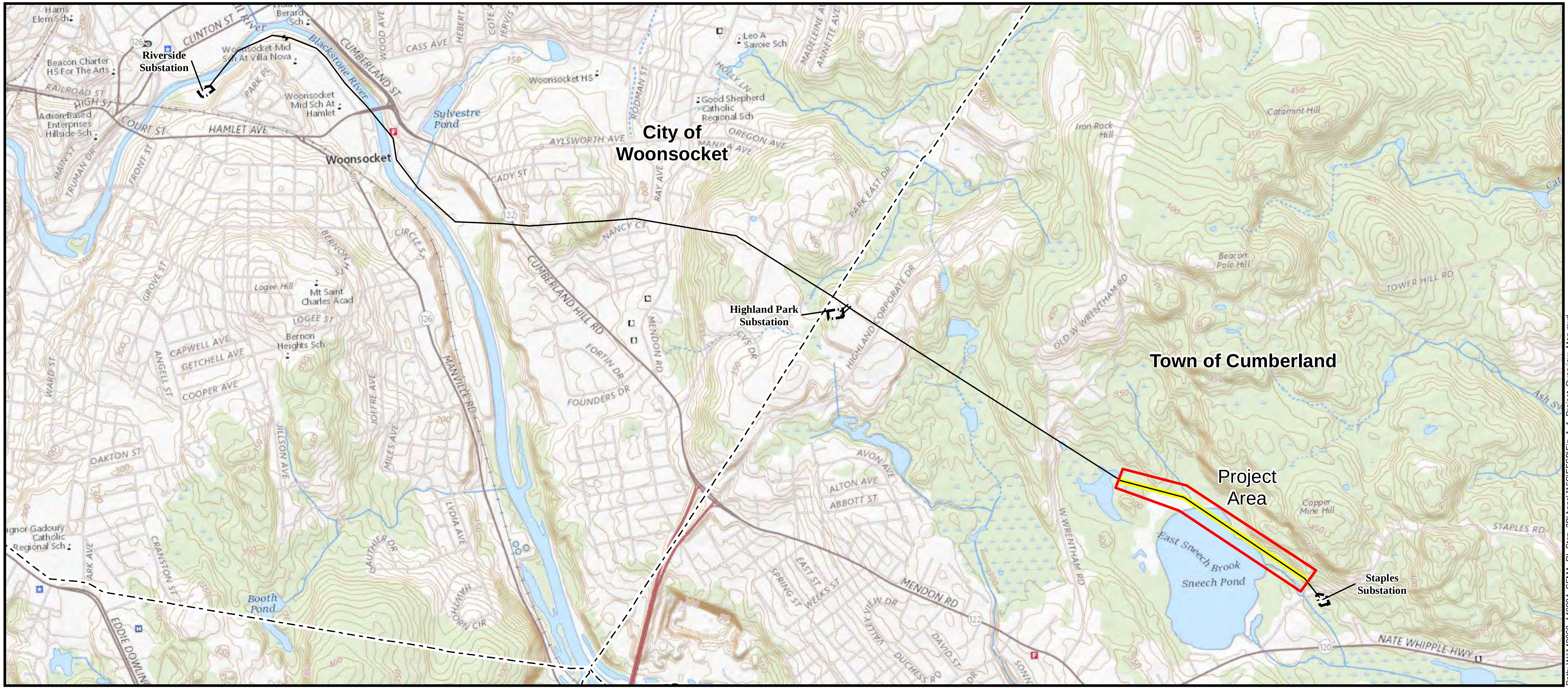
Statewide Digital Flood Insurance Rate Map Database (DFIRM); DFIRM_Statewide15. Rhode Island Geographic Information System (RIGIS) Data Distribution System, URL: http://www.rigis.org, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 26 October 2015).

The Town of Cumberland, Rhode Island. 2016 Comprehensive Plan 2016-2036. https://www.cumberlandri.org/office-planning-and-community-development/pages/2016-cumberland-comprehensive-plan. Accessed June 25, 2018.

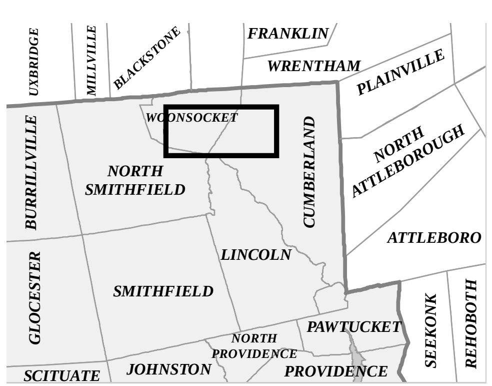
United States Fish and Wildlife Service. 2015. Northern Long-Eared Bat. Myotis septentrionalis. April 2015. https://www.fws.gov/midwest/endangered/mammals/nleb/pdf/NLEBFactSheet01April2015.pdf. Accessed June 25, 2018.

United States Geological Survey. 2018. National Hydrography Dataset 2007-2014. http://nhd.usgs.gov. Accessed June 25, 2018.

APPENDIX A PROJECT FIGURES:



Project Vicinity



Legend

- Project Transmission Line
- J16 and R9 Lines
- Existing Station
- Municipal Boundary

J16S 115 kV Line Reconductoring Project

Figure 1-1

Project Overview Map

State of Rhode Island

Providence County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 0.5 Miles

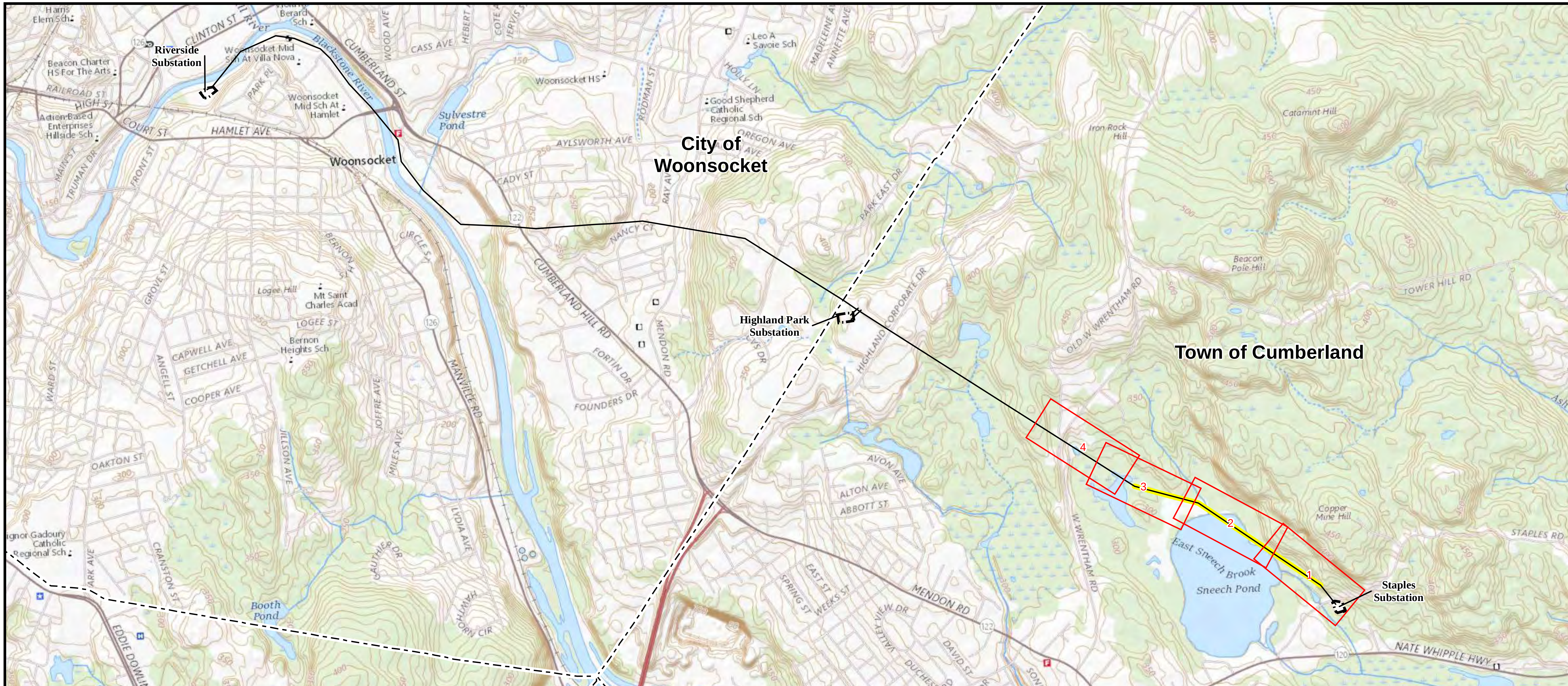
1 " = 1,500 '

nationalgrid

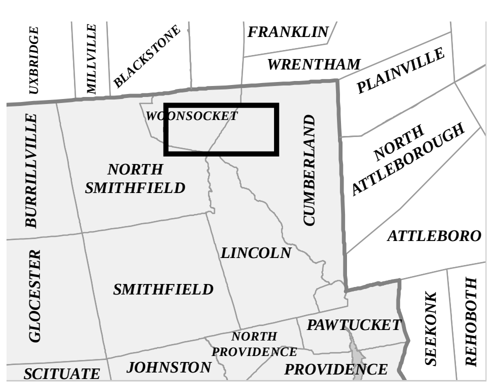
NOT FOR CONSTRUCTION

Date: 12/3/2020

Author: TDH



Project Vicinity



Legend

- Page Boundary
- Project Transmission Line
- J16 Line
- Existing Station
- Municipal Boundary

J16S 115 kV Transmission Line Thermal Upgrade Project

Figure 3-1 Project Alignment Drawings

Index Map

State of Rhode Island

Providence County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 — 0.5 Miles

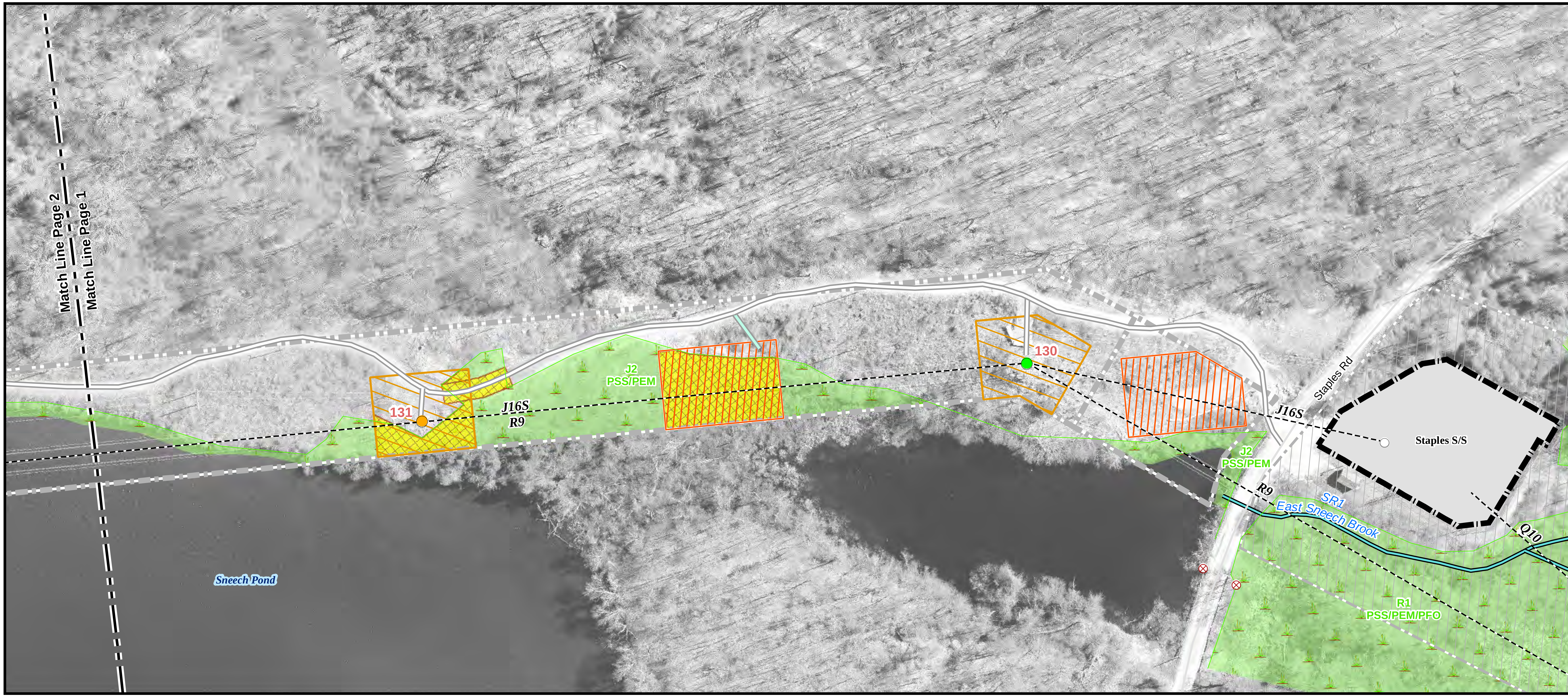
1 " = 1,500 '

nationalgrid

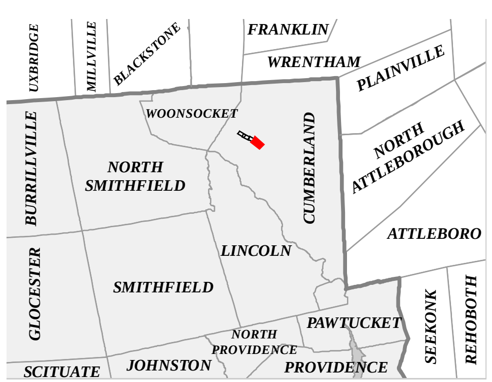
NOT FOR CONSTRUCTION

Date: 12/17/2020

Author:



Project Vicinity



Legend

- Reinforce Structure
- Replace Hanger Members
- Use Existing Access Road
- Construct New Access Road
- Wire Pulling Station
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Structure
- Existing Transmission Line
- Existing Substation
- Easement
- National Grid Owned Land
- Local Road
- Culvert
- Wetland Border
- Perennial Stream or River
- Field Delineated Wetland

J16S 115 kV Transmission Line Thermal Upgrade Project

Figure 3-1 Project Alignment Drawings

Page 1 of 4

State of Rhode Island

Providence County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N E S W

0 100 200 Feet

1 " = 100 '

nationalgrid

NOT FOR CONSTRUCTION

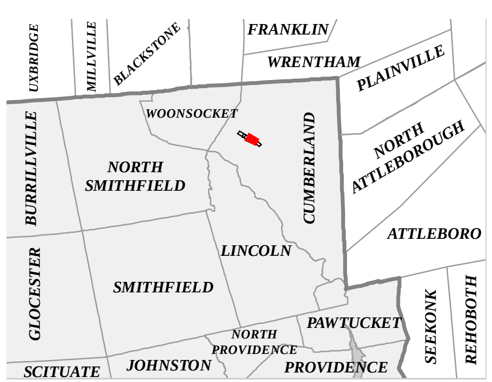
Date: 12/17/2020

Author:

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Project_Alignment\Figure_3_1_Project_Alignment_Drawings.mxd

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Project_Alignment\Figure_3_1_Project_Alignment_Drawings.mxd

Project Vicinity



Legend

- Replace with Steel Pole Structure
- Convert to Suspension and Replace Hanger Members
- Use Existing Access Road
- Wire Pulling Station
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Structure
- Existing Transmission Line
- Easement
- Wetland Border
- Field Delineated Wetland

J16S 115 kV Transmission Line Thermal Upgrade Project

Figure 3-1 Project Alignment Drawings

Page 2 of 4

State of Rhode Island

Providence County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N E S W

0 100 200 Feet

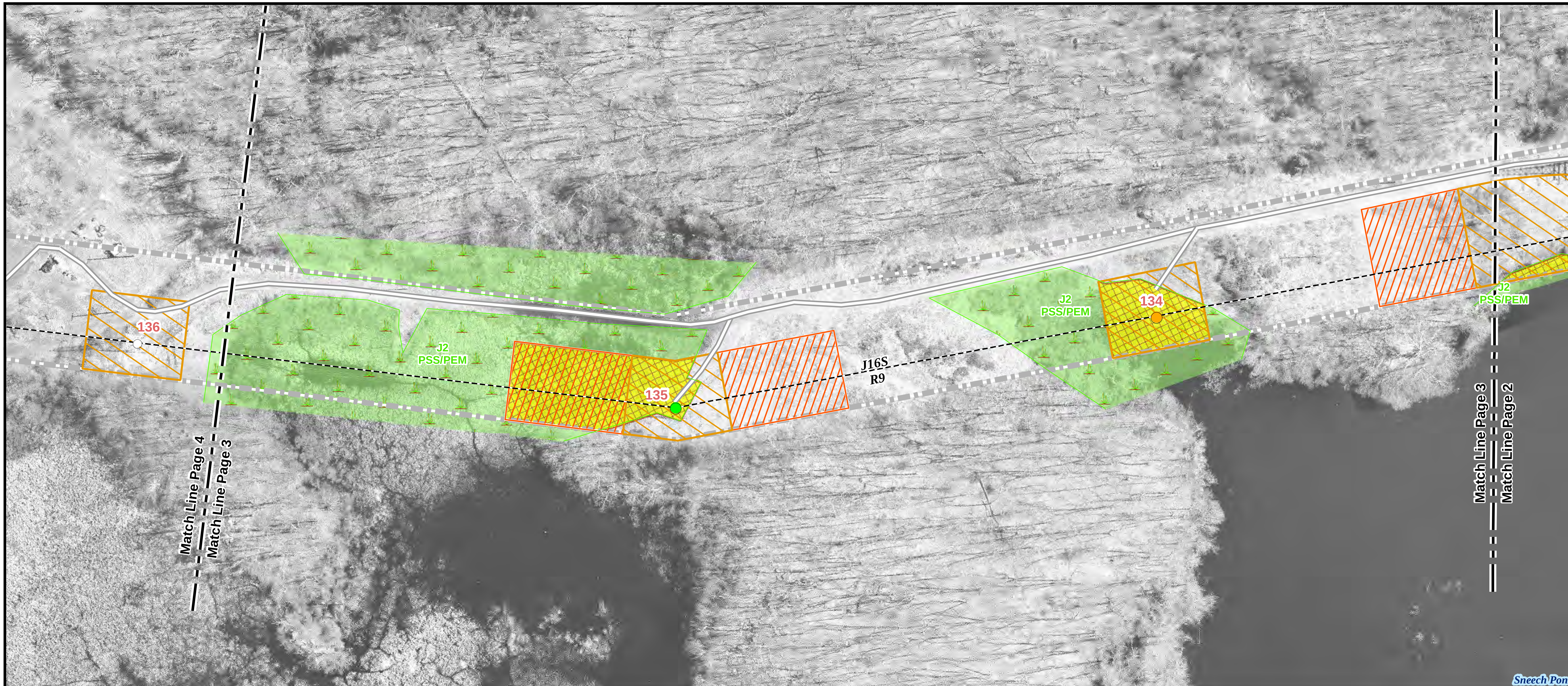
1 " = 100 '

nationalgrid

NOT FOR CONSTRUCTION

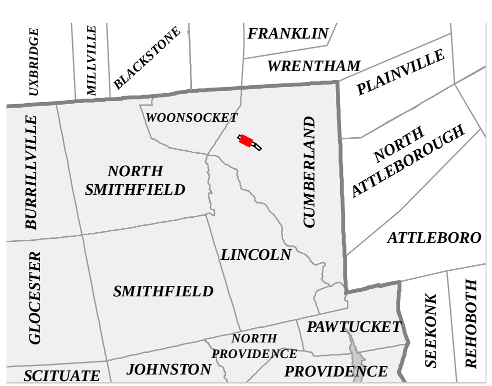
Date: 12/17/2020

Author:



Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Project_Alignment\Figure_3_1_Project_Alignment_Drawings.mxd

Project Vicinity



Legend

- Reinforce Structure
- Replace Hanger Members
- Use Existing Access Road
- Wire Pulling Station
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Structure
- Existing Transmission Line
- Easement
- Wetland Border
- Field Delineated Wetland

J16S 115 kV Transmission Line Thermal Upgrade Project

Figure 3-1 Project Alignment Drawings

Page 3 of 4

State of Rhode Island

Providence County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N E S W

0 100 200 Feet

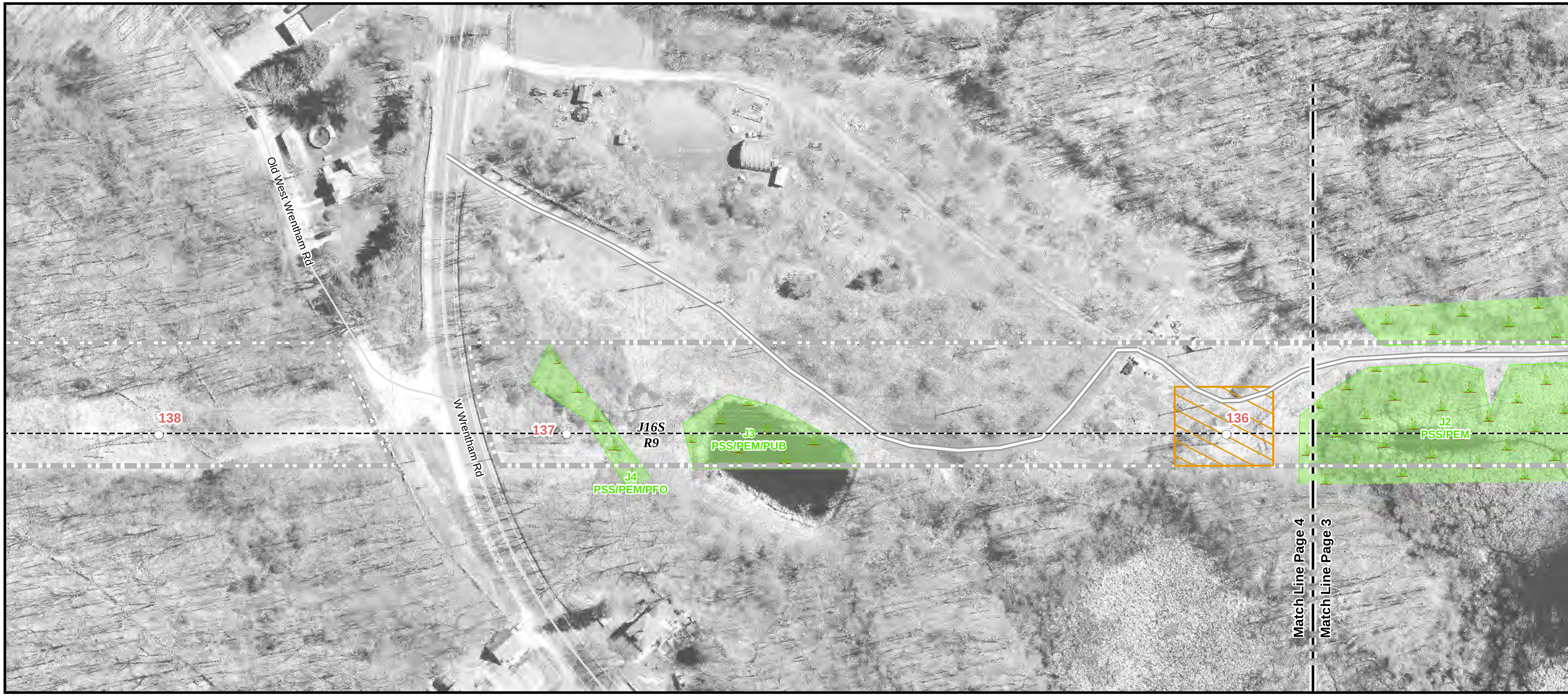
1 " = 100 '

nationalgrid

NOT FOR CONSTRUCTION

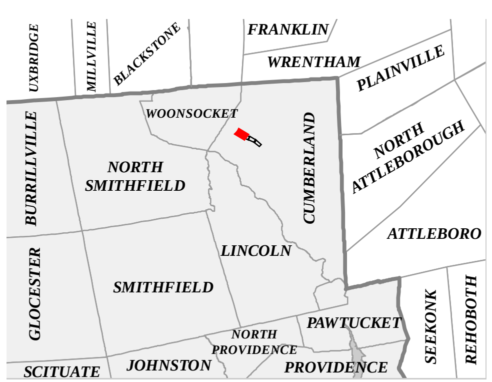
Date: 12/17/2020

Author:



Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Project_Alignment\Figure_3_1_Project_Alignment_Drawings.mxd

Project Vicinity



Legend

- Use Existing Access Road
- Work Pad / Area
- Existing Structure
- Existing Transmission Line
- Easement
- Local Road
- Wetland Border
- Field Delineated Wetland

J16S 115 kV Transmission Line Thermal Upgrade Project

Figure 3-1 Project Alignment Drawings

Page 4 of 4

State of Rhode Island

Providence County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N E S W

0 100 200 Feet

1 " = 100 '

nationalgrid

NOT FOR CONSTRUCTION

Date: 12/17/2020

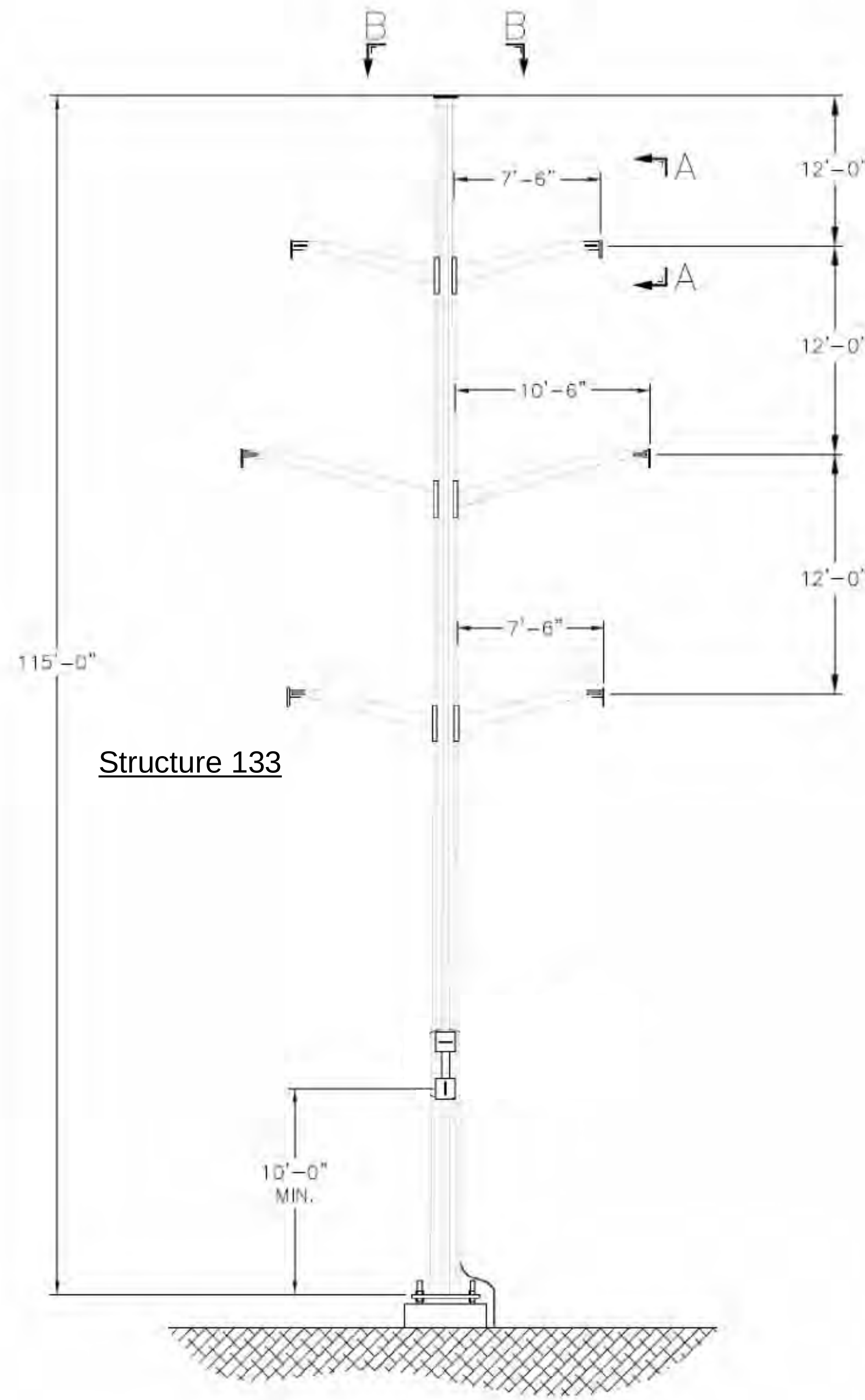
Author:

PHOTOGRAPHIC LOG			
Client Name: TNEC		**Site Location:** J16S Transmission Line	**Project No.**
Photo No. 1	**Date:** 04/17/20		
Direction Photo Taken: West			
Description: View of structure #133 from across Sneech Pond.			

PHOTOGRAPHIC LOG			
Client Name: TNEC		**Site Location:** J16S Transmission Line	**Project No.**
Photo No. 2	**Date:** 04/17/20		
Direction Photo Taken: West			
Description: View of structure #133 located in upland. Structure #133 is proposed to be replaced. Wetland J2 is located to the East, South, and Southwest of the structure.			

PHOTOGRAPHIC LOG			
Client Name: TNEC		**Site Location:** J16S Transmission Line	**Project No.**
Photo No. 3	**Date:** 04/17/20		
Direction Photo Taken: Southeast			
Description: View of structure #130 which is located in upland. structure #130 is the eastern most structure in the work span and connects to the Staples Substation.			

PHOTOGRAPHIC LOG			
Client Name: TNEC		**Site Location:** J16S Transmission Line	**Project No.**
Photo No. 4	**Date:** 04/17/20		
Direction Photo Taken: East			
Description: View of Structure #132 located on an upland peninsula surrounded by Sneech Pond. Proposed work at this structure includes conversion to a suspension structure and replacement of hanger members.			



Structure 133

Legend

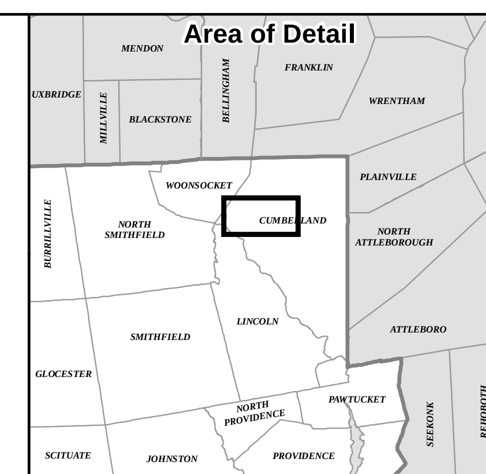


FIGURE 3-3

Typical Structure Details

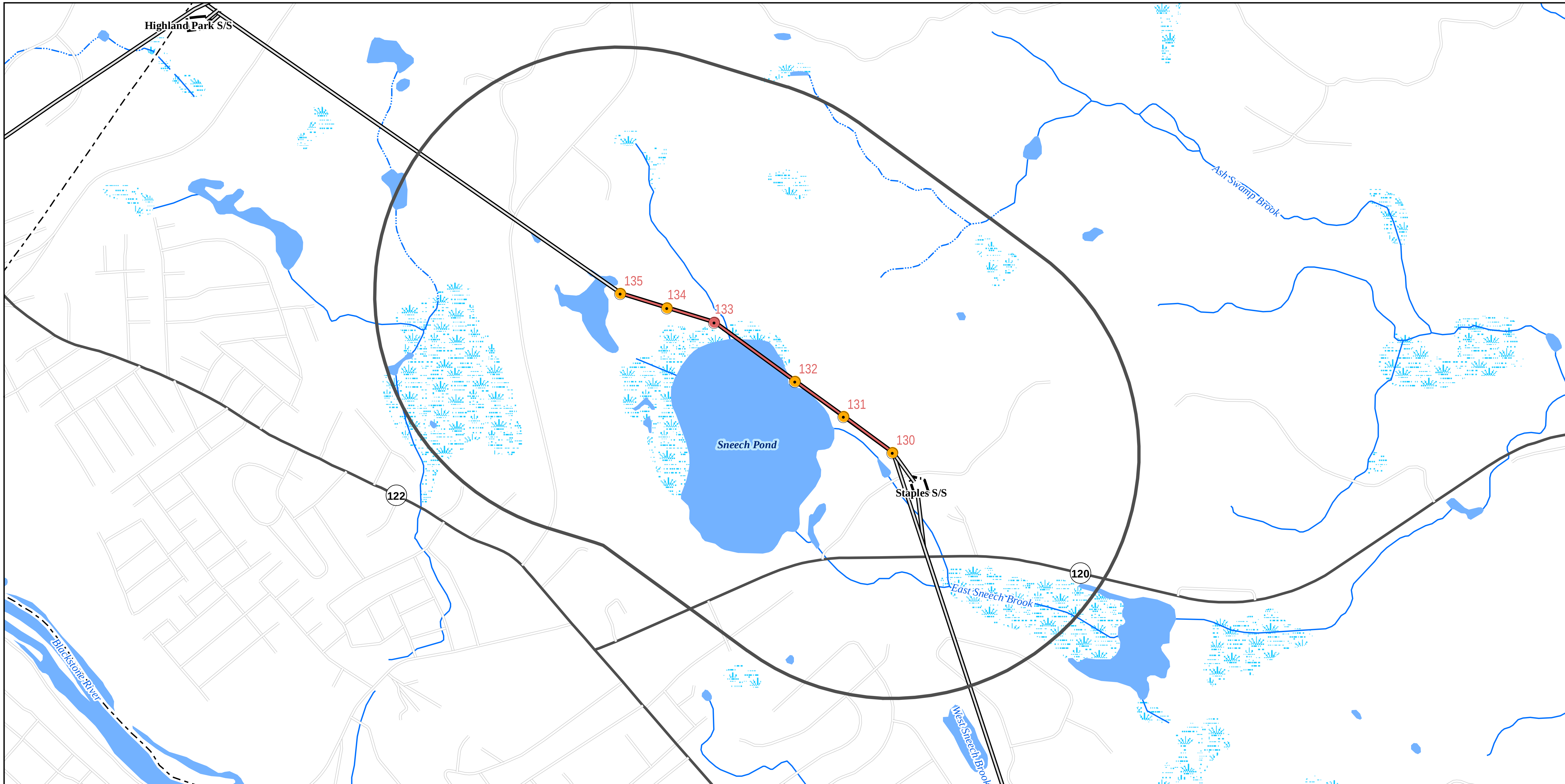
J16S 115 kV Line
Reconductoring Project

POWER ENGINEERS

nationalgrid

Date: 12/3/2020

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Fig_3_2_Typical_Structure_Details.mxd



Legend

Project Features

- Structure Being Replaced
- Structure Being Modified
- Project Spans
- Other Transmission Line
- 5000 Foot Study Area
- Substation Site

Transportation Features

- State Highway
- Other Road

Political Boundaries

- Town Boundary

Water features

- River or Stream
- Lake or Pond
- Swamp or Marsh

Area of Detail

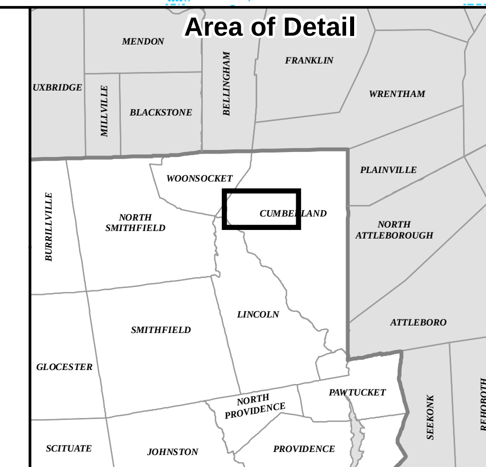


FIGURE 5-1

Study Area

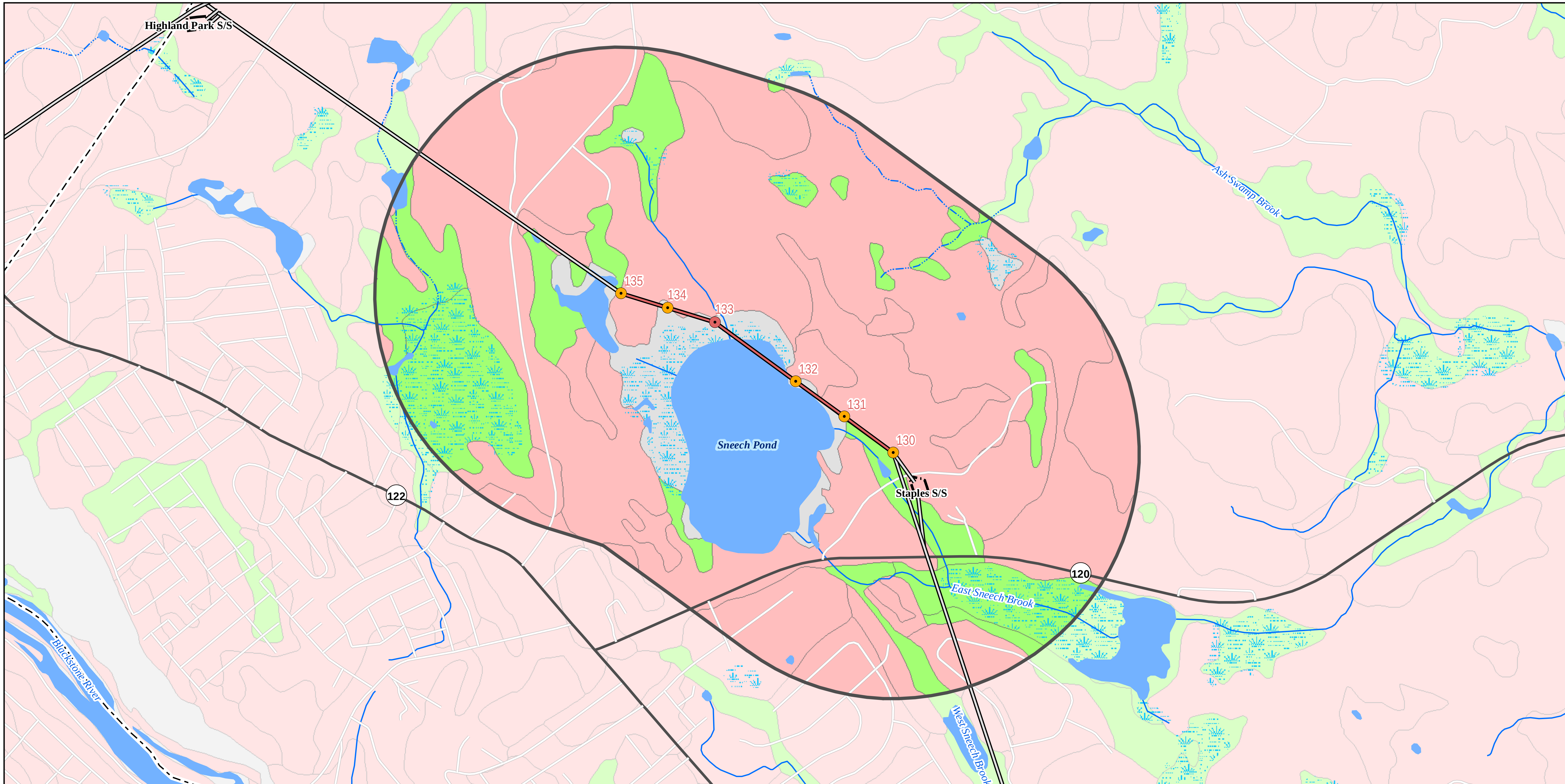
J16S 115 kV Line
Reconductoring Project

0 1,000 2,000
Feet

POWER ENGINEERS
nationalgrid

Date: 12/3/2020

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Fig_5_1_Study_Area.mxd



Legend

Project Features
- Structure Being Replaced
- Structure Being Modified
- Project Spans
- Other Transmission Line
- 5000 Foot Study Area
- Substation Site

Transportation Features
- State Highway
- Other Road

Political Boundaries
- Town Boundary

Water features
- River or Stream
- Lake or Pond
- Swamp or Marsh

Hydric Rating
- Yes
- No
- Unranked

Area of Detail

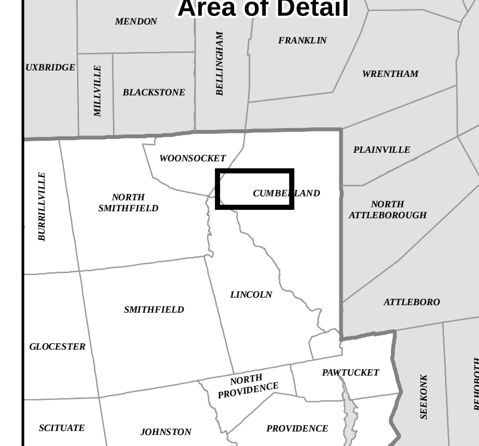


FIGURE 5-2

Hydric Soils

J16S 115 kV Line
Reconductoring Project

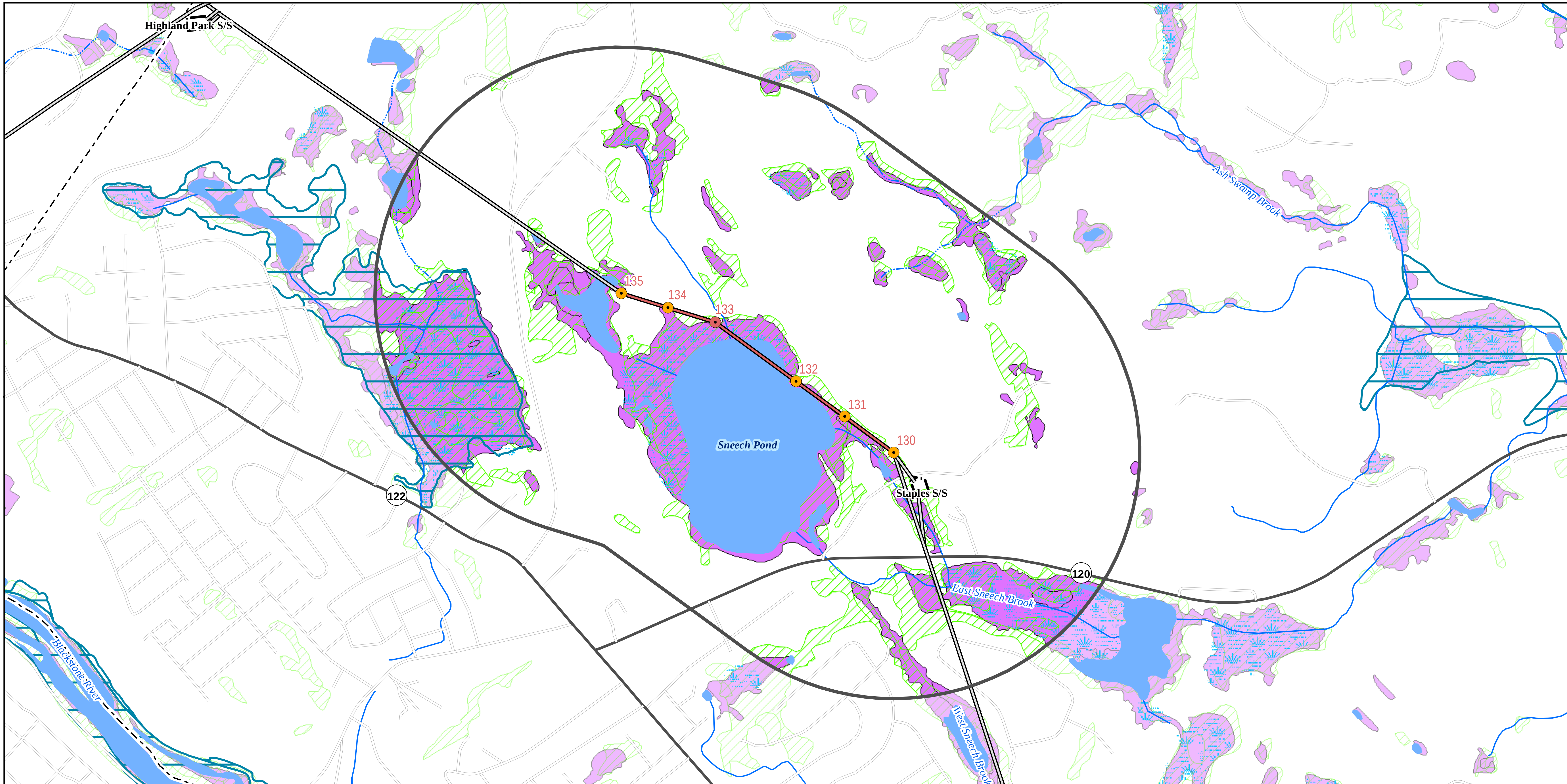
0 1,000 2,000
Feet

POWER ENGINEERS

nationalgrid

Date: 12/3/2020

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Fig_5_2_Hydric_Soils.mxd



Legend

Project Features

- Structure Being Replaced
- Structure Being Modified
- Project Spans
- Other Transmission Line
- 5000 Foot Study Area
- Substation Site

Transportation Features

- State Highway
- Other Road

Political Boundaries

- Town Boundary

Water features

- River or Stream
- Lake or Pond
- Swamp or Marsh

FEMA Flood Hazard (DFIRM 100yr)

Wetlands

- RI Freshwater Wetland
- NWI Wetland

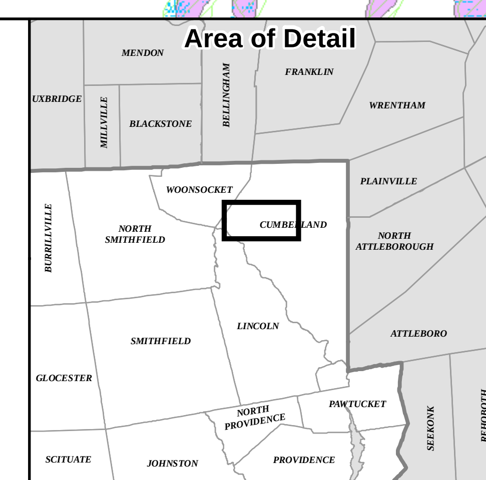


FIGURE 5-3

Wetland Resources

J16S 115 kV Line
Reconductoring Project

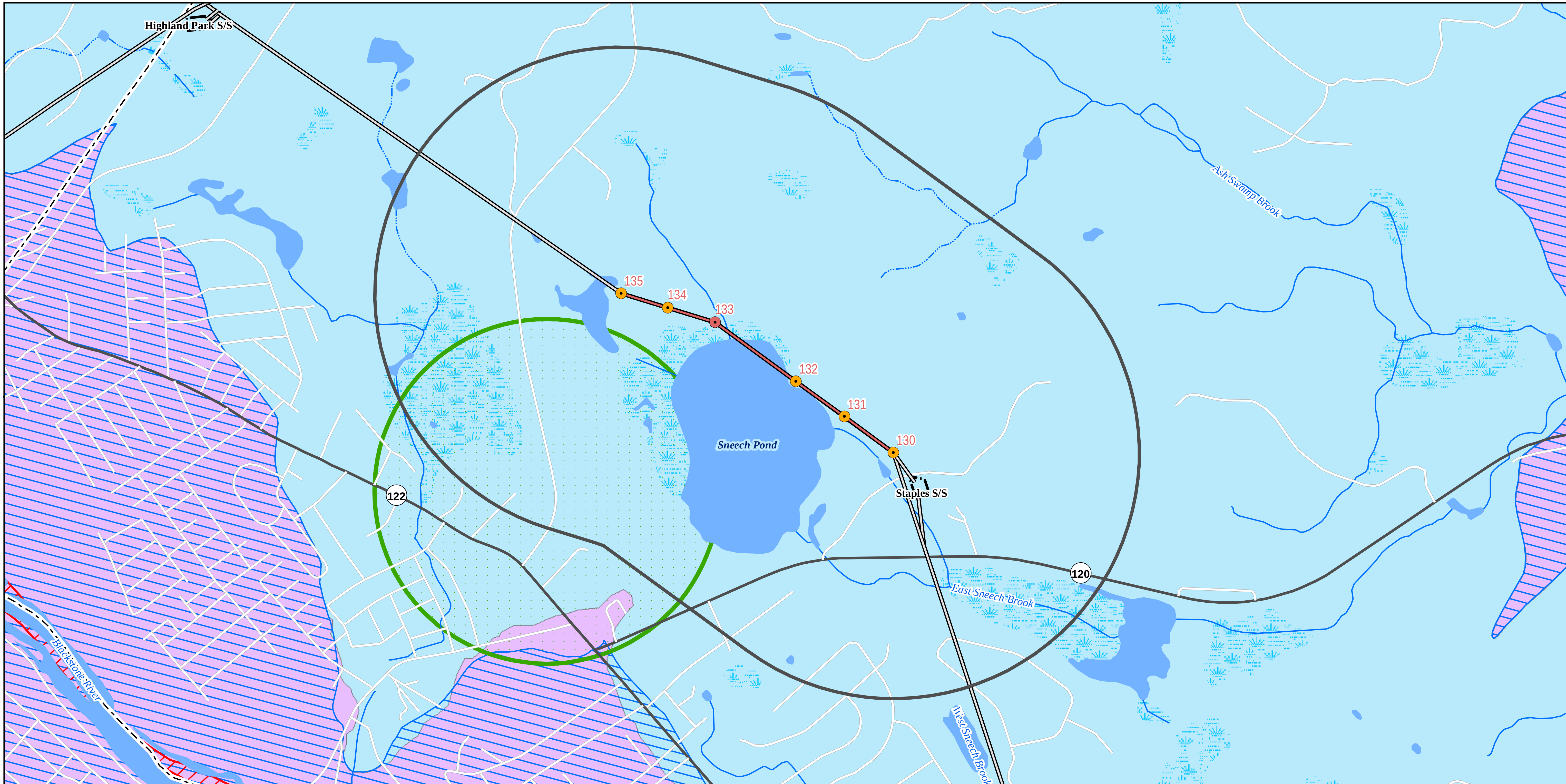
0 1,000 2,000
Feet

POWER ENGINEERS

nationalgrid

Date: 12/3/2020

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Fig_5_3_Wetland_Resources_new.mxd



Legend

Project Features
- Structure Being Replaced
- Structure Being Modified
- Project Spans
- Other Transmission Line
- 5000 Foot Study Area
- Substation Site

Transportation Features
- State Highway
- Other Road

Political Boundaries
- Town Boundary

Water features
- River or Stream
- Lake or Pond
- Swamp or Marsh

Groundwater Resources
- Groundwater Reservoir
- Groundwater Recharge
- Non-Community Wellhead Protection Areas

Groundwater Quality Standard
- GA
- GAA

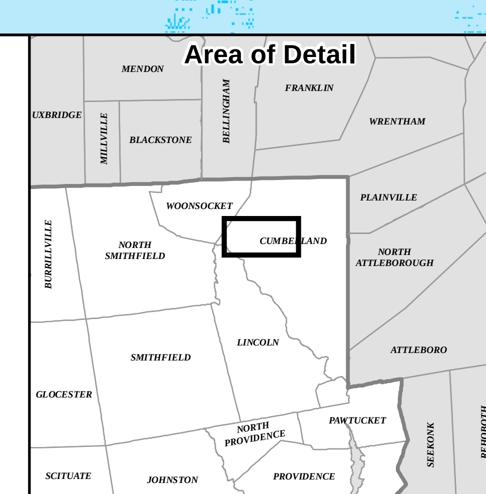


FIGURE 5-4

Groundwater Resources

J16S 115 kV Line
Reconductoring Project

0 1,000 2,000
Feet

POWER ENGINEERS

nationalgrid

Date: 12/3/2020

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\EFSB\Fig_5_4_Groundwater_Resources_new.mxd

APPENDIX B CURRENT STATUS OF RESEARCH ON EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNET FIELDS AND HEALTH RHODE ISLAND TRANSMISSION LINE PROJECTS. THE NARRAGANSETT ELECTRIC COMPANY D/B/A NATIONAL GRID (FEBRUARY 22, 2019)

Health Sciences Practice

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

2014-2018

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

2014-2018

Prepared for:

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

Prepared by:

Exponent
17000 Science Drive, Suite 200
Bowie, MD 20715

February 22, 2019

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

μT	Microtesla
AC	Alternating current
ALL	Acute lymphoblastic leukemia
ALS	Amyotrophic lateral sclerosis
ALT	Alanine aminotransferase
AMI	Acute myocardial infarction
AST	Aspartate aminotransferase
CI	Confidence interval
CNS	Central nervous system
DMBA	7,12-dimethylbenz[a]anthracene
DNA	Deoxyribonucleic acid
EHC	Environmental Health Criteria
ELF	Extremely low frequency
EMF	Electric and magnetic fields
EPA	Environmental Protection Agency
G	Gauss
HCN	Health Council of the Netherlands
HLRN	Hemolymphoreticular neoplasia
Hz	Hertz
IARC	International Agency for Research on Cancer
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
JEM	Job exposure matrix
kV	Kilovolt
kV/m	Kilovolts per meter
LSPC	Lotus seedpod procyanidins
MDA	Malondialdehyde
mG	Milligauss
mg/L	milligrams per liter
OR	Odds ratio

RR	Relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SCHEER	Scientific Committee on Health, Environmental and Emerging Risks
SOD	Superoxide dismutase
TWA	Time weighted average
V/m	Volts per meter
WHO	World Health Organization

Limitations

At the request of the New England Power Company, d/b/a National Grid, Exponent, Inc., 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 extremely low frequency (ELF) electric and magnetic fields (EMF) and health for the Rhode Island Energy Facility Siting Board at the request of The Narragansett Electric Company d/b/a National Grid.

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 a 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 applications 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 40 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. This research considered many aspects of physiology and diseases, including cancers in children and adults, neurodegenerative diseases, reproductive effects, and cardiovascular disease.

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. Policy makers and the public should look to the conclusions of these reviews, since they are conducted using set scientific standards by scientists representing the various disciplines required to assess the topic at hand. In a health risk assessment of any exposure, it is essential that scientists evaluate the type and strength of research studies available. Human health studies vary in methodological rigor; therefore they vary in their capacity to extrapolate findings to the population at large. Furthermore, three types of studies—epidemiology, *in vivo,* and *in vitro*—

relevant to the particular research topic must be evaluated concurrently to understand possible health risks. Section 3 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 they evaluated. 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 [*sic*]. 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).

Exponent's report provides a systematic literature review and a critical evaluation of relevant epidemiologic and *in vivo* studies published from December 2014 through December 2018. These recent studies did not provide sufficient evidence to alter the basic conclusion of the WHO—the research does not confirm that electric fields or magnetic fields are a cause of cancer or any other disease at the levels we encounter in our everyday environment. The current guidance from the WHO on its website states that "[b]ased on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields."[1]

[1] https://www.who.int/peh-emf/about/WhatisEMF/en/index1.html. Accessed January 19, 2019.

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 exposure limits established by the International Commission on Non-Ionizing Radiation Protection or the International Committee for Electromagnetic Safety for the prevention of acute health effects at high exposure levels. In light of their assessments of the scientific research, some scientific organizations recommend low-cost interventions to reduce ELF EMF exposure. While the large body of existing research does not confirm any likely harm associated with ELF EMF exposure at low levels, research on this topic will continue to reduce remaining uncertainty.

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 is 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 review 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 they evaluated.

National Grid requested that Exponent provide an easily-referenced document that updates a report previously prepared for the Rhode Island Energy Facility Siting Board as part of its Applications for the 2015 Rhode Island Transmission Projects.[2] Exponent's 2015 report systematically evaluated peer-reviewed research and reviews by scientific panels published through November 2014. This current report updates this earlier report with a systematic evaluation of peer-reviewed research and reviews by scientific panels published from December 2014 through December 2018 and describes if and how these recent results affect conclusions reached by the WHO in 2007.

Nature of extremely low frequency electric and magnetic fields

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

[2] Exponent, Inc. *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 the Rhode Island Energy Facility Siting Board. March 9, 2015.

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); 1 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 of gauss (G) or 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, magnetic-field 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 fields 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 and everyday life (e.g., transportation systems, homes, and businesses), people living in modern communities 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 V/m to 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 to evaluate 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).
  - Several 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 metal piping, and homes close to

[4] TWA is the average exposure over a given specified time period (i.e., an 8-hour workday or 24 hours) 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.

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 (NIEHS, 2002).

- *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, as illustrated in Figure 2, and as discussed in a National Institute of Environmental Health Sciences booklet on EMF (NIEHS, 2002).

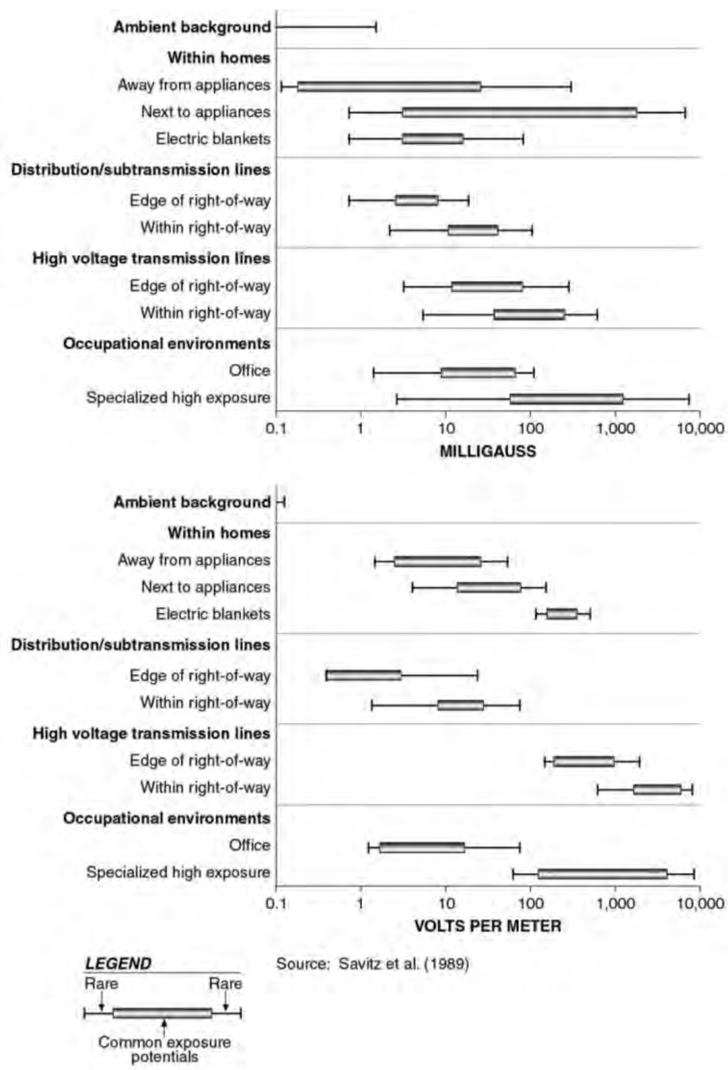


Figure 2. Electric- and magnetic-field strengths in the environment.

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 (ICNIRP, 2010). 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 there are no real-life situations where these levels are exceeded on a regular basis. Standards and guidelines are discussed in more detail in Section 8.

3 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 to ensure that studies with a given result are not selectively chosen from available studies 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 present 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 typically are conducted within the larger framework of health risk assessments or evaluations of particular exposures or exposure circumstances that qualitatively and quantitatively define health risks. Several agencies have described weight-of-evidence and health risk assessment methods, 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; the United States Environmental Protection Agency (EPA), which sets guidance for public exposures; the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR); and the United States National Toxicology Program (USEPA, 1993, 1996; WHO, 1994; SCENIHR, 2012; NTP, 2015). 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 ELF EMF in a weight-of-evidence review, including exposure considerations, study design, and 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

Methods to evaluate exposure range widely in studies of ELF EMF. They include 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 a house (e.g., a child's bedroom); calculated magnetic-field levels based on the characteristics of nearby power installations; and personal measurements of magnetic fields for a 24-hour or 48-hour period.

Each of these methods has strengths and limitations (Kheifets and Oksuzyan, 2008). Magnetic-field exposure is ubiquitous, but it varies for each individual over a lifetime as the locations one frequents change and as the ELF EMF sources in those locations also change. This lack of consistency makes 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.[5] 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 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). There was significant variation in this study between the measured TWA magnetic-field levels for workers in many of the International Standard Classification of Occupations' job categories, which the authors attributed to variation in industry within these task-defined categories.

Types of health research studies

Research studies can be broadly classified into two groups: 1) epidemiologic observations of people and 2) experimental studies of humans, animals (*in vivo*), and cells and tissues (*in vitro*) conducted in laboratory settings. Epidemiologic studies investigate how disease is distributed in populations and what factors influence or determine this disease distribution (Gordis, 2000). Epidemiologic studies attempt to identify potential causes for human disease while observing

[5] 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.

people as they go about their 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 epidemiologic 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* studies of animals and *in vitro* experimental studies also are 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. The responses of cells and tissues outside the body, however, 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 to assess whether a particular agent could cause adverse health effects using both epidemiologic and experimental studies.

Both of these approaches—epidemiologic and experimental laboratory studies—have been used to evaluate whether exposure to ELF EMF has any adverse effects on human health.

Epidemiologic studies are valuable because they are conducted in human populations, but they are limited by their non-experimental design and typical retrospective nature. In epidemiologic 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, epidemiologic 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 is included to provide a foundation for understanding and interpreting statistical associations in epidemiologic 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. For example, the absolute risk of invasive childhood cancer in children 0 to 19 years of age 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 0 to 19 years of age had an estimated absolute risk of childhood cancer of 15.4 per 100,000 in 2004, and African American children in the same age range 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 an 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 epidemiologic 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 versus 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 epidemiologic 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%) of including 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.

The CI range 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 the true RR estimate. If the 95% CI does not include 1.0, the probability that an association is due to chance alone is 5% or lower, and the result is considered statistically significant, as discussed above.

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 to 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 important tools 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 (Linet, 2003). Therefore, meta- and pooled analyses are used not only to synthesize or combine data but also to understand which 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 epidemiologic studies

One key reason that the results of epidemiologic 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 epidemiologic 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 epidemiologic 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 epidemiologic 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 also tend to 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 versus association and evaluating evidence regarding causal associations

Epidemiologic 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 their studies are exposed, and diseases can be caused by a complex interaction of many factors, the results of epidemiologic studies must be interpreted with caution. A single epidemiologic 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, the Surgeon General outlined nine criteria for evaluating epidemiologic studies (along with experimental data) for causality. In a more recent edition of this report, these criteria have been reorganized into seven criteria. In the earlier report, 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 list 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 between exposure and disease, the less likely such an effect is the result of chance or unmeasured confounding.
Specificity	The exposure is the single cause or one of a few causes 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	The observation that the stronger or greater the exposure, the stronger or greater the effect, also known as a dose-response relationship.
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 populations.

Source: Department of Health and Human Services, 2004

The criteria were meant to be applied to statistically significant associations observed in the cumulative epidemiologic literature (i.e., if no statistically significant association is 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, except for temporality, rule out causation.

In summary, the judicious consideration of these criteria is useful in evaluating epidemiologic 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, epidemiologic 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 that report consistent results across many different populations and study designs and are supported by experimental data collected from *in vivo* and *in vitro* studies.

Biological response versus 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 the cause of disease. For example, as a person 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 a biological response to the change in light conditions. Pupil constriction, however, is neither a disease itself, nor is it known to cause disease.

4 The WHO 2007 Report: Methods and Conclusions

The WHO is a scientific organization within the United Nations system with the mandate to provide leadership on global health matters, shape health research agendas, and set 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 3, 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,[6] 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

[6] 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.

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. As identified in Figure 3, categories include (from highest to lowest risk): *carcinogenic to humans*; *probably carcinogenic to humans*; *possibly carcinogenic to humans*; *not classifiable as to its carcinogenicity to humans*; 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 epidemiologic studies and less than sufficient evidence of carcinogenicity in studies of experimental animals. *In vitro* research is not described in Figure 3 because it provides ancillary information; it is used to a lesser degree in evaluating carcinogenicity and is classified simply as strong, moderate, or weak.

	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 over 1,000 substances and exposure circumstances to evaluate their potential carcinogenicity. Eighty percent of exposures fall in the categories *possibly carcinogenic* (31 percent) or *not classifiable* (49 percent).[7] This occurs because 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

[7] https://monographs.iarc.fr/agents-classified-by-the-iarc/. Accessed January 19, 2019.

history of the IARC, only one agent has been classified as *probably not carcinogenic*, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

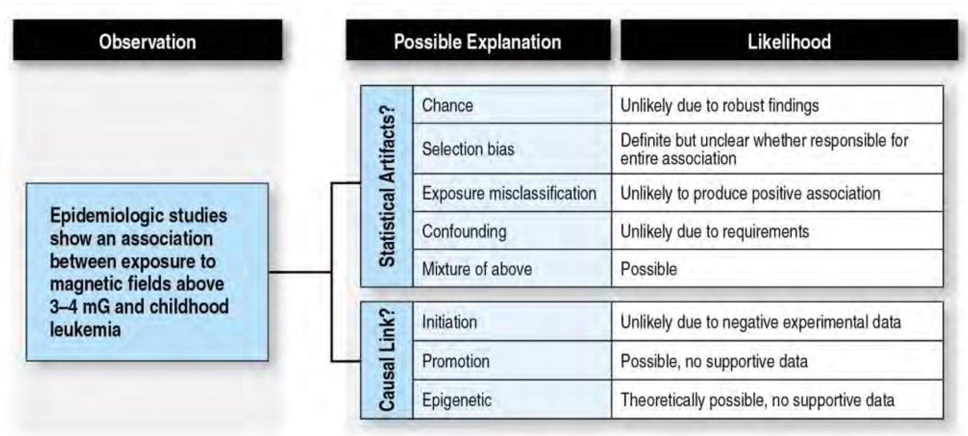
The WHO report provided the following overall conclusions with regard to ELF EMF:

> 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 [*sic*]. 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 to 4 mG (Ahlbom et al., 2000; Greenland et al., 2000). These data, categorized as limited epidemiologic evidence, 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 large 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 experimental findings (i.e., no hazard or risk observed) 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 to 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 [*sic*], 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 [*sic*]. The evidence that ELF field exposure can enhance tumour [*sic*] 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 epidemiologic 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 epidemiologic 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.

5 Current Scientific Consensus

The following sections identify and describe epidemiologic and *in vivo* studies related to ELF EMF and health published between December 2014 and December 2018. 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 4. A previous Exponent report summarized the literature through November 2014[8] and concluded that those 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 English language literature indexed between December 2014 and December 2018.[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. The following specific inclusion criteria were applied:

1. **Outcome**. Included studies evaluated one of the following diseases: cancer; reproductive or developmental 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, so research evolves more slowly.

---

8 Exponent, Inc. *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 the Rhode Island Energy Facility Siting Board. March 9, 2015.

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 December 2018, 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).

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

3. **Exposure assessment methods**. Included studies evaluate exposure beyond self-report of an activity or occupation. Included studies estimated exposure through various methods including calculated EMF levels using distance from power lines; measured TWA exposure; and average exposure estimated from JEMs.

4. **Study design**. Study design includes epidemiologic studies, meta-analyses, pooled analyses, human experimental studies, and *in vivo* studies of carcinogenicity. 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 4) 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.

Epidemiologic 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 from December 2014 through December 2018 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 (Ahlbom et al., 2000; Greenland et al., 2000), a statistically significant two-fold association was observed between childhood leukemia and estimated average exposure to high levels of magnetic fields (i.e., greater than 3 to 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*, which as noted previously is 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 their 2007 review.

Since the WHO conducted their review, childhood leukemia continues to be a main focus of ELF EMF epidemiologic research. Kheifets et al. (2010) provided an update to the analyses conducted by Ahlbom et al. (2000) and Greenland et al. (2000) by reporting the results of a pooled analysis of seven case-control studies of childhood leukemia and ELF EMF published between 2000 and 2010. Although the authors included a large number of cases (n=10,865) in this analysis, only 23 cases had measured fields and 3 cases had calculated fields in the highest exposure category (≥3 mG). A moderate and statistically not significant association was reported for the highest exposure category (OR 1.44, 95% CI 0.88-2.36), which was weaker than the association reported in the previous pooled analyses (Ahlbom et al., 2000; Greenland et al., 2000).

More recently, three large case-control studies from France (Sermage-Faure et al., 2013), Denmark (Pedersen et al., 2014a), and the United Kingdom (Bunch et al., 2014) assessed the risk of childhood leukemia in relation to residential proximity to high-voltage power lines. None of these studies reported consistent overall associations between childhood leukemia development and residential distance to high-voltage power lines. The largest of these studies (Bunch et al., 2014) was an update of an earlier study in the United Kingdom (Draper et al., 2005) and included over 53,000 childhood cancer cases diagnosed between 1962 and 2008 and over 66,000 healthy children as controls. Overall, the authors reported no association between childhood leukemia development and residential proximity to power lines with any of the voltage categories. The statistical association reported in the earlier study (Draper et al., 2005) was no longer apparent in the updated analysis (Bunch et al., 2014).

All three case-control studies had large sample sizes and were population-based studies requiring no subject participation, which minimizes the potential for selection bias. The main limitation of these studies was the reliance on distance to power lines as the main exposure metric, which is known to be a poor predictor of actual residential magnetic-field exposure. Several observers in the scientific literature discussed the limitations of distance as an exposure proxy in the context of the French study by Sermage-Faure et al. (Bonnet-Belfais et al., 2013; Clavel et al., 2013). In addition, Chang et al. (2014) provided a detailed discussion of the limitations of exposure assessment methods based on geographical information systems. Swanson et al. (2014) also concluded, based on their analysis of data from the British study (Bunch et al., 2014), that geocoding information not based on exact address, but only on post code information, is "probably not acceptable for assessing magnetic-field effects" (Swanson et al., 2014a, p. N81).

Recent studies (December 2014 through December 2018)

Several recent studies analyzed the same populations used in two of the three case-control studies summarized above (Bunch et al., 2014; Pedersen et al., 2014a).

The authors of the previous Danish study (Pedersen et al., 2014a) also evaluated whether consideration of other potential risk factors for childhood leukemia may influence the results in relation to distance to power lines (Pedersen et al., 2014b). Adjustments for socioeconomic status, mother's age, birth order, domestic radon exposure, or traffic-related air pollution were reported not to affect associations relating to power lines. The authors reported a statistical interaction between distance to power lines and radon exposure; however, they attributed these findings to chance, as these results were based on a small number of cases. Pedersen et al. (2015) reported the results of another case-control study using a study population that mostly overlapped with the previous two papers (Pedersen et al., 2014a, 2014b). Pedersen et al. (2015) included all children in Denmark diagnosed before 15 years of age with a first primary leukemia (n=1,536), central nervous system (CNS) tumor (n=1,324), or malignant lymphoma (n=417) between 1968 and 2003. Cases were identified from the Danish Cancer Registry. Two to five controls (n=9,129) for each case were selected randomly from the Danish childhood population and were matched to cases based on their sex and year of birth. For all study subjects, average magnetic-field exposure levels were calculated from overhead 50- to 400- kilovolt (kV) power lines based on their residential addresses from 9 months before birth until the diagnosis. The authors reported no statistically significant associations between all cancers combined and the three types of cancers separately and estimated exposures ≥0.4 microtesla (μT) (4 mG) compared to <0.1 μT (1 mG). The large number of cases and controls in the study, the inclusion of residential history and exposure assessment throughout the children's entire lifetime, control for some potential confounders (including radon exposure, traffic-related air pollution, and socioeconomic status) and the reliance on reliable population-based cancer and population registries in Denmark are among the strengths of the study. Reliance on calculated magnetic-field levels for exposure assessment and lack of details on the accuracy of the input data to these calculations, including historical line loading and distance to residence, and the small number of cases in the highest exposure categories despite that large study size, are among the limitations of the paper.

In a separate analysis of the previous study population in the United Kingdom (Bunch et al., 2014), the investigators also examined the distance of high-voltage underground cables (mostly AC 275 kV and 400 kV) to case and control residences (Bunch et al., 2015). Over 52,000 cases of childhood cancer occurring between 1962 and 2008 in England and Wales, along with their matched controls, were included in these analyses. The authors reported no statistically significant associations or exposure-response trends between childhood leukemia and distance to power lines or calculated magnetic-field levels from the underground cables. The authors concluded that their results further detract from the hypothesis that exposure to magnetic fields explains the associations observed in earlier studies.

Based on additional analyses of the data, Bunch et al. (2016) reported that the association with distance to power lines observed in earlier years, which was more pronounced among older children (10 to 14 years of age), and for myeloid leukemia, were linked to calendar year of birth or year of cancer diagnosis, rather than the age of the power lines. The authors noted this finding implies that whatever factor or factors might have resulted in the apparent risk increase in the earlier years of the study are less likely to be linked to the newly built or existing power lines and more likely to be related to a yet to be identified characteristic of the population (or chance variation) in those years. Analyses by regions of the country did not suggest any clear pattern. The authors concluded that their findings, overall, do not provide support for the etiologic role of magnetic fields in the reported associations. Furthermore, Swanson and Bunch (2018) reanalyzed the data in Bunch et al. (2014) by using finer distance categories with cut-points at every 50-meter distance from the power lines in various periods from 1962 to 2008. The authors reported that no overall associations between distance categories and childhood leukemia were observed for the period including 1980 and later, and that associations for periods prior to 1980 showed no monotonic or consistent pattern with distance. Thus, Swanson and Bunch concluded that their finding "weakens the evidence that any elevated risks are related to magnetic fields" (Swanson and Bunch, 2018, p. N30).

Crespi et al. (2016) reported the results of a large, record-based, case-control study of childhood leukemia (n=5,788) and CNS tumors (n= 3,308) diagnosed between 1986 and 2008 and residential proximity to high-voltage overhead power lines (60 kV to 500 kV) in California. Cases were identified from the California Cancer Registry. Controls were selected from the California Birth Registry and matched to cases based on their age and sex; birth records were also obtained for cases. For all subjects, distance of the address at birth to the nearest power line was estimated using geographic information systems, aerial imaging from Google Earth, and site visits for a subset of subjects. Additional details on methods are presented in Kheifets et al. (2015). Crespi et al. (2016) reported no consistent overall associations between risk of leukemia or CNS tumor and residential distance to power lines with voltage of ≥200 kV. A statistically non-significant increase was reported for childhood leukemia among subjects with addresses closer than 50 meters to power lines at ≥200 kV. Analyses that also included lower voltage lines revealed no associations with either leukemia or CNS tumors.

Kheifets et al. (2017a) and Amoon et al. (2018a) conducted additional analyses using the same California study population as Crespi et al. (2016). Kheifets et al. (2017a) reported on childhood leukemia and calculated magnetic fields from California power lines. The authors calculated magnetic-field levels at birth address using geographic information systems, aerial imagery, historical information on load and phasing, and site visits; additional details on the magnetic-field calculations are presented in a separate publication (Vergara et al., 2015). In the main analyses by Kheifets et al. (2017a), which included all cases of leukemia and primary controls with geocode accuracy, the authors used unconditional logistic regression models that controlled for age, sex, race/ethnicity, and socioeconomic status. Overall, the authors reported no consistent pattern of association; they reported a slight, statistically non-significant, negative association in the intermediate exposure categories (1 to 2 mG and 2 to 4 mG) compared to the lowest exposure category (<1 mG), and a small, statistically non-significant, positive association in the highest exposure category (≥4 mG) (OR 1.5, 95% CI 0.7-3.2). The authors reported similar results in subgroup and sensitivity analyses and commented that all estimates had wide CIs. The authors concluded that their study "does not in itself provide clear evidence for risk associated with greater exposure to magnetic fields from power lines, but could be viewed as consistent with previous findings of increased risk" (Kheifets et al., 2017a, p. 1117). Thomas (2018) commented that while the Kheifets et al. (2017a) study had low potential for selection bias due to its record-based methods, the study may be subject to exposure misclassification resulting in bias towards the null because the exposure assessment considered residential proximity only to high-voltage power lines and other sources, including distribution lines, were ignored.

Amoon et al. (2018a) assessed the potential impact of residential mobility of the study subjects (i.e., moving residences between birth and diagnosis) on the associations reported in Crespi et al. (2016). The authors reported that while children that moved tended to be older, lived in housing other than a single-family home, had younger mothers and fewer siblings, and were of lower socioeconomic status, changing residences was not associated with either calculated fields or proximity to ≥200-kV power lines. Thus, the authors concluded that "[m]obility appears to be an unlikely explanation for the associations observed between power lines [*sic*] exposure and childhood leukemia" in the California study (Amoon et al., 2018a, p. 459).

Epidemiologists from Italy published two papers that describe the methods (Magnani et al., 2014) and results (Salvan et al., 2015) of a case-control study of childhood leukemia and residential exposure to 50-Hz magnetic fields. The study included a total of 412 leukemia cases less than 10 years of age diagnosed between 1998 and 2001 and 587 controls matched to cases based on sex, date of birth, and geographic location. The authors assessed exposure to residential ELF magnetic fields by extended measurements (24 to 48 hours) in the children's bedroom. The authors used conditional logistic regression to calculate RR and adjust for potentially confounding variables. In their analyses, the researchers evaluated various exposure metrics (e.g., measures of central tendency or peak-exposure measures; continuous or categorical exposures based on measurements during nighttime, weekend, or entire measurement periods). The authors also assessed the potential role of residential mobility of the subjects in the observed associations. None of the analyses reported consistent exposure-response patterns. The main limitations of the study include the potential for differential participation of controls and cases and differences in participation rates of the study subjects based on their socioeconomic status, which in combination may result in a reference group that is not fully representative of the underlying population at risk. In turn, this may bias the calculated effect estimates. The low prevalence of subjects with higher estimated average exposures (particularly exposure >3 mG) results in a limitation of the statistical power of the study.

Amoon et al. (2018b) conducted a meta-analysis of epidemiologic studies of residential distance to power lines and childhood leukemia. The authors pooled the data from 11 studies with record-based assessments of residential distance from high-voltage power lines from 10 countries (Australia, Brazil, Denmark, France, Italy, Norway, Sweden, Switzerland, the United Kingdom, and the United States); this included the previously mentioned studies by Pedersen et al. (2014a), Sermage-Faure et al. (2013), Bunch et al. (2014), and Crespi et al. (2016). In total, 29,049 cases and 68,231 controls were included in the analyses. The authors reported no association when proximity to transmission lines with any voltage was investigated; the adjusted OR for residential distance <50 meters, as compared to distances ≥300 meters, was 1.01 [95% CI, 0.85-1.21]). For power lines with voltages of ≥200 kV, the adjusted OR (1.13) for distances <50 meters also was not statistically significant (95% CI, 0.92-1.93). The reported associations were slightly stronger for leukemia case diagnoses before 5 years of age and in study periods prior to 1980. Adjustment for various potential confounders (e.g., socioeconomic status, dwelling type, residential mobility) had little effect on the estimated the associations.

Kheifets et al. (2017b) conducted a comparative analysis of epidemiologic studies of childhood leukemia that investigated the association between childhood leukemia and ionizing radiation (i.e., radon or gamma radiation) or non-ionizing radiation (i.e., ELF EMF), or both, in an attempt to evaluate to what extent bias, confounding, and other methodological issues might be responsible for the reported associations. The authors reported that while they found some indication of bias, they found little evidence that confounding has a substantial influence on results.

A small cross-sectional study of 22 cases of childhood ALL and 100 controls from Iran reported a statistically significant association with "prenatal and postnatal childhood exposure to high voltage power lines" (Tabrizi and Bigdoli, 2015, p. 2347). The study, however, would carry very little weight, if any, in an overall evaluation, because of its cross-sectional study design, very small sample size, and a complete lack of information on exposure assessment in the study. Tabrizi and Hossein (2015) published an apparent duplication of the study with near identical results and limitations. A letter to the editor that highlighted major flaws in the study pointed out the apparent duplication and suggested retraction of the second publication (Dechent and Driessen, 2016).

A Greek case-control study examined the association between parental occupational exposures and childhood acute leukemia at a major pediatric hospital in Athens (Kyriakopoulou et al., 2018). The study included 108 cases of ALL or acute myeloid leukemia under the age of 15, and 108 controls matched on age, gender, and ethnicity. The parents' job titles held during four different exposure periods (1 year before conception, during pregnancy, during breastfeeding, and from birth until diagnosis) were evaluated for exposure (exposed versus unexposed) to four agents (high contact level, chemicals, electromagnetic fields, and ionizing radiation) based on the authors' review of literature and their professional judgment. A total of six cases (5.6%) and six controls (5.6%) were categorized as exposed to electromagnetic[11] fields. No statistically significant associations were observed between electromagnetic-field exposure and childhood acute leukemia for any of the four periods of exposure. No associations were observed between childhood acute leukemia and the remaining exposure categories; however, the authors did observe that high birth weight and family history of cancer were associated with the development of leukemia.

Chinese researchers have published several meta-analyses in recent years. Su et al. (2016) conducted a meta-analysis of 11 case-control studies and 1 cohort study that investigated the association between parental exposure to ELF magnetic fields and risk of childhood leukemia in the offspring. Overall, neither maternal nor paternal occupational ELF magnetic-field exposure was associated with childhood leukemia risk.

The authors noted, however, that they observed an association when they combined small and low-quality studies, but not when they combined larger and high-quality studies. This indicates that sampling and other biases may contribute to the reported associations in small, low-quality studies.

Zhang et al. (2016) combined epidemiologic studies of all types of cancer in their meta-analyses, including studies of adult and childhood cancers. Since various adult and childhood cancers have very different etiologies and biological mechanisms, it is scientifically not defensible to expect that any specific exposure will have an identical effect on the risk of all types of cancers, which renders the study's main results mostly meaningless, or difficult to interpret at best.

Assessment of residential exposure to EMF among children also continues to be of interest. While not linked to any specific health outcomes, EMF exposure assessment studies of children were recently reported from Australia, Italy, Spain, and Switzerland (Karipidis, 2015; Struchen et al., 2016; Liorni et al., 2016; Gallastegi et al., 2016). Magne et al. (2017) conducted a national survey of ELF magnetic-field exposure in France, including a representative sample of close to 1,000 children 0 to 14 years of age. The study was purely an exposure assessment study and the authors did not investigate any health outcome in relation to magnetic-field exposure. The authors conducted 24-hour measurements of ELF magnetic-field exposure for the included children and reported that 3.1% of the study participants had a 24-hour average exposure >0.4 μT (4 mG). Only 0.8% of the children, however, had 24-hour average exposure >0.4 μT (>4 mG) when exposure from alarm clocks was excluded. The authors also reported that none of the children with 24-hour average exposure >0.4 μT (>4 mG) lived within 125 meters of a 225-kV transmission line or within 200 meters of a 400-kV transmission line.

Assessment

In summary, while most of the recently published large and methodologically advanced studies showed no statistically significant associations between estimates of exposures from power lines (e.g., Bunch et al., 2014, Pedersen et al., 2014a, 2014b, Pedersen et al., 2015; Crespi et al., 2016; Kheifets et al., 2017a), and the most recent pooled analyses indicated weaker and statistically non-significant associations (Amoon et al., 2018b), the association between childhood leukemia and magnetic fields observed in some earlier studies remains unexplained. Thus, the results of

[11] In this context, electromagnetic is used to refer to ELF magnetic fields.

recent studies do not change the classification of the epidemiologic data as limited. This is the assessment of the most recent weight-of-evidence review released in 2015 by SCENIHR,[12] which concluded that the epidemiologic studies on childhood leukemia and EMF exposure continued to “prevent a causal interpretation” (SCENIHR, 2015). A similar conclusion was reached in a recent assessment conducted by a research consortium funded by the European Union, which concluded that recent research results have not provided new evidence that would change the overall conclusion reached by IARC in 2002, and the current evidence is consistent with the *possibly carcinogenic* classification (Schüz et al., 2016).

Table 2. Relevant studies of childhood leukemia

Author	Year	Study Title
Amoon et al.	2018a	Residential mobility and childhood leukemia.
Amoon et al.	2018b	Proximity to overhead power lines and childhood leukaemia: an international pooled analysis.
Bunch et al.	2015	Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables.
Bunch et al.	2016	Epidemiological study of power lines and childhood cancer in the UK: further analyses.
Chang et al.	2014	Validity of geographically modeled environmental exposure estimates.
Crespi et al.	2016	Childhood leukaemia and distance from power lines in California: a population-based case-control study.
Dechent and Driessen	2016	Re: Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase - a Case Control Study in Tehran, Iran.
Gallastegi et al.	2016	Characterisation of exposure to non-ionising electromagnetic fields in the Spanish INMA birth cohort: study protocol.
Karipidis et al.	2015	Survey of residential power-frequency magnetic fields in Melbourne, Australia.
Kheifets et al.	2015	Epidemiologic study of residential proximity to transmission lines and childhood cancer in California: description of design, epidemiologic methods and study population.
Kheifets et al.	2017a	Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California.
Kheifets et al.	2017b	Comparative analyses of studies of childhood leukemia and magnetic fields, radon and gamma radiation.
Kyriakopoulou et al.	2018	Parental occupational exposures and risk of childhood acute leukemia.

[12] On July 8, 2015, SCENIHR was renamed the Scientific Committee on Health, Environment, and Emerging Risks (SCHEER). Since any publications by this body referenced in this report were published before the name was changed, all citations to their publications note SCENIHR rather than SCHEER.

Author	Year	Study Title
Liorni et al.	2016	Children's personal exposure measurements to extremely low frequency magnetic fields in Italy.
Magnani et al	2014	SETIL: Italian multicentric epidemiological case-control study on risk factors for childhood leukaemia, non hodgkin lymphoma and neuroblastoma: study population and prevalence of risk factors in Italy.
Magne et al.	2017	Exposure of children to extremely low frequency magnetic fields in France: Results of the EXPERS study.
Pedersen et al.	2014b	Distance to high-voltage power lines and risk of childhood leukemia – an analysis of confounding by and interaction with other potential risk factors.
Pedersen et al.	2015	Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukemia, CNS tumour and lymphoma in Denmark.
Salvan et al.	2015	Childhood leukemia and 50 Hz magnetic fields: findings from the Italian SETIL case-control study.
Schüz et al.	2016	Extremely low-frequency magnetic fields and risk of childhood leukemia: A risk assessment by the ARIMMORA consortium.
Struchen et al.	2016	Analysis of personal and bedroom exposure to ELF-MFs in children in Italy and Switzerland.
Su et al.	2016	Associations of parental occupational exposure to extremely low-frequency magnetic fields with childhood leukemia risk.
Swanson and Bunch	2018	Reanalysis of risks of childhood leukaemia with distance from overhead power lines in the UK.
Tabrizi and Bidgoli	2015	Increased risk of childhood acute lymphoblastic leukemia (ALL) by prenatal and postnatal exposure to high voltage power lines: a case control study in Isfahan, Iran.
Tabrizi and Hosseini	2015	Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase--a Case Control Study in Tehran, Iran.
Vergara et al.	2015	Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991-1999.
Zhang et al.	2016	Meta-analysis of extremely low frequency electromagnetic fields and cancer risk: a pooled analysis of epidemiologic studies.
Comment on Kheifets et al. (2017a)		
Thomas	2018	Re: Kheifets et al. (2017): Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California.

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 [*sic*], 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).

Addressing these recommendations, researchers conducted both a meta-analysis (Mezei et al., 2008) and a pooled analysis (Kheifets et al., 2010b) of available studies. The meta-analysis by Mezei et al. (2008) reported no overall association but reported a statistically non-significant weak association with calculated or measured magnetic fields above 3 to 4 mG based on a sub-analysis of five studies. The pooled analysis by Kheifets et al. (2010b) included data from 10 studies of childhood brain cancer or CNS cancer with long-term measurements, calculated fields, or spot measurements of residential magnetic-field exposure published from 1979 to 2010. Similar to childhood leukemia, few cases of childhood brain cancer had estimated magnetic-field exposures greater than 3 to 4 mG. None of the analyses showed statistically significant increases, and while some categories of high exposure had an OR >1.0, the overall patterns were not consistent with an association and no dose-response trends were apparent. The authors concluded that their results provide little evidence for an association between magnetic fields and childhood brain tumors.

In addition, the childhood leukemia study by Bunch et al. (2014), 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 between brain cancer or other cancers and distance to transmission lines.

Recent studies (December 2014 through December 2018)

Several of the same epidemiologic studies discussed in the childhood leukemia section investigated the potential relationship between residential proximity to overhead and underground transmission lines and childhood brain cancer (Bunch et al., 2015; Bunch et al., 2016; Pedersen et al., 2015; Crespi et al., 2016). None of these studies reported any consistent association between distance to power lines and childhood brain cancer risk. In Bunch et al. (2015), the authors reported a statistical association for childhood brain cancer and an intermediate category of distance (20 to 49.9 meters), but noted that "such an elevation does not form part of a coherent pattern with other studies" and thus they were "therefore inclined to regard this as a chance result" (Bunch et al., 2015, p. 695). The authors observed no statistically significant trend with distance. Follow-up analyses of the same population that investigated the occurrence of cancer separately among younger and older children (Bunch et al., 2016) identified no "persuasive or consistent pattern" for brain tumors. The epidemiologic studies of childhood cancer conducted in Denmark and California also included cases of CNS tumors (Pedersen et al., 2015; Crespi et al., 2016). Pedersen et al. (2015) reported a non-statistically significant association between CNS tumors and exposure, regardless of the period investigated. Crespi et al. (2016) reported no evidence of increased risk for CNS cancers (all types).

An Italian case-control study examined the risk of neuroblastoma among children 0 to 10 years of age in relation to maternal characteristics and perinatal exposures (Parodi et al., 2014). A total of 207 cases diagnosed between 1998 and 2001 and 1,475 controls were included in the study. Exposure to ELF magnetic fields was based on 48-hour measurements in the children's beds. The authors reported no associations either with measures of central tendency (arithmetic and geometric means) or with peak exposure measures (90th and 95th percentiles) of ELF magnetic fields. The authors did report statistically significant associations, however, with maternal exposure to hair dye and solvents.

Su et al. (2018) conducted a meta-analysis of epidemiologic studies that investigated the association between parental occupational exposure to ELF magnetic fields and childhood CNS tumors. The authors included a total of 22 case-control and cohort studies published as of December 2017 in their analysis. For CNS tumors, they reported no statistically significant associations for paternal exposure to ELF magnetic fields, but reported a weak statistically significant association (OR = 1.16, 95% CI 1.06, 1.26) for maternal exposure based on a subset of eight studies. The authors reported no association for neuroblastoma with either maternal or paternal exposure to ELF magnetic fields. Study quality, as assessed by the authors, had inconsistent effects on the associations reported for maternal and paternal exposure. The authors noted that, when based on higher quality studies, observed associations were stronger for maternal exposure but weaker for paternal exposure. It is noteworthy that associations were statistically significant only when studies using non-quantitative exposure methods (i.e., relying on job titles only) were pooled, but no associations were reported based on studies with a quantitative exposure assessment. The authors also reported evidence for publication bias. While most of the included studies investigated cancer among children, some of the studies also included persons with tumors diagnosed up to 30 years of age, which is an additional limitation of the analysis.

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, as they did not report any consistent and convincing evidence for an association. This is in line with the 2015 SCENIHR review, which concluded that "no association has been observed for the risk of childhood brain tumours [*sic*]" (SCENIHR, 2015, p. 158).

Table 3. Relevant studies of childhood brain cancer

Authors	Year	Study
Bunch et al.	2015	Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables.
Bunch et al.	2016	Epidemiological study of power lines and childhood cancer in the UK: further analyses.
Crespi et al.	2016	Childhood leukaemia and distance from power lines in California: a population-based case-control study.
Parodi et al.	2014	Risk of neuroblastoma, maternal characteristics and perinatal exposures: the SETIL study.
Pedersen et al.	2015	Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukaemia, CNS tumour and lymphoma in Denmark.
Su et al.	2018	Association between parental occupational exposure to extremely low frequency magnetic fields and childhood nervous system tumors risk: A meta-analysis.

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. Research in this area provided additional support for the WHO's conclusion that there is no association between exposure to ELF EMF and breast cancer development. A large case-control study that investigated the risk of several types of adult cancers and residential distance to high-voltage power lines reported no association between female breast cancer and residential distance to power lines or estimated exposure to magnetic fields (Elliott et al., 2013). Several occupational epidemiologic studies of female and male breast cancers also provided no support for an association between ELF EMF exposure and breast cancer development (Sorahan, 2012; Li et al., 2013; Koeman et al., 2014)

Recent studies (December 2014 through December 2018)

Grundy et al. (2016) conducted a population-based case-control study of male breast cancer and occupational exposure to magnetic fields. The authors identified cases (n=115) from eight Canadian provinces through the provincial cancer registries between 1994 and 1998, and selected controls (n=570), matched on age and sex, from provincial health insurance plans or using random-digit dialing. The authors obtained information on demographic characteristics and occupational history through self-administered questionnaires. An expert review assessed occupational exposure to magnetic fields. Each occupation was assigned an average exposure value; these values were then grouped into three categories (<0.3 μT [<3 mG], 0.3 to <0.6 [3 to <6 mG], and ≥0.6 μT [≥6 mG]) using cut-points based on the distribution of residential exposures reported in a previous study (Green et al., 1999). The authors reported statistically non-significant risk increases with the highest average exposure ≥0.6 μT (≥6 mG) compared to exposure <0.3 μT (<3 mG), and with having an exposed job (≥0.3 μT [≥3 mG]) for at least 30 years compared to never having an exposed job. The authors noted that the remaining results were "inconsistent" and thus the study provides "limited support" for the hypothesis that magnetic-field exposure increases the risk of breast cancer in men (Grundy et al., 2016, p. 586). Selection of a subset of the controls using random-digit dialing, and reliance on self-reported information for exposure assessment represent a limitation of the study.

As summarized in the section on childhood leukemia, Zhang et al. (2016) combined epidemiologic studies of all types of cancer in their meta-analysis, including studies of adult and childhood cancers. This renders their main conclusions mostly meaningless, or difficult to interpret at best. Based on a sub-analysis that included 23 epidemiologic studies, the authors reported no statistically significant associations for breast cancer.

Assessment

The conclusion that there is no association between ELF EMF and breast cancer, as also expressed by the WHO, continues to be valid. The most recent case-control study, which reported no statistically significant associations with male breast cancer, adds to the growing body of null evidence for a role for magnetic-field exposure in breast cancer development in either residential or occupational settings. The recent review by SCENIHR (2015) concluded that overall studies on "adult cancers show no consistent associations" (p. 158).

Table 4. Relevant studies of breast cancer

Authors	Year	Study
Grundy et al.	2016	Occupational exposure to magnetic fields and breast cancer among Canadian men.
Zhang et al.	2016	Meta-analysis of extremely low frequency electromagnetic fields and cancer risk: a pooled analysis of epidemiologic studies.

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).

Overall, the epidemiologic studies of ELF EMF and adult brain cancer that have been reviewed in our previous reports predominantly support no association with brain cancer in adults but remain limited due to the exposure assessment methods and insufficient data available on specific brain cancer subtypes.

Recent studies (December 2014 through December 2018)

Carlberg et al. (2017, 2018) published the results of two case-control epidemiologic studies of occupational exposure to ELF EMF and brain cancer. Both studies relied on data from previously published case-control studies in Sweden (Hardell et al., 2006, 2013; Carlberg et al., 2013, 2015). Carlberg et al. (2017) included 1,346 living glioma cases diagnosed between the periods of 1997 to 2003 and 2007 to 2009 and 3,485 controls, ascertained from the Swedish Population Registry, who were matched to cases on sex and 5-year age group. Occupational exposure to ELF EMF was assessed from self-reported questionnaires on lifetime occupational history and a previously developed JEM (Turner et al., 2014). Overall, the authors observed no association with cumulative exposure to ELF EMF. Statistically signification associations were reported for grade IV astrocytoma and cumulative and average exposure when restricted to exposure experienced during the more recent exposure periods (1 to 14 years prior to diagnosis). The authors reported no association, however, with more distant exposure periods (15 to 20+ years) and observed no associations for other tumor grades. The authors hypothesized that the observed association for grade IV astrocytoma in the recent exposure periods is the result of a potential effect on cancer promotion. Because deceased subjects were excluded from the analyses, and the reported association was limited to tumors of the highest grade (with the highest mortality rate), there is a high likelihood that the reported pattern of results arose due to differential exclusion of rapidly fatal cases among patients with the highest-grade tumors.

Carlberg et al. (2018) included 1,592 meningioma cases and 3,485 controls. The investigators used a similar approach and methods as in the previous study (Carlberg et al., 2017). The authors reported no trend or association between meningioma development and any of the investigated metrics of occupational exposure to ELF EMF (i.e., average occupational exposure, highest exposed job, or cumulative exposure) regardless of the time windows investigated (i.e., exposure during 1 to 14 years prior to diagnosis, or exposure more than 15 years prior to diagnosis).

Turner et al. (2017) investigated the potential interaction between occupational exposure to ELF magnetic fields; various chemicals, including cadmium, chromium, iron, and nickel; solvents, benzo(a)pyrene, polycyclic aromatic hydrocarbons; and environmental tobacco smoke, on brain cancer development within the INTEROCC case-control study. The current study presented additional analyses to an earlier study that examined ELF magnetic fields and brain cancer (Turner et al., 2014), and included 1,939 glioma and 1,822 meningioma cases, along with 5,404 controls matched on sex and age. Occupational exposure to both ELF magnetic fields and the chemicals of interest were assessed using JEMs. While some of the sub-analyses in the earlier study (Turner et al., 2014) reported both positive and negative associations for brain cancer development, overall there was no association with lifetime cumulative or average exposure for either main type of brain cancer. In the Turner et al. (2017) follow-up analysis, the authors reported that there was "no clear evidence" for an interaction between occupational exposure to ELF magnetic fields and occupational exposure to any of the included chemicals for either glioma or meningioma (p. 802).

Assessment

Recent studies do not provide support for an association between exposure to magnetic fields and brain cancer development. As mentioned above, the most recent SCENIHR report states that, overall, studies on "adult cancers show no consistent associations" (SCENIHR, 2015, p. 158).

Table 5. Relevant studies of adult brain cancer

Authors	Year	Study
Carlberg et al.	2017	Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk.
Carlberg et al.	2018	Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and the association with meningioma.
Turner et al.	2017	Occupational exposure to extremely low frequency magnetic fields and brain tumor risks in the INTEROCC study.

Adult leukemia and lymphoma

There is a vast literature on adult leukemia and ELF EMF, most of which is related to occupational exposure. Overall, the findings of these studies are inconsistent—some studies report a positive association between measures of ELF EMF and leukemia and other studies show 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 occupational cohorts and updating a meta-analysis on occupational magnetic-field exposure. Subsequently, Kheifets et al. (2008) provided an update to two meta-analyses they published in the 1990s. Their updated meta-analysis indicated that pooled risk estimates from more recent studies were lower than in past meta-analyses and that no consistent pattern was observed by leukemia subtypes. Thus, the combined results were not in support of a causal association between occupational EMF exposure and adult leukemia. Studies reviewed in the previous Exponent report did not change the WHO conclusion.

Recent studies (December 2014 through December 2018)

Talibov et al. (2015) conducted a study of acute myeloid leukemia and occupational exposure to ELF magnetic fields and electric shocks within the Nordic Occupational Cancer study population. The case-control study included 5,409 cases diagnosed between 1961 and 2005 in Finland, Iceland, Norway, and Sweden, and 27,045 controls matched on age, sex, and country. Lifetime occupational exposure to ELF magnetic fields and shocks were assessed with JEMs based on jobs reported on the censuses. Potential confounding variables, including work-related exposure to benzene and ionizing radiation, were adjusted for in the analyses. The authors reported no associations between leukemia and exposure to ELF magnetic fields or electric shocks among either men or women, and the authors concluded that "the evidence base linking ELF-MF [magnetic fields] with AML [acute myeloid leukemia] risk remains weak" (Talibov et al., 2015, p. 1084).

Huss et al. (2018a) conducted a census-based retrospective cohort study examining exposure to ELF magnetic fields and death from several types of hematopoietic malignancies within the Swiss National Cohort. The authors included a total of 3.1 million economically active individuals between 30 and 65 years of age (for men) or 62 years of age (for women) who participated in the 1990 or 2000 census, or both, in Switzerland. Mortality from different malignant neoplasms of the lymphoid and hematopoietic tissue (i.e., various types of acute and chronic leukemias and lymphomas) was evaluated from 1990 to 2008. The authors included death due to lung cancer in the analyses as a "negative control outcome"—the authors hypothesized *a priori* that lung cancer was not associated with exposure to ELF magnetic fields (Huss et al., 2018a, p. 468). Occupational exposure to ELF magnetic fields was assessed based on the study subjects' job title as reported at the time of the census and a JEM developed for ELF magnetic fields. In addition, they assessed potential confounding by other occupational exposures, including solvents, pesticides, herbicides, metals, and electric shocks by applying corresponding JEMs to the study subjects' job titles and adjusting for the exposures in the main analyses.

None of the hematopoietic cancer types included in the main analyses was statistically associated with either exposure corresponding to a median intensity of 0.19 μT or a higher exposure of 0.52 μT in the fully-adjusted models. Adjustment for the other occupational exposures had a very small effect on the risk estimates. The authors reported statistically significant associations for myeloid leukemia among men who were ever highly exposed at the time of both censuses (n=6) and for acute myeloid leukemia among men who were ever highly exposed at the time of both censuses and additionally during their vocational training (n=5). As noted, both estimates were based on a very small number of cases. Lung cancer mortality, included as a negative control, showed statistically significant associations and a clear exposure-response pattern with exposure to ELF magnetic fields. This finding clearly indicates that confounding by smoking, which is a well-established cause of both lung cancer and leukemias/lymphomas, remains a major weakness of the study, and may explain the association reported in some of the sub-analyses. The authors concluded that their analysis "provided no convincing evidence for an increased risk of death" from hematopoietic cancers in workers occupationally exposed to ELF magnetic fields (Huss et al., 2018a, p. 467).

In the same study, Huss et al. (2018a) also conducted a meta-analysis of 28 epidemiologic studies of occupational exposure to ELF magnetic fields and acute myeloid leukemia published until September 2017. The authors reported a weak overall association, with a summary RR of 1.21 (95% CI: 1.08, 1.37).

Assessment

Recent studies did not provide substantial evidence for an association between EMF and leukemia overall, leukemia sub-types, or lymphoma in adults. Thus, the previous conclusion that the evidence is inadequate for adult leukemia remains appropriate. While some scientific uncertainty remains on a potential relationship between adult lymphohematopoietic malignancies and magnetic-field exposure because of continued deficiencies in study methods, the current database of studies provides inadequate evidence for an association (EFHRAN, 2012; SCENIHR, 2015).

Table 6. Relevant studies of adult leukemia

Authors	Year	Study
Huss et al.	2018a	Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers - Swiss National Cohort analysis and updated meta-analysis.
Talibov et al.	2015	Occupational exposure to extremely low-frequency magnetic fields and electrical shocks and acute myeloid leukemia in four Nordic countries.

Reproductive and developmental effects

In 2002, two studies 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 also was assessed using 24-hour personal magnetic-field measurements (earlier studies on miscarriage were limited because they used surrogate measures of exposure, including visual display terminal use, electric blanket use, or wire code data). The Li et al. (2002) study, however, was criticized by the National Radiological Protection Board *inter alia* because of the potential for selection bias, a low compliance rate, measurement of exposure after miscarriages, and apparent selection of exposure categories after inspection of the data (NRPB, 2002). The scientific panels that 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, "[t]here is some evidence for increased risk of miscarriage associated with measured maternal magnetic-field exposure, but this evidence is inadequate" and recommended further epidemiologic research (WHO, 2007, p. 254).

Following the publication of these two studies, 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 (i.e., less physically active) and women who miscarried (i.e., more physically active after miscarriage) (Savitz, 2002). It was proposed that physical activity is associated with an increased opportunity for peak magnetic-field exposure, 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 environmental exposure to peak magnetic fields while going about in the community. This hypothesis received empirical support from studies that reported consistent associations between activity (mobility during the day) and various metrics of peak magnetic-field exposure measurements (Mezei et al., 2006; Savitz et al., 2006; Lewis et al., 2015). These findings suggest that the association between maximum magnetic-field exposure and miscarriage was due to differing activity patterns of the cases and controls, not to a magnetic-field effect on embryonic development and viability.

Studies on ELF EMF exposure and reproductive or development effects published subsequent to the WHO 2007 report included ones focusing on miscarriage or stillbirth (Wang et al., 2013; Shamsi Mahmoudabadi et al., 2013; Auger et al., 2012) and birth outcomes (de Vocht et al., 2014; Mahram and Ghazavi, 2013). These additional publications provided little new insight on pregnancy and reproductive outcomes and did not change the classification of the data from earlier assessments as inadequate. These authors' recommendations for future studies included, among others, the selection of appropriate study populations, the assessment and control for potential confounding by the mothers' physical activity, the careful characterization of exposure, and the analysis of various exposure metrics in the study.

Recent studies (December 2014 through December 2018)

Several epidemiologic studies investigated the potential association between ELF magnetic-field exposure and miscarriage (Li et al., 2017; Sadeghi et al., 2017) or birth outcomes (de Vocht et al., 2014; Eskelinen et al., 2016; Migault et al. 2018). Li et al. (2017) examined the association between magnetic-field exposure and miscarriage in a cohort of 913 pregnant women in California. Exposure was assessed using 24-hour personal magnetic-field measurements collected on a single day during pregnancy, and the 99th percentile value observed during the 24-hour measurement period was used as the exposure of interest by the authors. The authors reported an increased risk of miscarriage in women with higher magnetic-field exposure (i.e., the 99th percentile value during the 24-hour measurement of ≥2.5 mG) compared to women with lower magnetic-field exposure (<2.5 mG) when measurements were collected on a typical day (defined as a day reflecting participants' typical pattern of work and leisure activities during pregnancy). They reported no association, however, among those women whose magnetic-field exposure was measured on a non-typical day, and no trend was observed for miscarriage risk with increasing magnetic-field exposures >2.5 mG. The authors did not report the overall TWA for the 24-hours of exposure that could be compared to previous studies.

While personal exposure measurements are an improvement over some of the earlier studies, the collection of only one measurement over a single 24-hour period during pregnancy is a limitation of the Li et al. (2017) study, as day-to-day changes in exposure cannot be captured. No information was provided in the paper on the exact timing of the measurement (i.e., whether the measurement day preceded or followed the occurrence of miscarriage among cases); this is a substantial limitation as measurements taken following miscarriage in a substantial fraction of cases was a major criticism of the previous study by the same research team (Li et al., 2002). Li et al. (2017) also failed to measure mobility during the measurement day, a potential major source of confounding in the study (e.g., Savitz, 2002; Mezei et al., 2006; Savitz et al., 2006). Varying levels of mobility between women with healthy pregnancies and women who suffer a miscarriage remain a viable alternative explanation for the findings in both the previous and the current studies.

Iranian scientists (Sadeghi et al., 2017) conducted a case-control analysis of preterm birth and residential distance to high-voltage overhead power lines. The researchers identified 135 cases of live spontaneous preterm birth in an Iranian hospital between 2013 and 2014 and compared their estimated exposure to 150 controls with term live births selected using randomized-digit dialing. Exposure was defined as maternal residence during pregnancy located within 600 meters of a high-voltage power line as determined by use of a geographical information system. The study reported no statistically significant association between preterm birth and the mothers' residential distance from power lines (<600 meters compared to ≥600 meters). The authors reported a similar absence of an association with birth defects, which were more common among children with preterm birth. One of the main limitations of the study is the reliance on maternal address within 600 meters to high-voltage power lines as a surrogate for exposure. No elevation of ELF EMF levels can be expected for distances from approximately 100 to 600 meters in that zone; thus, no valid conclusions can be drawn from the study with respect to exposure to EMF.

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; distance to the nearest power lines were determined using geographical information data. 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 (e.g., preterm birth, small for gestational age, low birth weight). The limitations of the study include its reliance on distance for exposure assessment and the potential for confounding by socioeconomic status, which were discussed by the authors. A follow-up analysis of the same data suggested that the observed association in the de Vocht et al. (2014) study, at least partially, may be due to confounding and missing data (de Vocht and Lee, 2014).

Eskelinen et al. (2016) examined the potential association between residential exposure to magnetic fields and time to pregnancy, low birth weight, and being small for gestational age among 373 mothers who gave birth between 1990 and 1994 in Kuopio University Hospital, Finland. The study population was selected from the birth registry of the hospital. To increase the prevalence of women with high exposure to EMF and the range of exposure levels in the study, the scientists selected mothers with residences in close proximity to nearby sources (e.g., transmission lines, underground cables, transformers). They assessed exposure to magnetic fields through spot measurements in the home and through a questionnaire that requested information on occupational and residential sources of EMF (e.g., electrical appliances and equipment). None of the exposure metrics used to assess EMF exposure in the study was statistically associated with measures of fetal growth or time to pregnancy. Consideration of various metrics, including residential measurements and availability of personal level information on potential confounders, were among the strengths of the study, while the relatively few subjects with higher estimated average exposures (>0.4 µT [>4 mG]) subjects limited the study's statistical precision, which was noted by de Vocht and Burstyn (2016).

Migault et al. (2018) studied the relationship between maternal cumulative exposure to ELF EMF and two pregnancy outcomes (moderate prematurity and being small for gestational age) within the Elfe study. The Elfe study is a prospective birth cohort that included 18,329 infants born at 33 weeks of gestation or more in France during 2011 and is designed to follow the children until 20 years of age. Cumulative exposure to both occupational and residential ELF EMF during pregnancy was assessed using the mothers' self-reported occupation and the INTEROCC JEM. The JEM also included exposure estimates for five non-professional categories, including housewife, student, and unemployed, that were used to estimate residential exposure. The authors observed no statistically significant association between maternal cumulative exposure and moderate prematurity or small for gestational age when they evaluated any of the exposure metrics (categorical, binary, or continuous). The authors noted that the ability to consider both occupational and residential exposures in their cumulative estimates is a strength of the study but suggested that the small sample size in the high exposure categories limited the study's power to detect a potential association.

Using data from the Danish National Birth Cohort, Sudan et al. (2017) conducted a follow-up study to a previously reported association between intrauterine exposure to magnetic fields and childhood asthma (Li et al., 2011). The researchers examined 92,675 children born to 91,661 mothers who were pregnant between 1996 and 2002 and assessed intrauterine exposure of the children using distance from the residence of the mother during pregnancy to the nearest power line. They observed no association between magnetic-field exposure estimated by distance from power lines and asthma development, regardless of how the asthma diagnosis was defined. The authors noted, however, that the majority of mothers and children in the dataset had no residential exposure from power lines (i.e., lived in a home that was located outside a specified distance to the nearest power line), thus limiting the ability to make firm conclusions. In addition, potential errors in the estimation of distances to power lines, which were used in the calculations of magnetic-field levels, are a limitation of the study's exposure assessment (Chang et al., 2014).

Darbandi et al. (2017) reviewed some of the human and animal studies published between 1978 and June 2016 that assessed the effects of EMF on male reproductive functions. The authors noted that the studies "provided contradictory results that were highly dependent on the exposure parameters," including intensity and duration of exposure. The inconsistent findings summarized in this paper provide little new insight into this area of research.

Lewis et al. (2016) assessed the scientific literature on ELF EMF exposure and measures of infertility and adverse pregnancy outcomes published between 2002 and 2015. The authors reviewed the strengths and limitations of 13 published studies and concluded that design limitations in most studies may explain their inconsistent findings. The authors' recommendations for future studies included the selection of appropriate study populations, the assessment and control for potential confounding by the mothers' physical activity, the careful characterization of exposure to minimize measurement error, and the consideration of various exposure metrics within the study, among other recommendations.

Assessment

The recent epidemiologic studies evaluated do not provide substantial new evidence in support of an association between EMF and reproductive or developmental outcomes and thus the classification of the data as inadequate remains appropriate. Studies in this research area still suffer from limitations in study design, sample size, and exposure assessment method. The most recent review by SCENIHR concluded that "recent results do not show an effect of ELF MF [magnetic field] exposure on reproductive function in humans." (SCENIHR, 2015)

Table 7. Relevant studies of reproductive and developmental effects

Authors	Year	Study
Darbandi et al.	2017	The effects of exposure to low frequency electromagnetic fields on male fertility.
de Vocht et al.	2014	Maternal residential proximity to sources of extremely low frequency electromagnetic fields and adverse birth outcomes in a UK cohort.
de Vocht and Lee	2014	Residential proximity to electromagnetic field sources and birth weight: Minimizing residual confounding using multiple imputation and propensity score matching.
Eskelinen et al.	2016	Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth.
Lewis et al.	2016	Exposure to Power-Frequency Magnetic Fields and the Risk of Infertility and Adverse Pregnancy Outcomes: Update on the Human Evidence and Recommendations for Future Study Designs.
Li et al.	2017	Exposure to magnetic field non-ionizing radiation and the risk of miscarriage: a prospective cohort study.
Migault et al.	2018	Maternal cumulative exposure to extremely low frequency electromagnetic fields and pregnancy outcomes in the Elfe cohort.
Sadeghi et al.	2017	Preterm birth among women living within 600 meters of high voltage overhead Power Lines: a case-control study.
Sudan et al.	2017	Re-examining the association between residential exposure to magnetic fields from power lines and childhood asthma in the Danish National Birth Cohort.
Comment on Eskelinen et al. (2016)		
de Vocht and Burstyn	2016	Comments on “Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth.”

Neurodegenerative diseases

Research into the possible effect of magnetic fields on the development of neurodegenerative diseases began in 1995; the majority of research since then has focused on Alzheimer’s disease and a specific type of motor neuron disease called 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 scientific 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 studies reviewed 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 are inadequate data in support of an association between magnetic fields and Alzheimer's disease or ALS, stating that, "[w]hen 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). The panel recommended more research in this area using improved methods; in particular they recommended studies that enrolled incident Alzheimer's disease cases (rather than ascertaining cases from death certificates), as well as studies that estimated electrical shock history in ALS cases.

Following the research recommendations of the WHO, scientists conducted epidemiologic research that studied exposure to ELF EMF and development of neurodegenerative diseases. Overall, these studies did not provide consistent and convincing support for an association. Several meta-analyses of these studies reported weak to no evidence of an association between occupational exposure to ELF magnetic fields and neurodegenerative disease (Zhou et al., 2012; Vergara et al., 2013). The authors of these meta-analyses concluded that potential within-study biases, evidence of publication bias, and uncertainties in the various exposure assessments greatly limit the ability to infer an association, if any, between occupational exposure to magnetic fields and neurodegenerative disease.

Several studies have examined the potential role of electric shocks in occupational environments as a possible explanation for the weak and inconsistent association between ELF EMF and ALS. The studies that addressed the issue of electric shocks in the development of neurodegenerative and neurological diseases presented no convincing evidence for an association (Das et al., 2012; Grell et al., 2012; van der Mark et al., 2014; Vergara et al., 2015; Fischer et al., 2015).

Recent studies (December 2014 through December 2018)

Koeman et al. (2015) studied the relationship between various occupational exposures and non-vascular dementia-related mortality using data from the Netherlands Cohort Study, a longitudinal follow-up study of approximately 120,000 men and women 55 to 69 years of age at enrollment. The study authors identified 798 male and 1,171 female cases in the cohort diagnosed between 1986 and 2003 and obtained their lifetime occupational history by questionnaire. Using various JEMs, they assessed occupational exposures to solvents, pesticides, metals, ELF magnetic fields, electric shocks, and diesel exhaust. The authors reported moderate, but statistically non-significant, associations for non-vascular dementia and the highest estimates of exposures to metals, chlorinated solvents, and ELF magnetic fields. The association for magnetic fields, however, showed no exposure-response relationship based on cumulative exposure, and the authors concluded that the association observed for ELF magnetic fields and solvents might be attributable to confounding by exposure to metals. They reported no association for non-vascular dementia and exposure to electric shock.

Koeman et al. (2017) conducted a nested case-control analysis within the Netherlands Cohort Study that again assessed various occupational exposures, including solvents, pesticides, metals, ELF magnetic fields and electric shocks, and ALS mortality. The analysis included ALS cases (n=136) and a random subset (n=4,344) of the cohort study population. The authors reported a statistically significant association among men with "ever high" exposure; however, this was based on a small number of cases (n=9) in the high exposure category. In addition, they reported a statistically significant association between the ALS mortality among men for those with the highest 30 percent or more of cumulative ELF magnetic-field exposure; this association was no longer statistically significant when adjusted for the effects of other occupational exposures, including insecticides. They reported no statistically significant associations for other occupational exposures investigated in the study and that due to the overall low number of exposed women, risk analyses for women were "largely uninformative."

Additional case-control studies of EMF exposure and ALS were conducted by Fischer et al. (2015), Vinceti et al. (2017), and Yu et al. (2014). Fischer et al. (2015) conducted a population-based case-control study of occupational exposure to electric shocks and magnetic fields and ALS in Sweden. The base population of the study included all individuals born in Sweden between 1901 and 1970 who were enumerated during the 1990 Swedish census. All cases of ALS in the study population, newly diagnosed between 1990 and 2010, were identified by record linkages to the Swedish patient and death registries. Five controls, individually matched to cases on birth year and sex, were selected for each case from the study base. A total of 4,709 cases and 23,335 controls were included in the study. Occupational exposures were assessed by linking census-based information on occupations to previously developed JEMs. Overall, neither magnetic fields nor electric shocks were related to ALS. Among subjects <65 years of age, the authors reported statistically significant associations between ALS and exposure to electric shocks; however, they also observed a statistically non-significant decrease among subjects 65 years of age and older. The study has a number of strengths, which include its large sample size, population-based design, inclusion of incidence cases, and the reliance on multiple JEMs (three for EMF and two for electric shocks) for the exposure assessment.

Vinceti et al. (2017) conducted a population-based, case-control study of magnetic fields from high-voltage power lines and ALS within two regions in Italy. The authors included 703 ALS cases, diagnosed between 1998 and 2011, and a sample of 2,737 randomly selected controls from the same provinces. Based on information on residential addresses of the cases and controls, and information on high-voltage power lines with voltages between 132 and 380 kV, the authors modeled magnetic-field exposure at the study subjects' residences. The authors reported no statistically significant associations between ALS and calculated magnetic-field levels, and they observed no exposure-response trend. The authors concluded that their findings "appear to confirm" that exposure to magnetic fields from power lines occurring in the general population is not associated with an increased risk of ALS (Vincente et al., 2017, p. 583).

Yu et al. (2014) reported the results of a small case-control study of ALS that included 66 cases and 66 controls, and examined various lifestyle, environmental, and work-related variables as potential risk factors. Their results on occupational exposure to EMF, however, cannot be interpreted because of a severe error of combining estimates of ionizing and non-ionizing radiation exposures in their analysis.

Researchers have conducted several meta-analyses that examined exposure to ELF magnetic fields and ALS. Capozzella et al. (2014) reported the results of a meta-analysis of occupational exposure to ELF magnetic fields and various chemical agents and ALS; the authors reported weak associations with ELF magnetic fields. Two meta-analyses were published in 2018—one reviewed studies of residential exposure (Röösli and Jalilian, 2018), and the other reviewed studies of occupational exposures (Huss et al., 2018b). Röösli and Jalilian (2018) combined data from five epidemiologic studies that examined residential exposure to ELF magnetic fields from high-voltage power lines and ALS. The authors reported no statistically significant associations; the pooled RR for the most exposed populations (either <200 meters from high-voltage lines or >0.1 µT [>1 mG]) was 0.71 (95% CI, 0.48-1.07). Huss et al. (2018b) conducted a meta-analysis combining data from 20 studies of occupational exposure to ELF magnetic fields and ALS. Overall, the authors reported a weak association with borderline statistical significance for ALS and estimated ELF magnetic-field levels (summary RR 1.14; 95% CI, 1.00-1.30). The authors reported a somewhat stronger association in a subset of six studies with full occupational history compared to studies where occupation was available only at certain time points. The authors also reported substantial heterogeneity among studies, evidence for publication bias, and the lack of a clear exposure-response relationship between estimates of ELF magnetic fields and ALS.

Recent reviews of environmental, occupational, and intrinsic risk factors for ALS did not conclude that there is a clear relationship between ELF magnetic fields or electric shocks and ALS (Ingre et al., 2015; Bozzoni et al., 2016).

Pedersen et al. (2017) updated a prior cohort study (Johansen, 2000) of occupational exposure to ELF magnetic fields and CNS disease, including dementia, motor neuron disease, Parkinson's disease, multiple sclerosis, and epilepsy, among more than 32,000 male electric utility workers in Denmark. The authors identified cases within the occupational cohort of electric utility workers from the Danish National Patient Registry diagnosed from 1982 to 2010. They estimated exposure to ELF magnetic fields using a JEM and company records of job title and area of work and classified into three categories (<0.1 µT [<1 mG], 0.1-0.99 µT [1-9.9 mG], and ≥1.0 µT [≥10 mG]).

Both external and internal comparisons were conducted: 1) disease incidence within the cohort was compared to disease incidence in the general population of Danish men (external comparison); and 2) disease incidence within exposed workers was compared to disease incidence among unexposed workers to account for the potential healthy-worker effect (internal comparison). No consistent pattern of disease association was reported by the authors for any of the investigated outcomes. While the external comparison indicated statistically significant associations for all types of dementia in the highest exposure category of ELF magnetic fields, the internal comparison, which is the more appropriate comparison, reported no such associations. The authors reported no statistically significant increases with exposure to ELF magnetic fields for motor neuron disease, Parkinson's disease, multiple sclerosis, or epilepsy in either external or internal comparisons.

Brouwer et al. (2015) identified cases of Parkinson's disease diagnosed between 1986 and 2003 in a cohort of approximately 120,000 adults (i.e., the Netherlands Cohort Study, noted above). They assessed occupational exposure to EMF and electric shocks among the study subjects using JEMs. Based on a total of 609 cases of Parkinson's disease, the authors concluded that their results generally do not provide strong support for an association with EMF or electric shocks. A hospital-based case-control study in the Netherlands included 444 cases of Parkinson's disease and 876 matched controls (van der Mark et al., 2014). The authors assessed occupational exposure to EMF and electric shocks using work history and a JEM, and they reported no associations between any of the exposure metrics and Parkinson's disease.

Checkoway et al. (2018) investigated the association between Parkinsonism[13] and occupational exposure to several agents, including endotoxin, solvents, shift work, and magnetic fields, among female Shanghai textile workers. The study included 537 retired cotton factory workers who were at least 50 years of age, and 286 age-matched controls who were retired cotton factory workers not exposed to cotton dust (which was used to define endotoxin exposure). Exposure to magnetic fields was assessed using a JEM. The authors reported no statistically significant associations between occupational exposure to magnetic fields and parkinsonism. They further did not observe statistically significant associations with endotoxin, shift work, or solvent exposure. Huss et al. (2015) conducted a meta-analysis of 11 studies of occupational exposure to ELF magnetic fields and Parkinson's disease. The authors observed no statistically significant association (summary RR 1.05, 95% CI 0.98-1.13) and they reported that overall, there was "no evidence that the exposure to ELF-MF [magnetic fields] increases the risk of Parkinson's disease" (Huss et al., 2015, p. 7348).

---

[13] Parkinsonism is defined by Checkoway et al. (2018) as "a syndrome whose cardinal clinical features are bradykinesia, rest tremor, muscle rigidity, and postural instability. Parkinson disease is the most common neurodegenerative form of parkinsonism" (p. 887).

Jalilian et al. (2018) conducted a meta-analysis of 20 epidemiologic studies of occupational exposure to ELF magnetic fields and Alzheimer's disease. The authors reported a moderate, but statistically significant overall association for Alzheimer's disease (summary RR 1.63; 95% CI, 1.35-1.96), with weaker associations in cohort studies than in case-control studies. The authors also reported substantial heterogeneity among studies, and evidence for publication bias. Pooling results from studies with "higher risk" of bias, as assessed by the authors, resulted in stronger associations, suggesting that bias in the studies likely contributed to the reported associations.

A review of environmental risk factors for dementia concluded that the evidence for an association with ELF EMF was "mixed" and "moderate" and that "this complicated exposure requires some unpicking" (Killin et al., 2016, pp. 5, 23).

Assessment

In recent years, multiple studies examined the potential relationship between EMF, electric shocks, and neurodegenerative diseases. Many of these studies represented methodological improvements (e.g., increased sample size, improved exposure assessment, inclusion of incidence cases) compared to previous studies. In spite of these methodological improvements, the overall evidence from these studies provided no consistent or convincing support for a causal association. The most recent SCENIHR report (2015) concluded that newly published studies "do not provide convincing evidence of an increased risk of neurodegenerative diseases, including dementia, related to ELF MF [magnetic field] exposure" (SCENIHR, 2015, p. 186). Results of recent studies have not materially changed this overall assessment.

Table 8. Relevant studies of neurodegenerative disease

Authors	Year	Study
Bozzoni et al.	2016	Amyotrophic lateral sclerosis and environmental factors.
Brouwer et al	2015	Occupational exposures and Parkinson's disease mortality in a prospective Dutch cohort.
Capozzella et al.	2014	Work related etiology of amyotrophic lateral sclerosis (ALS): a meta-analysis.
Checkoway et al.	2018	Occupational exposures and parkinsonism among Shanghai women textile workers.

Authors	Year	Study
Fischer et al.	2015	Occupational exposure to electric shocks and magnetic fields and amyotrophic lateral sclerosis in Sweden.
Huss et al.	2015	Extremely low frequency magnetic field exposure and parkinson's disease--a systematic review and meta-analysis of the data.
Huss et al.	2018b	Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: A systematic review and meta-analysis.
Ingre et al.	2015	Risk factors for amyotrophic lateral sclerosis.
Jalilian et al.	2018	Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis.
Killin et al.	2016	Environmental risk factors for dementia: a systematic review.
Koeman et al.	2015	Occupational exposures and risk of dementia-related mortality in the prospective Netherlands Cohort Study.
Koeman et al.	2017	Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort.
Pedersen et al.	2017	Occupational exposure to extremely low-frequency magnetic fields and risk for central nervous system disease: an update of a Danish cohort study among utility workers.
Röösli and Jalilian	2018	A meta-analysis on residential exposure to magnetic fields and the risk of amyotrophic lateral sclerosis.
Vinceti et al.	2017	Magnetic fields exposure from high-voltage power lines and risk of amyotrophic lateral sclerosis in two Italian populations.
Yu et al.	2014	Environmental risk factors and amyotrophic lateral sclerosis (ALS): a case-control study of ALS in Michigan.

Cardiovascular disease

A hypothesis asserts 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 (December 2014 through December 2018)

Elmas (2016) summarized some of the literature examining the effects of EMF exposure on the heart. The review included studies that assessed the relationship between long-term occupational exposure and heart rate, as well as several studies examining short-term exposure and various health impacts. The author concluded that "despite these studies, the effects of EMFs on the heart remain unclear" and that there is "not yet any consensus in these works about possible mechanisms by which effects of EMF exposure may occur" (Elmas, 2016, p. 80).

Assessment

The conclusion that there is no association between magnetic fields and cardiovascular diseases has not changed. No original research studies have been identified on EMF and cardiovascular disease since Exponent's previous report. Thus, earlier conclusions on the lack of an association between magnetic fields and cardiovascular disease remain relevant.

Table 9. Relevant studies of cardiovascular disease

Authors	Year	Study
Elmas	2016	Effects of electromagnetic field exposure on the heart: a systematic review.

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 tumors in many organs. These studies are known as chronic bioassays.

In some of these studies, magnetic-field exposure was administered alone (to test for the ability of magnetic fields to act as a complete carcinogen). Other studies exposed animals to magnetic fields at the same time that they were exposed to a known carcinogen to assess their cancer promoting capability. A third type of study exposed animals to magnetic fields and examined biological processes of only indirect relevance to the development of cancer but are nonetheless of interest to scientists. These three types of studies were reviewed by the WHO.

Chronic bioassays

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 review. Some animals, however, develop a type of lymphoma similar to childhood ALL and studies exposing these 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). Following the release of the WHO review, Bernard et al. (2009) reported that magnetic-field exposure did not affect development of the most common form of childhood leukemia induced in a rat model by a chemical carcinogen.

Carcinogenic agents plus magnetic fields (combined)

Studies investigating whether exposure to magnetic fields can promote cancer or act as a co-carcinogen treated animals to magnetic fields in combination with known cancer-causing agents, such as ionizing radiation, ultraviolet radiation, or other chemicals. No effects were observed in these studies on chemically-induced pre-neoplastic liver lesions, leukemia or lymphoma, skin tumors, or brain tumors WHO, 2007, Tables 78-79). However, the WHO review did note that 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 tumors initiated by this chemical carcinogen. 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) and Fedrowitz and Löscher (2008), 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.[14]

Magnetic-field effects on biological processes potentially relevant to cancer

Some studies reviewed by the WHO 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. More recent studies in which animals were exposed to higher levels of magnetic fields for longer exposure periods reported no increase in damage to DNA (Saha et al., 2014; Korr et al., 2014). Indicators of biological processes that might lead to DNA damage are being constantly investigated, but while short-term effects on indicators of oxidation in tissues show some effects at very high levels (100,000 mG), effects at lower (but still high) levels (1,000 mG) are inconsistent and longer exposures do not result in greater responses (Glinka et al., 2013; Hassan and Abdelkawai, 2014; Manikonda et al., 2014; Akdag et al., 2013).

In summary, the WHO concluded the following with respect to *in vivo* research related to cancer: "There is no evidence that ELF [EMF] exposure alone causes tumours [*sic*]. The evidence that ELF field exposure can enhance tumour [*sic*] development in combination with carcinogens is inadequate" (WHO, 2007, p. 322). Subsequent research, as reviewed below, has not provided any clear support for the idea that magnetic fields promote the development of tumors initiated by carcinogenic chemicals or that magnetic fields have any confirmed effect on oxidative processes that might damage DNA or other cellular components linked to cancer.

Recent in vivo studies of carcinogenesis (December 2014 through December 2018)

Cancer bioassays

As noted above, none of the past large-scale, long-term bioassays of magnetic-field exposures reported that lifetime exposure to magnetic fields initiate or promote tumor development in rodents. Several newer studies that examined the tumor incidence in animals exposed to magnetic fields compared to that of unexposed controls over short or long periods of time are reviewed below.

[14] 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).

Qi et al. (2015) compared the development of tumors in mice that had been exposed to 50-Hz, 500-mG magnetic fields or control conditions for 12 hours per day beginning 1 week prenatally and continuing until 15.5 months after birth. The exposed mice had significantly reduced body weights compared to controls. Tumors were not increased in males, but chronic myeloid leukemias were significantly higher in exposed females compared to controls. Interpretation of these data is difficult because of the limited experimental detail provided and because the authors did not report data on overall survival or the expected background incidence of tumors in these mice. In addition, no details on how the mice were exposed to magnetic fields or controls for potential effects of important housing variables (noise vibration, light) were provided. The study also did not report whether the analyses of the data were performed by experimenters who were unaware of the exposure history of the mice.

The Ramazzini Institute in Italy measured the effects of 50-Hz magnetic fields (Experiment BT 1CEM) on the body weight, tumor incidence, and mortality of male and female rats exposed to 0 mG, 20 mG, 200 mG, 1,000 mG, 10,000 mG, or intermittent 1,000 mG magnetic fields (30 minutes on and 30 minutes off) for 19 hours per day from day 12 of gestation until death (Bua et al., 2018). Bua et al. (2018) reported no effect of magnetic-field exposure on the incidence of total tumors in any group exposed to magnetic fields or on food and water consumption, body weight, or survival. These results are not consistent with the Qi et al. (2015) study discussed above.

Bua et al (2018) reported a statistically significant 26.6% decrease in malignant tumors in male rats following lifelong exposure to a 1,000 mG magnetic field. Exposures of other groups of male or female rats to magnetic fields across a range from 200 mG to 10,000 mG did not affect the incidences of the specific types of malignancies reported, specifically mammary gland tumors, schwannomas of the heart, thyroid C-cell carcinomas, and hemolymphoreticular neoplasia (HLRN).

Bua et al. (2018) concluded that the study “provided no evidence of any carcinogenic effect related to the exposure of ELF EMF alone” (p. 274) This result is consistent with a previous report from this same laboratory (Soffritti, 2010) on Experiment BT 3CEM in which the incidence of benign or malignant mammary tumors or survival of female rats exposed to

10,000 mG magnetic fields for 19 hours per day beginning before birth and continuing for their remaining lifetime did not differ from unexposed controls. Contrary to good experimental practice, the control group in this study was the same as used in the other studies from this laboratory discussed below (Experiments BT2 CEM and BT3 CEM), and the 10,000 mG exposure group in the Bua et al. (2018) study is the same as in Experiment BT 3 CEM (Soffritti, 2010).

In Experiment BT 2 CEM, Soffritti et al. (2016a) reported that the incidences of benign and malignant tumors in male and female rats exposed to a 10,000 mG magnetic field over their lifetime were no different from those of control rats. Nor did they observe any differences between these groups with respect to C-cell tumors of the thyroid or HLRN.

These are only some of studies of EMF conducted by this laboratory and so their strengths and weaknesses will be discussed *in toto* in the next section.

Carcinogenic agents plus magnetic fields (combined)

The Ramazzini Institute reported two other studies in which rats were exposed to known carcinogenic agents combined with magnetic fields. Soffritti et al. (2016b) reported no effects of gamma radiation plus magnetic field treatment on the body weights or survival rates of male or female rats in Experiment BT3 CEM. The percent of animals with actual cancers of the mammary gland was slightly, but not significantly, greater in female rats exposed to radiation alone (7.6%) than radiation plus 200 mG magnetic fields (7.5%) but was significantly less than the percent of females with mammary tumors exposed to radiation plus 10,000 mG magnetic fields (16.1%). The incidence of mammary tumors in male rats exposed to radiation alone was no different from those exposed to radiation plus 200 mG magnetic fields or radiation plus 10,000 mG magnetic fields. The incidence of HLRN observed in the radiation group was not increased by the addition of 200 mG magnetic field but was increased by the addition of a10,000 mG magnetic field. The authors assessed the incidence of malignant schwannomas in the heart, but there was no statistical difference between male rats treated with radiation or radiation plus magnetic fields at either field level or between any groups of exposed or control female rats. This particular study is deficient because it did not include groups of rats exposed just to 200 mG or 10,000 mG magnetic fields without radiation.

Soffritti et al. (2016b) used the same exposure apparatus and general methods as in Experiment BT 2 CEM to examine the effects of oral exposure to 50 milligrams per liter (mg/L) of formaldehyde, a known carcinogen, in drinking water for two years in combination with 10,000 mG, 50-Hz magnetic-field exposure. Controls were either unexposed (the same control group as reported in Experiments BT 1CEM and BT 3CEM) or treated with formaldehyde in drinking water only.

None of the treatment groups differed with respect to body weight or survival. Exposure to either magnetic fields alone or formaldehyde alone did not increase the incidence of total benign or malignant tumors above that observed in the control group, but the authors did not disclose the distribution of tumors across the different tissues, including the mammary gland, to this total. The incidences of malignant tumors, including C-cell carcinomas of the thyroid and lymphatic tumors, in male rats exposed to both formaldehyde plus magnetic fields were significantly different than those seen with formaldehyde treatment alone. These results were confounded, however, by the substantially reduced water intake levels over the first year of the study in males receiving formaldehyde in the drinking water with or without magnetic-field exposure. No effects were seen in females, except for an increase in thyroid adenomas and carcinomas in groups exposed to formaldehyde alone.

The strengths of the studies reported from the Ramazzini Institute include the large numbers of rats in each group and exposures over the animals' lifespan. These strengths, however, are outweighed by gross limitations in the design of the experiments and data analyses. The rats do not appear to have been randomly allocated to exposure groups and no data were presented to confirm the absence of the potentially confounding effects of noise and vibration. Cage lighting within the exposure room was not uniform, and the authors did not describe taking any measures to control this confounder. More important, the statistical analysis incorrectly treated each rat as the unit of analysis; however, because the rats were exposed in groups, each cage should have been the unit of analysis (Festing and Altmann, 2002). For some tumor types, the authors based their conclusions on only a few animals. Additionally, the large number of statistical tests performed could be expected to lead to false positive results by chance alone, but the authors did not adjust the statistical criteria to correct for this.

An additional concern is that the incidence of mammary cancers in unexposed controls in the Soffritti et al. (2016b) study and the Soffritti et al. (2015) study differs by more than two-fold, as does the incidence of cancers in rats exposed to 0.1 Gray[15] of ionizing radiation. The large variation in the control incidence of mammary tumors across studies calls into question the biological relevance of the small differences in tumor incidences seen with and without different treatments within any single study.

Based on concerns about the ability of the Ramazzini scientists to properly distinguish between leukemias and lymphomas in certain tissues, the EPA has "decided not to rely on data from the RI [Ramazzini Institute] on lymphomas and leukemias in these IRIS [Integrated Risk Information System] assessments" (USEPA, 2017). Furthermore, scientists from EPA and the National Institute for Environmental Health Sciences have taken an unprecedented step to warn risk assessors about problems with cancer bioassays that have been conducted by the Ramazzini Institute, like those described above (Gift et al., 2013).

One other study investigated the therapeutic potential of high magnetic-field exposures in the treatment of tumors but it was conducted for a short duration only. Mahna et al. (2014), injected female mice with mouse mammary tumor cells, then exposed them to 150,000 mG, 50-Hz magnetic fields (10 minutes per day for 12 days). Other animal groups were exposed to magnetic fields and electrochemotherapy (a combination of chemotherapy with pulsed electric current applied to the skin to increase permeability of cancers cells to the drugs). A sham-exposed control group was included, but analyses were not conducted in a blinded manner. The authors reported that magnetic-field exposure alone or in combination with the other treatments reduced tumor volume. Although these studies suffer from various limitations, the results suggest that magnetic-field exposure may have therapeutic applications in the treatment of tumors. Field strengths, however, were relatively high, and it is possible that the observed responses were due to effects of an induced electric field, not the magnetic field per se.

[15] Gray is the unit in which the absorbed dose of ionizing radiation, e.g., x-rays, is measured.

Magnetic-field effects on biological processes potentially relevant to cancer

While the case could be made that almost any biochemical process might be related to cancer, historically, processes relating to damage to deoxyribonucleic acid (DNA) and chromosomes have been given most attention and weight (IARC, 1999).

Alcaraz et al. (2014) exposed male mice to 2,000 mG, 50-Hz magnetic fields for 7 to 28 days. The study included no sham-exposed controls. Mice exposed to 50 centi-Grays of X-rays, which are known for their ability to damage DNA, served as positive controls and the analyses were conducted blind. The authors reported an increase in micronuclei produced by double-strand breaks of chromosomes in bone marrow erythrocytes 24 hours after magnetic-field exposure. The increase was not duration-dependent, however, and was substantially lower than that induced by X-rays.

Wilson et al. (2015) examined the effect of exposure to 100 to 3,000 mG, 50-Hz magnetic fields for 2 or 15 hours on the gene mutation frequency in the sperm and blood cells of mice. Sham-exposed mice were included as negative controls; mice exposed to X-rays served as positive controls. Mutation frequencies in blood cells of magnetic-field exposed mice were similar to those of the negative controls at 12 weeks after exposure. Mutation frequencies in sperm cells were slightly, but significantly, increased among magnetic-field exposed mice, although not in a dose-related manner. In contrast, X-rays significantly increased the mutation frequency in both cell types.

In a follow-on study to the report by Wilson et al., the same research team using the same experimental system tested whether concomitant exposure to magnetic fields and X-rays had a greater effect than X-rays alone (Woodbine et al., 2015). Mouse embryos were exposed to 3,000 mG, 50-Hz magnetic fields for 3 hours before and up to 9 hours after X-ray treatment. Controls were X-irradiated- and sham-exposed to magnetic fields. Additional controls were unexposed, sham-exposed, exposed to X-rays only (with or without sham-exposure), or exposed only to magnetic-fields. X-rays significantly increased DNA double-strand breaks at 1 hour after exposure and the number of breaks decreased to control levels within 6 to 11 hours post-exposure as the cells detected and repaired the DNA breaks. Magnetic-field exposure did not increase the amount of DNA breaks produced by X-rays nor affect the repair of DNA damage caused by X-rays. One weakness of these studies is that the number of maternal animals per group was relatively small (n=1 to 4 per group).

Two recent studies examined DNA damage in human subjects exposed to EMF. Tiwari et al. (2015) investigated DNA damage in peripheral blood lymphocytes among 293 subjects in a cross-sectional study.[16] The authors considered 142 subjects as "exposed to EMFs emitted from high-voltage (132-kV) substations for more than 2 years of occupational exposure" (Tiwari et al., 2015, p. 57). The authors provided no further details on how they determined exposure status. The exposed subjects were compared to 151 non-exposed individuals (controls) of similar socioeconomic status, but the authors did not indicate how they selected control subjects. The analyses did not consider nor control for the potential confounding effect of other occupational exposures, including chemicals. The authors assessed DNA damage using the alkaline Comet assay and coded examination of slides; they also assessed other parameters related to plasma epinephrine concentrations, lipid peroxidation, and nitric oxide expression levels. Although the Comet tail length exhibited a slightly larger range in the exposed group, there was no significant difference between the two groups in the degree of DNA damage observed. The levels of lipid peroxidation and nitric oxide, but not stress (as measured by epinephrine levels), increased in the substation group relative to the control group but, "[t]he oxidative stress markers showed no relationship with exposure variables as assessed from regression analysis" (Tiwari et al., 2015, p. 59).

Villarini et al. (2015) studied a group of 21 electric arc welders in a cross-sectional study**.** The authors used an alkaline Comet assay to assess DNA damage in the white blood cells of arc welders and controls. The occupational exposures of arc welders include various metal fumes, chemicals, and magnetic fields. The control group included non-exposed individuals (healthy blood donors) of similar age, residence, and smoking status. Exposed individuals wore personal dosimeters for a single work shift to measure magnetic fields, which averaged 78 mG. The study did not assess magnetic-field exposure (or other exposures such as to chemicals) in the non-exposed controls. Comet tail lengths were similar in both groups; however, the welders exhibited significantly lower tail intensity and tail moment values than did controls, suggesting

[16] In a cross-sectional study, the investigators determine the study subjects' exposure and outcome status at the same time, thus, these types of studies are not suitable to draw any conclusion on a potential causal association.

that they had a lower degree of DNA damage. The authors suggested that this unexpected finding may be related to the type of DNA damage that might occur with exposure to various metal fumes, including chromium and nickel; both may induce DNA-protein cross-links that would migrate to a lesser degree than non-cross-linked DNA in the assay. The absence of magnetic-field measurements of persons serving as controls precludes the drawing of any conclusions regarding the effects of EMF exposure on DNA damage.

Normal cellular processes produce reactive oxygen species, and while they are effectively managed by other cellular functions, when they are produced in great excess, they can be damaging to DNA and other cell components and may support some carcinogenic processes. Three studies investigated a variety of tissue indicators of oxidative stress. It is important, however, to not simply assume that substances that increase oxidative stress are harmful, and antioxidants, including some vitamins, are beneficial. For example, there are clinical trials and other studies which report that antioxidants may damage DNA (Fox et al., 2012), may not protect against cancer in humans (Goodman et al., 2011), and may increase cancer risk and tumor progression (Sayin et al., 2014).

Because most cancers elicit a response from the immune system, blood levels of certain chemokines (important to inducing immune system functions) are reported to increase when various types of cancer occur. Li et al. (2018) investigated the chemokine response of Balb/c mice (100 per group) exposed to 50-Hz magnetic fields at levels of 0 (sham controls), 1,000 mG, 5,000 mG, and 25,000 mG for <1, 1, 10, 30, or 90 days. The mice were not randomly allocated to these groups and were housed in groups of 10. The mice were, however, randomly selected for weighing on alternate days. At each time point, blood was drawn from four mice and the average value reported. The investigators analyzed the samples for nine different chemokines that affect the immune response by promoting pro-inflammatory functions and recruiting immune cells to sites of infection. The investigators reported that exposure to magnetic fields over 90 days did not affect the body weight of the mice. Nor did the level of magnetic-field exposure have a significant effect on the chemokine levels in blood measured by immunoassay, with two exceptions: MCP-1 and EOTAXIN-1. The change in these chemokines was confirmed by ELISA assay and the clearest increase in levels was at 5,000 mG; magnetic field exposure at the higher level of 25,000 mG reduced the increase in these chemokines. The authors report that they did not see the expected dose-dependent rise in chemokines.

Given the large number of mice (n=900) exposed in total using an exposure system in which only 10 mice could be exposed at a time for 8 hours per day, data collection must have continued for many months; thus, variations in multiple environmental and experimental variables likely affected the results. The 10 exposed mice in each group should have been used as the experimental unit in the statistical analyses, not the individual animals, and the failure to do so overestimates the differences between exposure conditions. Despite the large number of animals used in this study, only a small number of mice were included in each group for the purposes of data analysis and the reported variability of the cytokine measurement suggests that the results may not be very reliable. Given the limitations in the design and analysis of the study and the lack of dose-response, it is not clear that the differences reported are attributable to magnetic-field exposure *per se*. Further, because chemokines are important in eliciting immune reactions, an increase in chemokine levels may be indicative of a protective effect rather than increased susceptibility to cancer.

Luo et al. (2016) investigated potential effects of magnetic-field exposure on a variety of physiologic measures related to cellular oxidative processes. This study was predicated upon the theory that prolonged, uncompensated, high levels of oxidative products might contribute to cancer and neurodegenerative disease. The WHO (2007) and SCENIHR (2015) previously reviewed similar studies. Luo et al. (2016) suggested that a decline in superoxide dismutase (SOD) and a rise in malondialdehyde (MDA) in blood and the brain cortex are indicative of oxidative stress in cells.

Luo et al. (2016) randomly assigned male ICR mice in groups of 12 to 50-Hz, 40,000 mG, 60,000 mG, 80,000 mG, 100,000 mG magnetic fields, or sham-exposure (control) conditions for 4 hours per day and assayed the blood and brain for SOD and MDA levels after 7, 14, and 21 days. The authors observed noticeable and statistically significant changes in these two indicators with exposures at or above 80,000 mG in the predicted directions. The design of the study and the effects reported are similar to those reported in a previous study from this laboratory (Duan et al., 2014).

In the Luo et al. (2016) study, other groups of mice exposed to 80,000 mG magnetic fields also were orally administered 60, 90, or 120 mg of an antioxidant (lotus seedpod procyanidins [LSPC]) for 15 days before magnetic-field exposure and daily thereafter with magnetic-field exposure for an additional 28 days. The highest LSPC dose reversed the changes in SOD activity and MDA levels in the blood and brain cortex compared to mice exposed to magnetic fields only; changes in other oxidative indicators, including catalase, glutathione peroxidase, glutathione reductase, and glutathione-S-transferase, were also reversed. A strength of the study is that the authors tested for effects of magnetic fields at multiple exposure levels and randomized the mice to the experimental groups, which minimizes systematic bias. Yet, while the study was reported in detail, the analysis of the data was not performed blind, the authors reported no controls on noise and vibration from the magnetic-field coils and power supply, and like Bua et al. (2018), the authors did not properly account for the multiple animals exposed in each cage in the statistical analyses.

Another study also reported that extremely high levels of magnetic fields affected oxidative stress marker levels in blood and tissue. Li et al. (2015)[17] randomly assigned eight male Wistar rats to each of the following groups: sham control and 50-Hz, 50,000 mG, 100,000 mG, or 200,000 mG magnetic fields for 10 weeks. At the conclusion of the experiment, the authors analyzed blood samples for indicators of liver damage (alanine aminotransferase [ALT] and aspartate aminotransferase [AST]) and oxidative stress indicators (SOD and MDA) in blood, liver, and spleen. In addition, immunoglobulin G, immunoglobulin A, and immunoglobulin M antibodies were measured in the blood as indicators of immune system function. The investigators report that magnetic-field exposure significantly increased ALT and AST levels in blood, which may reflect changes in liver function. The results also showed a dose-related decrease in SOD and an increase in MDA in blood, liver, and spleen, particularly at the 100,000 mG and 200,000 mG levels. All levels of magnetic-field exposure reportedly decreased antibody concentrations in blood. The design of this study was superior in a number of ways to those of the other studies reviewed above with respect to randomization. It is not clear, however, if the animals were exposed individually or in groups, the authors did not report if the analyses were performed in a blind fashion, and the exposure system that generated the extremely high

[17] This is not the same scientist as the lead author of Li et al. (2018).

levels of magnetic fields to which the mice were exposed likely would have produced considerable noise and vibration that was not controlled for.

Assessment

One animal bioassay reported increased chronic myeloid leukemia in female, but not in male, mice exposed to magnetic fields from prior to birth through 15.5 months of age—a finding that conflicts with those of the other large-scale rodent bioassays reviewed by the WHO in 2007. Three other animal bioassays of long-term magnetic-field exposure as a possible carcinogen were published between 2014 and 2018, and as in previous studies of similar design, they demonstrated that magnetic fields do not cause cancer even when the exposure is life-long. Despite these results, there are serious concerns about the methods utilized in two of these studies and in two additional studies from the Ramazzini Institute in which lifelong exposures of rats to magnetic fields were combined with exposures to known carcinogens—ionizing radiation and formaldehyde. Neither of these latter studies showed convincing evidence in light of the studies' limitations that exposure to magnetic field plus carcinogens increased the overall incidence of tumors in male or female rats above that produced by these carcinogens alone. In a third study, the authors reported that extraordinarily high magnetic-field exposure (150,000 mG) compared to ICNIRP or ICES guidelines for public or occupational exposure, either alone or in combination with chemical therapeutic agents, for 10 days decreased the volume of tumors initiated by injecting mice with mammary tumor cells.

Recent studies also investigated two potential mechanisms related to carcinogenesis: genotoxicity and oxidative stress. Two of three studies of magnetic fields on DNA or chromosomes in animals reported no effects and two studies on indicators of DNA damage in human subjects reported no relationship to magnetic fields. Three other animal studies reported that magnetic-field exposure increased indicators of oxidative stress in blood and other tissues. The clearest effects of magnetic fields were reported at magnetic-field levels between 80,000 mG and 200,000 mG. All these studies had methodological limitations and the relevance of animal studies at such high field levels to persons in communities with far lower exposures is uncertain. These studies do not change the WHO's conclusion that the overall evidence from *in vivo* studies does not support the role of EMF exposures in genotoxic effects.

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

Table 10. Relevant *in vivo* studies related to carcinogenesis

Authors	Year	Study
Alcaraz et al.	2014	Effect of long-term 50 Hz magnetic field exposure on the micronucleated polychromatic erythrocytes of mice.
Bua et al.	2018	Results of lifespan exposure to continuous and intermittent extremely low frequency electromagnetic fields (ELFEMF) administered alone to Sprague Dawley rats
Li et al.	2015	Effect of long-term pulsed electromagnetic field exposure on hepatic and immunologic functions of rats
Li et al.	2018	Eotaxin-1 and MCP-1 serve as circulating indicators in response to power frequency electromagnetic field exposure in mice
Luo et al.	2016	Chemoprotective action of lotus seedpod procyanidins on oxidative stress in mice induced by extremely low-frequency electromagnetic field exposure
Mahna et al.	2014	The effect of ELF magnetic field on tumor growth after electrochemotherapy.
Qi et al.	2015	Effects of extremely low-frequency electromagnetic fields (ELF-EMF) exposure on B6C3F1 mice
Soffritti et al.	2015	Life-span carcinogenicity studies on Sprague-Dawley rats exposed to gamma-radiation: design of the project and report on the tumor occurrence after post-natal radiation exposure (6 weeks of age) delivered in a single acute exposure
Soffritti et al.	2016a	Life-span exposure to sinusoidal-50 Hz magnetic field and acute low-dose γ radiation induce carcinogenic effects in Sprague-Dawley rats
Soffritti et al.	2016b	Synergism between sinusoidal-50 Hz magnetic field and formaldehyde in triggering carcinogenic effects in male Sprague-Dawley Rats
Tiwari et al.	2015	Epinephrine, DNA integrity and oxidative stress in workers exposed to extremely low-frequency electromagnetic fields (ELF-EMFs) at 132 kV substations
Villarini et al.	2015	Primary DNA damage in welders occupational exposed to extremely-low-frequency magnetic fields (ELF-MF)
Wilson et al.	2015	The effects of extremely low frequency magnetic fields on mutation induction in mice.
Woodbine et al.	2015	The rate of X-ray-induced DNA double-strand break repair in the embryonic mouse brain is unaffected by exposure to 50 Hz magnetic fields

6 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 5.

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/IMS-EFHRAN_09072010.pdf (EFHRAN, 2010 [*in vitro* and *in vivo* studies])
  - http://efhran.polimi.it/docs/D2_Finalversion_oct2012.pdf (EFHRAN, 2012 [human exposure])
- **The Health Council of Netherlands**
  - http://www.gezondheidsraad.nl/en/publications/bioinitiative-report-0 (HCN, 2008a)
  - http://www.gezondheidsraad.nl/en/publications/high-voltage-power-lines-0 (HCN, 2008b)
  - 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)
- **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/Publikationer/Rapport/Stralskydd/2013/201319/ (SSM, 2013)
  - https://www.stralsakerhetsmyndigheten.se/contentassets/08b2f497b3ad48cf9e29a1d0008e7d82/201416-recent-research-on-emf-and-health-risk-ninth-report-from-ssms-scientific-council-on-electromagnetic-fields-2014 (SSM, 2014)

- https://www.stralsakerhetsmyndigheten.se/contentassets/ee7b28e0fee04e80bcaf84c24663a004/201519-recent-research-on-emf-and-health-risk---tenth-report-from-ssms-scientific-council-on-electromagnetic-fields-2015 (SSM, 2015)

- https://www.stralsakerhetsmyndigheten.se/contentassets/98d67d9e3301450da4b8d2e0f6107313/201615-recent-research-on-emf-and-health-risk-eleventh-report-from-ssms-scientific-council-on-electromagnetic-fields-2016 (SSM, 2016)

- https://www.stralsakerhetsmyndigheten.se/contentassets/f34de8333acd4ac2b22a9b072d9b33f9/201809-recent-research-on-emf-and-health-risk (SSM, 2018)

7 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. 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, 1990; FDER, 1989; FDEP, 1996). The basis for these limits, however, was to maintain the status quo so that fields from new transmission lines would be no higher than those produced by existing transmission lines.

Rhode Island does not have an EMF standard for transmission lines but the Energy Facility Siting Board in Rhode Island has encouraged the use of practical and cost-effective designs to minimize magnetic-field levels along the edges of transmission line rights-of-way. This approach is consistent with recommendations of the WHO (2007) for addressing ELF EMF.

Table 11. 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

8 Summary

A significant number of epidemiologic and *in vivo* studies have been published on ELF EMF and health since the WHO 2007 report was released. A suggested 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 tend to show no overall associations. The previously reported association in some studies remains unexplained and unsupported by experimental studies. The recent *in vivo* experimental studies confirm the lack of experimental data supporting a leukemogenic or other cancer risk associated with magnetic-field exposure. Publications on other cancer and non-cancer outcomes provided no substantial new information to alter the previous conclusion that the evidence is inadequate to conclude that ELF EMF exposure is harmful at typical environmental levels.

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

9 References

Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, Linet M, McBride M, Michaelis J, Olsen JH, Tynes T, Verkasalo PK. A pooled analysis of magnetic fields and childhood leukaemia. Br J Cancer 83: 692-698, 2000.

Akdag MZ, Dasdag S, Cakir DU, Yokus B, Kizil G, Kizil M. Do 100- and 500-muT ELF magnetic fields alter beta-amyloid protein, protein carbonyl and malondialdehyde in rat brains? Electromagn Biol Med 32: 363-372, 2013.

Alcaraz M, Olmos E, Alcaraz-Saura M, Achel DG, Castillo J. Effect of long-term 50 Hz magnetic field exposure on the micronucleated polychromatic erythrocytes of mice. Electromagn Biol Med 33: 51-47, 2014.

Amoon AT, Oksuzyan S, Crespi CM, Arah OA, Cockburn M, Vergara X, Kheifets L. Residential mobility and childhood leukemia. Environ Res 164: 459-466, 2018a.

Amoon AT, Crespi CM, Ahlbom A, Bhatnagar M, Bray I, Bunch KJ, Clavel J, Feychting M, Hemon D, Johansen C, Kreis C, Malagoli C, Marquant F, Pedersen C, Raaschou-Nielsen O, Röösli M, Spycher BD, Sudan M, Swanson J, Tittarelli A, Tuck DM, Tynes T, Vergara X, Vinceti M, Wunsch-Filho V, Kheifets L. Proximity to overhead power lines and childhood leukaemia: an international pooled analysis. Br J Cancer 119: 364-373, 2018b.

Anderson LE, Boorman GA, Morris JE, Sasser LB, Mann PC, Grumbein SL, Hailey JR, McNally A, Sills RC, Haseman JK. Effect of 13 week magnetic field exposures on DMBA-initiated mammary gland carcinomas in female Sprague-Dawley rats. Carcinogenesis 20: 1615-20, 1999.

Auger N, Park AL, Yacouba S, Goneau M, Zayed J Stillbirth and residential proximity to extremely low frequency power transmission lines: a retrospective cohort study. Occup Environ Med 69: 147-149, 2012.

Baum A, Mevissen M, Kamino K, Mohr U, Löscher W. A histopathological study on alterations in DMBA-induced mammary carcinogenesis in rats with 50 Hz, 100 muT magnetic field exposure. Carcinogenesis 16: 119-125, 1995.

Bonnet-Belfais M, Lambrozo J, Aurengo A. Comment: childhood leukaemia and power lines--the Geocap study: is proximity an appropriate MF exposure surrogate? Br J Cancer 109: 1382-1383, 2013.

Boorman GA, Anderson LE, Morris JE, Sasser LB, Mann PC, Grumbein SL, Hailey JR, McNally A, Sills RC, Haseman JK. Effect of 26 week magnetic field exposures in a DMBA initiation-promotion mammary gland model in Sprague-Dawley rats. Carcinogenesis 20: 899-904, 1999a.

Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, Kovatch RM, Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. Toxicol Pathol 27: 267-278, 1999b.

Bozzoni V, Pansarasa O, Diamanti L, Nosari G, Cereda C, Ceroni M. Amyotrophic lateral sclerosis and environmental factors. Funct Neurol 31: 7-19, 2016.

Brouwer M, Koeman T, van den Brandt PA, Kromhout H, Schouten LJ, Peters S, Huss A, Vermeulen R. Occupational exposures and Parkinson's disease mortality in a prospective Dutch cohort. Occup Environ Med 72: 448-455, 2015.

Bua L, Tibaldi E, Falcioni L, Lauriola M, De Angelis L, Gnudi F, Manservigi M, Manservisi F, Manzoli I, Menghetti I, Montella R, Panzacchi S, Sgargi D, Strollo V, Vornoli A, Mandrioli D, Belpoggi F. Results of lifespan exposure to continuous and intermittent extremely low frequency electromagnetic fields (ELFEMF) administered alone to Sprague Dawley rats. Environ Res 164: 271-279, 2018.

Bunch KJ, Keegan TJ, Swanson J, Vincent TJ, Murphy MF. Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962-2008. Br J Cancer 110: 1402-1408, 2014.

Bunch KJ, Swanson J, Vincent TJ, Murphy MF. Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables. J Radiol Prot 35: 695-705, 2015.

Bunch KJ, Swanson J, Vincent TJ, Murphy MF. Epidemiological study of power lines and childhood cancer in the UK: further analyses. J Radiol Prot 36: 437-455, 2016.

Capozzella A, Sacco C, Chighine A, Loreti B, Scala B, Casale T, Sinibaldi F, Tomei G, Giubilati R, Tomei F, Rosati MV. Work related etiology of amyotrophic lateral sclerosis (ALS): a meta-analysis. Ann Ig 26: 456-472, 2014.

Carlberg M, Soderqvist F, Hansson Mild K, Hardell L. Meningioma patients diagnosed 2007-2009 and the association with use of mobile and cordless phones: a case-control study. Environ Health 12: 60, 2013.

Carlberg M, Koppel T, Ahonen M, Hardell L. Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk. Am J Ind Med 60: 494-503, 2017.

Carlberg M, Koppel T, Ahonen M, Hardell L. Case-Control Study on Occupational Exposure to Extremely Low-Frequency Electromagnetic Fields and the Association with Meningioma. Biomed Res Int 2018: 5912394, 2018.

Chang ET, Adami HO, Bailey WH, Boffetta P, Krieger RI, Moolgavkar SH, Mandel JS. Validity of geographically modeled environmental exposure estimates. Crit Rev Toxicol 44: 450-466, 2014.

Checkoway H, Ilango S, Li W, Ray RM, Tanner CM, Hu SC, Wang X, Nielsen S, Gao DL, Thomas DB. Occupational exposures and parkinsonism among Shanghai women textile workers. Am J Ind Med 61: 886-892, 2018.

Clavel J, Sermage-Faure C, Demoury C, Rudant J, Goujon-Bellec S, Guyot-Goubin A, Deschamps F, Hemon D. Reply: comment on 'Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007'--is proximity an appropriate MF exposure surrogate? Br J Cancer 109: 1383-1384, 2013.

Crespi CM, Vergara XP, Hooper C, Oksuzyan S, Wu S, Cockburn M, Kheifets L. Childhood leukaemia and distance from power lines in California: a population-based case-control study. Br J Cancer 115: 122-128, 2016.

Darbandi M, Darbandi S, Agarwal A, Henkle R, Sadeghi MR. The Effects of Exposure to Low Frequency Electromagnetic Fields on Male Fertility. Altern Ther Health Med, 2017 [epub ahead of print].

Das K, Nag C, Ghosh M. Familial, environmental, and occupational risk factors in development of amyotrophic lateral sclerosis. N Am J Med Sci 4: 350-355, 2012.

de Vocht F, Hannam K, Baker P, Agius R. Maternal residential proximity to sources of extremely low frequency electromagnetic fields and adverse birth outcomes in a UK cohort. Bioelectromagnetics 35: 201-209, 2014.

de Vocht F and Lee B. Residential proximity to electromagnetic field sources and birth weight: Minimizing residual confounding using multiple imputation and propensity score matching. Environ Int 69: 51-57, 2014.

de Vocht F and Burstyn I. Comments on "Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth". Environ Int 96: 190-191, 2016.

Dechent D and Driessen S. Re: Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase - a Case Control Study in Tehran, Iran. Asian Pac J Cancer Prev 17: 877-878, 2016.

Draper G, Vincent T, Kroll ME, Swanson J. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. BMJ 330: 1290, 2005.

Duan W, Liu C, Wu H, Chen C, Zhang T, Gao P, Luo X, Yu Z, Zhou Z. Effects of exposure to extremely low frequency magnetic fields on spermatogenesis in adult rats. Bioelectromagnetics 35: 58-69, 2014.

Elliott P, Shaddick G, Douglass M, de Hoogh K, Briggs DJ, Toledano MB. Adult cancers near high-voltage overhead power lines. Epidemiology 24: 184-190, 2013.

Elmas O. Effects of electromagnetic field exposure on the heart: a systematic review. Toxicol Ind Health 32: 76-82, 2016.

Eskelinen T, Roivainen P, Makela P, Keinanen J, Kauhanen O, Saarikoski S, Juutilainen J. Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth. Environ Int 94: 620-625, 2016.

European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN). Report on the Analysis of Risks Associated to Exposure to EMF: *In Vitro* and *In Vivo* (Animals) Studies. Milan, Italy: EFHRAN, 2010.

European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN). Risk Analysis of Human Exposure to Electromagnetic Fields (Revised). Report D2 of the EFHRAN Project. Milan, Italy: EFHRAN, 2012.

Federal-Provincial-Territorial Radiation Protection Committee (FPTRPC). Health Effects and Exposure Guidelines Related to Extremely Low Frequency Electric and Magnetic Fields - An Overview. Ottawa: Health Canada, 2005.

Fedrowitz M, Kamino K, Löscher W. Significant differences in the effects of magnetic field exposure on 7,12-dimethylbenz(a)anthracene-induced mammary carcinogenesis in two substrains of Sprague-Dawley rats. Cancer Res 64: 243-251, 2004.

Fedrowitz M and Loscher W. Exposure of Fischer 344 rats to a weak power frequency magnetic field facilitates mammary tumorigenesis in the DMBA model of breast cancer. Carcinogenesis 29: 186-193, 2008.

Festing MF and Altman DG. Guidelines for the design and statistical analysis of experiments using laboratory animals. ILAR J 43: 244-258, 2002.

Fischer H, Kheifets L, Huss A, Peters TL, Vermeulen R, Ye W, Fang F, Wiebert P, Vergara XP, Feychting M. Occupational Exposure to Electric Shocks and Magnetic Fields and Amyotrophic Lateral Sclerosis in Sweden. Epidemiology 26: 824-830, 2015.

Florida Department of Environmental Protection (FDEP). Electric and Magnetic Fields. Chapter 62-814. 1996.

Florida Department of Environmental Regulation (FDER). Electric and Magnetic Fields. Chapter 17-274. 1989.

Fox JT, Sakamuru S, Huang R, Teneva N, Simmons SO, Xia M, Tice RR, Austin CP, Myung K. High-throughput genotoxicity assay identifies antioxidants as inducers of DNA damage response and cell death. Proc Natl Acad Sci U S A 109: 5423-5428, 2012.

Gallastegi M, Guxens M, Jimenez-Zabala A, Calvente I, Fernandez M, Birks L, Struchen B, Vrijheid M, Estarlich M, Fernandez MF, Torrent M, Ballester F, Aurrekoetxea JJ, Ibarluzea J, Guerra D, Gonzalez J, Röösli M, Santa-Marina L. Characterisation of exposure to non-ionising electromagnetic fields in the Spanish INMA birth cohort: study protocol. BMC Public Health 16: 167, 2016.

Gauger JR. Household appliance magnetic field survey. IEEE Trans Power App Syst 104: 2436-

2444, 1985.

Gift JS, Caldwell JC, Jinot J, Evans MV, Cote I, Vandenberg JJ. Scientific considerations for evaluating cancer bioassays conducted by the Ramazzini Institute. Environ Health Perspect 121: 1253-1263, 2013.

Glinka M, Sieron A, Birkner E, Cieslar G. Influence of extremely low-frequency magnetic field on the activity of antioxidant enzymes during skin wound healing in rats. Electromagn Biol Med 32: 463-470, 2013.

Gobba F, Bravo G, Rossi P, Contessa GM, Scaringi M. Occupational and environmental exposure to extremely low frequency-magnetic fields: a personal monitoring study in a large group of workers in Italy. J Expo Sci Environ Epidemiol 21: 634-645, 2011

Goodman M, Bostick RM, Kucuk O, Jones DP. Clinical trials of antioxidants as cancer prevention agents: past, present, and future. Free Radic Biol Med 51: 1068-1084, 2011.

Gordis L. Epidemiology. Philadelphia: WB Saunders Company, 2000.

Green LM, Miller AB, Agnew DA, Greenberg ML, Li J, Villeneuve PJ, Tibshirani R. Childhood leukemia and personal monitoring of residential exposures to electric and magnetic fields in Ontario, Canada. Cancer Causes Control 10: 233-243, 1999.

Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Childhood Leukemia-EMF Study Group. Epidemiology 11: 624-634, 2000.

Grell K, Meersohn A, Schüz J, Johansen C. Risk of neurological diseases among survivors of electric shocks: a nationwide cohort study, Denmark, 1968-2008. Bioelectromagnetics 33: 459-465, 2012.

Grundy A, Harris SA, Demers PA, Johnson KC, Agnew DA, Villeneuve PJ. Occupational exposure to magnetic fields and breast cancer among Canadian men. Cancer Med 5: 586-596, 2016.

Hardell L, Carlberg M, Mild KH. Case-control study of the association between the use of cellular and cordless telephones and malignant brain tumors diagnosed during 2000-2003. Environ Res 100: 232-241, 2006.

Harris AW, Basten A, Gebski V, Noonan D, Finnie J, Bath ML, Bangay MJ, Repacholi MH. A test of lymphoma induction by long-term exposure of E mu-Pim1 trangenic mice to 50 Hz magnetic fields. Radiat Res 149: 300-307, 1998.

Hassan NS and Abdelkawi SA. Assessing of plasma protein denaturation induced by exposure to cadmium, electromagnetic fields and their combined actions on rat. Electromagn Biol Med 33: 147-153, 2014.

Health Council of the Netherlands (HCN). BioInitiative Report. The Hague: Health Council of the Netherlands, 2008a.

Health Council of the Netherlands (HCN). High-Voltage Power Lines. Publication Number: 2008/04E. The Hague: Health Council of the Netherlands, 2008b.

Health Council of the Netherlands (HCN). Electromagnetic Fields: Annual Update. Publication No. 2009/02. The Hague: Health Council of the Netherlands, 2009a.

Health Council of the Netherlands (HCN). Advisory letter - Power lines and Alzheimer's disease. The Hague: Health Council of the Netherlands, 2009b.

Health Protection Agency (HPA). Power frequency electromagnetic fields, melatonin and the risk of breast cancer: report of an independent advisory group on non-ionising radiation. Documents of the Health Protection Agency. Series B: Radiation, Chemical and Environmental Hazards. Oxfordshire: HPA, 2006.

Hill AB. The Environment and Disease: Association or Causation? Proc R Soc Med 58: 295-300, 1965.

Huss A, Koeman T, Kromhout H, Vermeulen R. Extremely Low Frequency Magnetic Field Exposure and Parkinson's Disease--A Systematic Review and Meta-Analysis of the Data. Int J Environ Res Public Health 12: 7348-56, 2015.

Huss A, Spoerri A, Egger M, Kromhout H, Vermeulen R. Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers - Swiss National Cohort analysis and updated meta-analysis. Environ Res 164: 467-474, 2018a.

Huss A, Peters S, Vermeulen R. Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: A systematic review and meta-analysis. Bioelectromagnetics 39: 156-163, 2018b.

Ingre C, Roos PM, Piehl F, Kamel F, Fang F. Risk factors for amyotrophic lateral sclerosis. Clin Epidemiol 7: 181-193, 2015.

International Agency for Research on Cancer (IARC). The Use of Short- and Medium-Term Tests for Carcinogens and Data on Genetic Effects in Carcinogenic Hazard Evaluation. Lyon, France: International Agency for Research on Cancer (IARC), 1999.

International Agency for Research on Cancer (IARC). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 80: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields. Lyon, France: IARC Press, 2002.

International Commission on Non-ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys 99: 818-836, 2010.

International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz. Piscataway, NJ: IEEE, 2002; Reaffirmed 2007.

Jalilian H, Teshnizi SH, Röösli M, Neghab M. Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis. Neurotoxicology 69:242-252, 2018.

Johansen C. Exposure to electromagnetic fields and risk of central nervous system disease in utility workers. Epidemiology 11: 539-543, 2000.

Karipidis KK. Survey of residential power-frequency magnetic fields in Melbourne, Australia. Radiat Prot Dosimetry 163: 81-91, 2015.

Kheifets L, Monroe J, Vergara X, Mezei G, Afifi AA. Occupational electromagnetic fields and leukemia and brain cancer: an update to two meta-analyses. J Occup Environ Med 50: 677-688, 2008.

Kheifets L and Oksuzyan S. Exposure assessment and other challenges in non-ionizing radiation studies of childhood leukaemia. Radiat Prot Dosimetry 132: 139-147, 2008.

Kheifets L, Bowman JD, Checkoway H, Feychting M, Harrington JM, Kavet R, Marsh G, Mezei G, Renew DC, van Wijngaarden E. Future needs of occupational epidemiology of extremely low frequency electric and magnetic fields: review and recommendations. Occup Environ Med 66: 72-80, 2009.

Kheifets L, Ahlbom A, Crespi CM, Draper G, Hagihara J, Lowenthal RM, Mezei G, Oksuzyan S, Schüz J, Swanson J, Tittarelli A, Vinceti M, Wunsch Filho V. Pooled analysis of recent studies on magnetic fields and childhood leukaemia. Br J Cancer 103: 1128-1135, 2010a.

Kheifets L, Ahlbom A, Crespi CM, Feychting M, Johansen C, Monroe J, Murphy MF, Oksuzyan S, Preston-Martin S, Roman E, Saito T, Savitz D, Schüz J, Simpson J, Swanson J, Tynes T, Verkasalo P, Mezei G. A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors. Am J Epidemiol 172: 752-761, 2010b.

Kheifets L, Crespi CM, Hooper C, Oksuzyan S, Cockburn M, Ly T, Mezei G. Epidemiologic study of residential proximity to transmission lines and childhood cancer in California: description of design, epidemiologic methods and study population. J Expo Sci Environ Epidemiol 25: 45-52, 2015.

Kheifets L, Crespi CM, Hooper C, Cockburn M, Amoon AT, Vergara XP. Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California. Cancer Causes Control 28: 1117-1123, 2017a.

Kheifets L, Swanson J, Yuan Y, Kusters C, Vergara X. Comparative analyses of studies of childhood leukemia and magnetic fields, radon and gamma radiation. J Radiol Prot 37: 459-491, 2017b.

Killin LO, Starr JM, Shiue IJ, Russ TC. Environmental risk factors for dementia: a systematic review. BMC Geriatr 16: 175, 2016.

Koeman T, van den Brandt PA, Slottje P, Schouten LJ, Goldbohm RA, Kromhout H, Vermeulen R. Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort. Cancer Causes Control 25: 203-214, 2014.

Koeman T, Schouten LJ, van den Brandt PA, Slottje P, Huss A, Peters S, Kromhout H, Vermeulen R. Occupational exposures and risk of dementia-related mortality in the prospective Netherlands Cohort Study. Am J Ind Med 58: 625-635, 2015.

Koeman T, Slottje P, Schouten LJ, Peters S, Huss A, Veldink JH, Kromhout H, van den Brandt PA, Vermeulen R. Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort. Occup Environ Med 74: 578-585, 2017.

Korr H, Angstman NB, Born TB, Bosse K, Brauns B, Demmler M, Fueller K, Kantor O, Kever BM, Rahimyar N, Salimi S, Silny J, Schmitz C. 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. PLoS One 9: e109774, 2014.

Kyriakopoulou A, Meimeti E, Moisoglou I, Psarrou A, Provatopoulou X, Dounias G. Parental Occupational Exposures and Risk of Childhood Acute Leukemia. Mater Sociomed 30: 209-214, 2018.

Lai H and Singh NP. Magnetic-field induced DNA strand breaks in brain cells of the rat. Environ Health Perspect 113: 687-694, 2004.

Lee GM, Neutra RR, Hristova L, Yost M, Hiatt RA. A nested case-control study of residential and personal magnetic field measures and miscarriages. Epidemiology 13: 21-31, 2002.

Lewis RC, Evenson KR, Savitz DA, Meeker JD. Temporal variability of daily personal magnetic field exposure metrics in pregnant women. J Expo Sci Environ Epidemiol 25: 58-64, 2015.

Lewis RC, Hauser R, Maynard AD, Neitzel RL, Wang L, Kavet R, Meeker JD. Exposure to Power-Frequency Magnetic Fields and the Risk of Infertility and Adverse Pregnancy Outcomes: Update on the Human Evidence and Recommendations for Future Study Designs. J Toxicol Environ Health B Crit Rev 19: 29-45, 2016.

Li DK, Odouli R, Wi S, Janevic T, Golditch I, Bracken TD, Senior R, Rankin R, Iriye R. A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage. Epidemiology 13: 9-20, 2002.

Li DK, Chen H, Odouli R. Maternal Exposure to Magnetic Fields During Pregnancy in Relation to the Risk of Asthma in Offspring. Arch Pediatr Adolesc Med 165: 945-950, 2011.

Li W, Ray RM, Thomas DB, Yost M, Davis S, Breslow N, Gao DL, Fitzgibbons ED, Camp JE, Wong E, Wernli KJ, Checkoway H. Occupational exposure to magnetic fields and breast cancer among women textile workers in Shanghai, China. Am J Epidemiol 178: 1038-1045, 2013.

Li L, Xiong DF, Liu JW, Li ZX, Zeng GC, Li HL. A cross-sectional study on oxidative stress in workers exposed to extremely low frequency electromagnetic fields. Int J Radiat Biol 91: 420-425, 2015.

Li DK, Chen H, Ferber JR, Odouli R, Quesenberry C. Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study. Sci Rep 7: 17541, 2017.

Li H, Lin L, Li L, Zhou L, Hao S, Zhang Y, Ding Z. Eotaxin1 and MCP1 serve as circulating indicators in response to power frequency electromagnetic field exposure in mice. Mol Med Rep 18: 2832-2840, 2018.

Linet MS, Wacholder S, Zahm SH. Interpreting epidemiologic research: Lessons from studies of childhood cancer. Pediatrics 112: 218-232, 2003.

Liorni I, Parazzini M, Fiocchi S, Douglas M, Capstick M, Kuster N, Ravazzani P. Computational assessment of pregnant woman models exposed to uniform ELF-magnetic fields: Compliance with the European current exposure regulations for the general public and occupational exposures at 50 Hz. Radiat Prot Dosimetry 172: 382-392, 2016.

Löscher W, Wahnschaffe U, Mevissen M, Lerchl A, Stamm A. Effects of weak alternating magnetic fields on nocturnal melatonin production and mammary carcinogenesis in rats. Oncology 51: 288-295, 1994.

Löscher W, Mevissen M, Lehmacher W, Stamm A. Tumor promotion in a breast cancer model by exposure to a weak alternating magnetic field. Cancer Lett 71: 75-81, 1993.

Löscher W and Mevissen M. Linear relationship between flux density and tumor co-promoting effect of prolonged magnetic field exposure in a breast cancer model. Cancer Lett 96: 175-180, 1995.

Löscher W, Mevissen M, Haussler B. Seasonal influence on 7,12-dimethylbenz[a]anthracene-induced mammary carcinogenesis in Spague-Dawley rats under controlled laboratory conditions. Pharmacol Toxicol 81: 265-270, 1997.

Luo X, Chen M, Duan Y, Duan W, Zhang H, He Y, Yin C, Sun G, Sun X. Chemoprotective action of lotus seedpod procyanidins on oxidative stress in mice induced by extremely low-frequency electromagnetic field exposure. Biomed Pharmacother 82: 640-648, 2016.

Magnani A, Balbo P, Facchini E, Occhetta E, Marino P. Lack of interference of electromagnetic navigation bronchoscopy to implanted cardioverter-defibrillator: in-vivo study. Europace 16: 1767-1771, 2014.

Magne I, Souques M, Bureau I, Duburcq A, Remy E, Lambrozo J. Exposure of children to extremely low frequency magnetic fields in France: Results of the EXPERS study. J Expo Sci Environ Epidemiol 27: 505-512, 2017.

Mahna A, Firoozabadi SM, Shankayi Z. The effect of ELF magnetic field on tumor growth after electrochemotherapy. J Membr Biol 247: 9-15, 2014.

Mahram M and Ghazavi M. The effect of extremely low frequency electromagnetic fields on pregnancy and fetal growth, and development. Arch Iran Med 16: 221-224, 2013.

Mandeville R, Franco E, Sidrac-Ghall S, Paris-Nadon L, Rocheleau N, Mercier G, Desy M, Gaboury L. Evaluation of the potential carcinogenicity of 60 Hz linear sinusoidal continuous-wave magnetic fields in Fisher F344 rats. FAESB Journal 11: 1127-1136, 1997.

Manikonda PK, Rajendra P, Devendranath D, Gunasekaran B, Channakeshava, Aradhya SR, Sashidhar RB, Subramanyam C. Extremely low frequency magnetic fields induce oxidative stress in rat brain. Gen Physiol Biophys 33: 81-90, 2014.

McCormick DL, Ryan B, Findlay JC, Gauger JR, Johnson TR, Morrissey R, Boorman GA. Exposure to 60 Hz magnetic fields and risk of lymphoma in PIM transgenic and TSG-*p53* (*p53* knockout) mice. Carcinogenesis 19: 1649-1653, 1998.

McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, Pletcher JM, Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice. Toxicol Pathol 27: 279-285, 1999.

Mevissen M, Stamm A, Buntenkotter S, Zwingleberg R, Wahnschaffe U, Löscher W. Effects of magnetic fields on mmmary tumor development induced by 7,12-dimethylbenz(a)anthracene in rats. Bioelectromagnetics 14: 131-143, 1993a.

Mevissen M, Stamm A, Buntenkotter S, Zwingleberg R, Wahnschaffe U, Löscher W. Effects of AC Magnetic Field on DMBA-induced Mammary Carcinogenesis in Sprague-Dawley Rats. In Electricity and Magnetism in Biology and Medicine, edited by M. Blank. San Francisco, CA: San Francisco Press, 1993b.

Mezei G, Bracken TD, Senior R, Kavet R. Analyses of magnetic-field peak-exposure summary measures. J Expo Sci Environ Epidemiol 16: 477-485, 2006.

Mezei G, Gadallah M, Kheifets L. Residential magnetic field exposure and childhood brain cancer: a meta-analysis. Epidemiology 19: 424-430, 2008.

Migault L, Piel C, Carles C, Delva F, Lacourt A, Cardis E, Zaros C, de Seze R, Baldi I, Bouvier G. Maternal cumulative exposure to extremely low frequency electromagnetic fields and pregnancy outcomes in the Elfe cohort. Environ Int 112: 165-173, 2018.

National Institute of Environmental Health Sciences (NIEHS). EMF Questions & Answsers (NIH Publication 02-4493). Research Triangle Park, NC: NIEHS, 2002.

National Radiological Protection Board (NRPB). Review of the Scientific Evidence for Limiting Exposure to Electromagnetic Fields (0-300 GHz), Volume 15, No. 3. Chilton, UK: National Radiological Protection Board (NRPB), 2004.

National Radiological Protection Board (NRPB). Magnetic fields and miscarriage. Radiol Prot Bull No 1 (The eBulliten), June 2002.

National Toxicology Program (NTP). 2015. “Descriptions of NTP Study Types.” U.S. Department of Health and Human Services. https://ntp.niehs.nih.gov/testing/types/index.html.

New York Public Service Commission (NYPSC). Opinion No. 78-13. Opinion and Order Determining Health and Safety Issues, Imposing Operating Conditions, and Authorizing, in Case 26529, Operation Pursuant to those Conditions, 1978.

New York Public Service Commission (NYPSC). Statement of Interim Policy on Magnetic Fields of Major Transmission Facilities. Cases 26529 and 26559 Proceeding on Motion of the Commission, 1990.

Parodi S, Merlo DF, Ranucci A, Miligi L, Benvenuti A, Rondelli R, Magnani C, Haupt R. Risk of neuroblastoma, maternal characteristics and perinatal exposures: the SETIL study. Cancer Epidemiol 38: 686-694, 2014.

Pedersen C, Raaschou-Nielsen O, Rod NH, Frei P, Poulsen AH, Johansen C, Schüz J. Distance from residence to power line and risk of childhood leukemia: a population-based case-control study in Denmark. Cancer Causes Control 25: 171-177, 2014a.

Pedersen C, Brauner EV, Rod NH, Albieri V, Andersen CE, Ulbak K, Hertel O, Johansen C, Schüz J, Raaschou-Nielsen O. Distance to high-voltage power lines and risk of childhood leukemia - an analysis of confounding by and interaction with other potential risk factors. PLoS One 9: e107096, 2014b.

Pedersen C, Johansen C, Schüz J, Olsen JH, Raaschou-Nielsen O. Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukaemia, CNS tumour and lymphoma in Denmark. Br J Cancer 113: 1370-1374, 2015.

Pedersen C, Poulsen AH, Rod NH, Frei P, Hansen J, Grell K, Raaschou-Nielsen O, Schüz J, Johansen C. Occupational exposure to extremely low-frequency magnetic fields and risk for central nervous system disease: an update of a Danish cohort study among utility workers. Int Arch Occup Environ Health 90: 619-628, 2017.

Qi G, Zuo X, Zhou L, Aoki E, Okamula A, Watanebe M, Wang H, Wu Q, Lu H, Tuncel H, Watanabe H, Zeng S, Shimamoto F. Effects of extremely low-frequency electromagnetic fields (ELF-EMF) exposure on B6C3F1 mice. Environ Health Prev Med 20: 287-293, 2015.

Ries L, Smith MA, Gurney JG, Linet M, Tamra T, Young JL, Bunin GR, eds. Cancer Incidence and Survival among Children and Adolescents: United States SEER Program 1975-1995 (NIH Publication No. 99-4649). Bethesda, MD: National Cancer Institute, 1999.

Röösli M and Jalilian H. A meta-analysis on residential exposure to magnetic fields and the risk of amyotrophic lateral sclerosis. Rev Environ Health 33: 295-299, 2018.

Rothman KJ and Greenland S. Modern Epidemiology. Philadelphia: Lippencott-Raven Publishers, 1998.

Sadeghi T, Ahmadi A, Javadian M, Gholamian SA, Delavar MA, Esmailzadeh S, Ahmadi B, Hadighi MSH. Preterm birth among women living within 600 meters of high voltage overhead Power Lines: a case-control study. Rom J Intern Med 55: 145-150, 2017.

Saha S, Woodbine L, Haines J, Coster M, Ricket N, Barazzuol L, Ainsbury E, Sienkiewicz Z, Jeggo P. 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. J R Soc Interface 11: 20140783, 2014.

Salvan A, Ranucci A, Lagorio S, Magnani C. Childhood leukemia and 50 Hz magnetic fields: findings from the Italian SETIL case-control study. Int J Environ Res Public Health 12: 2184-2204, 2015.

Savitz DA, Liao D, Sastre A, Kleckner RC, Kavet R. Magnetic field exposure and cardiovascular disease mortality among electric utility workers. Am J Epidemiol 149: 135-142, 1999.

Savitz DA. Magnetic fields and miscarriage. Epidemiology 13: 1-4, 2002.

Savitz DA, Herring AH, Mezei G, Evenson KR, Terry JW, Jr., Kavet R. Physical activity and magnetic field exposure in pregnancy. Epidemiology 17: 222-225, 2006.

Sayin VI, Ibrahim MX, Larsson E, Nilsson JA, Lindahl P, Bergo MO. Antioxidants accelerate lung cancer progression in mice. Sci Transl Med 6: 221ra15, 2014.

Schüz J, Dasenbrock C, Ravazzani P, Röösli M, Schar P, Bounds PL, Erdmann F, Borkhardt A, Cobaleda C, Fedrowitz M, Hamnerius Y, Sanchez-Garcia I, Seger R, Schmiegelow K, Ziegelberger G, Capstick M, Manser M, Muller M, Schmid CD, Schurmann D, Struchen B, Kuster N. Extremely low-frequency magnetic fields and risk of childhood leukemia: A risk assessment by the ARIMMORA consortium. Bioelectromagnetics 37:183-189, 2016.

Scientific Committee of Emerging and Newly Identified Health Risks (SCENIHR) for the Directorate-General for Health & Consumers of the European Commission. Possible Effects of Electromagnetic Fields (EMF) on Human Health. Brussels, Belgium: European Commission, 2007.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Health Effects of Exposure to EMF. Brussels, Belgium: European Commission, 2009.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Opinion on Potential Health Effects of Exposure to Electromagnetic Fields (EMF). Brussels, Belgium: European Commission, 2015.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Memorandum on the use of the scientific literature for human risk assessment purposes – weighing of evidence and expression of uncertainty. Brussels, Belgium: European Commission, 2012.

Sermage-Faure C, Demoury C, Rudant J, Goujon-Bellec S, Guyot-Goubin A, Deschamps F, Hemon D, Clavel J. Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007. Br J Cancer 108: 1899-1906, 2013.

Shamsi Mahmoudabadi F, Ziaei S, Firoozabadi M, Kazemnejad A. Exposure to Extremely Low Frequency Electromagnetic Fields during Pregnancy and the Risk of Spontaneous Abortion: A Case-Control Study. J Res Health Sci 13: 131-134, 2013.

Soffritti M, Belpoggi F, Lauriola M, Tibaldi E, Manser M, Accurso D, Chiozzotto D, Giuliani L. Mega-experiments on the carcinogenicity of Extremely Low Frequency Magnetic Fields (ELFMF) on Sprague-Dawley rats exposed from fetal life until spontaneous death: plant of the project and early results on mammary carcinogenesis. In Non-Thermal Effects and Mechanisms of Interaction between Electromagnetic Fields and Living Matter-An ICEMS Monograph (Eur J Oncol - Library Vol 5), edited by L. Giuliani and M. Soffritti. Bologna, Italy: National Institute for the Study and Control of Cancer and Environmental Diseases “Bernardino Ramazzini,” 2010.

Soffritti M, Tibaldi E, Bua L, Padovani M, Falcioni L, Lauriola M, Manservigi M, Manservisi F, Belpoggi F. Life-span carcinogenicity studies on Sprague-Dawley rats exposed to gamma-radiation: design of the project and report on the tumor occurrence after post-natal radiation exposure (6 weeks of age) delivered in a single acute exposure. Am J Ind Med 58: 46-60, 2015.

Soffritti M, Tibaldi E, Padovani M, Hoel DG, Giuliani L, Bua L, Lauriola M, Falcioni L, Manservigi M, Manservisi F, Panzacchi S, Belpoggi F. Life-span exposure to sinusoidal-50 Hz magnetic field and acute low-dose gamma radiation induce carcinogenic effects in Sprague-Dawley rats. Int J Radiat Biol 92: 202-14, 2016a.

Soffritti M, Tibaldi E, Padovani M, Hoel DG, Giuliani L, Bua L, Lauriola M, Falcioni L, Manservigi M, Manservisi F, Belpoggi F. Synergism between sinusoidal-50 Hz magnetic field and formaldehyde in triggering carcinogenic effects in male Sprague-Dawley rats. Am J Ind Med 59: 509-21, 2016b.

Sommer AM and Lerchl A. The risk of lymphoma in AKR/J mice does not rise with chronic exposure to 50 Hz magnetic fields (1 microT and 100 microT). Radiat Res 162: 194-200, 2004.

Sorahan T. Cancer incidence in UK electricity generation and transmission workers, 1973-2008. Occup Med (Lond) 62: 496-505, 2012.

Stroup DF, Thacker SB, Olson CM, Glass RM, Hutwagner L. Characteristics of meta-analyses related to acceptance for publication in a medical journal. J Clinical Epidemiol 54: 655-660, 2001.

Struchen B, Liorni I, Parazzini M, Gangler S, Ravazzani P, Röösli M. Analysis of personal and bedroom exposure to ELF-MFs in children in Italy and Switzerland. J Expo Sci Environ Epidemiol 26: 586-596, 2016.

Su L, Fei Y, Wei X, Guo J, Jiang X, Lu L, Chen G. Associations of parental occupational exposure to extremely low-frequency magnetic fields with childhood leukemia risk. Leuk Lymphoma 57: 2855-2862, 2016.

Su L, Zhao C, Jin Y, Lei Y, Lu L, Chen G. Association between parental occupational exposure to extremely low frequency magnetic fields and childhood nervous system tumors risk: A meta-analysis. Sci Total Environ 642: 1406-1414, 2018.

Sudan M, Arah OA, Becker T, Levy Y, Sigsgaard T, Olsen J, Vergara X, Kheifets L. Re-examining the association between residential exposure to magnetic fields from power lines and childhood asthma in the Danish National Birth Cohort. PLoS One 12: e0177651, 2017.

Swanson J, Bunch KJ, Vincent TJ, Murphy MF. Childhood cancer and exposure to corona ions from power lines: an epidemiological test. J Radiol Prot 34: 873-889, 2014.

Swanson J and Bunch KJ. Reanalysis of risks of childhood leukaemia with distance from overhead power lines in the UK. J Radiol Prot 38: N30-N35, 2018.

Swedish Radiation Protection Authority (SSI). Fourth annual report from SSI's Independent Expert Group on Electromagnetic Fields, 2006: Recent Research on EMF and Health Risks. SSI Rapport 2007:04. Stockholm, Sweden: Swedish Radiation Protection Authority, 2007.

Swedish Radiation Protection Authority (SSI). Fifth annual report from SSI's Independent Expert Group on Electromagnetic Fields, 2007. SSI Rapport 2008:12. Stockholm, Sweden: Swedish Radiation Protection Authority, 2008.

Swedish Radiation Safety Authority (SSM). Research 2013:19. Eighth Report from SSM:s Scientific Council on Electromagnetic Fields. Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2013.

Swedish Radiation Safety Authority (SSM). Research 2014:16. Recent Research on EMF and Health Risk. Ninth report from SSM's Scientific Council on Electromagnetic Fields. Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2014.

Swedish Radiation Safety Authority (SSM). Research 2015:19. Recent Research on EMF and Health Risk - Tenth report from SSM's Scientific Council on Electromagnetic Fields. Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2015.

Swedish Radiation Safety Authority (SSM). Research 2016:15. Recent Research on EMF and Health Risk - Eleventh report from SSM's Scientific Council on Electromagnetic Fields, 2016. Including Thirteen years of electromagnetic field research

monitored by SSM's Scientific Council on EMF and health: How has the evidence changed over time? Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2016.

Swedish Radiation Safety Authority (SSM). Research 2018:09. Recent Research on EMF and Health Risk - Twelfth report from SSM's Scientific Council on Electromagnetic Fields, 2017. . Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2018.

Tabrizi MM and Bidgoli SA. Increased risk of childhood acute lymphoblastic leukemia (ALL) by prenatal and postnatal exposure to high voltage power lines: a case control study in Isfahan, Iran. Asian Pac J Cancer Prev 16: 2347-2350, 2015.

Tabrizi MM and Hosseini SA. Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase--a Case Control Study in Tehran, Iran. Asian Pac J Cancer Prev 16: 7613-7618, 2015.

Talibov M, Guxens M, Pukkala E, Huss A, Kromhout H, Slottje P, Martinsen JI, Kjaerheim K, Sparen P, Weiderpass E, Tryggvadottir L, Uuksulainen S, Vermeulen R. Occupational exposure to extremely low-frequency magnetic fields and electrical shocks and acute myeloid leukemia in four Nordic countries. Cancer Causes Control 26: 1079-1085, 2015.

Thomas DC. Re: Kheifets et al. (2017): Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California. Cancer Causes Control 2018 [epub ahead of print].

Tiwari R, Lakshmi NK, Bhargava SC, Ahuja YR. Epinephrine, DNA integrity and oxidative stress in workers exposed to extremely low-frequency electromagnetic fields (ELF-EMFs) at 132 kV substations. Electromagn Biol Med 34: 56-62, 2015.

Turner MC, Benke G, Bowman JD, Figuerola J, Fleming S, Hours M, Kincl L, Krewski D, McLean D, Parent ME, Richardson L, Sadetzki S, Schlaefer K, Schlehofer B, Schüz J, Siemiatycki J, Van Tongeren M, Cardis E. Occupational exposure to extremely low frequency magnetic fields and brain tumour risks in the INTEROCC study. Cancer Epidemiol Biomarkers Prev 23: 1863-1872, 2014.

Turner MC, Benke G, Bowman JD, Figuerola J, Fleming S, Hours M, Kincl L, Krewski D, McLean D, Parent ME, Richardson L, Sadetzki S, Schlaefer K, Schlehofer B, Schüz J, Siemiatycki J, Tongeren MV, Cardis E. Interactions between occupational exposure to extremely low frequency magnetic fields and chemicals for brain tumour risk in the INTEROCC study. Occup Environ Med 74: 802-809, 2017.

US Department of Health and Human Services (HHS). Health Consequences of Smoking: A Report to the Surgeon General. Washington, DC: US Department of Health and Human Services, 2004.

US Department of Health Education and Welfare (HEW). Smoking and Health: Report of the Advisory Committee to the Surgeon General of the Public Health Service. PHS Publication No. 1103. Washington, DC: US Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, 1964.

US Environmental Protection Agency (USEPA). Reference Dose (RfD): Description and Use in Health Risk Assessments. Washington, DC: USEPA, 1993.

US Environmental Protection Agency (USEPA). Proposed Guidelines for Carcinogen Risk Assessments. EPA/600/P-92/003C. Washington, DC: USEPA, 1996.

US Environmental Protection Agency (USEPA). Update on Ramazzini Institute Data in IRIS Assessments. https://www.epa.gov/iris/update-ramazzini-institute-data-iris-assessments. Last updated June 14, 2017.

van der Mark M, Vermeulen R, Nijssen PC, Mulleners WM, Sas AM, van Laar T, Kromhout H, Huss A. Extremely low-frequency magnetic field exposure, electrical shocks and risk of Parkinson's disease. Int Arch Occup Environ Health 88:227-234, 2014.

Vergara X, Kheifets L, Greenland S, Oksuzyan S, Cho YS, Mezei G. Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: a meta-analysis. J Occup Environ Med 55: 135-146, 2013.

Vergara X, Mezei G, Kheifets L. Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991-1999. J Expo Sci Environ Epidemiol 25: 65-71, 2015.

Villarini M, Dominici L, Fatigoni C, Levorato S, Vannini S, Monarca S, Moretti M. Primary DNA damage in welders occupationally exposed to extremely-low-frequency magnetic fields (ELF-MF). Ann Ig 27: 511-519, 2015.

Vinceti M, Malagoli C, Fabbi S, Kheifets L, Violi F, Poli M, Caldara S, Sesti D, Violanti S, Zanichelli P, Notari B, Fava R, Arena A, Calzolari R, Filippini T, Iacuzio L, Arcolin E, Mandrioli J, Fini N, Odone A, Signorelli C, Patti F, Zappia M, Pietrini V, Oleari P, Teggi S, Ghermandi G, Dimartino A, Ledda C, Mauceri C, Sciacca S, Fiore M, Ferrante M. Magnetic fields exposure from high-voltage power lines and risk of amyotrophic lateral sclerosis in two Italian populations. Amyotroph Lateral Scler Frontotemporal Degener 18: 583-589, 2017.

Wang X, Zhao K, Wang D, Adams W, Fu Y, Sun H, Liu X, Yu H, Ma Y. Effects of exposure to a 50 Hz sinusoidal magnetic field during the early adolescent period on spatial memory in mice. Bioelectromagnetics 34: 275-84, 2013.

Wilson JW, Haines J, Sienkiewicz Z, Dubrova YE. The effects of extremely low frequency magnetic fields on mutation induction in mice. Mutat Res 773: 22-26, 2015.

Woodbine L, Haines J, Coster M, Barazzuol L, Ainsbury E, Sienkiewicz Z, Jeggo P. The rate of X-ray-induced DNA double-strand break repair in the embryonic mouse brain is unaffected by exposure to 50 Hz magnetic fields. Int J Radiat Biol 91: 495-499, 2015.

World Health Organization (WHO). International Programme on Chemical Safety (IPCS). Environmental Health Criteria 170 Assessing Human Health Risks of Chemicals: Derivation of Guidance Values for Health-based Exposure Limits. Geneva, Switzerland: World Health Organization, 1994.

World Health Organization (WHO). Framework for Developing Health-Based Standards. Geneva, Switzerland: World Health Organization: World Health Organization, 2006.

World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. Geneva, Switzerland: World Health Organization, 2007.

Yasui M, Kikuchi T, Ogawa M, Otaka Y, Tsuchitani M, Iwata H. Carcinogenicity test of 50 H sinusoidal magnetic fields in rats. Leuk Lymphoma 49: 531-540, 1997.

Yu Y, Su FC, Callaghan BC, Goutman SA, Batterman SA, Feldman EL. Environmental risk factors and amyotrophic lateral sclerosis (ALS): a case-control study of ALS in Michigan. PLoS One 9: e101186, 2014.

Zaffanella LE. Survey of Residential Magnetic Field Sources. Volume 2: Protocol, Data Analysis, and Management. EPRI TR-102759-V2. Palo Alto, CA: EPRI, 1993.

Zaffanella LE and Kalton GW. Survey of Personal Magnetic Field Exposure Phase II: 1,000 Person Survey. EMF Rapid Program, Engineering Project #6. Lee, Massachusetts: Enertech Consultants, 1998.

Zhang Y, Lai J, Ruan G, Chen C, Wang DW. Meta-analysis of extremely low frequency electromagnetic fields and cancer risk: a pooled analysis of epidemiologic studies. Environ Int 88: 36-43, 2016.

Zhou H, Chen G, Chen C, Yu Y, Xu Z. Association between extremely low-frequency electromagnetic fields occupations and amyotrophic lateral sclerosis: a meta-analysis. PLoS One 7: e48354, 2012.

APPENDIX C AGENCY CORRESPONDENCE

U.S. FISH AND WILDLIFE SERVICE: IPAC OFFICIAL SPECIES LIST; NOVEMBER 19, 2020

United States Department of the Interior

FISH AND WILDLIFE SERVICE
New England Ecological Services Field Office
70 Commercial Street, Suite 300
Concord, NH 03301-5094
Phone: (603) 223-2541 Fax: (603) 223-0104
http://www.fws.gov/newengland

In Reply Refer To: November 19, 2020
Consultation Code: 05E1NE00-2021-SLI-0492
Event Code: 05E1NE00-2021-E-01479
Project Name: J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project

Subject: List of threatened and endangered species that may occur in your proposed project location, and/or may be affected by your proposed project

To Whom It May Concern:

The enclosed species list identifies threatened, endangered, proposed and candidate species, as well as proposed and final designated critical habitat, that may occur within the boundary of your proposed project and/or may be affected by your proposed project. The species list fulfills the requirements of the U.S. Fish and Wildlife Service (Service) under section 7(c) of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 *et seq.*).

New information based on updated surveys, changes in the abundance and distribution of species, changed habitat conditions, or other factors could change this list. Please feel free to contact us if you need more current information or assistance regarding the potential impacts to federally proposed, listed, and candidate species and federally designated and proposed critical habitat. Please note that under 50 CFR 402.12(e) of the regulations implementing section 7 of the Act, the accuracy of this species list should be verified after 90 days. This verification can be completed formally or informally as desired. The Service recommends that verification be completed by visiting the ECOS-IPaC website at regular intervals during project planning and implementation for updates to species lists and information. An updated list may be requested through the ECOS-IPaC system by completing the same process used to receive the enclosed list.

The purpose of the Act is to provide a means whereby threatened and endangered species and the ecosystems upon which they depend may be conserved. Under sections 7(a)(1) and 7(a)(2) of the Act and its implementing regulations (50 CFR 402 *et seq.*), Federal agencies are required to utilize their authorities to carry out programs for the conservation of threatened and endangered species and to determine whether projects may affect threatened and endangered species and/or designated critical habitat.

A Biological Assessment is required for construction projects (or other undertakings having similar physical impacts) that are major Federal actions significantly affecting the quality of the human environment as defined in the National Environmental Policy Act (42 U.S.C. 4332(2)(c)). For projects other than major construction activities, the Service suggests that a biological evaluation similar to a Biological Assessment be prepared to determine whether the project may affect listed or proposed species and/or designated or proposed critical habitat. Recommended contents of a Biological Assessment are described at 50 CFR 402.12.

If a Federal agency determines, based on the Biological Assessment or biological evaluation, that listed species and/or designated critical habitat may be affected by the proposed project, the agency is required to consult with the Service pursuant to 50 CFR 402. In addition, the Service recommends that candidate species, proposed species and proposed critical habitat be addressed within the consultation. More information on the regulations and procedures for section 7 consultation, including the role of permit or license applicants, can be found in the "Endangered Species Consultation Handbook" at:

http://www.fws.gov/endangered/esa-library/pdf/TOC-GLOS.PDF

Please be aware that bald and golden eagles are protected under the Bald and Golden Eagle Protection Act (16 U.S.C. 668 *et seq.*), and projects affecting these species may require development of an eagle conservation plan (http://www.fws.gov/windenergy/eagle_guidance.html). Additionally, wind energy projects should follow the wind energy guidelines (http://www.fws.gov/windenergy/) for minimizing impacts to migratory birds and bats.

Guidance for minimizing impacts to migratory birds for projects including communications towers (e.g., cellular, digital television, radio, and emergency broadcast) can be found at: http://www.fws.gov/migratorybirds/CurrentBirdIssues/Hazards/towers/towers.htm; http://www.towerkill.com; and http://www.fws.gov/migratorybirds/CurrentBirdIssues/Hazards/towers/comtow.html.

We appreciate your concern for threatened and endangered species. The Service encourages Federal agencies to include conservation of threatened and endangered species into their project planning to further the purposes of the Act. Please include the Consultation Tracking Number in the header of this letter with any request for consultation or correspondence about your project that you submit to our office.

Attachment(s):

- Official Species List

Official Species List

This list is provided pursuant to Section 7 of the Endangered Species Act, and fulfills the requirement for Federal agencies to "request of the Secretary of the Interior information whether any species which is listed or proposed to be listed may be present in the area of a proposed action".

This species list is provided by:

New England Ecological Services Field Office
70 Commercial Street, Suite 300
Concord, NH 03301-5094
(603) 223-2541

Project Summary

Consultation Code: 05E1NE00-2021-SLI-0492

Event Code: 05E1NE00-2021-E-01479

Project Name: J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project

Project Type: TRANSMISSION LINE

Project Description: The Narragansett Electric Company d/b/a National Grid (TNEC) is proposing a thermal upgrade of the existing J16S transmission line (J16S Line) and the reconductoring of the R9 transmission line (R9 Line). The J16S Line is 1.7 miles long and originates at Staples Substation and terminates at the Highland Park Substation, both in Cumberland, Rhode Island. The R9 Line is 10.4 miles long and runs between Riverside Substation in Woonsocket through the towns of Cumberland and North Attleboro, Massachusetts, and terminates at Valley Street Substation in Cumberland. The two lines share Structures from 143A through 130 in Cumberland. TNEC is proposing to reconductor five spans of the J16S Line between Structures 130 and 135 and three spans of the R9 Line between Structures 130 to 133 for a total of 3,242 feet (0.61 miles) (Figure 1). The need for this Project is driven by contingencies identified which could lead to thermal overloads on the J16S and R9 Lines. There is proposed minimal tree-clearing and vegetation removal in certain areas within the existing right-of-way (ROW) for accessibility to existing structures and to create a safe work area, such as work pads, for personnel and equipment. Temporary construction matting may be used for access and work space in wetlands within the ROW.

Project Location:

Approximate location of the project can be viewed in Google Maps: https://www.google.com/maps/place/41.983870129168274N71.45080683838877W

Counties: Providence, RI

Endangered Species Act Species

There is a total of 1 threatened, endangered, or candidate species on this species list.

Species on this list should be considered in an effects analysis for your project and could include species that exist in another geographic area. For example, certain fish may appear on the species list because a project could affect downstream species.

IPaC does not display listed species or critical habitats under the sole jurisdiction of NOAA Fisheries[1], as USFWS does not have the authority to speak on behalf of NOAA and the Department of Commerce.

See the "Critical habitats" section below for those critical habitats that lie wholly or partially within your project area under this office's jurisdiction. Please contact the designated FWS office if you have questions.

---

1. NOAA Fisheries, also known as the National Marine Fisheries Service (NMFS), is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce.

Mammals

NAME	STATUS
Northern Long-eared Bat *Myotis septentrionalis* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/9045	Threatened

Critical habitats

THERE ARE NO CRITICAL HABITATS WITHIN YOUR PROJECT AREA UNDER THIS OFFICE'S JURISDICTION.

U.S. FISH AND WILDLIFE SERVICE: IPAC NORTHERN LONG-EARED BAT (NLEB) VERIFICATION LETTER; NOVEMBER 19, 2020 AND CORRESPONDENCE WITH RIDEM: NLEB MATERNITY ROOSTS AND HIBERNACULA, NOVEMBER 19, 2020

United States Department of the Interior

FISH AND WILDLIFE SERVICE
New England Ecological Services Field Office
70 Commercial Street, Suite 300
Concord, NH 03301-5094
Phone: (603) 223-2541 Fax: (603) 223-0104
http://www.fws.gov/newengland

In Reply Refer To: November 19, 2020
Consultation Code: 05E1NE00-2021-TA-0492
Event Code: 05E1NE00-2021-E-01483
Project Name: J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project

Subject: Verification letter for the 'J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project' project under the January 5, 2016, Programmatic Biological Opinion on Final 4(d) Rule for the Northern Long-eared Bat and Activities Excepted from Take Prohibitions.

Dear Devon Robinson:

The U.S. Fish and Wildlife Service (Service) received on November 19, 2020 your effects determination for the 'J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project' (the Action) using the northern long-eared bat (*Myotis septentrionalis*) key within the Information for Planning and Consultation (IPaC) system. This IPaC key assists users in determining whether a Federal action is consistent with the activities analyzed in the Service's January 5, 2016, Programmatic Biological Opinion (PBO). The PBO addresses activities excepted from "take"[1] prohibitions applicable to the northern long-eared bat under the Endangered Species Act of 1973 (ESA) (87 Stat.884, as amended; 16 U.S.C. 1531 et seq.).

Based upon your IPaC submission, the Action is consistent with activities analyzed in the PBO. The Action may affect the northern long-eared bat; however, any take that may occur as a result of the Action is not prohibited under the ESA Section 4(d) rule adopted for this species at 50 CFR §17.40(o). Unless the Service advises you within 30 days of the date of this letter that your IPaC-assisted determination was incorrect, this letter verifies that the PBO satisfies and concludes your responsibilities for this Action under ESA Section 7(a)(2) with respect to the northern long-eared bat.

Please report to our office any changes to the information about the Action that you submitted in IPaC, the results of any bat surveys conducted in the Action area, and any dead, injured, or sick northern long-eared bats that are found during Action implementation. If the Action is not completed within one year of the date of this letter, you must update and resubmit the information required in the IPaC key.

If the Action may affect other federally listed species besides the northern long-eared bat, a proposed species, and/or designated critical habitat, additional consultation between you and this Service office is required. If the Action may disturb bald or golden eagles, additional coordination with the Service under the Bald and Golden Eagle Protection Act is recommended.

---

[1]Take means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct [ESA Section 3(19)].

Action Description
You provided to IPaC the following name and description for the subject Action.

1. Name

J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project

2. Description

The following description was provided for the project 'J16S 115kV Transmission Line Thermal Upgrade and R9 Reconductoring Project':

> The Narragansett Electric Company d/b/a National Grid (TNEC) is proposing a thermal upgrade of the existing J16S transmission line (J16S Line) and the reconductoring of the R9 transmission line (R9 Line). The J16S Line is 1.7 miles long and originates at Staples Substation and terminates at the Highland Park Substation, both in Cumberland, Rhode Island. The R9 Line is 10.4 miles long and runs between Riverside Substation in Woonsocket through the towns of Cumberland and North Attleboro, Massachusetts, and terminates at Valley Street Substation in Cumberland. The two lines share Structures from 143A through 130 in Cumberland. TNEC is proposing to reconductor five spans of the J16S Line between Structures 130 and 135 and three spans of the R9 Line between Structures 130 to 133 for a total of 3,242 feet (0.61 miles) (Figure 1). The need for this Project is driven by contingencies identified which could lead to thermal overloads on the J16S and R9 Lines. There is proposed minimal tree-clearing and vegetation removal in certain areas within the existing right-of-way (ROW) for accessibility to existing structures and to create a safe work area, such as work pads, for personnel and equipment. Temporary construction matting may be used for access and work space in wetlands within the ROW.

Approximate location of the project can be viewed in Google Maps: https://www.google.com/maps/place/41.983870129168274N71.45080683838877W

Determination Key Result

This Federal Action may affect the northern long-eared bat in a manner consistent with the description of activities addressed by the Service's PBO dated January 5, 2016. Any taking that may occur incidental to this Action is not prohibited under the final 4(d) rule at 50 CFR §17.40(o). Therefore, the PBO satisfies your responsibilities for this Action under ESA Section 7(a)(2) relative to the northern long-eared bat.

Determination Key Description: Northern Long-eared Bat 4(d) Rule

This key was last updated in IPaC on May 15, 2017. Keys are subject to periodic revision.

This key is intended for actions that may affect the threatened northern long-eared bat.

The purpose of the key for Federal actions is to assist determinations as to whether proposed actions are consistent with those analyzed in the Service's PBO dated January 5, 2016.

Federal actions that may cause prohibited take of northern long-eared bats, affect ESA-listed species other than the northern long-eared bat, or affect any designated critical habitat, require ESA Section 7(a)(2) consultation in addition to the use of this key. Federal actions that may affect species proposed for listing or critical habitat proposed for designation may require a conference under ESA Section 7(a)(4).

Determination Key Result

This project may affect the threatened Northern long-eared bat; therefore, consultation with the Service pursuant to Section 7(a)(2) of the Endangered Species Act of 1973 (87 Stat.884, as amended; 16 U.S.C. 1531 et seq.) is required. However, based on the information you provided, this project may rely on the Service's January 5, 2016, *Programmatic Biological Opinion on Final 4(d) Rule for the Northern Long-Eared Bat and Activities Excepted from Take Prohibitions* to fulfill its Section 7(a)(2) consultation obligation.

Qualification Interview

1. Is the action authorized, funded, or being carried out by a Federal agency?

   Yes

2. Have you determined that the proposed action will have "no effect" on the northern long-eared bat? (If you are unsure select "No")

   No

3. Will your activity purposefully **Take** northern long-eared bats?

   No

4. [Semantic] Is the project action area located wholly outside the White-nose Syndrome Zone?

   Automatically answered
   No

5. Have you contacted the appropriate agency to determine if your project is near a known hibernaculum or maternity roost tree?

   Location information for northern long-eared bat hibernacula is generally kept in state Natural Heritage Inventory databases – the availability of this data varies state-by-state. Many states provide online access to their data, either directly by providing maps or by providing the opportunity to make a data request. In some cases, to protect those resources, access to the information may be limited. A web page with links to state Natural Heritage Inventory databases and other sources of information on the locations of northern long-eared bat roost trees and hibernacula is available at www.fws.gov/midwest/endangered/mammals/nleb/nhisites.html.

   Yes

6. Will the action affect a cave or mine where northern long-eared bats are known to hibernate (i.e., hibernaculum) or could it alter the entrance or the environment (physical or other alteration) of a hibernaculum?

   No

7. Will the action involve Tree Removal?

   Yes

8. Will the action only remove hazardous trees for the protection of human life or property?

   No

9. Will the action remove trees within 0.25 miles of a known northern long-eared bat hibernaculum at any time of year?

   No

10. Will the action remove a known occupied northern long-eared bat maternity roost tree or any trees within 150 feet of a known occupied maternity roost tree from June 1 through July 31?

    No

Project Questionnaire

If the project includes forest conversion, report the appropriate acreages below. Otherwise, type '0' in questions 1-3.

1. Estimated total acres of forest conversion:

0.05

2. If known, estimated acres of forest conversion from April 1 to October 31

0.05

3. If known, estimated acres of forest conversion from June 1 to July 31

0

If the project includes timber harvest, report the appropriate acreages below. Otherwise, type '0' in questions 4-6.

4. Estimated total acres of timber harvest

0

5. If known, estimated acres of timber harvest from April 1 to October 31

0

6. If known, estimated acres of timber harvest from June 1 to July 31

0

If the project includes prescribed fire, report the appropriate acreages below. Otherwise, type '0' in questions 7-9.

7. Estimated total acres of prescribed fire

0

8. If known, estimated acres of prescribed fire from April 1 to October 31

0

9. If known, estimated acres of prescribed fire from June 1 to July 31

0

If the project includes new wind turbines, report the megawatts of wind capacity below. Otherwise, type '0' in question 10.

10. What is the estimated wind capacity (in megawatts) of the new turbine(s)?

0

Halliwell, David

Subject: RE: [EXTERNAL] : Requesting Northern Long-Eared Bat Information - J16S Transmission Line Right-of-Way

From: Brown, Charles (DEM) <charles.brown@dem.ri.gov>
Sent: Thursday, November 19, 2020 1:47 PM
To: Robinson, Devon <devon.robinson@powereng.com>
Subject: RE: [EXTERNAL] : Requesting Northern Long-Eared Bat Information - J16S Transmission Line Right-of-Way

HI Devon,
I have reviewed the plan for the proposed project you describe below in Cumberland. There are no known northern long-eared bat maternity roost trees or hibernacula in or near the project area. If you have any questions please feel free to contact me.

Charlie Brown
Wildlife Biologist
R.I. Division of Fish and Wildlife
(401) 789-0281

From: devon.robinson@powereng.com <devon.robinson@powereng.com>
Sent: Thursday, November 19, 2020 12:46 PM
To: Brown, Charles (DEM) <charles.brown@dem.ri.gov>
Cc: david.halliwell@powereng.com; brittany.ryan@powereng.com
Subject: [EXTERNAL] : Requesting Northern Long-Eared Bat Information - J16S Transmission Line Right-of-Way

Mr. Brown,

I am contacting you to request some information on the Northern Long-Eared Bat (NLEB). I am working on a project for National Grid located in Cumberland, Rhode Island and I am looking to see if there are any known NLEB maternity roosts and/or hibernacula locations in the vicinity of the project. As part of the USFWS IPaC process, the appropriate agency needs to be contacted to verify that the project is not near a known NLEB hibernaculum or maternity roost. The project consists of work within an existing transmission line right-of-way which spans from Staples Road northwest to Highland Corporate Drive, please see the attached map. Could you please provide locations of any known NLEB hibernacula and/or maternity roosts that are within the project area or within ~5 miles of the project? Please let me know if you have any questions.

Thank you,
Devon

DEVON ROBINSON
ASSISTANT ENVIRONMENTAL SPECIALIST

(774) 643-1858
(774) 266-6186 Cell

POWER Engineers, Inc.
www.powereng.com [powereng.com]
Energy ▪ Facilities ▪ Communications ▪ Environmental
www.powereng.com [powereng.com]

Halliwell, David

From: Jordan, Paul (DEM) <paul.jordan@dem.ri.gov>
Sent: Thursday, November 19, 2020 2:26 PM
To: Lamothe, Meaghan
Cc: Halliwell, David; Ryan, Brittany
Subject: Re: [EXTERNAL] : Cumberland Rare Species Study Area

Meaghan,

Within the shapefile footprint:
(Large-spiked) Beak-rush, Horned-rush, state concern, 1986 observation

Within 1/4 mile:
Small-flowered Crowfoot, state endangered, 2014
(Horsetail) Spike-rush, state concern, 1985
Humped Bladderwort, state concern, 1985

Paul

Paul Jordan
Supervising GIS Specialist
RI Dept. Of Environmental Management
235 Promenade Street
Providence, RI 02908
(401) 222-2776 x4315
paul.jordan@dem.ri.gov

From: meaghan.lamothe@powereng.com <meaghan.lamothe@powereng.com>
Sent: Thursday, November 19, 2020 2:05 PM
To: Jordan, Paul (DEM) <paul.jordan@dem.ri.gov>
Cc: david.halliwell@powereng.com <david.halliwell@powereng.com>; brittany.ryan@powereng.com <brittany.ryan@powereng.com>
Subject: [EXTERNAL] : Cumberland Rare Species Study Area

Dear Mr. Jordan,

Attached please find a Rare Species Consultation Letter, a map, and a shapefile for your review. I am requesting a list of species in the vicinity of a proposed project in Cumberland.

If you have any questions please contact me at (208) 606-6027 or meaghan.lamothe@powereng.com.

Thank you very much. I greatly appreciate your assistance.

Meaghan

MEAGHAN LAMOTHE
BIOLOGIST

RIDEM: RARE SPECIES CONSULTATION LETTER, NOVEMBER 19, 2020

POWER ENGINEERS, INC.
2 HAMPSHIRE STREET
SUITE 301
FOXBOROUGH, MA 02035 USA
PHONE 774-643-1800
FAX 774-643-1899

November 19, 2020

Mr. Paul Jordan
Rhode Island Department of Environmental Management
Division of Planning and Development
235 Promenade Street
Providence, RI 02908-5767

Subject: The Narragansett Electric Company d/b/a National Grid Request for Rare, Threatened, and Endangered Species, and Natural Heritage Areas in Cumberland, RI

Dear Mr. Jordan:

The Narragansett Electric Company d/b/a National Grid (TNEC) is proposing a thermal upgrade of the existing J16S transmission line (J16S Line) and the reconductoring of the R9 transmission line (R9 Line). The J16S Line is 1.7 miles long and originates at Staples Substation and terminates at the Highland Park Substation, both in Cumberland, Rhode Island. The R9 Line is 10.4 miles long and runs between Riverside Substation in Woonsocket through the towns of Cumberland and North Attleboro, Massachusetts, and terminates at Valley Street Substation in Cumberland. The two lines share Structures from 143A through 130 in Cumberland. TNEC is proposing to reconductor five spans of the J16S Line between Structures 130 and 135 and three spans of the R9 Line between Structures 130 to 133 for a total of 3,242 feet (0.61 miles) (Figure 1). The need for this Project is driven by contingencies identified which could lead to thermal overloads on the J16S and R9 Lines.

All work will occur within the existing transmission line rights-of-way in Cumberland. Construction is tentatively scheduled to take approximately four months and commence in January 2022. We are seeking information from the Department of Environmental Management to assist with the planning phase of the project.

Request for Data on Rare, Threatened and Endangered Species, and Natural Heritage Areas
The attached map shows the area proposed for the thermal upgrade and the reconductoring of the transmission lines on United States Geological Survey (USGS) 7.5 minute series topographic mapping (Figure 1). POWER Engineers, Inc. has taken several steps to review the area by comparing online natural heritage data available from the RIGIS website. Since there is overlap between natural heritage data and the area, we are contacting your office for information on the listed species.

In addition, we are providing one shapefile of the project area data for your convenience. We are sending this information with the understanding that all rare species data will remain confidential and will not be distributed publicly. TNEC is seeking input from the RIDEM on any known Element Occurrences and Natural Heritage Areas; and relevant information regarding taxa of

conservation concern in the areas, State or Federally-listed Threatened or Endangered species, RI Species of Special Concern, and exemplary or critical natural habitat areas.
This request specifically addresses the requirement for documented consultation with regard to compliance with the Endangered Species Act ("ESA") of 1973 and Rhode Island Endangered Species Statues (R.I. Gen. Law §§ 20-37-1-5 (1977)).

If you have any questions or would like more information, please do not hesitate to contact me at (774) 643-1861 (david.halliwell@powereng.com), or Meaghan Lamothe at (208) 606-6027 (meaghan.lamothe@powereng.com).

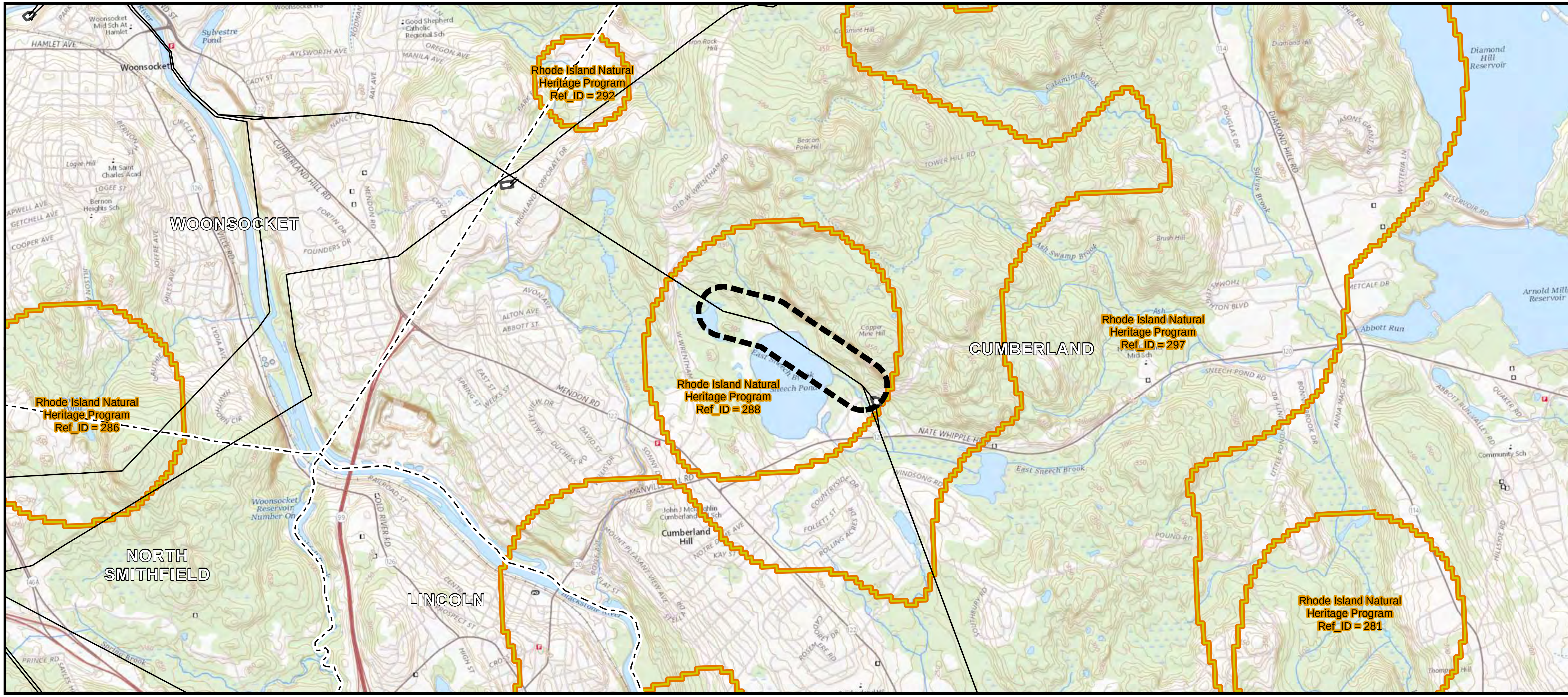
Sincerely,

David Halliwell
Project Manager
POWER Engineers, Inc.

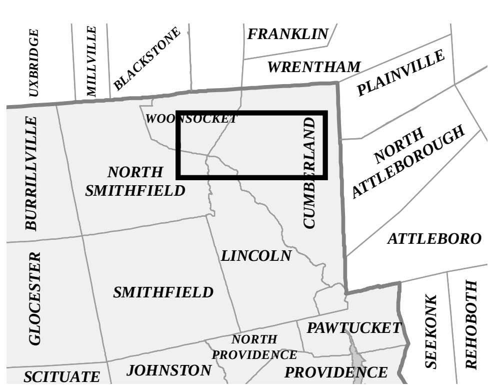
Enclosures:

1. J16S The Study Area – Figure 1 Natural Heritage Program Data
2. J16S_500foot_Buffer.zip

c: Kevin O'Brion, National Grid
Erin Whoriskey Cahill, National Grid
Brittany Ryan, POWER Engineers, Inc



Project Vicinity



Legend

- Study Area (500' Buffer)
- Transmission Line
- Existing Power Facility
- Town Boundary
- Rhode Island Natural Heritage Areas

The Study Area

Figure 1

Natural Heritage Program Data

Town of Cumberland

State of Rhode Island:
Providence County

NAD 1983 UTM Zone 18N USFt
Foot US
Transverse Mercator
North American 1983

N W E S

0 1,000 2,000 3,000 4,000 Feet

1 " = 2,000 '

NOT FOR CONSTRUCTION

Date: 9/8/2020

Author: TDH

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\U16S\U16S_Natural_Heritage_Data_Request.mxd

LETTER FROM RHODE ISLAND HISTORICAL PRESERVATION & HERITAGE COMISSON TO PAL, INC.; AUGUST 10, 2020.

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
HISTORICAL PRESERVATION & HERITAGE COMMISSION
Old State House • 150 Benefit Street • Providence, R.I. 02903-1209
TEL (401) 222-2678 FAX (401) 222-2968
TTY / Relay 711 Website www.preservation.ri.gov

10 August, 2020

Gregory Dubell
PAL Inc.
26 Main Street
Pawtucket RI 02860
(via email)

Re: National Grid – Line J16S Thermal Upgrade Project – Cumberland, Rhode Island
Cultural Resource Assessment
PAL #4002

Dear Mr. Dubell,

The RIHPHC concurs with PAL's conclusion that in as much as the proposed Line J16S Thermal Upgrade Project area is within an area where PAL has previously conducted archaeological and historic architectural properties surveys, with no significant cultural resources found, this project will have no effect on any significant cultural resources (listed in or eligible for listing in the National Register of Historic Places).

These comments are provided in accordance with Section 106 of the National Historic Preservation Act. If you have any questions, please contact Charlotte Taylor or Timothy Ives, archaeologists at this office.

Very truly yours,

J. Paul Loether
Executive Director
State Historic Preservation Officer

200810.01

LETTER TO RHODE ISLAND HISTORICAL PRESERVATION & HERITAGE COMISSON FROM PAL, INC.; JULY 28, 2020.

July 28, 2020

J. Paul Loether
Executive Director and State Historic Preservation Officer
Rhode Island Historical Preservation & Heritage Commission
150 Benefit Street
Providence, Rhode Island 02903

Re: National Grid – Line J16S Thermal Upgrade Project – Cumberland, Rhode Island
Cultural Resource Assessment
PAL #4002

Dear Mr. Loether:

The Narragansett Electric Company d/b/a National Grid is planning thermal upgrades at existing structures along the existing Line J16S 115kV Transmission Line (Line J16S or Project) located in Cumberland, Rhode Island. The Project includes overhead wirework between Structure Nos. 130 and 135, including the replacement of Structure 133. National Grid proposes to install work pads/wire pulling stations and will use existing access roads to construct the Project along this segment of right-of-way (ROW) (see enclosed Project mapping). The Project requires the use of temporary construction matting in Waters of the U.S. (WOTUS) for access and will require permitting under the U.S. Army Corps of Engineers (USACE), therefore the Project is subject to Section 106 of the National Historic Preservation Act of 1966, as amended.

National Grid has contracted The Public Archaeology Laboratory, Inc. (PAL) to address the Section 106 obligations of the USACE and seek the comments of the Rhode Island Historical Preservation & Heritage Commission (RIHPHC). PAL staff conducted background research and a desktop review of the Project workspace. Background research involved a review of cultural resources reports, correspondence, and previously-recorded archaeological sites on file at the RIHPHC and PAL.

The proposed Project area is within ½ mile of two (2) pre-contact archaeological sites (RI-0866 and RI-2728) and one (1) aboveground historic architectural resource (the West Wrentham Road Historic District) (see enclosed due diligence map). In 2017, PAL conducted a cultural resource due diligence and archaeological sensitivity assessment as well as a Phase I archaeological survey for the Line R9 Reconductoring Project (PAL #3251); the investigations resulted in the identification of the Sneech Pond Site (RI-2728), a pre-contact archaeological site consisting of a temporary campsite within truncated B-horizon subsoils overlain by redeposited A/B soils and fill deposits. PAL recommended that the site lacked complexity and integrity and was not eligible for listing in the National Register of Historic Places.

The remainder of the Project ROW was assessed as having low/no archaeological sensitivity based on the presence of inundated soils within a delineated wetland complex, steep slope, and/or exposed rock and ledge. The RIHPHC concurred with PAL's recommendations for the Line R9/J16S Reconductoring report in letters dated October 2 and 19, 2018 (see copies enclosed). Therefore, since the proposed Line J16S Thermal Upgrade Project area is within areas that PAL has previously conducted archaeological and historic architectural properties surveys, PAL recommends that no historic properties will be affected by this undertaking. With this letter, we are requesting the RIHPHC's concurrence with this recommendation.

PAL is providing the enclosed Project and due diligence mapping to the Narragansett Tribe for their concurrent review, pursuant to the requirements of the USACE Rhode Island General Permit. If you have any questions or require additional information, please do not hesitate to contact Deborah C. Cox, President, or me, at your convenience.

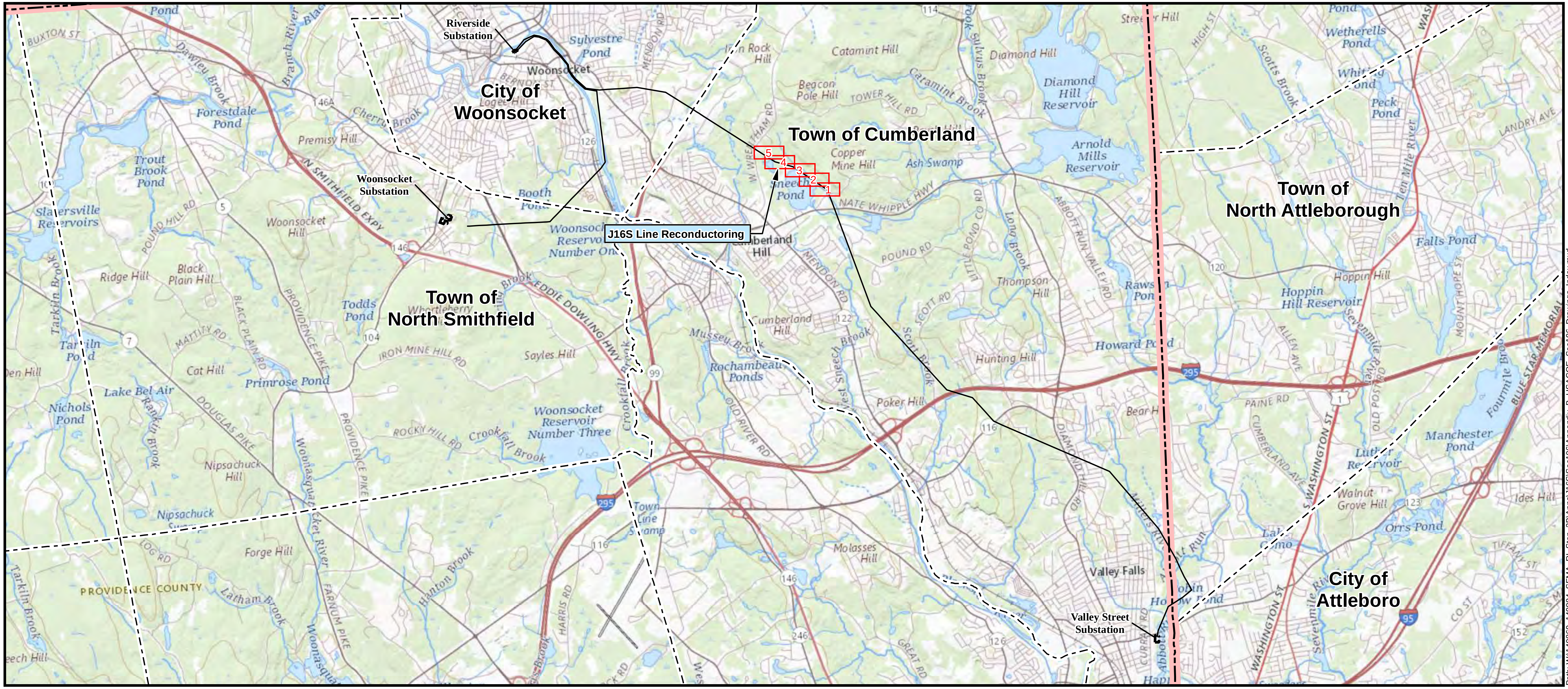
Sincerely,

Gregory R. Dubell

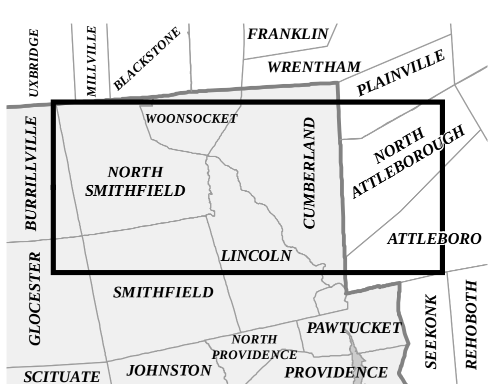
Gregory R. Dubell, RPA
Energy Projects Manager

Enclosures

cc: Erin Whoriskey, National Grid (w/encl. – via email)
Kevin O'Brion, National Grid (w/encl. – via email)
David Halliwell, POWER Engineers, Inc. (w/encl. – via email)
Michael S. Wierbonics, USACE (w/encl. – via email)
John Brown, III, Narragansett Indian Tribe (w/encl.)
John Brown, IV, Narragansett Indian Tribe (w/encl. – via email)



Project Vicinity



Legend

- Project Transmission Line
- Existing Substation
- State Boundary
- Town Boundary

J16S Reconductoring Project

Appendix B Section 106 Permit Drawings

Index Map

State of Rhode Island and Commonwealth of Massachusetts

Providence and Bristol Counties:
City of Woonsocket,Towns of Cumberland and North Attleborough

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 1 2 Miles

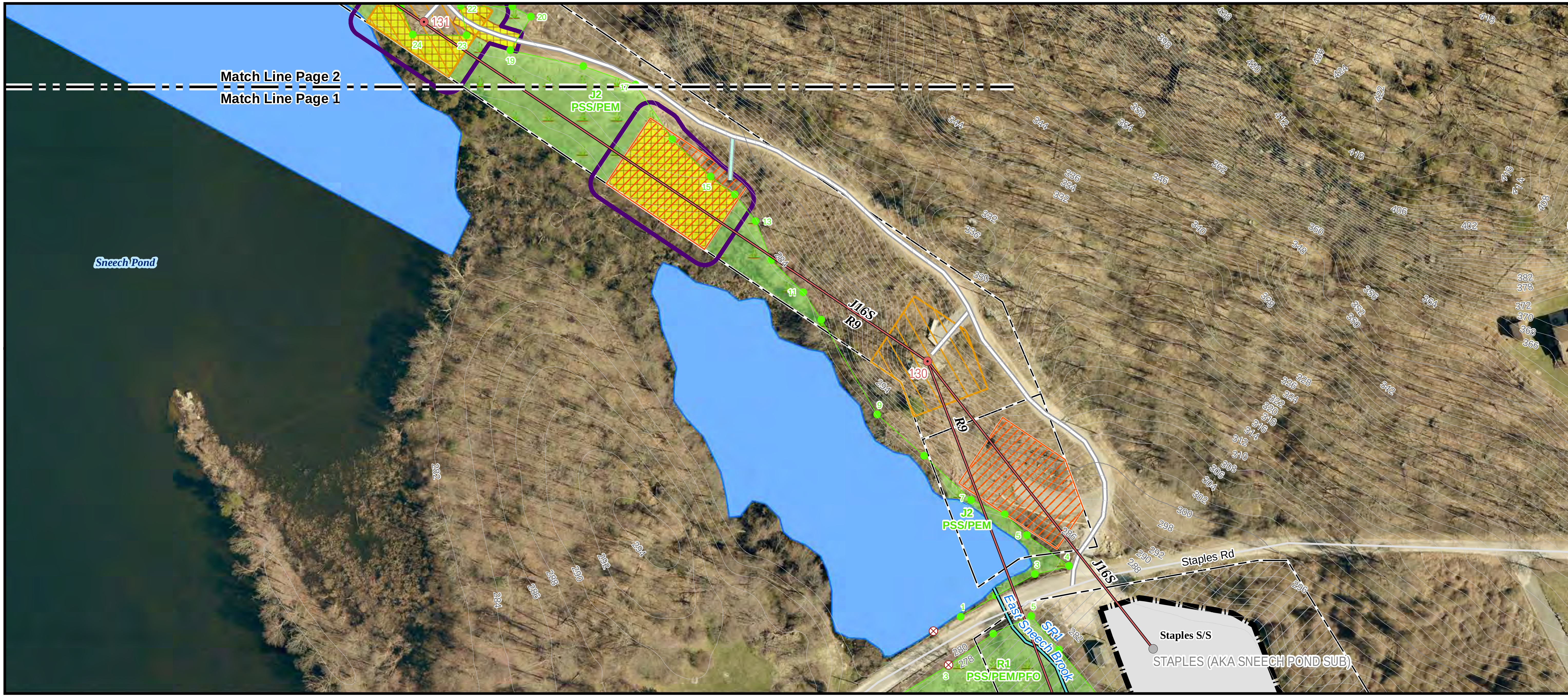
1 " = 5,280 '

nationalgrid

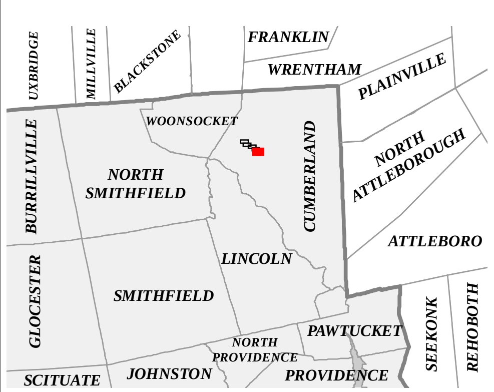
NOT FOR CONSTRUCTION

Date: 6/16/2020

Author: TDH



Project Vicinity



Legend

- Existing Structure
- Substation Bus
- Use Existing Access Road
- Construct New Access Road
- Section 106 Permit Area
- Wire Pulling Station
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Transmission Line
- Existing Substation
- Existing Right of Way
- National Grid Owned Lands (RI)
- Local Road
- Culvert
- Perennial Stream or River
- Wetland Border
- Delineated Open Water
- Wetland Flag
- Field Delineated Wetland
- Index Contour (100' Interval)
- Index Contour (50' Interval)
- Contour (2' Interval)

J16S Reconductoring Project

Appendix B Section 106 Permit Drawings

Page 1 of 5

DRAFT

State of Rhode Island

Providencel County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 100 200 Feet

1 " = 100 '

nationalgrid

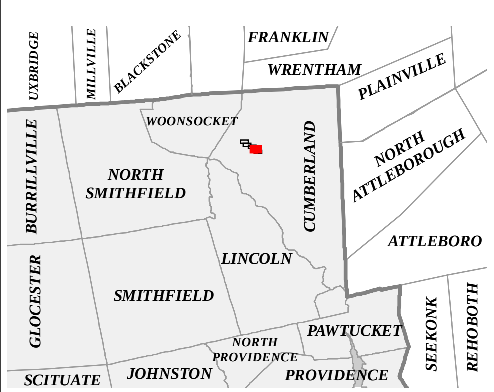
NOT FOR CONSTRUCTION

Date: 6/16/2020

Author: TDH

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\Sec106\Appendix_B_USACOE_Sec106_Drawings.mxd

Project Vicinity



Legend

- Existing Structure
- Use Existing Access Road
- Construct New Access Road
- Section 106 Permit Area
- Wire Pulling Station
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Transmission Line
- Existing Right of Way
- Wetland Border
- Delineated Open Water
- Wetland Flag
- Field Delineated Wetland
- Index Contour (100' Interval)
- Index Contour (50' Interval)
- Contour (2' Interval)

J16S Reconductoring Project

Appendix B Section 106 Permit Drawings

Page 2 of 5

DRAFT

State of Rhode Island

Providencel County: Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 100 200 Feet

1 " = 100 '

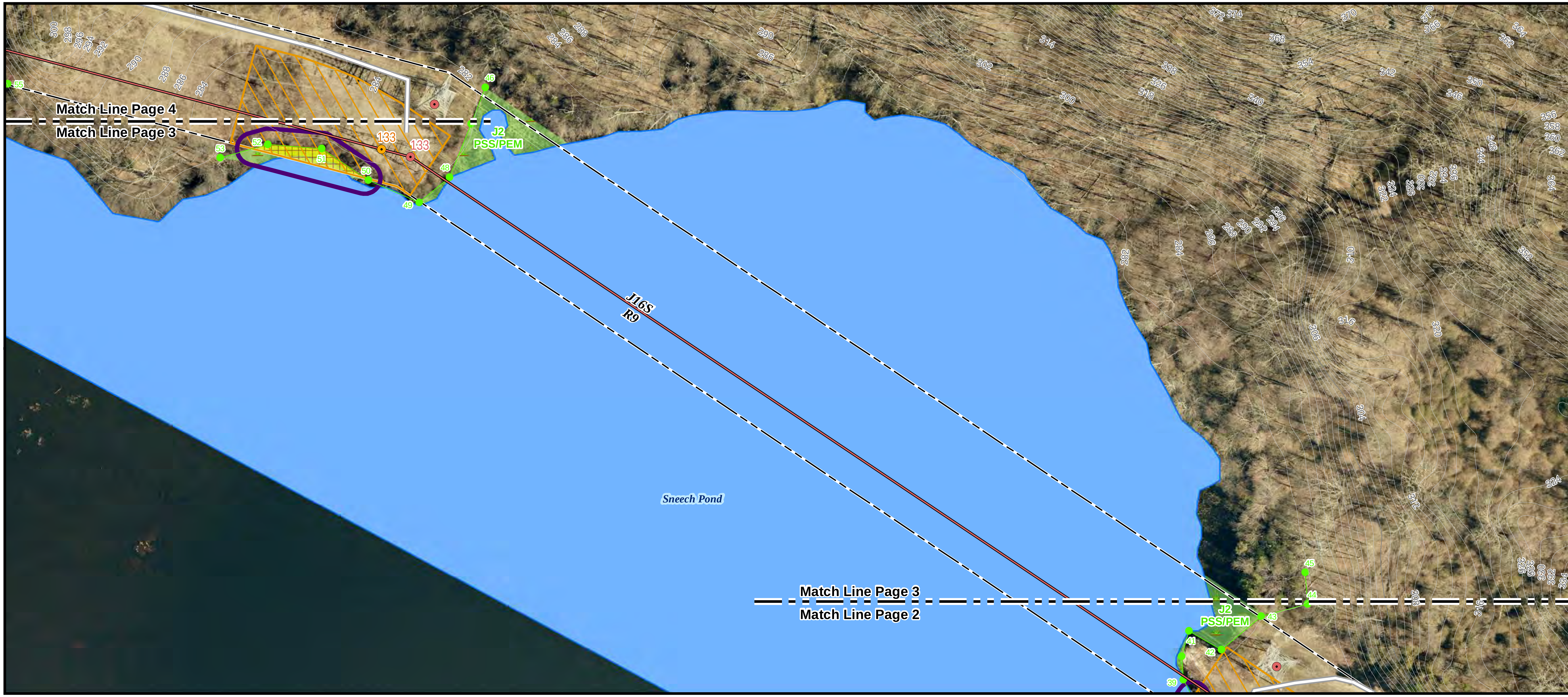
nationalgrid

NOT FOR CONSTRUCTION

Date: 6/16/2020

Author: TDH

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\Sec106\Appendix_B_USACOE_Sec106_Drawings.mxd



Project Vicinity

Legend

- Replacement Structure
- Existing Structure
- Use Existing Access Road
- Section 106 Permit Area
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Transmission Line
- Existing Right of Way
- Wetland Border
- Delineated Open Water
- Wetland Flag
- Field Delineated Wetland
- Index Contour (100' Interval)
- Index Contour (50' Interval)
- Contour (2' Interval)

J16S Reconductoring Project

Appendix B Section 106 Permit Drawings

Page 3 of 5

DRAFT

State of Rhode Island

Providencel County:
Town of Cumberland

POWER ENGINEERS

N W E S

nationalgrid

NAD 1983 UTM Zone 18N USFt

NOT FOR CONSTRUCTION

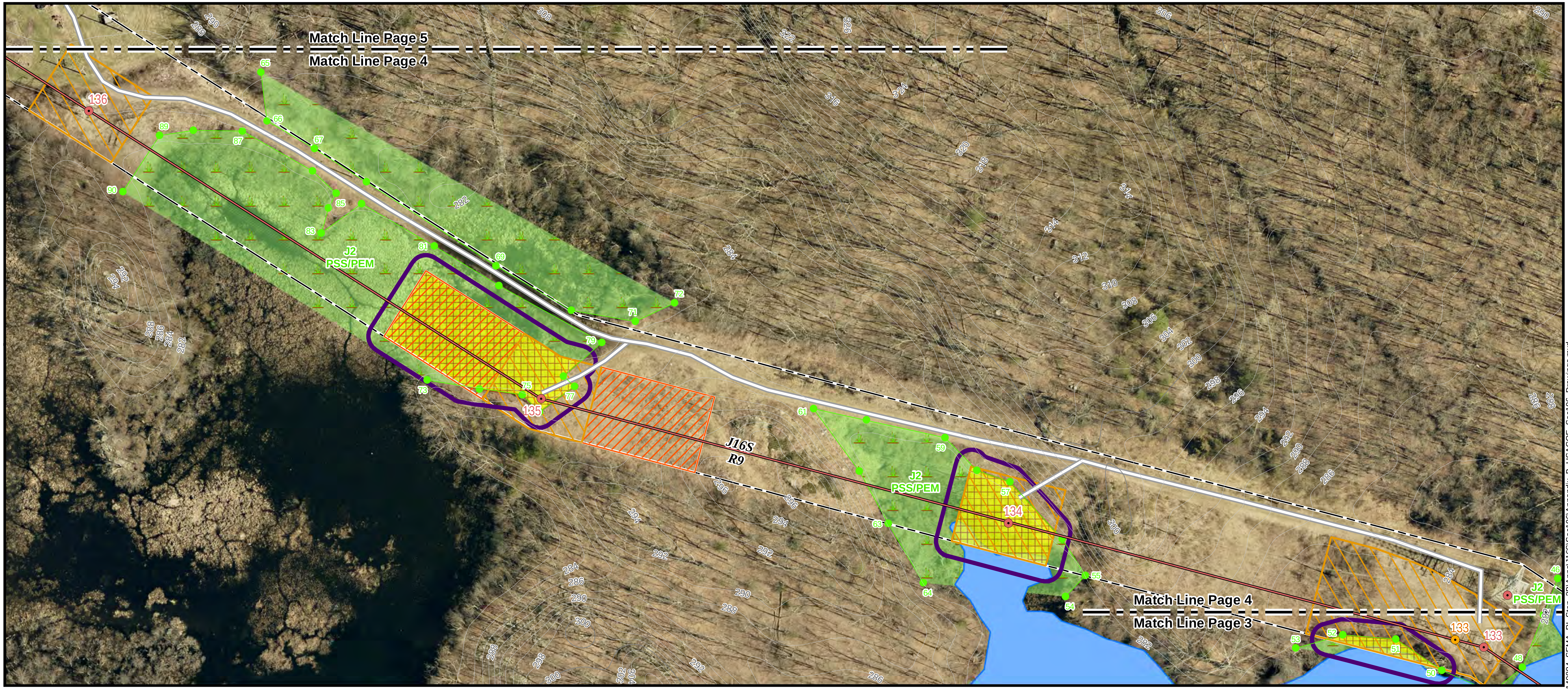
0 100 200 Feet

1 " = 100 '

Date: 6/16/2020

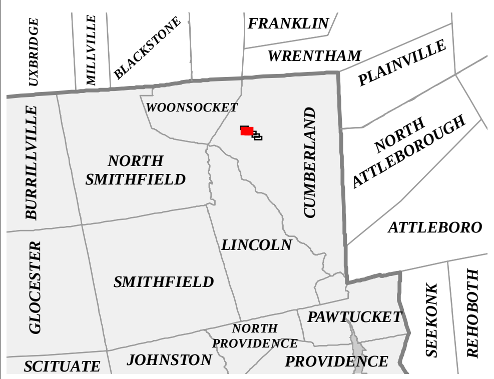
Author: TDH

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\Sec106\Appendix_B_USACOE_Sec106_Drawings.mxd



Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\Sec106\Appendix_B_USACOE_Sec106_Drawings.mxd

Project Vicinity



Legend

- Replacement Structure
- Existing Structure
- Use Existing Access Road
- Section 106 Permit Area
- Wire Pulling Station
- Work Pad / Area
- Swamp Mat (Access or Construction)
- Existing Transmission Line
- Existing Right of Way
- Wetland Border
- Delineated Open Water
- Wetland Flag
- Field Delineated Wetland
- Index Contour (100' Interval)
- Contour (2' Interval)

J16S Reconductoring Project

Appendix B Section 106 Permit Drawings

Page 4 of 5

DRAFT

State of Rhode Island

Providencel County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 100 200 Feet

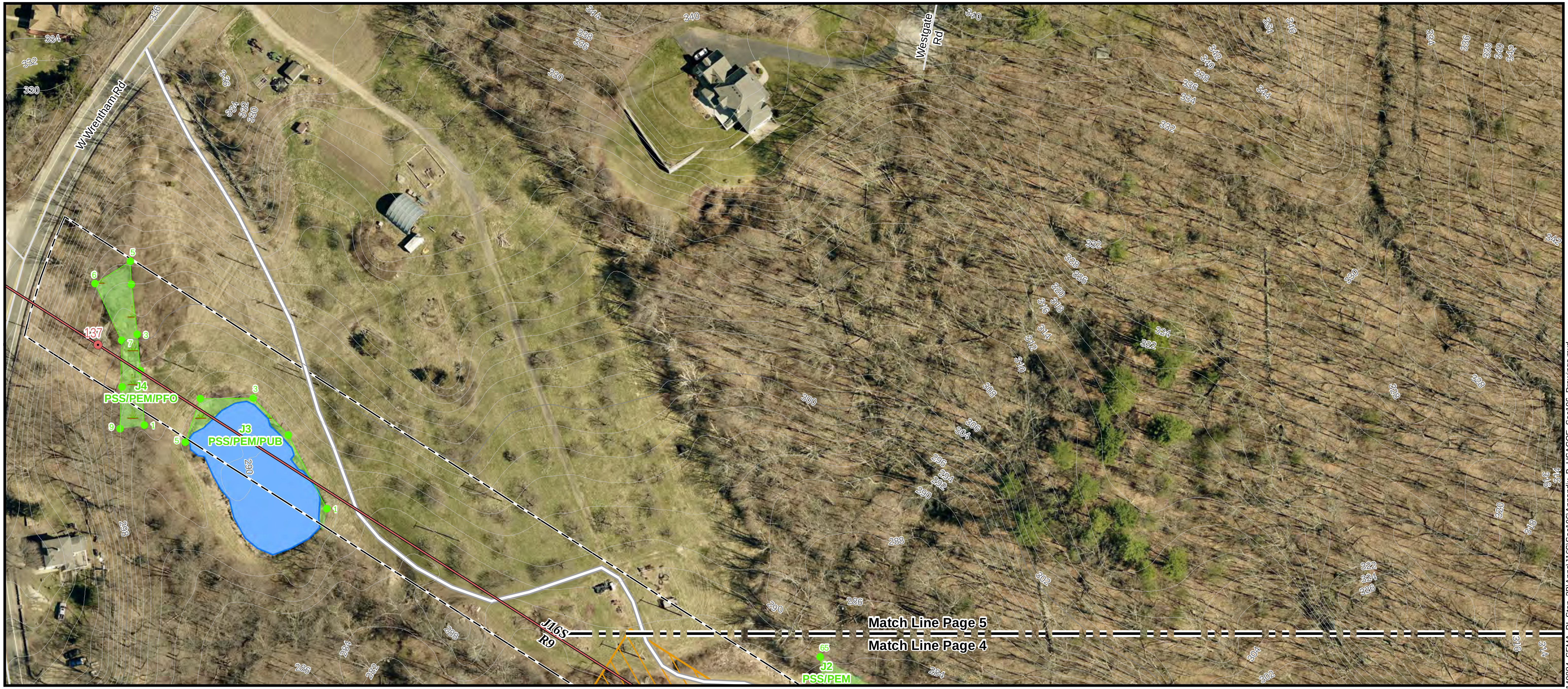
1 " = 100 '

nationalgrid

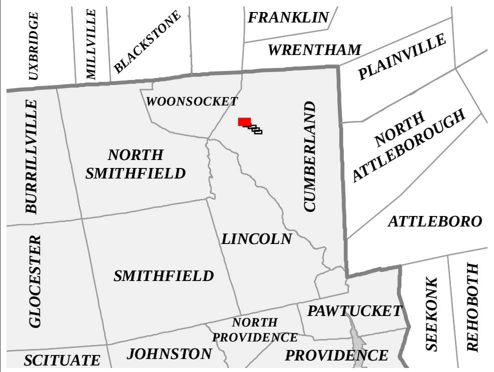
NOT FOR CONSTRUCTION

Date: 6/16/2020

Author: TDH



Project Vicinity



Legend

- Existing Structure
- Use Existing Access Road
- Work Pad / Area
- Existing Transmission Line
- Existing Right of Way
- Local Road
- Wetland Border
- Delineated Open Water
- Wetland Flag
- Field Delineated Wetland
- Index Contour (100' Interval)
- Index Contour (50' Interval)
- Contour (2' Interval)

J16S Reconductoring Project

Appendix B Section 106 Permit Drawings

DRAFT

State of Rhode Island

Providencel County:
Town of Cumberland

POWER ENGINEERS

NAD 1983 UTM Zone 18N USFt

N W E S

0 100 200 Feet

1 " = 100 '

nationalgrid

NOT FOR CONSTRUCTION

Date: 6/16/2020

Author: TDH

Path: W:\140869_140884_SEMA_RI_Step_2B\Apps\J16S\Sec106\Appendix_B_USACOE_Sec106_Drawings.mxd

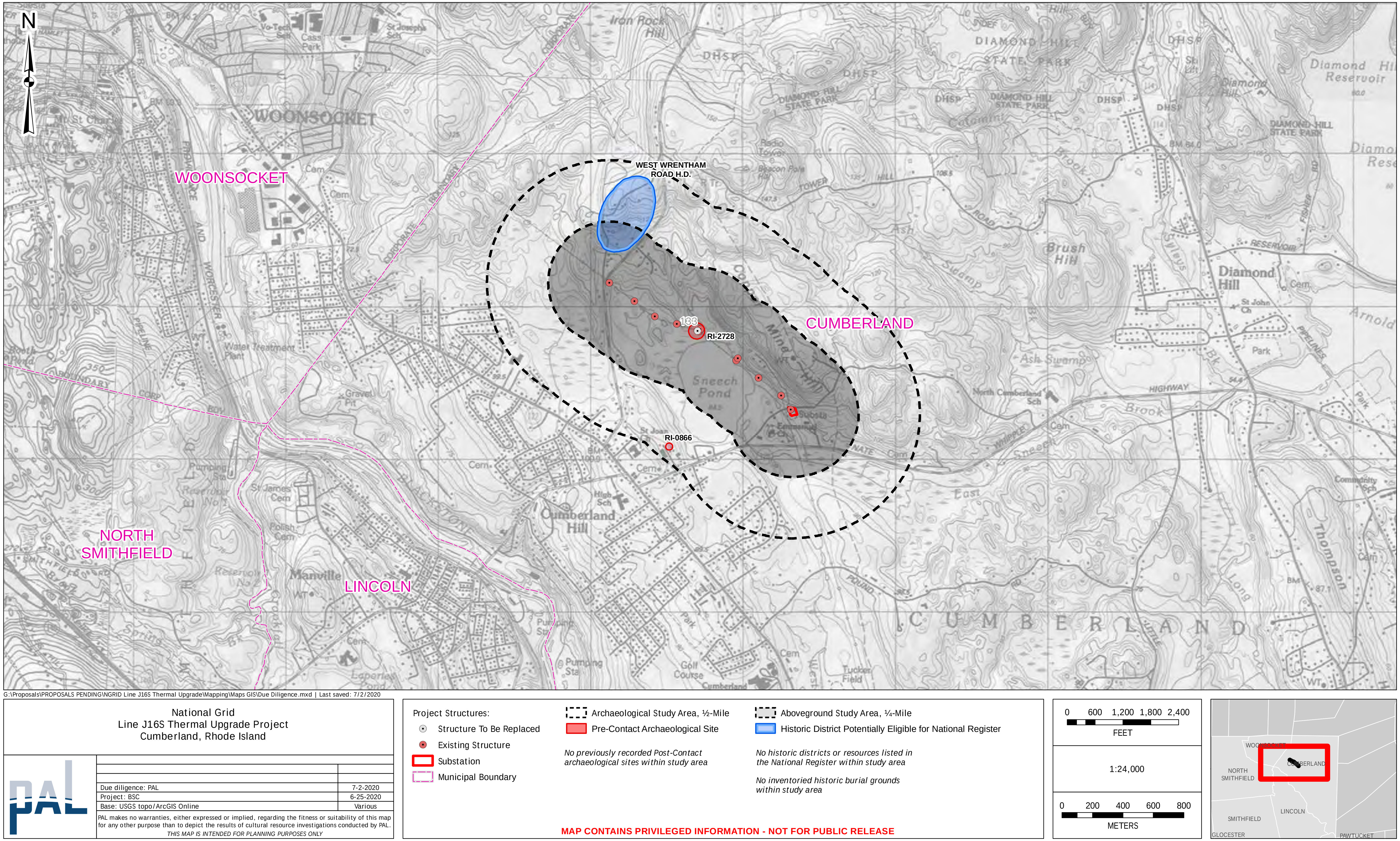


Figure 2. Recorded archaeological sites within a half-mile and inventoried or listed aboveground resources within a quarter-mile of the National Grid Line J16S Thermal Upgrade Project on the Pawtucket USGS topographic quadrangle, 7.5 minute series.

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
HISTORICAL PRESERVATION & HERITAGE COMMISSION
Old State House • 150 Benefit Street • Providence, R.I. 02903-1209
TEL (401) 222-2678 FAX (401) 222-2968
TTY / Relay 711 Website www.preservation.ri.gov

2 October, 2018

Deborah Cox
Public Archaeology Laboratory, Inc.
26 Main Street
Pawtucket, RI 02860

RE: Phase I Archaeological Survey
National Grid—Lines R9/J16S Reconductoring
Woonsocket and Cumberland, RI

Dear Ms. Cox,

The Rhode Island Historical Preservation and Heritage Commission staff has received PAL's report of the above-referenced survey. We concur with PAL's conclusion that the Sneech Pond site (RI 2728) and the Robbin Hollow Foundation (RI 2609) are not eligible for listing on the National Register of Historic Places. Additional archaeological investigation of these sites is not necessary.

We further concur that the Millers River Site (RI 2610) is a potentially significant archaeological resource. An avoidance and protection plan should be developed for this site, and if avoidance is not possible, additional archaeological survey would be required in advance of any ground disturbance.

These comments are provided in accordance with Section 106 of the National Historic Preservation Act. If you have any questions, please contact Charlotte Taylor, Staff Archaeologist, of this office.

Very truly yours,

Charlotte Taylor (for)
Paul Loether
Executive Director
State Historic Preservation Officer

Cc: Erin Whoriskey, National Grid
John Brown, Narragansett Tribal Historic Preservation Officer

181002.05

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
HISTORICAL PRESERVATION & HERITAGE COMMISSION
Old State House • 150 Benefit Street • Providence, R.I. 02903-1209
TEL (401) 222-2678 FAX (401) 222-2968
TTY / Relay 711 Website www.preservation.ri.gov

19 October, 2018

Deborah Cox
Public Archaeology Laboratory, Inc.
26 Main Street
Pawtucket, RI 02860

RE: *Technical Memorandum, Line R9 and J16S Reconductoring Project Access Roads, Phase I Intensive Archaeological Survey, Woonsocket and Cumberland, Rhode Island and North Attleborough, Massachusetts – September 26, 2018*

Dear Ms. Cox,

The Rhode Island Historical Preservation and Heritage Commission staff has received PAL's technical memorandum of the above-referenced survey. We concur with PAL's conclusion that the historic cultural materials found within the project's proposed access roads do not constitute significant archaeological resources. We therefore conclude that the proposed construction of these access roads will have no effect on any significant cultural resources that are listed on or eligible for listing on the National Register of Historic Places.

These comments are provided in accordance with Rhode Island Antiquities Act. If you have any questions, please contact Timothy Ives, Principal Archaeologist, of this office.

Very truly yours,

for Paul Loether
Executive Director

Cc: Erin Whoriskey, National Grid

181019.01