



Proactive by Design



RHODE ISLAND ENERGY FACILITY SITING BOARD ENVIRONMENTAL REPORT

The Narragansett Electric Company d/b/a
National Grid

Franklin Square Substation to South Street
Substation 115 kV Underground Transmission
Line Project

May 2016

PREPARED FOR:

National Grid
Providence, Rhode Island

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This document has been reviewed for Critical Energy Infrastructure
Information (CEI). [May 2016]



1.0	INTRODUCTION	1
2.0	PURPOSE AND NEED	2
2.1	INTRODUCTION.....	2
2.2	PROJECT BACKGROUND.....	2
2.3	PURPOSE	2
2.4	CONSEQUENCES OF NOT UNDERGROUNDING THE LINES	2
3.0	PROJECT DESCRIPTION AND PROPOSED ACTION	3
3.1	INTRODUCTION.....	3
3.2	DESCRIPTION OF THE EXISTING TRANSMISSION LINES	3
3.3	PROPOSED PROJECT.....	3
3.3.1	Underground Routes	3
3.3.2	Cable Rating	3
3.3.3	Cable Types	4
3.3.4	Circuit and Trench Arrangements.....	4
3.3.5	Relocation and Burial.....	4
3.4	CONSTRUCTION PRACTICES.....	4
3.5	RIGHT-OF-WAY (ROW) MAINTENANCE	4
3.6	SAFETY AND PUBLIC HEALTH CONSIDERATIONS	5
3.7	PROJECT COSTS	5
3.8	PROJECT SCHEDULE	5
3.9	PROJECT OUTREACH	6
4.0	ALTERNATIVES TO THE PROPOSED ACTION	7
4.1	INTRODUCTION.....	7
4.2	NO BUILD	7
4.3	WATERFRONT ROUTE	7



4.4	DAVOL SQUARE ROUTE.....	7
4.5	RICHMOND STREET ROUTE.....	7
5.0	DESCRIPTION OF AFFECTED NATURAL ENVIRONMENT	8
5.1	INTRODUCTION.....	8
5.2	SOILS	8
5.3	GROUNDWATER.....	8
5.4	SURFACE WATER.....	8
5.5	VEGETATION	9
5.6	AIR QUALITY	9
6.0	DESCRIPTION OF AFFECTED SOCIAL ENVIRONMENT	10
6.1	INTRODUCTION.....	10
6.2	LAND USE	10
6.3	HISTORIC AND CULTURAL RESOURCES.....	10
6.4	VISUAL RESOURCES.....	10
6.5	NOISE	10
6.6	MAGNETIC FIELDS.....	10
7.0	IMPACT ANALYSIS.....	12
7.1	INTRODUCTION.....	12
7.2	SOILS	12
7.3	GROUNDWATER.....	12
7.4	SURFACE WATER.....	12
7.5	VEGETATION	13
7.6	AIR QUALITY	13
7.7	LAND USE AND RECREATION	13
7.8	COMMUNITY IMPACTS	13
7.9	TRAFFIC	13



7.10	VISUAL RESOURCES.....	14
7.11	NOISE	14
7.12	HISTORIC AND CULTURAL RESOURCES.....	14
7.13	SAFETY AND PUBLIC HEALTH	14
7.14	MAGNETIC FIELDS.....	14
8.0	MITIGATION MEASURES.....	16
8.1	INTRODUCTION.....	16
8.2	ENVIRONMENTAL MITIGATION	16
8.2.1	Sediment and Erosion Controls	16
8.2.2	Soil Management.....	16
8.2.3	Dewatering Liquids	16
8.2.4	Dust and Odor.....	16
8.2.5	Vibrations.....	17
8.2.6	Supervision and Monitoring	17
8.2.7	Health and Safety.....	17
9.0	CONCLUSION	19

FIGURES

FIGURE 1	PROJECT SITE LOCATION
FIGURE 2	PROJECT ALIGNMENT – EXISTING AND PROPOSED
FIGURE 3	EXISTING TRANSMISSION LINE TOWERS
FIGURE 4	PROPOSED TRANSMISSION LINE CROSS SECTIONS
FIGURE 5	UNDERGROUND TRANSMISSION LINE ALTERNATIVE ROUTE
FIGURE 6	STUDY AREA PLAN
FIGURE 7	LAND USE PLAN



APPENDICES

APPENDIX A 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, EXPONENT, INC. (MARCH 9, 2015)



1.0 INTRODUCTION

This Environmental Report (“ER”) has been prepared in accordance with Rule 1.6(f) of the Rhode Island Energy Facility Siting Board (“EFSB”) Rules of Practice and Procedure in support of The Narragansett Electric Company d/b/a National Grid’s (“TNEC”) Notice of Intent (“NOI”) for the relocation and burial of three existing 115 kilovolt (“kV”) overhead electrical transmission lines (“Project”). The transmission lines are known as T1, T2, and T3 (collectively, the “Existing Lines”) and are collectively supported by three steel structures. The Existing Lines connect the Franklin Square Substation located at 460 Eddy Street (“Franklin Square Substation Property”) to the South Street Substation located at 342 Eddy Street in Providence, Rhode Island (“Substation Property”). The general area is shown on the attached Figure 1. The existing and proposed locations of the transmission lines are shown on the attached Figure 2.

Due to asset condition concerns, TNEC is currently in the process of constructing a new South Street Substation on the Substation Property to replace the existing South Street Substation.¹ The owner/developer of the properties located between the South Street Substation and Franklin Square Substation, CV South Street Landing LLC (“Developer”), has requested that TNEC relocate the Existing Lines underground as it would benefit the Developer’s redevelopment of the adjacent properties. The Project is not required for the new substation so TNEC and the Developer have entered into an agreement whereby the Developer agrees to pay for the cost to relocate the Existing Lines underground.

This report summarizes the Project components, proposed alternatives, need, potential environmental and social impacts, and planned mitigation measures.

¹ The Board has interpreted the definition of “major energy facility” to include an “‘ancillary facility integral and dedicated’ to the transmission of electricity...” like a switching station and substation that is integral to the larger project. In re The Narragansett Electric Company d/b/a National Grid (Interstate Reliability Project), Docket No. SB-2012-01, Decision and Order, p. 4 (Order No. 68, June 14, 2013). Since the Project need is independent of the substation, the new substation does not fall under the jurisdiction of the EFSB and was permitted through Coastal Resources Management Council (“CRMC”), Rhode Island Department of Environmental Management (“RIDEM”) and Providence boards and agencies.



2.0 PURPOSE AND NEED

2.1 INTRODUCTION

The Project is being undertaken at Developer's request in connection with its redevelopment of the South Street Landing (the old South Street Power Station which was more recently known as the Dynamo House) on the adjoining property ("South Street Landing Parcel"). The Dynamo House has been renamed South Street Landing by the Developer and is being redeveloped to house university administrative offices and a nursing education center. The Developer is also building a parking garage on the parcel between the Substation Property and Eddy Street.

2.2 PROJECT BACKGROUND

The existing South Street Substation was constructed in the early 1900's and it distributes electricity to downtown Providence and surrounding communities. The Existing Lines serve as the supply lines to the substation. The Substation Property is an approximately 5.545 acre parcel that is owned by TNEC. TNEC is building a new substation on the Substation Property to replace the existing substation. The new substation is necessary because the existing substation's building constraints make it impossible for TNEC to upgrade the equipment in the existing substation control building. Power to the new substation will continue to be supplied from the Franklin Square Substation. Upon completion of the Project, the supply will be by way of the new underground lines.

Once the Project is completed and the new substation is in service, TNEC will remove the Existing Lines, the three steel towers supporting those lines, and the control house. In addition, as part of its redevelopment efforts the Developer has agreed to install a new pedestrian waterfront walkway as required by the Rhode Island Coastal Resources Management Council ("CRMC"). The walkway will be installed after the Project is completed and is in furtherance of CRMC's urban coastal greenway policy ("UCG"), which strives to improve public access to the waterfront, improve water quality by providing treatment of storm water runoff, and preserve and restore habitat corridors and aesthetic value of the shoreline.

TNEC has obtained the necessary approvals for the new substation from CRMC, the Rhode Island Department of Environmental Management ("RIDEM"), the City of Providence Downtown Design Review Board, the City of Providence Building Department, and the City of Providence Zoning Board of Review. CRMC has also reviewed and approved the constructions plans for the Project.

2.3 PURPOSE

The sole purpose of the Project is to satisfy the Developer's request to move the Existing Lines underground. As such, the Developer has agreed to reimburse TNEC for the costs to rebuild the Existing Lines underground.

2.4 CONSEQUENCES OF NOT UNDERGROUNDING THE LINES

While some modifications to the north end of the Existing Lines would be required to connect the lines to the new South Street Substation, such a configuration would provide a reliable connection between the Franklin Square Substation and the new South Street Substation. However, the Developer has requested that TNEC relocate the Existing Lines underground and entered into an agreement to pay for the costs of the Project, so leaving the lines in place would be unresponsive to the Developer's request and may impact the Developer's redevelopment of the adjacent properties.



3.0 PROJECT DESCRIPTION AND PROPOSED ACTION

3.1 INTRODUCTION

This section of the ER describes the existing facilities, scope of the proposed Project, TNEC's construction practices, estimated Project costs, and Project schedule.

3.2 DESCRIPTION OF THE EXISTING TRANSMISSION LINES

The Existing Lines extend approximately 1,300 feet along the west side of the Providence River and connect the South Street Substation with the Franklin Square Substation. The lines are collectively supported by three steel structures. The Existing Lines are shown on the attached Figure 3.

3.3 PROPOSED PROJECT

The Developer has asked TNEC to relocate the Existing Lines underground. This ER is in support of the NOI application to relocate those lines. The planned alignment of the new underground transmission lines, together with the existing and proposed substation, are shown on Figure 2. After the underground transmission lines are in service, TNEC will remove the Existing Lines.

3.3.1 Underground Routes

A principle tenet of the transmission line routing selection process was to provide protection from failure due to accidental severance of all three lines in a single incident. Two routes were chosen to protect the lines from such an event: the Waterfront Route (T2 and T3) and the Davol Square Route (T1), shown on Figures 2 and 4 and described in ER Sections 4.3 and 4.4.

The Waterfront Route follows the route of the existing overhead transmission lines. The route extends north from the Franklin Square Substation, across Point Street, along an existing walkway, and behind the South Street Landing Parcel to the Substation Property. A portion of this route will run parallel to an active TNEC distribution duct bank from Point Street to the Substation Property. TNEC has the necessary underground property rights to install the underground transmission lines along this route. A potential challenge for this route is the presence of abandoned foundations and structures that once served the South Street power plant.

The Davol Square Route extends north from the Franklin Square Substation parking lot, across Point Street and continues through a private parking lot and along open green space areas within the private River House development, turns west along South Street, and then north on the South Street Landing Parcel, to the Substation Property. The Developer has agreed to grant the easements required for this route.

Separating the lines into two different routes will provide sufficient redundancy to minimize interruptions in service should a line be severed.

3.3.2 Cable Rating

TNEC determined that three lines are needed to replace the Existing Lines. In the event one of the new underground lines is out of service, the two remaining lines will supply the new substation. The cables are rated to maintain the load in such an event.



3.3.3 Cable Types

There are several possible cable types that could be used for the transmission lines between the South Street Substation and the Franklin Square Substation. The cable types evaluated for this Project included High Pressure Gas-Filled (“HPGF”) Pipe-Type Cable System, and extruded cross-linked polyethylene (“XLPE”) Dielectric Cable System. Because of its widespread use in the United States for new transmission cable installations, TNEC proposes to use the XLPE Dielectric Cable System. The individual conductors are insulated with XLPE, a metallic shield, radial moisture barrier and a jacket are applied, and then the individual cables are pulled into individual plastic ducts in concrete encased duct banks.

3.3.4 Circuit and Trench Arrangements

Figure 4 shows a cross section of the single circuit duct bank proposed for the Davol Square Route and a cross section of the double circuit duct bank proposed for the Waterfront Route. The duct bank configuration for each circuit will consist of three 6-inch PVC conduits for the 115 kV cables and one 2-inch PVC conduit for installation of ground continuity conductors. Each duct bank will have an additional 6-inch PVC conduit for communications and control fiber optic cable. The conduits will be encased in 3,000 pounds per square inch (“psi”) strength concrete to protect the conduits and cables from mechanical damage. The duct banks will be installed at a depth of 42 inches to the center of the top most row of conduits. Overlapping steel plates have been included in the two circuit trench arrangement for the Waterfront Route to provide additional mechanical protection against a dig-in from damaging more than one circuit.

3.3.5 Relocation and Burial

The scope of work associated with replacing the existing overhead electrical transmission lines consists of the following:

- Removing the existing pavement and excavating approximately 2,000 cubic yards of soil at the affected parcels;
- Constructing 2,700 feet of manhole and concrete encased duct bank system;
- Installing the supply cables in the manhole and duct bank;
- Performing final grading over the excavated areas; and
- Removing the existing overhead lines and the three triple circuit steel towers currently supporting the T1, T2, and T3 lines.

3.4 CONSTRUCTION PRACTICES

The Project will be constructed using conventional underground electric transmission line construction techniques. Construction work hours will comply with local requirements. At times, crews may be working in close proximity to energized equipment during the installation of both above and below ground facilities, as well as during the demolition phase. The crews will observe proper working clearances in accordance with TNEC safety procedures.

The construction of portions of the Project will take place on active roadways; and crews will be aware of their surroundings at all times and will use proper worksite protection. Local requirements for police protection and safety signage will be observed.

3.5 RIGHT-OF-WAY (ROW) MAINTENANCE

There is little ROW maintenance required for underground lines. TNEC will periodically inspect the ROW to confirm that no permanent structures are constructed over the duct banks, no woody vegetation is located near the duct banks, no material/soils are stored over the duct banks, and there are no obstructions to accessing the ROW. TNEC will also perform periodic inspections of the equipment inside the manholes.



3.6 SAFETY AND PUBLIC HEALTH CONSIDERATIONS

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

3.7 PROJECT COSTS

TNEC has prepared project grade estimates of the underground transmission line cost. The estimated capital costs associated with the underground project are as follows.

Estimated Costs – Underground Transmission Lines	
Install three 115 kV underground transmission lines consisting of concrete encased duct banks and 115 kV XLPE cable, with two lines along the Waterfront Route, and one line along the Davol Square Route	\$ 7,296,416
Franklin Square Substation transitions and relay/protection upgrades	\$ 2,339,301
Total Cost for the Project	\$ 9,635,717

The Developer has entered into a Cost Reimbursement Agreement (“CRA”) with TNEC whereby the Developer agrees to reimburse TNEC for the Project cost. Relocating the lines underground will save TNEC the cost of extending portions of the Existing Lines to connect to the new substation. The “Above-Ground Cost” represents the cost that would have been incurred by TNEC to connect the Existing Lines to the new South Street Substation. The “Above-Ground Cost” of \$2,652,295 is for the extension of the three 115 kV lines for two spans and the installation of three transmission towers. TNEC will reduce the charge to the Developer by this amount.

Adjusted Cost to Developer	
Total Cost for the Project:	\$9,635,717
Less: Above Ground Cost:	(\$2,652,295)
Adjusted Cost to Developer:	\$6,983,422

If the cost incurred by TNEC for the Project is greater than the total of the payments made by the Developer to TNEC, the Developer will pay the difference to TNEC in accordance with the terms of the CRA. If the total cost incurred by TNEC is less than the total of the payments made by the Developer to TNEC, TNEC will refund the difference to Developer in accordance with the CRA.

3.8 PROJECT SCHEDULE

TNEC expects to complete Project permitting in 2016. Construction of the Project is scheduled to start the Summer of 2016. After the energization and cutovers at the substation are completed, the existing overhead lines and supporting structures will be removed. The Project is scheduled to be completed by the Summer of 2019.



3.9 PROJECT OUTREACH

TNEC's outreach has included working closely with the Developer to conform the Project schedules with the Developer's adjacent projects. In addition, the permitting process for the new substation was before the Providence Downtown Design Review Committee and the City of Providence Zoning Board, so abutters within 200 feet of the Substation Property have received notice of the new substation. References to the Project were included in the applications and presentations for the local zoning proceedings. TNEC also reviewed the Project with other interested parties. Because the Project is an underground project, the outreach effort was limited.



4.0 ALTERNATIVES TO THE PROPOSED ACTION

4.1 INTRODUCTION

TNEC evaluated three different alternatives for this Project plus a no build alternative. As shown on Figures 2 and 5, the Waterfront Route runs along the Providence River waterfront and through parking areas. The Davol Square Route is located along the parking lot and green space pathways on private property. A third route that was evaluated by TNEC is the Richmond Street Route that uses the public streets to interconnect the two substations. The three alternatives were evaluated for cost, safety, environmental impacts, feasibility, and social/cultural impacts. During the final review process, the Waterfront Route and Davol Square Route were selected as the preferred routes.

4.2 NO BUILD

Since the purpose of the Project is to respond to the Developer's request to relocate the overhead transmission lines underground at the Developer's Cost, the no build alternative was not deemed to be a viable alternative.

4.3 WATERFRONT ROUTE

The Waterfront Route follows the existing overhead transmission lines beginning at the Franklin Square Substation and extending north across Point Street, in a right-of-way under a walkway, and behind South Street Landing to the Substation Property. This route is approximately 1,300 feet long. There are numerous abandoned foundations and structures that once served South Street Landing buried along this route. A challenge for this route will be avoiding and/or removing the abandoned foundations and structures. A portion of the route will parallel an active TNEC distribution duct bank from Point Street to the Substation Property.

4.4 DAVOL SQUARE ROUTE

The Davol Square Route extends: north from the Franklin Square Substation parking lot; crosses Point Street and continues through a parking lot in Davol Square, along open green space areas within a private development; west along South Street, north on South Street Landing property; and then to the Substation Property. This route is approximately 1,400 feet long. The Developer has agreed to grant TNEC the easements required for this route. A challenge for this route will be navigating around significant subsurface utilities and structures.

4.5 RICHMOND STREET ROUTE

A third alternative that was considered is the Richmond Street Route which is shown on Figure 5. This route is approximately 2,400 feet long and is entirely within public streets. The route extends westward from the Franklin Square Substation on Point Street, northward on Richmond Street to Ship Street, and eastward on Ship Street to the Substation Property. This route is almost twice as long as the other routes. Although Richmond Street contains many subsurface utilities, it appears to have the fewest number of obstructions of the three routes. This route was rejected because of its additional length and potential traffic impacts during the construction phase.



5.0 DESCRIPTION OF AFFECTED NATURAL ENVIRONMENT

5.1 INTRODUCTION

The Project is located on the following parcels; Providence Assessor's Plat 21, Lots 453, 439, 430, 440, 438, and Plat 22, Lot 353, which are collectively hereinafter referred to as the "Project Area" as shown on Figure 1. The Project Area and the surrounding area are developed industrial/commercial properties. According to the EFSB Rules, a detailed description of the environmental characteristics of the "Study Area" is required. As shown on Figure 6, the Study Area is the area within 1/4 mile of the Project. As permitted by EFSB Rule 1.6(f), several natural and social environmental resources (i.e. climate and weather, geology, wetlands, and wildlife) have not been addressed in this document, since the Project will have no potential to impact them.

5.2 SOILS

Soils along the proposed routes consist of primarily urban fill materials. According to the Natural Resources Conservation Service ("NRCS") web soil survey, the entire area from the Franklin Square Substation to the South Street Substation is identified as urban land. Based on previous investigations at the Substation Property, soils generally consist of 1 to 2 inches of topsoil in unpaved portions underlain by granular urban fill (as characterized by the presence of brick, concrete debris, etc.). Ash materials at various thicknesses were also observed.

The Substation Property and portions of the Davol Square property and Franklin Square Substation Property have been identified as individual State-listed Sites regulated by RIDEM's Office of Waste Management due to certain impacts to soils and groundwater from historical operations. As a result, Environmental Land Use Restrictions ("ELUR") exist for these Sites. The ELURs are specific to each property and provide restrictions on use, soil management, and notification requirements to RIDEM.

5.3 GROUNDWATER

The Study Area falls within a RIDEM designated GB groundwater resource area (i.e., assumed unsuitable for drinking without treatment). Businesses and residences in the area are connected to the Providence municipal water supply. Based on previous investigations completed in the vicinity of the substations, groundwater flow is generally to the east towards the Providence River. There are no known well head protection areas within the Study Area. Therefore, this Project is not expected to impact drinking water resources such as well head protection areas, or sole source aquifers.

Based on data collected at the Substation Property during previous investigations, groundwater is approximately 5 to 7 feet below grade. Groundwater may be encountered during excavation activities conducted as part of the Project and construction dewatering is anticipated to be necessary. If dewatering occurs, the dewatering water may require treatment prior to discharge. This Project is not anticipated to adversely impact groundwater quality.

5.4 SURFACE WATER

The Project is bordered to the east by the tidally influenced Providence River. The section of the Providence River that abuts the Project (waterbody identification No. RI0007020E-01B) is listed as a SB1{a} water body that is impaired due to fecal coliform, total nitrogen, and dissolved oxygen. The primary use of the Providence River is limited because of poor water quality.

The Providence River in the area is classified by CRMC as Type 5, Commercial and Recreational Harbor. Type 5 waters are defined as waters that are adjacent to waterfront areas that support a variety of tourist, recreational, and commercial activities. The Project will not impact recreational and commercial activities along the waterfront. There are no other surface water resources (streams, ponds) on or adjacent to the Project Area.



5.5 VEGETATION

The existing pervious areas of the parcels are predominantly vegetated with grass with some areas of shrubbery and trees. The proposed urban coastal greenway would create vegetated greenspace along the waterfront.

5.6 AIR QUALITY

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



6.0 DESCRIPTION OF AFFECTED SOCIAL ENVIRONMENT

6.1 INTRODUCTION

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

6.2 LAND USE

Land use in the area is generally characterized as commercial/industrial (see Figure 7, Land Use). The surrounding properties currently consist of South Street Landing, the former I-195 properties, and commercial buildings. The Substation Property and the majority of the Study Area are in the Downtown District, Educational Institutional Overlay District, and Healthcare Institutional Overlay District. The southern portion of the Franklin Square Substation Property is in the General Industrial District.

6.3 HISTORIC AND CULTURAL RESOURCES

A review of available materials indicates that there are no archaeological areas of significance in the Project Area. The Substation Property was previously used for power generation. All of the Project Area soils are predominantly urban fill with no native, undisturbed areas.

The existing substation control house and South Street Landing are listed on the National Register of Historic Places. The existing substation control house adjoins the north side of the South Street Landing. It is expected that the South Street Landing will remain listed as a historic property.

There are no known tribal activities or resources in the Project Area.

6.4 VISUAL RESOURCES

The visual resources within the Study Area are an important characteristic of the river front. The area is characterized by a mix of commercial industrial uses and the Providence River.

6.5 NOISE

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

6.6 MAGNETIC FIELDS

Electric and magnetic fields are present whenever electricity is used. The voltage causes an electric field which is usually measured in kilovolts per meter (kV/m). The current causes a magnetic field which is usually measured in milligauss (mG). Magnetic fields were modeled and calculated to determine the field strengths with the Existing Lines.² These calculations were

² As noted in Section 3 of Appendix A, conducting objects, including fences and buildings easily block electric fields. For this reason, this report does not address electric fields because the sheathing of the cables and the ground will block the electric fields.



made based upon pre-Project Projected 2016 annual average load (AAL) and annual peak load (APL). The magnetic field levels for the Existing Lines at AAL and APL are shown on Tables 6-1 and 6-2, respectively.^{3,4}

Table 6-1. Calculated magnetic field levels (mG) for Existing configurations under average loading (2016)

Section	Configuration	-90 ft	-60 ft	-30 ft	0 ft	+30 ft	+60 ft	+90 ft
XS-2	Existing	1.4	2.3	4.6	11	23	28	9.8

Table 6-2. Calculated magnetic field levels (mG) for Existing configurations under peak loading (2016)

Section	Configuration	-90 ft	-60 ft	-30 ft	0 ft	+30 ft	+60 ft	+90 ft
XS-2	Existing	2.3	3.9	7.7	18	39	47	16

³ XS-2 is the cross section of the Existing Lines and the proposed Waterfront Route at Point Street. The existing magnetic fields of the Davol Square Route were not modeled because the route is more than 200 feet west of the Existing Lines.

⁴ The centerline of the existing overhead transmission lines is approximately +30 feet from the centerline of the proposed duct bank in XS-2. The distances on Tables 6-1 and 6-2 are shown relative to the centerline of the proposed duct bank.



7.0 IMPACT ANALYSIS

7.1 INTRODUCTION

This section provides a description and analysis of potential impacts of the Project on the natural and social environments within the vicinity of the Project Area. The impacts are expected to be minimal.

7.2 SOILS

Excavation activities occurring at the Substation Property and Davol Square property will be performed consistent with the Remedial Action Work Plan ("RAWP") approved by the RIDEM Office of Waste Management ("OWM") in January 2015. The RAWP includes a materials handling plan, which details procedures to be followed during construction related to the handling, management, disposal, and re-use of potentially impacted soil and groundwater. The Project will be completed in a manner that is consistent with the planned integral RIDEM approved engineered cap for the Substation Property. Excavation activities performed on sites with an existing ELUR will be performed in accordance with the RAWP and Soil Management Plan ("SMP") recorded with the ELUR.

During construction activities, portions of the Project Area will be exposed to wind and precipitation that have the potential to increase erosion and sedimentation. Existing pervious areas may experience temporary decrease in infiltration rates due to soil compaction from equipment operations. To minimize these impacts, best management practices ("BMPs") will be employed throughout the construction period until disturbed areas have been stabilized. These will consist of straw bales, silt fences, straw wattles, and other forms of erosion control measures. As part of the permitting process, a Storm Water Management Plan ("SWMP") and Soil Erosion and Sediment Control ("SESC") plan have been developed and will be implemented during the construction period. These plans detail specific BMPs to be employed and will identify where in the Project Area they will be installed. The plan will also necessitate regular monitoring and maintenance of all BMPs during the construction period.

Excess soil produced at the Project Area will have the potential to impact the surrounding natural environment. The soil at the Substation Property is known to be impacted from previous/historical use. A Soil Management Plan has been developed and will be implemented during construction activities. This plan will provide specific guidance to minimize impacts to surrounding areas and provide safety protocols for workers on the site. The Project will also include the installation of a RIDEM approved engineered cap designed to mitigate potential exposures to underlying impacted materials.

7.3 GROUNDWATER

Recent groundwater sampling and testing suggests that groundwater at the Project Area is generally free of contamination. RIDEM has designated groundwater at the site as GB, or water that is not suitable for human consumption without treatment. Project construction and operation is not expected to impact the Project Area or the surrounding area groundwater quality.

Since the Substation Property is listed with the RIDEM Office of Waste Management and some historical impacts to groundwater were previously noted, proper management of impacted groundwater for construction purposes will be required. The RAWP provides specific methods that will be used to manage potentially contaminated groundwater.

7.4 SURFACE WATER

Special attention will be provided to prevent impacts to the Providence River during construction activities. One potential impact to water quality from construction activities is the introduction of turbid stormwater caused by soil erosion and sedimentation from the disturbed soils. Another potential impact is fuel spillage near the Providence River from the heavy equipment on the site during construction. Both of these potential impacts will be minimized through the implementation of the SWMP/SESC. Soil materials that may be temporarily stored on the site will be stored on and covered with polyethylene



sheeting and surrounded by straw bales. Equipment will not be refueled or maintained near the Providence River. It is anticipated that detrimental impacts to the Providence River during construction will be minimal.

7.5 VEGETATION

There will be no impacts to existing vegetation as a result of this Project because the Project Area does not currently contain any significant vegetation. However, certain areas on the Substation Property will receive new vegetation (shrubs and trees) as a result of this Project.

7.6 AIR QUALITY

During construction activities, exposed soils will be moistened and stabilized as necessary to suppress dust generation. All access road entrances to public roadways will be fitted with crushed stone aprons. These measures will be designed to keep fugitive dust emissions low. Emissions generated by the operation of construction machinery (carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter) are short duration and generally not considered significant. Air quality monitoring for dust and volatile organic compounds will be performed throughout the construction phase to ensure that BMPs are effective in minimizing generation of air quality impacts.

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

7.7 LAND USE AND RECREATION

In general, land use impacts can be separated into short term and long term impacts. Short term impacts generally occur during the construction phases and will be temporary. The Project is expected to have no long term impacts. The Project will benefit the area by allowing for the construction of the UCG which will provide public access to the Providence River shoreline.

7.8 COMMUNITY IMPACTS

The Project will not require nor will it lead to residential or business power outages. Temporary impacts from construction activities will primarily be related to construction traffic and equipment operations; these are expected to be minor. The Project will not adversely impact the overall social and economic condition of the surrounding area. The required UCG will dramatically improve public access to the Providence Riverfront and provide significant visual quality improvements. TNEC is working closely with the Developer to minimize any short term social impacts by coordinating construction schedules for the Project and South Street Landing.

7.9 TRAFFIC

Transportation needs in the vicinity of the Project Area are served by several state and local roadways. Eddy Street is the major artery that runs along the western side of the property. This is a generally four lane roadway that carries most of the traffic along the western side of the Providence River. Work on the underground transmission cables will involve restricting access to certain streets during certain times of the construction. No traffic impacts beyond temporary construction related activities are anticipated to be associated with this Project.



7.10 VISUAL RESOURCES

The Project should have a positive impact on the visual resources in the area as the Project will replace the existing overhead supply lines and associated structures with underground lines. Once the new lines are in service, the existing overhead lines and associated structures will be removed.

7.11 NOISE

The noise impacts from the Project will be temporary and limited to the construction of the Project. During construction, noise reduction measures such as use of mufflers or dampers will be employed as required. Once in service, the underground lines are not expected to generate any noise.

7.12 HISTORIC AND CULTURAL RESOURCES

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

TNEC has entered into a Memorandum of Agreement with the Rhode Island Historical Preservation and Heritage Commission because the existing South Street Substation control house is listed on the National Register of Historic Places. The Memorandum of Agreement requires TNEC to complete a report with written documentation, drawings and photographs of the control house before it is demolished. The Existing Lines are not part of the historic listing so the documentation requirement is outside the scope of the Project.

7.13 SAFETY AND PUBLIC HEALTH

The proposed underground transmission lines will not be readily accessible to members of the public and will be designed, built and maintained in accordance with applicable standards and codes. As discussed in Section 3.6, public health and safety will be protected.

7.14 MAGNETIC FIELDS

EMF modelling projected the magnetic fields based on loading conditions now and in 2021, after the Project is completed. The relocation of the lines underground means that the levels will change from those shown in Table 6-1.⁵ The magnetic field levels for the Davol Square Route (XS-1) and the Waterfront Route (XS-2) have been modeled and calculated. These calculations were based upon Projected 2021 AAL and APL loads. The calculated magnetic field levels for the XS-1 and XS-2 at AAL and APL are shown on Tables 7-1 and 7-2, respectively.^{6,7}

A discussion of the current status of the health research relevant to exposure to electric and magnetic fields ("EMF") is attached as Appendix A.

⁵ As noted Section 6.6, conducting objects, including fences and buildings block electric fields. As such this report does not address electric fields because the sheathing of the cables and the ground will block the electric fields.

⁶ XS-1 is the cross section of the Davol Square Route at Point Street. XS-2 is the cross section of the Existing Lines and the proposed Waterfront Route at Point Street. The existing magnetic fields of the Davol Square Route were not modeled because the route is more than 200 feet west of the Existing Lines.

⁷ The centerline of the existing overhead transmission lines is approximately +30 feet from the centerline of the proposed duct bank in XS-2. The distances on Tables 7-1 and 7-2 are shown relative to the centerline of the proposed duct bank.



Table 7-1. Calculated magnetic field levels (mG) for Existing and Proposed configurations under average loading

Section	Configuration	-90 ft	-60 ft	-30 ft	0 ft	+30 ft	+60 ft	+90 ft
XS-1	Proposed (2021)	0.2	0.2	0.6	8.8	0.8	0.3	0.2
XS-2	Existing (2016)	1.4	2.3	4.6	11	23	28	9.8
	Proposed (2021)	0.6	0.9	2.1	18	1.6	0.8	0.5

Table 7-2. Calculated magnetic field levels (mG) for Existing and Proposed configurations under peak loading

Section	Configuration	-90 ft	-60 ft	-30 ft	0 ft	+30 ft	+60 ft	+90 ft
XS-1	Proposed (2021)	0.3	0.4	1.0	15	1.3	0.5	0.3
XS-2	Existing (2016)	2.3	3.9	7.7	18	39	47	16
	Proposed (2021)	1.0	1.5	3.5	30	2.6	1.3	0.9



8.0 MITIGATION MEASURES

8.1 INTRODUCTION

The Project is not anticipated to have any long-term impacts to the natural or social environment of the Study Area so mitigation efforts are focused on the construction phase.

8.2 ENVIRONMENTAL MITIGATION

TNEC will use proven methods employed at other underground transmission line construction projects.

8.2.1 Sediment and Erosion Controls

During construction activities involving disturbance of soils, sediment and erosion controls will be installed and maintained to mitigate migration of sediment into the Providence River and site catch basins. A SESC Plan has been developed and will be implemented. Erosion control measures will include the installation and maintenance of silt fencing, straw bales, straw wattles, and silt sacks. These measures will be inspected regularly during construction and maintained as necessary in accordance with the Rhode Island Pollutant Discharge Elimination System ("RIPDES") General Permit for Storm Water Discharge Associated with Construction Activity. Upon completion of construction activities, pervious areas will be stabilized with an assortment of low maintenance shrubs and trees within mulched planting areas.

8.2.2 Soil Management

Excess soils produced during construction will be managed in accordance with the RIDEM approved RAWP. Soil stockpiles will be stored on and covered with polyethylene sheeting on a daily basis. All import fill materials will be certified clean consistent with RIDEM requirements prior to shipment to the site. Post-construction soil stabilization will follow requirements detailed in the SMP.

8.2.3 Dewatering Liquids

Dewatering fluids produced during excavation activities will be managed in accordance with the RIDEM approved RAWP. Proper management of impacted groundwater for construction purposes will be required as the site is listed with the RIDEM Office of Waste Management and some historical impacts to groundwater were previously noted. If dewatering is necessary, all water shall be containerized for off-site disposal or be containerized within fractionation tanks and processed through filtration units for the removal of suspended soils. In accordance with the RAWP, ultimate disposal of dewatering fluids will be through on-site infiltration.

8.2.4 Dust and Odor

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

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



8.2.5 Vibrations

The anticipated construction activities are not expected to generate excess vibrations and sensitive structures and other facilities susceptible to damage from vibrations have not been identified. TNEC will perform both pre and post construction condition assessments of the site and certain surrounding areas to assess any damage caused during construction. If necessary, vibrations will be monitored during construction and work practices will be modified if necessary to reduce observed vibrations.

8.2.6 Supervision and Monitoring

TNEC will retain services of an environmental monitor during the entire construction phase of the Project to ensure all applicable regulations and permit requirements are followed. The environmental monitor will be a trained individual capable of supervising construction sites and experienced in sediment and erosion control practices, impacted soil and groundwater management, and environmental monitoring.

Specific work-zone and perimeter monitoring will be performed continuously during construction to ensure BMPs are effective in mitigating any potential environmental impacts from dust and odors.

8.2.7 Health and Safety

TNEC will design, build, and maintain the underground electric facilities such that the health and safety of the public are protected. TNEC will adhere to applicable regulations, industry standards, and guidelines established for the protection of the public. Specifically, the Project will be designed, built, and maintained in accordance with the NESC. The facilities will be designed in accordance with sound engineering practices using established design codes and guides published by, among others, IEEE, ASCE, ACI, and the ANSI.

Practices that will be used to protect the public during construction will include, but not be limited to, establishing traffic control plans for construction traffic on busy streets to maintain safe driving conditions, and restricting public access to potentially hazardous work areas. Following construction, all transmission infrastructure and substation facilities will be clearly marked with warning signs to alert the public of potential hazards if entered.

The basic health and safety procedures outlined below will be implemented and maintained while performing any excavation or similar activity at the Project Area. Actual procedures are detailed in a site specific Health and Safety Plan ("HASP"). The HASP are prepared in compliance with applicable sections of Occupational Safety and Health Administration ("OSHA") 29 Code of Federal Regulations ("CFR") 1926 and 1910. The HASP will establish, in detail, the protocols necessary for protecting workers, on-site personnel, visitors and trespassers from potential physical and chemical hazards encountered during the Work.

Only 40 hour OSHA trained crews shall perform construction in the Project Area. At a minimum, the following personal protection equipment ("PPE") will be required for all on-site workers potentially exposed to impacted materials:

- EH Rated Safety Shoes
- Work Gloves
- Safety Glasses
- Hard Hat
- Flame Resistant ("FR") Rated Traffic Vest
- FR Rated Clothing

Based on the type of chemical constituents present at the site, the potential routes of exposure to on-site excavation or construction workers include dermal contact (absorption) or accidental ingestion of impacted soil, the possibility of



contaminants through broken skin and inhalation. Utilization of the appropriate PPE and the general safety guidelines provided below will minimize the potential for worker exposure to impacted media:

1. All work conducted on-site will be coordinated through TNEC and will be consistent with the HASP.
2. The location of all utilities in the vicinity of the excavation will be established prior to beginning work;
3. All workers will remain at a safe distance from the excavation and under no circumstances will approach the excavation without the consent of TNEC;
4. A pre-work meeting shall be conducted at the beginning of each day to discuss the health and safety procedures;
5. All equipment used in an excavation will be properly cleaned and maintained in good working order. Equipment will be inspected for signs of defect and/or contamination before use; and
6. Eating, drinking, chewing gum, and smoking will be prohibited in active excavation areas.



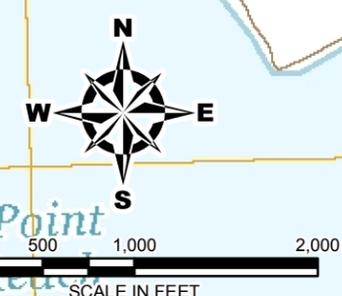
9.0 CONCLUSION

This document presents a comprehensive overview of the Project, including the existing natural and social environment, potential impacts, and the measures that will be implemented to avoid, minimize or mitigate these impacts.

Based on the analysis presented herein, there are no significant long-term impacts associated with the Project. The implementation of appropriate BMPs and mitigation measures during construction will avoid or minimize the construction-phase impacts to environmental resources and the social environment. Thus the short-term impacts will be temporary and negligible.



FIGURES



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SOUTH STREET SUBSTATION REDEVELOPMENT
 342 EDDY STREET
 PROVIDENCE, RHODE ISLAND

PROJECT SITE LOCATION

LEGEND
 Project Limits

SOURCES:
 1) 2015 1:24,000 PROVIDENCE, RI United States Geological Survey (USGS) electronic topographic map.

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PROJ MGR: MSK	REVIEWED BY: RB	CHECKED BY: DL	FIGURE
DESIGNED BY: JR	DRAWN BY: DJB	SCALE: 1" = 1,000 FEET	1
DATE: MAY, 2016	PROJECT NO: 03.0033964.01	REVISION NO: 0	



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SOUTH STREET SUBSTATION REDEVELOPMENT
342 EDDY STREET
PROVIDENCE, RHODE ISLAND

PROJECT ALIGNMENT
EXISTING AND PROPOSED

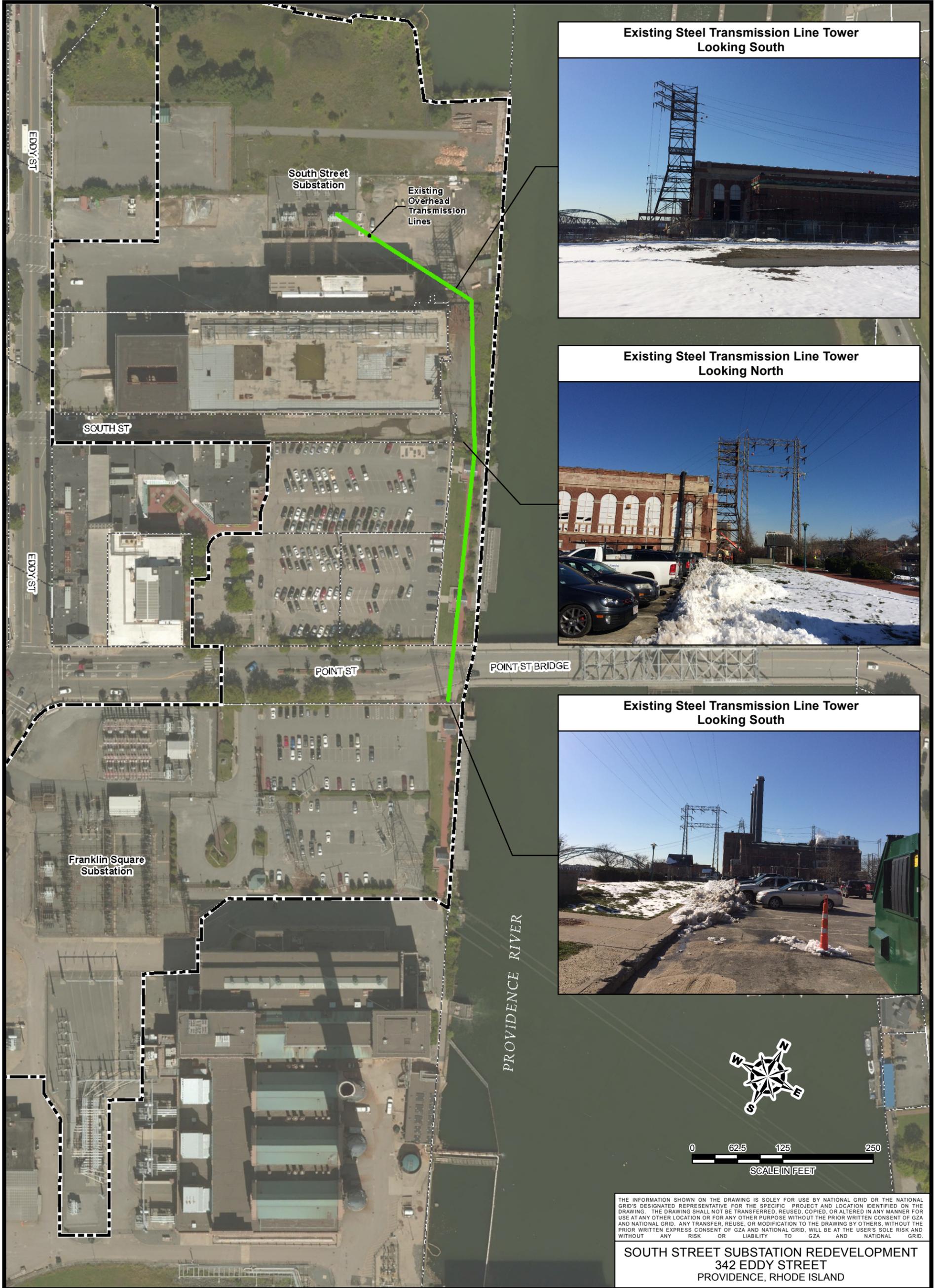
LEGEND

- Existing Overhead Transmission Lines
- Proposed Conduit Alignments
- Project Limits
- Parcel Boundaries

SOURCES:

1) THIS MAP CONTAINS THE BING MAPS AERIAL LAYER PACKAGE. THIS SERVICE USES UNIFORM NATIONALLY RECOGNIZED DATUM AND CARTOGRAPHY STANDARDS AND A VARIETY OF AVAILABLE SOURCES FROM SEVERAL DATA PROVIDERS.

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PROJ MGR: MSK	REVIEWED BY: RB	CHECKED BY: DL	FIGURE 2
DESIGNED BY: IR	DRAWN BY: DJB	SCALE: 1" = 125 FEET	
DATE: MAY, 2016	PROJECT NO. 03.0033964.01	REVISION NO. 0	



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**SOUTH STREET SUBSTATION REDEVELOPMENT
342 EDDY STREET
PROVIDENCE, RHODE ISLAND**

EXISTING TRANSMISSION LINE TOWERS

LEGEND

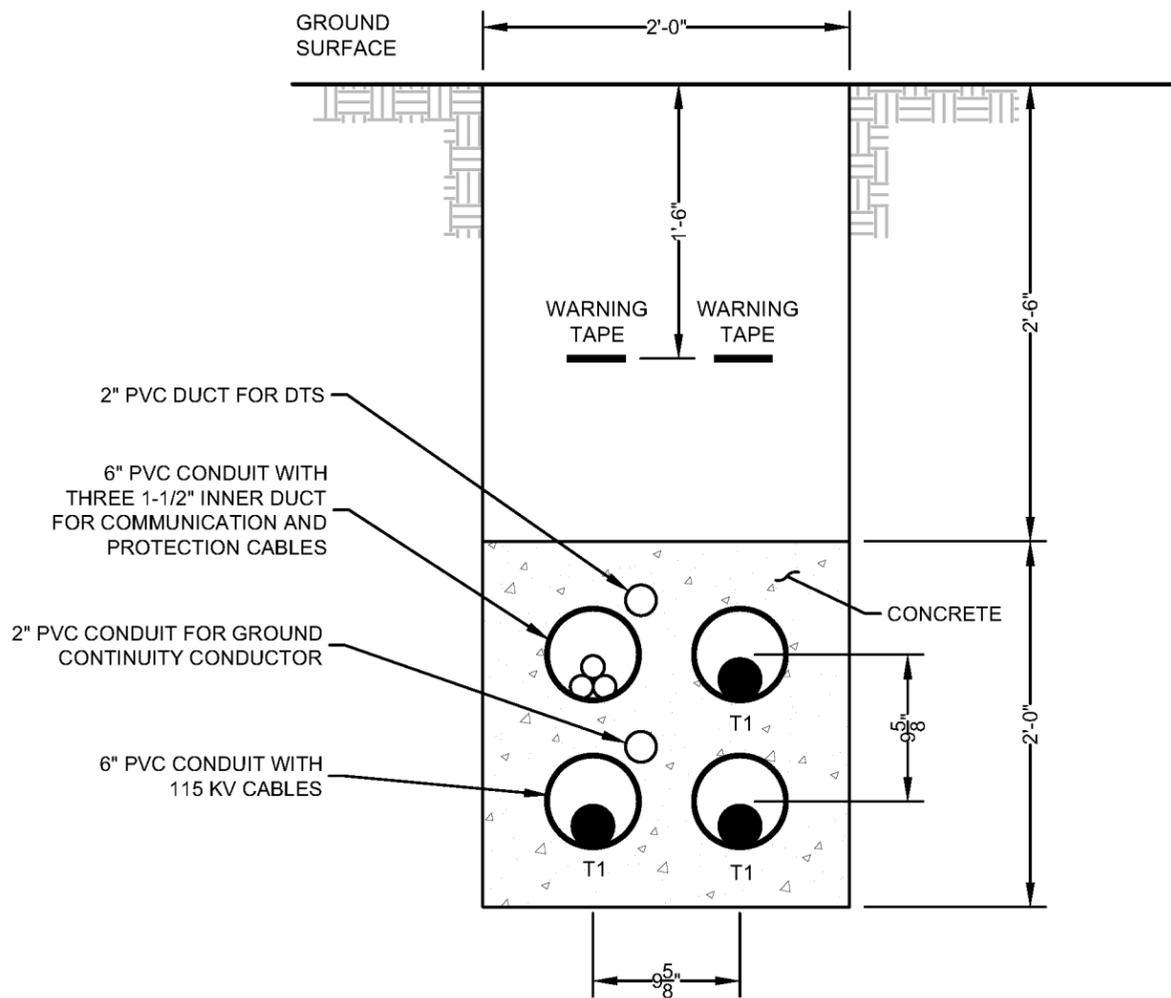
- Existing Overhead Transmission Lines
- Project Limits
- Parcel Boundaries

SOURCES:

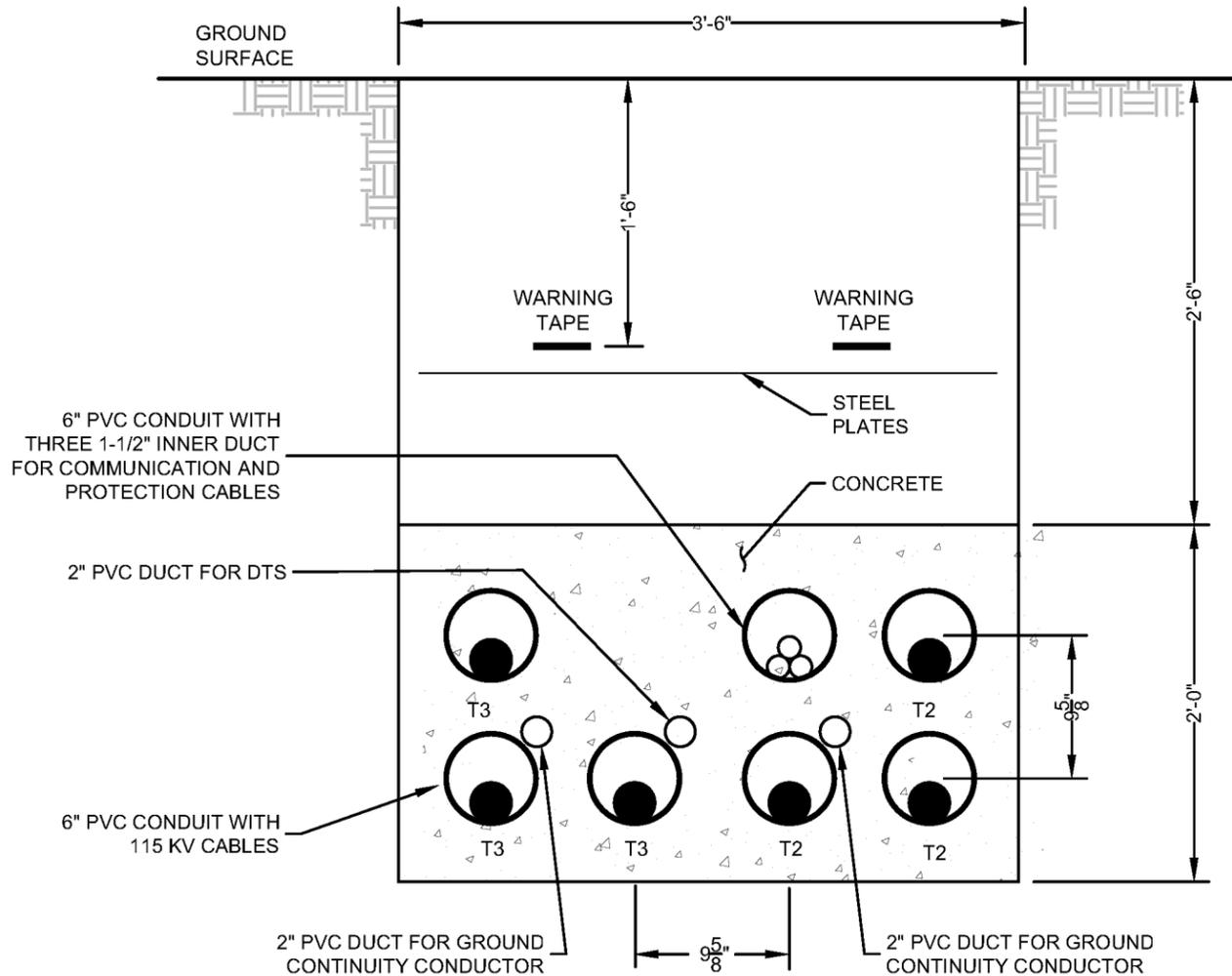
1) THIS MAP CONTAINS THE MICROSOFT BING MAPS AERIAL LAYER PACKAGE. THIS SERVICE USES UNIFORM NATIONALLY RECOGNIZED DATUM AND CARTOGRAPHY STANDARDS AND A VARIETY OF AVAILABLE SOURCES FROM SEVERAL DATA PROVIDERS.

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PROJ MGR: MSK DESIGNED BY: IR DATE: MAY, 2016	REVIEWED BY: RB DRAWN BY: DJB PROJECT NO. 03.0033964.01	CHECKED BY: DL SCALE: 1" = 125 FEET REVISION NO. 0	FIGURE 3

DAVOL SQUARE ROUTE T1 DUCT BANK
LOOKING NORTH TOWARDS SOUTH STREET SUBSTATION



WATERFRONT ROUTE T2 AND T3 DUCT BANK
LOOKING NORTH TOWARDS SOUTH STREET SUBSTATION

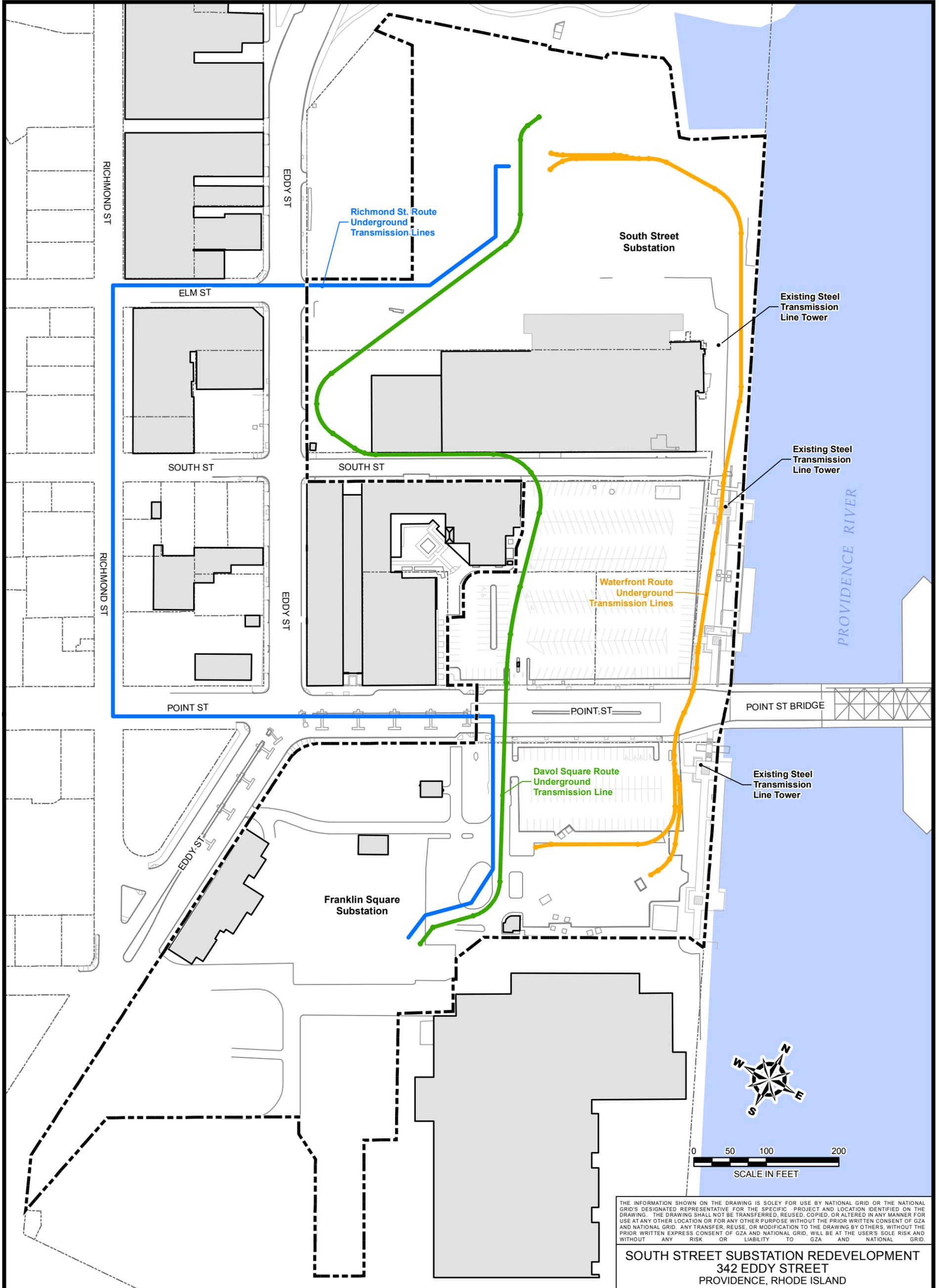


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SOUTH STREET SUBSTATION REDEVELOPMENT
342 EDDY STREET
PROVIDENCE, RHODE ISLAND

PROPOSED TRANSMISSION LINE
CROSS SECTIONS

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**SOUTH STREET SUBSTATION REDEVELOPMENT
342 EDDY STREET
PROVIDENCE, RHODE ISLAND**

**UNDERGROUND TRANSMISSION LINE
ALTERNATIVE ROUTES**

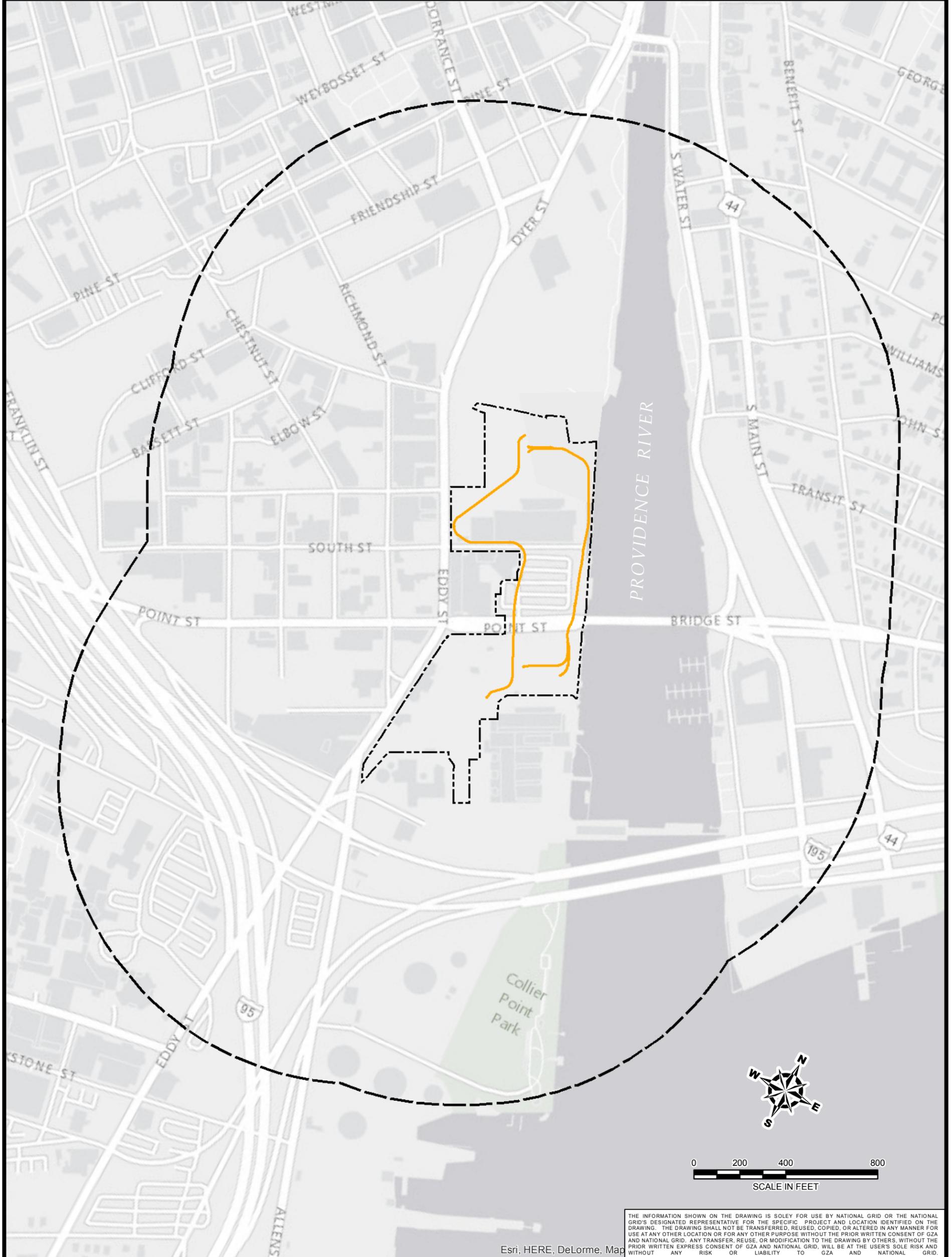
LEGEND

- Project Limits
- Richmond Route
- Davol Square Route
- Waterfront Route
- Parcel Boundaries

SOURCES:

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PROJ MGR: MSK	REVIEWED BY: RB	CHECKED BY: DL	FIGURE 5
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Esri, HERE, DeLorme, Map

LEGEND

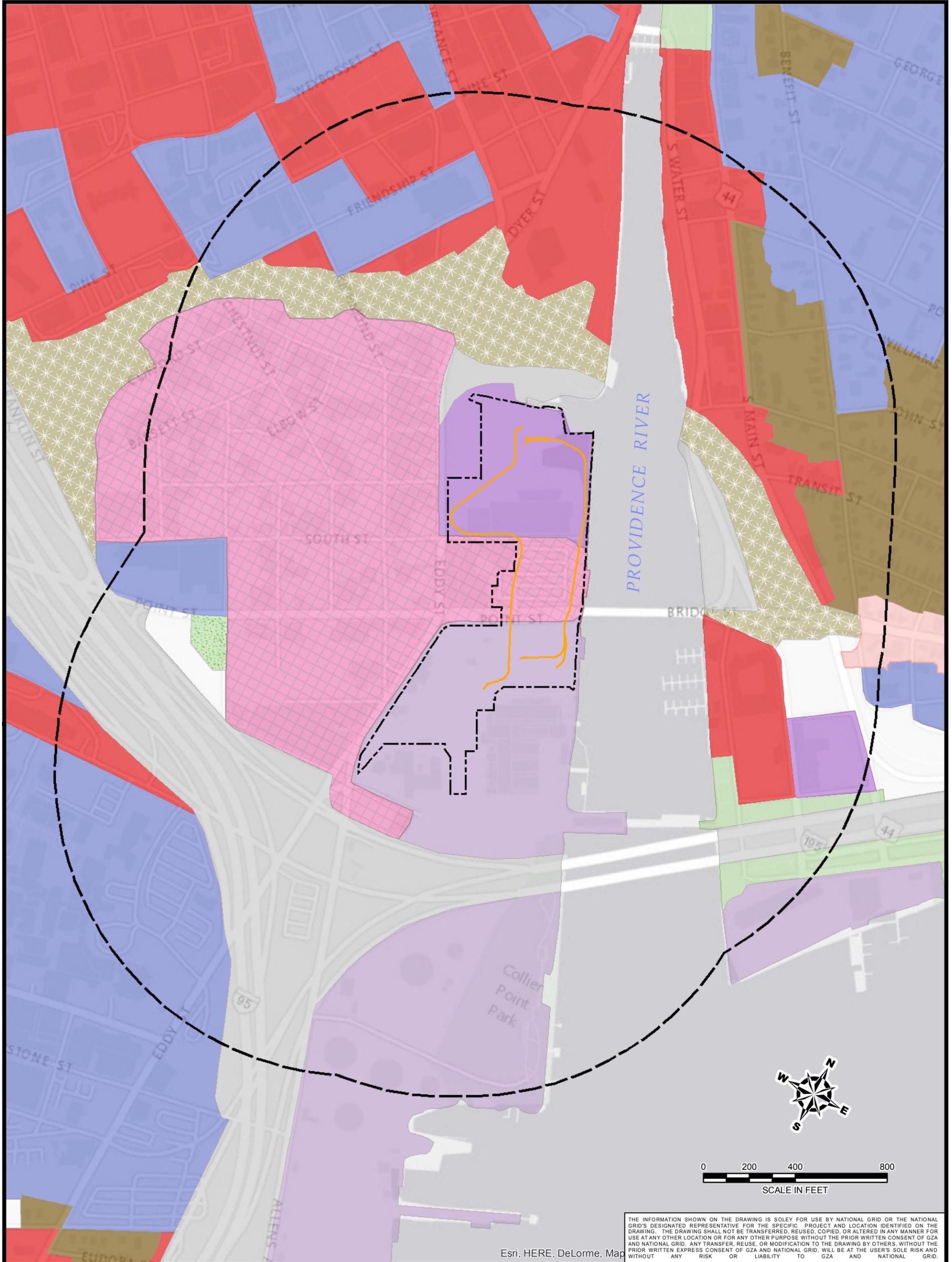
-  1/4 Mile Radius from Project Limits
-  Project Limits
-  Proposed Conduit Alignments
-  water_mask

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**SOUTH STREET SUBSTATION REDEVELOPMENT
342 EDDY STREET
PROVIDENCE, RHODE ISLAND**

STUDY AREA PLAN

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Esri, HERE, DeLorme, Map

LEGEND

- 1/4 Mile Radius from Project Limits
- Project Limits
- Proposed Conduit Alignments
- 2011 Land Use**
- High Density Residential (<1/8 acre lots)
- Commercial (Sale of products and services)
- Commercial/Residential Mixed
- Commercial/Industrial Mixed
- Industrial (manufacturing, design, etc.)
- Institutional (schools, hospitals, churches, etc.)
- Roads (divided highways > 200' + related fac.)
- Other Transportation (terminals, docks, etc.)
- Developed Recreation
- Brushland
- Vacant Land
- Transitional Areas (urban open)

SOURCES:

- 1) 2011 LAND USE - RIGIS, Photo Science Inc., Rhode Island Department of Environmental Management, Rhode Island Statewide Planning Program

**SOUTH STREET SUBSTATION REDEVELOPMENT
342 EDDY STREET
PROVIDENCE, RHODE ISLAND**

LAND USE PLAN

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DATE: MAY, 2016	PROJECT NO: 03.0033964.01	REVISION NO: 0	



APPENDIX A

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

Exponent[®]

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

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

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

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

Prepared for:

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

Prepared by:

Exponent
17000 Science Drive, Suite 200
Bowie, MD 20715

March 9, 2015

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Table of Contents

Table of Contents	i
List of Figures	i
List of Tables	ii
Acronyms and Abbreviations	iii
Limitations	iv
1 Executive Summary	v
2 Introduction	1
3 Extremely Low Frequency Electric and Magnetic Fields: Nature, Sources, Exposure, and Known Effects	2
Nature of ELF EMF	2
Sources and exposure	3
Known effects	5
4 Methods for Evaluating Scientific Research	7
Weight-of-evidence reviews	7
5 The WHO 2007 Report: Methods and Conclusions	15
6 Current Scientific Consensus	20
Childhood health outcomes	21
Adult health outcomes	26
Adult leukemia	29
Reproductive and developmental effects	30
Neurodegenerative diseases	32
Cardiovascular disease	35
<i>In vivo</i> studies related to carcinogenesis	36
7 Reviews Published by Scientific Organizations	41

8	Standards and Guidelines	43
9	Summary	45
10	References	46

List of Figures

Figure 1.	Numerous sources of ELF EMF in our homes (appliances, wiring, currents running on water pipes, and nearby distribution and transmission lines).	3
Figure 2.	Electric- and magnetic-field strengths in the environment.	5
Figure 3.	Basic IARC method for classifying exposures based on potential carcinogenicity.	16
Figure 4.	Possible explanations for the observed association between magnetic fields and childhood leukemia.	18

List of Tables

Table 1.	Criteria for evaluating whether an association is causal	13
Table 2.	Relevant studies of childhood leukemia	24
Table 3.	Relevant studies of childhood brain cancer	26
Table 4.	Relevant studies of breast cancer	27
Table 5.	Relevant studies of adult brain cancer	29
Table 6.	Relevant studies of adult leukemia	30
Table 7.	Relevant studies of reproductive and developmental effects	32
Table 8.	Relevant studies of neurodegenerative disease	35
Table 9.	Relevant <i>in vivo</i> studies related to carcinogenesis	40
Table 10.	Screening guidelines for EMF exposure	44

Acronyms and Abbreviations

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

Limitations

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

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

1 Executive Summary

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

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

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

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

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

New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (WHO, 2007, p. 347).

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

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

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

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

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

2 Introduction

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

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

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

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

Nature of ELF EMF

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

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

- **Electric fields** are the result of voltages applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m); one kV/m is equal to 1,000 V/m. Conducting objects including fences, buildings, and our own skin and muscle easily block electric fields. Therefore, certain appliances within homes and workplaces are the major source of electric fields indoors, while transmission and distribution lines are the major source of electric fields outdoors.
- **Magnetic fields** are produced by the flow of electric currents; however, unlike electric fields, most materials do not readily block magnetic fields. The strength of a magnetic field is expressed as magnetic flux density in units called gauss (G), or in milligauss (mG), where 1 G = 1,000 mG.³ The strength of the magnetic field at any point depends on characteristics of the source; in the case of power lines, strength is dependent on the arrangement of conductors, the amount of current flow, and distance from the conductors.

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



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

Sources and exposure

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

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

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

difficult to approximate, and exposure assessment is a major source of uncertainty in studies of ELF EMF and health (WHO, 2007).

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

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

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

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

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

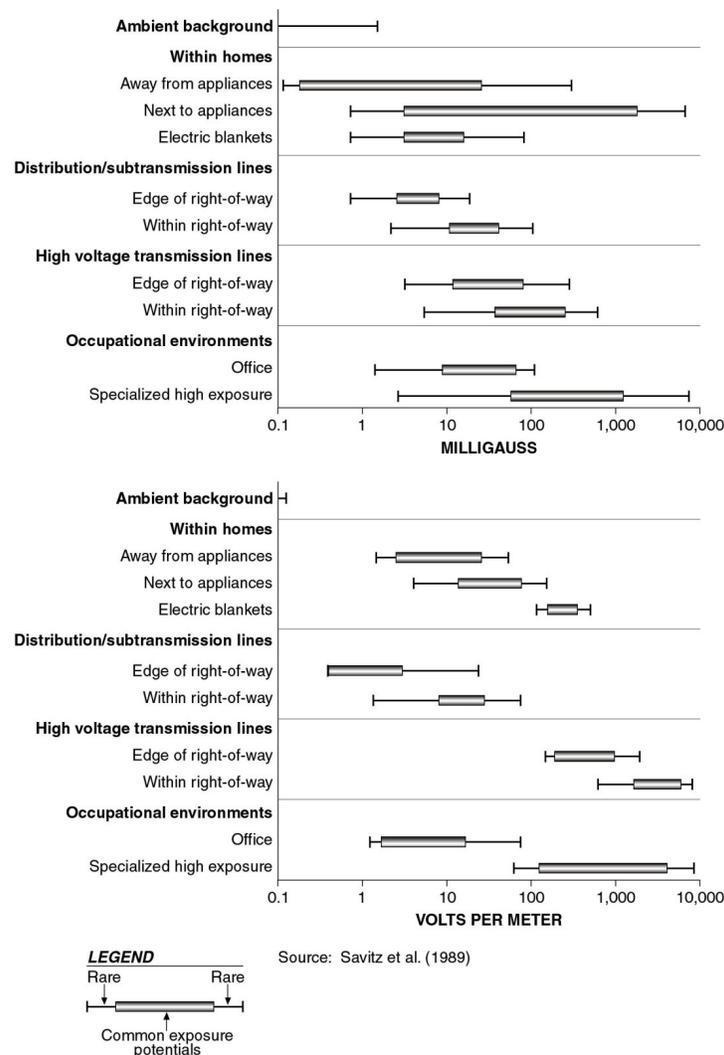


Figure 2. Electric- and magnetic-field strengths in the environment.

Known effects

Similar to virtually any exposure, adverse effects can be expected from exposure to very high levels of ELF EMF. If the current density or electric field induced by an extremely strong magnetic field exceeds a certain threshold, excitation of muscles and nerves is possible. Also,

strong electric fields can induce charges on the surface of the body that can lead to small shocks, i.e., micro shocks. These are acute and shock-like effects that cause no long-term damage or health consequences. Limits for the general public and workplace have been set to prevent these effects, but real-life situations where these levels would be exceeded are rare. Standards and guidelines are discussed in more detail in Section 8.

4 Methods for Evaluating Scientific Research

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

Weight-of-evidence reviews

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

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

Exposure considerations

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

measurements of magnetic fields in a particular location in the house (e.g., a child's bedroom); calculated magnetic-field levels based on the characteristics of nearby power installations; and, finally, personal 24-hour and 48-hour magnetic-field measurements.

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

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

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

Types of health research studies

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

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

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

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

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

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

Estimating risk

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

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

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

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

Statistical significance

Statistical significance testing provides an idea of whether or not a statistical association is a chance occurrence or whether the association is likely to be observed upon repeated testing. The terms “statistically significant” or “statistically significant association” are used in epidemiology studies to describe the tendency of the level of exposure and the occurrence of disease to be linked, with chance as an unlikely explanation. Statistically significant associations, however,

are not necessarily an indication of cause-and-effect, because the interpretation of statistically significant associations depends on many other factors associated with the design and conduct of the study, including how the data were collected and the number of study participants.

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

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

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

Meta-analysis and pooled analysis

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

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

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

Bias in epidemiology studies

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

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

Cause vs. association and evaluating evidence regarding causal associations

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

In 1964, the Surgeon General of the United States published a landmark report on smoking-related diseases (HEW, 1964). As part of this report, nine criteria for evaluating epidemiology studies (along with experimental data) for causality were outlined. In a more recent version of this report, these criteria have been reorganized into seven criteria. In the earlier version, which was based on the commonly referenced Hill criteria (Hill, 1965), coherence, plausibility, and

analogy were considered as distinct items, but are now summarized together because they have been treated in practice as essentially reflecting one concept (HHS, 2004). Table 1 provides a listing and brief description of each criterion.

Table 1. Criteria for evaluating whether an association is causal

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

Source: Department of Health and Human Services, 2004

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

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

Biological response vs. disease in human health

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

5 The WHO 2007 Report: Methods and Conclusions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (p. 347).

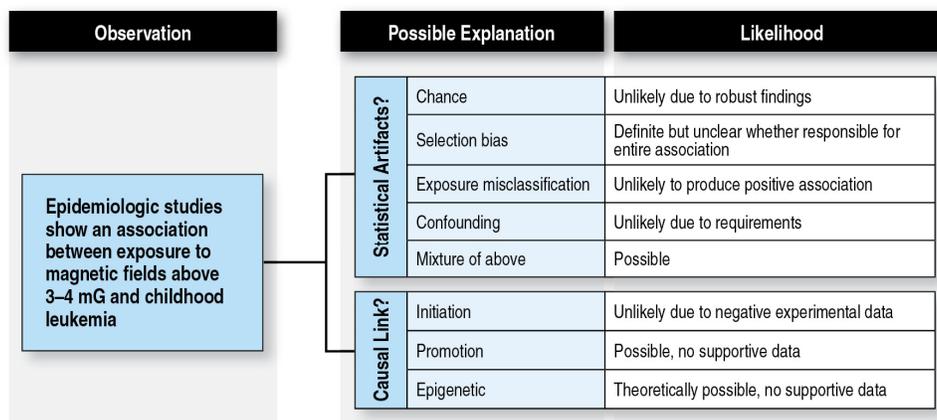
Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines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

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

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

The WHO report systematically evaluated several factors that might be partially, or fully, responsible for the consistent association, including: chance, misclassification of magnetic-field exposure, confounding from hypothesized or unknown risk factors, and selection bias. The authors concluded that chance is an unlikely explanation since the pooled analyses had a larger sample size and decreased variability; control selection bias probably occurs to some extent in these studies and would result in an overestimate of the true association, but would not explain the entire observed association; it is less likely that confounding occurs, although the possibility that some yet-to-be identified confounder is responsible for the association cannot be fully excluded; and, finally, exposure misclassification would likely result in an underestimate of the true association, although it is not entirely clear (see Figure 4 below). The WHO concluded that reconciling the epidemiologic data on childhood leukemia and the negative (i.e., no hazard or risk observed) experimental findings through innovative research is currently the highest priority

in the field of ELF EMF research. Given that few children are expected to have long-term *average* magnetic-field exposures greater than 3-4 mG, however, the WHO stated that the public health impact of magnetic fields on childhood leukemia would likely be minimal, if the association was determined to be causal.



Source: Adapted from Schüz and Ahlbom (2008)

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

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

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

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

In vivo research on carcinogenesis. The WHO concluded the following with respect to *in vivo* research, “[t]here is no evidence that ELF [EMF] exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate” (WHO, 2007, p. 10). Recommendations for future research included the

development of a rodent model for childhood acute lymphoblastic leukemia (ALL) and the continued investigation of whether magnetic fields can act as a co-carcinogen.

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

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

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

6 Current Scientific Consensus

The following sections identify and describe epidemiology and *in vivo* studies related to ELF EMF and health published between July 2013 and November 2014. The purpose of this section is to evaluate whether the findings of these recent studies alter the conclusions published by the WHO in their 2007 report, as described in Section 5. The previous Exponent report that summarized the literature up to July 2013⁸ concluded that recent results did not provide sufficient evidence to alter the basic conclusion of the WHO EHC published in 2007.

A structured literature search was conducted using PubMed, a search engine provided by the National Library of Medicine and the National Institutes of Health that includes over 15 million up-to-date citations from MEDLINE and other life science journals for biomedical articles (<http://www.pubmed.gov>). A well-defined search strategy was used to identify literature indexed between July 2013 and November 2014.⁹ All fields (e.g., title, abstract, keywords) were searched with various search strings that referenced the exposure and disease of interest.¹⁰ A researcher with experience in this area reviewed the titles and abstracts of these publications for inclusion in this evaluation. Only peer-reviewed, epidemiology studies, meta-analyses, and human experimental studies of 50/60-Hz AC ELF EMF and recognized disease entities, along with whole animal *in vivo* studies of carcinogenesis, were included. The following specific inclusion criteria were applied:

1. **Outcome.** Included studies evaluated one of the following diseases: cancer; reproductive effects; neurodegenerative diseases; or cardiovascular disease. Research on other outcomes was not included (e.g., psychological effects, behavioral effects, hypersensitivity). Few studies are available in these research areas and, as such, research evolves more slowly.
2. **Exposure.** The study must have evaluated 50/60-Hz AC ELF EMF.
3. **Exposure assessment methods.** Exposure must have been evaluated beyond self-report of an activity or occupation. Included studies estimated exposure through various methods including calculated EMF levels using distance from power lines; time-weighted average EMF exposures; and average exposure estimated from JEMs.
4. **Study design.** Epidemiology studies, meta-analyses, human experimental studies, and *in*

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

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

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

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

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

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

Childhood health outcomes

Childhood leukemia

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

Recent studies (July 2013 to November 2014)

Childhood leukemia remains one of the most studied health outcomes in ELF EMF epidemiologic research. Three large case-control studies from France, Denmark, and the United Kingdom have assessed the risk of childhood leukemia in relation to residential proximity to high-voltage power lines (Sermage-Faure et al., 2013; Bunch et al., 2014; Pedersen et al., 2014). The French study, which was discussed in the previous update, included 2,779 cases of childhood leukemia diagnosed between 2002 and 2007 and 30,000 control children (Sermage-Faure et al., 2013). The authors used geocoded information on residential address at the time of diagnosis for cases and at time of selection for controls. They reported no statistically significant increase in leukemia risk with distance to power lines. The authors, however, noted a statistically non-significant risk increase in a sub-analysis within 50 meters of 225-400 kV lines, but this was based on a small number of cases (n=9). The ensuing scientific correspondence

following the publication of the study focused on the magnitude of inaccuracies in distance assessment with geocoding as a main limitation of the study, and its implication on the inference that can be drawn from the study. The correspondence also addressed the statistical uncertainties of the results that are based on small numbers (Bonnet-Belfais et al. 2013; Magana Torres and Garcia, 2013).

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

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

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

The meta-analysis conducted by Zhao et al. (2014a) included nine case-control studies of EMF exposure and childhood leukemia published between 1997 and 2013. Zhao et al. reported a statistically significant association between average exposure above 4 mG and all types of childhood leukemia (OR 1.57; 95% CI 1.03-2.4). The meta-analysis relied on published results

from some of the same studies included in previous pooled analyses, and thus, provided little new insight.

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

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

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

Assessment

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

One of the major limitations of recent work remains the limited validity of the exposure assessment methods. Magnetic-field estimates have largely been based on calculated levels from nearby power lines, distance from nearby power lines, and measured, short-term residential

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

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

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

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

Table 2. Relevant studies of childhood leukemia

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

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

Childhood brain cancer

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

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

Recent studies (July 2013 to November 2014)

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

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

Assessment

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

Table 3. Relevant studies of childhood brain cancer

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

Adult health outcomes

Breast cancer

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

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

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

Recent studies (July 2013 to November 2014)

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

cancer with the level of estimated ELF magnetic-field exposure, the length of employment, or cumulative exposure in the exposed jobs.

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

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

Assessment

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

Table 4. Relevant studies of breast cancer

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

Adult brain cancer

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

The WHO stated the following:

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

Recent studies (July 2013 to November 2014)

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

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

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

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

Assessment

Findings from the recent literature predominantly support no association between exposure to ELF EMF and brain cancer in adults, but remain limited due to the exposure assessment methods and insufficient data available on specific brain cancer subtypes. Currently, the literature provides very weak evidence of an association in some studies, if any, between magnetic fields

and brain cancer.¹¹ The overall evidence for brain cancer has not materially changed and remains inadequate as classified by the WHO in 2007.

Table 5. Relevant studies of adult brain cancer

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

Adult leukemia

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

Recent studies (July 2013 to November 2014)

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

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

Assessment

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

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

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

Table 6. Relevant studies of adult leukemia

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

Reproductive and developmental effects

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

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

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

Recent studies (July 2013 to November 2014)

Two epidemiologic studies investigated the potential association between ELF EMF exposure and miscarriage or stillbirth. A hospital-based case-control study from Iran included 58 women with spontaneous abortion and 58 pregnant women (Shamsi Mahmoudabadi et al., 2013). The authors reported that measured magnetic-field levels were statistically significantly higher

among the cases than among controls. The study was small and provided little information on subject recruitment, exposure assessment, type of metric used to summarize exposure, and potential confounders; thus, it contributes little weight to an overall assessment.

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

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

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

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

pregnancies, but these results have implications for earlier studies that reported association for spontaneous abortions with peak measures but not with measures of central tendency.

Assessment

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

Table 7. Relevant studies of reproductive and developmental effects

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

Neurodegenerative diseases

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

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

of an association between estimated ELF exposure and [Alzheimer's] disease risk" (WHO 2007, p. 194).

Recent studies (July 2013 to November 2014)

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

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

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

investigated exposures and concluded that their results suggest no association with Parkinson's disease.

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

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

Assessment

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

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

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

Table 8. Relevant studies of neurodegenerative disease

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

Cardiovascular disease

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

The WHO concluded:

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

Recent studies (July 2013 to November 2014)

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

Assessment

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

In vivo studies related to carcinogenesis

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

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

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

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

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

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

Recent studies (July 2013 to November 2014)

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

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

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

Oxidative stress is a condition in which oxygen free radical levels in the body are elevated and is one mechanism by which DNA damage, as well as other forms of cellular damage, may occur. Numerous recent *in vivo* studies have evaluated whether magnetic-field exposure may be

associated with oxidative stress, with mixed results. Seifirad et al. (2014) examined the expression of various markers, including the lipid peroxidation markers malondialdehyde, conjugated dienes, and total antioxidant capacity, in the blood following exposure of rats to a 5,000 mG, 60-Hz magnetic fields for either 4 hours (acute) or 14 days (chronic). The acute exposure was associated with increased total antioxidant capacity, while the chronic exposure was associated with increased malondialdehyde levels and a reduced total antioxidant capacity. Although the controls were reportedly sham-exposed, it is not known if this was for the acute or chronic exposure condition, making interpretation difficult. Blinded analyses and control of environmental conditions also were not reported.

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

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

Manikonda et al. (2014) looked at the effects in rats of continuous, 90-day exposure to much lower magnetic field strengths (500 mG and 1,000 mG, 50-Hz). Controls were sham exposed in a similar exposure apparatus, but with the equipment turned off. Analyses were not reported to have been conducted in a blinded manner. Reactive oxygen species, thiobarbituric acid reactive substances (a marker of lipid peroxidation), and glutathione peroxidase were significantly increased compared to control levels in the hippocampus and cerebellum with both exposure conditions; they were also increased in the cortex, but at 1,000 mG only. Superoxide dismutase levels were also increased in all three tissues at 1,000 mG, while the thiol status (GSH/GSSG)

was reduced with exposure in these tissues. Generally, the cortex was less responsive than the other brain tissues examined. It should be noted, however, that the exposed rats showed significantly higher levels of physical activity than the controls, which may have confounded the study results. Finally, Akdag et al. (2013) examined the effects of more long-term magnetic-field exposure. Rats were continuously exposed to a 1,000 or 5,000 mG, 50-Hz magnetic field for 2 hours per day for 10 months. Control rats were sham exposed (with the exposure system turned off) and analyses were reported to have been conducted in a blinded manner. Neither exposure condition affected the expression of various oxidant/anti-oxidant markers in the testes, although expression of an apoptosis marker seemed to be increased in an exposure-related manner.

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

Assessment

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

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

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

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

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

7 Reviews Published by Scientific Organizations

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

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

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

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

The Swedish Radiation Protection Authority

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

8 Standards and Guidelines

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

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

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

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

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

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

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

Table 10. Screening guidelines for EMF exposure

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

Sources: ICNIRP, 2010; ICES, 2002

9 Summary

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

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

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