B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Big Eddy-Knight Transmission Project

Final Environmental Impact Statement

Volume 2: Appendices

July 2011

DOE/EIS-0421

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BONNEVILLE POWER ADMINISTRATION

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Appendix A

Living and Working Safely Around High-Voltage Power Lines

BONNEVILLE POWER ADMINISTRATION

Living and Working Safely

Around High-voltage Power Lines

High-voltage power lines can be just as safe as the electrical wiring in our homes — or just as danger-ous. The key is learning to act safely around them.

This booklet is a basic safety guide for those who live and work around power lines. It deals primarily with nuisance shocks caused by induced voltages and with possible electric shock hazards from contact with high-voltage lines.

In preparing this booklet, the Bonneville Power Administration has drawn on more than 70 years of experience with high-voltage power lines. BPA operates one of the world's largest networks of long-distance, high-voltage lines, ranging from 69,000 volts to 500,000 volts. This system has more than 200 substations and more than 15,000 miles of power lines.

BPA's lines make up the main electrical grid for the Pacific Northwest. The grid delivers large blocks of power to substations located near load centers. Public and investor-owned utilities and rural cooperatives take delivery of the power at these points and deliver it to the ultimate customers.

BPA's lines cross all types of property: residential, agricultural, industrial, commercial and recreational.

If you have questions about safe practices near power lines, call BPA.

Due to safety considerations many of the practices suggested in this booklet are restrictive. This is because they attempt to cover all possible situa-tions, and the worst conditions are assumed. In certain circumstances, the restrictions can be re-evaluated. To determine what practices are applicable to your case, contact BPA at 1-800-836-6619 or find the contact information for the local BPA office at *www.transmission.bpa.gov/LanCom/Real_Property.cfm*.

Using the Right-of-Way

Before a power line is built, BPA negotiates with the landowner for the right to cross the land as required for the construction, operation and maintenance of the line. Usually, BPA acquires right-of-way rights to construct, operate and maintain a power line and the right to keep the right-of-way clear of all structures, fire hazards, vegetation and any other use that may interfere with the operation or maintenance of the line. Most crops, less than 10 feet in height, can be grown safely under power lines. Orchards, Christmas trees and structure-supported crops (i.e., trellises) require special consideration.

Call BPA if you plan to use the right-of-way for any use.

BPA's "Landowner's Guide for Compatible Use of BPA Rights-of-Way" explains how to apply for permission to use a portion of a BPA right-of-way for approved purposes. This document can be found online at *www.transmission.bpa.gov/LanCom/Real_ Property.cfm* or by contacting BPA at 1-800-836-6619.

Construction and maintenance of any structures are specifically prohibited within a BPA right-of-way. Coordinating with BPA early in your planning process can keep you safe and avoid wasting time and money.

Most crops, less than 10 feet in height, can be grown safely under power lines.

General Safe Practices

BPA designs and maintains its facilities to meet or exceed the rules set forth in the National Electrical Safety Code. BPA provides information on safe practices because serious accidents involving power lines can be avoided if simple precautions are taken. Every kind of electrical installation — from the 110-volt wiring in your home to a 500,000-volt power line — must be treated with respect.

The most significant risk of injury from a power line is the danger of electrical contact. Electrical contact between an object on the ground and an energized wire can occur even though the two do not actually touch. In the case of high-voltage lines, electricity can arc across an air gap. The gap distance varies with the voltage at which the line is operated. Unlike the wiring in a home, the wires of overhead power lines are not enclosed by electrical insulating material.

The most important safe practice is this:

Avoid bringing yourself, or any object you are holding, too close to an overhead power line.

In other words, do not lift, elevate, build or pass under a power line with any object, equipment, facility or vehicle that could come close to the energized wires.

BPA does not recommend that anyone attempt to calculate how close they can come to a power line. As a general precaution, when under a line, never put yourself or any object any higher than 14 feet above the ground.

The National Electrical Safety Code specifies a minimum safe clearance for each operating voltage. BPA builds its lines so the clearance between the wires of a power line and the ground meets or exceeds the minimum safe clearance set forth in the code. Therefore, do not alter the ground elevation; without first applying to BPA, call 1-800-836-6619 to ensure safe distances are maintained.

Vehicles and large equipment that do not extend more than 14 feet in height, such as harvesting combines, cranes, derricks and booms, can be operated safely under all BPA lines that pass over roads, driveways, parking lots, cultivated fields or grazing lands.

For your safety, coordinate with BPA if you need to exceed the 14-foot limitation.

Possible Shock Hazards

The previous section discussed dangerous electrical contact conditions that can occur when getting too close to the high-voltage wires. This section

Farm equipment or large machinery 14 feet or less in height may be operated safely under all BPA lines in cultivated fields.

will discuss the possible electrical shock hazards that can occur when touching transmission towers or metallic objects near the power line but away from the high-voltage wires.

These types of shocks are caused by a voltage induced from the power line into the nearby metallic objects. Typically the shocks can be avoided when the nearby metallic objects are grounded or connected to earth. The severity of these shocks depends on the operating voltage of the power line, the distance from the conductor, the size or length of the object, its orientation to the line and how well the object is grounded.

Normally, shocks do not occur when BPA's guidance is followed (see the following sections). However, under certain conditions, non-hazardous nuisance shocks can still occur and possibly cause discomfort.

The severity of nuisance shocks can vary in sensation from something similar to a shock you might receive when you cross a carpet and then touch a door knob to touching the spark-plug ignition wires on your lawnmower or car. The nuisance shock, however, would be continuous as long as you are touching the metallic object. Such objects include vehicles, fences, metal buildings or roofs and irrigation systems that are near the line or parallel the line for some distance.

The possibility of nuisance shocks can be eliminated by grounding metal pipe when unloading near BPA lines.

Irrigation Systems

All types of irrigation systems have been operated safely near BPA power lines for years. Nonetheless, caution should be used in storing, handling and installing irrigation pipe, and in operating spray irrigation systems near power lines.

To avoid electrical contact with power lines, two very important safety practices should be observed at all times:

1. While moving irrigation pipe under or near power lines, keep the equipment in a horizontal position to keep it away from overhead wires.
2. Electricity can be conducted through water so never allow the irrigation system to spray a continuous stream onto power lines or towers.

In addition, central pivot circular irrigation systems installed near or under power lines can develop hazardous shock potentials during operation and maintenance. To eliminate these hazards:

- Provide a good electrical ground for the pivot point.
- Do not touch the sprinkler pipe or its supporting structures when the system is operating under or parallel to and near a power line.
- Perform repairs/maintenance of the system with the sprinkler pipe perpendicular to the power line.

For more information on storing, handling, installing or operating an irrigation system on BPA rights-of-way and to apply to use BPA's right-of-way please contact BPA at 1-800-836-6619. A copy of "Guidelines for Installation and Operation of Irrigation Systems" will be provided when you contact BPA for approval. This document describes methods for safely installing and operating an irrigation system under high-voltage power lines. This document also can be obtained at *www.transmission.bpa.gov/LanCom/Real_ Property.cfm.*

Irrigation pipe should be moved in a horizonal position under and near all power lines to keep it away from the lines overhead.

Underground Pipes, Telephone Cables and Electric Cables

Underground pipes and cables may be compatible with power lines provided installation and maintenance are done properly. Pipes and cables should not be installed closer than 50 feet to a BPA tower, any associated guy wires or grounding systems. These grounding systems are long, buried wires that are sometimes attached to the structures and can run up to 300 feet along the right-of-way. These grounding systems are not visible above ground and must be located before installing any underground utilities.

Proper positioning of underground utilities is required to prevent an accident in an extreme case when an unusual condition might cause electricity to arc from the high-voltage wire to the tower and then to ground. This could produce a dangerous voltage on underground piping or cable system. Contact BPA at 1-800-836-6619 to apply before installing any underground utilities within a BPA power line right-of-way.

Fences

BPA strongly discourages locating fences within the right-of-way as they can cause a potential safety hazard and an access problem (particularly in high-density subdivisions). Contact BPA at 1-800-836-6619 if you are interested in submitting an application to place a fence on the right-of-way using the guideline that the location must be a minimum of 50 feet from BPA structures as well as other considerations discussed below.

Wire Fences

Barbed wire and woven wire fences insulated from ground on wood posts can assume an induced voltage when located near power lines. If you are having a shock-related problem, call BPA for an investigation. The fence may need to be grounded if:

- it is located within the right-of-way;
- it parallels the line within 125 feet of the outside wire and is longer than 150 feet; or
- it parallels the line 125 to 250 feet from the outside wire and is longer than 6,000 feet.

These fences should be grounded at each end and every 200 feet with a metal post driven at least 2 feet into the ground. Attach all wire strands of the fence to the metal post. Install the grounding posts at least 50 feet from the nearest transmission tower. If shocks are experienced when contacting a fence or gate, or if you have any questions about the need for grounding, call BPA at 1-800-836-6619.

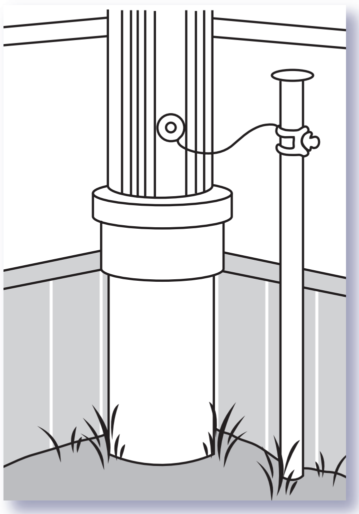
Electric Fences

In situations where a fence cannot be grounded (electric fences, for example), a filter may be installed to remove voltages induced by the power lines. BPA may provide this filter after an investigation has been conducted. Do not use fence chargers that are not approved by Underwriters' Laboratories, Inc. They may carry voltages and currents that are hazardous to anyone touching the fence — even if power lines are not present. For more information about fences, fence chargers or filters, call BPA at 1-800-836-6619.

Buildings

This section applies to buildings outside BPA's rights-of-way, since BPA prohibits buildings within a right-of-way.

Buildings located off BPA's rights-of-way may collect an induced voltage. This voltage is often drained through the building's plumbing, electrical service, metal sheeting or metal frame. If the voltage does not drain through the systems described above, then it can result in a nuisance shock situation.



Example of grounding a metal building at a down spout.

BPA recommends grounding metallic components on buildings near a power line when:

- the building is within 100 feet of the outside wire;
- the building has more than 2,000 square feet of metal surface and is within 100 to 150 feet of the outside wire; or
- the building is used to store flammable materials and is within 250 feet of the outside wire.

BPA will assist in grounding metallic objects after receiving a request and an investigation has been conducted. Call BPA at 1-800-836-6619 if you are having shock-related problems or if you have any question on grounding a building.

Vehicles

Under some high-voltage lines, vehicles can collect an induced voltage. This is particularly true if the vehicle is parked on a nonconductive surface such as asphalt or dry rock. You can drain the voltage from your vehicle to the ground by attaching a chain that reaches the ground or by leaning a metal bar against your vehicle. The only way to be sure you won't get shocked is to park your car away from the high-voltage power line.

BPA has specific restrictions for parking and roads within the right-of-way to keep possible shocks at a low level. Contact BPA at 1-800-836-6619 to apply before locating roads and parking areas within the BPA right-of-way.

Refueling vehicles is not allowed on BPA rights-of-way because there is a chance that a spark from an induced voltage could ignite the fuel.

Lightning

Lightning will usually strike the highest nearby object, which might be a power line tower or wire. Transmission facilities are designed to withstand lightning strikes by channeling them to ground at the tower.

Play it safe. Stay away from power lines and other tall objects during electrical storms. Lightning is dangerous if you are standing near where it enters the ground.

Fires

Smoke and hot gases from a large fire can create a conductive path for electricity. When a fire is burning under a power line, electricity could arc from the wire, through the smoke and to the ground, endangering people and objects near the arc. BPA does not permit burning within the right-of-way.

Field burning and other large fires in and around power lines can damage power lines and cause power outages. Water and other chemicals used to extinguish those fires should never be directed toward a power line.

Contact BPA at 1-800-836-6619 if you need to burn near a BPA right-of-way.

A fire burning under a power line can create a dangerous situation. Stay away from lines if a fire is nearby.

Kite Flying and Model Airplanes

BPA strongly discourages anyone from flying a kite or model airplane anywhere near a power line. The electricity from the line can travel through the string or hand line and electrocute a person on the other end. If your kite or model airplane is about to touch a power line, drop the string or hand line instantly, before it touches the line. Do not try to pull the kite or airplane down or climb up after it. Call the nearest electric utility.

Vandalism, Shooting and Trespassing

People entering high-voltage electrical facilities, such as substations and power line rights-of-way, for the purpose of vandalism or theft, run the risk of serious injury or death. For example, when hunting, do not shoot at transmission facilities. Gunshot damage can cause flashovers or may cause the wire to fall to the ground. This could be a serious hazard to anyone close to the power line. It could also cause a power outage and a fire.

Removal of equipment from substations or power line facilities can result in unsafe operating conditions and put people nearby at risk of serious injury or death. Those who cause willful damage to BPA transmission facilities or associated property can be prosecuted by the federal government, the property owner, or both.

Please report damage to transmission facilities to BPA's Crime Witness Program at 1-800-437-2744. The Crime Witness Program allows you to confidentially report an illegal activity that you witness against BPA's transmission system, property or personnel. This includes:

- Shooting at power lines, transmission towers or substation equipment.

- Dumping any waste or material on BPA property.
- Vandalism to BPA property, buildings and vehicles.
- Theft of BPA equipment, supplies, tools or materials.

This program offers rewards of up to $25,000 for information leading to the arrest and conviction of the perpetrator(s).

Tall Objects

Facilities

Temporary or permanent facilities within the right-of-way such as, light standards, signs, above-ground utilities, etc., can create unsafe situations when constructed too close to BPA power lines and structures. Permissable heights for such facilities can vary depending on site specfic conditions. Call BPA at 1-800-836-6619 to apply for these uses.

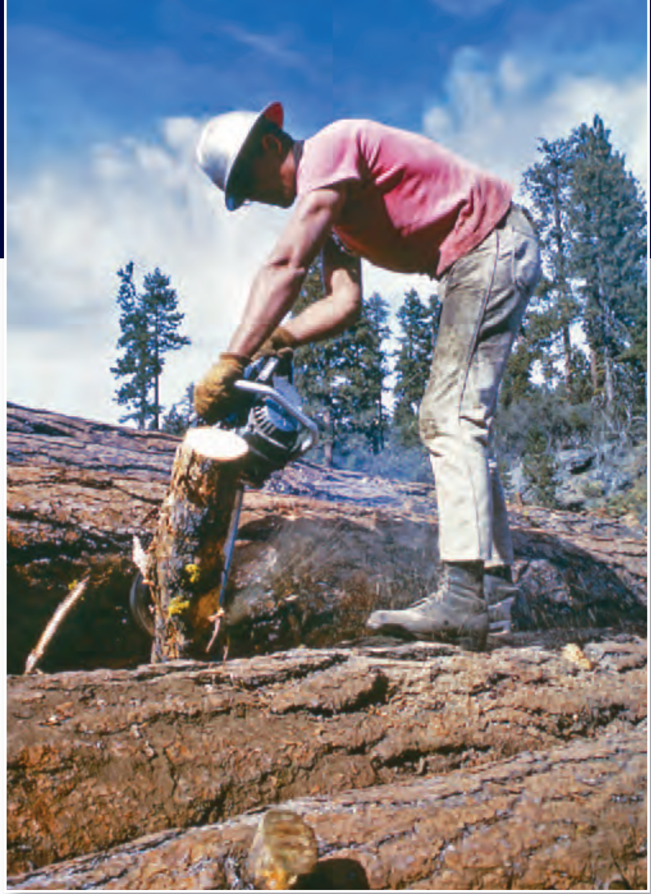
Activities

As a precautionary practice, do not raise any metal object more than 14 feet in the air underneath a power line. For example, when you mount an antenna on a vehicle that you plan to operate on a BPA right-of-way, do not let it extend more than 14 feet above the ground.

Before you sail a boat on a lake or river, check the allowable clearance under any power line. We recommend that all masts or guy wires above the deck be connected electrically to an underwater metallic part such as the keel or centerboard.

This precaution, which protects against lightning or accidental contact with a power line, may save your life.

Remember, if you plant, dig or build within the right-of-way an application is required. Any activities or use with a reach capacity greater than 14 feet (eg. cranes, dump trucks, irrigation systems, etc.) may cause safety concerns. Please specifically identify these uses and equipment in your application. Contact BPA to apply at 1-800-836-6619.



Cutting trees within power line rights-of-way can be dangerous. It is safer to have BPA do it for you.

Pools

BPA does not permit the building of swimming pools within BPA rights-of-way because it impedes our ability to operate and maintain the power line and presents a potential safety hazard to the public. Hazards range from possible electrical contact with the wires (with pool skimmers or rescue poles, for example) to dangers that can be encountered during and after lightning strikes on transmission facilities.

Climbing

Climbing on power line towers or guy wires can be extremely hazardous. Do not do it under any circumstance. It is dangerous and illegal.

Pacemakers

Under some circumstances, voltages and currents from power lines and electrical devices can interfere with the operation of some implanted cardiac pacemakers. However, we know of no case where a BPA line has harmed a pacemaker patient.

As a precaution, people who may have reason to be very near high-voltage facilities should consult with a physician to determine whether their particular implant may be susceptible to power line interference.

If a person with a pacemaker is in an electrical environment and the pacemaker begins to produce a regularly spaced pulse that is not related to a normal heartbeat, the person should leave the environment and consult a physician.

Trees and Logging

No logging or tree cutting should be done within BPA's right-of-way without first contacting BPA at 1-800-836-6619 to apply. In many cases, BPA owns the timber within its rights-of-way.

Additionally, logging or tree cutting near power lines can be very hazardous and requires special caution. Since trees conduct electricity, if one should fall into or close to a power line, the current could follow the tree trunk to the ground and endanger anyone standing near its base. Here are two simple rules:

1. If you come upon a tree that has fallen into a power line, stay away from it.
2. If you accidentally cause a tree to fall into a power line, run for your life! Do not go back to retrieve your saw or equipment. Call BPA or your local utility immediately.

If you have trees either on or close to the right-of-way that need to be cut, contact BPA at 1-800-836-6619. It is unsafe to do it yourself.

Since power line rights-of-way usually are not owned by BPA but are acquired through easements from landowners, trees or logs stacked within or alongside the rights-of-way are not public property. People removing trees and logs without permission are stealing and can be prosecuted.

Explosives

If you plan to detonate explosives near a BPA power line, apply to BPA well in advance by calling 1-800-836-6619 or find the contact information for your local office at *www.transmission.bpa.gov/LanCom/Real_ Property.cfm.* BPA will tell you if any special precautionary measures must be taken at a particular blasting site.

Any blasting near or within BPA rights-of-way must not damage any BPA facilities or permitted uses within the rights-of-way. Do not use electric detonating devices when blasting within 1,000 feet of a power line. Use of non-electric methods of detonation will avoid the danger of accidentally discharging an electric blasting cap due to induced voltages from energized transmission facilities.

Towers and Wires

- Do not climb towers.
- Do not shoot or otherwise damage transmission facilities.
- Never touch a fallen wire.
- Do not attempt to dismantle towers.
- Do not attach anything to towers.
- Stay away from towers and lines during extreme windstorms, thunderstorms, ice storms or under other extreme conditions.

Preventive measures include:

- Report any suspicious activities to BPA at 1-800-437-2744 or to your nearest electrical utility.
- Stay away from and report damage to transmission facilities to BPA at 1-800-437-2744 or your nearest electrical utility.
- Stay away from and report broken, damaged or abnormally low-hanging wires to BPA at 1-800-437-2744 or your nearest electrical utility.

Conclusion

We live in an age of electric power. Almost everything we do requires it. Consequently, high-voltage power lines have become about as commonplace as the wiring in our homes. Nevertheless, every year people are killed or seriously injured by power lines and home wiring. In almost every case, lives could have been saved and injuries avoided if the basic safety practices outlined in this booklet had been followed. BPA and your local utilities make every effort to design and build power lines that are safe to live and work around. Ultimately, however, the safety of high-voltage lines depends on people behaving safely around them. No line can practicably be made safe from a person who, through ignorance or foolishness, violates the basic principles of safety. Please take time now to learn the practices outlined in this booklet and share your knowledge with your family, friends and colleagues. Your own life, or that of a loved one, might well hang in the balance.

Related BPA Publications and Guidelines

For more information, call BPA at 1-800-836-6619 for the following publications:

1. **"Landowner's Guide for Compatible Use of BPA Rights-of-Way"** (DOE/BP-3657)

2. **"Landowner's Guide to Trees and Transmission Lines"** (DOE/BP-3076)

3. **"Keeping the Way Clear for Better Service"** (DOE/BP-2816)

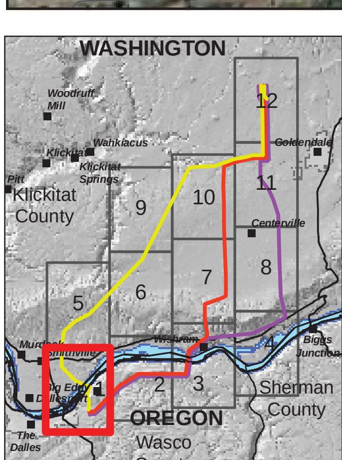
4. **"Guidelines for Installation and Operation of Irrigation Systems"**

These documents also can be found at *www.transmission.bpa.gov/LanCom/Real_Property.cfm.*

Bonneville Power Administration
PO Box 3621 Portland, Oregon 97208-3621
DOE/BP–3804 • October 2007 • 3M

Appendix B

Aerial Photomap Series



Existing Facilities
- BPA Substation
- BPA Tower
- BPA Transmission Line
- Railroad
- House/Business (Within about 800' of the Alternative)
- Wind Turbine
- Columbia River Gorge National Scenic Area

Proposed Facilities
- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads
- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
- Temporary Road

Wetland Survey
- Confirmed Wetland*
- Unverified Wetland*
- Wetland id — Potentially Impacted Wetland
- Woodland #

*Wetlands may be larger than depicted extending beyond the right-of-way.

N / W / E / S

0 0.2 0.4 0.6 0.8 Miles

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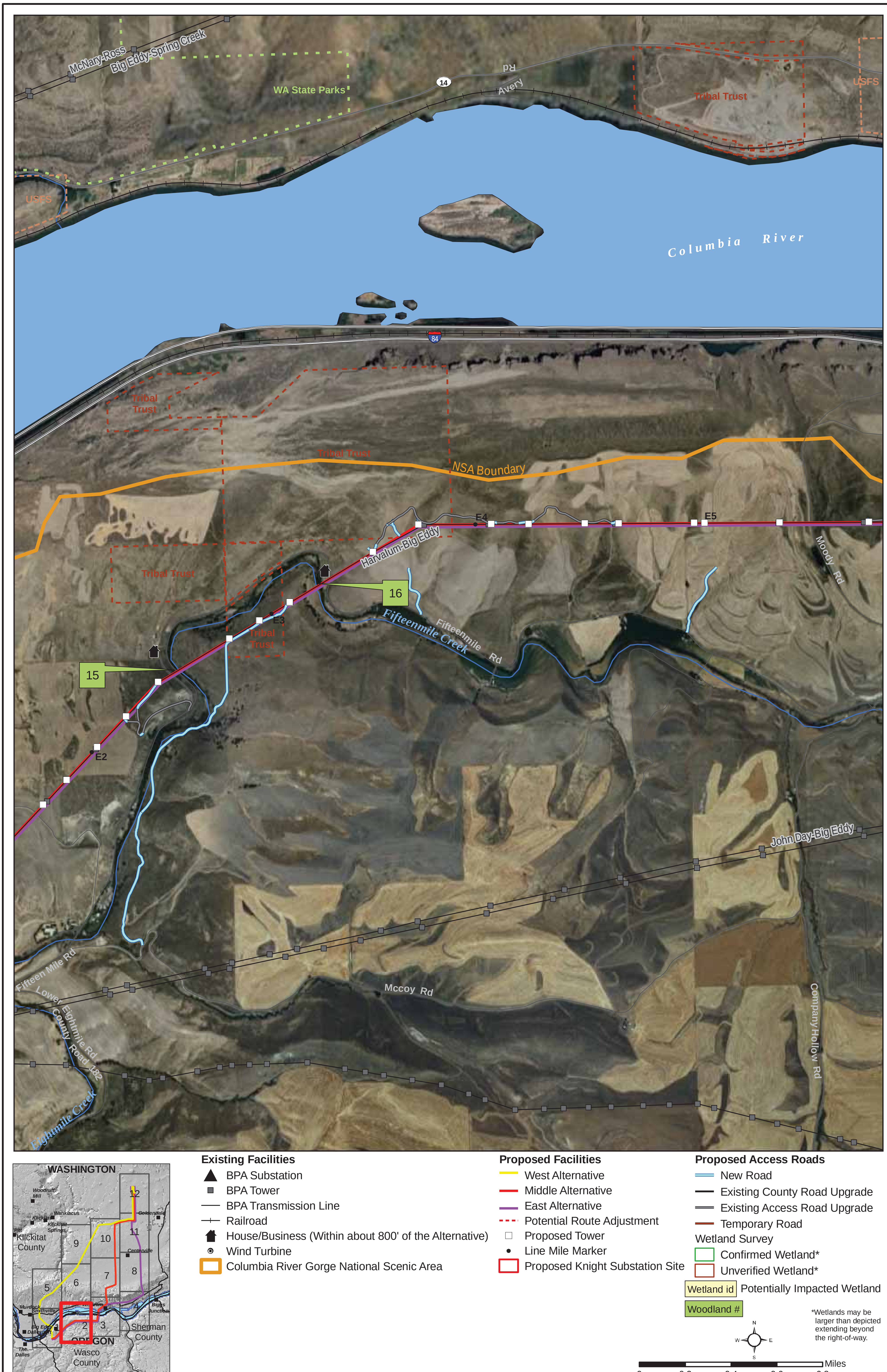
Map B-1. Aerial Photomap Series



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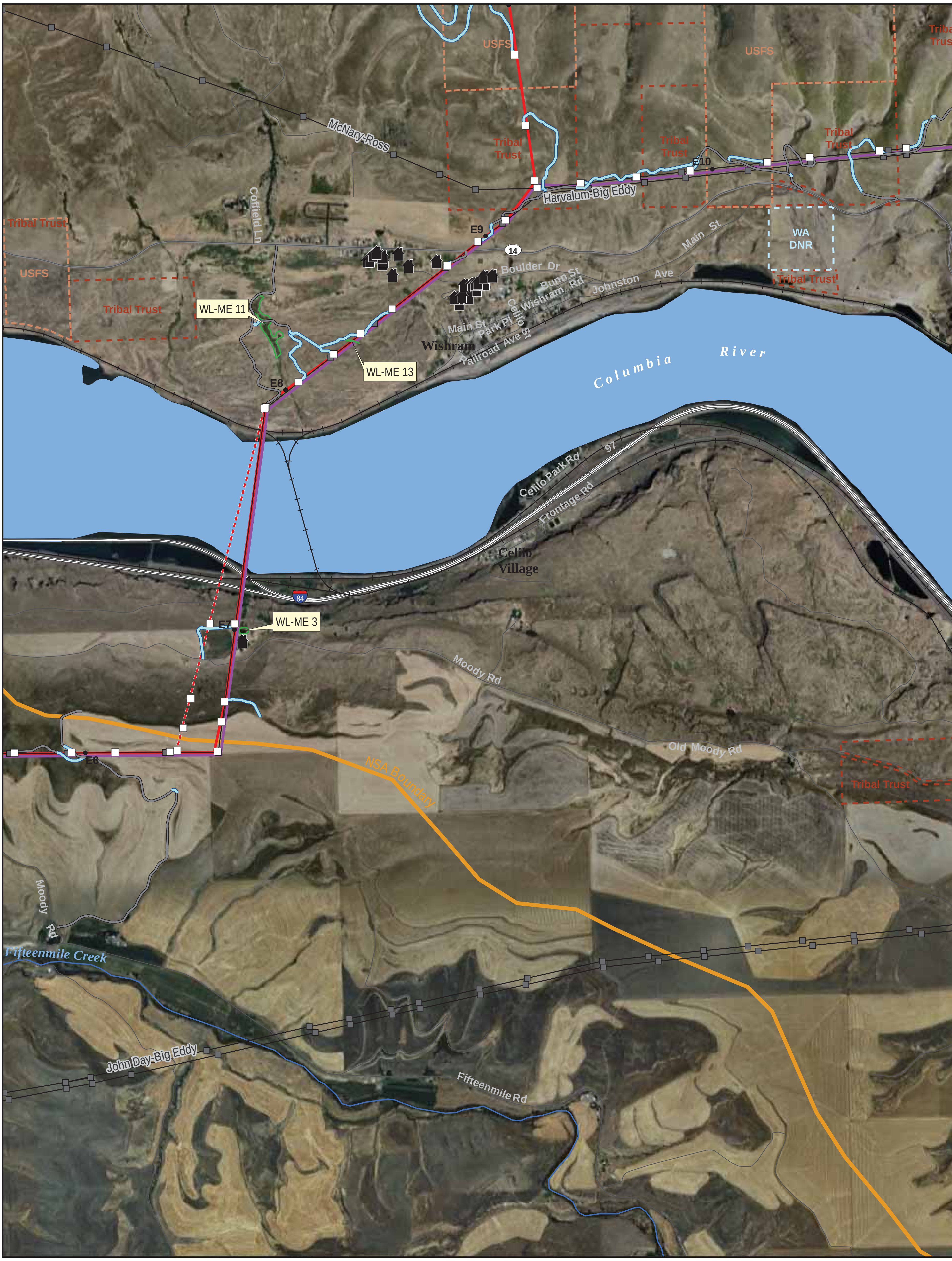
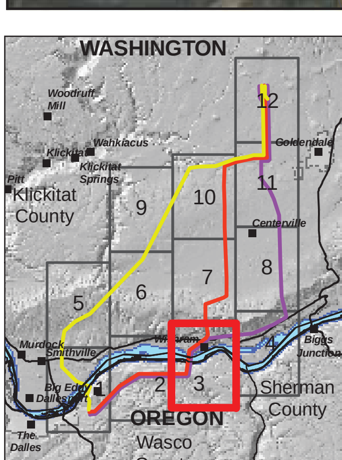
Map B-2. Aerial Photomap Series





Existing Facilities

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Proposed Facilities

- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads

- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
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Wetland Survey

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N W E S

0 0.2 0.4 0.6 0.8 Miles

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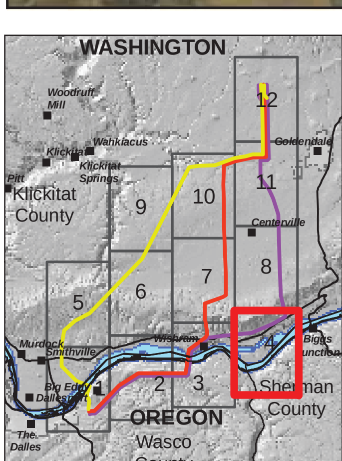
Map B-3. Aerial Photomap Series



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0 0.2 0.4 0.6 0.8 Miles

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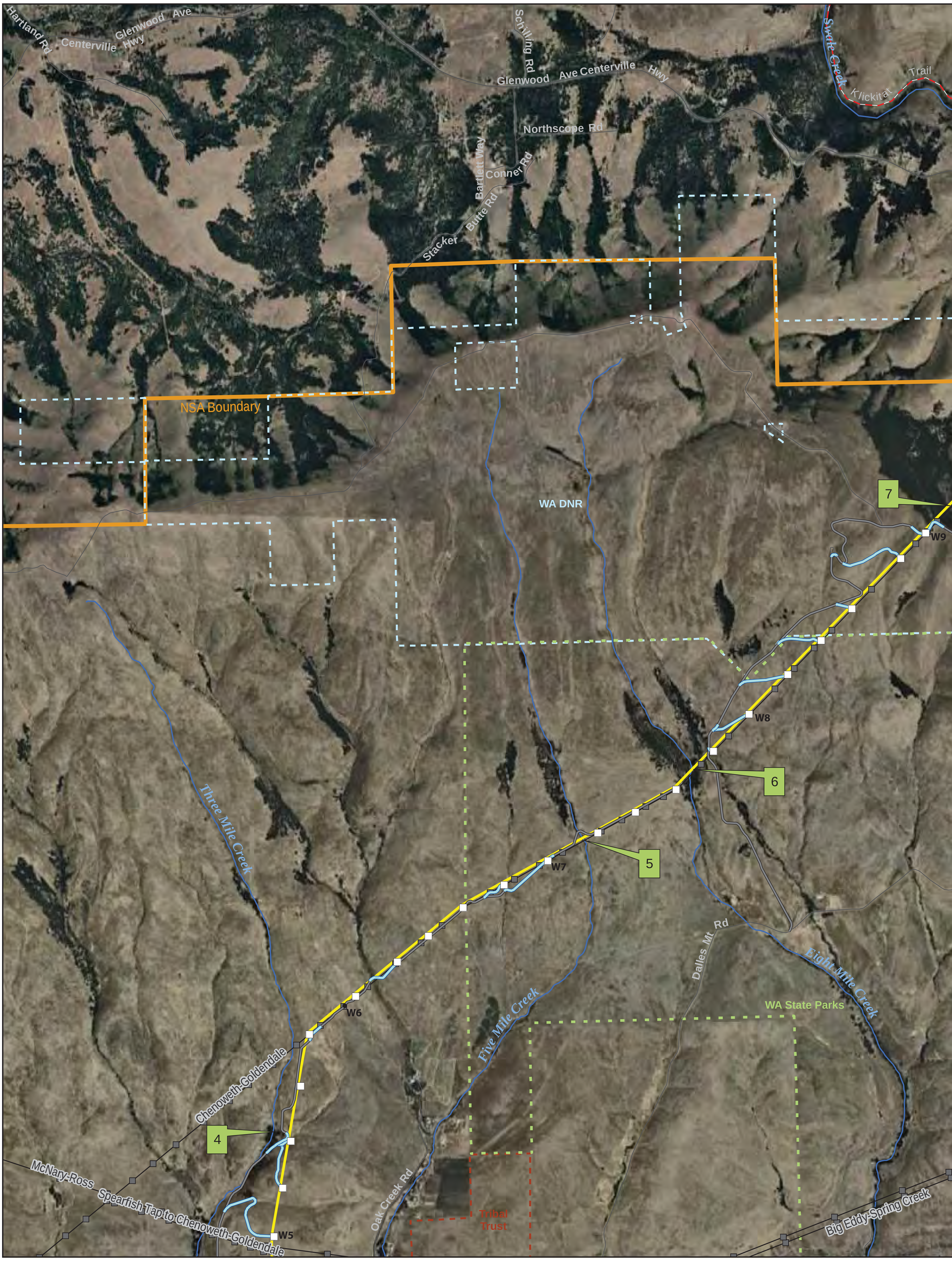
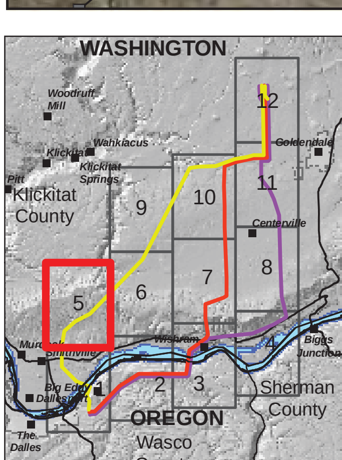
Map B-4. Aerial Photomap Series





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Woodland #

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Miles: 0, 0.2, 0.4, 0.6, 0.8

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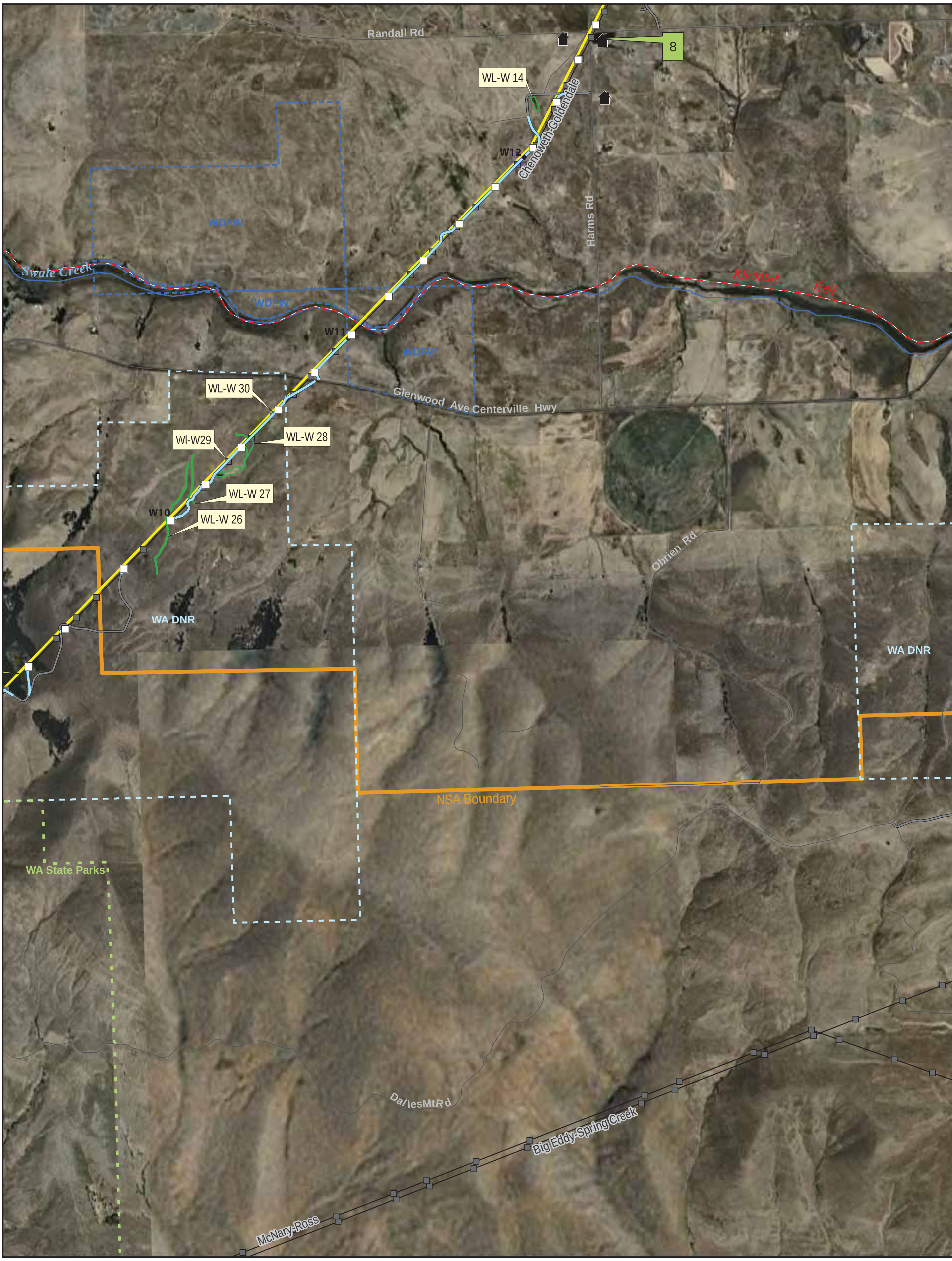
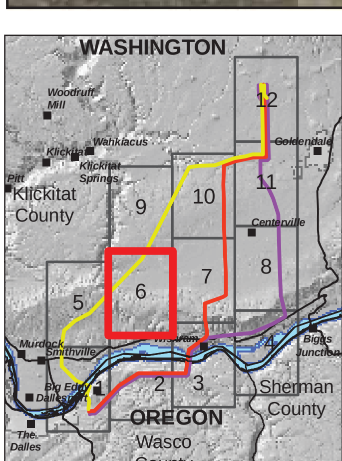
Map B-5. Aerial Photomap Series





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0 0.2 0.4 0.6 0.8 Miles

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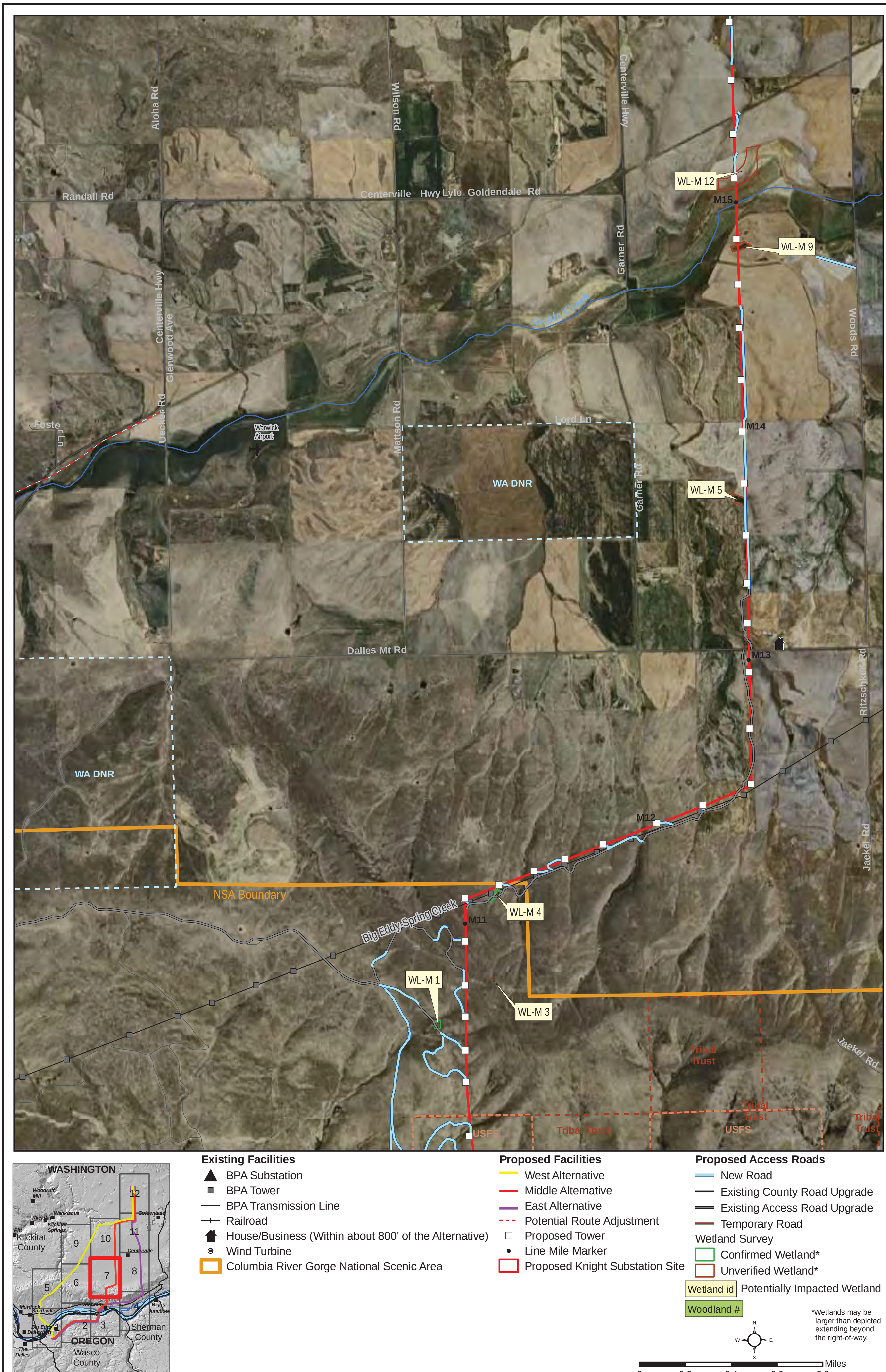
Map B-6. Aerial Photomap Series



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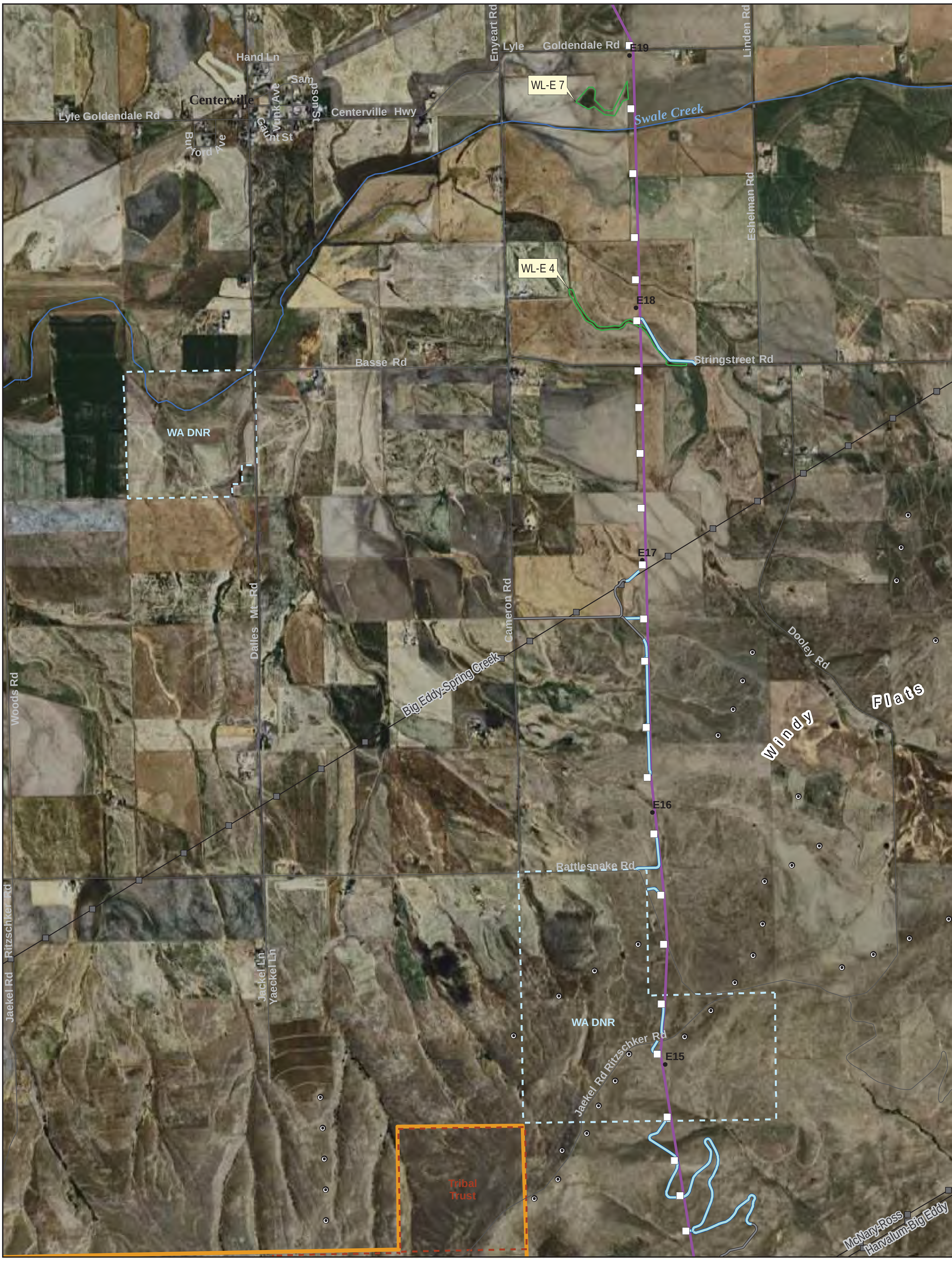
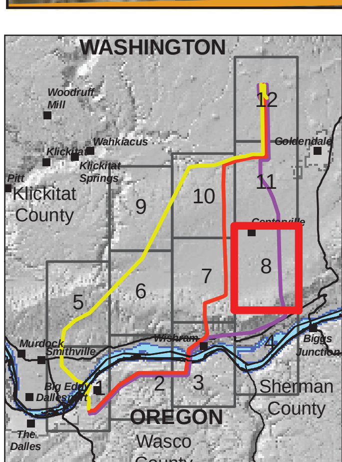
Map B-7. Aerial Photomap Series





Existing Facilities
- BPA Substation
- BPA Tower
- BPA Transmission Line
- Railroad
- House/Business (Within about 800' of the Alternative)
- Wind Turbine
- Columbia River Gorge National Scenic Area

Proposed Facilities
- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads
- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
- Temporary Road

Wetland Survey
- Confirmed Wetland*
- Unverified Wetland*

Wetland id Potentially Impacted Wetland

Woodland #

*Wetlands may be larger than depicted extending beyond the right-of-way.

N W E S

0 0.2 0.4 0.6 0.8 Miles

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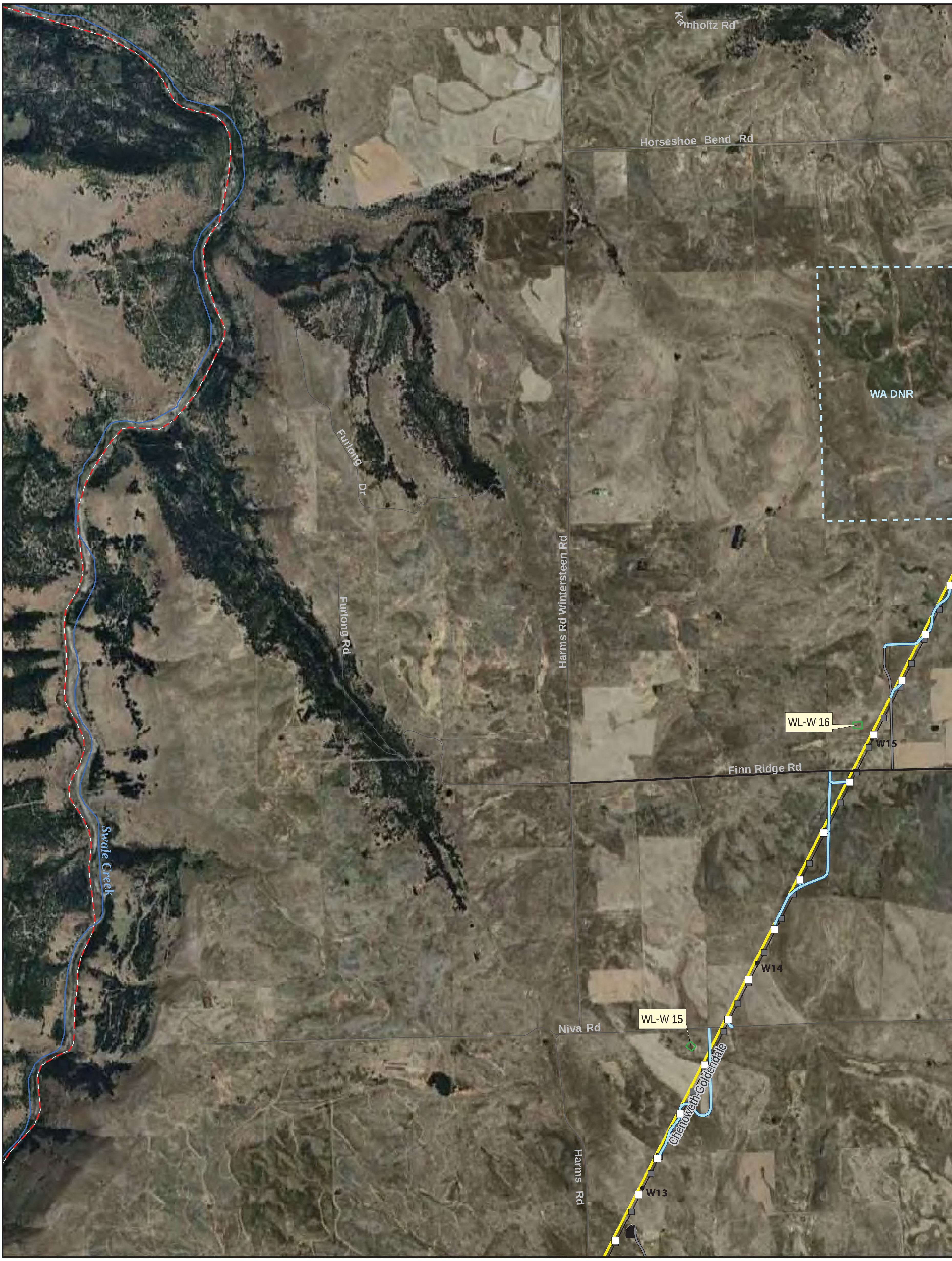
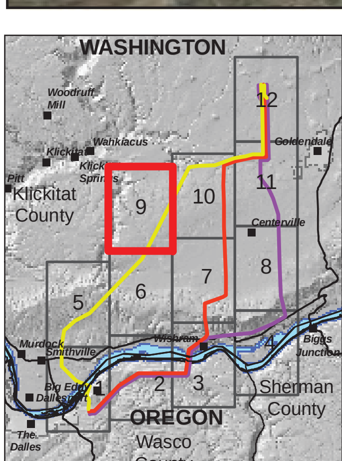
Map B-8. Aerial Photomap Series





Existing Facilities
- BPA Substation
- BPA Tower
- BPA Transmission Line
- Railroad
- House/Business (Within about 800' of the Alternative)
- Wind Turbine
- Columbia River Gorge National Scenic Area

Proposed Facilities
- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads
- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
- Temporary Road

Wetland Survey
- Confirmed Wetland*
- Unverified Wetland*

Wetland id — Potentially Impacted Wetland

Woodland #

*Wetlands may be larger than depicted extending beyond the right-of-way.

N S E W

0 0.2 0.4 0.6 0.8 Miles

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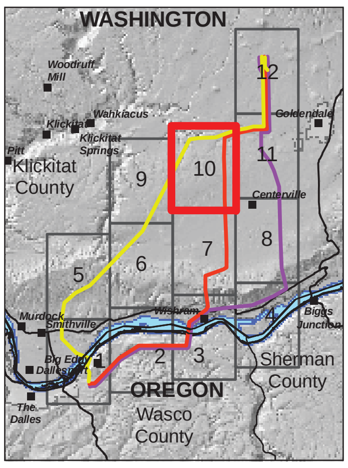
Map B-9. Aerial Photomap Series



Existing Facilities
- BPA Substation
- BPA Tower
- BPA Transmission Line
- Railroad
- House/Business (Within about 800' of the Alternative)
- Wind Turbine
- Columbia River Gorge National Scenic Area

Proposed Facilities
- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads
- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
- Temporary Road

Wetland Survey
- Confirmed Wetland*
- Unverified Wetland*

Wetland id Potentially Impacted Wetland

Woodland #

*Wetlands may be larger than depicted extending beyond the right-of-way.

Miles 0 0.2 0.4 0.6 0.8

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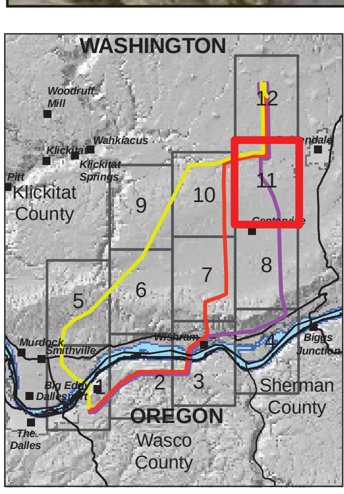
Map B-10. Aerial Photomap Series



Existing Facilities

- BPA Substation
- BPA Tower
- BPA Transmission Line
- Railroad
- House/Business (Within about 800' of the Alternative)
- Wind Turbine
- Columbia River Gorge National Scenic Area

Proposed Facilities

- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads

- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
- Temporary Road

Wetland Survey

- Confirmed Wetland*
- Unverified Wetland*

Wetland id Potentially Impacted Wetland

Woodland #

*Wetlands may be larger than depicted extending beyond the right-of-way.

N W E S

0 0.2 0.4 0.6 0.8 Miles

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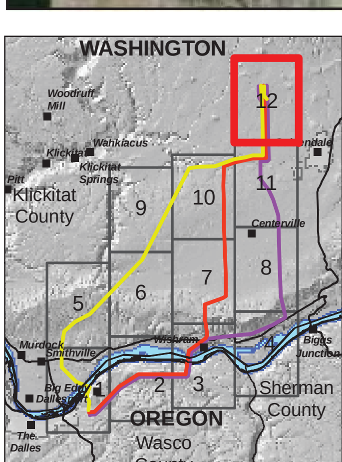
Map B-11. Aerial Photomap Series



Existing Facilities
- BPA Substation
- BPA Tower
- BPA Transmission Line
- Railroad
- House/Business (Within about 800' of the Alternative)
- Wind Turbine
- Columbia River Gorge National Scenic Area

Proposed Facilities
- West Alternative
- Middle Alternative
- East Alternative
- Potential Route Adjustment
- Proposed Tower
- Line Mile Marker
- Proposed Knight Substation Site

Proposed Access Roads
- New Road
- Existing County Road Upgrade
- Existing Access Road Upgrade
- Temporary Road

Wetland Survey
- Confirmed Wetland*
- Unverified Wetland*
- Wetland id Potentially Impacted Wetland
- Woodland #

*Wetlands may be larger than depicted extending beyond the right-of-way.

N W E S

0 0.2 0.4 0.6 0.8 Miles

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Map B-12. Aerial Photomap Series

Appendix C

Visual Resources

Contents:

- **Visual Resources Methodology**
- **Visual Simulation Methodology**
- **Visual Simulations from Hill Residence**
- **Skyline Assessment Results**
- **Viewshed Maps**
    - **Columbia River**
    - **Interstate 84**
    - **Washington State Route 14**
    - **Rowena Plateau**

Visual Resources Methodology

Terminology

The term *aesthetics* typically refers to the perceived visual impression of an area, such as a scenic view, open space, or architectural interest. The aesthetic value of an area is a measure of its *visual character* and *visual quality* combined with *viewer response* (Federal Highway Administration 1988). This combination may be affected by the components of a project (e.g., transmission towers constructed at a height that obstructs views, hillsides cut and graded, open space changed to a transmission line corridor), as well as changing elements such as light, weather, and the length and frequency of viewer exposure to the setting. Aesthetic impacts are thus defined as changes in viewer response as a result of project construction and operation.

Visual Character

Visual character is the appearance of the physical form of the landscape, composed of natural and human-made elements, including topography, water, vegetation, structures, roads, infrastructure, and utilities; and the relationships of these elements in terms of form, line, color, and texture.

Visual Quality

Visual quality is evaluated based on the relative degree of vividness, intactness, and unity as modified by the visual sensitivity of the viewer.

- *Vividness* is the visual power or memorableness of landscape components as they combine in striking or distinctive visual patterns.
- *Intactness* is the visual integrity of the natural and human-built landscape and its freedom from encroaching elements; this factor can be present in well-kept urban and rural landscapes, as well as natural settings.
- *Unity* is the visual coherence and compositional harmony of the landscape considered as a whole; it frequently attests to the careful design of individual components in the artificial landscape (Federal Highway Administration 1988).

High-quality views are highly vivid, relatively intact, and exhibit a high degree of visual unity. Low-quality views lack vividness, are not visually intact, and possess a low degree of visual unity.

Viewer Response

Viewer response is the psychological reaction of a person to visible changes in the viewshed. A viewshed is defined as all of the surface area visible from a particular location (e.g., an overlook) or sequence of locations (e.g., roadway or trail) (Federal Highway Administration 1988). The measure of the quality of a view must be tempered with the overall sensitivity of the viewer and viewer response. Viewer sensitivity is dependent on the number and type of viewers and the frequency (e.g., daily or seasonally) and duration of views (i.e., how long a scene is viewed). Visual sensitivity is also modified by viewer activity, awareness, and visual expectations in relation to the number of viewers and the viewing duration.

Visual Assessment Process

The concepts presented above are combined in a visual resource assessment process that involves identification of the following:

- visual character and quality of the project area,
- relevant policies and concerns for protection of visual resources,
- general visibility of the project area and site using descriptions and photographs, and
- viewer response and potential impacts.

Assumptions

Visual resources consist of views of the project area. Therefore, impacts are not limited to the specific alignment corridor as is often the case for other resources such as vegetation, waterways, and soils. Many viewsheds may be affected by any one given alternative, thus affecting a variety of viewer groups.

Topography plays an important role in providing and limiting views within the visual study area. Topography was evaluated using a geographic information system (GIS) viewshed analysis (Appendix A) to identify a preliminary list of vantage points from which the project could be visible. Because the GIS analysis does not include features such as vegetation or structures, it was used as a starting point to help guide the analysis and site visit.

Views of the study area were inventoried during a site visit that took place August 18 through 21, 2009, by identifying the locations and photographing views of and from the surrounding areas. Appendix B includes a map of all locations surveyed during the site visit and the photograph log for these points. Because the study area covers a large area, this analysis focuses on representative vantages from where views *of* the study area are present. Representative views are views that are representative of other views in the area, able to embody impacts on a given viewer group or number of viewer groups, and illustrative in describing the impact, nonimpact, or range in severity of impact on certain vantages.

Visual Simulation Methodology

General Approach

Visual simulations were prepared by developing a simplified 3D model of the proposed project, then using scenes captured from this model to develop more realistic simulations of the project in photographs taken from selected viewpoints throughout the project area.

Photographs

Photographs of existing conditions were taken at numerous locations throughout the project area to document visual conditions and assess visual impacts. Some photographs were selected for developing simulations that would represent views of project alternatives after construction in typical or sensitive viewsheds.

Modeling in Google Earth

A 3D model of the project was prepared using Google Earth Pro software. Google Earth provides a reasonably accurate digital terrain model draped with aerial and satellite imagery. The locations of proposed towers and access roads were added to Google Earth using georeferenced data imported in KMZ format. Markers were added for the locations of selected simulation viewpoints. View elevations and directions were set to emulate the views captured in the photographs.

Simple, box-like, 3D markers were created in Google SketchUp software for each tower that would be visible in each of the visual simulations. The tower markers were designed to represent the planned height (to the nearest meter) of each tower (both single-circuit and double-circuit options), using tower heights and location coordinates provided by BPA. These markers were imported to Google Earth to complete the schematic model of the project.

Simulations in Photoshop

Series of overlapping photographs had been taken at most of the selected simulation viewpoints. These images were aligned and blended in Adobe Photoshop Extended to prepare panoramic views. Panoramas generally enable better representation of the viewer's experience of the landscape than single-frame views, especially where multiple towers would be visible.

Views from photo locations in the Google Earth model were adjusted to emulate spatial relationships in the photographs as accurately as possible. Screen views were exported from Google Earth and aligned with the photographs in Photoshop to determine the position and height of each tower.

The detailed renderings of the towers used in the simulations were developed as detailed 3D models in Google SketchUp. One model was developed for each of the tower options (single-circuit and double-circuit) based on diagrams and photographs of representative towers provided by BPA. The SketchUp models were either imported to Photoshop and manipulated there for proper scale and orientation, or were rotated and scaled in SketchUp then exported to Photoshop as 2D images (the later method being easier for the software to process). Minor adjustments of color, contrast, and sharpness were made to the tower images in Photoshop for a more photo-realistic appearance. Cables between the towers were drawn as paths in Photoshop, then stroked (painted) and adjusted to approximate their visibility under conditions represented in the photographs.

Existing towers or poles were removed, as needed, by painting them out with colors and textures sampled from elsewhere in the image.

The locations of proposed new or improved access roads were determined in the same manner as the tower locations, by overlaying Google Earth views on the photographs in Photoshop. Roads were then painted digitally, in some cases using textures sampled from reference photographs of other graded dirt and gravel roads.

The towers, cables, roads, painted-out areas, and reference/positioning images were all placed on separate layers to facilitate adjustments and corrections. Layer masks were used extensively to control screening by foreground objects and to emulate atmospheric (aerial) perspective in more distant views.

View 1. Looking toward Mt. Adams from the Hill Residence

View 2. Panoramic View Looking Northwest to North from the Hill Residence

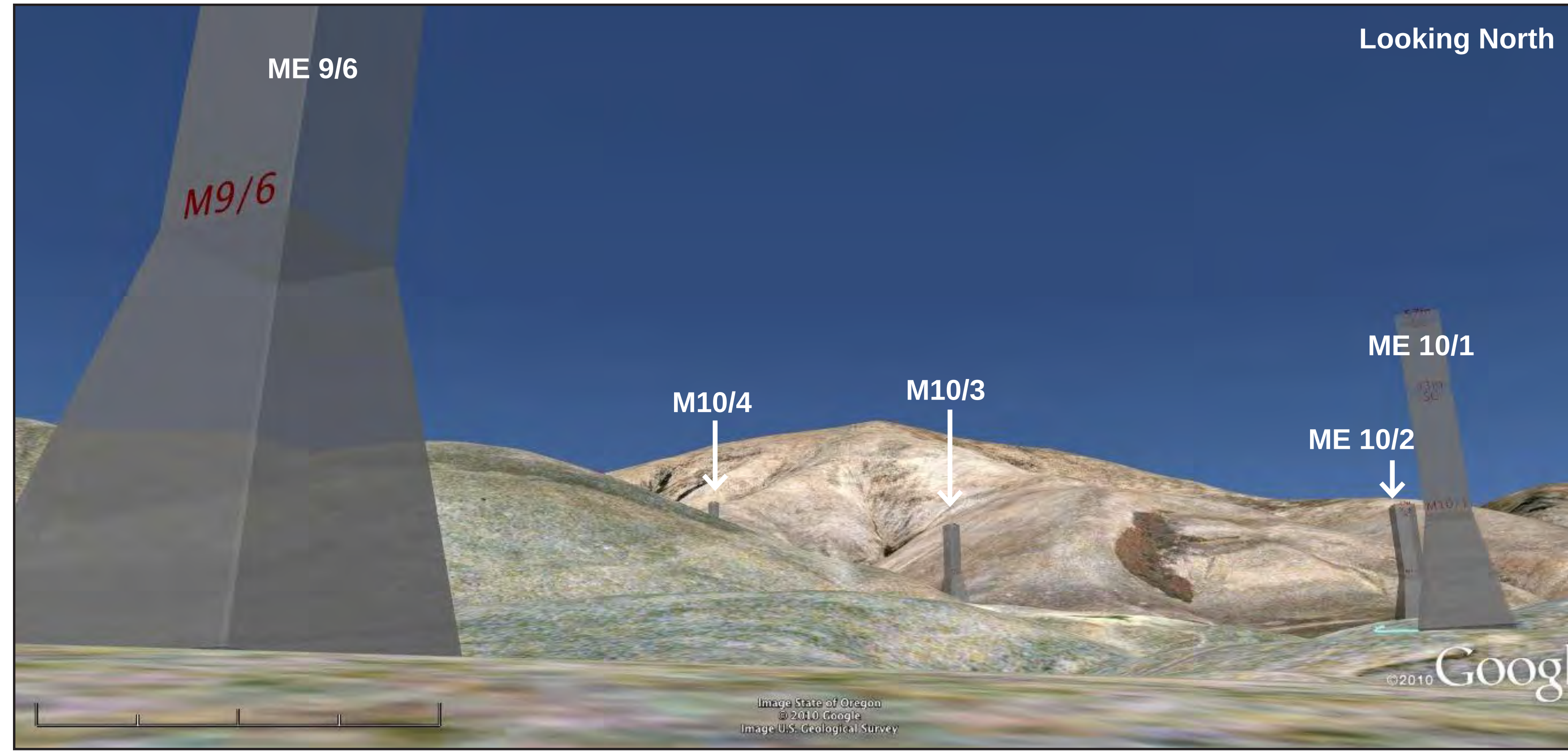
Location: State Route 14 above Wishram, approx. 2,000 feet east of Boulder Drive

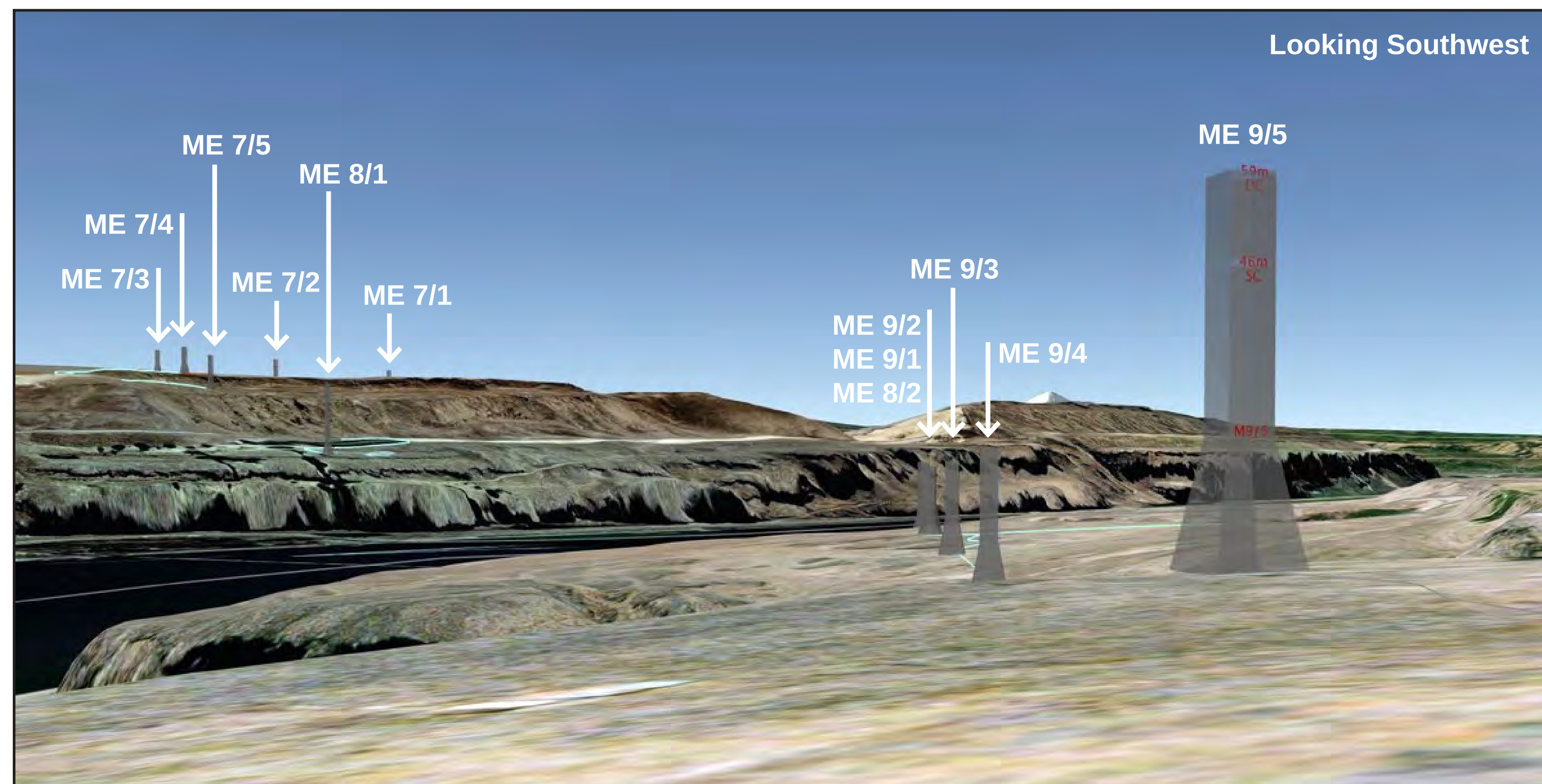
Looking north, towers M9/6 and M10/1 (single and double circuit) break the skyline. Looking southwest, M9/5 (single and double circuit) breaks the skyline. Across the river (approximately 2 miles distant) towers M7/1 through M7/5 (single and double circuit) break the skyline, but these are smaller and less visible because of their distance.

Looking North		
	Breaks Skyline?	
Visible Tower (distance)	Single Circuit	Double Circuit
M/E 9/6 (0.04 mi)	Yes	Yes
M/E 10/1 (0.16 mi)	Yes	Yes
M/E 10/2 (0.35 mi)	No	May touch skyline
M 10/3 (0.59 mi)	No	No
M 10/4 (0.80 mi)	Not visible	No

Looking Southwest		
	Breaks Skyline?	
Visible Tower (distance)	Single Circuit	Double Circuit
M/E 9/5 (0.16 mi)	Yes	Yes
M/E 9/4 (0.41 mi)	No	No
M/E 9/3 (0.55 mi)	No	No
M/E 9/2 (0.70 mi)	No	No
M/E 9/1 (0.87 mi)	No	No
M/E 8/2 (1.04 mi)	No	No
River		
M/E 8/1 (1.75 mi)	No	May touch skyline
M/E 7/5 (2.04 mi)	Yes	Yes
M/E 7/4 (2.13 mi)	Yes	Yes
M/E 7/3 (2.24 mi)	Yes	Yes
M/E 7/2 (2.33 mi)	Yes	Yes
M/E 7/1 (2.44 mi)	Maybe a little	Yes

All images: Google Inc. 2010. Google Earth Pro, Version 5.2. Mountain View, CA. Accessed: September 3, 2010.





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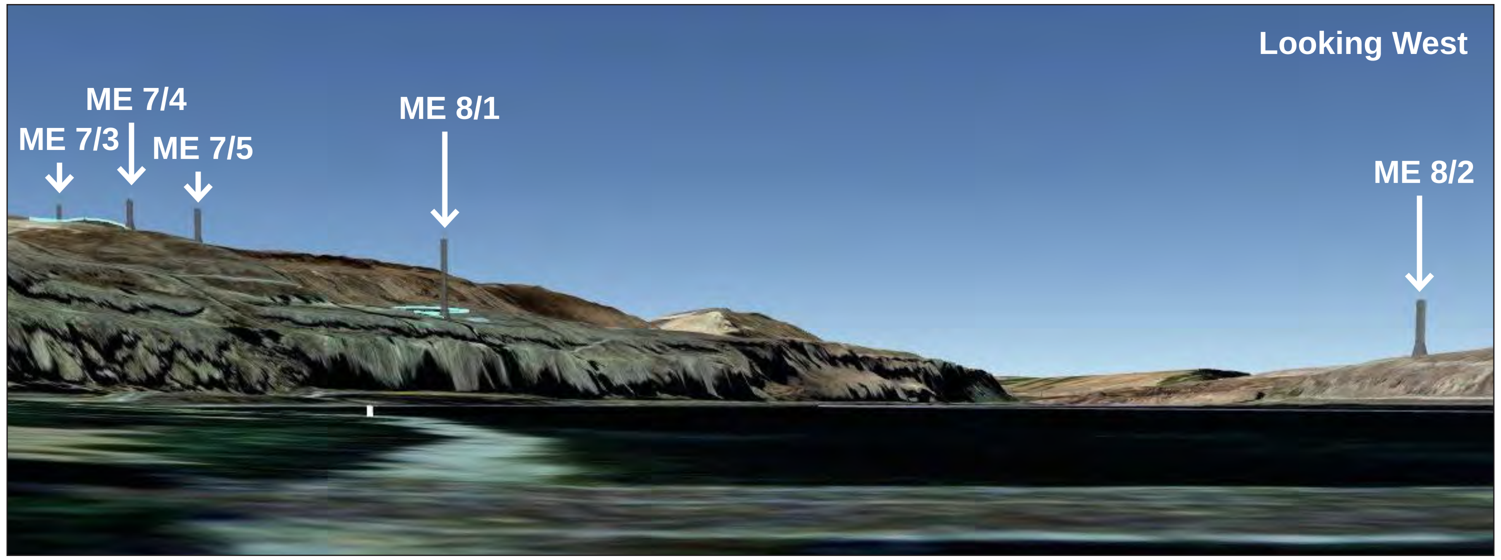
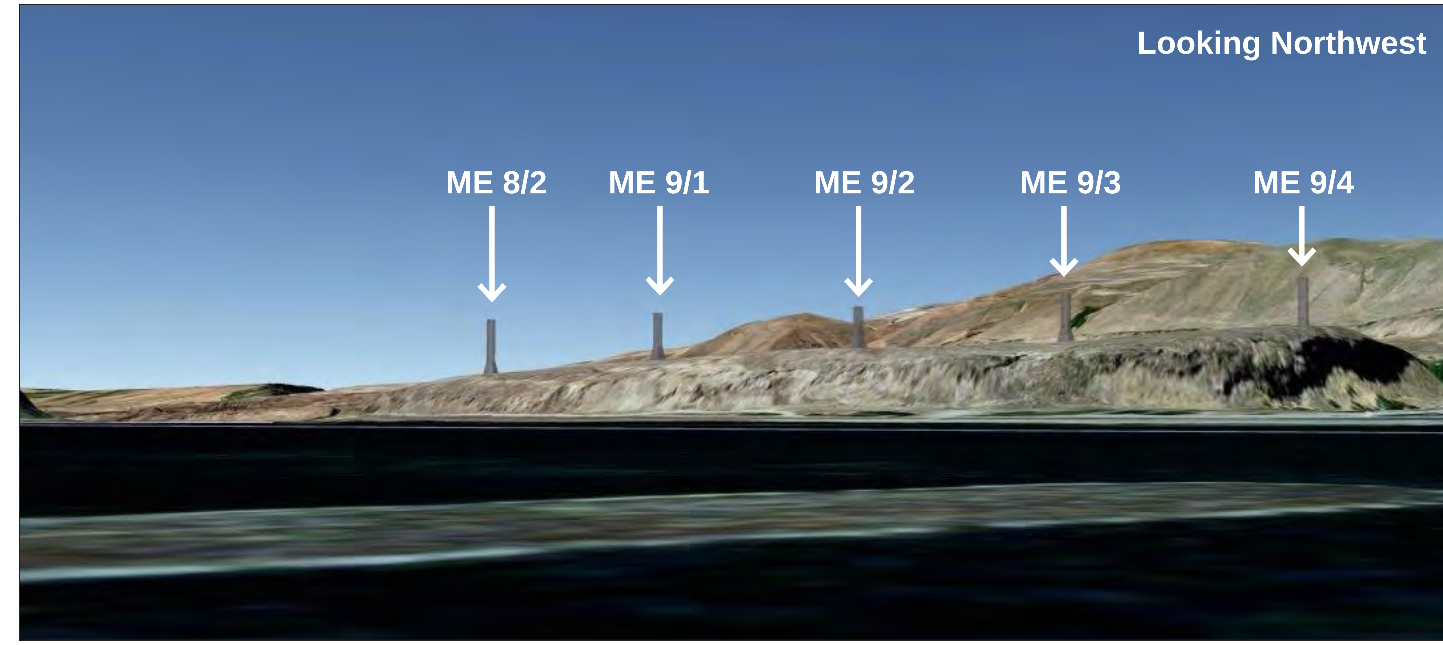
Skyline Assessment Results

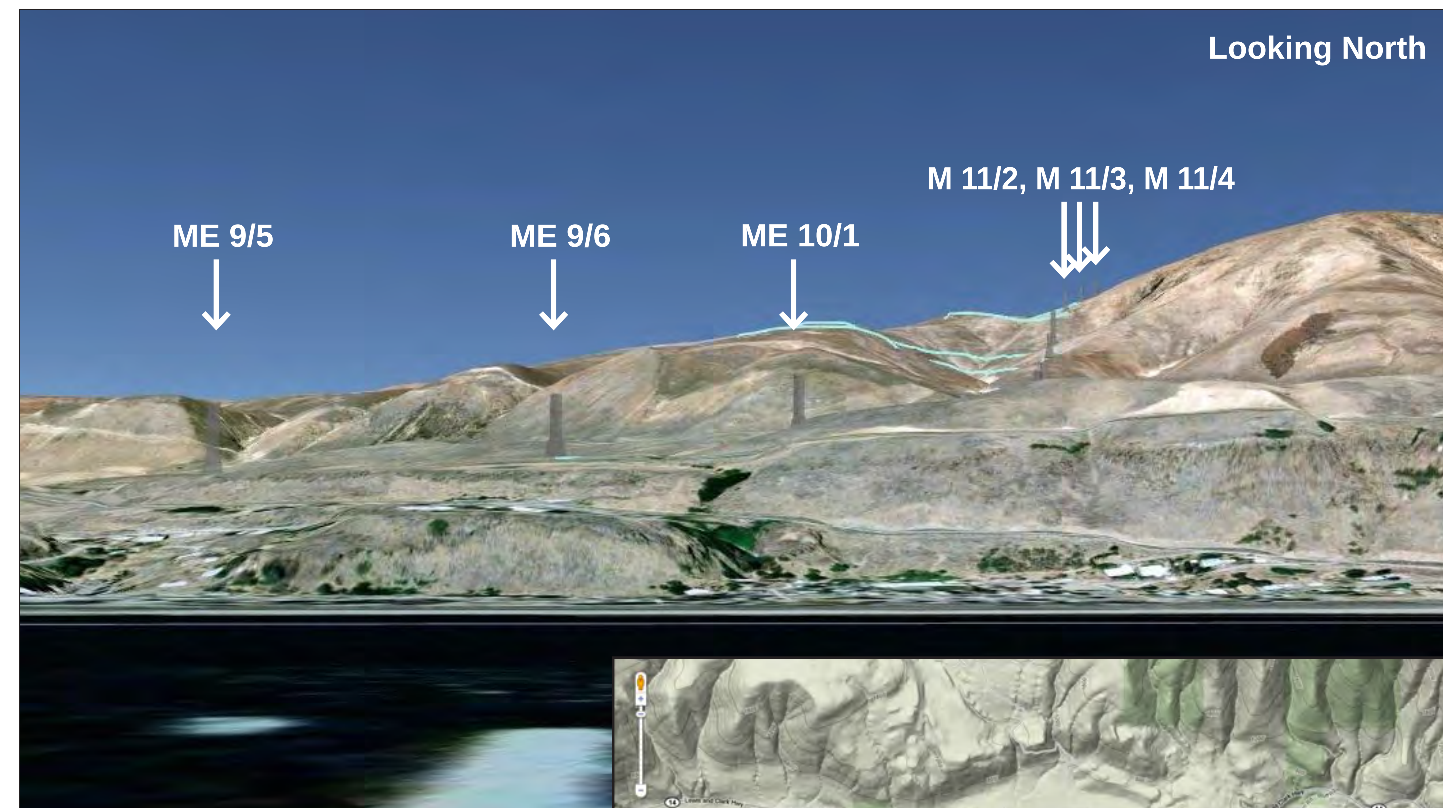




Location: Columbia River at Celilo Park Boat Ramp

Looking west, towers M7/3, M7/4, M7/5, and M8/1 (single and double circuit) break the skyline on the south side of the river. M8/2 and M9/1 (single and double circuit) and M9/2 (double circuit only) break the skyline on the north side of the river. Looking north, only towers M11/2, M11/3, and M11/4 near the top of the ridge break the skyline.

Looking West to North		
	Breaks Skyline?	
Visible Tower (distance)	**Single Circuit**	**Double Circuit**
M/E 7/3 (1.90 mi)	Yes	Yes
M/E 7/4 (1.81 mi)	Yes	Yes
M/E 7/5 (1.72 mi)	Yes	Yes
M/E 8/1 (1.52 mi)	May touch skyline	Yes
River		
M/E 8/2 (1.27 mi)	Yes	Yes
M/E 9/1 (1.14 mi)	Yes	Yes
M/E 9/2 (1.05 mi)	No	Yes
M/E 9/3 (0.96 mi)	No	No
M/E 9/4 (0.91 mi)	No	No
M/E 9/5 (0.88 mi)	No	No
M/E 9/6 (0.90 mi)	No	No
M/E 10/1 (0.94 mi)	No	No
M/E 10/2 (1.06 mi)	Not Visible	No
M 10/3 (1.29 mi)	No	No
M 10/4 (1.56 mi)	No	No
M 11/1 (1.84 mi)	No	May touch skyline
M 11/2 (2.09 mi)	Yes	Yes
M 11/3 (2.22 mi)	Yes	Yes
M 11/4 (2.36 mi)	Yes	Yes



All images: Google Inc. 2010. Google Earth Pro, Version 5.2. Mountain View, CA. Accessed: September 3, 2010.

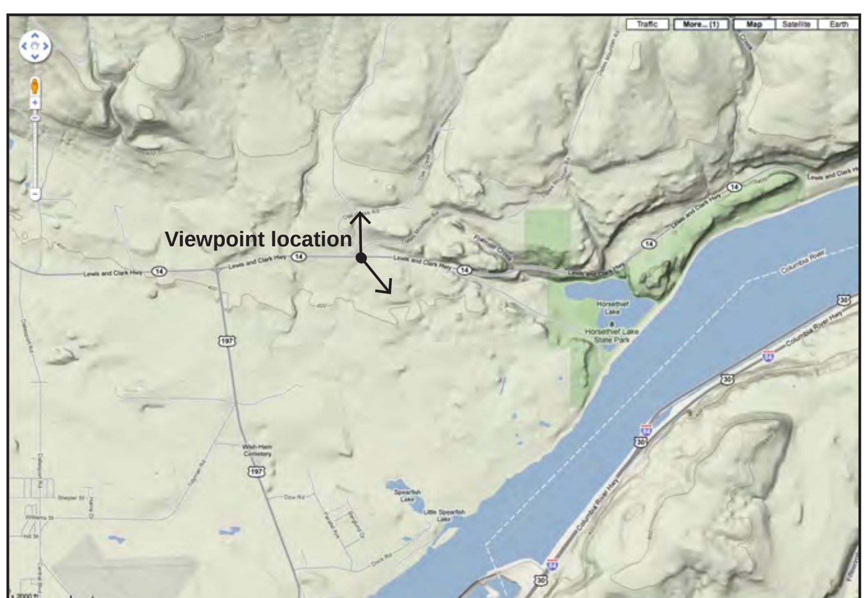
Skyline Assessment Results

Location: State Route 14 at intersection with Dalles Mountain Road

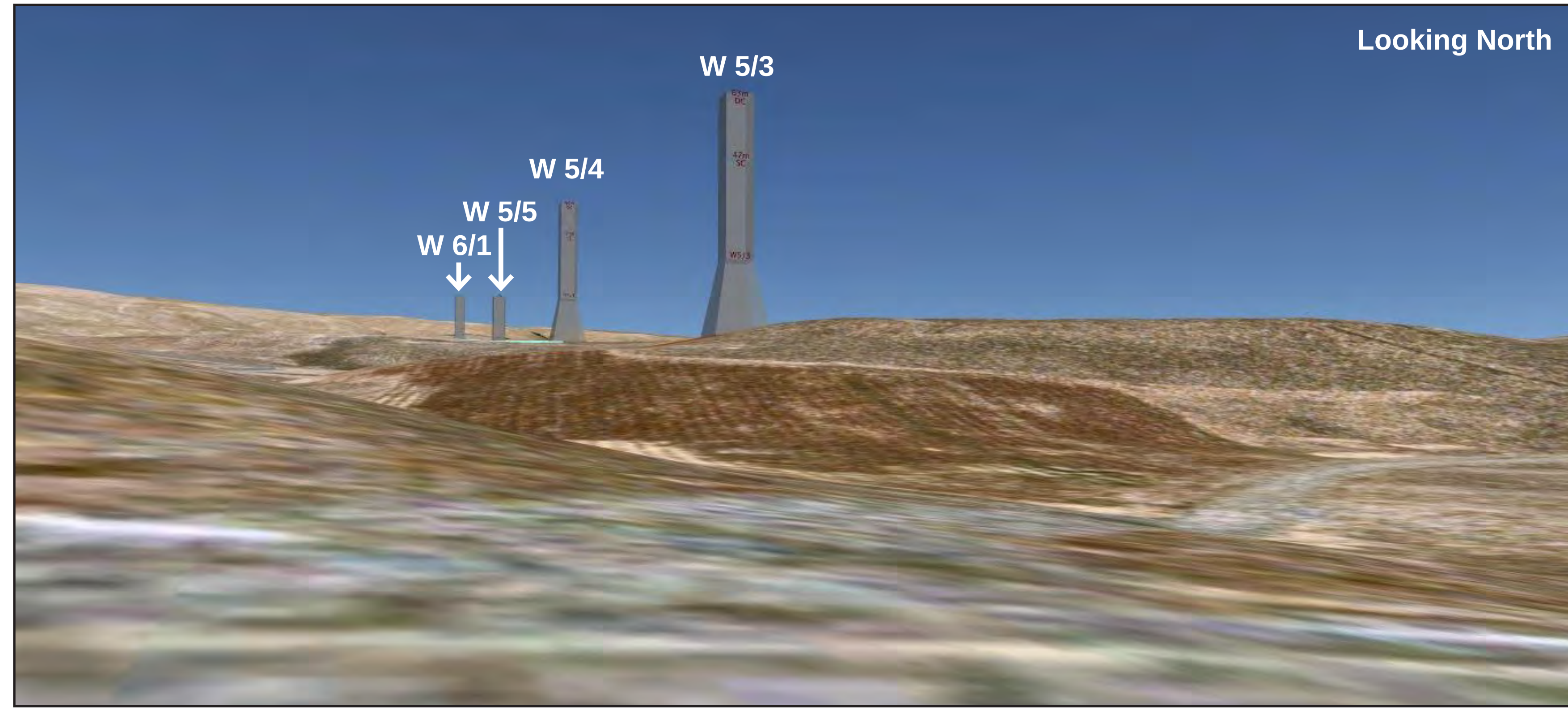
Looking north, towers W5/3, W5/4, W5/5, and W6/1 (single and double circuit) break the skyline. Looking south to southeast, tower W5/2 (single and double circuit) and W5/1(double circuit only) break the skyline.

Looking North		
	Breaks Skyline?	
Visible Tower (distance)	Single Circuit	Double Circuit
W 5/3 (0.21 mi)	Yes	Yes
W 5/4 (0.39 mi)	Yes	Yes
W 5/5 (0.56 mi)	Yes	Yes
W 6/1 (0.75 mi)	Yes	Yes

Looking Southeast		
	Breaks Skyline?	
Visible Tower (near to far)	Single Circuit	Double Circuit
W 5/2 (0.07 mi)	Yes	Yes
W 5/1 (0.20 mi)	May touch skyline	Yes
W 4/5 (0.41 mi)	No	No
W 4/4 (0.58 mi)	No	No
Others approaching river	No	No
W 2/2 (2.65 mi) (across river)	Yes	Yes



All images: Google Inc. 2010. Google Earth Pro, Version 5.2. Mountain View, CA. Accessed: September 3, 2010.



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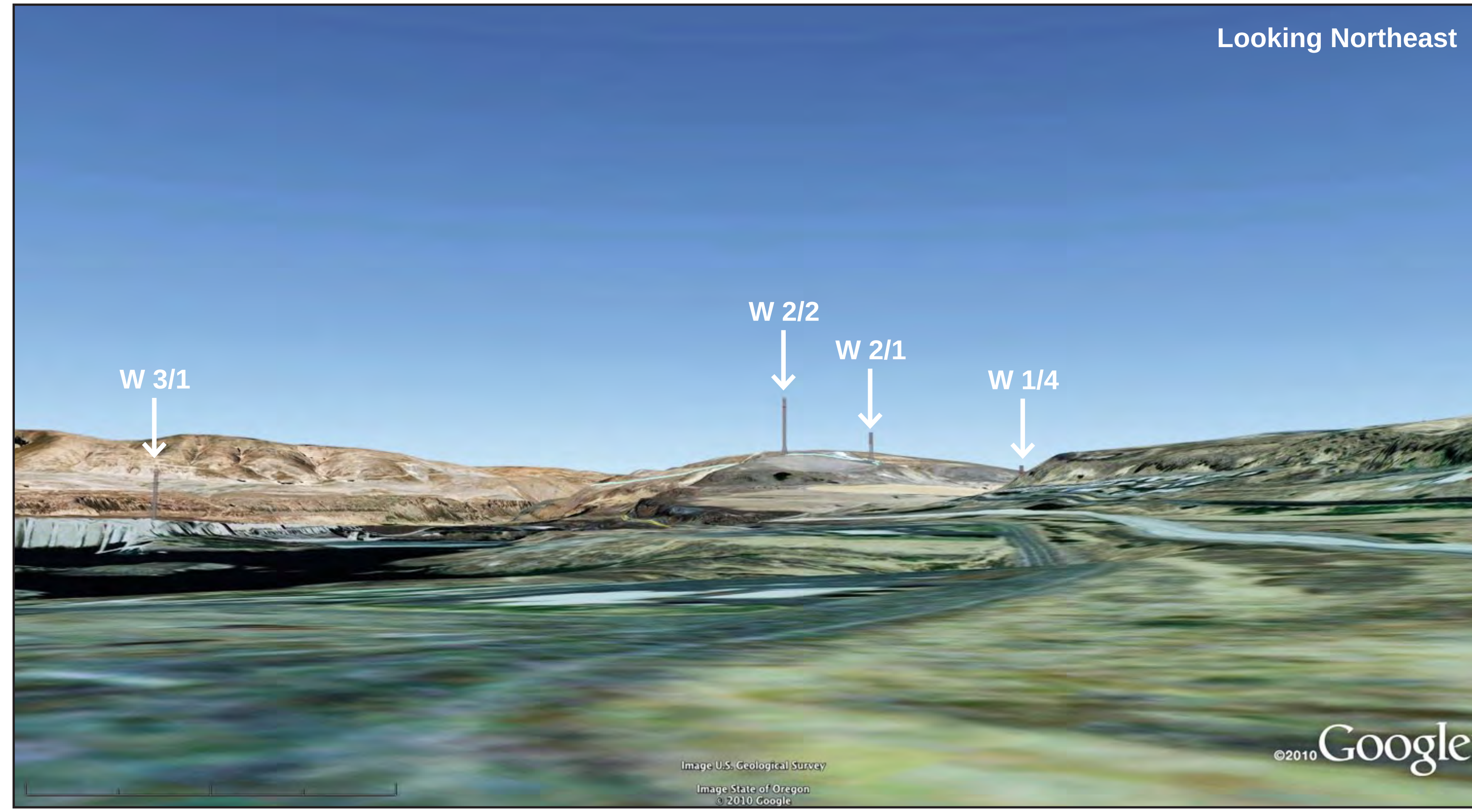
Skyline Assessment Results

Location: US Highway 197 at Interstate 84

Looking northeast, towers W1/4 (double circuit only), W2/1, and W2/2 (single and double circuit) break the skyline.

Towers W1/1, W1/2, and W1/3 are hidden by terrain. Other existing towers at the substation south of Columbia View Drive are visible.

Looking East		
	Breaks Skyline?	
Visible Tower (distance)	**Single Circuit**	**Double Circuit**
W 1/4 (1.81 mi)	No	Yes
W 2/1 (1.82 mi)	Yes	Yes
W 2/2 (1.83 mi)	Yes	Yes
W 3/1 (2.18 mi)	No	No



All images: Google Inc. 2010. Google Earth Pro, Version 5.2. Mountain View, CA. Accessed: September 3, 2010.

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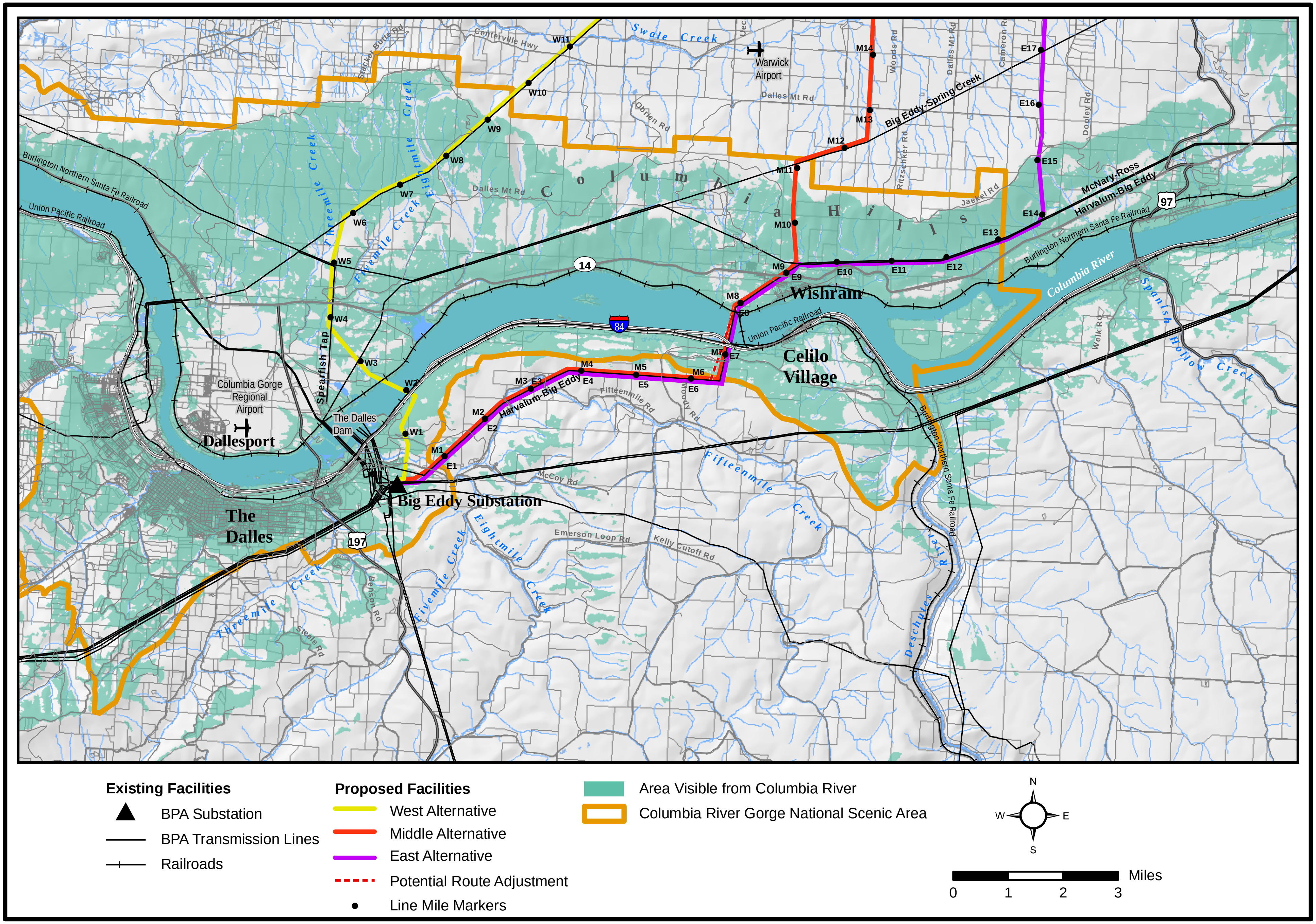

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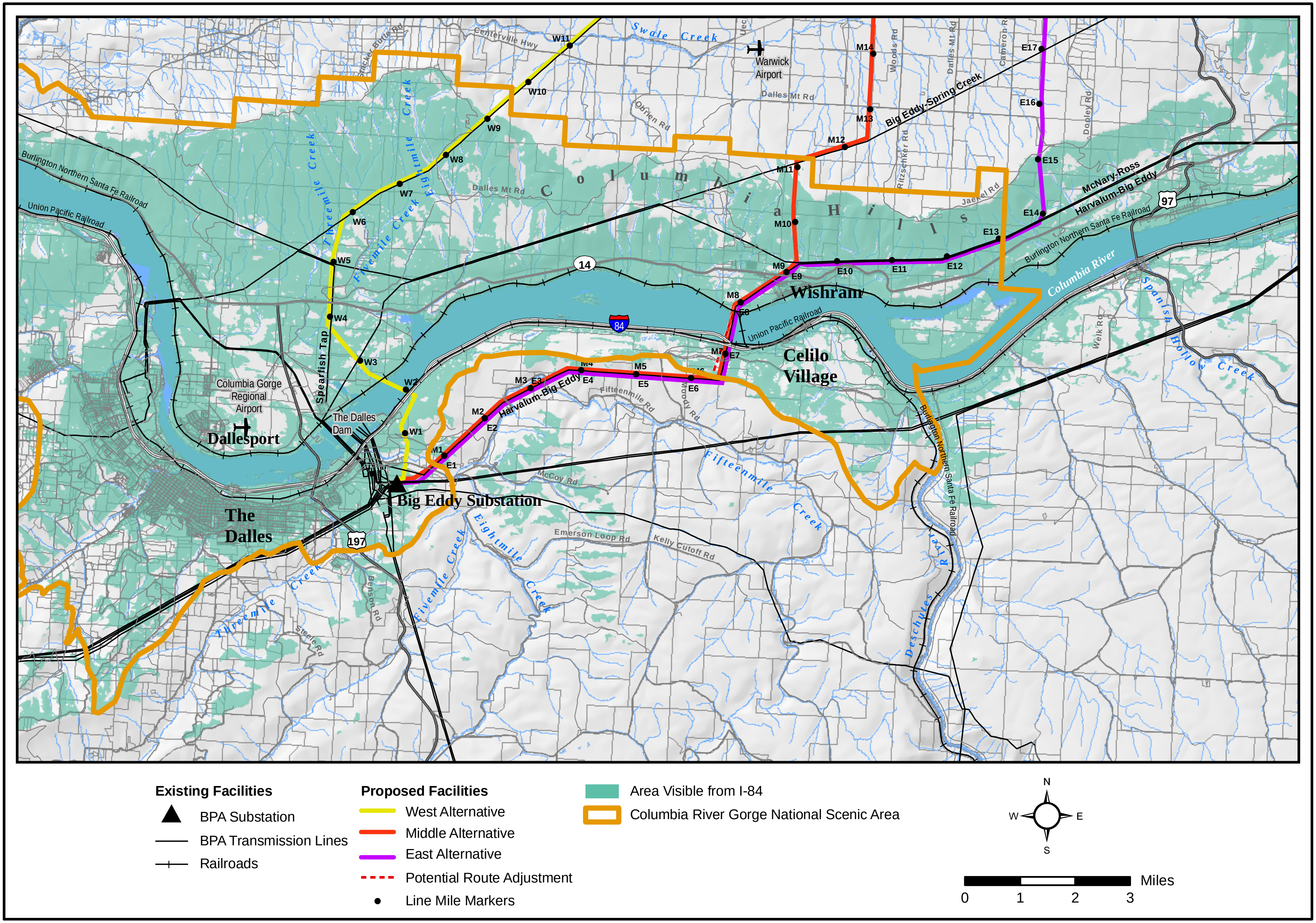
Map C-1. Columbia River Viewshed



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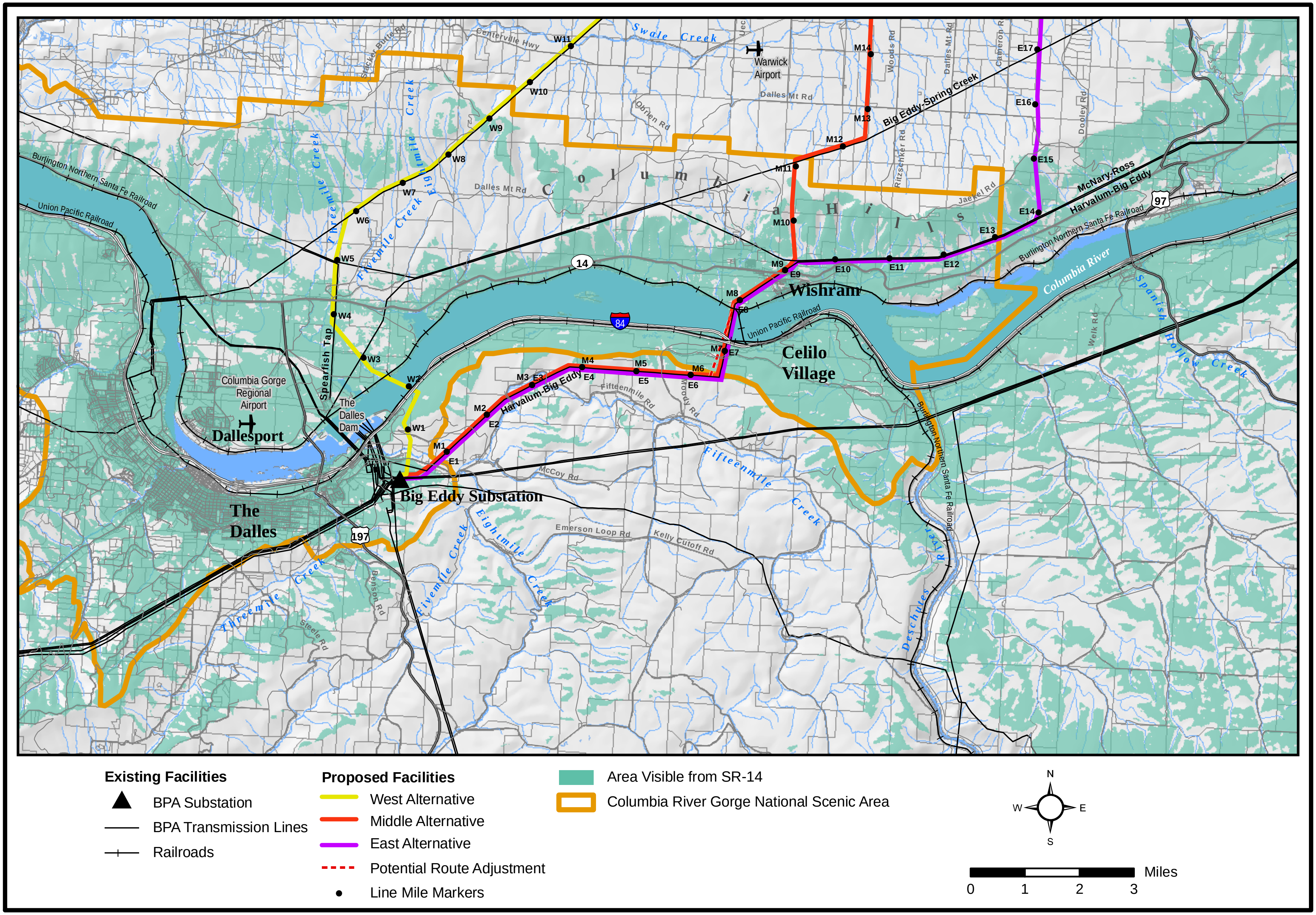
Map C-2. Interstate 84 Viewshed



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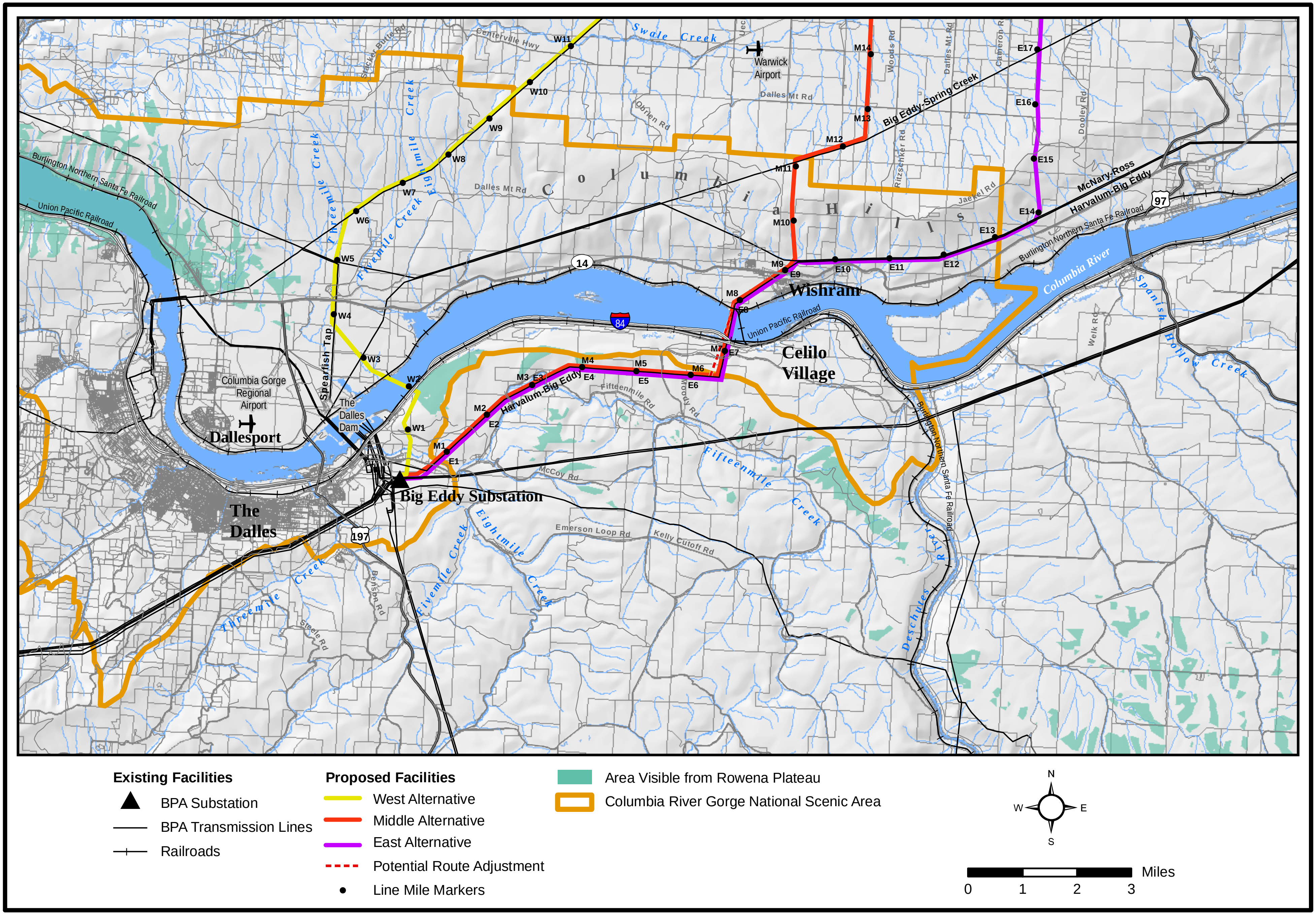
Map C-3. Washington State Route 14 Viewshed



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Map C-4. Rowena Plateau Viewshed

Appendix D

Special-Status Species and Habitats

Contents:

- **Oregon Department of Fish and Wildlife (ODFW) Habitat Impacts**
- **Federal Species Determination**
- **Potential Impacts on Sensitive Species of the Columbia River Gorge National Scenic Area and National Forest System**

Oregon Department of Fish and Wildlife (ODFW) Habitat Impacts

The six habitat categories listed below were established by the State of Oregon to help consistently identify appropriate mitigation measures for environmental impacts on different fish and wildlife habitats in Oregon (ODFW 2009). Impacts from the proposed action alternatives on each of these habitat categories are given in Tables D-1 and D-2.

Category 1 – is irreplaceable, essential habitat for a fish or wildlife species, population, or a unique assemblage of species and is limited on either a physiographic province or site-specific basis, depending on the individual species, population or unique assemblage. In the project vicinity, cliffs would be considered Category 1 habitat.

Category 2 - is essential habitat for a fish or wildlife species, population, or unique assemblage of species and is limited either on a physiographic province or site-specific basis depending on the individual species, population or unique assemblage. In the project vicinity, wetlands would be considered Category 2 habitat.

Category 3 – is essential habitat for fish and wildlife, or important habitat for fish and wildlife that is limited either on a physiographic province or site-specific basis, depending on the individual species or population. In the project vicinity, high-quality woodlands would be considered Category 3 habitat.

Category 4 - is important habitat for fish and wildlife species. In the project vicinity, disturbed grassland/shrub-steppe would be considered Category 4 habitat.

Category 5 - is habitat for fish and wildlife having high potential to become either essential or important habitat. There is no Category 5 habitat in the project vicinity.

Category 6 - is habitat that has low potential to become essential or important habitat for fish and wildlife. In the project vicinity, cropland or small areas of trees would be considered Category 6 habitat.

ODFW Habitat Impacts

Table D-1. West Alternative Acreage Impacts on Oregon Department of Fish and Wildlife Habitat Categories

	Permanent Impacts				Temporary Impacts		
Habitat Category[1]	Towers[2]	New Roads	Upgrading Existing Roads	Total Impacts per Habitat Category	Towers	Temporary Roads	Total Impacts per Habitat Category
Category 1	0	0	0	**0**	0	0	**0**
Category 2	0	0	0	**0**	0	0	**0**
Category 3	0	0	0	**0**	0	0	**0**
Category 4	0.5–0.7	2.0	1.1	**3.6–3.8**	1.5–2.1	0	**1.5–2.0**
Category 5	0	0	0	**0**	0	0	**0**
Category 6	0.5–0.7	1.0	0.1	**1.6–1.8**	1.5–2.1	0	**1.5–2.0**

[1] See the text for definitions of the six ODFW Habitat Categories.
[2] Impacts are presented as ranges from all possible tower options. The upper end of each range reflects the double-circuit options and includes the removal of the existing towers.

Table D-2. Middle and East Alternatives Acreage Impacts on Oregon Department of Fish and Wildlife Habitat Categories

	Permanent Impacts				Temporary Impacts		
Habitat Category[1]	Towers[2]	New Roads	Upgrading Existing Roads	Total Impacts per Habitat Category	Towers	Temporary Roads	Total Impacts per Habitat Category
Category 1	0	0	0	**0**	0	0	**0**
Category 2	0	0	0	**0**	0	0	**0**
Category 3	0	0	0	**0**	0	0	**0**
Category 4	2.4–8.8	5.4	6.7	**14.5–20.6**	7.1–29.6	0	**7.1–29.6**
Category 5	0	0	0	**0**	0	0	**0**
Category 6	1.5–5.7	0.9	1.1	**3.5–7.7**	4.5–19.2	0	**4.5–19.2**

[1] See the text for definitions of the six ODFW Habitat Categories.
[2] Impacts are presented as ranges from all possible tower options. The upper end of each range reflects the double-circuit options and includes the removal of the existing towers.

Federal Species Determination—Impacts on Species Listed Under the Endangered Species Act

Because BPA is a federal agency, it is required to analyze the effects of its actions on species listed under the Endangered Species Act (ESA) of 1973 as amended. Making a No Effect Determination is the appropriate conclusion when the proposed action will not affect a listed species or designated critical habitat.

The following ESA listed species were identified by USFWS and NOAA Fisheries as potentially being present in the project area (Wasco County, OR and Klickitat County, WA).

Table D-3. Wasco County, OR and Klickitat County, WA Species List

Species *(Scientific Name)*	ESA Status & Critical Habitat Designation	Effect of the Project
Gray wolf *(Canis lupus)*	Endangered	Not documented in or near project area. No effect
Northern spotted owl *(Strix occidentalis caurina)*	Threatened Critical Habitat	No suitable habitat, not documented in or near project area. No effect
Bull trout, Columbia River DPS *(Salvelinus confluentus)*	Threatened Critical Habitat	No streams will be affected by the project. No Effect
Chinook Salmon (*Oncorhynchus tshawytscha*)	Upper Columbia River spring-run ESU Endangered Snake River spring/summer-run ESU Threatened Snake River fall-run ESU Threatened	No streams will be affected by the project. No Effect
Coho Salmon (*Oncorhynchus kisutch*)	Lower Columbia River ESU Threatened	No streams will be affected by the project. No Effect
Sockeye Salmon (*Oncorhynchus nerka*)	Snake River ESU Endangered	No streams will be affected by the project. No Effect
Steelhead (*Oncorhynchus mykiss*)	Middle Columbia River DPS Threatened Snake River Basin DPS Threatened Upper Columbia River DPS Threatened	No streams will be affected by the project. No Effect
Ute ladies'-tresses ***Spiranthes diluvialis***	Threatened	Suitable habitat present. Surveys did not document any occurrences. No effect

Federal Species Determination

Gray Wolf
Gray wolves were historically present in the project area, but were extirpated from the region by the 1930's. Occasional wolf sightings have been recorded in the Cascades, which likely represent lone individuals rather than established wolf packs. Documented wolf packs exist in eastern Oregon and north eastern Washington, but none have been documented within 50 miles of the project area. In the unlikely even that individual wolves would be passing through the area during construction, they may avoid the area of active construction. No long term impacts to wolf prey species are likely from the proposed project. No wolf pack territory would be affected. Since there are no documented wolf packs nearby and it is unlikely that any transitory wolves would use the project area during construction, the project would have **no effect** upon the gray wolf.

Northern Spotted Owl
The project area is mostly shrub-steppe with some ponderosa pine and oak forests. These forested areas do not provide spotted owl habitat. There are no documented sightings of northern spotted owls within 5 miles of the project area and they are not expected to use the types of habitats present within or near the project area. Therefore, the project will have **no effect** upon the northern spotted owl.

Fish Species
The proposed project crosses streams and rivers that do contain listed fish species habitat. However, no new access roads would be constructed across these streams, no towers would be placed in or next to streams or rivers, or wetlands leading up to them. Sediment and spill control will be implemented at all construction sites to prevent any hazardous materials or sediments from entering waterways. A few trees would need to be removed in the riparian area adjacent to the non-fish bearing Threemile Creek in Washington. Other trees would need to be removed in upland areas on either side of some river and stream crossings. Because no sediment or chemical inputs to streams are expected and because no adverse changes to water temperature or stream function are anticipated from tree removal, the project will have **no effect** upon listed salmonids.

Ute Ladies-Tresses
Surveys for Ute ladies-tresses were conducted during the summer of 2010 within the project area. No occurrences were found. Because the plant is not present in the project area, the project will have **no effect** upon the Ute ladies-tresses.

Potential Impacts on Sensitive Species of the Columbia River Gorge National Scenic Area and National Forest System

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Fish								
Bull trout (Columbia River) *(Salvelinus confluentus)*	T OR-SC WA-C	Spawns and rears in cold streams and lakes. Adults will disperse and/or migrate in warmer systems such as the Columbia River mainstem. Also documented in Hood River, Drano Lake, and suspected in Klickitat River and Sandy River in the National Scenic Area (NSA).	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.
Steelhead trout (Snake River) *(Oncorhynchus mykiss)*	T WA-C	Anadromous. Presence in the NSA limited to migration corridor of the Columbia River.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.	Present in Columbia River	NE on species or designated critical habitat. No in-water work will occur.
Steelhead trout (mid-Columbia River) *(Oncorhynchus mykiss)*	T WA-C	Anadromous. Spawns and rears in Columbia River tributaries between Mosier and Yakima, in both OR and WA.	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.
Steelhead trout (upper Columbia River) *(Oncorhynchus mykiss)*	E WA-C	Anadromous. Presence in the NSA limited to migration corridor of the Columbia River.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.	Present in Columbia River	NE on species or designated critical habitat. No in-water work will occur.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.
Steelhead trout (lower Columbia River) *(Oncorhynchus mykiss)*	T OR-SC WA-C	Anadromous. Spawns and rears in Columbia River tributaries between the mouth of the Columbia River east to Hood River, in both OR and WA.	Present in Columbia River, downstream of project corridor	NE on species or designated critical habitat.	Present in Columbia River, downstream of project corridor	NE on species or designated critical habitat.	Present in Columbia River, downstream of project corridor	NE on species or designated critical habitat.
Chinook (mid-Columbia River spring run) *(Oncorhynchus tshawytscha)*	FS	Anadromous. Spawns and rears in Columbia River tributaries between Mosier and Yakima, in both OR and WA.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Chinook salmon (Snake River spring/summer/fall runs) *(O. tshawytscha)*	T OR-T WA-C	Anadromous. Presence in the NSA limited to migration corridor of the Columbia River.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.	Present in Columbia River	NE on species or designated critical habitat. No in-water work.
Chinook salmon (lower Columbia River) *(Oncorhynchus tshawytscha)*	T OR-SC (fall run) WA-C	Anadromous. Spawns and rears in Columbia River tributaries between the mouth of the Columbia R east to Hood River, in both OR and WA.	Present in Columbia River, downstream of the project corridor	NE on species or designated critical habitat.	Present in Columbia River, downstream of the project corridor	NE on species or designated critical habitat.	Present in Columbia River, downstream of the project corridor	NE on species or designated critical habitat.
Chinook salmon (upper Columbia River) (*Oncorhynchus tshawytscha*)	E WA-C	Anadromous. Presence in NSA limited to migration corridor of the Columbia River.	Present in Columbia River	NE on species or designated critical habitat. No in-water work	Present in Columbia River	NE on species or designated critical habitat. No in-water work	Present in Columbia River	NE on species or designated critical habitat. No in-water work
Sockeye salmon (Snake River) (*Oncorhynchus nerka*)	E WA-C	Anadromous. Presence in NSA limited to migration corridor of the Columbia River. Spawning area typically adjacent to or in lakes, where young rear.	Present in Columbia River	NE on species or documented critical habitat. No in-water work	Present in Columbia River	NE on species or documented critical habitat. No in-water work	Present in Columbia River	NE on species or documented critical habitat. No in-water work
Chum salmon (Columbia River) (*Oncorhynchus keta*)	T OR-SC WA-C	Anadromous. Spawns and rears in several locations on the Columbia River shoreline and in low-gradient tributaries, in both OR and WA. Historically documented spawning run as far east as the Umatilla and Walla Walla systems, but present population largely below Bonneville Dam. Some incidental spawning known to occur near the mouths of White Salmon River (WA) and Eagle Creek (OR).	Present in Columbia River, downstream of the project corridor	NE on species or designated critical habitat.	Present in Columbia River, downstream of the project corridor	NE on species or designated critical habitat.	Present in Columbia River, downstream of the project corridor	NE on species or designated critical habitat.
Coho (lower Columbia River) (*Oncorhynchus kisutch*)	T OR-E	Anadromous. Spawns and rears in Columbia River tributaries between the mouth of the Columbia River east to Hood River, in both OR and WA.	Present in Columbia River and the lower reaches of Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.	Present in Columbia River and the lower reaches of Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.	Present in Columbia River and the lower reaches of Fifteenmile Creek	NE on species or designated critical habitat. No in-water work.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Pacific lamprey (*Lampetra tridentata*)	OR-SV	Anadromous. Found sporadically throughout Columbia River Basin. Spawns in gravelly riffles in late spring or early summer. Ammocoetes rear for approximately 6 years in silt and fine sand before outmigration.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.
River lamprey (*Lampetra ayresi*)	WA-C	Anadromous. Historically occurred throughout the Columbia River system, but little information on current distribution or abundance. Difficult to identify as ammocoetes. Adults not documented in OR or WA since 1980.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.
Western brook lamprey (*Lampetra richardoni*)	OR-SV	Resident and nonparasitic. Documented in tributaries of the White Salmon and Klickitat Rivers.	Outside known range. No suitable habitat.	NI.	Outside known range. No suitable habitat.	NI. Species is not known to occur.	Outside known range. No suitable habitat.	NI. Species is not known to occur.
Eulachon (*Thaleichthys pacificus*)	T WA-C	Anadromous, with spawning in mainstem Columbia River and lower reaches of rivers, often in tidal influence (Sandy River in NSA). Historically migrated as far east as Hood River prior to construction of Bonneville Dam.	Present in Columbia River, downstream of the project corridor	NE on species or proposed critical habitat.	Present in Columbia River, downstream of the project corridor	NE on species or proposed critical habitat.	Present in Columbia River, downstream of the project corridor	NE on species or proposed critical habitat.
Leopard dace (*Rhinichthys falcatus*)	WA-C	Disjunct populations in Columbia River mainstem and Yakima, Snake, Similkameen Rivers. Habitat in large, slower flowing rivers and lakes. Lay adhesive eggs in riffles, late spring.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.
Mountain sucker (*Catostomus platyrhynchus*)	WA-C	Historic range in Columbia River system, largely east of Cascades, including the Columbia River mainstem and lower Klickitat River in the NSA. June/July spawner in riffles.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.	Present in Columbia River and Fifteenmile Creek	NI. No in-water work.
Herptiles								
Cope's giant salamander *(Dicamptodon copei)*	FS OR-SU	Western WA, northwestern OR. Clear, cold mountain streams with rocky substrate.	Outside known range. No suitable habitat.	NI.	Outside known range. No suitable habitat.	NI.	Outside known range. No suitable habitat.	NI.
Cascade torrent salamander *(Rhyacotriton cascadae)*	FS WA-C OR-SV	Cascade Mountains of southern WA and northern OR. In and adjacent to cold, fast mountain streams or seeps with rocky substrate.	Outside known range	NI	Outside known range	NI	Outside known range	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Dunn's salamander *(Plethodon dunni)*	WA-C	Coast range only WA and western OR. Moss-covered rock rubble, shady stream banks.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Oregon slender salamander *(Batrachoseps wrighti)*	FS OR-SU	North and central OR Cascades. Forests with large down logs and moist talus with abundant wood debris	Outside known range	NI	Outside known range	NI	Outside known range	NI
Larch Mountain salamander *(Plethodon larselli)*	FS WA-S OR-SV	Cascades of southern WA and northern OR. Moss-covered shady talus slopes, low to mid-elevation.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Columbia spotted frog *(Rana luteiventris)*	WA-C OR-SU	Columbia River Basin (east of Cascades). In or near permanent slow ponds, streams, marshes with abundant vegetation (one known site at Conboy National Wildlife Refuge). No currents sites in NSA.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Oregon spotted frog *(Rana pretiosa)*	FS WA-E OR-SC	Historically found in the Puget Trough from the Canadian border to the Columbia River and east into the southern Washington Cascades. In or near large perennial lakes and marshes. Closest extant population at Crane Prairie Reservoir in Deschutes County.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Northern leopard frog (*Rana pipiens*)	WA-E OR-SC	Lowland marshes and ponds with dense vegetation. Presently found only in Grant County. Likely extirpated in Columbia River Gorge.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Western toad (*Bufo boreas*)	WA-C OR-SV	Widespread distribution in WA and OR. Most common near marshes and small lakes (breeding sites in mid-spring); can travel readily overland to streams and seeps.	Likely occurs	MIIH. Project would not impact aquatic associated habitats, but may result in removal of upland habitat potentially used by species, as well as temporary construction impacts	Likely occurs	MIIH. Project would not impact aquatic associated habitats, but may result in removal of upland habitat potentially used by species, as well as temporary construction impacts	Likely occurs	MIIH. Project would not impact aquatic associated habitats, but may result in removal of upland habitat potentially used by species, as well as temporary construction impacts

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Northwestern pond turtle (*Clemmys marmorata*)	FS WA-E OR-SC	Streams, large rivers, slow sloughs, and quiet waters with nesting habitat (open meadow) within 0.5 mile. Occurs below 3,000-foot elevation.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Painted turtle (*Chrysemys picta*)	FS (OR) OR-SC	Slow water ponds, marshes, rivers below 3,000-foot elevation. Widely introduced outside Columbia River Gorge and Columbia River Basin.	Likely occurs	NI. Project will not impact aquatic habitats.	Likely occurs	NI. Project will not impact aquatic habitats.	Likely occurs	NI. Project will not impact aquatic habitats.
California mountain king snake (*Lampropeltis zonata*)	FS (WA) WA-C OR-SV	Main population in CA and Klamath Mountains, with disjunct population in Columbia River Gorge (Klickitat, Skamania County area). Oak and pine woodland, rocky riparian in logs and rocky cover. No confirmed specimens on OR side of NSA, although unconfirmed sightings in The Dalles and Maupin areas.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI
Sharptail snake (*Contia tenuis*)	FS (WA) WA-C OR-SV	East slope of WA Cascades, Columbia River Gorge, western OR. Rocky slopes often in open pine and oak woodland, preying on small slugs. Also in moist riparian east of Cascades. Usually found near streams. Largely subterranean during summer, appearing in spring and fall.	May occur along streams and riparian areas	NI. Project alignment will not affect aquatic or riparian habitat.	May occur along streams and riparian areas	NI. Project alignment will not affect aquatic or riparian habitat.	May occur along streams and riparian areas	NI. Project alignment will not affect aquatic or riparian habitat.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Night snake *(Hypsiglena torquata)*	FS (WA)	C. and E. Oregon. C. Washington. Found in semi arid areas of oak and talus. Rarely encountered due to entirely nocturnal habits.	May occur	MIIH. Project may result in habitat removal, temporary construction impacts and indirect impacts (e.g., new perches for raptors that may result in increased predation), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, temporary construction impacts and indirect impacts (e.g., new perches for raptors that may result in increased predation), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, temporary construction impacts and indirect impacts (e.g., new perches for raptors that may result in increased predation), but is not anticipated to result in a downward trend in the population.
Striped whipsnake (*Masticophis taeniatus*)	FS (WA) WA-C	South and central WA, eastern OR. Dry rocky sites, oak woodland, pine forests. Not documented in Klickitat County, WA.	Outside known range	NI	Outside known range	NI	Outside known range	NI
Birds								
Bald eagle *(Haliatus leucocephalus)*	WA-T OR-T	Shoreline (generally within 1 mile of large water bodies). Large trees and prey base of fish. Diet also includes waterfowl, turtles, and carrion.	Known to occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but not expected to cause a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Northern spotted owl *(Strix occidentalis caurina)*	T WA-E OR-T	Mature coniferous forest for nesting, roosting, and foraging. Will disperse in early or mid-seral forests.	Outside known range	NE	Outside known range	NE	Outside known range	NE
Ferruginous hawk *(Buteo regalis)*	FS (WA) WA-T OR-SC	Open prairie and shrub steppe in eastern WA and OR.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Peregrine falcon *(Falco peregrinus)*	FS OR-E WA-S	Tall cliff (nest) sites within 1 mile of water with small bird prey base.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.
Northern goshawk *(Accipiter gentilis)*	WA-C OR-SC	More common east of Cascades in a wide variety of forest ages, structural conditions, and successional stages. Nests in stands of mature forest at elevations of 1,900 to 6,100 feet in Oregon.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Golden eagle (*Aquila chrysaetos*)	WA-C	Various habitats in open country and forests. Often nests on steep cliffs or large trees.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.
Merlin (*Falco columbarius*)	WA-C	Forests, grasslands, marshes. Nests in WA Cascades, northeastern WA. Winters throughout the northwest.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	Known to occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Flammulated owl (*Otus flammeolus*)	WA-C OR-SC	East Cascades. Cavity nester in mature pine and mixed conifer forests at mid-elevations. Winters south of US border.	May occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of foraging habitat, construction impacts (e.g., disturbance) and indirect impacts (e.g., reduced foraging success during construction), but is not expected to cause a downward trend in the population.
Common loon (*Gavia immer*)	FS (WA) WA-S	Undisturbed lakes and ponds with fish and invertebrate prey base. Spring/fall migrant; winters in NSA.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats..	Possible winter resident along Columbia River	NI. Project not expected to impact habitats..	Possible winter resident along Columbia River	NI. Project not expected to impact habitats..
Western grebe (*Aechmophorus occidentalis*)	WA-C	Open lakes and marshes with rushes and tule. Winters in coastal estuaries and bays.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.
Clark's grebe (*Aechmophorus clarkii*)	FS (WA)	Winters in NSA on large rivers. Breeds in large lakes with tule or rushes.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.
Horned grebe (OR only) (*Podiceps grisegena*)	FS (OR) OR-SP	Common winter resident on Columbia River in NSA. Breeds on marshes and lakes in eastern WA and OR.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.
Red-necked grebe (*Podiceps grisegena*)	FS (OR) OR-SC	Rare winter migrant on the Columbia River. Uncommon breeder in eastern WA and OR.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Eared grebe (*Podiceps nigricollis*)	FS (WA)	Documented but uncommon winter resident of NSA. Breeds in eastern OR and WA lakes and reservoirs with rushes and cattails.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.
Harlequin duck (*Histrionicus histrionicus*)	FS	Winters at coast. Breeds at NSA on ground, usually within 10 meters of fast-moving Cascade tributaries of the lower and middle Columbia River, often on rocky islands and banks.	Breeds in Columbia River Gorge Cascade tributaries	NI. Project not expected to impact habitats.	Breeds in Columbia River Gorge Cascade tributaries	NI. Project not expected to impact habitats.	Breeds in Columbia River Gorge Cascade tributaries	NI. Project not expected to impact habitats.
Bufflehead *(Bucephala albeola)*	FS(OR)	Nests in tree cavities and winters in small flocks along the Columbia River	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.	Possible winter resident along Columbia River	NI. Project not expected to impact habitats.
American white pelican (*Pelecanus erythrorhynchos*)	WA-E OR-SV	Nest in large colonies on islands in shallow water and marshes free of human disturbance and mammalian predators. Post breeders sometimes seen in Columbia River (such as Klickitat Delta). Winters from southern US to Mexico.	Rare, but possible occurrence	NI. Project not expected to impact habitats.	Rare, but possible occurrence	NI. Project not expected to impact habitats.	Rare, but possible occurrence	NI. Project not expected to impact habitats.
Sandhill crane (*Grus canadensis*)	WA-E	Riverine wetland, isolated mountain meadows and basins. No current breeding populations in the NSA; some migration.	Rare, but possible occurrence	NI. Project not expected to impact habitats.	Rare, but possible occurrence	NI. Project not expected to impact habitats.	Rare, but possible occurrence	NI. Project not expected to impact habitats.
Yellow-billed cuckoo (*Coccyzus americanus*)	WA-C OR-SC	Historic range in WA and OR. No reported breeding occurrences since the 1950s, although periodically sighted east of Cascades. Riparian forests, with cottonwood and thick willow. Neotropical migrant.	Formerly considered extirpated from the CRGNSA; sightings at Sandy River Delta in 2009 and 2010.	NI. Project not expected to impact habitats.	Formerly considered extirpated from the CRGNSA; sightings at Sandy River Delta in 2009 and 2010.	NI. Project not expected to impact habitats.	Formerly considered extirpated from the CRGNSA; sightings at Sandy River Delta in 2009 and 2010.	NI. Project not expected to impact habitats.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Lewis' woodpecker (*Melanerpes lewis*)	WA-C OR-SC	Open pine and oak woodland, conifer forests, and riparian woodland. Neotropical migrant. Commonly seen in eastern dry forests of NSA.	May occur within wooded areas	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur within wooded areas	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur within wooded areas	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
White-headed woodpecker (*Picoides albolarvatus*)	WA-C OR-SC	Central and eastern WA and OR in mature and open coniferous forests, especially ponderosa pines. Cavity nester. Not currently documented in NSA.	May occur within wooded areas	NI. Species occurs further west of the project alignment in forested areas	May occur within wooded areas	NI. Species occurs further west of the project alignment in forested areas	May occur within wooded areas	NI. Species occurs further west of the project alignment in forested areas
Black-backed woodpecker (*Picoides arcticus*)	WA-C OR-SC	Uncommon Cascades resident usually at higher elevations (above 3,000 feet). Eastern Cascades in WA. Scattered distribution as populations are highly associated with post-fire habitats in mature forests (stand-replacement fires with snags), dependent on high density of dead and insect-ridden trees.	No suitable habitat	NI. Project alignment traverses the CRGNSA at elevations below those at which species typically occurs.	No suitable habitat	NI. Project alignment traverses the CRGNSA at elevations below those at which species typically occurs.	No suitable habitat	NI. Project alignment traverses the CRGNSA at elevations below those at which species typically occurs.
Acorn woodpecker (*Melanerpes formicivorus*)	FS (WA)	Highly associated resident of oaks and pine and oak woodlands. Klickitat County (near Lyle) is the only known location in WA, home to the northernmost population in its range. Primary cavity nester.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Pileated woodpecker (*Dryocopus pileatus*)	WA-C OR-SV	Conifer and mixed conifer forests, and deciduous stands in valley bottoms with large dead or live trees (or remnants) for foraging and nesting. Primary cavity nester.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Green-tailed towhee (*Pipilo chlorurus*)	FS (WA)	At moderate to higher elevations, nests in shrubby areas intermixed with small trees, often in areas maintained by fires or other disturbance. WA state is on its most northwesterly range peripherally, with most recorded in the Blue Mountains of southeast WA. Known occurrences in east Hood River County, OR.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Sharp-tailed grouse (*Tympanuchus phasianellus*)	WA-T	Grasslands and sagebrush. Historically found east of the Cascades, including much of Klickitat County, but extirpated in 1950s from most of range in WA and OR. Remnant population in northeastern WA.	Extirpated from this portion of historic range	NI	Extirpated from this portion of historic range	NI	Extirpated from this portion of historic range	NI
Lesser goldfinch (*Carduelis psaltria)*	FS (WA)	Open steppes and oak woodlands. A permanent resident in south-central WA. Klickitat County is its northernmost population across its range in western and southwestern US and Mexico.	May occur	MIIH. Project may remove open steppe habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove open steppe habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove open steppe habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Sage sparrow (*Amphispiza belli*)	WA-C	Eastern WA and OR. Flat terrain highly associated with big sagebrush; may also use chaparral, and dry foothills. On periphery of habitat in NSA; in the extreme eastern end. No known current populations, although migrants may pass through the NSA. Winters in southern OR and southwestern US.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Sage thrasher (*Oreoscoptes montanus*)	WA-C	Eastern WA and OR semiarid sagebrush plains and bottomlands. May have historically been in outlying east portion of NSA, but no current populations.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Loggerhead shrike (*Lanius ludovicianus*)	WA-C	East of Cascades. Dry grassland and sagebrush desert habitats. On periphery of habitat in NSA with sightings in east Klickitat County. Neotropical migrant.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Oregon vesper sparrow (*Pooecetes gramineus affinis*)	WA-C	Lowland valleys of western WA and OR (Willamette, Klamath, Puget Sound). Sparsely vegetated grasslands with scattered tall structures used for song perches, including agricultural lands. On periphery of habitat in NSA. Ground nester.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Slender-billed white-breasted nuthatch *(Sitta carolinensis aculeata)*	FS(WA)	A westside subspecies of the white-breasted nuthatch. Open oak and oak/Douglas-fir forests in western Washington (Skamania, Clark, and Cowlitz Counties). Decline directly related to loss of this habitat.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Gray flycatcher (*Empidonax wrightii*)	FS	Southeast WA and eastern OR. Ponderosa pine, sagebrush, and pinyon juniper woodlands. On periphery of habitat in NSA. Winters in southwest US and southward.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Ash-throated flycatcher (*Myiarchus cinerascens*)	FS(WA)	Oak and juniper woodlands. Nests in natural or artificial cavities. Winters in southwest US and southward.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Black swift (*Cypseloides niger*)	FS(OR) OR-SP	Nests in waterfalls, steep cliffs, and damp caves out of direct sunlight. Highly suspected to be in NSA, but NSA is outside current known range. Neotropical migrant.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Vaux's swift (*Chaetura vauxi*)	WA-C	Forests and urban areas with hollow trees, bark, or chimneys provide nesting sites. Neotropical migrant.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Purple martin (*Progne subis*)	OR-SC WA-C	Western WA and OR up the Columbia River Gorge to western Wasco County. Cavity and crevice nester, often near water. Forages over open water, fields, and forest canopy. Winters in South America.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Mammals								
Grizzly bear *(Ursus arctos)*	T WA-E	Historically in lower 48 states, presently restricted to areas with low human populations, such as North Cascades Range.	Project alignment does not intersect species current range	NE on species or proposed critical habitat.	Project alignment does not intersect species current range	NE on species or proposed critical habitat.	Project alignment does not intersect species current range	NE on species or proposed critical habitat.
Gray wolf *(Canis lupus)*	E WA-E	Historically found in almost all habitats in lower 48 states; presently reintroduced in steppe, woodland, and forest habitats.	Project alignment is outside known range	NE on species. Critical habitat has been neither proposed nor designated in WA or OR.	Project alignment is outside known range	NE on species. Critical habitat has been neither proposed nor designated in WA or OR.	Project alignment is outside known range	NE on species. Critical habitat has been neither proposed nor designated in WA or OR.
California wolverine *(Gulo gulo)*	FS WA-C OR-T	Conifer forests. Intolerant of human encounters or disturbance. Requires very large home ranges. One sighting in last several decades of road-killed juvenile male on I-84, near Starvation Creek, January 1990.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI
Pacific fisher *(Martes pennanti)*	FS WA-E OR-SC	Optimum habitat is dense, lower elevation, mature conifer forest, with large down logs for nesting. Likely extirpated in NSA and adjacent forests.	No suitable habitat.	NI	No suitable habitat	NI	No suitable habitat	NI
Columbian white-tailed deer (lower Columbia River population only) *(Odocoileus virginianus leucurus)*	E WA-E	Historic distribution in floodplains, bottomland riparian of Willamette and Lower Columbia River now limited to these lower southwest counties: Clark, Cowlitz, Pacific, Skamania, and Wahkiakum Counties, WA; Clatsop, Columbia, and Multnomah Counties, OR.	This portion of the CRGNSA is outside known range.	NE on species. Critical habitat has been neither proposed nor designated in WA or OR.	This portion of the CRGNSA is outside known range.	NE on species. Critical habitat has been neither proposed nor designated in WA or OR.	This portion of the CRGNSA is outside known range.	NE on species. Critical habitat has been neither proposed nor designated in WA or OR.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
White-tailed jackrabbit *(Lepus townsendii)*	WA-C OR-SU	East of Cascades. Open areas with native bunchgrass, sagebrush plains. Can also be found in coniferous forests and subalpine meadows. On periphery of habitat in NSA at The Dalles and Dallesport.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may remove habitats occupied by this species and result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Washington ground squirrel (*Spermophilus washingtoni*)	WA-C OR-E	Presently found in Columbia Basin of WA state in sagebrush/grassland w/ sandy soils; also Gilliam, Morrow and Umatilla counties, OR. May have historically been in the eastern edge of NSA.	Project alignment is outside known range.	NI	Project alignment is outside known range.	NI	Project alignment is outside known range.	NI
Western gray squirrel (*Sciurus griseus*)	FS (WA) OR-SU WA-T	Open mixed oak and conifer woodland, typically within 0.5 mile of water source. Core range for WA in Klickitat County. Known to occur in Hood River and in eastern OR. Easy to confuse with nonnative and invasive eastern gray squirrel.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Gray-tailed vole (*Microtus canicaudus*)	WA-C	Endemic to Clark County, WA and Willamette Valley, OR. Grassy and agricultural lands, meadows. On periphery of habitat in NSA. Common in OR.	Project alignment is outside known range.	NI	Project alignment is outside known range.	NI	Project alignment is outside known range.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Townsend's big-eared bat (*Corynorhinus townsendii*)	FS (WA) WA-C, OR-SC	Throughout western US. Roost and hibernaculum sites in caves, buildings, mines, and bridge undersides, with exacting temp, humidity, and physical requirements. Very intolerant of human disturbance, which results in loss of critical fat reserves during torpid period.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Pacific fringe-tailed bat (*Myotis thysanodes vespertinus*)	FS	Nursery colonies and roosts in mines, caves, buildings, and similar conditions. Intolerant of human disturbance. Documented in Little White Salmon Subbasin in 1996. More common in southwest WA.	Project alignment is outside known range.	NI	Project alignment is outside known range.	NI	Project alignment is outside known range.	NI
Pacific pallid bat (*Antrozous pallidus*)	FS (OR) OR-SV	Arid area specialist. Daytime roosts in buildings and crevices, less often in caves and other shelters. Feeds primarily on the ground on large insects, scorpions, and other small prey.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.	May occur	MIIH. Project may result in temporary construction impacts (e.g., disturbance), but is not anticipated to result in a downward trend in the population.
Invertebrates								
California floater mussel *(Anodonta californiensis)*	WA-C	Shallow areas of lakes, ponds, reservoirs, and large rivers with muddy or sandy substrate. Historically found throughout western US, but presently known to occur as remnant populations in Columbia, Okanogan, and lower Willamette River systems. Intolerant of fluctuating water levels that decimate local populations.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Western ridged mussel *(Gonidea angulata)*	FS	Low to mid-elevation cold clean streams and rivers of the western US. Mainly east of the Cascades. Known stronghold in the larger rivers of the Snake and Columbia River systems.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Giant Columbia River limpet *(Fisherola nuttalli)*	WA-C	Historically in almost the entire Columbia River Basin, now restricted to a few remnant sites. In WA, confirmed in Hanford Reach of the Columbia River, as well as the Okanogan, Wenatchee and Methow Rivers. In OR, only documented in Deschutes River.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Great Columbia River spire snail (*Fluminicola columbiana*)	WA-C	Historically, widespread throughout the Lower Snake and Columbia Rivers and their larger tributaries. Now limited to a few reaches of the Columbia River system that remain free-flowing and colder. Confirmed in a few sites along the Columbia, Okanogan, Wenatchee and Methow Rivers in WA, and the Deschutes River in OR.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Puget Oregonian (*Cryptomastix devia*)	FS	Western Cascades at low to mid- elevations. Moist conifer forests, associated with bigleaf maple. Often found on or under hardwood logs, leaf litter, or under swordfern, moist rocks and talus. Young devia may be under mosses on trunk of bigleaf maple.	Outside known range. No suitable habitat.	NI	Outside known range; no suitable habitat	NI	Outside known range. No suitable habitat.	NI
Columbia Oregonian (*Cryptomastix hendersoni*)	FS	Low to mid elevations. Columbia Gorge in Wasco, Sherman, Skamania, and Klickitat Counties. Terrestrial species usually within 100 meters of streams, seeps, and springs (low elevation) in steppe communities. May also be in mid- elevation mature closed canopy forests among moist talus, leaf litter, or shrubs, or under logs or other debris.	May occur in riparian areas	NI. Project is not anticipated to impact suitable riparian habitat.	May occur in riparian areas	NI. Project is not anticipated to impact suitable riparian habitat.	May occur in riparian areas	NI. Project is not anticipated to impact suitable riparian habitat.
Evening fieldslug *(Deroceras hesperium)*	FS	Low to mid-elevation from the Cascades to the Pacific Ocean, with most currently documented sites east of the Cascade crest. Terrestrial species associated with perennially wet meadows in forested habitat; microsites include a variety of low vegetation, litter and debris, and rocks or talus.	May occur in wetland habitats	NI. Project is not anticipated to impact suitable wetland habitat.	May occur in wetland habitats	NI. Project is not anticipated to impact suitable wetland habitat.	May occur in wetland habitats	NI. Project is not anticipated to impact suitable wetland habitat.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Malone's jumping slug (*Hemphilia malonei*)	FS-WA	Below 4,600-foot elevation. Benton County northward into western OR Cascades and into southwestern Cascades of WA. Terrestrial species associated with moist forest stands, generally older than 50 years, with more than 50% canopy cover, especially with dense swordfern and large woody material. Some found near marshy areas with low vegetation cover.	Outside known range. No suitable habitat.	NI. Project is not anticipated to impact suitable aquatic habitat.	Outside known range. No suitable habitat.	NI. Project is not anticipated to impact suitable aquatic habitat.	Outside known range. No suitable habitat.	NI. Project is not anticipated to impact suitable aquatic habitat.
Barren juga *(Juga hemphilli hemphilli)*	FS	Limited distribution in Columbia River Gorge (Clark and Skamania Counties, WA.), Johnson Creek, and Mt. Hood National Forest. Also likely to occur in Gifford-Pinchot National Forest. Found in smaller low-elevation streams, with low gradient, stable gravel substrate, moderate velocity, and highly oxygenated cold water.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Basalt juga (*Juga oreobasis, new sp. 2*)	FS (OR)	Occurs very sporadically in low elevation tributaries of the Columbia River in cold, oxygenated springs in central and eastern Columbia River Gorge (OR, WA). Sensitive to water temperature and sedimentation. Coexists with pristine springsnail and Columbia duskysnail.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Purple lipped juga (*Juga hemphilli manupinensis*)	FS (OR)	Suspected in NSA on the east side (OR). Documented in Deschutes River drainage. Found at low-elevation large streams in well-oxygenated and minimally affected gravel-cobble riffles in cold water.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Deschutes Mountain snail (*Oreohelix variabilis* ssp. *nov.*)	FS (OR)	Found on Deschutes Wild and Scenic River. Maybe in CRGNSA. Moderate xeric, rather open and dry areas, in large scale basalt taluses on steep, cool aspects. Assoc. w/ seeps springs, but not in wettest areas.	May occur in isolated areas in the Columbia Hills	NI. Project is not anticipated to impact suitable habitat.	May occur in isolated areas in the Columbia Hills	NI. Project is not anticipated to impact suitable habitat.	May occur in isolated areas in the Columbia Hills	NI. Project is not anticipated to impact suitable habitat.
Columbia Gorge caddisfly (*Neothremma andersoni*)	FS (OR)	Known only in the Columbia River Gorge in Wahkeena Creek in Multnomah County, OR, where it is apparently endemic. Larvae and pupa common above Gorge escarpment, less so as stream flows out onto the Columbia River floodplain.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Wahkeena Falls flightless stonefly (*Zapada wahkeena*)	FS	Flightless – dispersal is only by aquatic matures. Known only in waterfalls at Wahkeena Falls in the NSA. Water quality important.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Columbia duskysnail (*Lyogyrus* n. sp. 1)	FS	Counties include Klickitat, Skamania, Cowlitz, Clark, Washington, Multnomah, Clackamas, and Hood River). Springs and spring outflows in cold, clear, and well-oxygenated water. Usually slow flow with moss substrate.	May occur within aquatic habitats.	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Oregon megomphix *(Megomphix hemphilli)*	FS (WA)	Puget Sound and Coast range to west foothills of Cascades in moist coniferous forests. Often in association with bigleaf maple and swordfern. Photo-phobic; seldom found on surface.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Dalles sideband (*Monadenia fidelis minor*)	FS	Central and east Gorge; Wasco and Klickitat Counties. Terrestrial species usually found within 200 meters of streams, seeps, or springs, in steppe or dry forest plant communities (in talus and moist rocky areas). May be found among rocks, shrubs, vegetation, and down wood.	May occur in riparian habitats	NI. Project is not anticipated to impact suitable riparian habitat.	May occur within riparian habitats	NI. Project is not anticipated to impact suitable riparian habitat.	May occur within riparian habitats	NI. Project is not anticipated to impact suitable riparian habitat.
Crowned tightcoil *(Pristiloma pilsbryi)*	FS	Historic range probably from southern Alaska to southern Oregon. Currently known from Clallam and Pacific Counties, WA; suspected in Grays Harbor, Wahkiakum, Cowlitz, and Clark Counties, WA; and in Multnomah, Clatsop, and Columbia Counties, OR. Very moist forests, including floodplains, in decaying leaf litter, commonly under dense salal, vine maple, waterleaf or other deciduous vegetation.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Shiny tightcoil *(Pristiloma wascoense)*	FS (WA)	Reported from many widely separate (but imprecise) historic locations; in Wasco, Marion, and Wallowa Counties in Oregon; also reported from several counties in Idaho. Occurs rarely in Oregon; surveys in recent years in these areas have failed to relocate it. It is possible that *P. wascoense* is a small form or *P. cherisnella*, or represents a species complex in the northern portion of OR Cascades. Thought to generally occur in ponderosa pine and Douglas-fir plant associations at moderate to high elevations with likely preference for moist microsites such as basalt talus accumulations, usually with riparian influence.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Pristine springsnail *(Pristinicola hemphilli)*	FS (WA)	Scattered colonies in Columbia, Snake, and Willamette River watersheds, as well as southwest OR. Most sites are very small, undisturbed cold springs or seeps with slow to moderate flow; sometimes in larger springs and spring runs or spring-influenced portions of small streams.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.
Blue-gray taildropper (*Prophysaon coeruleum*)	FS (WA)	Widespread. Western Cascades and Puget trough, south to northern CA. Occurs on both sides of southern OR Cascades. Suspected on east slopes of Cascades in WA. Moist conifer and mixed conifer/hardwood forest, where litter is moist and shaded. Associated with decayed logs, leaf litter, mosses, and bigleaf maple and swordfern.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Columbia River tiger beetle (*Cicindela columbica*)	WA-C	Known to occur only in sandbars of Snake and Columbia River riparian area, east of Cascades.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.	May occur within aquatic habitats	NI. Project is not anticipated to impact suitable aquatic habitat.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Yuma skipper butterfly (*Ochlodes yuma*)	WA-C	Main population in Great Basin area with outliers in central and eastern OR and WA. Terrestrial species typically found near freshwater marshes, streams, ponds, lined with phragmites reeds. The only record in NSA found at Maryhill in 1999 on ornamental *Miscanthus*	May occur in riparian habitats	NI. Project is not anticipated to impact suitable riparian habitat.	May occur within riparian habitats	NI. Project is not anticipated to impact suitable riparian habitat.	May occur within riparian habitats	NI. Project is not anticipated to impact suitable riparian habitat.
Chinquapin hairstreak butterfly (*Habrodais grunus herri*)	WA-C	North-central OR, Skamania County, WA: Obligate with Chrysolepis chrysophylla. One known location near Stevenson, WA.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Johnson's hairstreak butterfly (*Callophry[*Mitoura] johnsoni)	WA-C	Cascades, Coast, Siskiyou, Blue, and Wallowa Mountains. Coniferous forest old-growth obligate.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Mardon skipper (*Polites mardon*)	WA-E	Historic distribution unknown. Present known distribution is disjunct northern CA, Puget Sound, and southern Cascades of WA. Open fescue grasslands, riparian, or meadows with nectar plant source. No known populations in the NSA but surveys by NSA office continue. Species decline likely due to loss of native grass-meadows and prairie habitat throughout northwest.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Vascular Plants								
Tall agoseris *(Agoseris elata)*	OR-2 WA-S FS-S	Meadows, open woods and exposed rocky ridge tops, from low elevations (2,900 feet) to timberline (7,800 feet).	Outside known range: project traverses the CRGNSA below 2,900 ft., below elevations where species generally occurs.	NI	Outside known range: project traverses the CRGNSA below 2,900 ft., below elevations where species generally occurs.	NI	Outside known range: project traverses the CRGNSA below 2,900 ft., below elevations where species generally occurs.	NI
Howell's bentgrass *(Agrostis howellii)*	OR-1 FS-S Endemic	Moist rocks on south side of Columbia River Gorge (Multnomah and Hood River Counties).	Outside known range.	NI	Outside known range.	NI	Outside known range.	NI
Sickle-pod rock cress *(Arabis sparsiflora* var. *atrorubens)*	OR-2 FS-S	Eastside, low elevation. Found in arid, sagebrush and ponderosa pine habitats.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Northern wormwood *(Artemesia campestris* spp. *borealis* var. *wormskioldii)*	OR-E OR-1 WA-E FS-S US-C	Gravely beach areas of Columbia River. Miller Island in Gorge.	May occur	NI. Project alignment will not affect Miller Island and no towers will be located within the floodplain of the Columbia River.	May occur	NI. Project alignment will not affect Miller Island and no towers will be located within the floodplain of the Columbia River.	May occur	NI. Project alignment will not affect Miller Island and no towers will be located within the floodplain of the Columbia River.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Hood River milk-vetch *(Astragalus hoodianus)*	OR-2 Endemic	Dry open areas of east Gorge.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.
Oregon bolandra (*Bolandra oregana*)	WA-S FS-S	Wet basalt cliffs.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Lance-leaved grape-fern (*Botrychium lanceolatum*)	OR-2 FS-S	Moist, wet areas in mountains.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Moonwort (*Botrychium lunaria*)	OR-2 FS-S	Moist wet areas but rarely in meadows. Low to high elevations in grassy slopes, meadows, turf ledges, open deciduous forests and hay fields.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Mountain grapefern (*Botrychium montanum*)	OR-2 FS-S	Forested and open areas in conifer forest zones.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Brewer reedgrass (*Calamagrostis breweri*)	OR-2 FS-S	Stream banks, lake margins, sub-alpine to alpine meadows.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Howell's reedgrass (*Calamagrostis howellii*)	Endemic	Steep north facing slopes at elevations ranging from 1,600 to 3,400 feet, generally within microsites that have very little soil development and limited development of competing vegetation. Rocky banks and crevices of cliffs in the Gorge.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Long-bearded sego lily *Calochortus longebarbatus* var. *longebarbatus*	WA-S FS-S	Found in open areas in vernally moist meadows, forest-meadow edges, and semi-open areas within coniferous woods. East slope of Cascades.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Dense sedge (*Carex densa*)	WA-T FS-S	Wet areas on both sides of Cascades. Occurs in habitats strongly influenced by fluctuating water levels, which may limit competition with other plants.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Lesser panicled sedge *Carex diandra*	OR-1 FS(OR)-S	Wet areas with saturated soils. Swampy, marshy or boggy areas including features such as wet meadows, fens, muskegs, floating mats, and shores of lakes and ponds.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Different nerve sedge *Carex heteroneura* (*Carex atrata* var. *erecta*)	FS-S	Montaine.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Pale sedge (*Carex livida*)	OR-2 FS-S	Willamette Valley.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Large-awn sedge (*Carex macrochaeta*)	WA-T OR-2 FS-S	Moist open places, coastal but suspected in Gorge.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Native sedge (*Carex vernacula*)	OR-2 FS-S	Alpine to sub-alpine. Dwarf size.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Golden paintbrush (*Castilleja levisecta*)	T OR-E OR-1 WA-E FS-S	Open fields, west side of Cascades.	Outside known range of species	NE	Outside known range of species	NE	Outside known range of species	NE
Cliff paintbrush (*Castilleja rubicola*)	OR-2 FS-S	Rocky cliffs at low to moderate elevations.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.
Golden chinquapin (*Chrysolepis chrysophylla*)	WA-S FS-S	Open to closed forest openings Low to mid elevations.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI
Bulb-bearing water-hemlock (*Cicuta bulbifera*)	OR-2 WA-S FS-S	Wet places to standing water. Low elevations.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Tall bugbane (*Cimicifuga elata*)	OR-1 WA-S FS-S	Hardwood and mixed forest on west side.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Few-flowered blue-eyed Mary (*Collinsia sparaiflora* var. *bruceae*)	WA-S FS-S	Dry slopes with sparse vegetation on east side of Cascades. Low elevations.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.
Three-leaf goldthread (*Coptis trifolia*)	OR-2 WA-1 FS-S	Wasco County. Prefers wet to mesic forests, bogs, muskegs, willow scrub and tundra, often with mosses. Prefers partially shaded, cool, wet areas, and relatively infertile, acidic, poorly drained organic soils. The WA population grows in a coastal cedar bog.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI
Cold-water corydalis (*Corydalis aqua-gelidae*)	OR-1 WA-S FS-S	Along cold streams on west side of Cascades.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Beaked cryptantha (*Cryptantha rostellata*)	WA-T FS-S	Dry open areas, east side Cascades.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Shining cyperus (*Cyperus bipartitus*)	FS-S	Wet places. Low elevation.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.
Clustered lady's-slipper (*Cypripedium fasiculatum*)	OR-2 WA-S FS-S	Open to closed forested woodlands. East side of Cascades.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI
Fringed waterplantain (*Damasonium californicum*)	WA-T FS-S	Sloughs, marshes, and other standing waters.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Pale larkspur (*Delphinium leucophaeum*)	WA-E OR-1	West side (Multnomah County).	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Nuttall's larkspur (*Delphinium nuttallii*)	OR-2	Moist open ground and basaltic cliffs. Common on the gravelly outwash "prairie" remnants of prehistoric glaciations. Occurs west of the Cascades.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Smooth-leaf douglasia (*Douglasii laevigata var. laevigata*)	Endemi c	Basalt cliffs and rocky outcrops, low elevation through the Gorge.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Howell's daisy (*Erigeron howellii*)	OR-1 WA-T Endemic FS-S	Open areas on ridges and rocky areas, primarily on north-facing slopes at elevations ranging from 1,600 to 3,400 ft. Found in microsites with minor soil development and little development of competing vegetation.	Outside known range of species	NI	Outside known range of species	NI	Outside known range of species	NI
Columbia Gorge daisy (*Erigeron oreganus*)	OR-1 WA-T Endemic FS-S	Overhanging basalt cliffs.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.
Oregon coyote-thistle (*Eryngium petiolatum*)	WA-T FS-S	Dry ephemeral wetlands in east Gorge.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.
Western wahoo (*Euonymus occidentalis*)	WA-T FS-S	In woods in west Cascades.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Black lily (*Fritillaria camschatcensis*)	OR-2 WA-S FS-S	Moist areas in west Cascades from coast to mountains.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Currant-leaf alumroot (*Heuchera grossularifolia* var. *tenuifolia*)	WA-S FS-S	Cliffs, often shaded, along streams or rivers in eastern Gorge.	May occur	MIIH. Project may habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may habitat removal, but is not expected to cause a downward trend in the population.

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Long-bearded hawkweed (*Hieracium longiberbe*)	Endemic	Open areas throughout Gorge.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in habitat removal, but is not expected to cause a downward trend in the population.
Howellia (*Howellia aquatilis*)	T OR-1 WA-T FS-S	Occurs in low elevation wetlands within the forested portions of the channeled scablands. Requires seasonally inundated wetlands, which dry out in late summer or early fall.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Columbia lewisia (*Lewisia columbiana var. columbiana*)	OR-2 FS-S	Open rocky areas in western Gorge, generally middle to high elevations.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Baker's linanthus (*Linanthus bolanderi*)	WA-S FS-S	Dry open areas in eastern Gorge.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Twayblade (*Liparis loeselii*)	WA-E FS-S	Wet or damp areas in forest.	No suitable habitat	NI	No suitable habitat	NI	No suitable habitat	NI

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Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Smooth desert parsley (*Lomatium laevigatum*)	OR-2 WA-T FS-S Endemic	Basalt cliffs and crevices in eastern Gorge. Documented in the vicinity BEK project	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in direct mortality of individuals of this species if present along the alignment and habitat removal, but is not expected to cause a downward trend in the population.
Salmon River lomatium (*Lomatium salmoniflorum*)	OR-2	Wasco County.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Suksdorf's desert parsley (*Lomatium suksdorfii*)	OR-2 WA-S FS-S Endemic	Open wooded or open areas in eastern Gorge.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Watson's desert parsley (*Lomatium watsonii*)	OR-2 FS-S	Open hillsides and with sage brush, often amongst sagebrush on the eastside. Found in Kittitas, Yakima and Klickitat Counties in WA and Jefferson, Hood River and Wasco Counties in OR.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Columbia Gorge broad-leaf lupine (*Lupinus latifoius var thompsonianus*)	Endemi c	Open areas in pine and oak woodlands.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Northern bog clubmoss (*Lycopodiella inundata*)	OR-2 WA-S FS-S	Wet, sandy places, wetlands adjunct to lakes, and swampy ground. Westside.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Ground cedar (*Lycopodium complanatum*)	OR-2 FS-S	Westside.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
White meconella (*Meconella oregana*)	OR-1 WA-T FS-S	Oak woodlands in eastern Gorge.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Northern microseris (*Microseris borealis*)	WA-S FS-S	Low to mid elevation wetlands.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.

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Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Columbia monkey flower (*Mimulus jungermannioides*)	OR-1 FS-S	Wet areas in east Cascades.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Pulsifer's monkey-flower (*Mimulus pulsiferae*)	WA-S FS-S	Wet areas.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Suksdorf's monkey-flower (*Mimulus suksdorfii*)	WA-S FS-S	Open, moist, or rather dry places.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Branching montia (*Montia diffusa*)	WA-S FS-S	Upturned root disturbances in the forest of Cascades.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Howell's montia (*Montia howellii*)	FS-S	Multnomah County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

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Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Marigold navarretia (*Navarretia tagetina*)	WA-T FS-S	Open rocky places at elevations of 250 to 450 feet, where there is standing water or saturated soil in early spring. Adjacent forests are composed of ponderosa pine and Douglas-fir. Garry oak is also present. Occurs in the transition zone between the forested and nonforested areas at the east end of the Gorge.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Adder's-tongue (*Ophioglossum pusillum*)	OR-2 WA-T FS-S	Terrestrial in pastures, fields, roadside ditches and floodplain woods in seasonally wet, rather acid soils.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Fringed grass-of-parnassus (*Parnassia frimbriata var. hoodiana*)	WA-T FS-S	Bogs, stream banks, wet areas (Multnomah, Hood, and Washington Counties, Oregon).	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Barrett's penstemon (*Penstemon barrettiae*)	OR-1 WA-T FS-S Endemic	Rocky cliffs, talus slopes in eastern Gorge.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Hot-rock penstemon *(Penstemon deustus var. variabilis)*	OR-SNR WA-1,2 FS(WA)-S	Found on open, dry soils over basalt at elevations ranging from 1,800 to 2,400 feet.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Henderson phlox (*Phlox hendersonii*)	OR-2 FS-S	Hood River County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Pine-foot (*Pityopus californica*)	WA-T FS-S	Low-elevation mixed conifer forest.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Coral seeded popcorn flower (*Plagiobothrys figuratus* ssp. *corallicarpus*)	OR-1 FS-S	Open areas in low-lying wet meadows that dry out in summer.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Canyon bog-orchid (*Platanthera sparsiflora*)	WA-T FS-S	Wet, boggy areas.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Pacific bluegrass (*Poa gracillima var. multnomae*)	Endemi c	Mostly on south side of Gorge in rocky, shaded cliff near waterfalls.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Loose-flowered bluegrass (*Poa laxiflora*)	WA-S FS-S	Moist woods to open rocky slopes up to mid-elevations.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Wheeler's bluegrass (*Poa nervosa var. nervosa*)	WA-S FS-S	Limited to lower Columbia River and adjacent tributaries. Open slopes, ridges and talus slopes.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Great polemonium (*Polemonium carneum*)	WA-T FS-S	Mid-elevation forests in western Gorge.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Diverse-leaved cinquefoil (*Potentilla diversifolia var. perdissecta*)	WA-S FS-S	Moist, shady and open areas; gravelly soils of glacially carved areas; ledges and rocky slopes; stream banks.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Obscure buttercup (*Ranunculus reconditus*)	OR-E OR-1 WA-E FS-S Endemic	Meadow steppe habitat dominated by bunchgrasses and forbs. Mostly found on north-facing slopes and crests of basalt ridges overlain by loess deposits of varying depth. Elevations in WA of 1,900 to 4,000 feet.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Thompson mistmaiden (*Romanzoffia thompsonii*)	FS-S OR-1	Seasonally wet, open, sunny cliffs and gravelly slopes. Occurs west of the Cascades.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Columbia yellow cress (*Rorippa columbiae*)	OR-1 WA-E FS-S	Mud flats along Columbia River. Documented in western Klickitat County/eastern Skamania County.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI
Scheuchzeria (*Scheuchzeria palustris var. americana*)	OR-2 FS-S	Multnomah County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Water clubrush (*Scirpus subterminalis*)	OR-2	Wasco County.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Scribner-grass (*Scribneria bolanderi*)	WA-S FS-S	Dry, sandy to rocky soil. Documented in western Klickitat County/eastern Skamania County.	No suitable habitat.	NI	No suitable habitat.	NI	No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Pale blue-eyed grass (*Sisyrinchium sarmentosum*)	OR-1 WA-T FS-S	Meadows and small openings that fill with snow or water in winter and spring, and variously dominated by grasses and sedges. Conifers such as lodgepole pine and Engelmann spruce, and shrubs such as hardhack border the meadows and are occasional invaders. Most sites are in either the Little White Salmon River or the White Salmon River Sub-basins ranging from 1,600 to 4,200 feet.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Western ladies' tresses (*Spiranthes porrifolia*)	WA-S FS-S	Open moist meadows.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Kruhsea (*Streptopus streptopoides*)	OR-2	Hood River, Multnomah Counties.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Violet suksdorfia (*Suksdorfia violacea*)	OR-2 FS-S	Moist cliffs at low elevations in middle Gorge.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.	May occur	MIIH. Project may result in removal of suitable habitat, but is not expected to cause a downward trend in the population.
Oregon sullivantia (*Sullivantia oregana*)	OR-1 WA-E FS-S Endemic	Wet basalt cliffs near waterfalls at low elevations in the western Gorge.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Columbia kittentails (*Synthyris stellata*)	Endemic	Shaded banks, cliffs, and ridges in the western Gorge.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Strickland's tauschia (*Tauschia stricklandii*)	OR-2 FS-S	Wet subalpine meadows in the western Gorge.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Flat-leaved bladderwort (*Utricularia intermedia*)	WA-S FS-S	Slow-moving water or streams.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Lesser bladderwort (*Utricularia minor*)	OR-2	Found in low nutrient lakes and peat-bog pools in the lowland and montane zones at elevations from 135 – 4,000 ft. Obligate wetland species. Wasco County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Siskiyou False hellebore (*Veratrum insolitum*)	WA-T FS-S	Dry, open woods and brush in the middle Gorge. Documented in western Klickitat County/eastern Skamania County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Dotted water-meal (*Wolffia borealis*)	FS-S OR-2	Freshwater ponds and slow- flowing ditches with high levels of organic material. Natural ponds as well as in log and sewage treatment ponds. Willamette Valley and near the Columbia River in Columbia County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Columbia water-meal (*Wolffia columbiana*)	OR-2	Freshwater lakes, ponds, and slow streams below elevations of 650 feet.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact
Fungi								
Greening goat's foot *Albatrellus ellisii* (WA only)	OR-2,3 FS (WA)-S	Grows in woods, prefers conifers, and common in the mountains of western North America.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Giant polypore fungus *Bridgeoporus nobilissimus*	OR-1	On boles of noble firs. Multnomah County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Truffle eater *Cordyceps capitata* (Former S&M)	S&M	Grows on ground, associated with *Elaphomyces* truffles, which are generally associated with both hardwood and coniferous forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Cortinarius barlowensis (OR only)	OR-2 FS (OR)-S	Associated with conifer forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Cudonia monticola	OR-2,3 FS-S	Associated with conifer forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Gomphus kauffmanii	OR-3 FS-S	Associated with conifer forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Umbrella false morel *Gyromitra californica*	S&M	Associated with rotting wood in conifer forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Helvella crassitunicata	OR-2	Fungus. Hood River County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Hygrophorus caeruleus	OR-2	Fungus. Hood River County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Yellow false truffle *Leucogaster citrinus*	OR-3, 4 FS-S	Associated with conifer forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Macowanites mollis	OR-1	Fungus. Multnomah County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Mycena monticola (Former S&M)	S&M	Restricted to conifer forests above 1,000 meters in elevation.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Otidea smithii	OR-2 FS-S	Associated with Douglas-fir, western hemlock, and cottonwood.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Phaeocollybia attenuata	OR-3 FS-S	Associated with conifers.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Phaeocollybia californica (OR only)	OR-1	Fungus. Multnomah County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Olive Phaeocollybia *(Phaeocollybia* olivacea) (OR only)	FS (OR)-S	Associated with mixed woods and conifers.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Phaeocollybia oregonensis	OR-1	Fungus. Multnomah County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Phaeocollybia piceae	OR-3 FS-S	Associated with Douglas-fir, western hemlock, and Pacific silver fir.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Phaeocollybia pseudofestiva	OR-3 FS-S	Associated with conifers.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Phaeocollybia scatesiae	OR-3 FS-S	Associated with conifers and blueberry.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Ramaria amyloidea	OR-2 FS-S	Associated with conifers.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Ramaria cyaneigranosa (WA only)	FS (WA)-S	Associated with conifers and hardwoods.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Ramaria gelatiniaurantia	OR-2 FS-S	Associated with conifers.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Ramaria rubrievanescens (WA only)	OR-2 FS (WA)-S	Associated with conifers and hardwoods.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Violet hedgehog *Sarcodon fuscoindicus* (WA only)	OR-2,3 FS (WA)-S	Associated with mixed forest.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Sowerbyella rhenana	OR-3 FS-S	Associated with conifers.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Fairy fan *Spathularia flavida* (WA only)	FS (WA)-S	Associated with humus or rotten wood in coniferous forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Lichens								
Cetrelia cetrarioides (WA only)	S&M	WA—Grows primarily on bark, and occasionally on mossy rock. Most common host tree is *Alnus rubra*. Most common in moist riparian and valley bottom forests, especially older *A. rubra* stands over seepy or swampy ground.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Chaenotheca subroscida	S&M	WA, OR—Associated with humid intermontane old-growth forests at lower and middle elevations. Grows on conifer bark and occasionally wood.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Collema nigrescens (WA only)	S&M	WA—Grows on bark of hardwood trees and shrubs, including Garry oak, canyon live oak, bigleaf maple, cottonwood, and vine maple.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Dendriscocaulon intricatulum (WA only)	S&M	WA—In old-growth western forests and in open oak balds.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Dermatocarpon luridum	S&M	WA, OR—Aquatic on submerged or seasonally emergent rocks.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Hypogymnia duplicata (OR only)	S&M	OR—Western Cascade forests at mid-elevations of 1,000 to 5,500 feet.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Leptogium burnetiae var. hirsutum	S&M	WA, OR—Epiphytic on trees, logs, rocks, mosses.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Leptogium cyanescens	S&M	WA, OR—Tree bark both conifers and hardwoods, logs, rocks in cool, moist sites	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Lobaria linita (OR only)	S&M	OR—Cool, humid old-growth forest on boles of silver firs and boulders.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Nephroma bellum (WA only)	S&M	WA—Western Cascades, mostly on conifer branches.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Nephroma occultum	S&M	WA, OR — Moist old-growth forests at elevations below 4,000 feet.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Pannaria rubiginosa	S&M	WA, OR — Epiphyte on Hooker's willow at low elevations in old-growth western forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Peltigera neckeri (Former S&M)	S&M	WA, OR — Mossy logs, soil and tree bases in moist forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Peltigera pacifica	S&M	WA, OR — Mossy logs, soil and tree bases in moist forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Pilophorus nigricaulis (Former S&M)	S&M	WA, OR — On rocks in talus slopes, cliffs in old-growth forests.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Platismatia lacunosa (WA only)	S&M	WA —Western conifer forest.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Pseudocyphellaria rainierensis	S&M	WA, OR — Conifers in cool, humid, old-growth western forests	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Ramalina pollinaria (Former S&M)	S&M	CA only.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Tholurna dissimilis	S&M	WA, OR — High elevation, wind- swept trees.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Usnea longissima	S&M	WA, OR — Wet forest.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Bryophytes								
Ribbed mountain moss *(Conostomum tetragonum)*	OR-2	Hood River County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	**Status**	**Usual Habitat in Oregon and Washington**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**	**Potential Occurrence**	**Impact**
Crum's extinguisher moss *(Encalypta brevicolla var. crumiana)* (Former S&M)	OR-1 WA-1 FS-S	Associated with crevices and fractures on large igneous rock outcrops. Only reported from two sites, Mt. Rainier National Park and the Siskiyou National Forest.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Braided Frostwort *Gymnomitrion concinnatum*	OR-2	Liverwort, Hood River and Multnomah Counties.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Polytichium sphaerothecium	OR-2	Hood River County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Nake round moss *Rhizomnium nudum* (OR only)	OR-2	Very moist humus or soil, typically near seepage in conifer forest. Wasco County.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Goblin's gold *Schistostega pennata*	OR-2 FS-S	Fine-textured mineral soil in shaded pockets of overturned tree roots, often adjacent to shallow pools of standing water at the base of the root wad; also attached to rock or mineral soil around the entrance to caves, old cellars and animal burrows.	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI
Margined streamside moss *Scouleria marginata* (Former S&M)	OR-2 FS (WA)-S	Wet and often inundated rocks along watercourses, from low to high elevations.	May occur	NI. Species associated with aquatic habitat. Project not expected to impact suitable habitat for this species.	May occur	NI. Species associated with aquatic habitat. Project not expected to impact suitable habitat for this species.	May occur	NI. Species associated with aquatic habitat. Project not expected to impact suitable habitat for this species.
Tetraphis geniculata	OR-2	Moist forests with large down logs .	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI	Outside known range. No suitable habitat.	NI

			West Alternative		Middle Alternative		East Alternative	
Species (Population Segment)	Status	Usual Habitat in Oregon and Washington	Potential Occurrence	Impact	Potential Occurrence	Impact	Potential Occurrence	Impact

Notes:

Forest Service Region 6 (OR/WA) sensitive species = FS

Endangered Species Act (federal) listed species status codes: E, T, S, C, or P (see below)

WA = Washington State listed species status codes: E , T, S, or C (see below)

OR = Oregon state listed species status codes: E, T, or SC = Sensitive Critical, SV = Sensitive Vulnerable, SP = Sensitive Peripheral or naturally rare, SU = Sensitive Undetermined status

- E = Endangered
- T = Threatened
- S = Sensitive
- C = Candidate
- P = Proposed

Effect Determination Codes:

- NE = No Effect (for federally protected species)
- NI = no impact (for species not federally protected)
- MIIH = may impact individuals or habitat, but would not likely contribute to a trend toward federal listing or loss of viability to the population or species
- WIFV = will impact individuals or habitat with a consequence that the action may contribute to a trend toward federal listing or cause a loss of viability to the population or species
- BI = beneficial impact
- NLAA = may affect, but is not likely to adversely affect
- LAA = may affect, and will likely adversely affect

Appendix E

Electric Fields, Magnetic Fields, Noise, and Radio Interference

BIG EDDY – KNIGHT
500-kV TRANSMISSION PROJECT

APPENDIX E

ELECTRICAL EFFECTS

March 2010

Prepared by

T. Dan Bracken, Inc.

for

Bonneville Power Administration

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ELECTRICAL EFFECTS FROM THE PROPOSED BIG EDDY – KNIGHT 500-kV TRANSMISSION LINE PROJECT

1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to build an approximately 28-mile 500-kilovolt (kV) transmission line from the existing BPA Big Eddy Substation in Wasco County, Oregon to the proposed BPA Knight Substation near Goldendale in Klickitat, County, Washington. The proposed line is designated the Big Eddy – Knight transmission line. The proposed transmission line will traverse mostly arid pasture and agricultural land that is sparsely populated. However, there are scattered structures throughout the project area. Three alternative routes – West, Middle and East - are under consideration for the proposed transmission line as shown in Figure 1.

The purpose of this report is to describe and quantify the electrical effects of the proposed Big Eddy – Knight 500-kV transmission line along the alternative routes. These effects include the following:

- the levels of 60-hertz (Hz; cycles per second) electric and magnetic fields (EMF) at 3.28 feet (ft.) or 1 meter (m) above the ground,
- the effects associated with those fields,
- the levels of audible noise produced by the line, and
- electromagnetic interference associated with the line.

Electrical effects occur near all transmission lines, including those 500-kV lines already present in the area of the proposed route for the Big Eddy – Knight line. Therefore, the levels of these quantities for the proposed line are computed and compared with those from the existing lines in Oregon, Washington and elsewhere.

The proposed line would be built on new and existing right-of-way, paralleling existing lower voltage lines along portions of the route. The length of the sections with parallel line depends on the alternative route. Electrical effects were analyzed for all segments with or without parallel lines that had constant physical and electrical characteristics for over more than one mile. Shorter segments (< 1 mile) could occur where the line changes direction, crosses a roadway or enters a substation. The electrical effects associated with these short line segments would be very similar to those for the analyzed segments. The proposed project has 13 different line configurations (physical and electrical changes that could affect the field levels) with line segments greater than one mile in length. The 13 line configurations are described in Table 1.

The voltage on the conductors of transmission lines generates an electric field in the space between the conductors and the ground. The electric field is calculated or measured in units of volts-per-meter (V/m) or kilovolts-per-meter (kV/m) at a height of 3.28 feet (ft.) (1 meter [m]) above the ground. The current flowing in the conductors of the transmission line generates a magnetic field in the air and earth near the transmission line; current is expressed in units of amperes (A). The magnetic field is expressed in milligauss (mG), and is usually measured or calculated at a height of 3.28 ft. (1 m) above the ground. The electric field at the surface of the conductors causes the phenomenon of corona. Corona is the electrical breakdown or ionization of air in very strong electric fields, and is the source of audible noise, electromagnetic radiation, and visible light.

To quantify EMF levels along the route, the electric and magnetic fields from the proposed and existing lines were calculated using the BPA Corona and Field Effects Program (USDOE, undated). In this program, the calculation of 60-Hz fields uses standard superposition techniques for vector fields from several line sources: in this case, the line sources are transmission-line conductors. (Vector fields have both magnitude and direction: these must be taken into account when combining fields from different sources.) Important input parameters to the computer program are voltage, current, and geometric configuration of the line. The transmission-line conductors are assumed to be straight, parallel to each other, and located above and parallel to an infinite flat ground plane. Although such conditions do not occur under real lines because of conductor sag and variable terrain, the validity and limitations of calculations using these assumptions have been well verified by comparisons with measurements. This approach was used to estimate fields for the proposed Big Eddy -Knight line, where minimum clearances were assumed to provide worst-case (highest) estimates for the fields.

Electric fields are calculated using an imaging method. Fields from the conductors and their images in the ground plane are superimposed with the proper magnitude and phase to produce the total field at a selected location.

The total magnetic field is calculated from the vector summation of the fields from currents in all the transmission-line conductors. Balanced currents are assumed for each three-phase circuit and the contribution of induced image currents in the conductive earth is not included. Peak current and power flow direction for the proposed line were provided by BPA and are based on the projected system normal annual peak power loads in 2013.

Electric and magnetic fields for the proposed line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1987). Calculations were performed out to 300 ft. (91 m) from the centerline of the existing corridor. The validity and limitations of such calculations have been well verified by measurements. Because maximum voltage, maximum current, and minimum conductor height above-ground are used, ***the calculated values given here represent worst-case conditions:*** i.e., the calculated fields are higher than they would be in practice. Such worst-case conditions would seldom occur.

The corona performance of the proposed line was also predicted using the BPA Corona and Field Effects Program (USDOE, undated). Corona performance is calculated using empirical equations that have been developed over several years from the results of measurements on numerous high-voltage lines (Chartier and Stearns, 1981; Chartier, 1983). The validity of this approach for corona-generated audible noise has been demonstrated through comparisons with measurements on other lines all over the United States (IEEE Committee Report, 1982). The accuracy of this method for predicting corona-generated radio and television interference from transmission lines has also been established (Olsen et al., 1992). Important input parameters to the computer program are voltage, current, conductor size, and geometric configuration of the line.

Corona is a highly variable phenomenon that depends on conditions along a length of line. Predictions of the levels of corona effects are reported in statistical terms to account for this variability. Calculations of audible noise and electromagnetic interference levels were made under conditions of an estimated average operating voltage (536 kV for the proposed line) and with the average line height over a span of 47 ft. (14.3 m).

Levels of audible noise, radio interference, and television interference are predicted for both fair and foul weather; however, corona is basically a foul-weather phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Along the route of the proposed Big Eddy -Knight transmission line, such conditions are expected to occur about 1 percent of the time during a year, based on hourly precipitation records during years with complete records for Moro, Oregon (2000-2003) and Kennewick, WA (2006-2008).(NOAA, 2010) Corona activity also increases with altitude. For purposes of evaluating corona effects from the proposed line, an altitude that corresponded to the average where each line configuration would be constructed was assumed for that configuration. Assumed altitudes ranged from 350 to 1650 ft. (100 to 500 m).

2.0 Physical Description

2.1 Proposed Line

The proposed 500-kV transmission line would be a three-phase, single-circuit line. Each phase is carried on a separate set of conductors (wires). For the 500-kV line, each phase actually is carried on a bundle of three conductors (wires) and there are three bundles per circuit as shown in Figure 2.

The voltage and current waves on each phase are displaced by 120° in time (one-third of a cycle) from the waves on the other phases. The proposed line would be placed either on single-circuit towers with the phases arranged in a delta (triangular) configuration (Figure 2) or on double-circuit towers with three of six phase conductors or bundles arranged vertically on either side of the tower (Figure 8). The double-circuit towers would support both the proposed line and an existing parallel lower voltage line or just the proposed line with the proposed line located on the west side of the double-circuit tower. For some configurations, the proposed line would be operated as a split-phase line. In this case, each phase is split between two bundles, one on either side of the double-circuit tower. A total of 13 configurations were identified for the project based on parallel lines, tower type and conductors.

BPA provided the physical and operating characteristics of the proposed and existing lines. The electrical characteristics and physical dimensions for the configurations of the proposed line are shown in Table 2 and the configurations are shown in Figures 2 to 12.

The maximum phase-to-phase voltage for the proposed line would be 550 kV and the average voltage would be 536 kV. The maximum electrical current on the line would be 970 amperes (A) per phase, based on the BPA projected system annual peak load in 2013 as the base year. The load factor for this line will be about 0.50 (average load = peak load x load factor), resulting in an average current of 485 A.

For most of the configurations each bundle of the proposed 500-kV line will have three 1.300-inch diameter conductors arranged in an inverted triangle bundle configuration with approximately 17-in. (43.3 cm) spacing between conductors. Some portions of the line could have slightly larger conductors to meet a BPA design criterion for audible noise performance. In this case, the conductor bundles would be comprised of three 1.600-inch diameter conductors arranged in an inverted triangle with approximately 19-in. (48.9 cm) spacing.

For the double-circuit tower configurations the east circuit on the tower would be strung with a 1x1.300-in conductor for configurations with an existing 115-kV circuit on that side. For the two configurations where an existing 230- or 345-kV line would be placed on the double-circuit tower, then a 3x1.300-in bundle would be used. The three-conductor bundle would also be used if the proposed 500-kV line was split between the two sides of the tower.

For the single-circuit tower with the phases arranged in a triangle or delta configuration, the horizontal spacing between phases in the lower conductor positions would be 46 ft. (14 m). The vertical spacing between the conductor positions would be 31.5 ft. (9.6 m).

For the double-circuit tower the horizontal spacing between the top and bottom pairs of conductor bundles would be 36.5 ft. (11.1 m) and the spacing between the middle pair of conductor bundles would be 56.5 ft. (17.2 m). The vertical spacing between the bundles would be 36 ft. (11.0 m).

Minimum conductor-to-ground clearance would be 35 or 36 ft. (10.7 or 11.0 m) at a conductor temperature of 122°F (50°C). This temperature represents heavy operating conditions and high ambient air temperatures; clearances above ground would be greater under normal operating temperatures. The larger 36-foot clearance would be employed to ensure that the BPA criterion for maximum electric field at ground level (9 kV/m) is met along the entire route. The 35-foot clearance would be used for the single circuit towers except for Configuration 3 where it could be raised to 36 feet, depending on the relative phases of the proposed and adjacent 345-kV line. The 36-foot clearance would also be used for the double-circuit tower configurations (Configurations 7-12). The average clearance above ground along a span will be approximately 47 ft. (14.3 m); this value was used for corona calculations and to estimate average electric and magnetic fields along the line.

The minimum clearance of 35 ft (10.7-m) or greater provided by BPA exceeds the minimum distance of the conductors above ground required to meet the National Electric Safety Code (NESC) (IEEE, 2002). At road crossings, the ground clearance would be at least 50 ft. (15.2 m).

New right-of-way for the proposed line will be 150 ft. (46 m) wide. When placed on existing right-of-way the centerline of the proposed line will be at least 75 ft. (23 m) from the edge.

2.2 Existing Lines

The proposed Big Eddy – Knight 500-kV line would parallel existing transmission lines along parts of all three alternative routes. In all, there are five existing lines that could be paralleled: the Harvalum - Big Eddy 230-kV line, the McNary – Ross 345-kV line, the Chenowick – Goldendale 115-kV line, the Spearfish Tap 115-kV line and the Big Eddy – Spring Creek 230-kV line. The lines to be paralleled and lengths of their parallel segments are dependent on the route. Descriptions of the three routes and five existing lines and their associated routes are given in Tables 1 and 2.

3.0 Electric Field

3.1 Basic Concepts

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e., electric fields cause free charges to move). Electric field is a vector quantity: that is, it has both magnitude and direction. The direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative) and time-varying magnetic fields. Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of the unbalanced electrical charges associated with voltage on the conductors. On the power system in North America, the voltage and charge on the energized conductors are cyclic (plus to minus to plus) at a rate of 60 times per second. This changing voltage results in electric fields near sources that are also time-varying at a frequency of 60 hertz (Hz; a frequency unit equivalent to cycles per second).

As noted earlier, electric fields are expressed in units of volts per meter (V/m) or kilovolts (thousands of volts) per meter (kV/m). Electric- and magnetic-field magnitudes in this report are expressed in root-mean-square (rms) units. For sinusoidal waves, the rms amplitude is given as the peak amplitude divided by the square root of two.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground, under a transmission line, the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter). However, close to transmission- or distribution-line conductors, the field decreases rapidly with distance from the conductors. Similarly, near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric field exerts forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

At the boundary surface between air and the conducting object, the field in the air is perpendicular to the conductor surface and is much, much larger than the field in the conductor itself. For example, the average surface field on a human standing in a 10 kV/m field is 27 kV/m; the internal fields in the body are much smaller: approximately 0.008 V/m in the torso and 0.45 V/m in the ankles.

3.2 Transmission-line Electric Fields

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight parallel transmission lines. The most important transmission-line parameters that determine the electric field at a 1-m height are conductor height above ground and line voltage.

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vectorially, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable.

For evaluation of EMF from transmission lines, the fields must be calculated for a specific line condition. The NESC states the condition for evaluating electric-field-induced short-circuit current for lines with voltage above 98 kV, line-to-ground, as follows: conductors are at a minimum clearance from ground corresponding to a conductor temperature of 120°F (50°C), and at a maximum voltage (IEEE, 2002). BPA has supplied the needed information for calculating electric and magnetic fields from the proposed transmission lines: the maximum operating voltage, the estimated peak current in 2013, and the minimum conductor clearances.

There are standard techniques for measuring transmission-line electric fields (IEEE, 1987). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area at midspan, where conductors are closest to the ground (minimum clearance). As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably by shielding.

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values.

3.3 Calculated Values of Electric Fields

Table 3 shows the calculated values of electric field at 3.28 ft. (1 m) above ground for the proposed Big Eddy - Knight 500-kV transmission-line configurations. The maximum value on the right-of-way and the value at the edge of the right-of-way are given for the proposed configurations at minimum conductor clearance and at the estimated average clearance along a span. Both the maximum and average fields were computed with the line operating at the maximum voltage of 550 kV. Lateral profiles of the electric fields for the 13 configurations are shown in Figures 13 – 24.

The calculated maximum electric fields expected on the right-of-way of the proposed line range from 7.4 to 8.8 kV/m, depending on the configuration. For average clearance, the peak field ranges from 4.2 to 5.8 kV/m. As shown in Figures 13 to 24, the peak values would be present only at locations directly under the line, near mid-span, where the conductors are at the minimum clearance. The conditions of minimum conductor clearance at maximum current and maximum voltage occur very infrequently. The calculated peak levels are rarely reached under real-life conditions, because the actual line height is generally above the minimum value used in the computer model, because the actual voltage is below the maximum value used in the model, and because vegetation within and near the edge of the right-of-way tends to shield the field at ground level.

The average values expected at the edge of the right-of-way of the proposed line range from 2.4 to less than 0.1 kV/m. The largest field values at the edge of the right-of-way occur for configurations where the centerline of the proposed single-circuit delta tower is located 75 ft from the edge.

For comparison the electric fields along the existing corridors for the No-action alternative are also shown in Table 3. For the existing lines the maximum fields range from 0 to 4.5 kV/m and the average peak field ranges from 0 to 2.6 kV/m. Average fields at the edge of the right-of-way vary from 0 to 1.3 kV/m for the No-action alternative. The principal reason for the lower fields in the No-action alternative is the absence of a 500-kV line among the existing lines.

3.4 Environmental Electric Fields

The electric fields associated with the proposed Big Eddy - Knight transmission line can be compared with those found in other environments. Sources of 60-Hz electric (and magnetic) fields exist everywhere electricity is used; levels of these fields in the modern environment vary over a wide range. Electric-field levels associated with the use of electrical energy are orders of magnitude greater than the naturally occurring 60-Hz fields of about 0.0001 V/m, which stem from atmospheric and extraterrestrial sources.

Electric fields in outdoor, publicly accessible places range from less than 1 V/m to 12 kV/m; the large fields exist close to high-voltage transmission lines of 500 kV or higher. In remote areas without electrical service, 60-Hz field levels can be much lower than 1 V/m. Electric fields in home and work environments generally are not spatially uniform like those of transmission lines; therefore, care must be taken when making comparisons between fields from different sources such as appliances and electric lines. In addition, fields from all sources can be strongly modified by the presence of conducting objects. However, it is helpful to know the levels of electric fields generated in domestic and office environments in order to compare commonly experienced field levels with those near transmission lines.

Numerous measurements of residential electric fields have been reported for various parts of the United States, Canada, and Europe. Although there have been no large studies of residential electric fields, sufficient data are available to indicate field levels and characteristics. Measurements of domestic 60-Hz electric fields indicate that levels are highly variable and source-dependent. Electric-field levels are not easily predicted because walls and other objects act as shields, because conducting objects perturb the field, and because homes contain numerous localized sources. Internal sources (wiring, fixtures, and appliances) seem to predominate in producing electric fields inside houses. Average measured electric fields in residences are generally in the range of 5 to 20 V/m. In a large occupational exposure monitoring project that included electric-field measurements at homes, average exposures for all groups away from work were generally less than 10 V/m (Bracken, 1990).

Electric fields from household appliances are localized and decrease rapidly with distance from the source. Local electric fields measured at 1 ft. (0.3 m) from small household appliances are typically in the range of 30 to 60 V/m. In a survey, reported by Deno and Zaffanella (1982), field measurements at a 1-ft. (0.3-m) distance from common domestic and workshop sources were found to range from 3 to 70 V/m. The localized fields from appliances are not uniform, and care should be taken in comparing them with transmission-line fields.

Electric blankets can generate higher localized electric fields. Sheppard and Eisenbud (1977) reported fields of 250 V/m at a distance of approximately 1 ft. (0.3 m). Florig et al. (1987) carried out extensive empirical and theoretical analysis of electric-field exposure from electric blankets and presented results in terms of uniform equivalent fields such as those near transmission lines. Depending on what parameter was chosen to represent intensity of exposure and the grounding status of the subject, the equivalent vertical 60-Hz electric-field exposure ranged from 20 to over 3500 V/m. The largest equivalent field corresponds to the measured field on the chest with the blanket-user grounded. The average field on the chest of an ungrounded blanket-user yields an equivalent vertical field of 960 V/m. As manufacturers have become aware of the controversy surrounding EMF exposures, electric blankets have been redesigned to reduce magnetic fields. However, electric fields from these “low field” blankets are still comparable with those from older designs (Bassen et al., 1991).

Generally, people in occupations not directly related to high-voltage equipment are exposed to electric fields comparable with those of residential exposures. For example, the average electric field measured in 14 commercial and retail locations in rural Wisconsin and Michigan was 4.8 V/m (IIT Research Institute, 1984). Median electric field was about 3.4 V/m. These values are about one-third the values in residences reported in the same study. Electric-field levels in public buildings such as shops, offices, and malls appear to be comparable with levels in residences.

In a survey of 1,882 volunteers from utilities, electric-field exposures were measured for 2,082 work days and 657 non-work days (Bracken, 1990). Electric-field exposures for occupations other than those directly related to high-voltage equipment were equivalent to those for non-work exposure.

Thus, except for the relatively few occupations where high-voltage sources are prevalent, electric fields encountered in the workplace are probably similar to those of residential exposures. Even in electric utility occupations where high field sources are present, exposures to high fields are limited on average to minutes per day.

Electric fields found in publicly accessible areas near high-voltage transmission lines can typically range up to 3 kV/m for 230-kV lines, to 10 kV/m for 500-kV lines, and to 12 kV/m for 765-kV lines. Although these peak levels are considerably higher than the levels found in other public areas, they are present only in limited areas on rights-of-way.

The calculated electric fields for the proposed Big Eddy – Knight 500-kV transmission line are consistent with the levels reported for other 500-kV transmission lines in Washington, Oregon and elsewhere. The calculated electric fields on the right-of-way of the proposed transmission line would be much higher than levels normally encountered in residences and offices.

4.0 Magnetic Field

4.1 Basic Concepts

Magnetic fields can be characterized by the force they exert on a moving charge or on an electrical current. As with the electric field, the magnetic field is a vector quantity characterized by both magnitude and direction. Electrical currents generate magnetic fields. In the case of transmission lines, distribution lines, house wiring, and appliances, the 60-Hz electric current flowing in the conductors generates a time-varying, 60-Hz magnetic field in the vicinity of these sources. The strength of a magnetic field is measured in terms of magnetic lines of force per unit area, or magnetic flux density. The term “magnetic field,” as used here, is synonymous with magnetic flux density and is expressed in units of gauss (G) or milligauss (mG). (The tesla (T) is the unit of magnetic flux density preferred in scientific publications, where 1.0 gauss equals one ten-thousandth of a tesla (0.1 mT) and 1.0 mG equals 0.1 microtesla [µT]).

The uniformity of a magnetic field depends on the nature and proximity of the source, just as the uniformity of an electric field does. Transmission-line-generated magnetic fields are quite uniform over horizontal and vertical distances of several feet near the ground. However, for small sources such as appliances, the magnetic field decreases rapidly over distances comparable with the size of the device.

The interaction of a time-varying magnetic field with conducting objects results in induced electric fields and currents in the object. A changing magnetic field through an area generates a voltage around any conducting loop enclosing the area (Faraday's law). This is the physical basis for the operation of an electrical transformer. For a time-varying sinusoidal magnetic field, the magnitude of the induced voltage around the loop is proportional to the area of the loop, the frequency of the field, and the magnitude of the field. The induced voltage around the loop results in an induced electric field and current flow in the loop material. The induced current that flows in the loop depends on the conductivity of the loop as well as its area.

4.2 Transmission-line Magnetic Fields

The magnetic field generated by currents on transmission-line conductors extends from the conductors through the air and into the ground. The magnitude of the field at a height of 3.28 ft. (1 m) is frequently used to describe the magnetic field under transmission lines. Because the magnetic field is not affected by non-ferrous materials, the field is not influenced by normal objects on the ground under the line. The direction of the maximum field varies with location. (The electric field, by contrast, is essentially vertical near the ground.) The most important transmission-line parameters that determine the magnetic field at 3.28 ft. (1 m) height are conductor height above ground and magnitude of the currents flowing in the conductors. As distance from the transmission-line conductors increases, the magnetic field decreases.

Calculations of magnetic fields from transmission lines are performed using well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values usually represent the ideal straight parallel-conductor configuration. For simplicity, a flat earth is usually assumed. Balanced currents (currents of the same magnitude for each phase) are also assumed. This is usually valid for transmission lines, where loads on all three phases are maintained in balance during operation. Induced image currents in the earth are usually ignored for calculations of magnetic field under or near the right-of-way. The resulting error is negligible. Only at distances greater than 300 ft. (91 m) from a line do such contributions become significant (Deno and Zaffanella, 1982). The clearance for magnetic-field calculations for the proposed line was the same as that used for electric-field evaluations.

Standard techniques for measuring magnetic fields near transmission lines are described in ANSI IEEE Standard No. 644-1994 (1994). Measured magnetic fields agree well with calculated values, provided the currents and line heights that go into the calculation correspond to the actual values for the line. To realize such agreement, it is necessary to get accurate current readings during field measurements (because currents on transmission lines can vary considerably over short periods of time) and also to account for all field sources in the vicinity of the measurements.

As with electric fields, the maximum or peak magnetic fields occur in areas near the centerline and at midspan where the conductors are the lowest. The magnetic field at the edge of the right-of-way is not very dependent on line height. If more than one line is present, the peak field will depend on the relative electrical phasing of the conductors and the relative direction of power flow in the lines.

4.3 Calculated Values for Magnetic Fields

Table 4 gives the calculated values of the magnetic field at 3.28 ft. (1 m) height for the proposed 500-kV transmission-line configurations. Field values on the right-of-way and at the edge of the right-of-way are given for projected maximum currents and minimum clearance during system annual peak load in 2013. Field levels at the same locations for average current and average conductor clearance are also given. The projected maximum currents are 970 A on each of the three phases of the proposed line. For double-circuit configurations where the phases are split between two sets of conductors, the maximum current on each set of conductors would be 485 A. Average currents over the year would be about 50 percent of the maximum values.

Figures 25 to 38 show lateral profiles of magnetic fields under these same current and clearance conditions for the proposed 500-kV transmission line and the existing adjacent lines. The levels for maximum current and minimum clearance shown in the figures represent the highest magnetic fields under the proposed Big Eddy – Knight 500-kV line except under extreme temperature conditions. The actual day-to-day magnetic-field levels would be lower. They would vary as currents change daily and seasonally and as clearances change with ambient temperature. As shown in the figures, the average fields along the line over a year would be considerably reduced from the maximum values, as a result of increased clearances and reduced current.

The maximum calculated 60-Hz magnetic fields expected at 3.28 ft. (1 m) above ground for the proposed line range from 219mG to 60 mG for the 13 configurations of the proposed line. The highest fields would occur for single and double circuit towers that are adjacent to the existing Harvalum - Big Eddy 230-kV line (Configurations 2, 3 and 9). The lowest maximum fields would occur for the double-circuit tower configurations with split-phasing (Configurations 7 and 12). Maximum fields on the existing rights-of-way would range from 176 to 0 mG should the proposed line not be built – the No-action alternative. The maximum fields in this case would occur under the existing Big Eddy – Spring Creek and Harvalum - Big Eddy 230-kV lines.

The estimated average peak fields on the right-of-way for the proposed line would range from 65 to 17 mG. The average peak field on the existing rights-of-way would range from 48 to 0 mG for the No-action alternative.

At the edge of the right-of-way of the proposed line (on new right-of-way with no adjacent lines), estimated maximum fields would be 42 mG for the single-circuit tower (Configuration 1), 14 mG for the double-circuit tower with split phasing (Configurations 7) and 52 mG for the double-circuit tower with a single circuit on one side (Configurations 7A and 10). The peak average fields at the edge of the right-of-way for these configurations would be 18, 6, and 21 mG, respectively.

On existing rights-of-way with parallel adjacent lines, the calculated levels at the edge of the right-of-way obviously depend on the width of the right-of-way and the current on the existing line. Consequently, on existing rights-of-way, the maximum magnetic field at the edge of the right-of-way for maximum current conditions would range from 67 to less than 1 mG, while the average field at the edge would range from 23 to less than 1 mG. The maximum edge of right-of-way values for the No-action alternative would range from 67 to 0 mG, while the average values range from 23 to 0 mG. The highest edge of right-of-way levels for the No-action alternative occur adjacent to the Harvalum - Big Eddy and Big Eddy - Spring Creek 230-kV lines.

The magnetic field falls off rapidly as distance from the line increases. At a distance of 200 ft. (61 m) from the centerline of the proposed single-circuit tower line with maximum current, the field would be 6.4 mG and the average field would be about 3 mG. At the same current and distance from the double-circuit tower with the split phase configuration, the maximum and average fields would be less than 2 mG. For the double-circuit tower with only a single-circuit on one side, the maximum and average fields at 200 feet would be about 10 and 3 mG, respectively. The largest maximum and average fields at 200 feet from the existing lines for the No-action alternative would be 6-7 mG and 2-4 mG, respectively. These largest values for existing lines would occur adjacent to the Harvalum - Big Eddy 230-kV line, the Big Eddy – Spring Creek 230-kV line, and the McNary – Ross 345-kV line.

There would 2 to 5 houses within 300 feet of the proposed centerline and 10 to 12 houses within 500 ft, depending on which route and line designs are selected (Table 5). The average magnetic fields at these houses would range from 0.5 to 22.3 mG for the single-circuit configuration routes and from 0.1 to 3.5 mG for the double circuit routes. The range of maximum fields would be from 1.1 to 45 mG for the single-circuit routes and from 0.2 to 7 mG for the double circuit routes. (Note: A single house at 71 ft from the centerline of the proposed single-circuit configuration contributes the high upper ranges of average and maximum fields for the East and Middle alternatives shown in Table 5.)

In general, magnetic fields at houses would be higher for the East and Middle alternatives than for the West alternative when single circuit configurations are used. The opposite would be true if double-circuit configurations were used: in this case, magnetic fields would be higher at houses along the West alternative than along the other two routes.

4.4 Environmental Magnetic Fields

Transmission lines are not the only source of magnetic fields; as with 60-Hz electric fields, 60-Hz magnetic fields are present throughout the environment of a society that relies on electricity as a principal energy source. The magnetic fields associated with the proposed Big Eddy - Knight 500 kV line can be compared with fields from other sources. The range of 60-Hz magnetic-field exposures in publicly accessible locations such as open spaces, transmission-line rights-of-way, streets, pedestrian walkways, parks, shopping malls, parking lots, shops, hotels, public transportation, and so on range from less than 0.1 mG to about 1 G, with the highest values occurring near small appliances with electric motors. In occupational settings in electric utilities, where high currents are present, magnetic-field exposures for workers can be above 1 G. At 60 Hz, the magnitude of the natural magnetic field is approximately 0.0005 mG.

Several investigations of residential fields have been conducted. In a large study to identify and quantify significant sources of 60-Hz magnetic fields in residences, measurements were made in 996 houses, randomly selected throughout the country (Zaffanella, 1993). The most common sources of residential fields were power lines, the grounding system of residences, and appliances. Field levels were characterized by both point-in-time (spot) measurements and 24-hour measurements. Spot measurements averaged over all rooms in a house exceeded 0.6 mG in 50 percent of the houses and 2.9 mG in 5 percent of houses. Power lines generally produced the largest average fields in a house over a 24-hour period. On the other hand, grounding system currents proved to be a more significant source of the highest fields in a house. Appliances were found to produce the highest local fields; however, fields fell off rapidly with increased distance. For example, the median field near microwave ovens was 36.9 mG at a distance of 10.5 in (0.27 m) and 2.1 mG at 46 in (1.17 m). Across the entire sample of 996 houses, higher magnetic fields were found in, among others, urban areas (vs. rural); multi-unit dwellings (vs. single-family); old houses (vs. new); and houses with grounding to a municipal water system.

In an extensive measurement project to characterize the magnetic-field exposure of the general population, over 1000 randomly selected persons in the United States wore a personal exposure meter for 24 hours and recorded their location in a simple diary (Zaffanella and Kalton, 1998). Based on the measurements of 853 persons, the estimated 24-hour average exposure for the general population is 1.24 mG and the estimated median exposure is 0.88 mG. The average field "at home, not in bed" is 1.27 mG and "at home, in bed" is 1.11 mG. Average personal exposures were found to be largest "at work" (mean of 1.79 mG and median of 1.01 mG) and lowest "at home, in bed" (mean of 1.11 mG and median of 0.49 mG). Average fields in school were also low (mean of 0.88 mG and median of 0.69 mG). Factors associated with higher exposures at home were smaller residences, duplexes and apartments, metallic rather than plastic water pipes, and nearby overhead distribution lines.

As noted above, magnetic fields from appliances are localized and decrease rapidly with distance from the source. Localized 60-Hz magnetic fields have been measured near about 100 household appliances such as ranges, refrigerators, electric drills, food mixers, and shavers (Gauger, 1985). At a distance of 1 ft. (0.3 m), the maximum magnetic field ranged from 0.3 to 270 mG, with 95 percent of the measurements below 100 mG. Ninety-five percent of the levels at a distance of 4.9 ft. (1.5 m) were less than 1 mG. Devices that use light-weight, high-torque motors with little magnetic shielding exhibited the largest fields. These included vacuum cleaners and small hand-held appliances and tools. Microwave ovens with large power transformers also exhibited relatively large fields. Electric blankets have been a much-studied source of magnetic-field exposure because of the length of time they are used and because of the close proximity to the body. Florig and Hoburg (1988) estimated that the average magnetic field in a person using an electric blanket was 15 mG, and that the maximum field could be 100 mG. New "low-field" blankets have magnetic fields at least 10 times lower than those from conventional blankets (Bassen et al., 1991).

In a domestic magnetic-field survey, Silva et al. (1989) measured fields near different appliances at locations typifying normal use (e.g., sitting at a typewriter or standing at a stove). Specific appliances with relatively large fields included can openers (n = 9), with typical fields ranging from 30 to 225 mG and a maximum value up to 2.7 G; shavers (n = 4), with typical fields from 50 to 300 mG and maximum fields up to 6.9 G; and electric drills (n = 2), with typical fields from 56 to 190 mG and maximum fields up to 1.5 G. The fields from such appliances fall off very rapidly with distance and are only present for short periods. Thus, although instantaneous magnetic-field levels close to small hand-held appliances can be quite large, they do not contribute to average area levels in residences. The technology of newer energy-efficient appliances is likely to reduce fields from appliances further.

Although studies of residential magnetic fields have not all considered the same independent parameters, the following consistent characterization of residential magnetic fields emerges from the data:

(1) External sources play a large role in determining residential magnetic-field levels. Transmission lines, when nearby, are an important external source. Unbalanced ground currents on neutral conductors and other conductors, such as water pipes in and near a house, can represent a significant source of magnetic field. Distribution lines per se, unless they are quite close to a residence, do not appear to be a traditional distance-dependent source.

(2) Homes with overhead electrical service appear to have higher average fields than those with underground service.

(3) Appliances represent a localized source of magnetic fields that can be much higher than average or area fields. However, fields from appliances approach area levels at distances greater than 3 ft. (1 m) from the device.

Although important variables in determining residential magnetic fields have been identified, quantification and modeling of their influence on fields at specific locations is not yet possible. However, a general characterization of residential magnetic-field level is possible: average levels in the United States are in the range of 0.5 to 1.0 mG, with the average field in a small number of homes exceeding this range by as much as a factor of 10 or more. Average personal exposure levels are slightly higher, possibly due to use of appliances and varying distances to other sources. Maximum fields can be much higher.

Magnetic fields in commercial and retail locations are comparable with those in residences. As with appliances, certain equipment or machines can be a local source of higher magnetic fields. Utility workers who work close to transformers, generators, cables, transmission lines, and distribution systems clearly experience high-level fields. Other sources of fields in the workplace include motors, welding machines, computers, and office equipment. In publicly accessible indoor areas, such as offices and stores, field levels are generally comparable with residential levels, unless a high-current source is nearby.

Because high-current sources of magnetic field are more prevalent than high-voltage sources, occupational environments with relatively high magnetic fields encompass a more diverse set of occupations than do those with high electric fields. For example, in occupational magnetic-field measurements reported by Bowman et al. (1988), the geometric mean field from 105 measurements of magnetic field in "electrical worker" job locations was 5.0 mG. "Electrical worker" environments showed the following elevated magnetic-field levels (geometric mean greater than 20 mG): industrial power supplies, alternating current (ac) welding machines, and sputtering systems for electronic assembly.

Measurements of personal exposure to magnetic fields were made for 1,882 volunteer utility workers for a total of 4,411 workdays (Bracken, 1990). Median workday mean exposures ranged from 0.5 mG for clerical workers without computers to 7.2 mG for substation operators. Occupations not specifically associated with transmission and distribution facilities had median workday exposures less than 1.5 mG, while those associated with such facilities had median exposures above 2.3 mG. Magnetic-field exposures measured in homes during this study were comparable with those recorded in offices.

Magnetic fields in publicly accessible outdoor areas seem to be, as expected, directly related to proximity to electric-power transmission and distribution facilities. Near such facilities, magnetic fields are generally higher than indoors (residential). Higher-voltage facilities tend to have higher fields. Typical maximum magnetic fields in publicly accessible areas near transmission facilities can range from less than a few milligauss up to 300 mG or more, near heavily loaded lines operated at 230 to 765 kV. The levels depend on the line load, conductor height, and location on the right-of-way. Because magnetic fields near high-voltage transmission lines depend on the current in the line, they can vary daily and seasonally.

Fields near distribution lines and equipment are generally lower than those near transmission lines. Measurements in Montreal indicated that typical fields directly above underground distribution systems were 5 to 19 mG (Heroux, 1987). Beneath overhead distribution lines, typical fields were 1.5 to 5 mG on the primary side of the transformer, and 4 to 10 mG on the secondary side. Near ground-based transformers used in residential areas, fields were 80 to 1000 mG at the surface and 10 to 100 mG at a distance of 1 ft. (0.3 m).

The magnetic fields from the proposed line would be comparable to or less than those from existing 500-kV lines in Washington and elsewhere. On and near the right-of-way of the proposed line, magnetic fields would be well above average residential levels. However, the fields from the line would decrease rapidly and approach common ambient levels at distances greater than a few hundred feet from the line. Furthermore, the fields at the edge of the right-of-way would not be above those encountered during normal activities near common sources such as hand-held appliances.

5.0 Electric and Magnetic Field (EMF) Effects

Possible effects associated with the interaction of EMF from transmission lines with people on and near a right-of-way fall into two categories: short-term effects that can be perceived and may represent a nuisance, and possible long-term health effects. Only short-term effects are discussed here. The issue of whether there are long-term health effects associated with transmission-line fields is controversial. In recent years, considerable research on possible biological effects of EMF has been conducted. A review of these studies and their implications for health-related effects is provided in a separate technical report for the environmental assessment for the proposed Big Eddy – Knight 500-kV transmission line (Exponent, 2009).

5.1 Electric Fields: Short-term Effects

Short-term effects from transmission-line electric fields are associated with perception of induced currents and voltages or perception of the field. Induced current or spark discharge shocks can be experienced under certain conditions when a person contacts objects in an electric field. Such effects occur in the fields associated with transmission lines that have voltages of 230-kV or higher. These effects could occur infrequently under the proposed Big Eddy - Knight 500-kV line.

Steady-state currents are those that flow continuously after a person contacts an object and provides a path to ground for the induced current. The amplitude of the steady-state current depends on the induced current to the object in question and on the grounding path. The magnitude of the induced current to vehicles and objects under the proposed line will depend on the electric-field strength and the size and shape of the object. When an object is electrically grounded, the voltage on the object is reduced to zero, and it is not a source of current or voltage shocks. If the object is poorly grounded or not grounded at all, then it acquires some voltage relative to earth and is a possible source of current or voltage shocks.

The responses of persons to steady-state current shocks have been extensively studied, and levels of response documented (Keesey and Letcher, 1969; IEEE, 1978). Primary shocks are those that can result in direct physiological harm. Such shocks will not be possible from induced currents under the existing or proposed lines, because clearances above ground required by the NESC preclude such shocks from large vehicles and grounding practices eliminate large stationary objects as sources of such shocks.

Secondary shocks are defined as those that could cause an involuntary and potentially harmful movement, but no direct physiological harm. Secondary shocks could occur under the proposed 500-kV line when making contact with ungrounded conducting objects such as vehicles or equipment. However, such occurrences are anticipated to be very infrequent. Shocks, when they occur under the 500-kV line, are most likely to be below the nuisance level. Induced currents are extremely unlikely to be perceived off the right-of-way of the proposed line.

Induced currents are always present in electric fields under transmission lines and will be present near the proposed line. However, during initial construction, BPA routinely grounds metal objects that are located on or near the right-of-way. The grounding eliminates these objects as sources of induced current and voltage shocks. Multiple grounding points are used to provide redundant paths for induced current flow. After construction, BPA would respond to any complaints and install or repair grounding to mitigate nuisance shocks.

Unlike fences or buildings, mobile objects such as vehicles and farm machinery cannot be grounded permanently. Limiting the possibility of induced currents from such objects to persons is accomplished in several ways. First, required clearances for above-ground conductors tend to limit field strengths to levels that do not represent a hazard or nuisance. The NESC (2002) requires that, for lines with voltage exceeding 98 kV line-to-ground (170 kV line-to-line), sufficient conductor clearance be maintained to limit the induced short-circuit current in the largest anticipated vehicle under the line to 5 milliamperes (mA) or less. This can be accomplished by limiting access or by increasing conductor clearances in areas where large vehicles could be present. BPA and other utilities design and operate lines to be in compliance with the NESC.

For the proposed line, conductor clearances at 50°C conductor temperature would be increased to at least 50 ft. (15.2 m) over road crossings along the route to meet the BPA requirement that electric fields be less than 5.0 kV/m at road crossings. The actual clearance to meet the criterion would depend on the configuration and parallel lines. For example, in order for Configuration 3 to meet the 5.0 kV/m criterion at a clearance of 50 feet, adjacent phases of the proposed Big Eddy – Knight 500-kV line and the existing McNary – Ross 345-kV line could not be the same; for Configurations 7A and 10 clearance would have to be increased to 54 feet to meet the 5.0 kV/m criterion. In any case, the conductor clearance at each road crossing would be checked during the line design stage to ensure that the BPA 5-kV/m and NESC 5-mA criteria are met. Line clearances would also be increased in accordance with the NESC, such as over railroads and water areas suitable for sailboating.

The largest truck allowed on roads in Oregon and Washington without a special permit is 14 feet high by 8.5 feet wide by 75 feet long (4.3 x 2.6 x 22.9 m). The induced currents to such a vehicle oriented perpendicular to the line in a maximum field of 5 kV/m (at 3.28-foot height) would be 4.5 mA (Reilly, 1979). For smaller trucks, the maximum induced currents for perpendicular orientation to the proposed line would be less than this value. (Larger special-permitted trucks, such as triple trailers, can be up to 105 feet in length, but are not expected on the roads crossed by the proposed line. However, because they average the field over such a long distance, the maximum induced current to a 105-foot vehicle oriented perpendicular to the 500-kV line at a road crossing would be less than 4.5 mA.) Thus, the NESC 5-mA criterion would be met for perpendicular road crossings of the proposed line. These large vehicles are not anticipated to be off highways or oriented parallel and on the right –of-way of the proposed line. As discussed below, these are worst-case estimates of induced currents at road crossings; conditions for their occurrence are rare.

Several factors tend to reduce the levels of induced current shocks from vehicles:

(1) Activities are distributed over the whole right-of-way, and only a small percentage of time is spent in areas where the field is at or close to the maximum value.

(2) At road crossings, vehicles are aligned perpendicular to the conductors, resulting in a substantial reduction in induced current.

(3) The conductor clearance at road crossings may not be at minimum values because of lower conductor temperatures and/or location of the road crossing away from midspan.

(4) The largest vehicles are permitted only on certain highways.

(5) Off-road vehicles are in contact with soil or vegetation, which reduces shock currents substantially.

Induced voltages occur on objects, such as vehicles, in an electric field where there is an inadequate electrical ground. If the voltage is sufficiently high, then a spark discharge shock can occur as contact is made with the object. Such shocks are similar to "carpet" shocks that occur, for example, when a person touches a doorknob after walking across a carpet on a dry day. The number and severity of spark discharge shocks depend on electric-field strength. Based on the low frequency of complaints reported by Glasgow and Carstensen (1981) for 500-kV ac transmission lines (one complaint per year for each 1,500 mi. or 2400 km of 500-kV line), nuisance shocks, which are primarily spark discharges, do not appear to be a serious impediment to allowed activities under 500-kV lines. Recommended safety practices and restricted activities on BPA transmission line rights-of-way are described in the BPA booklet “Living and Working Safely Around High-Voltage Transmission Lines” (USDOE, 2007).

In electric fields higher than will occur under the proposed line, it is theoretically possible for a spark discharge from the induced voltage on a large vehicle to ignite gasoline vapor during refueling. The probability for exactly the right conditions to occur for ignition is extremely remote. The additional clearance of conductors provided at road crossings reduces the electric field in areas where vehicles are prevalent and reduces the chances for such events. Even so, BPA recommends that vehicles should not be refueled under the proposed line unless specific precautions are taken to ground the vehicle and the fueling source (USDOE, 2007).

Under certain conditions, the electric field can be perceived through hair movement on an upraised hand or arm of a person standing on the ground under high-voltage transmission lines. The median field for perception in this manner was 7 kV/m for 136 persons; only about 12 percent could perceive fields of 2 kV/m or less (Deno and Zaffanella, 1982). In areas under the conductors at midspan, the fields at ground level would exceed the levels where field perception normally occurs. In these instances, field perception could occur on the right-of-way of the proposed line. It is unlikely that the field would be perceived beyond the edge of the right-of-way. Where vegetation provides shielding, the field would not be perceived.

Conductive shielding reduces both the electric field and induced effects such as shocks. Persons inside a vehicle cab or canopy are shielded from the electric field. Similarly, a row of trees or a lower-voltage distribution line reduces the field on the ground in the vicinity. Metal pipes, wiring, and other conductors in a residence or building shield the interior from the transmission-line electric field.

The electric fields from the proposed 500-kV line would be comparable to those from existing 500-kV lines in the project area and elsewhere. Potential impacts of electric fields can be mitigated through grounding policies, adherence to the NESC, and increased clearances above the minimums specified by the NESC. Worst-case levels are used for safety analyses but, in practice, induced currents and voltages are reduced considerably by unintentional grounding. Shielding by conducting objects, such as vehicles and vegetation, also reduces the potential for electric-field effects.

5.2 Magnetic Field: Short-term Effects

Magnetic fields associated with transmission and distribution systems can induce voltage and current in long conducting objects that are parallel to the transmission line. As with electric-field induction, these induced voltages and currents are a potential source of shocks. A fence, irrigation pipe, pipeline, electrical distribution line, or telephone line forms a conducting loop when it is grounded at both ends. The earth forms the other portion of the loop. The magnetic field from a transmission line can induce a current to flow in such a loop if it is oriented parallel to the line. If only one end of the fence is grounded, then an induced voltage appears across the open end of the loop. The possibility for a shock exists if a person closes the loop at the open end by contacting both the ground and the conductor. The magnitude of this potential shock depends on the following factors: the magnitude of the field; the length of the object (the longer the object, the larger the induced voltage); the orientation of the object with respect to the transmission line (parallel as opposed to perpendicular, where no induction would occur); and the amount of electrical resistance in the loop (high resistance limits the current flow).

Magnetically induced currents from power lines have been investigated for many years; calculation methods and mitigating measures are available. A comprehensive study of gas pipelines near transmission lines developed prediction methods and mitigation techniques specifically for induced voltages on pipelines (Dabkowski and Taflove, 1979; Taflove and Dabkowski, 1979). Similar techniques and procedures are available for irrigation pipes and fences. Grounding policies employed by utilities for long fences reduce the potential magnitude of induced voltage.

The magnitude of the coupling with both pipes and fences is very dependent on the electrical unbalance (unequal currents) among the three phases of the line. Thus, a distribution line where a phase outage may go unnoticed for long periods of time can represent a larger source of induced currents than a transmission line where the loads are well-balanced (Jaffa and Stewart, 1981).

Knowledge of the phenomenon, grounding practices, and the availability of mitigation measures mean that magnetic-induction effects from the proposed 500-kV transmission line will be minimal.

Magnetic fields from transmission and distribution facilities can interfere with certain electronic equipment. Magnetic fields have been observed to cause distortion of the image on older VDTs and computer monitors that employ cathode ray tubes. This can occur in fields as low as 10 mG, depending on the type and size of the monitor (Baishiki et al., 1990; Banfai et al., 2000). Generally, the problem arose when computer monitors were in use near electrical distribution facilities in large office buildings. Contemporary display devices using flat-panel technologies, such as liquid-crystal or plasma displays are not affected.

Interference from magnetic fields can be eliminated by shielding the affected device or moving it to an area with lower fields. Interference from 60-Hz fields with computers and control circuits in vehicles and other equipment is not anticipated at the field levels found under and near the proposed 500-kV transmission line.

The magnetic fields from the proposed line will be comparable to those from existing 500-kV lines in the area of the proposed line.

6.0 Regulations

Regulations that apply to transmission-line electric and magnetic fields fall into two categories. Safety standards or codes are intended to limit or eliminate electric shocks that could seriously injure or kill persons. Field limits or guidelines are intended to limit electric- and magnetic-field exposures that can cause nuisance shocks or might cause health effects. In no case has a limit or standard been established because of a known or demonstrated health effect.

The proposed line would be designed to meet the NESC (IEEE, 2002), which specifies how far transmission-line conductors must be from the ground and other objects. The clearances specified in the code provide safe distances that prevent harmful shocks to workers and the public. In addition, people who live and work near transmission lines must be aware of safety precautions to avoid electrical (which is not necessarily physical) contact with the conductors. For example, farmers should not up-end irrigation pipes under a transmission or other electrical line. In addition, as a matter of safety, the NESC specifies that electric-field-induced currents from transmission lines to vehicles must be below the 5 mA ("let go") threshold deemed a lower limit for primary shock. BPA publishes and distributes a booklet that describes safe practices to protect against shock hazards around power lines (USDOE, 2007).

Field limits or guidelines have been adopted in several states and countries and by national and international organizations (Maddock, 1992). Electric-field limits have generally been based on minimizing nuisance shocks or field perception. The intent of magnetic-field limits has been to limit exposures to existing levels, given the uncertainty of their potential for health effects.

General guidelines for EMF exposure have been established for occupational and public exposure by national and international organizations. The limits established by three such guidelines are described in Table 5.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values or TLVs) for occupational exposures to environmental agents (ACGIH, 2008). In general, a TLV represents the level below which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. For EMF, the TLVs represent ceiling levels. For 60-Hz electric fields, occupational exposures should not exceed the TLV of 25 kV/m. However, the ACGIH also recognizes the potential for startle reactions from spark discharges and short-circuit currents in fields greater than 5-7 kV/m, and recommends implementing grounding practices. They recommend the use of conductive clothing for work in fields exceeding 15 kV/m. The TLV for occupational exposure to 60-Hz magnetic fields is a ceiling level of 10 G (10,000 mG) (ACGIH, 2008).

The International Committee on Non-ionizing Radiation Protection (ICNIRP), working in cooperation with the World Health Organization (WHO) has developed guidelines for occupational and public exposures to EMF (ICNIRP, 1998). For occupational exposures at 60 Hz, the recommended limits to exposure are 8.3 kV/m for electric fields and 4.2 G (4,200 mG) for magnetic fields. The electric-field level can be exceeded, provided precautions are taken to prevent spark discharge and induced current shocks. For the general public, the ICNIRP guidelines recommend exposure limits of 4.2 kV/m for electric fields and 0.83 G (830 mG) for magnetic fields (ICNIRP, 1998).

More recently the International Committee on Electromagnetic Safety (ICES) under the auspices of the IEEE has established exposure guidelines for 60-Hz electric and magnetic fields (ICES, 2002). The ICES recommended limits for occupational exposures are 20 kV/m for electric fields and 27,100 mG for magnetic fields. The recommended limits for the general public are lower: 5 kV/m for the general public, except on power line rights-of-way where the limit is 10 kV/m; and 9,040 mG for magnetic fields.

Electric and magnetic fields from various sources (including automobile ignitions, appliances and, possibly, transmission lines) can interfere with implanted cardiac pacemakers. In light of this potential problem, manufacturers design devices to be immune from such interference. However, research has shown that these efforts have not been completely successful and that a few models of older pacemakers still in use could be affected by 60-Hz fields from transmission lines. There were also numerous models of pacemakers that were not affected by fields larger than those found under transmission lines. Because of the known potential for interference with pacemakers by 60-Hz fields, field limits for pacemaker wearers have been established by the ACGIH. They recommend that, lacking additional information about their pacemaker, wearers of pacemakers and similar medical-assist devices limit their exposure to electric fields of 1 kV/m or less and to magnetic fields to 1 G (1,000 mG) or less (ACGIH, 2008). Additional discussion of interference with implanted devices is given in the accompanying technical report on health effects (Exponent, 2009).

There are currently no national standards in the United States for 60-Hz electric and magnetic fields. The state of Washington does not have guidelines for electric or magnetic fields from transmission lines. However, several states have been active in establishing mandatory or suggested limits on 60-Hz electric and (in two cases) magnetic fields. Six states have specific electric-field limits that apply to transmission lines: Florida, Minnesota, Montana, New Jersey, New York, and Oregon. Florida and New York have established regulations for magnetic fields. These regulations are summarized in Table 6.

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 1996). BPA also has maximum-allowable electric field strengths of 5 kV/m, 3.5 kV/m, and 2.5 kV/m for road crossings, shopping center parking lots, and commercial/ industrial parking lots, respectively. The latter levels are based on limiting the maximum short-circuit currents from anticipated vehicles to less than 1 mA in shopping center lots and to less than 2 mA in commercial parking lots.

The electric fields from the proposed 500-kV line would meet the ACGIH standards, provided wearers of pacemakers and similar medical-assist devices are discouraged from unshielded right-of-way use. (A passenger in an automobile under the line would be shielded from the electric field.) The electric fields in limited areas on the right-of-way would exceed the ICNIRP guideline for public exposure, but would be below IEEE guideline limits. The magnetic fields from the proposed line would be below the ACGIH, ICNIRP, and IEEE limits.

The estimated peak electric fields on the right-of-way of the proposed transmission line would meet limits set in Florida, New York and Oregon, but not those of Minnesota and Montana (see Table 6). The BPA maximum allowable electric field limit would be met for all configurations of the proposed line. The edge of right-of-way electric fields from the proposed line would be below limits set in Florida and New Jersey, but above those in Montana and New York.

The magnetic field at the edge of the right-of-way from the proposed line would be below the regulatory levels of states where such regulations exist.

7.0 Audible Noise

7.1 Basic Concepts

Audible noise (AN), as defined here, represents an unwanted sound, as from a transmission line, transformer, airport, or vehicle traffic. Sound is a pressure wave caused by a sound source vibrating or displacing air. The ear converts the pressure fluctuations into auditory sensations. AN from a source is superimposed on the background or ambient noise that is present before the source is introduced.

The amplitude of a sound wave is the incremental pressure resulting from sound above atmospheric pressure. The sound-pressure level is the fundamental measure of AN; it is generally measured on a logarithmic scale with respect to a reference pressure. The sound-pressure level (SPL) in decibels (dB) is given by:

$$SPL = 20 \log (P/P_o)\text{dB}$$

where P is the effective rms (root-mean-square) sound pressure, P_o is the reference pressure, and the logarithm (log) is to the base 10. The reference pressure for measurements concerned with hearing is usually taken as 20 micropascals (Pa), which is the approximate threshold of hearing for the human ear. A logarithmic scale is used to encompass the wide range of sound levels present in the environment. The range of human hearing is from 0 dB up to about 140 dB, a ratio of 10 million in pressure (EPA, 1978).

Logarithmic scales, such as the decibel scale, are not directly additive: to combine decibel levels, the dB values must be converted back to their respective equivalent pressure values, the total rms pressure level found, and the dB value of the total recalculated. For example, adding two sounds of equal level on the dB scale results in a 3 dB increase in sound level. Such an increase in sound pressure level of 3 dB, which corresponds to a doubling of the energy in the sound wave, is barely discernible by the human ear. It requires an increase of about 10 dB in SPL to produce a subjective doubling of sound level for humans. The upper range of hearing for humans (140 dB) corresponds to a sharply painful response (EPA, 1978).

Humans respond to sounds in the frequency range of 16 to 20,000 Hz. The human response depends on frequency, with the most sensitive range roughly between 2000 and 4000 Hz. The frequency-dependent sensitivity is reflected in various weighting scales for measuring audible noise. The A-weighted scale weights the various frequency components of a noise in approximately the same way that the human ear responds. This scale is generally used to measure and describe levels of environmental sounds such as those from vehicles or occupational sources. The A-weighted scale is also used to characterize transmission-line noise. Sound levels measured on the A-scale are expressed in units of dB(A) or dBA.

AN levels and, in particular, corona-generated audible noise (see below) vary in time. In order to account for fluctuating sound levels, statistical descriptors have been developed for environmental noise. Exceedence levels (L levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the L_5 level refers to the noise level that is exceeded only 5 percent of the time. L_{50} refers to the sound level exceeded 50 percent of the time. Sound-level measurements and predictions for transmission lines are often expressed in terms of exceedence levels, with the L_5 level representing the maximum level and the L_{50} level representing a median level.

Table 7 shows AN levels from various common sources. Clearly, there is wide variation. Noise exposure depends on how much time an individual spends in different locations. Outdoor noise generally does not contribute to indoor levels (EPA, 1974). Activities in a building or residence generally dominate interior AN levels.

BPA has established a transmission-line design criterion for corona-generated audible noise (L_{50}, foul weather) of 50 dBA at the edge of the right-of-way (USDOE, 2006). This criterion applies to new line construction and is under typical conditions of foul weather, altitude, and system voltage for the line. It is generally only of concern for 500-kV lines. This criterion has been interpreted by the state and BPA to meet Oregon Noise Control Regulations (Perry, 1982).

The Washington Administrative Code provides noise limitations by class of property, residential, commercial or industrial (Washington State, 1975). Transmission lines are classified as industrial and may cause a maximum permissible noise level of 60 dBA to intrude into residential property. During nighttime hours (10:00 pm to 7:00 am), the maximum permissible limit for noise from industrial to residential areas is reduced to 50 dBA. This latter level applies to transmission lines that operate continuously. The state of Washington Department of Ecology accepts the 50 dBA level at the edge of the right-of-way for transmission lines, but encouraged BPA to design lines with lower audible noise levels (WDOE, 1981).

Audible noise from substations is generated predominantly by equipment such as transformers, reactors and other wire-wound equipment. It is characterized by a 120 Hz hum that is associated with magnetic-field caused vibrations in the equipment. Noise from such equipment varies by voltage and other operating conditions. The BPA design level for substation noise is 50 dBA at the substation property line for new construction (USDOE, 2006). The design level is met by obtaining equipment that meets specified noise limits and, for new substations, by securing a no-built buffer beyond the substation perimeter fence.

In industrial, business, commercial, or mixed use zones the AN level from substations may exceed 50 dBA but must still meet any state or local AN requirements. The design criteria also allows the 50 dBA design level to be exceeded in remote areas where development of noise sensitive properties is highly unlikely.

The EPA has established a guideline of 55 dBA for the annual average day-night level (L_{dn}) in outdoor areas [EPA, 1978]. In computing this value, a 10 dB correction (penalty) is added to night-time noise between the hours of 10 p.m. and 7 a.m.

7.2 Transmission-line Audible Noise

Corona is the partial electrical breakdown of the insulating properties of air around the conductors of a transmission line. In a small volume near the surface of the conductors, energy and heat are dissipated. Part of this energy is in the form of small local pressure changes that result in audible noise. Corona-generated audible noise can be characterized as a hissing, crackling sound that, under certain conditions, is accompanied by a 120-Hz hum. Corona-generated audible noise is of concern primarily for contemporary lines operating at voltages of 345 kV and higher during foul weather. The proposed 500-kV line will produce some noise under foul weather conditions.

The conductors of high-voltage transmission lines are designed to be corona-free under ideal conditions. However, protrusions on the conductor surface—particularly water droplets on or dripping off the conductors—cause electric fields near the conductor surface to exceed corona onset levels, and corona occurs. Therefore, audible noise from transmission lines is generally a foul-weather (wet-conductor) phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Based on hourly meteorologic records over several years from Kennewick, WA and Moro, OR , such conditions are expected to occur about 1 percent of the time during the year in the vicinity of the proposed line.

For a few months after line construction, residual grease or oil on the conductors can cause water to bead up on the surface. This results in more corona sources and slightly higher levels of audible noise and electromagnetic interference if the line is energized. However, the new conductors "age" in a few months, and the level of corona activity decreases to the predicted equilibrium value. During fair weather, insects and dust on the conductor can also serve as sources of corona.

All except Configuration 7 would use three 1.30-inch diameter conductors per phase to yield acceptable corona levels. However, Configuration 7 with split-phase 500-kV circuits on either side of the double circuit tower would employ three 1.60-inch diameter conductors per phase to achieve the required 50 dBA or less at the edge of the right-of-way.

7.3 Predicted Audible Noise Levels

Audible noise levels are calculated for average voltage of 536 kV and average conductor heights for fair- and foul-weather conditions. The predicted levels of corona-generated audible noise at the edge of the right-of-way for the proposed line configurations are given in Table 8. The L_{50} foul-weather levels for the proposed configurations range from 40 to 49 dBA. The highest levels would generally occur when the new 500-kV circuit is at the minimum distance of 75 feet from the edge of the right-of-way. This occurs for Configurations 1, 4, 6, 7, and 10. Predicted profiles of the L_{50} foul-weather levels for Configurations 1 and 7 are shown in Figure 37.

The audible noise levels for the No-action alternative are generally lower than the levels at the same locations with the proposed configurations. For the No-action alternative, the levels at the edges of existing rights-of-way range from ambient to 48 dBA. In this case, the existing McNary – Ross 345-kV and parallel Harvalum - Big Eddy 230-kV lines produce the highest noise levels.

During fair-weather conditions, which occur about 99 percent of the time, audible noise levels at the edge of the right-of-way would be about 20 dBA lower (if corona were present). These lower levels could be masked by ambient noise on and off the right-of-way.

7.4 Discussion

Along much of the proposed routes there would be increases in the perceived noise above ambient levels during foul weather at the edges of the right-of-way. This would be especially true in areas where the centerline of the proposed 500-kV line is at 75 feet from the edge of the right-of-way. However, even there, the corona-generated noise during foul weather would be masked to some extent by naturally occurring sounds such as wind and rain on foliage. The calculated foul-weather corona noise levels for the proposed line would be comparable to, or less, than those from existing 500-kV lines in Oregon and Washington. Relatively lower levels would be especially prevalent in line segments with existing wide rights-of-way where the proposed 500-kV line would be placed well away from the edge of the right-of-way.

Off the right-of-way corona-generated noise during fair weather will likely be masked or so low as to not be perceived even in fair weather. During foul-weather ambient noise levels can be high due to rain hitting foliage or buildings and wind. These sounds can mask corona noise both on and off the right-of-way. Furthermore people tend to be inside with windows closed, providing additional attenuation when corona noise is present.

Off the right-of-way, the foul-weather levels of audible noise from the proposed line would be well below the 55 dBA level that can produce interference with speech outdoors. Residential buildings provide significant sound attenuation (-12 dBA with windows open; -24 dBA with windows closed). Therefore indoor noise levels off the right-of-way would be well below the 45 dBA level where interference with speech indoors can occur and below the 35 dBA level where sleep interference can occur (EPA, 1973; EPA, 1978).

The highest noise level of 49-dBA for the configurations would meet the BPA design criterion and, hence, the statutory limits established in both Oregon and Washington. The computed annual L_{dn} level for transmission lines operating in areas with 1 to 2 percent foul weather is about $L_{dn} = L_{50} - 6$ dB (Bracken, 1987). Therefore, assuming such conditions in the Big Eddy Transmission Line Project area, the estimated worst case L_{dn} at the edge of the right-of-way would be approximately 43 dBA, which is below the EPA L_{dn} guideline of 55 dBA.

No transformers will be installed at the new Knight Substation so that the audible noise at the edge of the substation will be due to the transmission lines entering the substation. Since the proposed transmission line will meet the 50 dBA criterion at the edge of the right-of-way, this criterion as it applies to substations will also be met (USDOE, 2006).

At the existing Big Eddy substation audible noise levels will also be predominantly due to foul weather corona noise from incoming and outgoing transmission lines. Noise levels produced from the new transformers will be lower than that from the existing equipment and unnoticeable when added to the existing noise levels at the edge of the substation property.

Thus all applicable federal, state, and local regulations will be met by the proposed transmission line and substation addition and modification.

8.0 Electromagnetic Interference

8.1 Basic Concepts

Corona on transmission-line conductors can also generate electromagnetic noise in the frequency bands used for radio and television signals. The noise can cause radio and television interference (RI and TVI). In certain circumstances, corona-generated electromagnetic interference (EMI) can also affect communications systems and other sensitive receivers. Interference with electromagnetic signals by corona-generated noise is generally associated with lines operating at voltages of 345 kV or higher. This is especially true of interference with television signals. The bundle of three 1.3-inch (or 1.6-inch) diameter conductors used in the design of the proposed 500-kV line will mitigate corona generation and thus keep radio and television interference levels at acceptable levels.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines are a more common source of RI/TVI than is corona from high-voltage electrical systems. This gap-type interference is primarily a fair-weather phenomenon caused by loose hardware and wires. The proposed transmission line would be constructed with modern hardware that eliminates such problems and therefore minimizes gap noise. Consequently, this source of EMI is not anticipated for the proposed line.

No state has limits for either RI or TVI. In the United States, electromagnetic interference from power transmission systems is governed by the Federal Communications Commission (FCC) Rules and Regulations presently in existence (Federal Communications Commission, 1988). A power transmission system falls into the FCC category of "incidental radiation device," which is defined as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy." Such a device "shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." For purposes of these regulations, harmful interference is defined as: "any emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communication service operating in accordance with this chapter" (Federal Communications Commission, 1988: Vol II, part 15. 47CFR, Ch. 1).

Electric power companies have been able to work quite well under the present FCC rule because harmful interference can generally be eliminated. It has been estimated that more than 95 percent of power-line sources that caused interference were due to gap-type discharges. These can be found and completely eliminated, when required to prevent interference (USDOE, 1980). Complaints related to corona-generated interference occur infrequently. This is especially true due to increased use of FM radio, cable television and satellite television, which are not subject to corona-generated interference. Mitigation of corona-generated interference with conventional broadcast radio and television receivers can be accomplished in several ways, such as use of a directional antenna or relocation of an existing antenna (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

8.2 Radio Interference (RI)

Radio reception in the AM broadcast band (535 to 1605 kilohertz (kHz)) is most often affected by corona-generated EMI. FM radio reception is rarely affected. Generally, only residences very near to transmission lines can be affected by RI. The IEEE Radio Noise Design Guide identifies an acceptable limit of fair-weather RI as expressed in decibels above 1 microvolt per meter (dBμV/m) of about 40 dB(μV/m) at 1 megahertz (MHz) (IEEE Committee Report, 1971). This limit applies at 100 ft. (30 m) from the outside conductor. As a general rule, average levels during foul weather (when the conductors are wet) are 16 to 22 dBμV/m higher than average fair-weather levels.

8.3 Predicted RI Levels

The L_{50} fair-weather RI levels were predicted for all configurations at the furthest of 100 ft. (30 m) from the outside conductor or the edge of the right-of-way. The results are shown in Table 9. The L_{50} levels for all configurations are at or below the acceptable limit of about 40 dBμV/m and are therefore compliant with the IEEE guideline level. The RI levels for the proposed 500-kV configurations would exceed those from the existing lower voltage lines.

8.4 Television Interference (TVI)

Corona-caused TVI occurs during foul weather and is generally of concern for transmission lines with voltages of 345 kV or above, and only for conventional receivers within about 600 ft. (183 m) of a line. As is the case for RI, gap sources on distribution and low-voltage transmission lines are the principal observed sources of TVI. The use of modern hardware and construction practices for the proposed line would minimize such sources.

8.5 Predicted TVI Levels

The predicted foul-weather TVI levels at 75MHz from the proposed configurations operating at 536 kV are shown in Table 9. These levels are given for the further of 100 ft. (30 m) from the outside conductor or the edge of the right-of-way. The levels at these points range from 2 to 24 dBμV/m depending primarily on the distance from of the proposed 500-kV line. These levels are comparable to or lower than than those from existing 500-kV lines in Oregon and Washington. As with RI the largest values occur when the proposed 500-kV line is directly adjacent to the edge of the right-of-way.

At the highest predicted levels, there is a potential for interference with television signals at locations very near the proposed line in fringe reception areas. However, several factors reduce the likelihood of occurrence. Corona-generated TVI occurs only in foul weather; consequently, signals will not be interfered with most of the time, which is characterized by fair weather. Because television antennas are directional, the impact of TVI is related to the location and orientation of the antenna relative to the transmission line. If the antenna were pointed away from the line, then TVI from the line would affect reception much less than if the antenna were pointed towards the line. Since the level of TVI falls off with distance, the potential for interference becomes minimal at distances greater than several hundred feet from the centerline.

Other forms of TVI from transmission lines are signal reflection (ghosting) and signal blocking caused by the relative locations of the transmission structure and the receiving antenna with respect to the incoming television signal. Again only houses within several hundred feet of the proposed line would possibly be affected.

Television systems that operate at higher frequencies, such as satellite receivers, are not affected by corona-generated TVI. Cable television systems are also not affected.

Interference with television reception can be corrected by any of several approaches: improving the receiving antenna system; installing a remote antenna; installing an antenna for TV stations less vulnerable to interference; connecting to an existing cable system; or installing a translator (cf. USDOE, 1977). BPA has an active program to identify, investigate, and mitigate legitimate RI and TVI complaints. It is anticipated that any instances of TVI caused by the proposed line could be effectively mitigated.

8.6 Interference with Other Devices

Corona-generated interference can conceivably cause disruption on other communications bands such as the citizen's (CB) and mobile bands. However, mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). Similarly, cellular telephones operate at a frequency of about 900 MHz or higher, which is above the frequency where corona-generated interference is prevalent. In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for television and AM radio interference.

8.7 Conclusion

Predicted EMI levels for the proposed 500-kV transmission line are comparable to, or lower, than those that already exist near 500-kV lines and no impacts of corona-generated interference on radio, television, or other reception are anticipated. Based on land use surveys approximately 10 to 12 houses could be within 500 feet of the proposed line (Table 5) and possibly affected by interference. Whether interference occurs will depend on which 28-mile route alternative and line designs are selected as well as the type of television or radio receiver. Furthermore, if interference should occur, there are various methods for correcting it; BPA has a program to respond to legitimate complaints.

9.0 Other Corona Effects

Corona is visible as a bluish glow or as bluish plumes. On the proposed 500-kV line, corona levels would be very low, so that corona on the conductors would be observable only under the darkest conditions and only with the aid of binoculars, if at all. Without a period of adaptation for the eyes and without intentional looking for the corona, it would probably not be noticeable.

When corona is present, the air surrounding the conductors is ionized and many chemical reactions take place, producing small amounts of ozone and other oxidants. Ozone is approximately 90 percent of the oxidants, while the remaining 10 percent is composed principally of nitrogen oxides. The national primary ambient air quality standard for photochemical oxidants, of which ozone is the principal component, is 235 micrograms/cubic meter) or 120 parts per billion. The maximum incremental ozone levels at ground level produced by corona activity on the proposed transmission line during foul weather would be much less than 1 part per billion. This level is insignificant when compared with natural levels and fluctuations in natural levels.

10.0 Summary

The number of nearby houses/businesses that could be impacted by field or corona effects is small and fairly consistent among the three line route alternatives: ranging from 2 to 5 within 300 feet of centerline and from 10 to 12 within 500 feet.

Electric and magnetic fields from the proposed transmission line have been characterized using well-known techniques accepted within the scientific and engineering community. The expected electric-field levels from the proposed line at minimum design clearance would be comparable to those from existing 500-kV lines in Washington and elsewhere. The expected magnetic-field levels from the proposed line would be comparable to, or less than, those from other 500-kV lines in Washington, Oregon and elsewhere.

The peak electric field expected under the proposed line would be 8.8 kV/m; the maximum value at the edge of the right-of-way would be about 2.4 kV/m. Clearances at road crossings would be increased to reduce the peak electric-field value to 5 kV/m or less.

Under maximum current conditions, the maximum magnetic fields on and at the edge of the right-of-way vary considerably among configurations: ranging from 219 to 60 mG on the right-of-way and from 82 to less than 1 mG at the edge of the right-of-way. Average values of the fields are much reduced and also vary widely between configurations. The average field value at the edge of the right-of way adjacent to the proposed line ranges from 21 to less than 1 mG depending on right-of-way width and the presence of other lines.

For the No-action alternative, maximum magnetic fields would range from 163 to 0 mG on the right-of-way and from 67 to 0 mG at the edge. For this alternative average fields would be reduced to a maximum of 48 on the right-of-way and 23 at the edge.

The electric fields from the proposed line would meet regulatory limits for public exposure in some states and guidelines set established by IEEE. However, the electric fields from the line could exceed the regulatory limits or guidelines for peak fields established in some states and by ICNIRP. The magnetic fields from the proposed line would be within the regulatory limits of the two states that have established such limits and below the guidelines for public exposure established by ICNIRP and IEEE. Washington does not have any electric- or magnetic-field regulatory limits or guidelines.

Short-term effects from transmission-line fields are well understood and can be mitigated. Nuisance shocks arising from electric-field induced currents and voltages could be perceivable on the right-of-way of the proposed line. It is common practice to ground permanent conducting objects during and after construction to mitigate against such occurrences.

Corona-generated audible noise from the line would be perceivable during foul weather. The levels would be comparable to or less those near existing 500-kV transmission lines in Oregon and Washington, would be in compliance with noise regulations in Oregon and Washington, and would be below levels specified in EPA guidelines.

Corona-generated electromagnetic interference from the proposed line would be comparable to or less than that from existing 500-kV lines in Washington. Radio interference levels would be at or below limits identified as acceptable. Television interference, a foul-weather phenomenon, is anticipated to be comparable to or less than that from existing 500-kV lines in Washington. The presence of only 10 to 12 residences/businesses closer than 500 feet (183 m) to the line and the rarity of precipitation conditions when TVI occurs (about 1% of time) make it unlikely that television reception will be affected. However, if legitimate complaints arise, BPA has a mitigation program.

List of References Cited

ACGIH (American Conference of Governmental Industrial Hygienists). 2008. 2008 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists, Cincinnati. 251 pages.

Baishiki, R.S.; Johnson, G.B.; Zaffanella, L.E.; Bracken, T.D.; Sussman, S.S.; Rauch, G.B.; and Silva, J.M. 1990. Studies of Power System Magnetic Fields: Characterization of Sources in Residential Environments, Measurement of Exposure, Influence On Computer Screens. (36-104) CIGRE, Paris, France. 10 pages.

Banfai, B.; Karady, G.G.; Kim, C.J.; and Maracas, K.B. 2000. Magnetic field effects on CRT computer monitors. IEEE Trans. on Power Delivery 15, 307-312.

Bassen, H.; Casamento, J.; and Crowl, B. 1991. Reduction of electric and magnetic field emissions from electric blankets (Meeting abstract). *In*: Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City. Bioelectromagnetics Society, New York, 20.

Bowman, J.D.; Garabrant, D.H.; Sobel, E.; and Peters, J.M. June 1988. Exposures to Extremely Low Frequency (ELF) Electromagnetic Fields in Occupations With Elevated Leukemia Rates. Applied Industrial Hygienics, 3(6, June):189-194.

Bracken, T.D. 1987. Audible Noise from High Voltage Transmission Facilities. A Briefing Paper Prepared for State of Florida Department of Environmental Regulation. (DER Contract No. SP122) State of Florida Department of Environmental Regulation.

Bracken, T.D. 1990. The EMDEX Project: Technology Transfer and Occupational Measurements, Volumes 1-3 Interim Report. EPRI Report EN-7048. (EPRI EN-7048) Electric Power Research Institute, Palo Alto, CA.

Chartier, V.L. April 1983. Empirical Expressions for Calculating High Voltage Transmission Corona Phenomena, First Annual Seminar Technical Career Program for Professional Engineers. Bonneville Power Administration, Portland, Oregon. April 1983, 75-82.

Chartier, V.L. and Stearns, R.D. January 1981. Formulas for Predicting Audible Noise from Overhead High Voltage AC and DC Lines. IEEE Transactions on Power Apparatus and Systems, PAS-100(No. 1, January 1981):121-129.

Dabkowski, J. and Taflove, A. May/June 1979. Prediction Method for Buried Pipeline Voltages Due to 60 Hz AC Inductive Coupling. Part II: Field Test Verification. IEEE Transactions on Power Apparatus and Systems, PAS-98(3, May/June):788-794.

Deno, D.W. and Zaffanella, L. 1982. Field effects of overhead transmission lines and stations. Chap. 8. *In*: Transmission Line Reference Book: 345 KV and Above. Second ed. (Ed: LaForest, J.J.). Electric Power Research Institute, Palo Alto, CA, 329-419.

EPA (Environmental Protection Agency). July 1973. Public Health and Welfare Criteria for Noise. (No. 500/9-73-002, July 27, 1973.) U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1974. Information On Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety. (No. PB-239 429.) U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1978. Protective Noise Levels. Condensed Version of EPA Levels Document. (No. PB82-138827) U.S Environmental Protection Agency, Washington, DC.

Exponent. 2009. Update of EMF Research – 2009. Technical report prepared for Bonneville Power Administration by Exponent, New York, NY (April 2009).

Federal Communications Commission. 1988. Federal Communications Commission Rules and Regulations. 10-1-88 ed. Vol. II part 15, 47 CFR, Ch. 1.

Florig, H.K. and Hoburg, J.F. 1988. Electric and Magnetic Field Exposure Associated With Electric Blankets. Project Resume. Contractor's Review. U.S. Department of Energy/Electric Power Research Institute.

Florig, H.K.; Hoburg, J.F.; and Morgan, M.G. April 1987. Electric Field Exposure from Electric Blankets. IEEE Transactions on Power Delivery, PWRD-2(2, April):527-536.

Gauger, J. September 1985. Household Appliance Magnetic Field Survey. IEEE Transactions on Power Apparatus and Systems, 104(9, September):2436-2445.

Glasgow, A.R. and Carstensen, E.L. February 1981. The Shock Record for 500 and 750 KV Transmission Lines in North America. IEEE Transactions on Power Apparatus and Systems, 100(2, February):559-562.

Heroux, P. 1987. 60-Hz Electric and Magnetic Fields Generated By a Distribution Network. Bioelectromagnetics, 8(2):135-148.

ICES (International Committee on Electromagnetic Safety): 2002. IEEE PC95.6-2002 Standard for Safety Levels With Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz. Institute of Electrical and Electronics Engineers, Piscataway, NJ.

ICNIRP (International Committee on Non-ionizing Radiation Protection). April 1998. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz). Health Physics, 74(4, April):1-32.

IEEE (Institute of Electrical and Electronics Engineers, Inc.). 1978. Electric and Magnetic Field Coupling from High Voltage AC Power Transmission Lines -- Classification of Short-Term Effects On People. IEEE Transactions on Power Apparatus and Systems, PAS-97:2243-2252.

IEEE. 1994. IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines. ANSI/IEEE Std. 644-1994, New York, NY.

IEEE. 2002. National Electrical Safety Code. 2002 ed. Institute of Electrical and Electronics Engineers, Inc., New York, NY. 287 pages.

IEEE Committee Report. March/April 1971. Radio Noise Design Guide for High Voltage Transmission Lines. IEEE Transactions on Power Apparatus and Systems, PAS-90(No. 2, March/April):833-842.

IEEE Committee Report. October 1982. A Comparison of Methods for Calculating Audible Noise of High Voltage Transmission Lines. IEEE Transactions on Power Apparatus and Systems, 101(10, October):4090-4099.

IIT Research Institute. 1984. Representative Electromagnetic Field Intensities Near the Clam Lake (WI) and Republic (MI) ELF Facilities. Report Prepared for Naval Electronics Systems Command, PME 110 E Washington, D.C. 20360. (Under contract N00039-84-C0070.) IIT Research Institute, Chicago, IL. 60 pages.

Jaffa, K.C. and Stewart, J.B. March 1981. Magnetic Field Induction from Overhead Transmission and Distribution Power Lines On Buried Irrigation Pipelines. IEEE Transactions on Power Apparatus and Systems, PAS-100(3, March):990-1000.

Keesey, J.C. and Letcher, F.S. 1969. Minimum Thresholds for Physiological Responses to Flow of Alternating Electric Current Through the Human Body At Power-Transmission Frequencies. (Report No. 1) Naval Medical Research Institute, Project MR 005.08-0030B, Bethesda, MD. 25 pages.

Loftness, M.O.; Chartier, V.L.; and Reiner, G.L. 1981. EMI Correction Techniques for Transmission Line Corona. (August 18-20, 1981, pp. 351-361.) Proceedings of the 1981 IEEE International Symposium on Electromagnetic Compatibility, Boulder, CO.

Maddock, B.J. September 1992. Guidelines and Standards for Exposure to Electric and Magnetic Fields At Power Frequencies. (Panel 2-05, CIGRE meeting August 30-September 5, 1992) CIGRE, Paris.

NOAA, National Oceanic & Atmospheric Administration. 2010. National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/oa/ncdc.html

Olsen, R.G.; Schennum, S.D.; and Chartier, V.L. April 1992. Comparison of Several Methods for Calculating Power Line Electromagnetic Interference Levels and Calibration With Long Term Data. IEEE Transactions on Power Delivery, 7(April, 1992):903-913.

Perry, D. 1982. Sound Level Limits from BPA Facilities. BPA memorandum, May 26, 1982; Department of Environmental Quality, Noise Control Regulations, Chapter 340, Oregon Administrative Rules, Division 35, March 1, 1978.

Reilly, J.P. 1979. Electric Field Induction on Long Objects -- A Methodology for Transmission Line Impact Studies. IEEE Transactions on Power Apparatus and Systems, PAS-98(6, Nov/Dec):1841-1852.

Sheppard, A.R. and Eisenbud, M. 1977. Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency. New York University Press, New York.

Silva, M.; Hummon, N.; Rutter, D.; and Hooper, C. 1989. Power Frequency Magnetic Fields in the Home. IEEE Transactions on Power Delivery, 4:465-478.

Taflove, A. and Dabkowski, J. May/June 1979. Prediction Method for Buried Pipeline Voltages Due to 60 Hz AC Inductive Coupling. Part I: Analysis. IEEE Transactions on Power Apparatus and Systems, PAS-98(3, May/June):780-787.

USDOE (U.S. Department of Energy), Bonneville Power Administration. March 1977. A Practical Handbook for the Location, Prevention and Correction of Television Interference from Overhead Power Lines. Portland, OR.

USDOE, Bonneville Power Administration. May 1980. A Practical Handbook for the Correction of Radio Interference from Overhead Powerlines and Facilities. (May 1980.) Portland, OR.

USDOE, Bonneville Power Administration. 1986. Electrical and Biological Effects of Transmission Lines: A Review. (DOE/BP 524 January 1986) Portland, OR.

USDOE, Bonneville Power Administration. 1996. Electrical and Biological Effects of Transmission Lines: A Review. (DOE/BP 2938 December 1996 1M) Portland, OR.

USDOE, Bonneville Power Administration. 2006. Audible Noise Policy. TBL Policy T2006-1. Bonneville Power Administration, Portland, OR.

USDOE, Bonneville Power Administration. 2007. Living and Working Safely Around High-Voltage Power Lines. (DOE/BP-3804). Portland, OR. 12 pages.

USDOE, Bonneville Power Administration. undated. "Corona and Field Effects" Computer Program (Public Domain Software). Bonneville Power Administration, P.O. Box 491-ELE, Vancouver, WA 98666.

Washington, State of. 1975. Washington Administrative Code, Chapter 173-60 WAC Maximum Environmental Noise Levels. Department of Ecology, Olympia, WA.

WDOE (Washington Department of Ecology). 1981. Letter from D.E. Saunders to J.H. Brunke, BPA, dated 9/3/81 regarding EDNA classification for substations and transmission line. State of Washington Department of Ecology, Olympia, WA.

Zaffanella, L.E. 1993. Survey of Residential Magnetic Field Sources. Vol. 1: Goals, results, and conclusions. (EPRI TR-102759-V1, Project 3335-02) Electric Power Research Institute, Palo Alto, CA.

Zaffanella, L.E. and Kalton, G.W. 1998. Survey of personal magnetic field exposure, Phase II: 1000-perosn survey. Interim Report. EMF RAPID Program Engineering Project #6. Enertech Consultants, Lee, MA.

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Table 1: Description of line configurations and associated segments along the proposed Big-Eddy– Knight 500-kV transmission line alternative routes.

Configuration		Line segments[2]	Segment length, miles	Total configuration length by alternative, miles		
No.	**Description[1]**			**West**	**Middle**	**East**
1	BE-KN SglCkt	W-1 thru W-3 W-5 W-8 M-3 M-5 M-7 E-4	3.9 0.8 4.9 1.9 7.6 4.9 14.0	9.6	14.0	14.4
2	BE-KN SglCkt & || HARV-BE	M-1 and M-2 E-1 and E-2	9.2 9.2	-	9.2	9.2
3	BE-KN SglCkt & || McN-RO & || HARV-BE	E-3	4.8	-	-	4.8
4	BE-KN SglCkt & || CHE-GOL	W-6 and W-7 M-6	16.4 2.1	16.4	2.1	-
5	BE-KN SglCkt & || Spearfish Tap	W-4	1.1	1.1	-	-
6	BE-KN SglCkt & ||BE-SPR	M-4	1.3	-	1.3	-
7	BE-KN DblCkt split-phase w/ 3x1.6” bundles	W-1 thru W-3	3.9	3.9	-	-
7A	BE-KN DblCkt tower with SglCkt w/ 3x1.3” bundles on one side	W-1 thru W-3	3.9	3.9	-	-
8	BE-KN DblCkt w/ HARV-BE	M-1 and M-2 E-1 and E-2	9.2 9.2	-	9.2	9.2
9	BE-KN DblCkt w/ McN-RO & ||HARV-BE	E-3	4.8	-	-	4.8
10	BE-KN DblCkt w/ CHE-GOL	W-6 and W-7 M-6	16.4 2.1	16.4	2.1	-
11	BE-KN DblCkt w/ Spearfish Tap	W-4	1.1	1.1	-	-
12	BE-KN DblCkt split phase & || Spearfish Tap	W-4	1.1	1.1	-	-

Notes for Table 1:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum-Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SglCkt = Single circuit; DblCkt = Double circuit; || = parallel to.

2 Physical locations of alternative routes and segments are shown in Figure 1. Segments are numbered from Big Eddy to Knight by route: W = West alternative, M = Middle alternative; E = East alternative

Table 2: Physical and electrical characteristics of transmission lines in the Big Eddy – Knight 500-kV Transmission Line Project corridor.

Line Characteristics	Proposed Line		Existing Lines				
	Big Eddy – Knight 500-kV[2]		Harvalum-Big Eddy 230-kV	McNary-Ross 345-kV	Chenoweth-Goldendale 115-kV[5]	Spearfish Tap 115-kV	Big Eddy-Spring Creek 230 kV
Voltage, kV Maximum/Average[1]	550/536		241.5/232	362/350	0/0	121/118	241.5/237
Circuit Configuration[2]	Single	Double	Single	Single	Single	Single	Single
Proposed Current, A Peak/Average	970/485	485/243	1075/505	630/380	0/0	35/9	872/244
No-action Current, A Peak/Average	-	-	820/410	520/244	0/0	35/9	950/266
Electric Phasing (looking towards Knight)	B A C	A C B B C A	C B A	C A B	B C A	C B A	B A C
Clearance, ft. Minimum/Average[1, 3]	35/47	36/47	32.5/45.4	33.8/47.6	25.9/34.4	25.9/29.5	33.8/46.7
Tower configuration	Delta	DC-Vert	Flat	Flat	Flat	Flat	Flat
Phase spacing, ft.	46H, 31.5V	36.5, 56.5H 36V	27	32	12	12	27
Conductor: #/Diameter, in.	3/1.3	3/1.3 or 3x1.6[2]	1/1.382	1/1.602	1/0.563	1/0.642	1/1.382
Centerline distance to edge of ROW, ft.[4]	75	75	187.5/62.5	312.5/187.5	50	425/50	62.5
Centerline distance to proposed line, ft.	-	-	125	125	125	125	125
Average altitude, ft.	1500	1500	600	600	1600	350	1650

Notes for Table 2:

1 Average voltage and average clearance used for corona calculations.

2 When the proposed Big Eddy – Knight 500-kV line is energized on all six 3x1.6” phase bundles on a double circuit tower (Configuration 7), the three phases of the line will be split between six conductor bundles with each carrying one half of the single-circuit current. When the proposed Big Eddy – Knight 500-kV line is energized with only three 3x1.3” phase bundles on the double circuit tower (Configuration 7A), the non-energized phases will be left ungrounded. In Configuration 7A the energized circuit of the proposed line could be on either the west or east side of the tower. When the proposed Big-Eddy – Knight 500-kV line is on a double circuit tower with one of the existing parallel lines, the respective circuits will have the same voltages and currents as the individual single-circuit lines. When the existing Harvalum - Big Eddy or McNary – Ross line is the parallel line, they will have a 3x1.3” bundle (Configurations 8 and 9). The Chenoweth – Goldendale and Spearfish Tap lines would have a single 1.3” conductor when placed on the double circuit tower (Configurations 10 and 11).

3 To meet the BPA 9 kV/m limit for peak electric field and use consistent design clearances, the minimum clearance for all proposed double-circuit tower configurations was increased to 36 feet.

4 The distance to the west and east) edges of the right-of-way depends on the configuration as shown in Figures 2 – 10.

5 The Chenoweth – Goldendale 115-kV line is normally open at both ends with no current.

Table 3: Calculated maximum and average electric fields for the proposed Big Eddy – Knight 500-kV line operated at maximum voltage by configuration. Configurations are described in Tables 1 and 2. [Note: all 1.3" bundles except Config. 7]

Configuration		Electric Field, kV/m Proposed Alternative				Electric Field, kV/m No-action Alternative			
No.	Location	Peak on ROW		At Edge of ROW[2]		Peak on ROW		At Edge of ROW[2]	
	Field Description	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
1	BE-KN SglCkt	8.6	5.4	2.4, 2.4	2.3, 2.3	-	-	-	-
2	BE-KN SglCkt & HARV-BE	8.6	5.4	2.4, 1.5	2.4, 1.2	2.9	1.7	0.1, 1.3	0.1, 1.1
3	BE-KN SglCkt & McN-RO & HARV-BE[3] Use CAB phasing	8.8	5.8	0.2, 1.3	0.2, 1.1	4.5	2.6	<0.1, 1.3	<0.1, 1.1
4	BE-KN SglCkt & CHE-GOL	8.6	5.4	2.4, 0.3	2.3, 0.3	0.0	0.0	0.0	0.0
5	BE-KN SglCkt & Spearfish Tap	8.6	5.4	0.1, 0.2	0.1, 0.2	1.2	1.0	0.1, 0.4	0.2, 0.4
6	BE-KN SglCkt & BE-SPR	8.6	5.4	2.4, 1.4	2.3, 1.2	2.7	1.6	1.3, 1.3	1.1, 1.1
7	BE-KN DblCkt w/ 3x1.6" bundles[3]	7.3	4.3	1.3, 1.3	1.3, 1.3	-	-	-	-
7A	BE-KN DblCkt w/ only 1 circuit[3]	8.8	5.8	1.3, 0.1	1.4, 0.3	-	-	-	-
8	BE-KN DblCkt w/ HARV-BE[3]	7.9	4.9	0.3, 0.5	0.2, 0.4	2.9	1.7	1.3, 0.1	1.1, 0.1
9	BE-KN DblCkt w/ McN-RO & HARV-BE[3]	7.6	4.6	0.1, 1.3	0.1, 1.1	4.5	2.6	<0.1, 1.3	<0.1, 1.1
10	BE-KN DblCkt w/ CHE-GOL[3]	8.7	5.7	1.3, 0.1	1.4, 0.2	0.0	0.0	0.0	0.0
11	BE-KN DblCkt w/ Spearfish Tap[3]	8.5	5.6	0.1, 0.2	0.1, <0.1	1.2	1.0	0.0, 0.4	0.2, 0.4
12	BE-KN DblCkt & Spearfish Tap[3]	7.0	4.2	0.1, 0.3	0.1, 0.3	1.2	1.0	0.0, 0.4	0.2, 0.4

Notes for Table 3:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum- Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SngCkt = Single circuit; DblCkt = Double circuit

2 Field at west (north) edge of ROW shown first.

3 To meet the BPA 9 kV/m limit for peak electric field and use consistent design clearances, the minimum clearance for all proposed double-circuit tower configurations was increased to 36 feet.

Table 4: Calculated maximum and average magnetic fields for the proposed Big Eddy – Knight 500-kV line operated at maximum current/minimum clearance and average current/average clearance. Configurations are described in Tables 1 and 2.

Configuration[1]		Magnetic Field, mG Proposed Alternative				Magnetic Field, mG No-action Alternative			
No.	Location Field Description	Peak on ROW		At Edge of ROW[2]		Peak on ROW		At Edge of ROW[2]	
		Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
1	BE-KN SglCkt	159	50	42, 42	18, 18	-	-	-	-
2	BE-KN SglCkt & HARV-BE	219	65	49, 82	21, 31	163	48	7, 60	3, 22
3	BE-KN SglCkt & McN-RO & HARV-BE	214	62	7, 78	3, 29	161	46	3, 61	2, 23
4	BE-KN SglCkt & CHE-GOL	159	50	42, 8	18, 4	0	0	0	0
5	BE-KN SglCkt & Spearfish Tap	160	50	3, 8	1, 4	7	2	0, 2	0, <1
6	BE-KN SglCkt & BE-SPR	155	49	43, 64	18, 14	176	31	67, 67	15, 15
7	BE-KN DblCkt w/ 3x1.6” bundles	60	17	14, 14	6, 6	-	-	-	-
7A	BE-KN DblCkt w/ only 3 bundles	118	38	52, 29	21, 13	-	-	-	-
8	BE-KN DblCkt w/ HARV-BE	128	35	3, 33	2, 12	163	48	7, 60	3, 22
9	BE-KN DblCkt w/ McN-RO & HARV-BE	212	61	3, 79	1, 29	161	46	3, 61	2, 23
10	BE-KN DblCkt w/ CHE-GOL 36’	117	38	52, 29	21, 13	0	0	0	0
11	BE-KN DblCkt w/ Spearfish Tap 36’	116	38	3, 27	1, 13	7	2	0, 2	0, <1
12	BE-KN DblCkt & Spearfish Tap	60	17	<1, 3	<1, 1	7	2	0, 2	0, <1

Notes for Table 4:

1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum- Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SngCkt = Single circuit; DblCkt = Double circuit

2 Field at west (north) edge of ROW shown first.

3 To meet the BPA 9 kV/m limit for peak electric field and use consistent design clearances, the minimum clearance for all proposed double-circuit tower configurations was increased to 36 feet.

Table 5: Locations and ranges of average and maximum magnetic fields at residences and businesses near proposed line by primary circuit configuration and line route.

Primary Configuration	Single Circuit			Double Circuit+		
Route Alternative	**East***	**Middle***	**West**	**East**	**Middle**	**West**
Houses < 300 ft	3	2	4	5	4	4
Houses < 500 ft	12	11	10	10	10	10
Range of Distances from Centerline, ft	71 - 484	71 - 425	203 - 486	191 - 484	191 - 495	203 - 486
Range of Average Magnetic Field, mG	0.5 - 22.3	0.7 - 22.3	0.5 - 3.1	0.3 - 1.8	0.1 - 1.8	0.1 - 3.5
Range of Maximum Magnetic Field, mG	1.1 - 45	1.4 - 45	1.1 - 6.2	0.7 - 4.6	0.2 - 4.5	0.2 - 7

* A single house at 71 feet from the proposed centerline contributes the high field levels along the East and Middle alternatives.

+ Double circuit configuration counts include houses from single circuit sections E-4 and M-5, where no double circuit is planned.

Table 6: Electric- and magnetic-field exposure guidelines.

ORGANIZATION	TYPE OF EXPOSURE	ELECTRIC FIELD, kV/m	MAGNETIC FIELD, mG
ACGIH	Occupational	25[1]	10,000
ICNIRP	Occupational	8.3[2]	4,200
	General Public	4.2	833
IEEE	Occupational	20	27,100
	General Public	5[3]	9,040

1 Grounding is recommended above 5 –7 kV/m and conductive clothing is recommended above 15 kV/m.
2 Increased to 16.7 kV/m if nuisance shocks are eliminated.
3 Within power line rights-of-way, the guideline is 10 kV/m.

Sources: ACGIH, 2008; ICNIRP, 1998; ICES, 2002

Table 7: States with transmission-line field limits.

STATE AGENCY	WITHIN RIGHT-OF-WAY	AT EDGE OF RIGHT-OF-WAY	COMMENTS
a. 60-Hz ELECTRIC-FIELD LIMIT, kV/m			
Florida Department of Environmental Regulation	8 (230 kV) 10 (500 kV)	2	Codified regulation, adopted after a public rulemaking hearing in 1989.
Minnesota Environmental Quality Board	8	–	12-kV/m limit on the high voltage direct current (HVDC) nominal electric field.
Montana Board of Natural Resources and Conservation	7[1]	1[2]	Codified regulation, adopted after a public rulemaking hearing in 1984.
New Jersey Department of Environmental Protection	–	3	Used only as a guideline for evaluating complaints.
New York State Public Service Commission	11.8 (7,11)[3]	1.6	Explicitly implemented in terms of a specified right-of-way width.
Oregon Facility Siting Council	9	–	Codified regulation, adopted after a public rulemaking hearing in 1980.
b. 60-Hz MAGNETIC-FIELD LIMIT, mG			
Florida Department of Environmental Regulation	–	150 (230 kV) 200 (500 kV)	Codified regulations, adopted after a public rulemaking hearing in 1989.
New York State Public Service Commission	–	200	Adopted August 29, 1990.

Notes for Table 6:
1 At road crossings
2 Landowner may waive limit
3 At highway and private road crossings, respectively

Source: USDOE, 1996

Table 8: Common noise levels.

Sound Level, dBA	Noise Source or Effect
130	Threshold of pain
110	Rock-and-roll band
80	Truck at 50 ft. (15.2 m)
70	Gas lawnmower at 100 ft. (30 m)
60	Normal conversation indoors
50	Moderate rainfall on foliage
49	Highest foul-weather L_{50} at edge of proposed 500-kV right-of-way
40	Refrigerator
25	Bedroom at night
0	Hearing threshold

Adapted from: USDOE, 1985; USDOE, 1996.

Table 9: Calculated median (L_{50}) foul-weather audible noise levels at the edge of the right-of-way for the proposed Big Eddy – Knight 500-kV line operated at average voltage. Configurations are described in Table 1.

Configuration		Foul weather L50 Audible Noise, dBA	
No.	**Description[1]**	**Proposed Alternative[2]**	**No-action Alternative[2]**
1	BE-KN SglCkt	49, 49	-
2	BE-KN SglCkt & HARV-BE	48, 45	30, 35
3	BE-KN SglCkt & McN-RO & HARV-BE	48, 49	45, 48
4	BE-KN SglCkt & CHE-GOL	49, 46	-
5	BE-KN SglCkt & Spearfish Tap	42, 45	13, 23
6	BE-KN SglCkt & BE-SPR	49, 46	37, 37
7	BE-KN DblCkt w/ 3x1.6” bundles	49, 49	-
7A	BE-KN DblCkt w/ only SglCkt on west side	48, 46	-
8	BE-KN DblCkt w/ HARV-BE	45, 47	30, 35
9	BE-KN DblCkt w/ McN-RO & HARV-BE	43, 44	45, 48
10	BE-KN DblCkt w/ CHE-GOL	49, 47	-
11	BE-KN DblCkt w/ Spearfish Tap	40, 46	13, 23
12	BE-KN DblCkt & Spearfish Tap	46, 48	13, 23

Notes for Table 8:
1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum-Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SglCkt = Single circuit; DblCkt = Double circuit
2 Field at west (north) edge of ROW shown first.

Table 10 Calculated median (L_{50}) fair-weather radio interference level and foul weather television level for the proposed Big Eddy – Knight 500-kV line operated at average voltage. Configurations are described in Table 1.

Configuration		L50 Fair-Weather RI Level at 1 MHz, dB(µV/m)[2]	Foul-Weather TVI at 75 MHz, dB(µV/m)[2]
No.	**Description[1]**		
1	BE-KN SglCkt	39, 39	24, 24
2	BE-KN SglCkt & HARV-BE	39, 31	23, 10
3	BE-KN SglCkt & McN-RO & HARV-BE	34, 31	16, 13
4	BE-KN SglCkt & CHE-GOL	39, 36	24, 17
5	BE-KN SglCkt & Spearfish Tap	29, 35	6, 16
6	BE-KN SglCkt & BE-SPR	39, 32	24, 11
7	BE-KN DblCkt w/ 3x1.6” bundles	38, 38	21, 21
7A	BE-KN DblCkt w/ only 3 bundles	41, 37	23, 18
8	BE-KN DblCkt w/ HARV-BE	37, 38	17, 18
9	BE-KN DblCkt w/ McN-RO & HARV-BE	33, 33	7, 8
10	BE-KN DblCkt w/ CHE-GOL	41, 37	23, 18
11	BE-KN DblCkt w/ Spearfish Tap	25, 36	2, 17
12	BE-KN DblCkt & Spearfish Tap	34, 36	8, 13

Notes for Table 9:
1 BE-KN = Big Eddy-Knight; HARV-BE = Harvalum- Big Eddy; McN-RO = McNary-Ross; CHE-GOL = Chenoweth-Goldendale; BE-SPR = Big Eddy Spring Creek; SglCkt = Single circuit; DblCkt = Double circuit
2 Field at west (north) side of ROW shown first. Calculated levels shown at 100 feet (30 m) from the outside conductor or at the edge of the right-of-way, whichever is further from the conductor.

Figure 1: Alternative Routes and Segments for the Proposed Big Eddy – Knight 500-kV Transmission Line.

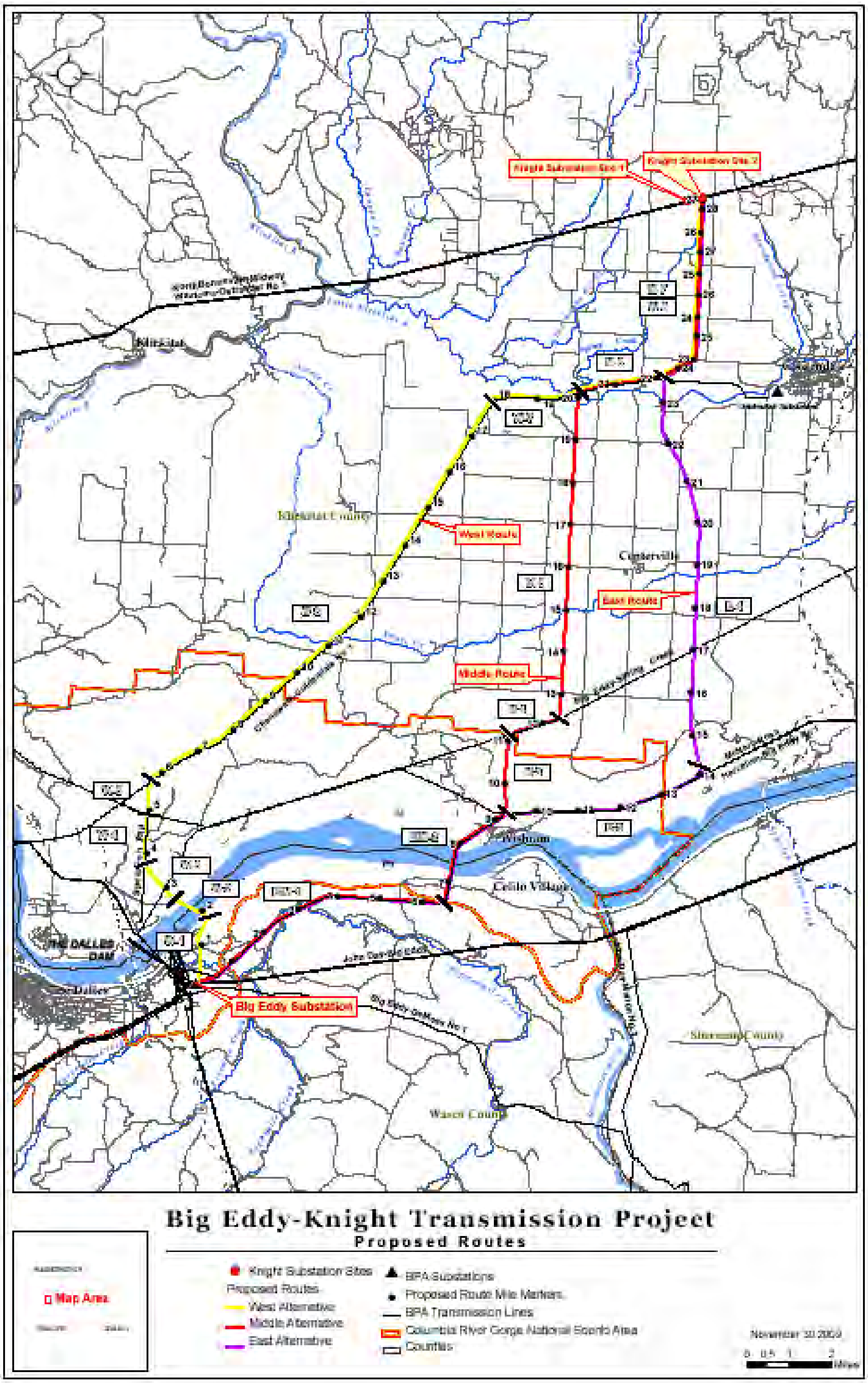


Figure 2: Single-circuit Configuration 1 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

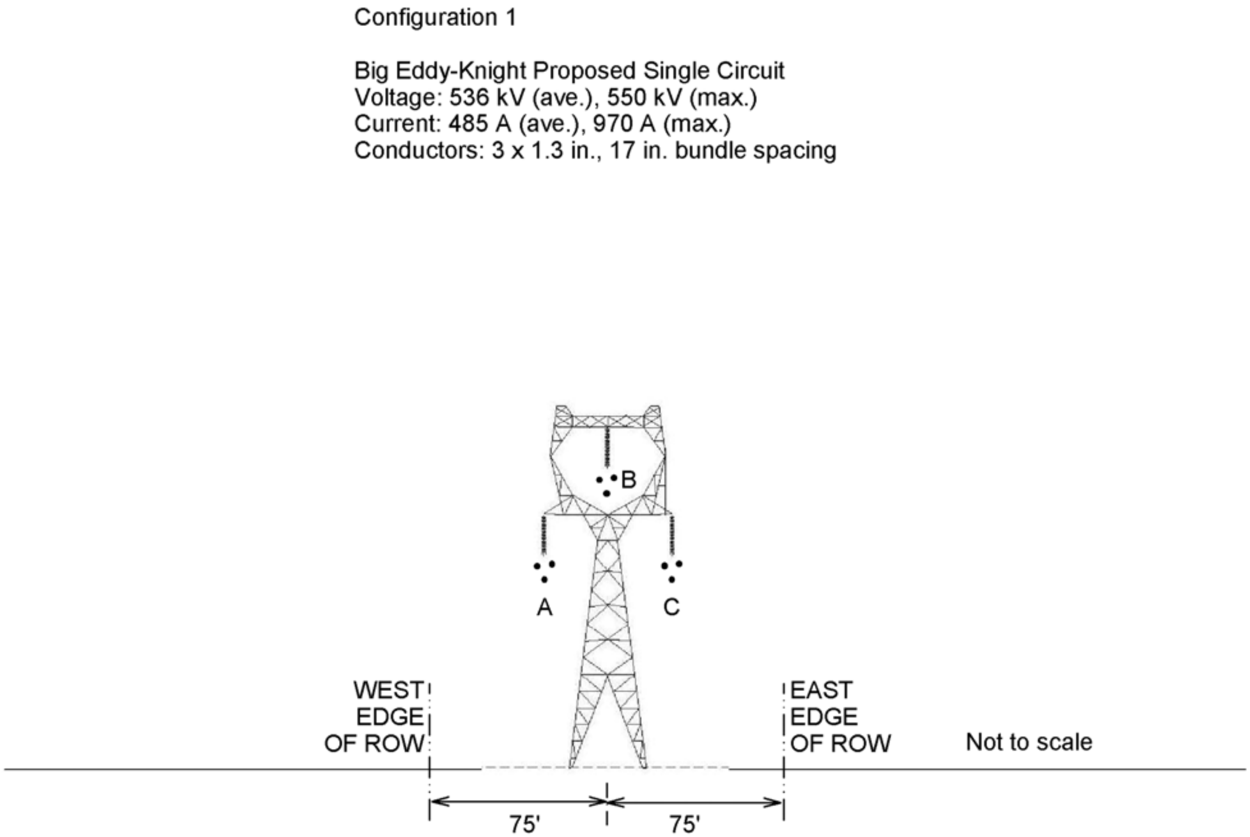


Figure 3: Single-circuit Configuration 2 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

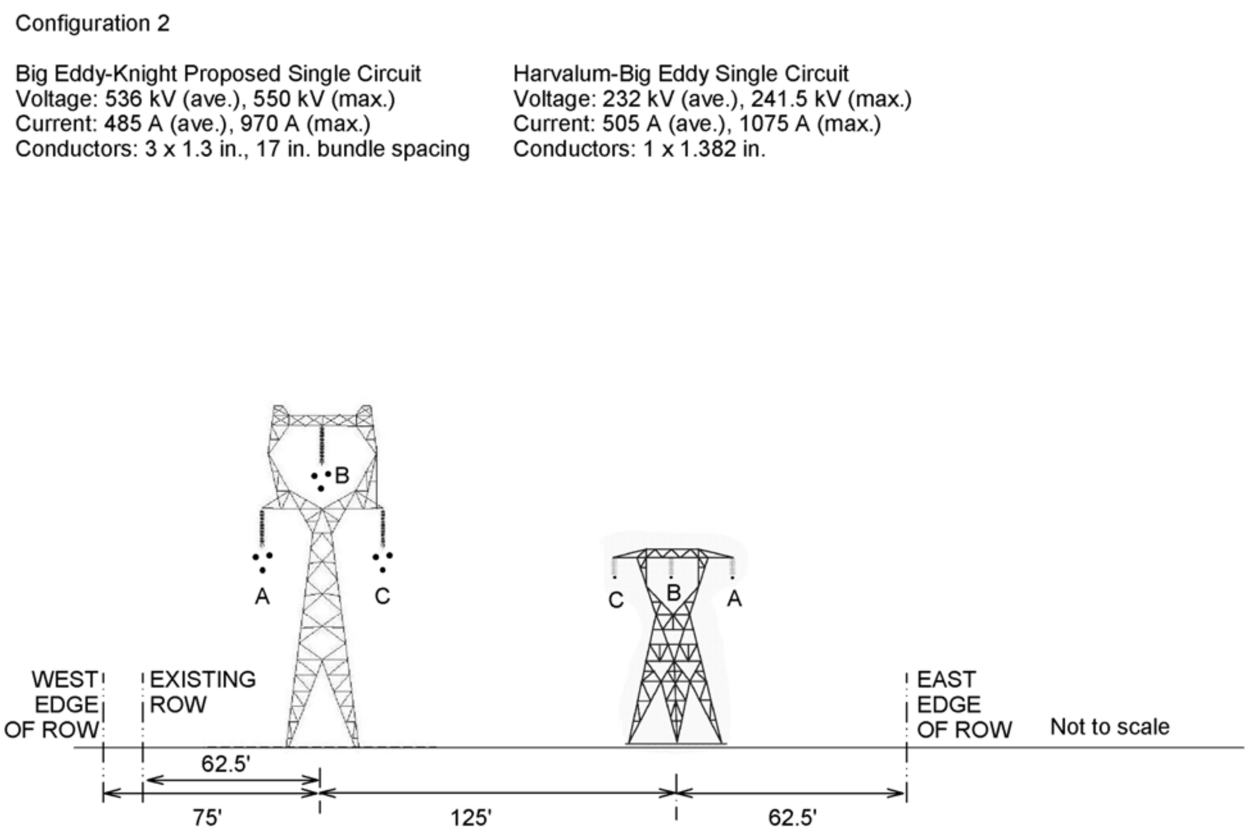


Figure 4: Single-circuit Configuration 3 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

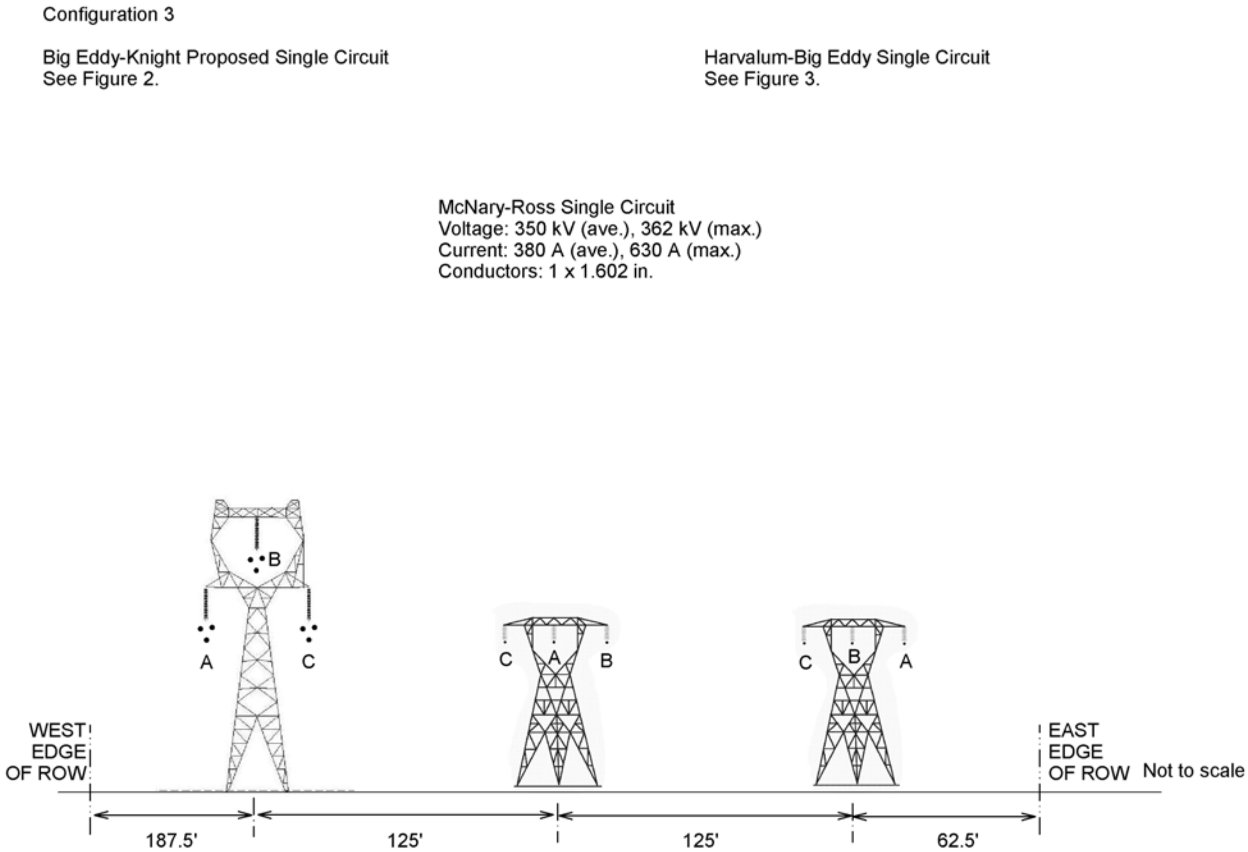


Figure 5: Single-circuit Configuration 4 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

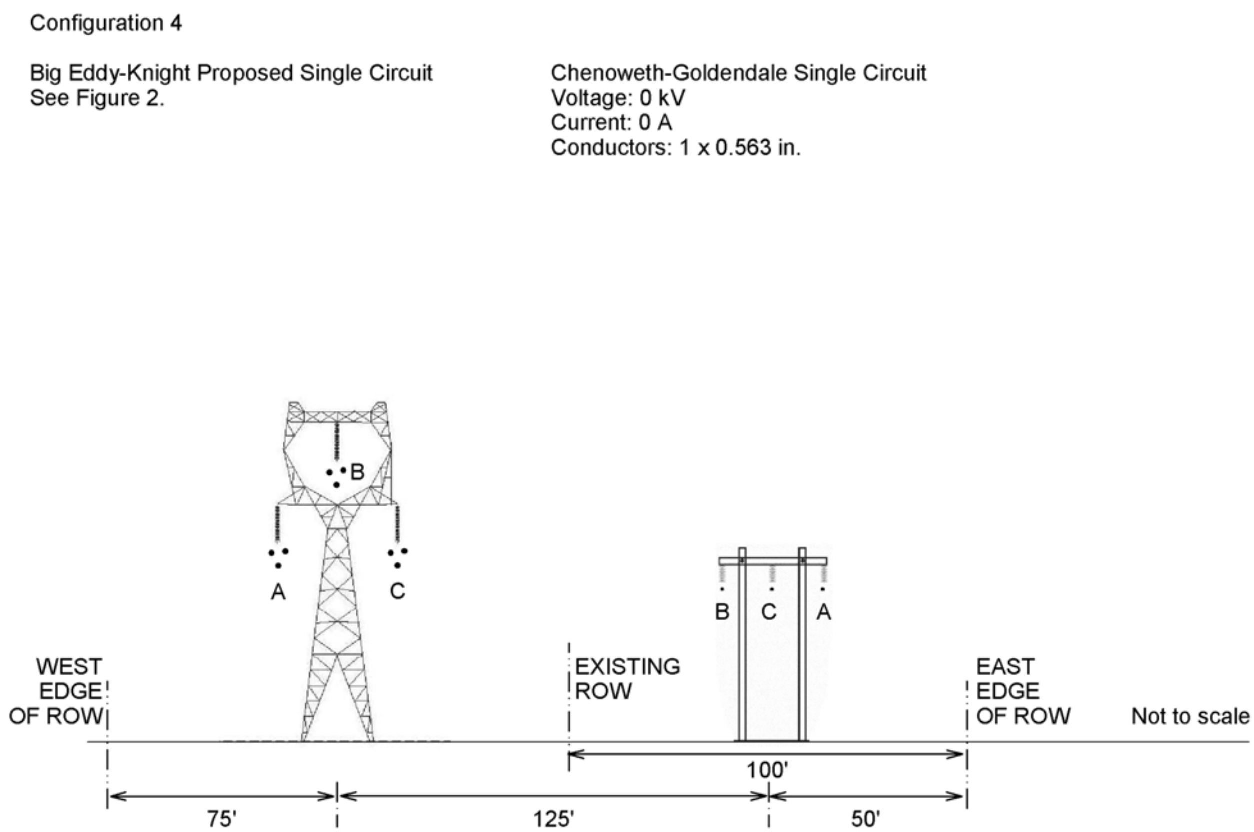


Figure 6: Single-circuit Configuration 5 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

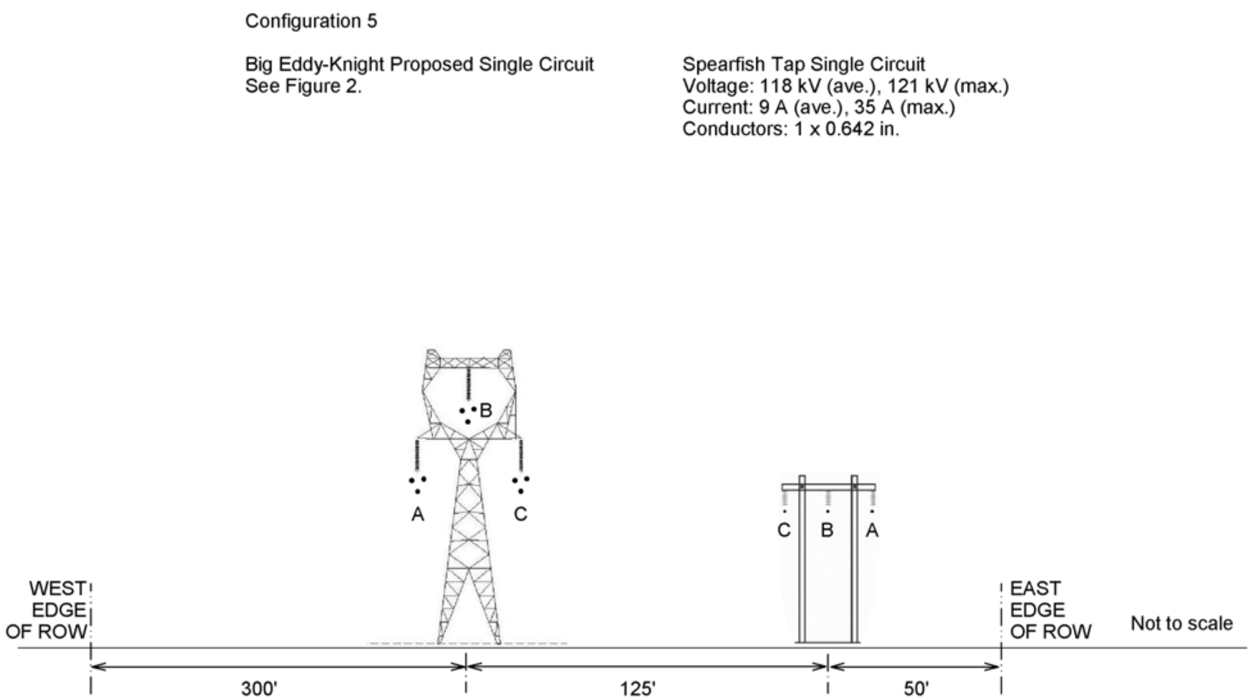


Figure 7: Single-circuit Configuration 6 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

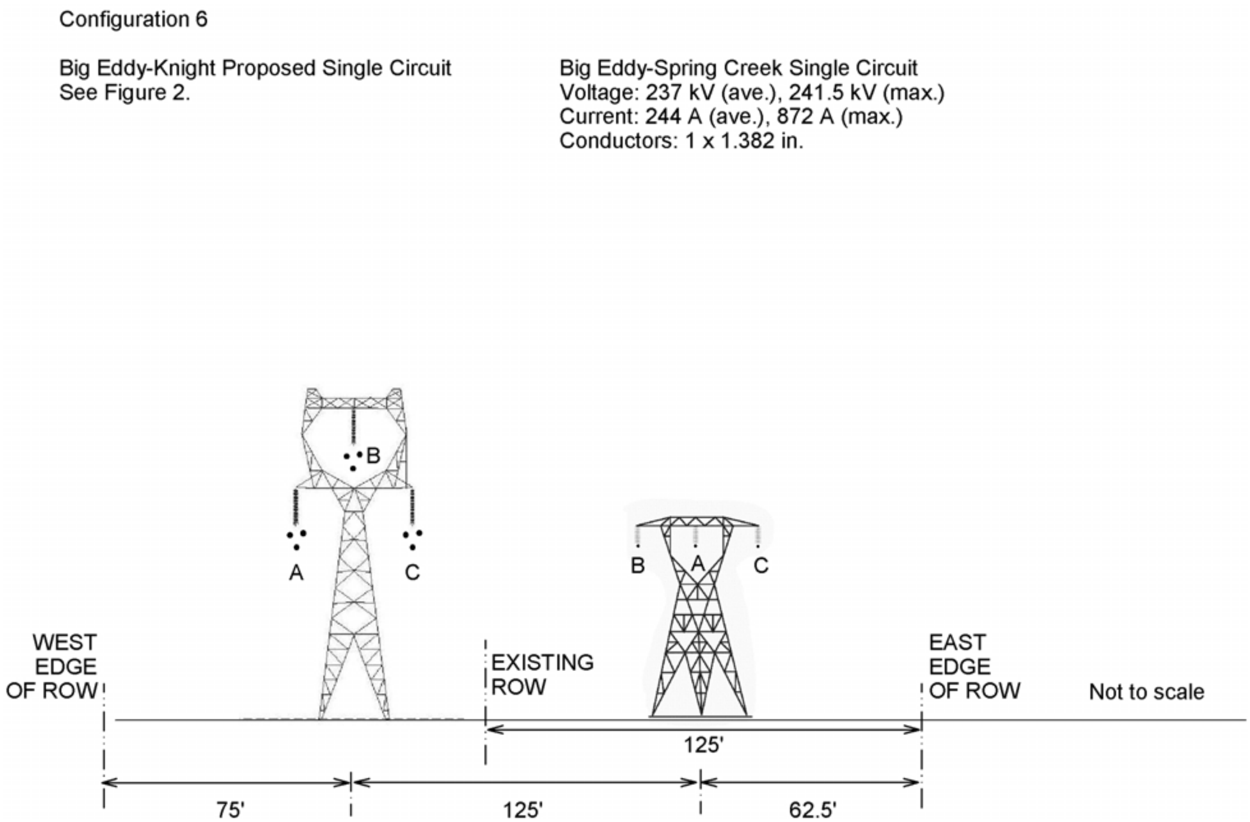


Figure 8: Double-circuit Configurations 7 and 7A for the proposed Big Eddy – Knight 500-kV line. The current is split between the two circuits in Configuration 7. The current is only on the west circuit in Configuration 7A and the east circuit conductors carry zero current and are not grounded. Configurations are described in Tables 1 and 2.

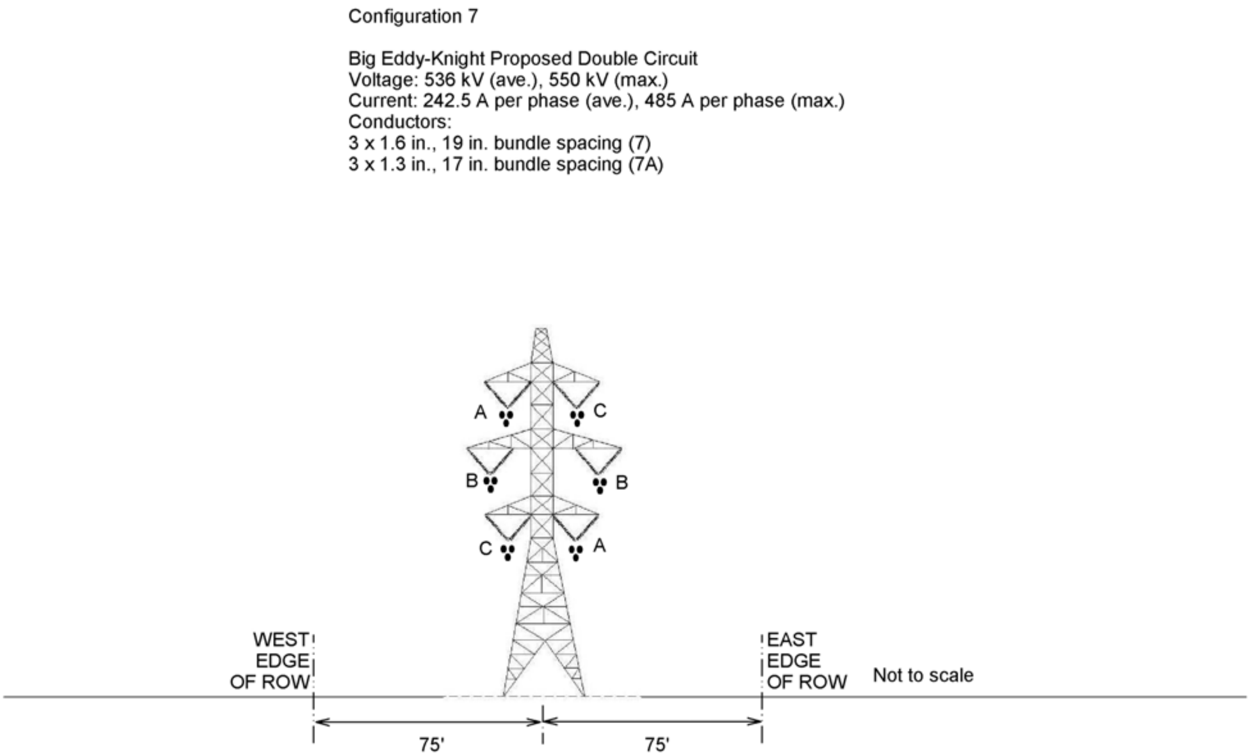


Figure 9: Double-circuit Configuration 8 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

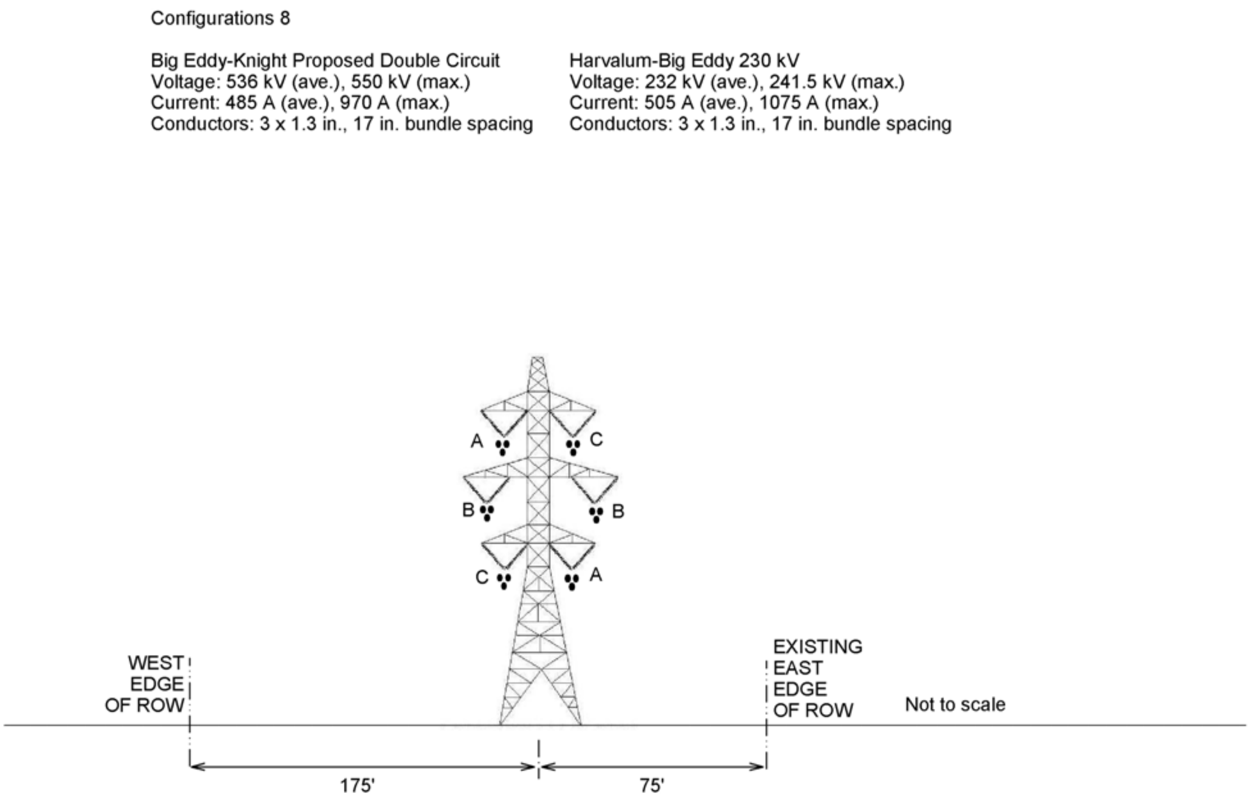


Figure 10: Double-circuit Configuration 9 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

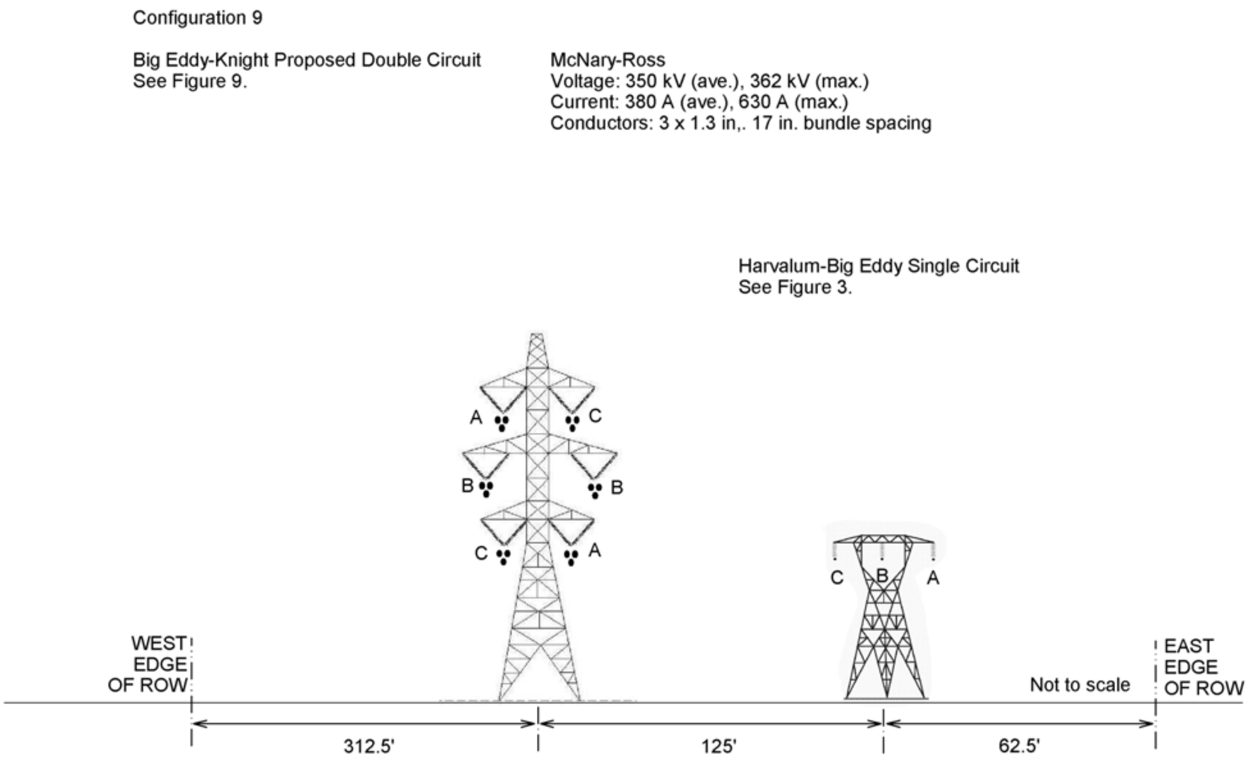


Figure 11: Double-circuit Configurations 10 and 11 for the proposed Big Eddy – Knight 500-kV line. The west circuit will be the proposed Big Eddy – Knight line and the east circuit will be the existing Chenoweth – Goldendale line (Configuration 10) or the existing Spearfish Tap line (Configuration 11). Configurations are described in Tables 1 and 2.

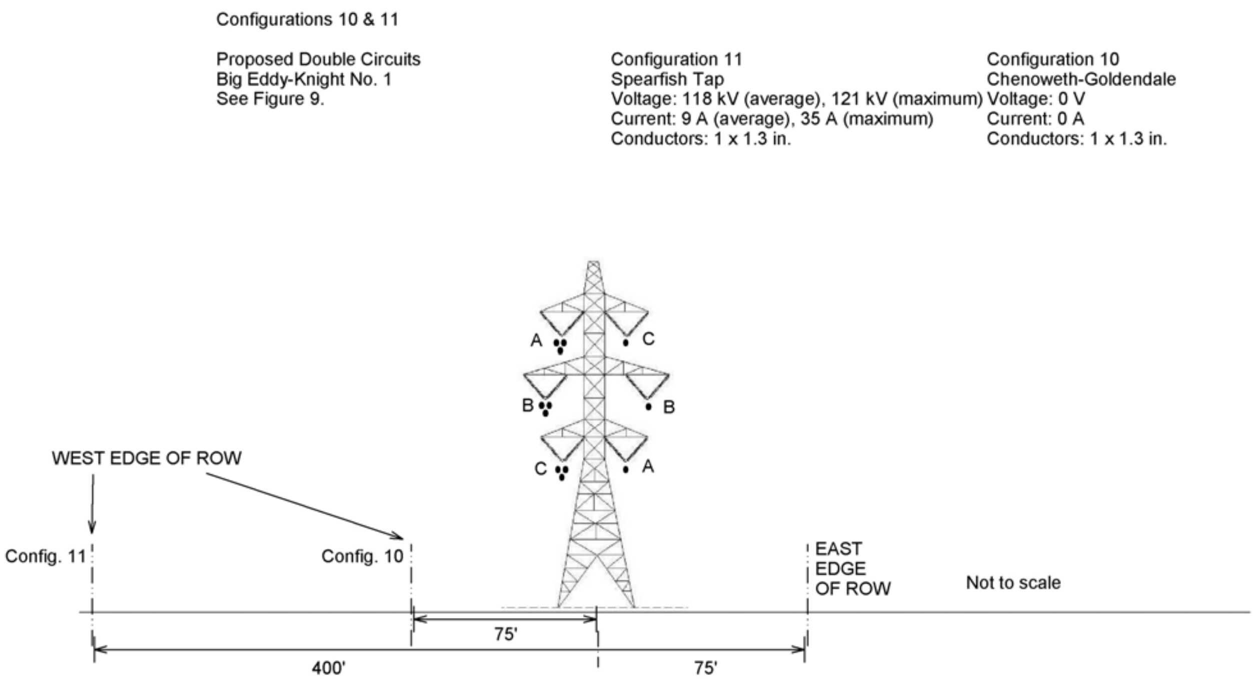


Figure 12: Double-circuit Configuration 12 for the proposed Big Eddy – Knight 500-kV line. Configurations are described in Tables 1 and 2.

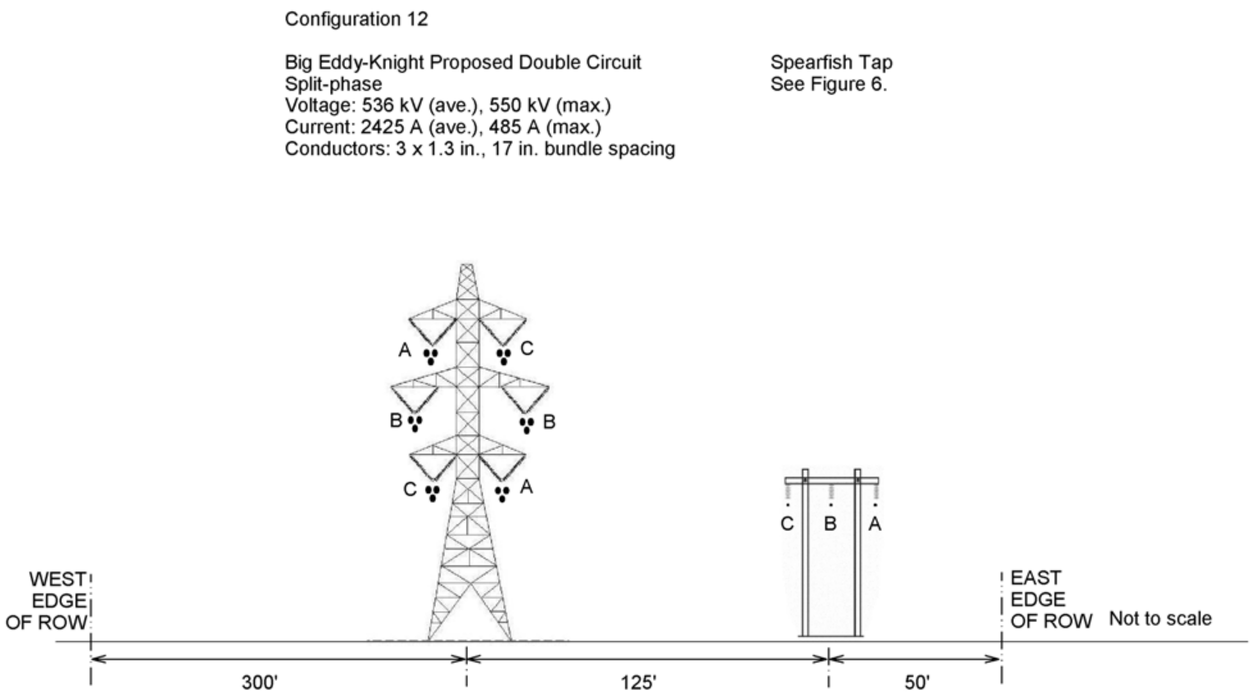


Figure 13: Electric-field profiles for single-circuit Configuration 1 of the proposed Big Eddy – Knight 500-kV line. Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

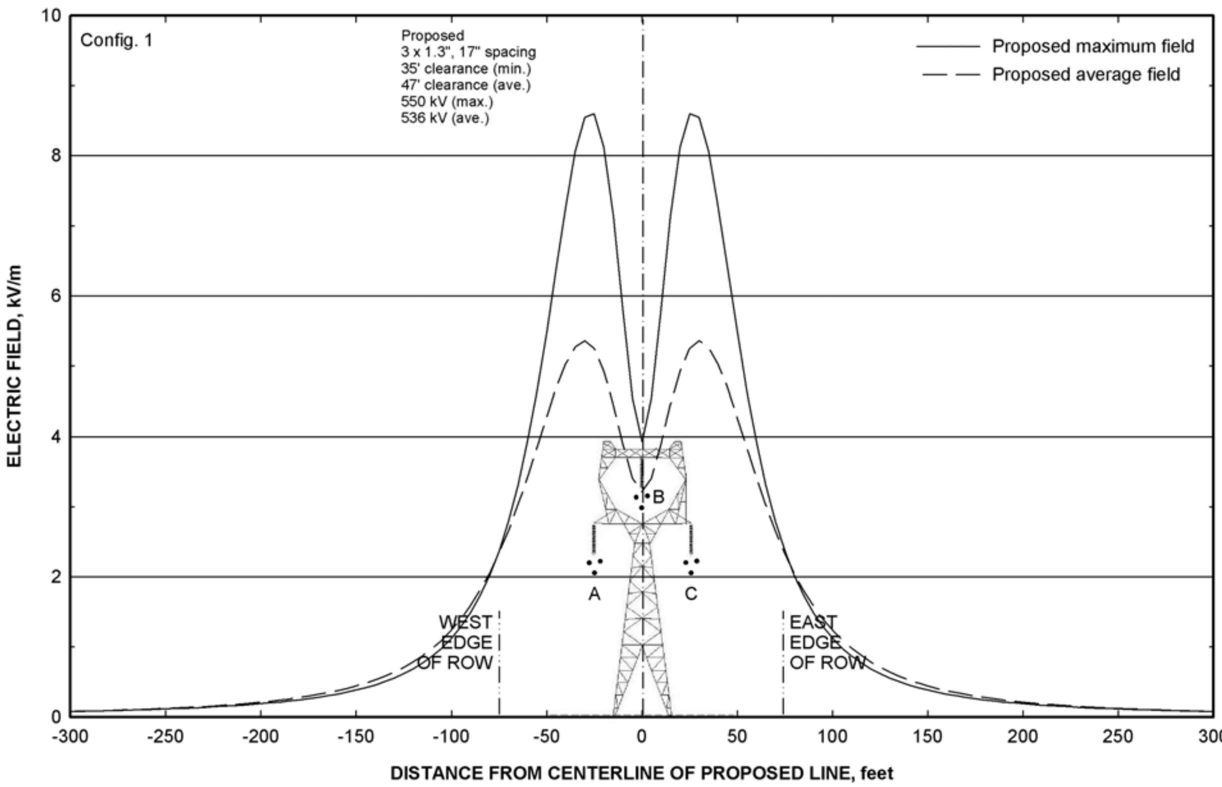


Figure 14: Electric-field profiles for single-circuit Configuration 2 of the proposed Big Eddy – Knight 500-kV line. Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

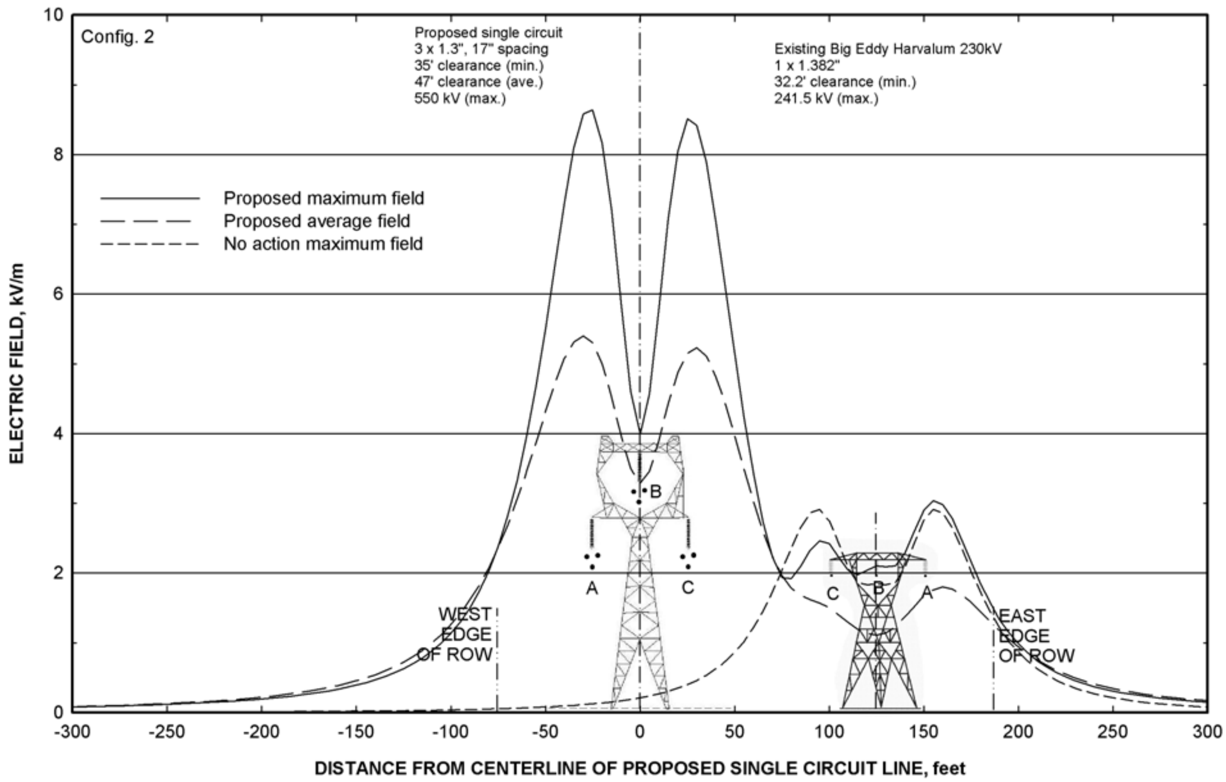


Figure 15: Electric-field profiles for single-circuit Configuration 3 of the proposed Big Eddy – Knight 500-kV line. Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

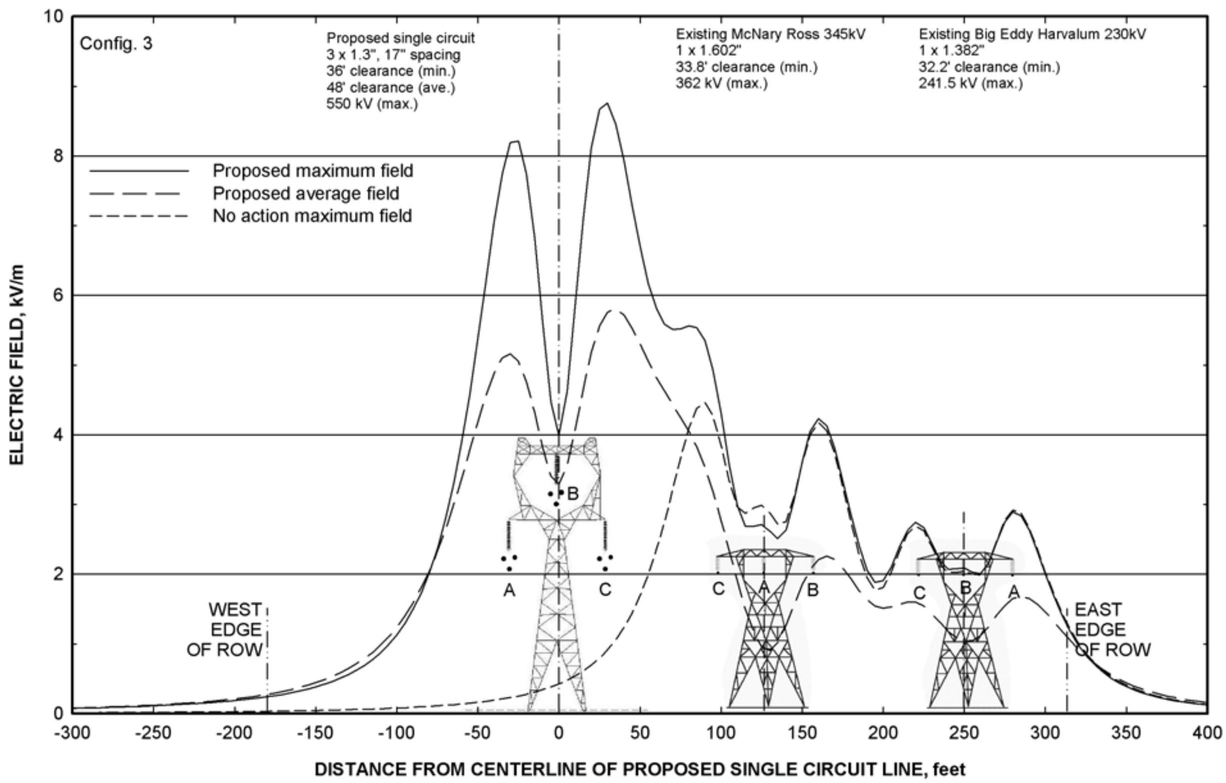


Figure 16: Electric-field profiles for single-circuit Configuration 4 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

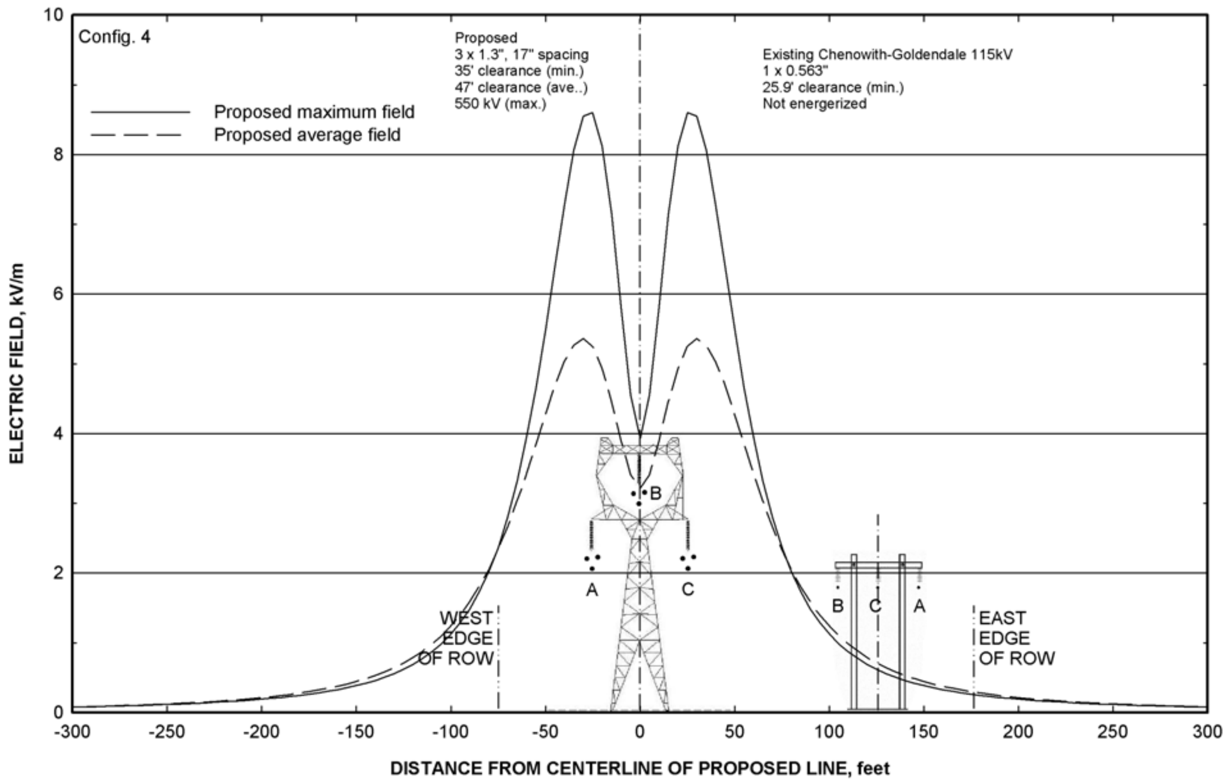


Figure 17: Electric-field profiles for single-circuit Configuration 5 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

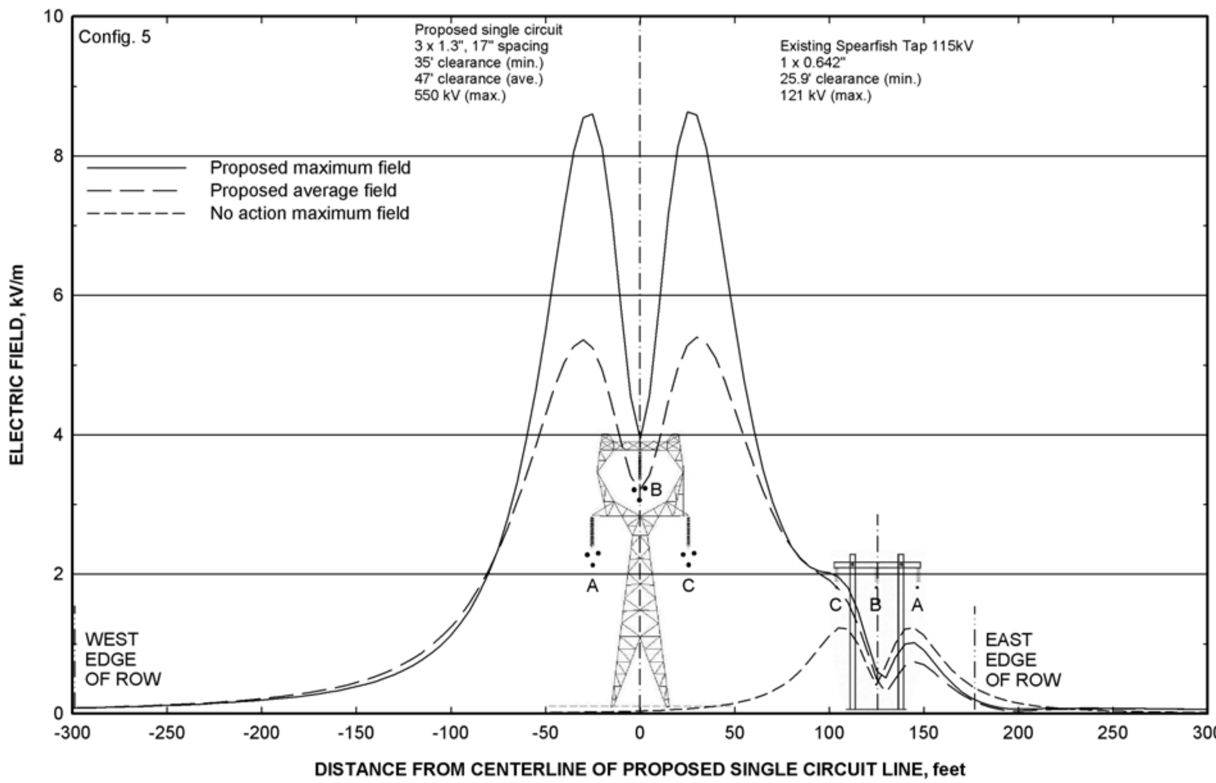


Figure 18: Electric-field profiles for single-circuit Configuration 6 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

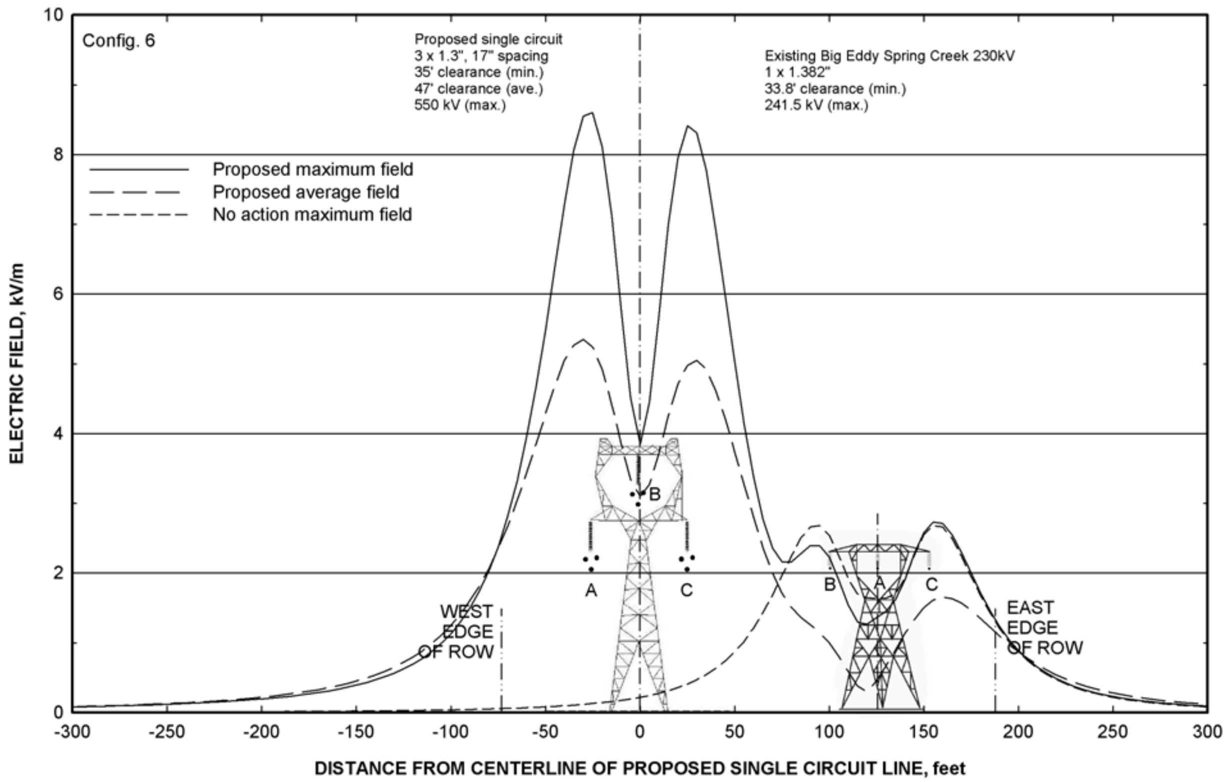


Figure 19: Electric-field profiles for double-circuit Configurations 7 and 7A of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

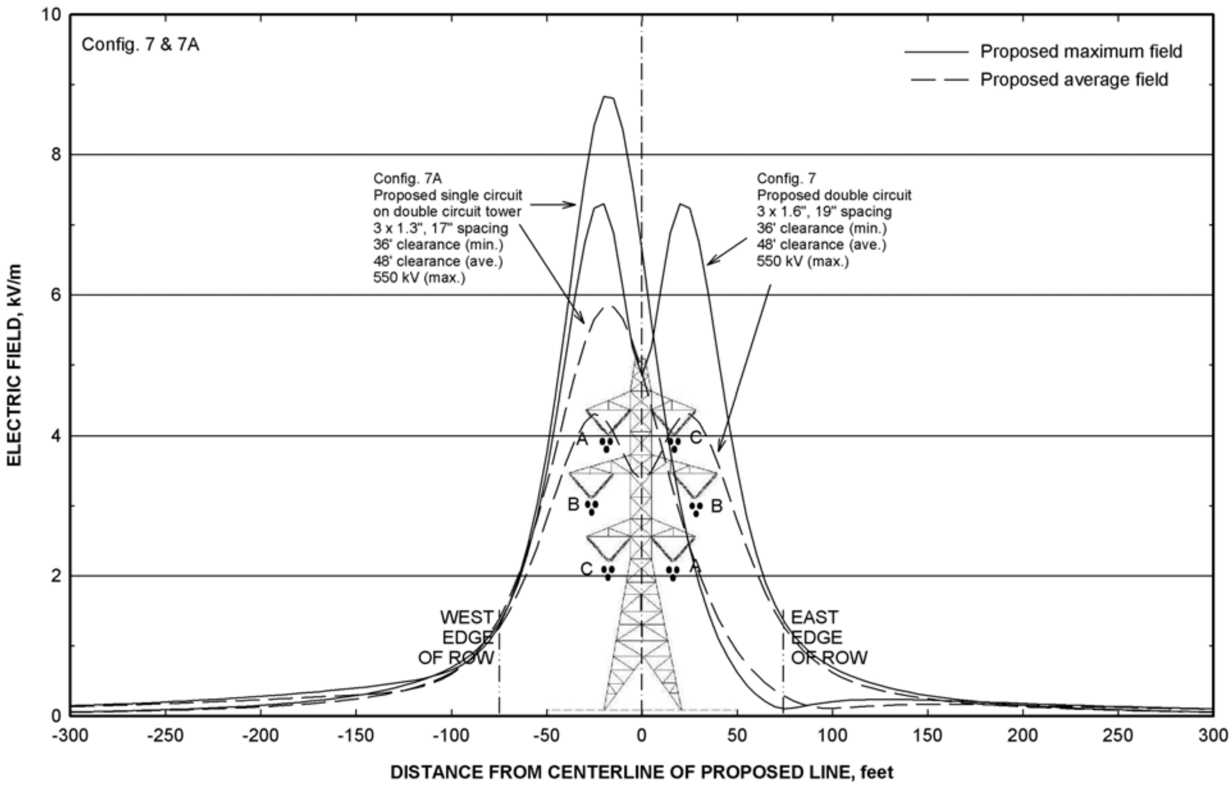


Figure 20: **Electric-field profiles for double-circuit Configuration 8 of the proposed Big Eddy – Knight 500-kV line.** Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

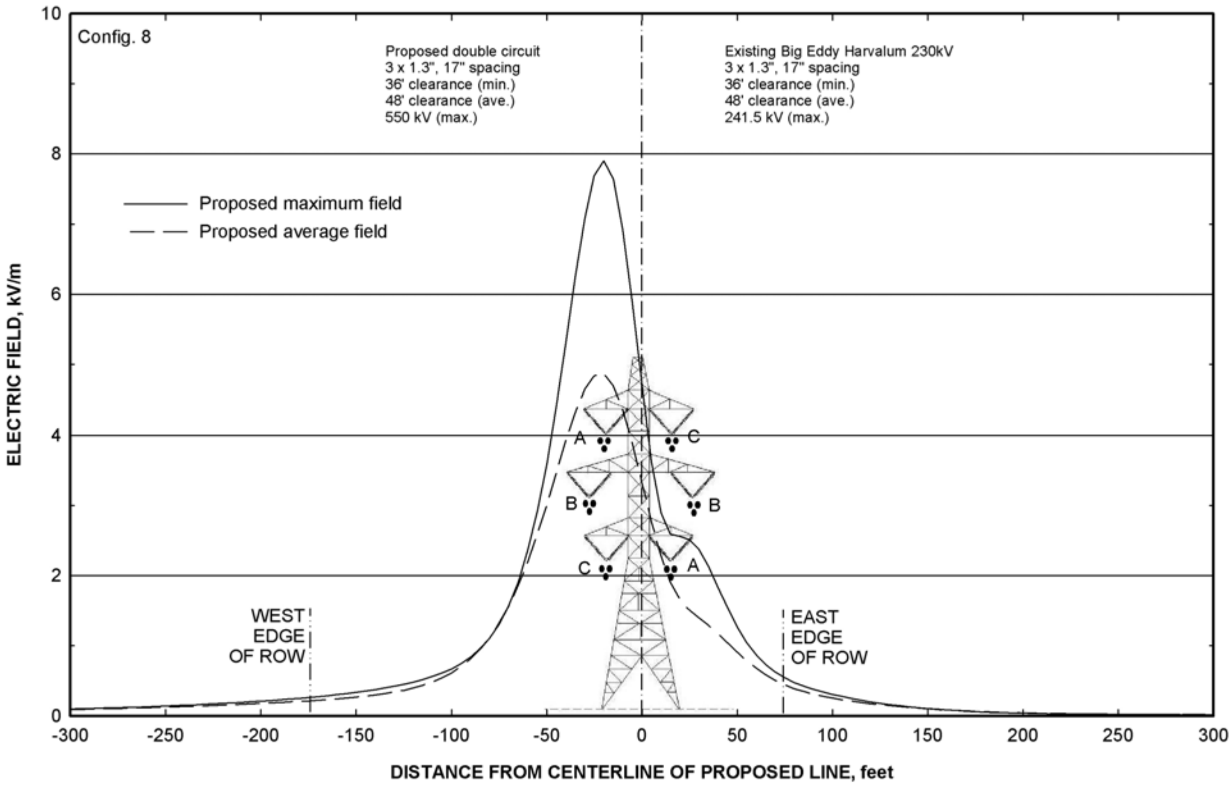


Figure 21: Electric-field profiles for double-circuit Configuration 9 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

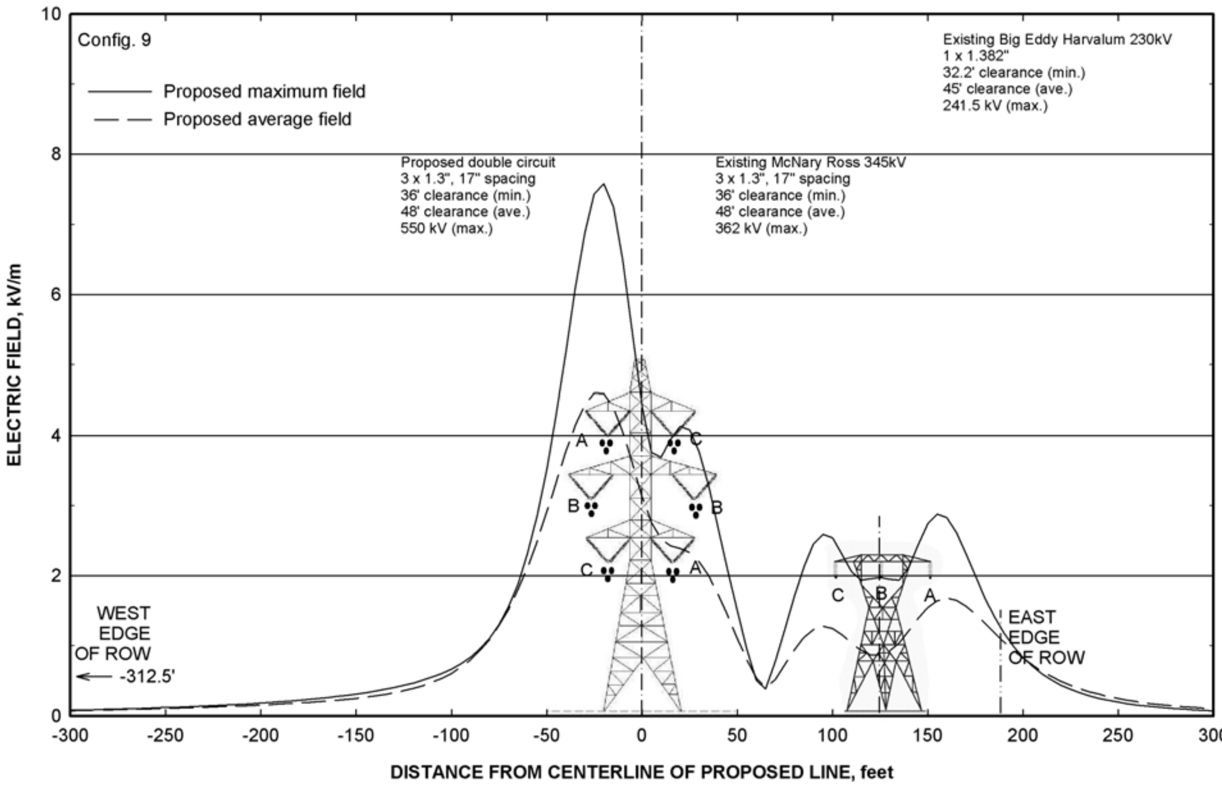


Figure 22: Electric-field profiles for double-circuit Configuration 10 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

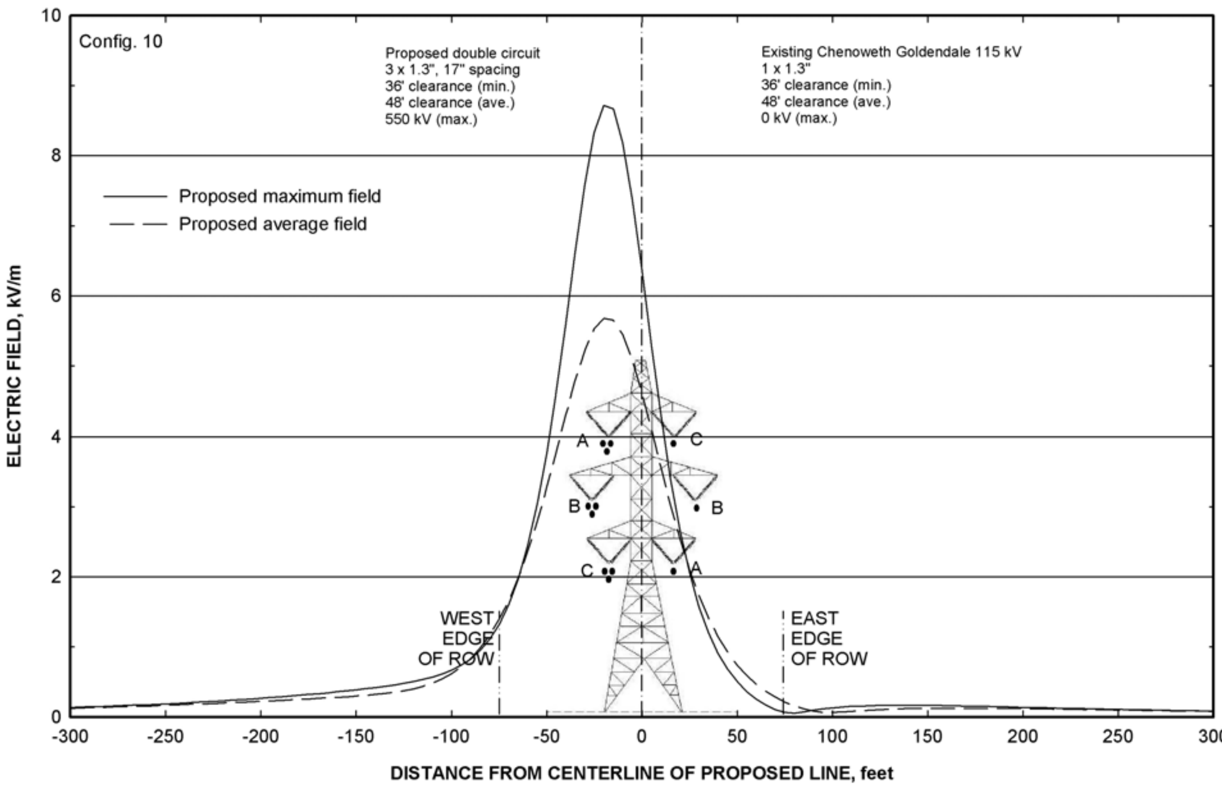


Figure 23: Electric-field profiles for double-circuit Configuration 11 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

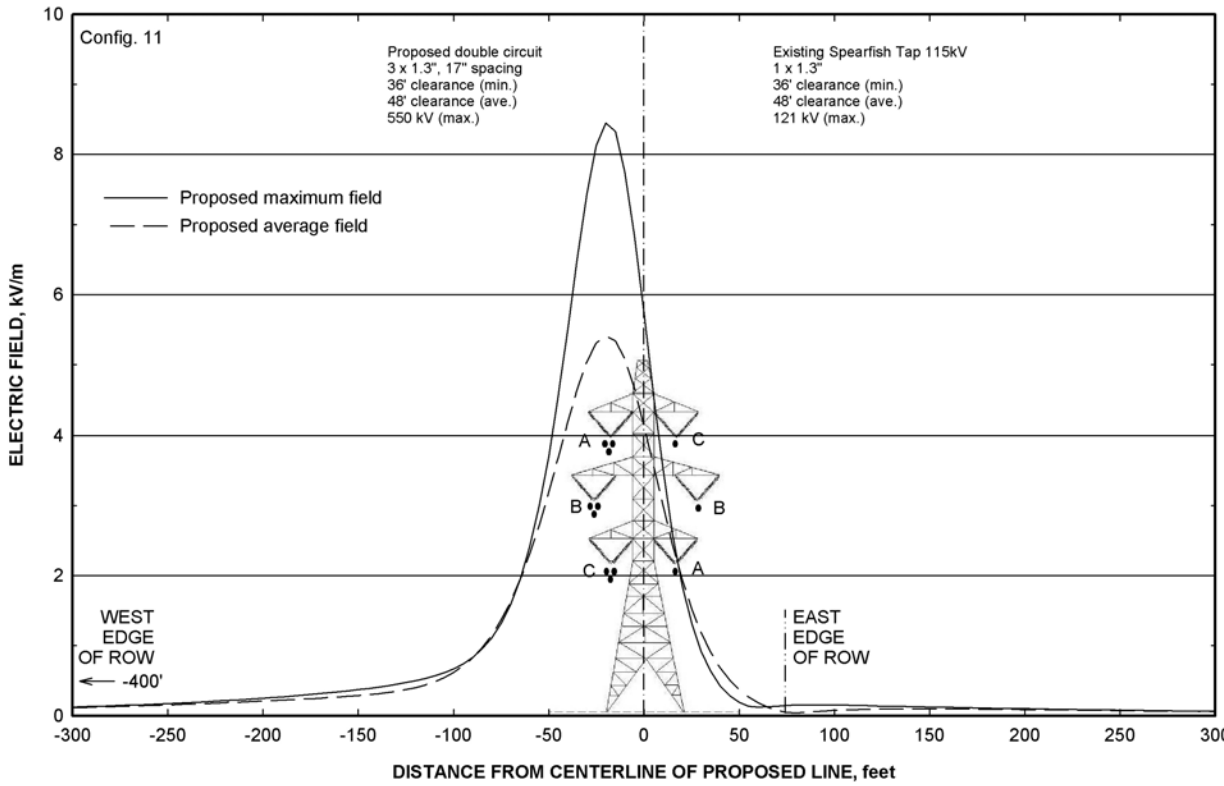


Figure 24: Electric-field profiles for double-circuit Configuration 12 of the proposed Big Eddy – Knight 500-kV line: Fields for maximum voltage with minimum and average clearances are shown. Configurations are described in Tables 1 and 2.

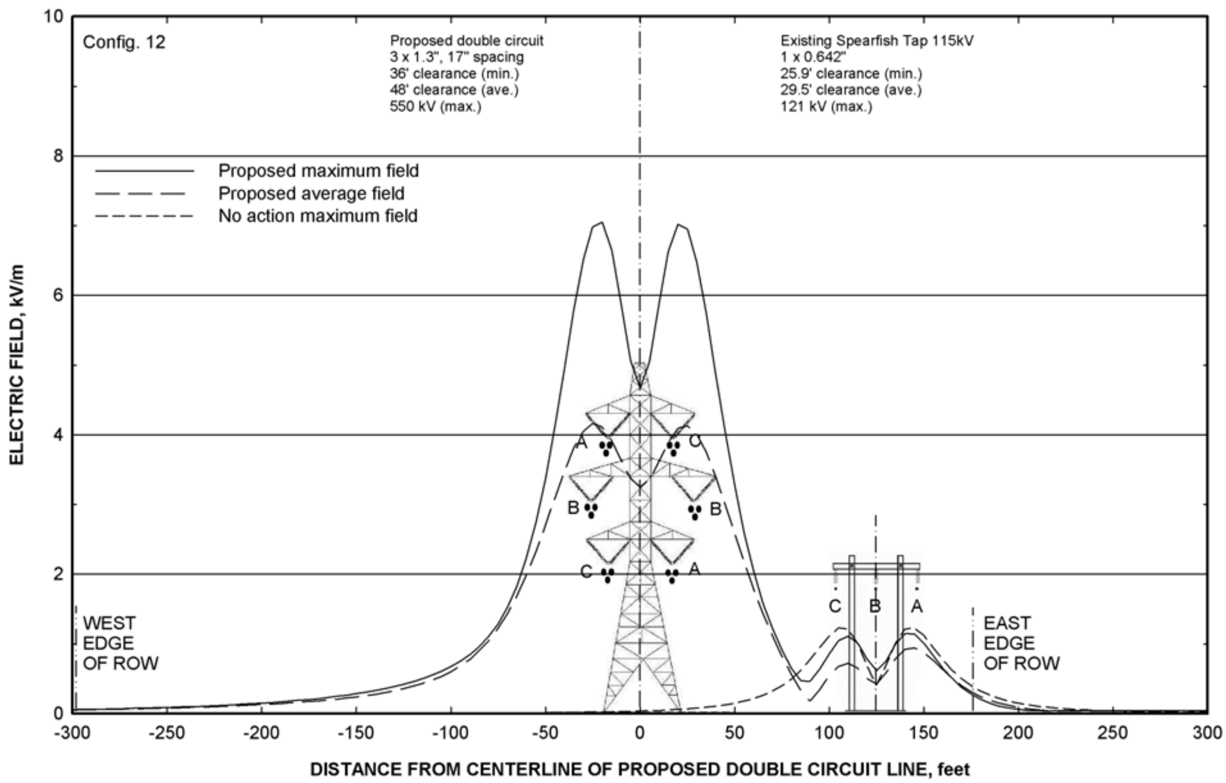


Figure 25: Magnetic-field profiles for single-circuit Configuration 1 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

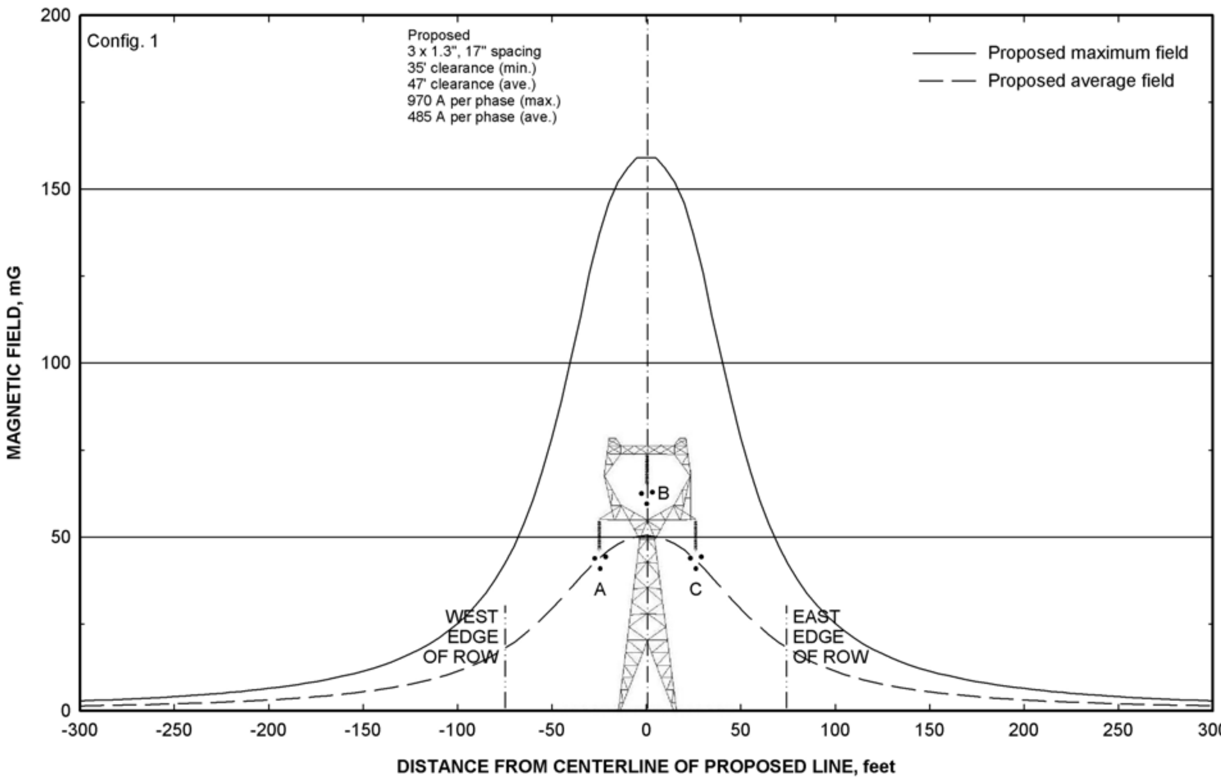


Figure 26: **Magnetic-field profiles for single-circuit Configuration 2 of the proposed Big Eddy – Knight 500-kV line.** Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

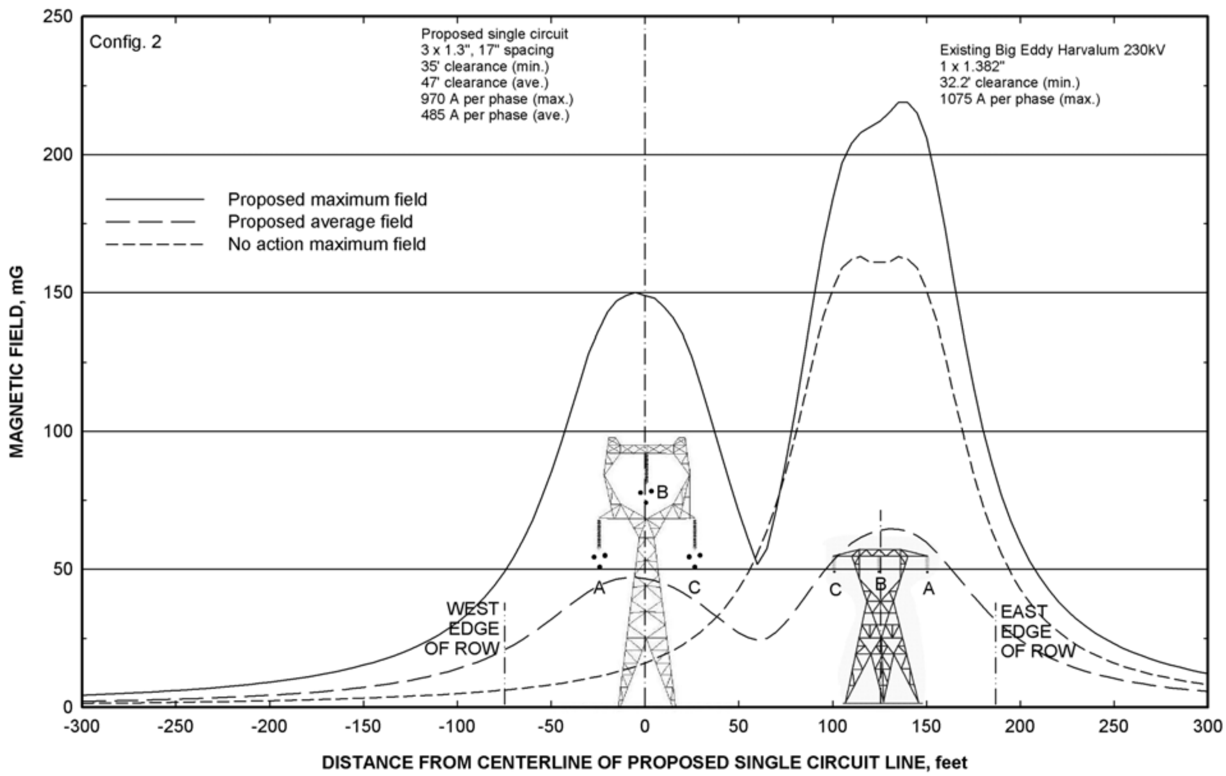


Figure 27: Magnetic-field profiles for single-circuit Configuration 3 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

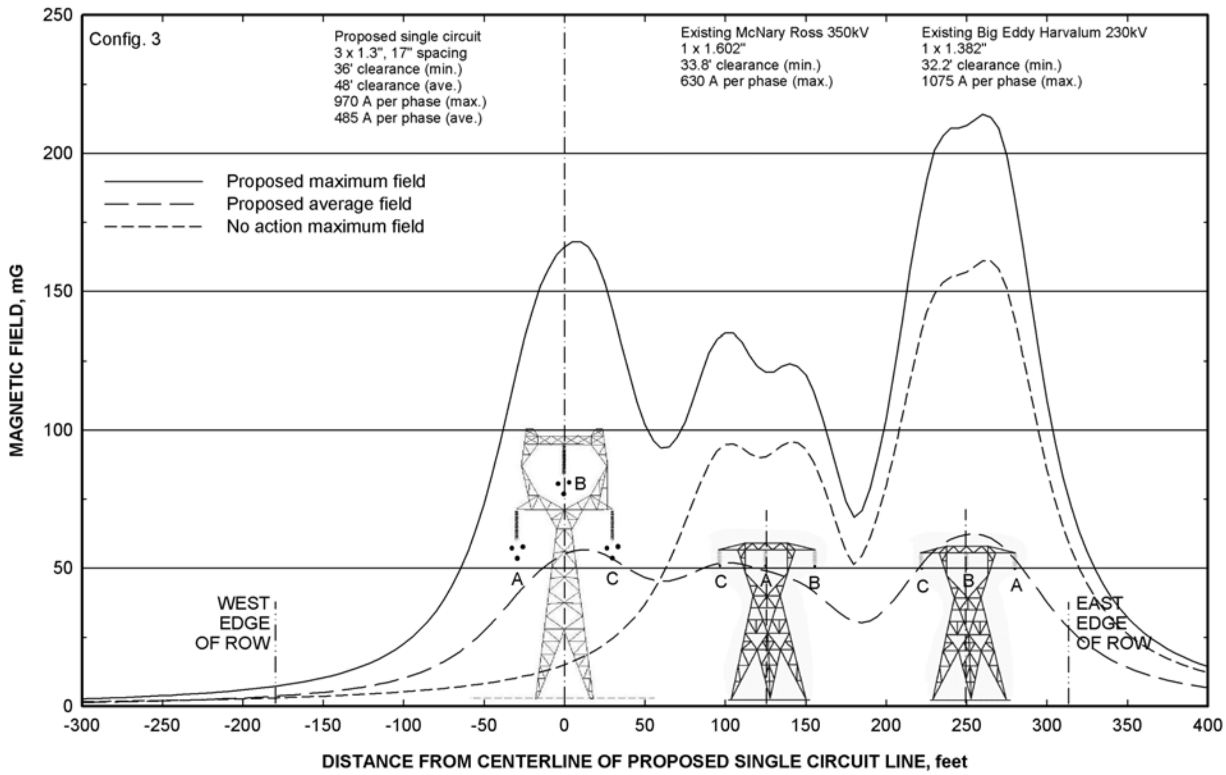


Figure 28: Magnetic-field profiles for single-circuit Configuration 4 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

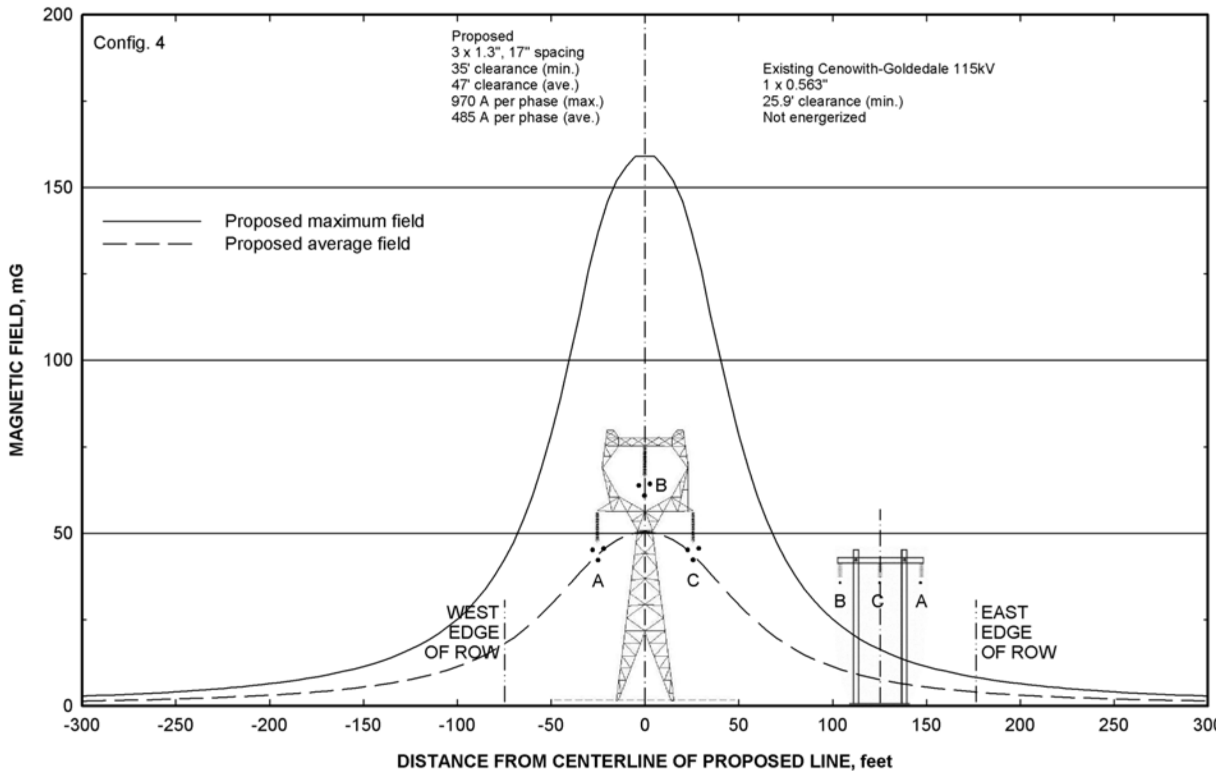


Figure 29: Magnetic-field profiles for single-circuit Configuration 5 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

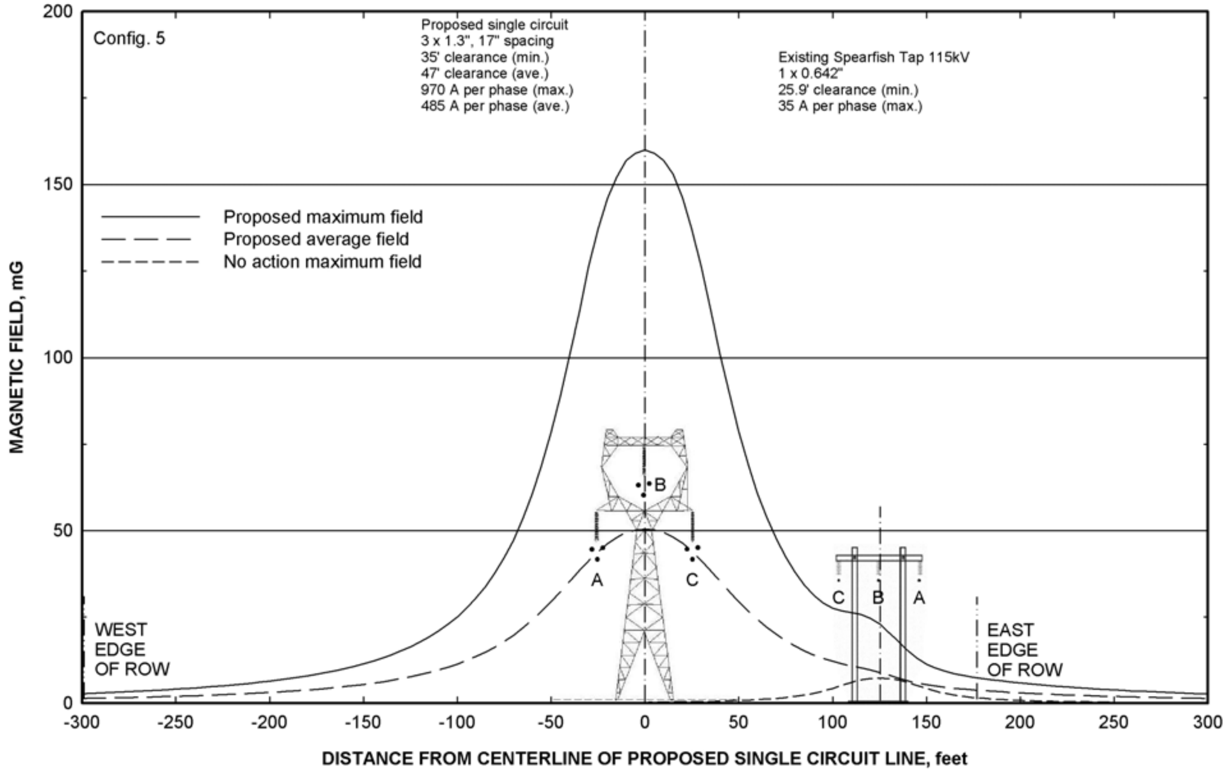


Figure 30: Magnetic-field profiles for single-circuit Configuration 6 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

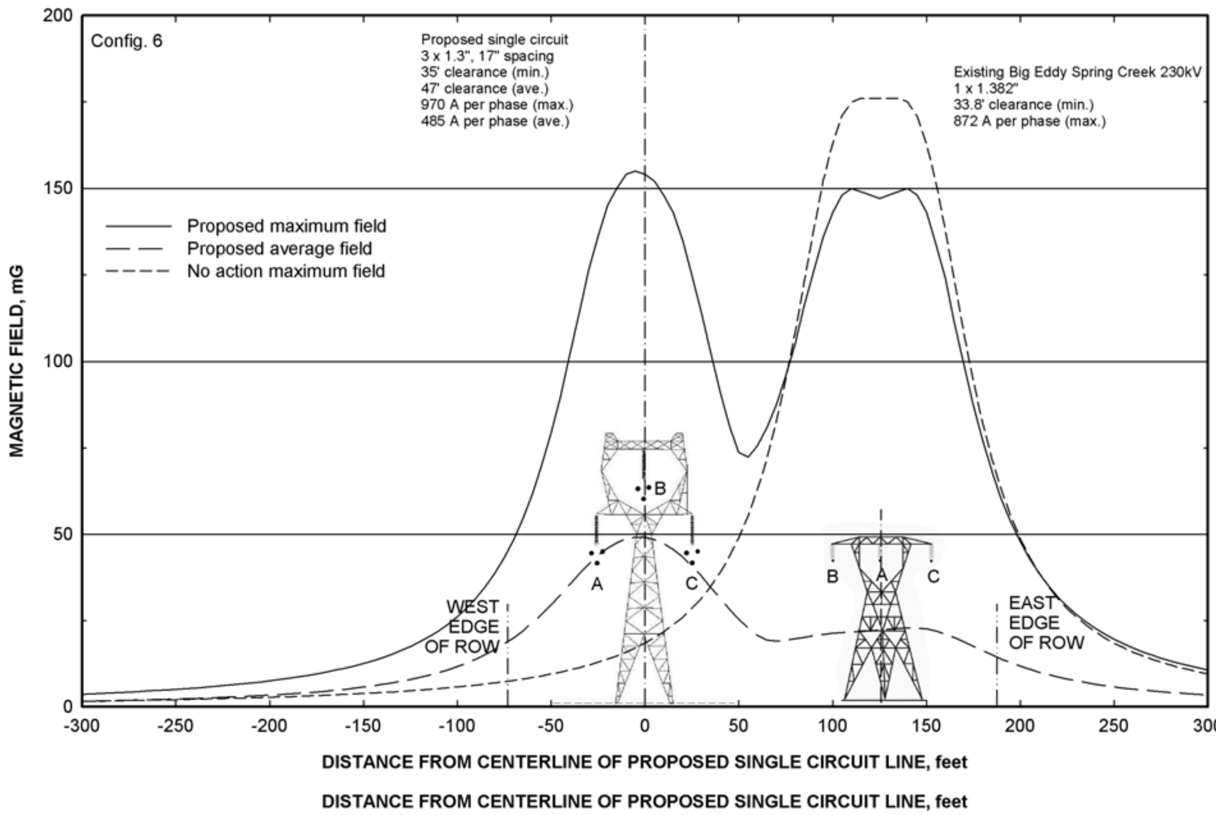


Figure 31: Magnetic-field profiles for double-circuit Configurations 7 and 7A of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

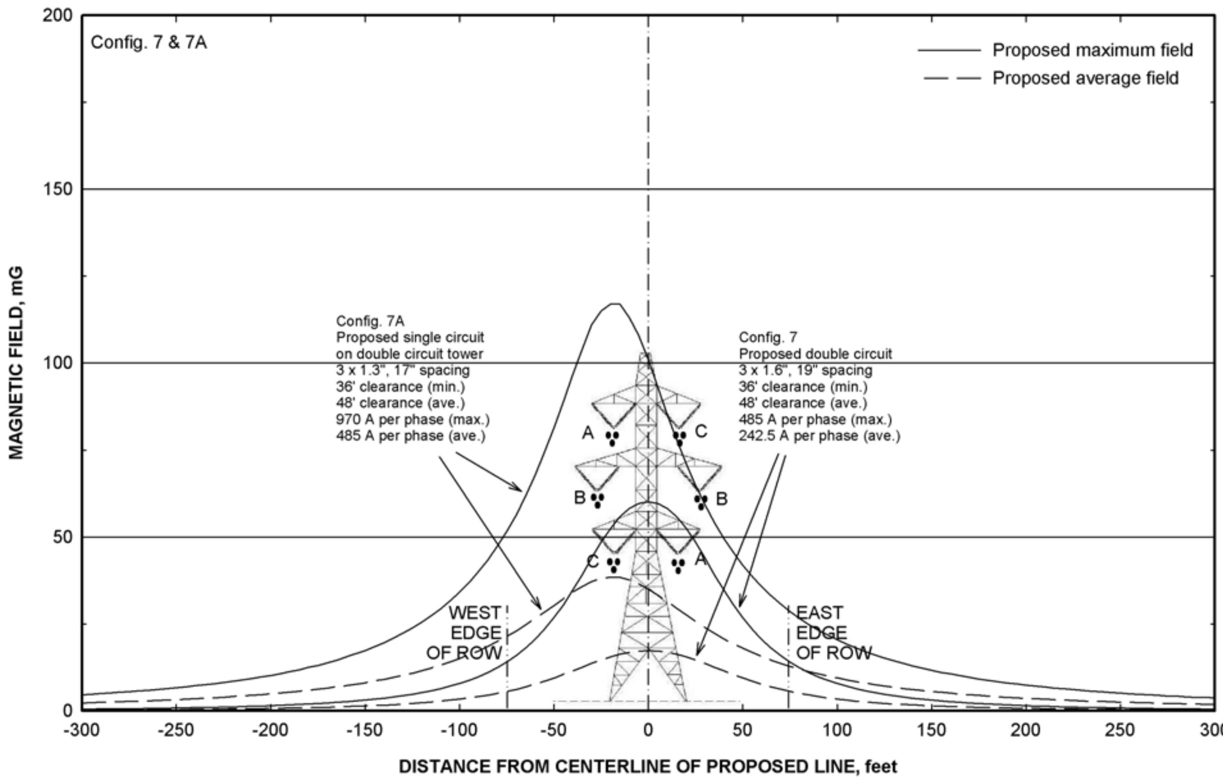


Figure 32: Magnetic-field profiles for double-circuit Configuration 8 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

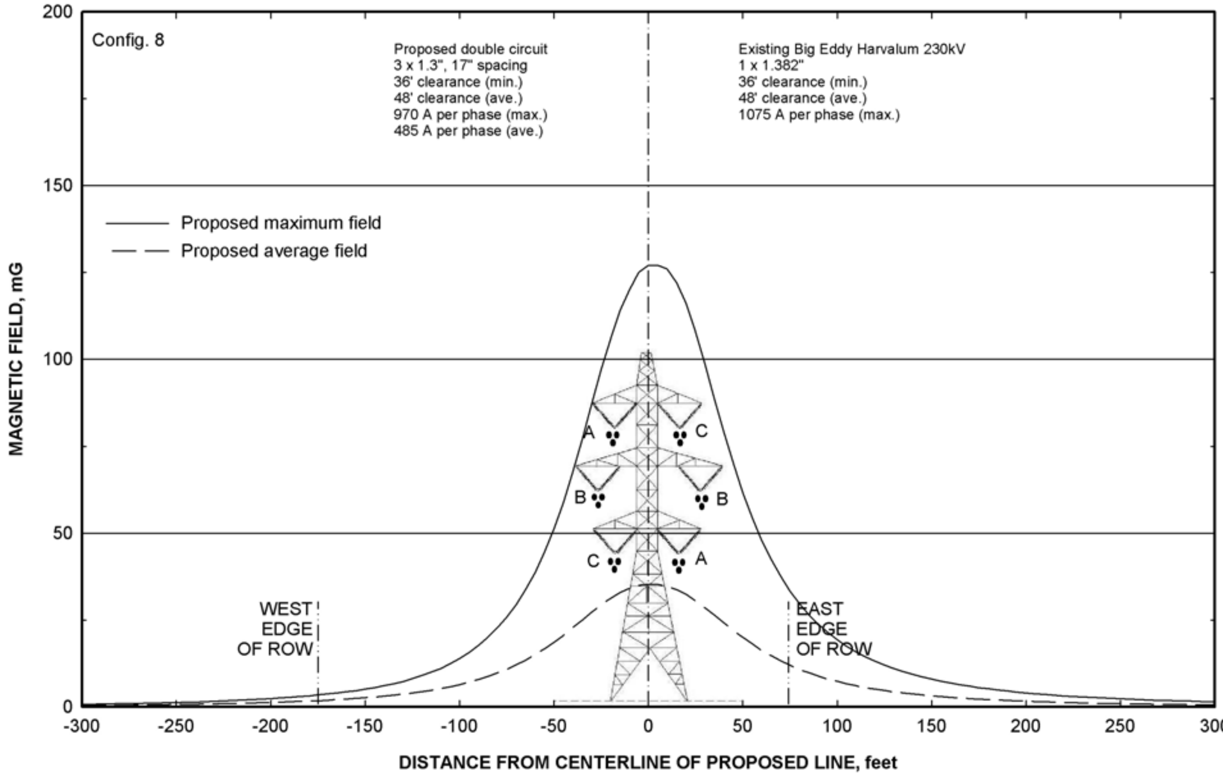


Figure 33: Magnetic-field profiles for double-circuit Configuration 9 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

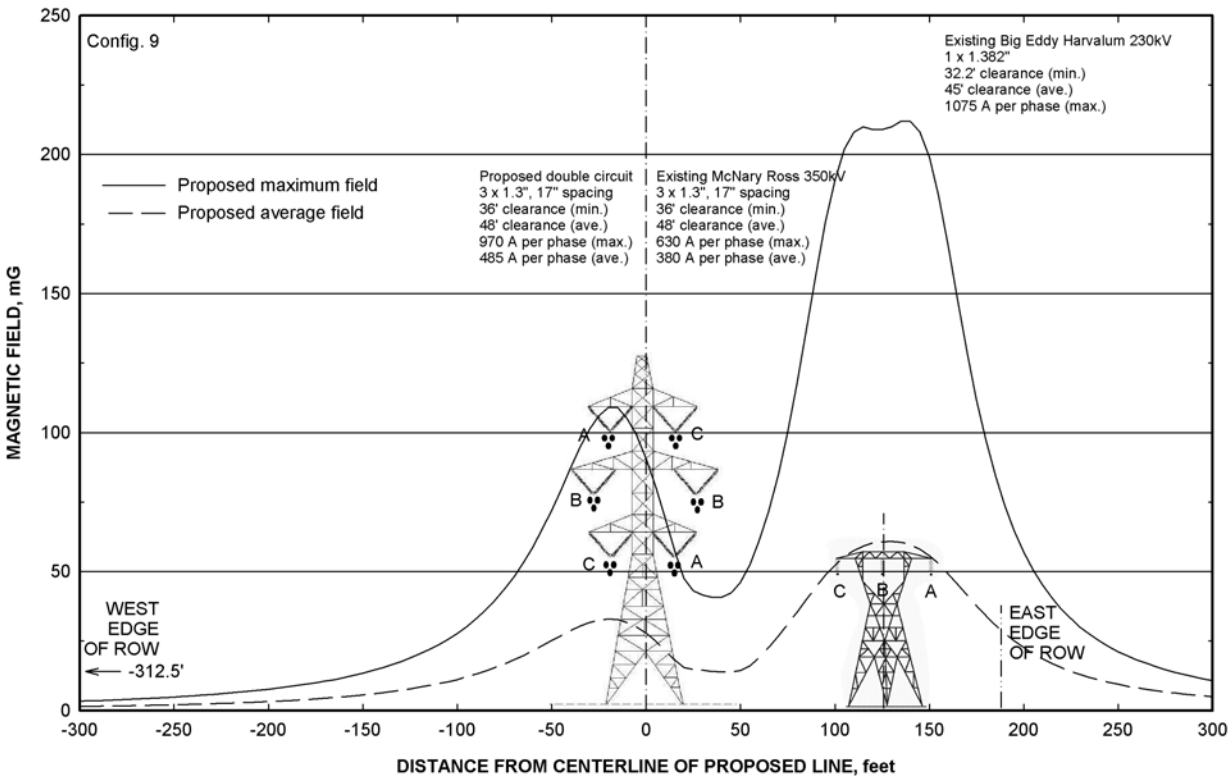


Figure 34: Magnetic-field profiles for double-circuit Configuration 10 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

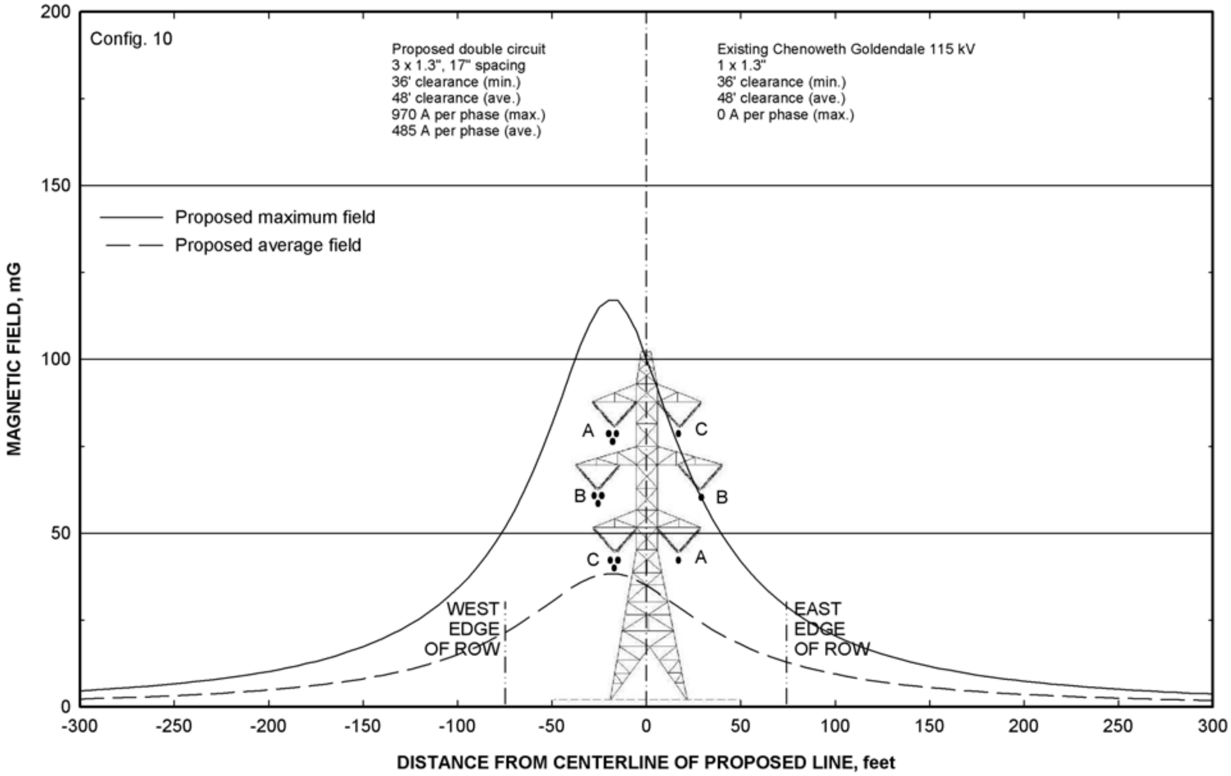


Figure 35: Magnetic-field profiles for double-circuit Configuration 11 of the proposed Big Eddy – Knight 500-kV line. Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

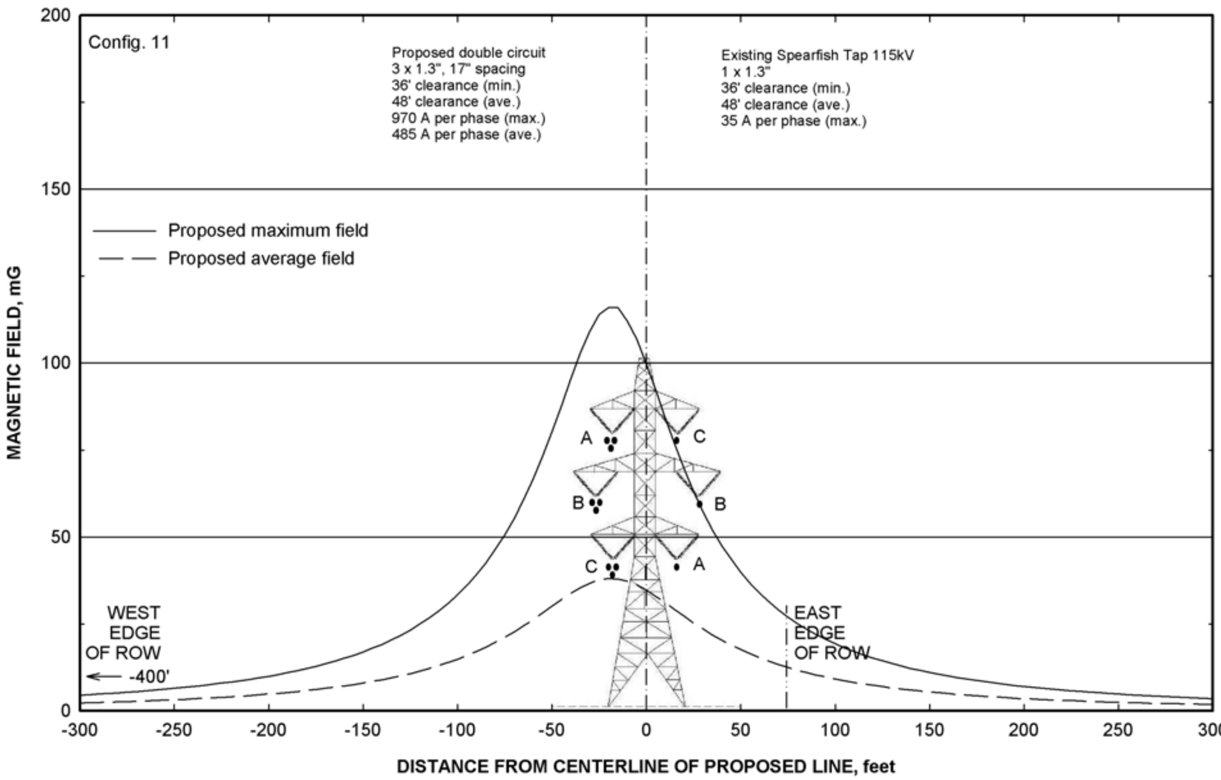


Figure 36: **Magnetic-field profiles for double-circuit Configuration 12 of the proposed Big Eddy – Knight 500-kV line.** Fields computed for maximum current with minimum clearance and for average current with average clearance are shown. Configurations are described in Tables 1 and 2.

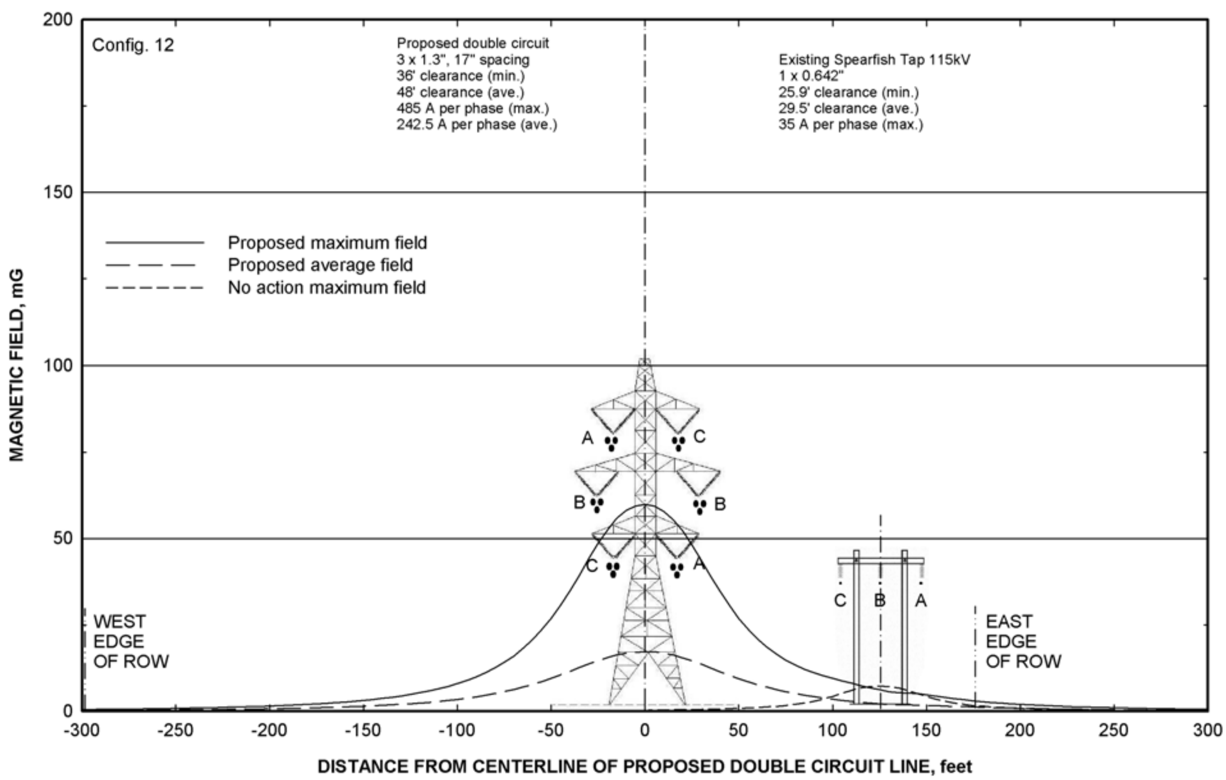
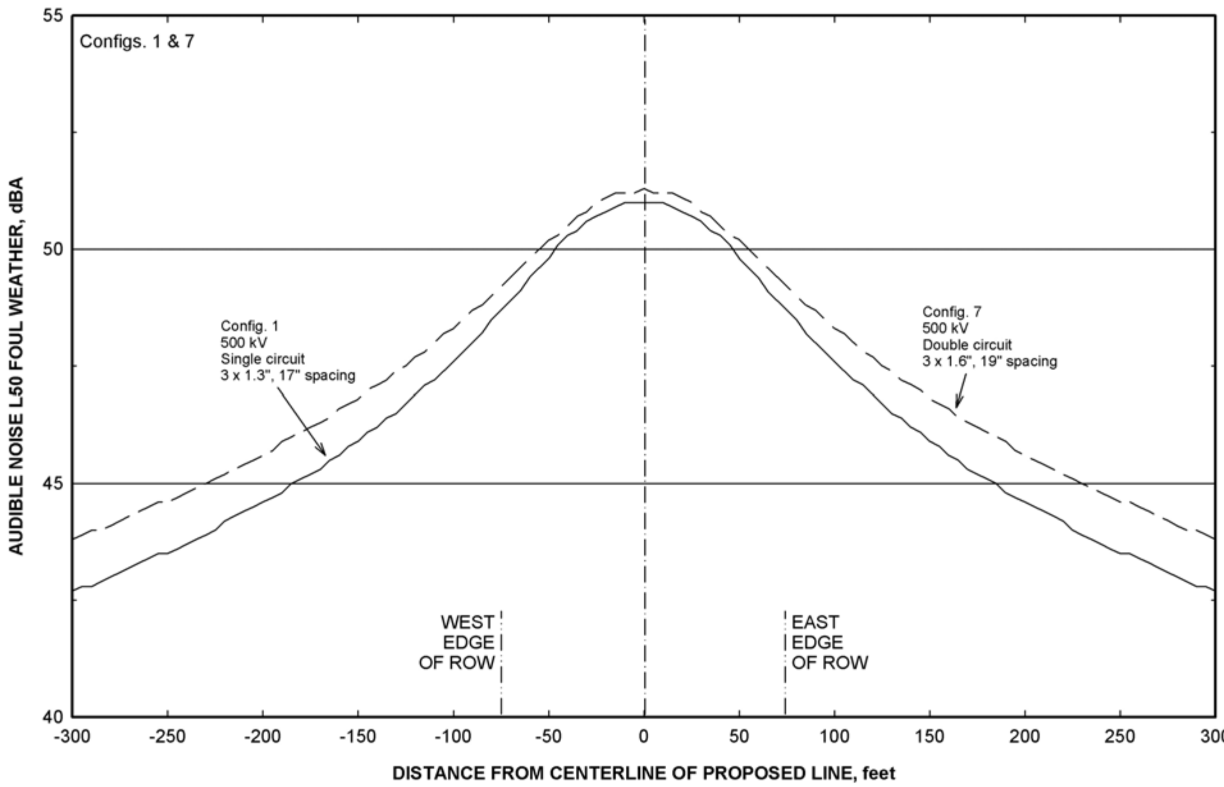


Figure 37: Audible Noise Profile for Proposed Big Eddy – Knight 500-kV Transmission Line Configurations 1 and 7 with No Adjacent Transmission Lines. Calculations performed for average voltage and average height. Configurations are described in Tables 1 and 2.



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Appendix F

Electric and Magnetic Fields Research on Health Effects

Exponent®

Health Sciences

Research on Extremely Low Frequency Electric and Magnetic Fields and Health

Research on Extremely Low Frequency Electric and Magnetic Fields and Health

Prepared for:

The Bonneville Power Administration

Prepared by:

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420 Lexington Avenue, Suite 1740
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January 2011

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Acronyms and Abbreviations

AC	Alternating current
ACGIH	American Conference of Governmental Industrial Hygienists
ALL	Acute lymphoblastic leukemia
AML	Acute myeloid leukemia
BNU	n-butylnitrosourea
BPA	Bonneville Power Administration
CI	Confidence interval
DMBA	7,12-dimethylbenz[a]anthracene
G	Gauss
ELF	Extremely low frequency
EMF	Electric and magnetic fields
EMI	Electromagnetic interference
ENU	ethylnitrosourea
EPRI	Electric Power Research Institute
HR	Hazard ratio
Hz	Hertz
IARC	International Agency for Research on Cancer
ICD	Implanted cardiac device
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IGF-1	Insulin-like growth factor 1
m	Meter
mG	Milligauss
MPD	Myeloproliferative disorder
NIEHS	National Institute of Environmental Health Sciences
NHL	Non-Hodgkin’s lymphoma
NK	Natural killer
OR	Odds Ratio
ROW	Right-of-way
RR	Relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks

SES	Socioeconomic status
SSI	Swedish Radiation Protection Authority
TWA	Time-weighted average
WHO	World Health Organization

Introduction

Electrical objects produce two field types—electric fields and magnetic fields. The term field is used to describe the way an object influences its surrounding area. A temperature field, for example, surrounds a warm object, such as a space heater or campfire. Electric and magnetic fields (EMF) surround any object that generates, transmits, or uses electricity, including appliances, electrical wiring, office equipment, generators, and any other electrical devices. These fields are invisible, and they cannot be felt or heard.

Electric fields occur as a result of the electric potential (i.e., voltage) on these objects, and **magnetic fields** occur as a result of current flow through these objects.[1] Just like a temperature field, both electric fields and magnetic fields can be measured, and their levels depend on the properties of the source of the field (e.g., voltage, current, and configuration) and the distance from the source of the field, among other things.

Both electric fields and magnetic fields decrease rapidly with distance from the source, such that a magnetic field of 300 milligauss (mG) within 6 inches of a vacuum cleaner diminishes to 1 mG at 4 feet (NIEHS, 2002). This is similar to the way that the heat generated by a space heater or a campfire lessens as a person moves farther away from it. Although ordinary objects do not block magnetic fields, objects such as trees and buildings easily block electric fields.

The electrical power system in the United States produces alternating current (AC) EMF that changes direction and intensity 60 times per second—i.e., a frequency of 60 Hertz (Hz).[2] This frequency is in the extremely low frequency (ELF) range of the electromagnetic spectrum. Electricity produced by generating stations flows as 60-Hz current through transmission and distribution lines and provides power to the many appliances and electrical devices that we use in our homes, schools, and workplaces. Magnetic fields are found throughout our environment

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[1] The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m); 1 kilovolt per meter is equal to 1,000 V/m. The strength of magnetic fields is expressed as magnetic flux density in units called gauss (G), or in milligauss (mG), where 1 G is equal to 1,000 mG.

[2] Europe's electrical system produces 50-Hz EMF. Since 50-Hz EMF is also in the ELF range, research on 50-Hz EMF is relevant to questions on 60-Hz EMF.

because electricity is needed for so many things in our daily lives, from lighting, heating, and cooling our homes to powering our refrigerators and computers.

Questions about whether these ubiquitous exposures could affect our health began to be raised in the 1970s. Since then, researchers from many different scientific disciplines have investigated this question, and hundreds of studies have been conducted. The public frequently expresses concern about ELF EMF, particularly in the context of new transmission lines. The intent of this report is to describe what this large body of research has told us about ELF EMF and the precautions, if any, recommended by public health agencies

In July 2007, Exponent provided a report to the Bonneville Power Administration (BPA) that described the conclusions of a comprehensive, weight-of-evidence review published by the World Health Organization (WHO) in June 2007; the portion of Exponent's 2007 report that describes the conclusions of the WHO report is attached as Appendix 1 for reference.[3] The WHO review still represents the most recent comprehensive review of the literature by a multidisciplinary scientific panel. The WHO organized a multidisciplinary Task Group of 21 scientists from around the world to draft a Monograph that summarized the research and provided conclusions as to whether there are risks associated with ELF EMF and, if so, at what exposure levels (WHO, 2007a). The report concluded that the only established effects of ELF EMF exposure are acute neurostimulatory effects (i.e., shock-like effects) that occur at very high levels of exposure; these exposure levels are not encountered in ordinary residential or occupational environments. The fact sheet from the WHO review is attached as Appendix 2 (WHO, 2007b) and can be found at http://www.who.int/mediacentre/factsheets/fs322/en/print.html.

Research is a constantly evolving process. Despite the volume of research available on ELF EMF and the large reduction in uncertainty that research has achieved over the years, scientists continue research in this area with the goal of clarifying and replicating old findings and testing new hypotheses. New studies on ELF EMF are published every month. While the WHO review provides a comprehensive and relatively up-to-date summary of the status of research on

[3] Exponent. Assessment of Research Regarding EMF and Health and Environmental Effects. Olympic Peninsula Reinforcement Transmission Line Project. July 2007.

this topic, new research has the potential to modify or strengthen conclusions. The BPA has, therefore, requested an update on the research with regard to ELF EMF and health. This report provides an overview of the cumulative body of research published since the WHO review (January 1, 2006-October 1, 2010) and provides the reader with perspective on if, and how, recent research changes the WHO's conclusions.

A summary of the methods scientists use to conduct studies and make decisions about health risks is included in Section 1 as a framework for understanding later discussions. In Section 2, the discussion of new research is broadly grouped by health outcome—cancer, reproductive effects, developmental effects, and neurodegenerative diseases. This discussion summarizes two types of research—epidemiology studies and experimental studies in animals (*in vivo*)—within each health outcome category. Experimental studies in cells and tissues (*in vitro*) of carcinogenesis are discussed briefly in Section 2. Other areas of research not reviewed by WHO are discussed in Section 3, including the possible effects of ELF EMF on the functioning of pacemakers, on flora and fauna, and on marine life. Finally, guidelines for ELF EMF exposure developed by scientific organizations to prevent against established health effects are summarized in Section 4.

1 Scientific Methods

Weight-of-evidence review

Most of what we encounter in our every day environment has no effect on our health. Other exposures, however, may affect our health in either a beneficial or a harmful way, including such ubiquitous interactions with our environment as the air we breathe, the water we drink, and our exposure to sunlight. Much time and money is spent by scientists around the world designing, conducting, and publishing research to determine what factors may affect our health, including environmental exposures (like ELF EMF), infectious agents, and our genetics. The process for arriving at a conclusion about whether there is a health risk associated with any of these factors often is not straightforward or definitive. Rather, it is a long process that requires repeated hypothesis generation and testing.

The process begins when a scientist forms a hypothesis and conducts a study to test that hypothesis. Studies are conducted by scientists at academic universities and scientific institutions around the world. Once a study is complete, the authors submit it to a scientific journal for publication, where it undergoes peer review prior to publication. The evidence to evaluate any health risk includes all of the relevant studies published in the peer-reviewed literature.

These individual research studies can be thought of as puzzle pieces. When all of the research is placed together, we have some understanding of possible health effects; no conclusions can be reached, however, by looking at only one study, just as no picture can be formed with just one puzzle piece. Each study provides a different piece of information to the puzzle because of its unique strengths and weaknesses—if the study used valid methods and had no obvious sources of bias, it may provide a wealth of information or, if the study was not well conducted, it may add little or no information to our understanding.

This process of evaluating all of the research together to determine whether something poses either a health benefit or health risk is referred to as a weight-of-evidence review. There are three types of research that are considered in a weight-of-evidence review: epidemiology studies of people, experimental studies in animals (*in vivo* research), and experimental studies in cells and tissues (*in vitro* research). It is important to consider all three types of research together because they provide complementary information:

- Epidemiology studies collect observational data about human populations in their every day environments to determine whether there are patterns between exposures and diseases. These studies measure statistical associations to evaluate whether a disease and exposure occur together more often than expected. An important limitation of these studies is that, if an association is measured, they do not tell scientists how the exposure is truly related to the disease. That conclusion can only be reached by considering the entire body of research. Most of the studies evaluating ELF EMF examine whether people with a particular disease have had higher estimates of ELF EMF exposure in the past compared to people without that disease.

- Experimental studies in which scientists expose animals (*in vivo*) to varying levels of electric or magnetic fields (some as high as 50,000 mG) are an important source of information. These studies compare the amount of disease they observe in exposed animals to the amount of disease they observe in animals that have not been exposed. The strength of animal studies is that scientists are able to control all aspects of the animals' lives to minimize the potential confounding effects of factors other than the exposure of interest. The most valuable experimental studies for understanding disease are those in which the animals receive life-long exposures.

- Experimental studies *in vitro* involve the exposure of isolated cells and tissues to the agent of interest, in this case ELF EMF, and compare the characteristics of exposed and unexposed samples to look for differences that are indicative of a disease process. These studies are limited because what occurs to exposed cells or tissues outside of a human body may not be the same as what occurs to cells and tissues inside a body.

The weight-of-evidence approach is the standard process used worldwide by scientists, scientific organizations, and regulatory agencies to assess the possible health benefits and risks associated with exposures. A weight-of-evidence review begins with a systematic review of published, peer-reviewed epidemiology, *in vivo*, and *in vitro* research. The weight that individual studies provide to the overall conclusions is not equal—studies vary widely in terms of the sophistication and validity of their methods. Therefore, each study from each discipline must be evaluated critically and assigned a weight. A final conclusion is then reached by considering the cumulative body of research, giving more weight to studies of higher quality (Figure 1).

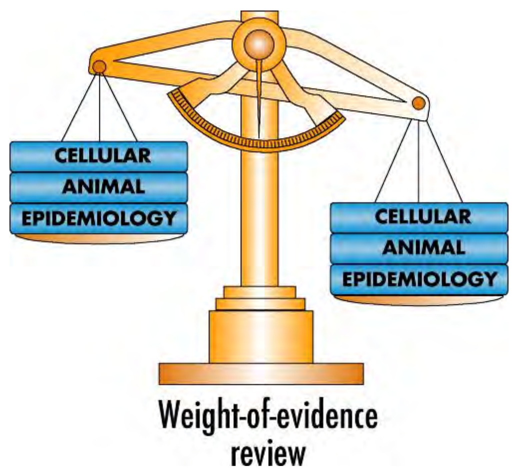

Figure 1. Weight-of-evidence reviews consider three types of research

Continuing with the puzzle example from above, the picture that is formed when the individual studies are assembled can take on many different shapes. In some cases (e.g., smoking and lung cancer), a clear picture of an adverse health effect was presented by the research within a relatively short time. In most cases, however, the picture is unclear and more questions are raised than answered. It is impossible to prove the negative in science—i.e., to say that any exposure is completely safe—therefore, research studies can only reduce the uncertainty that there is a health effect through continued research. The only way to reduce this uncertainty is to conduct high quality studies with meaningful results that are replicated across study populations (in the case of epidemiology studies) and by different laboratories (in the case of *in vivo* and *in vitro* research). Thus, in most areas of research, unless the data clearly indicate an increased risk at defined exposure levels, scientific panels will conclude that the research is inadequate or limited and requires further study until the uncertainty has been reduced below an acceptable level. While the public may interpret this conclusion as indicating concern, it is natural for scientists to recommend future research to reduce uncertainty around a largely negative body of research or to replicate findings that appear positive.

Scientific and health organizations put together panels of scientists to conduct weight-of-evidence reviews. These panels consist of experts from around the world in the areas of interest (e.g., epidemiology, neurophysiology, toxicology, etc.) and they follow standard scientific methods for arriving at conclusions about possible health risks. The conclusions of these reviews are looked to for the current scientific consensus on a particular topic and form the basis of recommendations made by organizations and governments on exposure standards and precautionary measures.

Scientific reviews on ELF EMF

Numerous national and international organizations responsible for public health have convened multidisciplinary panels of scientists to conduct weight-of-evidence reviews and arrive at conclusions about the possible risks associated with ELF EMF. These organizations include the following (in ascending, chronological order of their most recent publication):

- The **National Institute for Environmental Health Sciences** (**NIEHS**) in the United States assembled a 30-person Working Group to review the cumulative body of epidemiologic and experimental data on ELF EMF and provide conclusions and recommendations to the government (NIEHS, 1998, 1999).

- The **International Agency for Research on Cancer** (**IARC**) completed a full carcinogenic evaluation of ELF EMF in 2002 (IARC, 2002).

- The **World Health Organization (WHO)** released a review in June 2007 as part of its International EMF Program to assess the scientific evidence related to ELF EMF in the frequency range from 0 to 300 GHz (WHO, 2007a). Appendix 1 summarizes the conclusions of this review.

- The **Swedish Radiation Protection Authority (SSI),**[4] using other major scientific reviews as a starting point, evaluated new studies in consecutive annual reports (SSI, 2007; SSI, 2008).

- The **Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)** issued a report in March 2007 and March 2009 (SCENIHR, 2007; SCENIHR, 2009) updating previous conclusions (SSC, 1998; CSTEE, 2001) to the Health Directorate of the European Commission.

- The **National Radiological Protection Board** (**NRPB**)[5] of the United Kingdom issued full evaluations of the research in 1992, 2001, and 2004, with supplemental updates (NRPB, 1993; NRPB, 1994a) and topic-specific reports (NRPB, 1994b; NRPB, 2001b; HPA, 2006) published in the interim. In a letter addressing a related topic, the Director of the Health Protection Agency of Great Britain (HPA) reiterated their position on ELF EMF and appropriate precautionary measures (HMG, 2009).

- The **International Commission on Non-Ionizing Radiation Protection** (**ICNIRP**), the formally recognized organization for providing guidance on standards for non-ionizing radiation exposure for the WHO**,** published a review of the cumulative body of epidemiologic and experimental data on ELF EMF in 2003. The ICNIRP released draft exposure guidelines for ELF EMF in July 2009 (ICNIRP, 2009). While the ICNIRP panel stated that they relied heavily on previous reviews of the literature related to long-term ELF EMF exposures, they provided relevant conclusions as part of the drafting of these guidelines.

Dissenting opinion on ELF EMF

In August 2007, an *ad hoc* group of 14 scientists and public health and policy consultants published an on-line report titled "*The BioInitiative Report: A Rationale for a Biologically-*

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[4] The Swedish Radiation Safety Authority (Sträl säkerhets myndigheten [SSM]) has superseded the SSI, which ceased to exist on 30 June 2008. The SSM is a managing authority of Sweden's Ministry of the Environment and has "national collective responsibility within the areas of radiation protection and nuclear safety," which includes EMF research (http://www.stralsakerhetsmyndigheten.se).

[5] The NRPB merged with the Health Protection Agency in April 2005 to form its new Radiation Protection Division.

based Public Exposure Standard for Electromagnetic Fields (ELF and RF)." The group's objective was to "assess scientific evidence on health impacts from electromagnetic radiation below current public exposure limits and evaluate what changes in these limits are warranted now to reduce possible public health risks in the future" (p. 4). The report was followed by several publications related to ELF EMF that summarized some of the online report's conclusions (Hardell and Sage, 2008; Davanipour and Sobel, 2009; Johansson 2009). The individuals who comprised this group did not represent any well-established regulatory agency nor were they convened by a recognized scientific authority. The report has been criticized by scientific agencies because it did not follow the methods of a standard weight-of-evidence review and, for this reason, its conclusions and recommendations are not considered further in this report (Danish National Board of Health, 2007; ACRBR, 2008; HCN, 2008).[6] Appendix 3 provides a full criticism of the report.

Epidemiology basics

This section briefly describes the main types of epidemiology studies and the major issues that are relevant to evaluating their results. The two, main types of epidemiology studies are cohort studies and case-control studies (Figure 2).

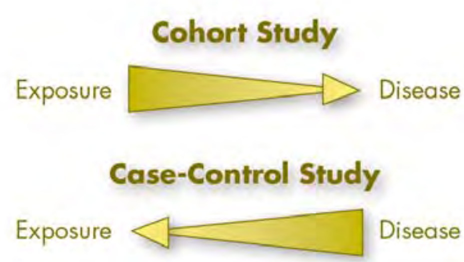

Figure 2. Basic design of cohort and case-control studies

A case-control study compares the characteristics of people that have been diagnosed with a disease (i.e., cases) to a similar group of people who do not have the disease (i.e., controls). The prevalence and extent of past exposure to a particular agent is estimated in both groups and

6 http://www.gezondheidsraad.nl/en/publications/bioinitiative-report-0

compared to assess whether the cases have a higher exposure level than the controls, or vice versa.

In a case-control study, this comparison (or statistical association) is estimated quantitatively with an odds ratio (OR). An OR is the ratio of the odds of exposure among persons with a disease to the odds of exposure among persons without a disease. The general interpretation of an OR equal to 1.0 is that the odds of exposure are the same in the case and control groups (i.e., there is no statistical association between the exposure and disease). If the OR is greater than 1.0, the inference is that the odds of exposure are greater in the case group or, in other words, the exposure may increase the risk of the disease (Figure 3).

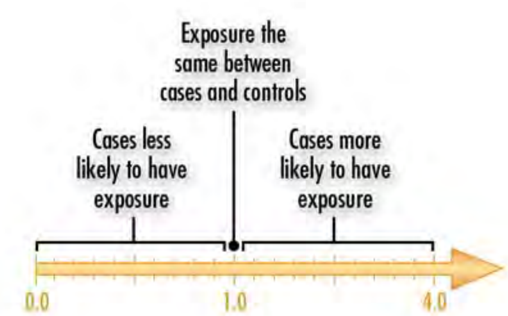

Figure 3. Interpretation of an odds ratio in a case-control study

Each OR is reported with a confidence interval (CI), which is a range of OR values that have a specified probability of occurring if the study is assumed to be repeated a large number of times. A 95% CI, for example, provides the range of values that are likely to occur in 95% of repeated experiments. In short, a CI indicates how certain (or confident) the researcher is about the OR calculated from his or her data; if the CI includes 1.0, the researcher cannot statistically exclude the possibility that the OR is 1.0, meaning the odds of exposure are the same in the case and control groups.

A cohort study is conducted in the reverse manner—in the most traditional sense, researchers study a population *without disease* and follow them over time to see if persons with a certain exposure develop disease at a higher rate than unexposed persons. The comparisons conducted in cohort studies are similar to the comparisons conducted in case-control studies, although the risk estimate is referred to as a relative risk (RR) rather than an OR. The RR is equal to rate of disease in the exposed group divided by the rate of disease in the unexposed group, with values greater than 1.0 suggesting that the exposed group has a higher rate of disease.

The resulting RR or OR is simply a comparative measure of how often a disease and exposure occur together in exposed and unexposed study populations—it does not mean that there is a known or causal relationship. Before any conclusions can be drawn, all studies considering a particular exposure and disease must be identified, and each study must be evaluated to determine the possible role that factors such as chance, bias, and confounding may have played in the study's results.

- *Chance* refers to a random event, i.e., a coincidence. An association can be observed between an exposure and disease that simply is the result of a chance occurrence. Statistics, such as the CI, are calculated to determine whether chance is a likely explanation for the findings.
- *Bias* refers to any error in the design, conduct, or analysis of a study that would cause a distorted estimate of an exposure's effect on the risk of disease. There are many different types of bias; for example, selection bias may occur if the characteristics of persons that participate in a study differ in a meaningful way from the characteristics of those subjects that do not participate (e.g., cases living near power lines might be more likely to participate than controls because the cases are concerned about this possible exposure).
- *Confounding* is a situation in which an association is distorted because the exposure being studied is associated with other risk factors for the disease. For example, a link between coffee drinking in mothers and low birth weight babies may be observed in a study, but some women who drink coffee also smoke cigarettes. When the smoking habits of mothers are taken into account, coffee drinking may not be associated with low birth weight babies because the confounding effect of smoking has been removed.

As part of the weight-of-evidence review process, each study's design and methods are evaluated critically to determine if and how chance, bias, and confounding may have affected the results and, subsequently, the weight that should be placed on the study's findings.

IARC classifications

This section briefly describes the method that the IARC uses following a weight-of-evidence review to classify exposures based on the evidence in support of carcinogenicity. The WHO adopted this method in their 2007 review on ELF EMF, and other scientific agencies refer to this classification system, as well.

First, each research type (epidemiology, *in vivo*, and *in vitro*) is evaluated to determine the strength of evidence in support of carcinogenicity (as defined in Figure 4). Epidemiology studies are characterized as having *sufficient evidence* for carcinogenicity if an association is found and chance, bias, and confounding can be ruled out with "reasonable confidence." *Limited evidence* is used to describe a body of research where the findings are inconsistent or where an association is observed but there are outstanding questions about study design or other methodological issues that preclude making strong conclusions. *Inadequate evidence* describes a body of 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. The same overall categories apply for *in vivo* research. *In vitro* research is not described in Figure 4 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.

Agents are then classified into five overall categories using the combined categories from epidemiology, *in vivo*, and *in vitro* research (listed from highest to lowest risk): (1) known carcinogen, (2) probable carcinogen, (3) possible carcinogen, (4) non-classifiable, and (5) probably not a carcinogen.

As summarized in Figure 4, the category possible carcinogen typically denotes exposures for which there is limited evidence of carcinogenicity in epidemiology studies, and *in vivo* studies provide limited or inadequate evidence of carcinogenicity.

The IARC has reviewed over 900 substances and exposure circumstances to evaluate their potential carcinogenicity. Figure 5 provides examples of some of the more common exposures that have been classified in each category. As Figure 5 shows, over 80% of exposures fall in the categories possible carcinogen (27%) or non-classifiable (55%). 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.

Over half of the agents are non-classifiable in terms of carcinogenicity, i.e., it is unclear whether they can cause cancer—hair coloring products, jet fuel, and tea are included in this category. Possible carcinogens include occupation as a firefighter, coffee, and pickled vegetables, in addition to magnetic fields. Exposures identified as probable carcinogens include high temperature frying and occupation as a hairdresser. Finally, known carcinogens include benzene, asbestos, solar radiation, use of tanning beds, and tobacco smoking. As Figure 5 shows, there is much uncertainty about whether certain agents will lead to cancer, and possible and probable carcinogens include substances to which we are commonly exposed or are common exposure circumstances.

	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 4. Basic IARC method for classifying exposures based on potential carcinogenicity

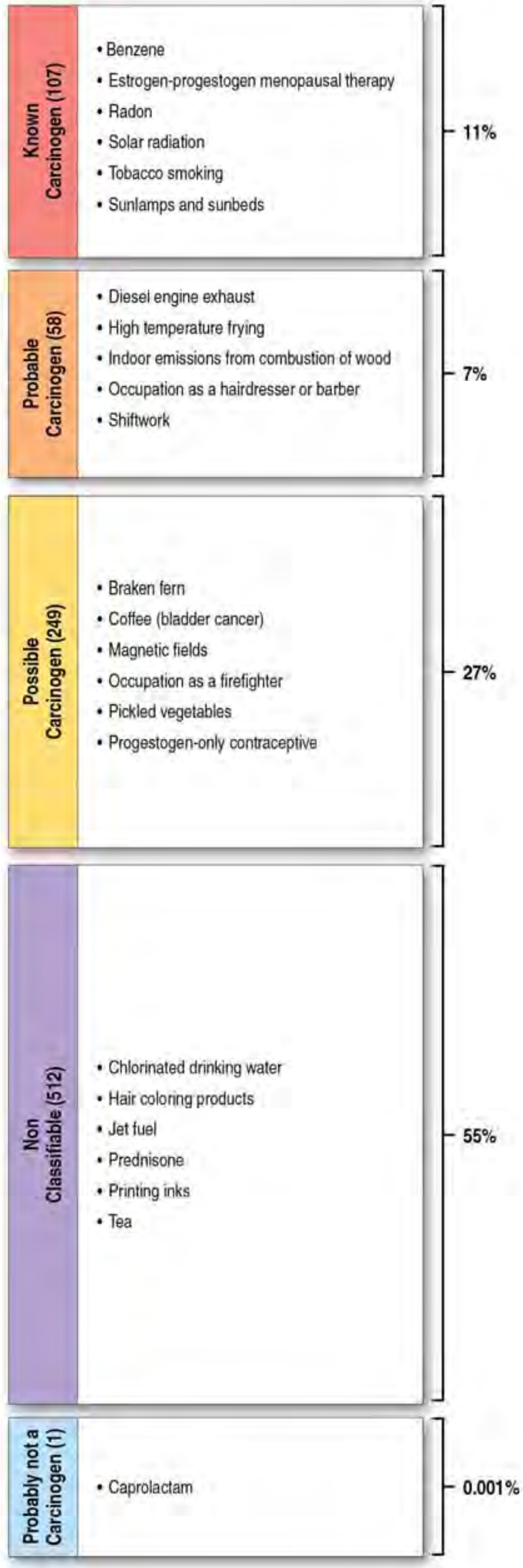

Figure 5. Percentage of substances classified in each IARC category with examples

2 Human Health Research

The following sections provide an overview of peer-reviewed research published between January 1, 2006 and October 1, 2010. A literature review was conducted to identify new epidemiologic, *in vivo,* and *in vitro* research published on 50 or 60-Hz ELF EMF. A large number of search strings referencing the exposure and diseases of interest, as well as authors who regularly publish in this area, were included as search terms in the PubMed database, a service of the U.S. National Library of Medicine that includes over 17 million citations from MEDLINE and other life science journals for biomedical articles dating to the 1950s.[7] A scientist with experience in this area reviewed the search results to identify relevant studies.

This report focuses on the diseases that have received the most attention—cancer, reproductive effects, developmental effects, and neurodegenerative diseases. Other health effects have been studied (i.e., rare cancer types, suicide, depression, electrical hypersensitivity, and cardiovascular effects), but for brevity and because research on these topics evolves slowly, these topics are not summarized here. The WHO review provides a good resource for the status of research on these additional health effects.

This update focuses on identifying and summarizing new epidemiologic and major *in vivo* research, since these study types are the most informative for risk assessment in this field; for the status of *in vitro* research, we include our discussion from the July 2007 report.

Cancer

Childhood leukemia

What was previously known about childhood leukemia and what did the WHO review conclude?

Scientific panels have concluded consistently that magnetic fields are a possible carcinogen largely because of findings from studies of childhood leukemia. Since 1979, approximately 35

[7] PubMed includes links to full text articles and other related resources (http://www.ncbi.nlm.nih.gov/PubMed/).

studies conducted in the United States, Canada, Europe, New Zealand, and Asia have evaluated the relationship between childhood leukemia and magnetic fields using various methods to estimate exposure. These methods have included long-term (48-hour) personal monitoring; spot or long-term (24- or 48-hour) measurements in structures and outdoors; calculations using loading, line configuration, and distance of nearby power installations to estimate historical, residential exposure; and wire code categories.[8] As a group of independent studies, they did not show a clear or consistent association between magnetic fields and childhood leukemia. The largest and most methodologically sound case-control studies to estimate personal magnetic field exposure directly did not report a consistent relationship (Linet et al., 1997; McBride et al., 1999; UKCCS, 2000). When two independent pooled analyses combined the data from these case-control studies, however, a statistically significant association was observed between rare average magnetic field exposure above 3-4 mG and childhood leukemia (Ahlbom et al., 2000; Greenland et al., 2000). Both pooled analyses indicated that children with leukemia were about two times more likely to have had estimated magnetic field exposures above 3-4 mG. Average exposures at this level are uncommon; according to the WHO, results from several extensive surveys showed that approximately 0.5–7.0% of children had time-averaged exposures in excess of 3 mG and 0.4–3.3% had time-averaged exposures in excess of 4 mG (WHO, 2007a). While these analyses provide a valuable quantitative summary of the data, pooled analyses are limited by the disparate methods used to collect the underlying data. Questions have been raised as to whether the original studies, particularly those that are large and estimated exposure directly, provide a more valid estimate of the association than the pooled analyses (Elwood, 2006).

Despite the association observed in these pooled analyses, health agencies have not concluded that magnetic fields are a known or probable cause of childhood leukemia. The studies are of insufficient strength to rule out with "reasonable confidence" the role that chance, bias, and confounding may have had on the observed statistical association. In other words, researchers do not have enough confidence in the way these studies were conducted to conclude that the measured statistical association represents a true relationship between magnetic fields and childhood leukemia. Furthermore, experimental data do not provide evidence for a risk in the

8 Wire code categories are categories used to classify the potential magnetic field exposures at residences based on the characteristics of nearby power installations.

more highly-controlled *in vivo* studies, and *in vitro* studies do not provide evidence of a plausible biological mechanism whereby magnetic fields lead to carcinogenesis.

Since chance, bias, and confounding could not be ruled out as an explanation for the association, the IARC concluded in 2002 that the data on childhood leukemia provided limited evidence of carcinogenicity (IARC, 2002). In 2007, the WHO reviewed studies on childhood leukemia and magnetic field exposure published since the 2002 IARC review (WHO, 2007a). They concluded that the new epidemiologic studies were consistent with the classification of limited epidemiologic evidence in support of carcinogenicity and, together with the largely negative *in vivo* and *in vitro* research, consistent with the classification of magnetic fields as a possible carcinogen (Figure 4).[9]

Since it is unclear whether the association is real, the WHO review evaluated other factors that might be partially, or fully, responsible for the association, including chance, control selection bias, confounding from hypothesized or unknown risk factors, and misclassification of magnetic field exposure (Figure 6). The following is a summary of their evaluation:

- ✓ The WHO review concluded that **chance** is an unlikely explanation since the pooled analyses had a large sample size and decreased variability.

- ✓ **Control selection bias** occurs when the controls that decide to participate in the study do not represent the true exposure experience of the non-diseased population. In the case of magnetic fields, the WHO speculates that controls with a higher socioeconomic status (SES) may participate in studies more often than controls with a lower SES. Since persons with a higher SES may have lower magnetic field exposures or tend to live farther from transmission lines, the control group's magnetic field exposure may be artificially low. Thus, when the exposure experience of the control group is compared to the case group, there is a difference between the case and control group that does not exist in the source population. The WHO concluded that **control selection bias** is

[9] The WHO concluded the following: "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. 355-6, WHO, 2007a).

probably occurring in these studies and would result in an overestimate of the true association, but would not explain the entire observed statistical association

- ✓ The WHO panel concluded that **confounding** is less likely to be causing the observed association than other factors, although the possibility that some yet-to-be identified confounder is responsible for the association cannot be excluded completely. Suggested risk factors that may be confounding the relationship include SES, residential mobility, contact currents, and traffic density.[10]

- ✓ The WHO stated that the possible effects of **exposure misclassification** are the most difficult to predict. EMF presents unique challenges in exposure assessment because it is ubiquitous, imperceptible, and has many sources (Kheifets and Oksuzyan, 2008). No target exposure or exposure window has been identified, and the numerous methods of estimating exposure likely result in a different degree of error within and between studies. Most reviews have concluded that exposure misclassification would likely result in an underestimate of the true association, meaning the association we observe is lower than the true value; however, the extent to which this might occur varies widely and is difficult to assess (Greenland et al., 2000). The WHO concluded that exposure misclassification likely is present in these studies, but is unlikely to provide an entire explanation for the association.

[10] For example, if dwellings near power lines encounter higher traffic density and pollution from traffic density causes childhood leukemia, traffic density may cause an association between magnetic field exposure and childhood leukemia, where a relationship does not truly exist.

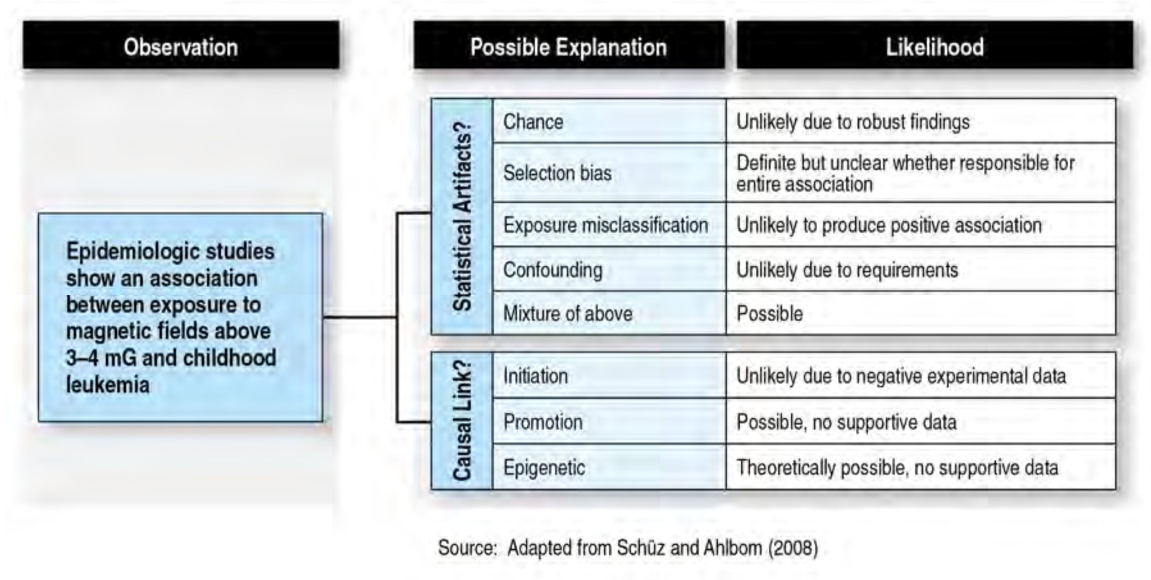

Figure 6. Possible explanations for the observed association between magnetic fields and childhood leukemia

The WHO review stated 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 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 be low if the association was determined to be causal.

What relevant studies have been published since the WHO review?

A number of studies investigating childhood leukemia and magnetic fields have been published since the WHO review (Table 1). Recent studies continue to support a weak association between elevated magnetic field levels and childhood leukemia, but they lack the methodological improvements required to advance this field; the evidence remains limited and the observed statistical association is still unexplained. 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).

Most notably, Kheifets et al. (2010) conducted a pooled analysis of studies published between 2000 and 2010 that was intended to mirror the earlier pooled analyses of studies published between 1974 and 1999 (Ahlbom et al., 2000; Greenland et al., 2000). Kheifets et al. identified six studies for the main analysis that met their inclusion criteria (i.e., population-based studies of childhood leukemia that measured or calculated magnetic fields inside a home); three of the studies in this analysis were considered in the WHO review, while two are described here (Kroll et al., 2010; Malagoli et al., 2010).[11] An additional Brazilian study remains unpublished, but the results were provided via personal communication to Kheifets et al. (Wunsch Filho, personal communication, 2009).[12] A large number of cases were identified by Kheifets et al. (10,865), but a relatively small number of cases (23) were classified in the highest exposure category (>3 mG). A positive association was reported (OR=1.44), but it was weaker than the previous pooled estimates and not statistically significant (95% CI=0.88–2.36); a dose-response relationship was apparent and the association was stronger when the Brazilian study was excluded.

The largest number of cases in Kheifets et al. (2010) was from a large, case-control study conducted in the United Kingdom by Kroll et al. (2010). Kroll et al. expands upon an earlier study (Draper et al., 2005) by replacing residential distance to nearby transmission lines as the exposure metric with calculated magnetic fields from nearby transmission lines; both studies included all children diagnosed with cancer in the United Kingdom from 1962 through 1995. Draper et al. (2005) reported that children with leukemia were more likely to have lived at birth within 600 meters (m) of a high-voltage transmission line, although the authors questioned the significance of this finding since magnetic fields from power lines do not extend to distances of 600 m.[13] Kroll et al. calculated average yearly residential magnetic-field levels for children

[11] A seventh study was included in Kheifets et al. (2010), but only in the pooled analysis of childhood leukemia and residential distance to power lines (Lowenthal et al., 2007). This study is not discussed further in this section because published findings only report on a combined category of lymphoproliferative and myeloproliferative disorders for both adults and children combined.

[12] The study evaluated acute lymphoblastic leukemia among children less than 8 years of age and measured exposure using 24-hour measurements in the children's bedrooms.

[13] The WHO concluded the following with respect to the Draper et al. (2005) findings: "[the] observation of the excess risk so far from the power lines, both noted by the authors and others, is surprising. Furthermore, distance is known to be a very poor predictor of magnetic field exposure, and therefore, results of this material based on calculated magnetic fields, when completed, should be much more informative" (p. 270, WHO 2007a).

living within 400 m of power lines at birth; modeling estimated that magnetic field levels above 1 mG could be predicted reliability only at residences within 400 m of a transmission line. Only 1% of children had a residence at birth within 400 m of a transmission line and only 0.07% had calculated exposures greater than 1 mG. Furthermore, nearly 25% of the residences within 400 m of a transmission line lacked data to calculate residential magnetic-field levels. An OR of 2.0 was calculated for the two cases of childhood leukemia and one control with calculated magnetic fields greater than 4 mG (95% CI=0.18 to 22.04); no dose-response relationship was apparent. As a result of small numbers and incomplete information, no strong conclusions can be drawn from this study. The authors stated that the study "slightly strengthens" the evidence for an association between magnetic fields and childhood leukemia.

Malagoli et al. (2010) was also included in the pooled analysis. This Italian study identified all childhood hematological malignancies diagnosed between 1967 and 2007 in two Italian municipalities (64 cases) and recruited four controls per case matched on sex, age, and municipality of residence.[14] Exposure was defined as having lived for at least 6 months prior to diagnosis at a residence with calculated power-line magnetic field levels above 1 mG or above 4 mG; magnetic-field levels were calculated using 2001 average line loading, rather than loading during the year of birth or diagnosis. Few children lived in a residence with power-line magnetic field levels above 1 mG (2 cases and 5 controls) or 4 mG (1 case and 2 controls); thus, estimated associations were unstable. The RR for leukemia and residence in an area with exposure $\geq$1 mG was 3.2 (6.7 adjusting for SES), but the estimate was statistically unstable (95% CI=0.4-23.4), and there was no indication of a dose-response relationship. Similar to Kroll et al. (2010), this study's strength is the lack of participation required, but it is limited by small numbers, the related imprecision, and the lack of an exposure-response relationship.

Two studies published since the WHO review confirmed an association with residential distance to power lines and childhood leukemia (Feizi and Arabi, 2007 [< 500 m vs. >500 m]; Abdul Rahman et al., 2008 [< 200 m vs. >200 m]). While these two studies were excluded from the pooled analysis because they were hospital-based, Kheifets et al. (2010) pooled data on distance and childhood leukemia from other studies and confirmed an elevated OR at distances less than

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[14] Hematological cancers include all types of leukemias, lymphomas, and Hodgkin's disease.

200 m. The association remains unexplained, however, and a recent study confirms that distance is a poor proxy for measurements of residential magnetic fields; Maslanyj et al. (2009) reported that only 13% of homes in a 100 m corridor of 220-440-kV power lines had a measured magnetic field level above 2 mG.

Other recent studies were not included in the pooled analysis because they reported on leukemia subgroups and magnetic fields. These studies reported that children with leukemia and estimates of average magnetic-field exposures greater than 3-4 mG had poorer survival (Foliart et al., 2006, 2007; Svendsen et al., 2007); children with Down syndrome and childhood leukemia were more likely to have spot measurements at the door of their home greater than 6 mG compared to children with Down syndrome only (Mejia-Arangure et al., 2007); and one genetic polymorphism related to DNA repair (but with no known relationship to leukemia) was reported to be more common among children with leukemia living close to an electrical installation compared to children with leukemia living at a distance (Yang et al., 2008). The results of these recent studies were limited by small numbers, incomplete adjustment for potential risk factors, and the lack of a biological explanation to explain the observed associations, among other methodological issues. Additional epidemiologic and biological research is required in these new fields of inquiry.

Another new field of inquiry is the relevance of pre- or post-conception EMF exposure of a parent to cancer in their offspring. Hug et al (2010) studied the pre-conception occupational exposures of parents of children with leukemia and compared them to the exposures of parents of healthy children. No association was found between childhood leukemia and magnetic-field exposure pre-conception in either parent. Another recent study reported an association between childhood leukemia and a paternal history of electrical work, but is limited because exposure is based solely on occupational title (Pearce et al., 2007).

Scientists have also pursued the influence of bias and confounding in recent years. Recent studies confirmed that control selection bias appears to be operating in case-control studies of childhood leukemia and magnetic fields, although the exact degree of its influence is still unknown (Mezei and Kheifets, 2006; Mezei et al., 2008a, 2008b). A study has also found that contact currents from residential grounding systems show characteristics of a confounding variable (Kavet and Hooper, 2009). Finally, a recent study confirmed that the time of day when magnetic-field measurement are made is not contributing to exposure misclassification; no difference in the magnitude or pattern of results was found for nighttime vs. 24-hour or 48-hour measurements, refuting the hypothesis that nighttime exposures are more strongly associated with childhood leukemia because magnetic fields might affect carcinogenesis through a melatonin-driven pathway (Schüz et al., 2007).

In summary, the studies conducted since the WHO review support an association with magnetic fields and childhood leukemia. In particular, scientific data published since the WHO review:

- confirms the rarity of living in close proximity to a power line or having estimated or measured exposures greater than 1 mG;
- confirms a positive association between average magnetic field levels greater than 3 mG and childhood leukemia, but the association cannot be distinguished from chance due to small numbers;
- confirms an association with residential proximity to power lines and childhood leukemia, but reports that distance is not a reliable predictor of in-home magnetic field levels; and,
- suggests that control selection bias may play some role in the observed association.

These findings do not alter previous conclusions that the epidemiologic evidence on magnetic fields and childhood leukemia is limited. Chance, confounding, and several sources of bias cannot be ruled out. Conclusions from reviews (Kheifets and Oksuzyan, 2008; Schüz and Ahlbom, 2008) and scientific organizations (SSI, 2007; SSI, 2008; HCN, 2009; SCENIHR, 2009) published since the WHO review support this conclusion.

Table 1. Relevant studies of childhood leukemia published after the WHO review

Author	Year	Study Title
Abdul Rahman et al.	2008	A case-control study on the association between environmental factors and the occurrence of acute leukemia among children in Klang Valley, Malaysia.
Fezei and Arabi	2007	Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines – a risk factor in Iran
Foliart et al.	2006	Magnetic field exposure and long-term survival among children with leukaemia
Foliart et al.	2007	Magnetic field exposure and prognostic factors in childhood leukemia
Hug et al.	2010	Parental occupational exposure to extremely low frequency magnetic fields and childhood cancer: a German case-control study
Kavet and Hooper	2009	Residential magnetic fields and measures of neutral-to-earth voltage: variability within and between residences
Kheifets et al.	2010	Pooled analysis of recent studies on magnetic fields and childhood leukaemia
Kroll et al.	2010	Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: a case-control study
Malagoli et al.	2010	Risk of hematological malignancies associated with magnetic fields exposure from power lines: a case control study in two municipalities in northern Italy
Maslanyj et al.	2009	Power frequency magnetic fields and risk of childhood leukaemia: Misclassification of exposure from the use of the 'distance from power line' exposure surrogate
Mejia-Arangure et al.	2007	Magnetic fields and acute leukemia in children with Down syndrome
Mezei and Kheifets	2006	Selection bias and its implications for case-control studies: A case study of magnetic field exposure and childhood leukaemia
Mezei et al.	2008a	Assessment of selection bias in the Canadian case-control study of residential magnetic field exposure and childhood leukemia
Pearce et al.	2007	Paternal occupational exposure to electro-magnetic fields as a risk factor for cancer in children and young adults: A case-control study from the North of England
Schüz et al.	2007	Nighttime exposure to electromagnetic fields and childhood leukemia: An extended pooled analysis
Svendson et al.	2007	Exposure to magnetic fields and survival after diagnosis of childhood leukemia: An extended pooled analysis
Yang et al.	2008	Case-only of interactions between DNA repair genes (hMLH1, APEX1, MGMT, XRCC1, and XPD) and low frequency electromagnetic fields in childhood acute leukemia

Childhood brain cancer

What was previously known about childhood brain cancer and what did the WHO review conclude?

The research related to magnetic fields and childhood brain cancer has been less consistent than that observed for 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 (p. 18, WHO 2007a).*

What relevant studies have been published since the WHO review?

The relevant studies of childhood brain cancer and magnetic field exposure are listed in Table 2 below. In response to the WHO recommendation above, Mezei et al. (2008b) conducted a meta-analysis of studies on childhood brain tumors and residential magnetic field exposure. Thirteen epidemiologic studies were identified that used various proxies of magnetic field exposure (distance, wire codes, calculated magnetic fields, and measured magnetic fields). The combined effect estimate was close to 1.0 and not statistically significant, indicating no association between magnetic field exposure and childhood brain tumors. A sub-group of five studies, however, with information on childhood brain tumors and calculated or measured magnetic fields greater than 3-4 mG reported a combined OR that was elevated but not statistically significant (OR=1.68, 95% CI=0.83-3.43). The authors suggested two explanations for this elevated OR. First, they suggested that an increased risk of childhood brain tumors could not be excluded at high exposure levels (i.e., >3-4 mG). Second, they stated that the similarity of this result to the findings of the pooled analyses of childhood leukemia suggests that control selection bias is operating in both analyses. Overall, the authors concluded that the analysis did not find a significant increase in childhood brain cancer risk using various proxies of residential exposure to magnetic fields.

Two case-control studies were completed after this pooled analysis (Kroll et al., 2010; Saito et al., 2010). In their study of 55 cases of childhood brain cancer, Saito et al. (2010) reported that children with brain cancer were more likely to have average magnetic-field exposure levels greater than 4 mG, compared to children without brain cancer.[15] The association was based on three cases and one control; interpretations of the data were, therefore, limited by small numbers in the upper exposure category. The strength of this study is the exposure assessment; measurements were taken continuously over a weeklong period in the child's bedroom approximately 1 year after diagnosis. An important limitation, however, is the very poor participation rates among study subjects; poor participation rates introduce the possibility of selection bias, among other biases. As described above, Kroll et al. (2010) included 6,584 cases of brain cancer diagnosed over a 33-year period in the United Kingdom. No associations were reported in any analysis of brain cancer, including calculated magnetic fields ≥1-2 mG, 2-4 mG, and 4mG.

Studies of parental occupational magnetic field exposure and childhood brain tumors have produced inconsistent results. In a recent pooled analysis of two Canadian case-control studies, Li et al. (2009) calculated individual maternal occupational magnetic field exposure pre- and post-conception and analyzed these estimates in relation to brain cancer in offspring. Associations were reported between childhood brain cancer and average magnetic-field exposures greater than approximately 3 mG for exposure in the 2 years prior to conception and during conception; no associations were found using the cumulative and peak exposure metrics. More research is required in this area.

Recent studies provide some suggestion of an association between magnetic field exposures prior to diagnosis or *in utero* and the development of childhood brain cancer. The data receive little weight in an overall assessment, however, due to methodological shortcomings. The recent data do not alter the classification of the epidemiologic data in this field as inadequate.

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[15] The unpublished results of this study were included in Mezei et al. (2008b).

Table 2. Relevant studies of childhood brain cancer published after the WHO review

Authors	Year	Study
Kroll et al.	2010	Pooled analysis of recent studies on magnetic fields and childhood leukaemia
Li et al.	2009	Maternal occupational exposure to extremely low frequency magnetic fields and the risk of brain cancer in the offspring
Mezei et al.	2008b	Residential magnetic field exposure and childhood brain cancer: a meta-analysis
Saito et al.	2010	Power frequency magnetic fields and childhood brain tumors: A case-control study in Japan

Breast cancer

What was previously known about breast cancer and what did the WHO review conclude?

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, and the WHO concluded that, since the recent body of research was higher in quality compared with previous studies, it provided strong support to previous consensus statements that magnetic field exposure does not influence the risk of breast cancer.[16] The WHO recommended no further research with respect to breast cancer and magnetic field exposure.

What relevant studies have been published since the WHO review?

Two case-control studies (McElroy et al., 2007; Ray et al., 2007) and one cohort study (Johansen et al., 2007) have been published, all of which evaluated occupational magnetic field exposure.[17] In addition, a meta-analysis of 15 studies of breast cancer and occupational magnetic field exposure was published (Chen et al., 2010), which included one of the case-control studies (McElroy et al 2007).

[16] The WHO concluded, "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" (p. 307, WHO 2007a).

[17] In addition to the studies described in the text, another study was identified. Peplonska et al. (2007) is a case-control study of female breast cancer reporting associations for a wide range of occupations and industries. It is not considered in depth in this report because no qualitative or quantitative estimates of magnetic field exposure were made, beyond occupation and industry titles.

Ray et al. (2007) was a nested case-control study in a cohort of approximately 250,000 textile workers in China followed for breast cancer incidence, and McElroy et al. (2007) evaluated occupational exposures to high, low, medium, or background EMF levels in a large number of breast cancer cases and controls. Neither study observed a significant association between breast cancer and higher estimated magnetic field exposure. A large cohort study of utility workers in Denmark also reported that women exposed to higher occupational magnetic field levels did not have higher rates of breast cancer (Johansen et al., 2007).

Chen et al. (2010) published a meta-analysis of all published case-control studies of female breast cancer and magnetic field exposure meeting defined inclusion criteria. Fifteen studies published between 2000 and 2009 were identified examining residential and occupational exposure and electric blanket usage. The authors crudely re-categorized data from the original studies to reflect a common comparison of <2 mG and >2mG and reported an overall OR of 0.988 (95% CI = 0.898–1.088). The advantage of this meta-analysis is its very large size. Its main limitation is that data from a wide range of exposure definitions and cut-points were combined.

These studies, particularly the large cohort of utility workers, add to growing support against a causal role for magnetic fields in breast cancer. This is consistent with the conclusion by the SCENIHR, which stated that an association is “unlikely” (p. 7, SCENIHR 2007).

Table 3. Relevant studies of breast cancer published after the WHO review

Authors	Year	Study
Chen et al.	2010	Extremely low-frequency electromagnetic fields exposure and female breast cancer risk: a meta-analysis based on 24,338 cases and 60,628 controls
Johansen et al.	2007	Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up
McElroy et al.	2007	Occupational exposure to electromagnetic field and breast cancer risk in a large, population-based, case-control study in the United States
Ray et al.	2007	Occupational exposures and breast cancer among women textile workers in Shanghai

Other adult cancers

What was previously known about other adult cancers and what did the WHO review conclude?

In general, scientific panels have concluded that there is not a strong or consistent relationship between other adult cancers (leukemia, lymphoma, or brain cancers) and exposure to magnetic fields; however, the possibility cannot be entirely ruled out because the findings have been inconsistent (IARC, 2002; WHO, 2007a). Stronger findings have not been observed in studies with better exposure assessment methods, which have led scientific panels to conclude that the evidence for an association is weak. The IARC classified the epidemiologic data with regard to adult leukemia, lymphoma, and brain cancer as "inadequate" in 2002, and the WHO confirmed this classification in 2007, with much of the remaining uncertainty attributed to limitations in exposure assessment methods.

Much of the research on EMF and adult cancers is related to occupational exposures, given the higher range of exposures encountered in the occupational environment. The main limitation of these studies, however, has been the methods used to assess exposure, with early studies relying simply on a person's occupational title (often taken from a death certificate) and later studies linking a person's full or partial occupational history to representative average exposures for each occupation (i.e., a job exposure matrix). The latter method, while advanced, still has some important limitations, as highlighted in a review summarizing an expert panel's findings by Kheifets et al. (2009).[18] While a person's occupation may provide some indication of the overall magnitude of their occupational magnetic field exposure, 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. Furthermore, since scientists do not know any mechanism by which magnetic fields could lead to cancer, an appropriate exposure metric is unknown.

In order to reduce the remaining uncertainty about whether there is an association between magnetic fields and these cancers, researchers have recommended (1) meta-analyses to clarify

[18] 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.

inconsistencies and (2) better exposure assessment methods that incorporate a greater level of detail on tasks and exposure characteristics such as spark discharge, contact current, harmonics, etc. (WHO, 2007a; Kheifets et al., 2009).

Adult brain cancer

What was previously known about adult brain cancer and what did the WHO review conclude?

As described above, 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.[19]

What relevant studies have been published since the WHO review?

Epidemiologic studies published after 2006 on adult brain cancer and EMF exposure are listed in Table 6 and include two case-control studies, two cohort studies, and a meta-analysis, all of which are related to occupational magnetic field exposure.

In response to the WHO's recommendation, two cohorts of approximately 20,000 occupationally-exposed persons each were updated: a cohort of utility workers in Denmark and a cohort of railway workers in Switzerland (Johansen et al., 2007; Röösli et al, 2007a). In both cohorts, brain cancer rates were similar between jobs with high magnetic field exposure and jobs with lower exposures. A case-control study of gliomas was conducted in Australia and reported no associations with higher estimated magnetic field exposure, using a standard job-exposure matrix (Karipidis et al., 2007a). Forssén et al. (2006) performed a large registry-based case-control study of acoustic neuroma and reported no association between higher occupational magnetic field exposures and this benign and rare brain cancer type. Another large case-control study was recently published of gliomas and meningiomas in the United States (Coble et al., 2009). For the first time, the exposure metric in this study incorporated the frequency of exposure to EMF sources, as well as the distance people worked from these sources, on an

[19] 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" (p. 307, WHO 2007a).

individual basis. The authors also evaluated exposure metrics in addition to the time-weighted average (TWA) exposure (maximum exposed job, total years of exposure above 1.5 mG, cumulative lifetime exposure, and average lifetime exposure). No association was reported between any of these exposure metrics and brain cancer.

As recommended in the WHO review, a meta-analysis of occupationally-exposed cohorts was performed by Khefeits et al. (2008). All relevant publications of occupational EMF exposure and adult leukemia or brain cancer were collected and summary risk estimates were calculated using various schemes to weight and categorize the study data. The authors reported a small and statistically significant increase of leukemia and brain cancer in relation to the highest estimate of magnetic field exposure in the individual studies. Several findings, however, led the authors to conclude that magnetic field exposure is not responsible for the observed associations, including the lack of a consistent pattern among leukemia subtypes when the past and new meta-analyses were compared. In addition, for brain cancer, the recent meta-analysis reported a weaker association than the previous meta-analysis, whereas a stronger association would be expected since the quality of studies has increased over time. The authors concluded, "the lack of a clear pattern of EMF exposure and outcome risk does not support a hypothesis that these exposures are responsible for the observed excess risk" (p. 677).

Recent studies have reduced possible exposure misclassification by improving exposure assessment methods (i.e., the expanded job-exposure matrix in Coble et al., 2009) and attempted to clarify inconsistencies by updating studies and meta-analyzing data (Johansen et al., 2007; Röösli et al., 2007a; Kheifets et al., 2008); however, despite these advancements, no association has been observed. While an association still cannot be *entirely* ruled out because of the remaining deficiencies in exposure assessment methods, the current database of studies provides weak evidence of an association between magnetic fields and brain cancer.[20] The recent report by the SCENIHR described the data on brain cancers as "uncertain" (p. 43, SCENIHR 2009).

[20] A recent 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" (p. 1958, Bondy et al., 2008).

Table 4. Relevant studies of adult brain cancer published after WHO review

Authors	Year	Study
Coble et al.	2009	Occupational exposure to magnetic fields and the risk of brain tumors
Forssén et al.	2006	Occupational magnetic field exposure and the risk of acoustic neuroma
Johansen et al.	2007	Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up
Karipidis et al.	2007a	Occupational exposure to low frequency magnetic fields and the risk of low grade and high grade glioma
Kheifets et al.	2008	Occupational electromagnetic fields and leukemia and brain cancer: An update to two meta-analyses
Röösli et al.	2007a	Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees

Adult leukemia and lymphoma

What was previously known about adult leukemia/lymphoma and what did the WHO review conclude?

The same issues discussed above with regard to adult brain cancer are relevant to research on adult leukemia and lymphoma. The WHO classified the epidemiologic evidence as “inadequate” and recommended updating the existing occupationally-exposed cohorts in Europe and the meta-analysis on occupational magnetic field exposure (p. 307, WHO 2007a).[21]

What relevant studies have been published since the WHO review?

Two cohorts of occupationally-exposed workers and a meta-analysis of occupational magnetic field exposure (all of which were described above) reported on the possible association of occupational magnetic field exposure and adult leukemia. Also, a case-control study described patterns of estimated residential magnetic field exposure and combined lymphoma and leukemia diagnostic categories (Lowenthal et al., 2007).

In the occupational cohort of Swiss railway workers, the authors noted a stronger association among occupations with higher estimates of magnetic field exposures, but the associations were not statistically significant (Röösli et al, 2007a). In the study of Danish utility workers, no increases in leukemia rates were observed in job titles that involved higher exposures to magnetic fields (Johansen et al., 2007). As described above, the updated meta-analysis by

[21] No specific conclusions were provided by the WHO with regard to lymphoma.

Kheifets et al. (2008) reported a weak association between estimated occupational magnetic field exposure and leukemia, but the authors felt that the data was not indicative of a true association.

Lowenthal et al. (2007) grouped cases in five diagnostic categories as lymphoproliferative disorders (LPD) (including acute lymphoblastic leukemia [ALL]) and cases in three diagnostic categories (including acute myeloid leukemia [AML] and other leukemias) as myeloproliferative disorders (MPD). These groups included both adults and children of all ages. The authors estimated exposure by obtaining a lifetime residential history and assessing distance of residences from 88-kV, 110-kV, and 220-kV power lines. They reported elevated, but not statistically significant, ORs for those who lived within 50 m of any of these power lines, and an indication of decreasing ORs with increasing distance. This study adds very little to the existing database of information on adult leukemia and residential exposure, however, because of fundamental limitations. For example, different cancer types were combined as were different ages of diagnosis. It is well known that cancer etiology varies by cancer type, cancer subtype, and diagnostic age.[22]

Very little is known about the etiology of Non-Hodgkin lymphoma (NHL), and few studies have been conducted in relation to magnetic field exposure. In one of the first studies to estimate cumulative occupational magnetic field exposure among NHL cases, Karipidis et al. (2007b) reported a statistically significant association between NHL and the highest category of exposure (OR=1.59, 95% CI=1.07-2.36). Overall, the study was well conducted, with its most significant limitation being the possibility of uncontrolled confounding. In another case-control study of NHL, Wong et al. (2010) identified 649 cases from a hospital in Shanghai. Among numerous questions in the interview, cases and controls were asked whether they had ever lived within 100 m of a high-voltage power line. Results showed no association (i.e., no differences in residential history between cases and controls), but the strength of the study is limited by the use of distance as a proxy for exposure. Of note, the cohort of railway workers in Switzerland did not report an increase in NHL deaths among the more highly exposed workers (Röösli et al, 2007a). Further research in this area is required.

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[22] The recent meta-analysis by Kheifets et al. (2010) implies that data are available from Lowenthal et al. (2007) for childhood leukemia as a separate diagnostic category. This information is not publicly accessible, however.

The recent literature also includes a novel study examining whether there are differences in the activity of the natural killer (NK) cell, a cytotoxic immune cell which attacks tumor cells and cells infected with viruses, among persons occupationally exposed to magnetic fields (Gobba et al., 2008). Higher measured magnetic field levels (i.e., >10 mG) during three complete work shifts were associated with reduced NK activity. Future studies are required to replicate this finding and understand the potential significance of NK activity in cancer.

A number of studies of adult leukemia have attempted to clarify inconsistencies by updating studies and meta-analyzing data (Johansen et al., 2007; Kheifets et al., 2008; Röösli et al, 2007a); however, despite these advancements, no clear or statistically significant association has been observed. While an association still cannot be *entirely* ruled out because of the remaining deficiencies in exposure assessment methods, the current database of studies provides weak evidence of an association between magnetic fields and leukemia. Preliminary results related to NHL have been published and require further investigation.

Table 5. Relevant studies of adult leukemia/lymphoma published after the WHO review

Authors	Year	Study
Gobba et al.	2008	Extremely low frequency-magnetic fields (ELF-EMF) occupational exposure and natural killer activity in peripheral blood lymphocytes
Johansen et al.	2007	Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up
Karipidis et al.	2007b	Occupational exposure to power frequency magnetic fields and risk of non-Hodgkin lymphoma
Kheifets et al.	2008	Occupational electromagnetic fields and leukemia and brain cancer: An update to two meta-analyses
Lowenthal et al.	2007	Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study
Röösli et al.	2007a	Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees
Wong et al.	2010	A hospital-based case-control study of non-Hodgkin lymphoid neoplasms in Shanghai: Analysis of personal characteristics, lifestyle, and environmental risk factors by subtypes of the WHO classification

In vivo studies of carcinogenesis

What was previously known about *in vivo* studies of carcinogenesis and what did the WHO review conclude?

It is standard procedure to conduct studies on laboratory animals to determine whether exposure to a specific agent leads to the development of cancer (USEPA, 2005). This approach is used because all known human carcinogens cause cancer in laboratory animals. 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 lymphoma (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; Baum et al., 1995; Löscher and Mevissen, 1995; Mevissen et al., 1993a,1993b, 1996a, 1996b, 1998), 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.[23]

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.

In summary, the WHO concluded the following with respect to *in vivo* research: "There is no evidence that ELF exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate" (p. 322, WHO 2007a). 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.

What relevant studies have been published since the WHO review?

In view of the available evidence that exposure to magnetic fields *alone* does not increase the occurrence of cancer, the literature published following the WHO review includes numerous *in vivo* studies testing different hypotheses of cancer promotion, including effects on brain cancer (Chung et al., 2008), breast cancer (Fedrowitz and Löscher, 2008), and lymphoma or leukemia (Bernard et al., 2008; Negishi et al., 2008), as referenced below. Studies of genotoxicity and oxidative damage *in vivo* have also been published since 2006, but these studies are just conceptually linked to carcinogenicity; this summary focuses on studies of tumor progression since these studies are the most relevant. In each of these studies, the animals were treated first with chemicals known to initiate the cancer process. Initiated animals are more likely to develop cancer, and a subsequent exposure, known as a promoter, is often needed for an initiated cell to reproduce into many cancer cells. Several studies treated the animals with the initiators ethylnitrosourea (ENU) (Chung et al., 2008), n-butylnitrosourea (BNU) (Bernard et al., 2008), and DMBA (Fedrowitz and Löscher, 2008; Negishi et al., 2008). An additional study

[23] 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" (p. 321, WHO 2007a).

by Sommer and Lerchel (2006) tested whether magnetic fields alone increased the incidence of lymphoma in mice virally predisposed to lymphoblastic lymphoma.

Chung et al. (2008) examined the possible role of 60-Hz magnetic fields in promoting brain tumors initiated by ENU injections *in utero*; the authors concluded that there was no evidence that exposure to 60-Hz magnetic fields up to 5,000 mG promoted tumor development in this study.

Fedrowitz and Löscher (2008) is the most recent study from the German laboratory that previously reported increases in DMBA-induced mammary tumors with high magnetic field exposure. In this recent study, the researchers exposed DMBA-treated Fischer 344 rats (the strain of inbred rats used in previous experiments) to either high levels of magnetic fields (1,000 mG) or no exposure for 26 weeks and reported that the incidence of mammary tumors was significantly elevated in the group exposed to magnetic fields (Fedrowitz and Löscher, 2008). No independent replication of this experiment has yet occurred and questions still remain about the effect of experimental protocol and species strain.

Sommer and Lerchl (2006) is a follow-up to an earlier study (Sommer and Lerchl, 2004) that reported no increases in lymphoma among predisposed animals chronically exposed to magnetic fields (up to 1,000 mG for 24 hours per day for 32 weeks). Sommer and Lerchl (2006) increased magnetic field exposure to 10,000 mG and exposed some of the animals only during the night to test the hypothesis that nighttime exposure may have a stronger effect than continuous exposure. Magnetic fields did not influence body weight, time to tumor, cancer incidence, or survival time in this study. In another study of lymphatic system cancers, researchers treated newborn mice with DMBA and magnetic fields up to 3,500 mG (Negishi et al., 2008). The authors reported that the percentage of mice with lymphoma or lymphatic leukemia was not higher in magnetic field-exposed groups, compared to the sham-exposed group.

In another study of lymphoid leukemia, Chung et al (2010) evaluated the effect of magnetic fields on AKR mice, which are genetically predisposed to thymic lymphoblastic lymphoma. Exposures ranged from 50-500 mG for 21 hours per day for 40 weeks, and cancer incidence was compared with a sham-exposed control group. Potential confounding variables (such as temperature, humidity, and magnetic-field variations) were monitored daily. The experiment was performed blind to ensure that biases were not introduced by investigator knowledge of exposure conditions. Magnetic-field exposures were not associated with changes in body weight, survival time, or the incidence of lymphoma compared to sham-treated controls. Exposure also did not affect components of the blood, micronuclei formation, or gene expression in the thymus.

A study by Bernard et al. (2008) provides a significant development, in that it is the first study to use an animal model of ALL, the most common leukemia type in children. All rats were exposed to BNU to initiate the leukemogenic process, and a sub-group of rats was exposed to magnetic fields of 1,000 mG for 18 hours per day for 52 weeks. No difference in leukemia incidence was observed between the BNU-treated group exposed to magnetic fields and the BNU-treated unexposed group. This study supports the hypothesis that magnetic fields do not affect the development of ALL and provides additional support to the conclusion that experimental data is not supportive for a role of magnetic fields in the incidence of childhood leukemia. The researchers followed guidelines for the experimentation and care of laboratory animals and conducted the analyses blind to the treatment group. Experience with this strain of rat is limited, however, so it is unclear whether the results are more or less reliable than other animal models; replication is required.

Thus, aside from the most recent replication of enhanced mammary carcinogenesis in a specific sub-strain of rats in a German laboratory, recent studies provide further evidence against a role for magnetic fields as a co-carcinogen. These studies strengthen the conclusion that there is inadequate evidence of carcinogenicity from *in vivo* research, although independent confirmation of the German results is of high priority.

Table 6. Relevant *in vivo* studies of carcinogenesis published after the WHO review

Authors	Year	Study
Bernard et al.	2008	Assessing the potential Leukemogenic effects of 50 Hz and their harmonics using an animal leukemia model
Chung et al.	2008	Lack of a co-promotion effect of 60 Hz rotating magnetic fields on n-ethyl-n-nitrosourea induced neurogenic tumors in F344 rats
Chung et al.	2010	Lack of a co-promotion effect of 60 Hz rotating magnetic fields on N-ethyl-N-nitrosourea induced neurogenic tumors in F344 rats
Fedrowitz and Löscher	2008	Exposure of Fischer 344 rats to a weak power frequency magnetic field facilitates mammary tumorigenesis in the DMBA model of breast cancer
Negishi et al.	2008	Lack of promotion effects of 50 Hz magnetic fields on 7,12-dimethylbenz(a)anthracene-induced malignant lymphoma/lymphatic leukemia in mice
Sommer and Lerchl	2006	50 Hz magnetic fields of 1 mT do not promote lymphoma development in AKR/J mice

In vitro studies of carcinogenesis

What did the WHO and other scientific panels conclude with respect to *in vitro* studies of carcinogenesis?

In vitro studies are widely used to investigate the mechanisms for effects that are observed in humans and animals. The relative value of *in vitro* tests to human health risk assessment, however, is much less than that of *in vivo* and epidemiology studies. Responses of cells and tissues outside the body may not always reflect the response of those same cells if maintained in a living system, so the relevance of *in vitro* studies cannot be assumed (IARC, 1992).

The IARC and other scientific review panels that systematically evaluated *in vitro* studies concluded that there is no clear evidence indicating how ELF magnetic fields could adversely affect biological processes in cells (IARC, 2002; ICNIRP, 2003; NRPB, 2004). The WHO panel reviewed the *in vitro* research published since the time of these reviews and reached the same conclusion. The WHO noted that previous studies have not indicated a genotoxic effect of ELF magnetic fields on mammalian cells, however a series of experiments reported DNA damage in human fibroblasts exposed intermittently to 50 Hz magnetic fields (Ivancsits et al., 2002a, 2002b; Ivancsits et al., 2003a, 2003b). These findings have not been replicated by other laboratories (Scarfi et al., 2005), and the WHO recommended continued research in this area. Recently, investigators reported that they were unable to confirm any evidence for damage to DNA in cells exposed to magnetic fields over a range of exposures from 50 to 10,000 mG (Burdak-Rothkamm et al., 2009). Research in the field of *in vitro* genotoxicity of magnetic fields combined with known DNA-damaging agents is also recommended, following suggestive findings from several laboratories. As noted by the SSI, however, the levels at which these effects were observed are much higher than the levels to which we are exposed in our everyday environments and are, therefore, not directly relevant to questions about low-level, chronic exposures (SSI, 2007). *In vitro* studies investigating other possible mechanisms, including gene activation, cell proliferation, apoptosis, calcium signaling, intercellular communication, heat shock protein expression, and malignant transformation have produced "inconsistent and inconclusive" results, according to the WHO (p. 347, WHO, 2007a).

Reproductive and developmental effects

What was previously known about reproductive and developmental effects and what did the WHO review conclude?

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

These two studies improved on the existing body of literature because average exposure 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 the miscarriages reported in the cohort by Li et al. had magnetic field measurements taken after miscarriage occurred, when changes in physical activity may have already occurred, and all measurements in Lee et al. 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, 2007a). The WHO concluded, “There is some evidence for increased risk of miscarriage associated with measured maternal magnetic field exposure, but this evidence is inadequate” (p. 254, WHO 2007a). The WHO stated that, given the potentially high public health impact of such an association, further epidemiologic research is recommended.

What relevant studies have been published since the WHO review?

No new original studies on magnetic field exposure and miscarriage have been conducted; however, recent methodological studies evaluated the likelihood that the observed association was due to bias. Epidemiologic and *in vivo* studies of ELF EMF and reproductive and developmental effects are summarized in Table 7.

It is not possible to directly “test” for the effects of this bias in the original studies, but two recent analyses examined whether reduced physical activity was associated with a lower probability of encountering peak magnetic fields (Mezei et al., 2006; Savitz et al., 2006). In a 7-day study of personal magnetic field measurements in 100 pregnant women, Savitz et al. (2006) reported that active pregnant women were more likely to encounter peak magnetic fields. In addition, an analysis by Mezei et al. (2006) of pre-existing databases of magnetic field measurements among pregnant and non-pregnant women found that increased activity levels were associated with peak magnetic fields. These findings are broadly supportive of the hypothesis that reduced activity among women in early pregnancies because of nausea and in later pregnancies because of cumbersomeness may explain the observed association between peak magnetic fields and miscarriage. As noted in a recent commentary on this issue, however, the possibility that there is a relationship between peak magnetic field exposure and miscarriage still cannot be excluded and further research that accounts for this possible bias should be conducted (Neutra and Li, 2008; Mezei et al., 2006). There remains no biological basis, however, to indicate that magnetic field exposure increases the risk of miscarriage (WHO, 2007a).

Two additional studies were published related to developmental outcomes and growth. Fadel et al. (2006) conducted a cross-sectional study in Egypt of 390 children 0-12 years of age living in an area within 50 m of an electrical power line and 390 children 0-12 years of age living in a region with no power lines in close proximity. Measurements were taken as proxies of growth retardation, and radiological assessments were performed on carpal bones. The authors reported that children living in the region near power lines had a statistically significant lower weight at birth and a reduced head and chest circumference and height at all ages. The authors concluded that "exposure to low frequency electromagnetic fields emerged [*sic*] from high voltage electric power lines increases the incidence of growth retardation among children" (p. 211). This conclusion, however, fails to adequately take into account the many limitations of their cross-sectional analysis (namely, inadequate control for the possible confounding effects of nutritional and SES status) and the pre-existing body of literature, which does not support such an association (WHO, 2007a). Public health statistics indicate that detrimental birth outcomes, including pre-term birth, low birth weight, or small for gestational age, occur more frequently in populations of lower SES (HHS, 2004); thus, analyses of adverse birth outcomes should be adjusted for these factors.

Auger et al. (2010) studied whether maternal residence near transmission lines was associated with adverse birth outcomes, adjusting for socioeconomic factors, among all live births in Montreal and Canada between 1990 and 2004. Maternal residential distances were measured within 400 m of nearby transmission lines for over 700,000 live births, and the proportion of adverse events was compared between mothers living >400 m and within 400 m, adjusting for mother's age, education, household income, and other potential confounding factors. The analysis found no association with distances in 50 m increments for any of the outcomes: pre-term birth, low birth weight, small for gestational age, or proportion of male births. The use of distance as a surrogate of EMF exposure limits the value of this study.

Among recent *in vivo* reproductive studies of ELF EMF, seven examined effects on the female reproductive system (Aksen et al., 2006; Roushanger and Soleimani Rad, 2007; Al-Akhras et al., 2008; Anselmo et al., 2009; Aydin et al., 2009; De Bruyen and De Jager, 2010; Rajaei et al., 2010). In most of these studies, the researchers did not clarify whether they incorporated blinding to minimize bias and failed to indicate whether they used appropriate statistical analyses (e.g., use of the litter, rather than the pup, as the unit for analysis since littermates are known to be more similar to each other than offspring derived from separate litters). Other limitations included the use of animals with extremely deficient diets and the use of only one magnetic field level so that dose-response could not be assessed. Although some of the studies reported biological changes, none of the studies reported strong evidence of adverse reproductive outcomes.

Studies of reproductive effects on males were conducted across a broad range of exposures and duration and also suffered from flaws that affect validity; most failed to report methods to ensure blinding, and some used short-term exposures to extremely high fields (Al-Akhras et al., 2006; Mostafa et al., 2006; Farkhad et al., 2007; Khaki et al., 2008; Kim et al., 2009; Bernabo et al., 2010). De Bruyn and de Jager (2010) reported decreases in sperm motility that do not translate to functional decrements in reproductive capacity.

Studies also were conducted of exposure during pregnancy (Anselmo et al., 2006, 2008; Okudan et al., 2006; Yao et al., 2007; Dundar et al., 2009; De Bruyn and De Jager, 2010). The studies entailed high and short-term exposures and had specific and narrows goals, e.g., evaluating changes in the eye or bone. Of note, De Bruyn and De Jager (2010) continuously exposed mice to a randomly varying 50-Hz magnetic field between 5mG and 770 mG from conception through two generations of offspring in a double-blind study. Both the treated and sham-exposed groups consisted of ten pairs of mice in each generation. No effects of exposure were observed on mean gestational and generational days, mean litter size, or total number of stillborn pups. Like the other studies, however, the authors did not indicate whether appropriate statistical methods were used to control for potential litter effects.

Thus, the recent epidemiologic research does not provide sufficient evidence to alter the conclusion that the evidence for reproductive or developmental effects is inadequate. Recent studies of animals *in vivo* also do not provide evidence to change the conclusions expressed by the WHO. Various deficiencies in the methods and reporting of these studies limit their use in health risk assessment.

Table 7. Relevant studies of reproductive and developmental effects published after the WHO review

Authors	Year	Study
Aksen et al.	2006	Effect of 50-Hz 1-mT magnetic field on the uterus and ovaries of rats (electron microscopy evaluation)
Al-Akhras et al.	2006	Influence of 50 Hz magnetic field on sex hormones and other fertility parameters of adult male rats
Al-Akhras et al.	2008	Influence of 50 Hz magnetic field on sex hormones and body, uterine, and ovarian weights of adult female rats
Anselmo et al.	2006	Influence of a 60 Hz, 3 microT, electromagnetic field on the reflex maturation of Wistar rats offspring from mothers fed a regional basic diet during pregnancy
Anselmo et al.	2008	Influence of a 60 Hz, microT, electromagnetic field on the somatic maturation of wistar rat offspring fed a regional basic diet during pregnancy
Anselmo et al.	2009	Effects of the electromagnetic field, 60 Hz, 3 microT, on the hormonal and metabolic regulation of undernourished pregnant rats
Auger et al.	2010	The relationship between residential proximity to extremely low frequency power transmission lines and adverse birth outcomes
Aydin et al.	2009	Evaluation of hormonal change, biochemical parameters, and histopathological status of uterus in rats exposed to 50-Hz electromagnetic field
Bernabó et al.	2010	Extremely low frequency electromagnetic field exposure affects fertilization outcome in swine animal model
De Bruyen and De Jager	2010	Effect of long-term exposure to a randomly varied 50 Hz power frequency magnetic field on the fertility of the mouse
Dundar et al.	2009	The effect of the prenatal and post-natal long-term exposure to 50 Hz electric field on growth, pubertal development and IGF-1 levels in female Wistar rats
Fadel et al.	2006	Growth assessment of children exposed to low frequency electromagnetic fields at the Abu Sultan area in Ismailia (Egypt)
Farkhad et al.	2007	Effects of extremely low frequency electromagnetic field on testes in guinea pig
Khaki et al.	2008	The effects of electromagnetic field on the microstructure of seminal vesicles in rat: a light and transmission electron microscope study
Kim et al.	2009	Effects of 60 Hz 14 µT magnetic field on the apoptosis of testicular germ cell in mice
Mezei et al.	2006	Analyses of magnetic-field peak-exposure summary measures
Mostafa et al	2006	Sex hormone status in male rats after exposure to 50 Hz, mT magnetic field
Neutra and Li	2008	Letter to the Editor – Magnetic fields and miscarriage: A commentary on Mezei et al., JESEE 2006
Okudan et al.	2006	DEXA analysis on the bones of rats exposed in utero and neonatally to static and 50 Hz electric fields
Rajei et al.	2010	Effects of extremely low-frequency electromagnetic field on fertility and heights of epithelial cells in pre-implantation stage, endometrium and fallopian tube in mice
Roushanger and Soleimani Rad	2007	Ultrastructural alterations an occurrence of apoptosis in developing follicles exposed to low frequency electromagnetic field in rat ovary
Savitz et al.	2006	Physical activity and magnetic field exposure in pregnancy
Yao et al.	2007	Absence of effect of power-frequency magnetic fields on exposure on mouse embryonic lens development

Neurodegenerative disease

What was previously known about neurodegenerative disease and what did the WHO review conclude?

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. The inconsistency of early Alzheimer's disease studies prompted the NRPB to conclude that there is "only weak evidence to suggest that it [ELF magnetic fields] could cause Alzheimer's disease" (p. 20, NRPB, 2001). 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 was 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.[24] 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.

[24] After considering the entire body of literature and its limitations, the WHO report 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" (p. 194, WHO 2007a).

What relevant studies have been published since the WHO review?

Six studies have been published since the WHO review. Two occupational cohorts were followed for neurodegenerative diseases—approximately 20,000 railroad workers in Switzerland (Röösli et al., 2007b) and over 80,000 electrical and generation workers in the United Kingdom (Sorahan and Kheifets, 2007). Two case-control studies collected incident cases of Alzheimer's disease and estimated occupational magnetic field exposure (Davanipour et al., 2007; Seidler et al., 2007), and a meta-analysis was conducted of occupational magnetic field exposure and Alzheimer's disease studies (García et al., 2008). The first study of non-occupational exposure followed the Swiss population to evaluate associations with residential distance to power lines and death due to neurodegenerative diseases (Huss et al., 2009).

García et al. (2008) identified 14 epidemiologic studies with information on Alzheimer's disease and occupational EMF exposure; the WHO considered the majority of these studies in their 2007 review. A statistically significant association between Alzheimer's disease and occupational EMF exposure was observed for both case-control and cohort studies (OR =2.03, 95% CI=1.38-3.00 and RR =1.62, 95% CI=1.16-2.27, respectively), although the results from the individual studies were so different that the authors cautioned against the validity of these combined results. While some subgroup analyses had statistically significant increased risks and were not significantly heterogeneous between studies, the findings were contradictory between study design types (e.g., elevated pooled risk estimates were reported for *men* in cohort studies and elevated pooled risk estimates were reported for *women* in case-control studies). The authors concluded that their results suggest an association between Alzheimer's disease and occupational magnetic field exposure, but noted the numerous limitations associated with these studies, including the difficulty of assessing EMF exposure during the appropriate time period, case ascertainment issues due to diagnostic difficulties, and differences in control selection. They recommended further research that uses more advanced methods.

An earlier publication by the same group of investigators documented the relatively poor quality of the studies included in the meta-analysis. Santibáñez et al. (2007) evaluated studies related to occupational exposure and Alzheimer's disease, which included seven of the studies in the García et al. meta-analysis. Two epidemiologists blindly evaluated each of these studies using a questionnaire to assess the possibility of a number of biases, with a score assigned to each study that represented the percentage of possible points that the study obtained (range 0-100%). Only one of the seven studies obtained a score above 50% (a retrospective cohort study by Savitz et al. in 1998), and disease and exposure misclassifications were the most prevalent biases.

Davanipour et al. (2007) extended an earlier hypothesis-generating study by Sobel et al. (1996) by collecting cases from eight California Alzheimer’s Disease Diagnostic and Treatment Centers. Self-reported primary occupation was collected from patients with verified diagnoses of Alzheimer’s disease and compared to occupational information collected from persons diagnosed with other dementia-related problems at the Centers. The results of this study were consistent with the previous studies by Sobel et al.; cases were approximately twice as likely to be classified as having medium/high magnetic field exposures, compared with controls. The strengths of this study included its large size and self-reported occupational information. The main limitation of this study was that the exposure assessment only considered a person’s primary occupation, classified as low, medium, or high magnetic field exposure. The WHO noted limitations of the 1996 publication that are relevant to this publication as well, including the use of controls with dementia (which some studies report have an increased risk of Alzheimer’s disease) and the classification of seamstresses, dressmakers, and tailors as “high exposure” occupations, which drives the increase in risk.

Seidler et al. (2007) conducted a similar case-control study in Germany, except cases included all types of dementia (55% of which had Alzheimer’s disease). Cumulative magnetic field exposure was estimated from occupational histories taken from proxy respondents, and no difference was reported between cases of dementia or probable Alzheimer’s disease and controls, although an association was reported among electrical and electronics workers. The authors reported that exposure misclassification was likely to be a significant problem and concluded that their results indicate a strong effect of low-dose EMF is “rather improbable” (p. 114).

Sorahan and Kheifets (2007) followed a cohort of approximately 84,000 electrical and generation workers in the United Kingdom for deaths attributed to neurodegenerative disease on death certificates. Cumulative magnetic field exposure was calculated for each worker, using job and facility information. The authors reported that the cohort did not have a significantly greater number of deaths due to Alzheimer’s disease or motor neuron disease compared to the general population in the United Kingdom. They also reported that persons with higher estimated magnetic field exposures did not have a consistent excess of death due to Alzheimer’s disease or motor neuron disease compared to persons with lower estimated magnetic field exposure. A statistically significant excess of deaths due to Parkinson’s disease was observed in the cohort, although there was no association between calculated magnetic field exposure and Parkinson’s disease. The authors concluded “our results provide no convincing evidence for an association between occupational exposure to magnetic fields and neurodegenerative disease” (p. 14). This result is consistent with two other Alzheimer’s mortality follow-up studies of electric utility workers in the United States (Savitz et al., 1998) and Denmark (Johansen and Olsen, 1998). The findings may be limited by the use of death certificate data, but are strengthened by the detailed exposure assessment.

Death from several neurodegenerative conditions was also evaluated in the cohort of more than 20,000 Swiss railway workers described above (Röösli et al., 2007b). Magnetic field exposure was characterized by specific job titles as recorded in employment records; stationmasters were considered to be in the lowest exposure category and were, therefore, used as the reference group. Train drivers were considered to have the highest exposure, and shunting yard engineers and train attendants were considered to have exposure intermediate to stationmasters and train drivers. Cumulative magnetic field exposure was also estimated for each occupation using on-site measurements and modeling of past exposures. The authors reported an excess of senile dementia disease among train drivers, compared to station masters, however, the difference was not statistically significant. The association was larger when restricted to Alzheimer’s disease, but was still not statistically significant (hazard ratio [HR]=3.15, 95% CI=0.90-11.04); an association was observed between cumulative magnetic field exposure and Alzheimer’s disease/senile dementia. No elevation in mortality was reported for multiple sclerosis, Parkinson’s disease, or ALS among train drivers, shunting yard engineers, or train attendants, compared with stationmasters, nor were more deaths from these causes observed for higher estimated magnetic field exposures. Similar to another recent Swedish study (Feychting et al., 2003), the authors reported that recent exposure was more strongly associated with Alzheimer’s disease than past exposure.

There are several strengths of this study relative to the existing body of data. First, there is little turnover among Swiss railway employees, which means that study participants are enrolled in the cohort and possibly exposed for long periods of time. The wide variation in exposure levels between different occupations in the same industry allows for comparison of similar workers with different levels of exposure. Another advantage is that the company kept detailed registers of employees, which means there is less potential for bias in the enumeration of the cohort and reconstruction of exposures. Finally, the authors reported that exposures to chemicals or electric shocks, which often occur in other occupational settings (for example, in electric utility workers or welders), are rare in this occupation.

Another cohort study conducted in Switzerland linked all persons older than 30 years of age at the 2000 census with a national database of death certificates from 2000 through 2005 (Huss et al., 2009). Residential location was also extracted from 1990 and 2000 census data and the closest distance of a person's home in 2000 to nearby 220-380 kV transmission lines was calculated. The authors reported that persons living within 50 m of these high-voltage transmission lines were more likely to have died from Alzheimer's disease, compared to those living farther than 600 m, although chance could not be ruled out as an explanation (HR=1.24, 95% CI=0.80-1.92). The association was stronger for persons that lived at the residence for at least 15 years (HR=2.00, 95% CI=1.21-3.33). Associations of similar magnitude were reported for senile dementia and residence within 50 m of a high-voltage line. No associations were reported beyond 50 m for Alzheimer's disease or senile dementia, and no associations were reported at any distance for Parkinson's disease, ALS, or multiple sclerosis.

The study's main limitation is the use of residential distance from transmission lines as a proxy for magnetic-field exposure (Maslanyj et al., 2009). It is also limited by the use of death certificate data, which are known to under-report Alzheimer's disease, and the lack of a full residential and occupational history. Furthermore, while the underlying cohort was very large, relatively few cases of Alzheimer's disease lived within 50 m of a high-voltage transmission line—20 cases total and 15 cases who lived at the residence for at least 15 years. This means that misclassification of a small number of cases could have a large impact on the risk estimate.

Another recent study used Sweden's large twin registry to assess whether occupational exposure to EMF was associated with dementia or Alzheimer's disease (Andel et al., 2010). Twins over the age of 65 were interviewed by phone to screen for possible dementia, and cases were identified for further evaluation to determine whether they had dementia or Alzheimer's disease (cases); study subjects without either diagnosis were considered the control group. Study subjects or their proxies were asked to identify their major lifetime occupation, which was linked with a job-exposure matrix to categorize EMF exposure into three, broad categories. In the overall twin population, EMF exposure was not associated with either dementia or Alzheimer's disease. An association with EMF was observed for those employed in manual labor and for those with early onset dementia (≤ 75 years at diagnosis), but not Alzheimer's disease. This study's strength is the recruitment of living cases; however, small numbers limited the subgroup analyses and robust associations were not found.

In summary, two cohort studies of the Swiss population of relatively high quality were followed for death due to neurodegenerative disease. Röösli et al. (2007b) reported an association between Alzheimer's disease or senile dementia and occupational magnetic-field exposure, while Huss et al. (2009) reported an association between Alzheimer's disease or senile dementia and living within 50 m of a high-voltage transmission line for at least 15 years. Neither study reported an association with any other neurodegenerative disease, including ALS. A cohort of utility workers, however, did not confirm an association with Alzheimer's disease mortality and magnetic field exposure. The meta-analysis and supporting evaluation of study quality by García, Santibáñez, and colleagues confirmed that the associations reported in previous occupational studies are highly inconsistent and the studies have many limitations (Santibáñez et al., 2007; García et al., 2008).

The main limitations of these studies include 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.

The recent epidemiologic studies do not alter the conclusion that there is inadequate data on Alzheimer's disease or ALS. While a good number of studies have been published since the WHO review, little progress has been made on clarifying these associations. Further research is still required, particularly on electrical occupations and ALS (Kheifets et al., 2008). There is currently no body of *in vivo* research to suggest an effect and two studies reported no effect of magnetic fields on ALS progression (Seyhan and Canseven, 2006; Poulletier de Gannes et al., 2008). These conclusions are consistent with the recent review by the SCENIHR (SCENIHR, 2009).

Table 8. Relevant studies of neurodegenerative disease published after the WHO review

Authors	Year	Study
Andel et al.	2010	Work-related exposure to extremely low-frequency magnetic fields and dementia: Results from the population-based study of dementia in Swedish twins
Davanipour et al.	2007	A case-control study of occupational magnetic field exposure and Alzheimer's disease: results from the California Alzheimer's Disease Diagnosis and Treatment Centers
García, et al.	2008	Occupational exposure to extremely low frequency electric and magnetic fields and Alzheimer disease: a meta-analysis
Huss, et al.	2009	Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population
Poulletier de Gannes et al.	2008	Amyotrophic lateral sclerosis (ALS) and extremely-low frequency (ELF) magnetic fields: a study in the SOD-1 transgenic mouse model
Röösli, et al.	2007b	Mortality from neurodegenerative disease and exposure to extremely low-frequency magnetic fields: 31 years of observations on Swiss railway employees
Santibáñez, et al.	2007	Occupational risk factors in Alzheimer's disease: a review assessing the quality of published epidemiological studies
Seidler et al.	2007	Occupational exposure to low frequency magnetic fields and dementia: a case-control study
Seyhan and Canseven	2006	In vivo effects of ELF MFs on collagen synthesis, free radical processes, natural antioxidant system, respiratory burst system, immune system activities, and electrolytes in the skin, plasma, spleen, lung, kidney, and brain tissues
Sorahan and Kheifets	2007	Mortality from Alzheimer's, motor neurone and Parkinson's disease in relation to magnetic field exposure: findings from the study of UK electricity generation and transmission workers, 1973-2004

3 Other Areas of Research

Pacemakers and implanted cardiac devices

The sensing system of pacemakers and other implanted cardiac devices (ICD) is designed to be responsive to the heart's electrical signal. For this reason, other electrical signals potentially can interfere with the normal functioning of pacemakers and ICDs, a phenomenon called electromagnetic interference (EMI). Most sources of EMF are too weak to affect a pacemaker or ICD; however, EMF from certain sources, e.g., some appliances and industrial equipment, may cause interference. This section considers potential EMI with implanted cardiac devices such as pacemakers and defibrillators.

In the presence of electromagnetic fields, pacemakers and ICDs can respond in different ways, defined as modes. The probability of interference occurring and the mode of the response depend on the strength of the interference signal, the patient's orientation in the electromagnetic field, the exact location of the device, and the variable parameters of the device that are specific to a patient.

There are a number of experimental studies dating back to the 1990s that were conducted to assess whether interference may occur when currents are induced in the patient's body by electric or magnetic fields (e.g., Toivonen et al., 1991; Astridge et al., 1993; Scholten and Silny, 2001). In general, pacing abnormalities in these tests occurred at magnetic field levels that are much higher than the levels a person would encounter on a daily basis. Electric fields did produce interference at levels that can be produced by certain electrical sources, but most pacemakers were not affected by high levels of electric fields (up to 20 kV/m) and did not exhibit any pacing abnormalities. Unipolar (single lead) pacemakers tended to be more sensitive to electric fields compared to bipolar (two lead) devices, which are designed specifically to reduce the effects of EMI.

A recent study by Joosten et al. (2009) confirmed earlier work by Scholten and Silny (2001). Both studies found that the performance of a pacemaker in the presence of external ELF electric fields varied considerably based on anatomical and physiological conditions. The 15 study subjects in Joosten et al. experienced a variance of up to 200% when the interference voltage was applied at the input of their cardiac pacemakers. This variance was due to individual, personal factors such as state of respiration, systole and diastole of the heart, filling of the stomach, and muscle activity. The authors' analyses further suggested that for a 50-Hz electric field to affect the function of the most sensitive unipolar pacemaker, the field levels would have to be between 4.3 kV/m and 6.2 kV/m. Unipolar pacemakers are less and less common today; the study authors found that in Germany, only 6% of the pacemakers in use have a unipolar sensing system.

Suggested exposure levels have been determined by the American Conference of Governmental Industrial Hygienists (ACGIH) and the Electric Power Research Institute (EPRI) to prevent against pacemaker EMI. Both organizations suggest that exposures be kept below 1.5-2 kV/m for electric fields and the ACGIH recommends an exposure level not to exceed 1 G for magnetic fields (ACGIH 2001, EPRI 2004). These recommendations are general in nature and do not address that classes of pacemakers from some manufacturers are quite immune to interference even at levels much greater than these recommended guidelines. Both the ACGIH and EPRI recommend that patients consult their physicians and the respective pacemaker manufacturers before following these organizations' guidelines.

In addition, the Food and Drug Administration's Center for Devices and Radiological Health has issued guidelines for both the development of pacemakers and the design of new electrical devices to minimize susceptibility to electrical interference from any source. Pacemakers are designed to filter out electrical stimuli from sources other than the heart, e.g., the muscles of the chest, currents encountered from touching household appliances, or currents induced by external electric or magnetic fields. Used in both temporary and permanent pacemakers, these electrical filters increase the pacemaker's ability to distinguish extraneous signals from legitimate cardiac signals (Toivonen et al., 1991). Furthermore, most circuitry of modern pacemakers is encapsulated by titanium metal, which insulates the device by shielding the pacemaker's pulse generator from electric fields. Some pacemakers also may be programmed to pace the heart automatically if interference from electric or magnetic fields is detected (fixed pacing mode). This supports cardiac function and allows the subject to feel the pacing and move away from the source.

Due to recent design improvements, many pacemakers currently in use would not be susceptible to low intensity electric fields. There remains a very small possibility that some pacemakers, particularly those of older design and with single-lead electrodes, may sense potentials induced on the electrodes and leads of the pacemaker and provide unnecessary stimulation to the heart.

In summary, interference from strong electric fields is theoretically possible under certain circumstances. The likelihood of interference occurring is low, however, particularly with respect to sources that produce low levels of electric fields and when modern devices are implanted. It is recommended that concerned patients contact their doctors to discuss the make and model of their implanted device, their clinical condition, and any lifestyle factors that put them in close contact with strong electric or magnetic fields.

Flora

Electric currents are involved in cell to cell communication in plants (Framm and Lautner, 2007). For this reason, numerous laboratory and on-site studies over the past 35 years have been conducted to assess the possible effects of exposure to ELF EMF from transmission lines on flora—including agricultural crops, trees, and forest and woodland vegetation (e.g., Hodges et al., 1975; Bankoske et al., 1976; McKee et al., 1978; Miller et al., 1979; Rogers et al., 1980; Lee and Clark, 1981; Warren et al., 1981; Rogers et al., 1982; Greene 1983; Hilson et al., 1983; Hodges and Mitchell, 1984; Brulfert et al., 1985; Parsch and Norman, 1986; Conti et al., 1989; Krizaj and Valencic 1989; Ruzic et al., 1992; Reed et al., 1993; Smith et al., 1993; Mihai et al., 1994; Davies 1996; Zapotosky et al., 1996). Researchers have found no adverse effects on plant responses from exposure to EMF levels comparable to that produced by high-voltage transmission lines, including seed germination, seedling emergence and growth, leaf area per plant, flowering, seed production, longevity, and biomass production. The one confirmed adverse effect was damage to the tops of trees growing under or within 40 feet of an *experimental* transmission line operating at a voltage of 1,200 kV, attributable to corona-induced damage to branch tips. The right-of-way (ROW) clearance on *operational* transmission lines is typically a 100 to 200 foot clearance on each side of the line; this area would be cleared of trees or the branches trimmed back sufficiently to prevent flashover and other interference. This effect is not relevant to trees growing at greater distances from the ROW clearance area.

Experimental studies of plants have suggested that magnetic fields increased plant size and weight for radish and barley but not mustard plants (Davies, 1996). Two more recent studies on the possible effects of EMF on plants were performed by Huang and Wang (2008) and Costanzo (2008). Huang and Wang evaluated the effects of magnetic fields induced on the early seed germination of mung beans. The exposures from an inverter system were applied at six different frequencies between 10 Hz and 60 Hz, producing magnetic-field levels from 6 mG to 20 mG. The authors found that magnetic-field exposure at frequencies of 20 and 60 Hz enhanced early mung bean growth, while magnetic fields induced by 10, 30, 40, and 50 Hz frequencies had an inhibitory effect on early mung bean growth. Costanzo (2008) performed a similar study of soy beans exposed *in vitro* to 50-Hz electric fields at strengths of 1.3 kV/m and 2.5 kV/m (root mean square). The author found that this exposure increased soy bean growth in length. In addition, this same study reported that direct current (DC) electric fields of the same peak to peak value had no effect (Costanzo, 2008).

Thus, researchers have found no adverse effects on plant responses at the levels of EMF produced by typical high- or low-voltage transmission lines.

Fauna

Since the 1970s, research has been conducted on the possible effect of EMF on wild and domestic animals in response to concerns about the effects of high-voltage and ultra-high-voltage transmission lines in the vicinity of farms and the natural habitat of wild animals. National agencies and universities have conducted research on an assortment of fauna using a variety of study designs including observational studies of animals in their natural habitats and highly-controlled experimental studies. The research to date does not suggest that AC magnetic or electric fields (or any other aspect of high-voltage transmission lines, such as audible noise) result in adverse effects on the health, behavior, or productivity of fauna, including livestock (e.g., dairy cows, sheep, and pigs) and a variety of other species (e.g., small mammals, deer, elk, birds, and bees).

Dairy Cattle and Deer

Burchard et al. (2007) is the most recent publication in a long-term series of controlled studies conducted at McGill University (e.g., Rodriquez et al., 2002, 2003, 2004; Burchard et al., 2003; 2004) on the possible effects of strong and continuous EMF exposure on the health, behavior, and productivity of dairy cattle. The broad goal of this research program was to assess whether EMF exposure could mimic the effect of days with long periods of light and increase milk production and feed intake through a hormonal pathway involving melatonin. In previous studies, some differences were reported between EMF-exposed and unexposed cows; however, they were not reported consistently between studies, the changes were still within the range of what is considered normal, and it did not appear that the changes were adverse in nature.

The study by Burchard et al. in 2007 differed from previous studies in that the exposure was restricted to magnetic fields; the outcomes evaluated included the hormones progesterone, melatonin, prolactin, and insulin-like growth factor 1 (IGF-1), as well as feed consumption. No significant differences in melatonin levels, progesterone levels, or feed intake were reported. Significant decreases in prolactin and IGF-1 levels were reported. Thus, similar to the previous studies by this group of investigators, Burchard et al. (2007) did not report findings that suggest magnetic fields cause changes in the melatonin pathway that could result in effects on reproduction or milk production.

The research does indicate that some species of animals are able to detect and orient to DC magnetic fields at levels associated with the earth's static geomagnetic field (~ 500 mG), and this detection may be important for navigational purposes (in particular for species such as birds). Based upon the characteristics of the major hypothesized detection mechanisms and testing in some species, it seems unlikely that a weak 60-Hz magnetic field would be detected or that it would perturb navigational functions.

Along these lines, two studies, both of which received considerable press attention, published analyses of the orientation of cattle and deer using satellite images and field observations that identify a possible geomagnetic component influencing the animals' behavior. A report by Begall et al. (2008) found that domestic cattle and red and roe deer tend to orient their bodies pointing in a northerly direction. The authors' hypothesize that this body orientation is related to the earth's static geomagnetic field because in areas where the earth's magnetic North Pole can be distinguished more easily from the geographic North Pole's high magnetic declination, body orientation appeared to point more towards the magnetic north rather than the geographic north. This northerly body orientation was not correlated with time of day or the position of the sun, and although the authors speculated that the orientation of the animals was not influenced by wind, no analyses were presented. Based on these limited and indirect data the authors raised the possibility that these species can detect the earth's geomagnetic field.

In the second study, Burda et al. (2009) also explored the possible magnetic basis for the northerly orientation of cattle and deer by analyzing their behavior in the vicinity of high-voltage power lines. They report that cattle within 150 m and deer within 50 m of high-voltage power lines exhibit a random body orientation with respect to magnetic north. Some of the effect might be attributed to the deflection of the geomagnetic field by steel towers close to the line, but the authors did not test this possibility. Other analyses indicated that the orientation of cattle differed around power lines running in an east-west or north-south direction, which suggests that neither sun nor wind cues explain the orientation of these animals with respect to magnetic north. If the observed orientations of cattle and deer are attributable to the earth's geomagnetic field, the biological significance is not clear and the authors suggest additional experimental study. With respect to deer, the authors commented that deer prefer to locate near power lines, perhaps because of the browse or shelter afforded.

Wild Bees and Honey Bees

Wild bees have an important role in natural plant and forest ecosystems. Research on wild bees was conducted at a site near a United States Navy communications system in Northern Michigan where two species of honeybees were observed living in the vicinity of this facility. The researchers studied the bees' exposure to 76-Hz electric and magnetic fields produced by the facility's communications system and compared the mortality, foraging behavior, and nest architecture to a group of honeybees living at a distance from the facility. A few differences were found in nesting parameters, although the effects were small, inconsistent, and likely due to other factors. Although a small increase in the overwinter mortality was reported in one of the two species studied, the researchers concluded that since the reported differences were small and inconsistent between experiments, there were no findings that raised concern about ELF EMF exposures to wild bees (Zapotosky et al., 1996). This conclusion was confirmed in a review by the United States National Academy of Sciences (NAS, 1997).

More research has focused on commercial honeybees since farmers often place hives on fields near transmission lines. Greenberg et al. (1981) studied the effect of a 765-kV transmission line on honeybee colonies placed at varying distances from the transmission line's centerline, with some hives exposed to EMF from the line and some shielded. Differences between the shielded and unshielded hives were reported at exposures above 4.1 kV/m, including decreases in hive weight, abnormal amounts of propolis at hive entrances, increased mortality and irritability, loss of the queen in some hives, and a decrease in the hive's overwinter survival.

These adverse effects were reported only in the unshielded group. Since the shielding only prevented exposure to electric fields, not magnetic fields, the results indicate that these adverse effects are attributable to electric field exposure. These results have been replicated by other investigators (Rogers et al., 1980, 1981, 1982). Further studies indicated that the effects were indirect, i.e., the electric fields were not affecting the bees directly, and that field levels greater than 200 kV/m were required to affect the behavior of free-flying bees. Thus, heating of the hive by induced currents caused some of the adverse effects and the rest were attributed to shocks within the hive (Bindokas et al., 1988a, 1988b, 1989). Prevention is easily accomplished by placing a grounded metal cover on top of the hive.

Since the nests of wild bees in the ground or in trees contain no metal or highly conductive materials, there appears to be little relevance of such effects to wild bees. At these locations, wild bees also are naturally shielded from electric fields. Laboratory studies indicate that bees are unable to discriminate 60-Hz magnetic fields reliably at intensities less than 4,300 mG, although they can detect fluctuations in the earth's static geomagnetic field as weak as 0.26 mG (Kirschvink et al., 1997). The difference in the sensitivity of honey bees is an illustration that a sensory mechanism has developed to detect static magnetic fields that effectively rejects extraneous signals, in this case AC (60-Hz) magnetic fields.

Birds

A recent study by Dell'omo et al. (2009) analyzed the effects of exposure to magnetic fields from high-voltage power lines during the embryonic and post-hatching period of kestrel nestling. The authors found that exposure does not have any significant short-term physiological effects on these birds.

The ability of birds to detect and use of the earth's geomagnetic field during migration does not translate to a capability to detect 60-Hz magnetic fields. Scientists have hypothesized that the mechanism for detection of the earth's geomagnetic field by birds (and bees), for which there is the most evidence, indicates they would be far less sensitive to 60-Hz magnetic fields. The WHO suggested that power frequency fields at intensities much less than the earth's geomagnetic field of around 500 mG are unlikely to be of much biological significance in relation to birds' navigational abilities because the changes produced by ELF magnetic fields and static magnetic fields are similar (WHO, 2007).

Finally, in a study by Elmusharaf et al. (2007), veterinarians in the Netherlands noted the beneficial effects of AC magnetic fields in poultry. The researchers infected broiler chickens with coccidiosis and reported that exposure to a 50 mG AC magnetic field for 30 minutes each day for a course of 15 days prior to infection provided significant protection against intestinal lesions and reduced growth characteristic of this disease.

Overall, the research over the course of the past 35 to 40 years does not suggest that electric or magnetic fields result in any adverse effects on the health, behavior, or productivity of fauna, including livestock, small mammals, deer, elk, birds, and bees.

Marine Life

Although transmission lines mostly traverse the land they also frequently cross water bodies as well. Therefore, the potential for effects on certain marine ecological systems are evaluated regarding the potential impact of EMF on aquatic species in rivers and creeks. To date, there is little or no evidence that fish, mammals, or birds exhibit any harmful effects when exposed to EMF of frequencies close to or at power frequencies (50-60 Hz) at levels found under transmission lines, even for a prolonged period of time (e.g., NRC, 1997a, 1997b; NIEHS 1998; WHO, 2007a). Thus, there is no concern that EMF would have any direct toxic effects on the marine biota.

A number of fish species, however, are reported to make use of the earth's geomagnetic field in navigation and migration, including Pacific salmon (*Oncorhynchus spp.*); the chinook salmon (*O. tschawytscha*) and the steelhead (*O. mykiss*) species particularly spend their adult lives in estuarine or oceanic environments and are well known for their annual spawning runs into freshwater, returning to the home streams and rivers where they were spawned and spent the first few months of their lives (Groot and Margolis, 1998). Pacific salmon are an important part of the history, ecology, and economy of the Pacific Northwest region.

Transmission lines will be a source of potential exposure to 60-Hz magnetic fields in rivers and streams below the conductors, but not electric field exposure because the water shields the fish from electric fields. Since the level of EMF decreases with distance from the source, maximum magnetic-field exposures of fish will occur when they are directly under the lines. The magnetic field levels in rivers and streams below transmission lines would be expected to be significantly lower than for spans on land because clearances for river and stream crossings are usually much higher. Additionally, prolonged exposure is not a critical issue as the fish species of most interest are migratory by nature and will only be exposed to magnetic fields during the relatively short time they take to spawn or travel down or up the river during their life cycle.

The Pacific salmon have been thought to navigate by several mechanisms: detecting and orienting to the earth's geomagnetic field, using a celestial compass (i.e., based on the position of the sun in the sky), and using their innate ability to imprint on their home stream by odor (Groot and Margolis, 1998, Quinn et al, 1981).

Generally, scientific studies have reported that, along with other cues or biological mechanisms, certain species of birds, bees, and fish may have magnetite in certain organs in their bodies, and use magnetite crystals as an aid in navigation (Bullock, 1977; Wiltschko and Wiltschko, 1991, Kirschvink et al, 1993, Walker et al. 1988). Crystals of magnetite have been found in Pacific salmon (Mann et al, 1998; Walker et al, 1998). These magnetite crystals are believed to serve as a compass that orients to the earth's magnetic field. Other studies, however, have not found magnetite in sockeye salmon (*Oncorhynchus nerka*) fry (Quinn et al., 1981). While salmon can apparently detect the geomagnetic field, their behavior is governed by multiple stimuli as demonstrated by the ineffectiveness of magnetic field stimuli in the daytime (Quinn et al., 1982) and the inability of strong magnetic fields from permanent magnets attached to sockeye salmon (Ueda et al., 1998) or other salmon (Yano et al., 1997) to alter their migration behavior.

An important consideration is that the earth's geomagnetic field is static (0 Hz), in contrast to the oscillating magnetic field created by AC transmission lines, which produce current that changes direction and intensity 60 times per second. Static magnetic fields have fixed polarity, i.e. the earth's magnetic north and south poles. AC transmission lines produce magnetic fields that do not have fixed polarity.

No studies have been conducted to date that specifically examine the effects of AC magnetic fields on the salmon's ability to orient to the earth's geomagnetic field. Theoretical calculations do not suggest that 60-Hz magnetic fields could affect magnetite at levels less than 50 mG (Adair 1994). Studies on the response of other organisms that also use magnetite crystals as one means of navigation can, however, provide useful insight regarding salmon. Kirschvink et al. (1993) reports studies of the effects of AC magnetic fields on honey bees, which use magnetite crystals to navigate. In this study, the honey bees only oriented to an AC magnetic field when it was one million times greater in intensity than the DC field needed to elicit the same orientation response. This difference in intensity indicates that the AC magnetic field is less influential than the DC magnetic field in the navigation of honey bees and potentially other organisms that orient to the earth's geomagnetic field using magnetite crystals (Kirschvink et al., 1993). The level of AC magnetic fields under transmission lines are well below the levels reported in that study.

The scientific literature does not support the conclusion that the EMF associated with the proposed transmission line will have an adverse impact on the survival, growth, and reproduction of organisms in a marine ecosystem. There are no data on the effects of AC EMF on salmon navigation, but based on a study with honey bees, it appears that organisms that use magnetite crystals to orient to the earth's geomagnetic field would be affected only when the field levels are very much greater than the levels expected from a transmission line. Given this evidence and the salmon’s ability to navigate using multiple sensory cues, overhead transmission lines are unlikely to have an adverse impact on these species of interest and the aquatic ecosystems of these creeks.

4 Standards and Guidelines

Scientific agencies develop exposure standards and guidelines to protect against known health effects following a thorough review of the relevant research. One of the main objectives of weight-of-evidence reviews is to identify the lowest exposure level below which no health hazards have been found (i.e., a threshold level). Exposure limits are then set *well below* the threshold level established by these reviews to take into account individual variability and sensitivity that may exist in susceptible populations.

The only effects known to be produced in humans by exposure to ELF EMF are seen at very high field levels to which the average person is not typically exposed. The effects are short-term, immediate, perceptible reactions to the electrical stimulation of the muscle and the nervous system. These effects are neither severe nor life-threatening.

Two international scientific organizations, ICNIRP and ICES, have published guidelines for limiting public exposure to ELF EMF to protect against these effects (ICNIRP, 1998, 2010; ICES, 2002). ICNIRP is an independent organization of scientists from various disciplines with expertise in the field of non-ionizing radiation assembled from around the world. It is the formally recognized, non-governmental organization that develops safety guidance for non-ionizing radiation for the WHO, the International Labour Organization, and the European Union.

The ICES is sponsored by the American National Standards Institute and IEEE. The mandate for ICES is the "Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the hazards of exposure to man … to such energy."[25] The ICES encourages a balanced international volunteer participation from several sectors: the interested general public; the scientific, health and engineering communities; agencies of governments; energy producers; and energy users.

[25] The ICES is a 50-year-old internationally recognized, EMF standard-setting organization, which is sponsored by the IEEE that itself was established in 1884. The ICES should not be confused with a group of scientists who have acted together as an advocacy group and banded together under the similar name of the International Commission for Electromagnetic Safety in 2003.

Although both organizations have the same objectives and use similar methods, their recommended exposure limits to 60-Hz EMF for the general public differ (Table 9). The ICNIRP recommends screening values for magnetic fields of 833 mG for the general public and 4,200 mG for workers (ICNIRP, 1998). The ICES recommends maximum permissible exposure of 9,040 mG for magnetic fields (ICES, 2002). The ICNIRP's screening value for exposure to 60-Hz electric fields for the general public is 4.2 kV/m and the ICES screening value is 5 kV/m. Both organizations allow higher exposures if it can be demonstrated that exposures do not produce current densities or electric fields within tissues that exceed basic restrictions on internal current densities or electric fields.

Table 9. Reference levels for whole body exposure to 60-Hz fields: general public

Organization recommending limit	**Magnetic fields**	**Electric fields**
ICNIRP restriction level	833 mG	4.2 kV/m
ICES maximum permissible exposure (MPE)	9,040 mG	5 kV/m 10 kV/m[a]

[a] This is an exception within transmission line ROWs because people do not spend a substantial amount of time in ROWs and very specific conditions are needed before a response is likely to occur (i.e., a person must be well insulated from ground and must contact a grounded conductor) (ICES, 2002, p. 27).

These guidelines were developed following a weight-of-evidence review of the literature by each organization, including epidemiologic and experimental evidence related to both short-term and long-term exposure. Both reviews concluded that the stimulation of nerves and the central nervous system could occur at very high exposure levels immediately upon exposure. While ICNIRP and ICES reference levels for electric fields are similar, the reference levels for magnetic fields differ by a factor of 10. As explained by Reilly (2005), this difference results from the way the two guidelines have extrapolated responses of the retina of the eye to magnetic fields at around 20 Hz to higher frequencies and other tissues. Their reviews also concluded that there was not sufficient evidence to support a causal role for EMF in the development of cancer or other long-term adverse health effects. Therefore, neither organization found a basis to recommend quantitative exposure guidelines to prevent effects at lower exposure levels.

Following the publication of their 1998 guidelines, the ICNIRP published an evaluation of the epidemiologic literature (ICNIRP, 2001) and a full weight-of-evidence evaluation of health research on EMF (ICNIRP, 2003), concluding again that there is no basis for exposure restrictions for long-term health effects. In June 2009, the ICNIRP published an updated review of the scientific literature related to potential short- and long-term adverse effects, and *draft* guidelines to replace their 1998 ELF EMF exposure guidelines (ICNIRP, 2009). The document recommended no changes to the screening values shown in Table 9, nor did the final standard that was published in December 2010. .

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 transmission line ROWs (150 mG and 200 mG, respectively) (NYPSC, 1978, 1990; FDER, 1989; FDEP, 1996). The basis for limiting magnetic fields from transmission lines was to maintain the status quo so that fields from new transmission lines would be no higher than those produced by existing transmission lines.

5 References

Abdul Rahman HI, Shah SA, Alias H, Ibrahim HM. A case-control study on the association between environmental factors and the occurrence of acute leukemia among children in Klang Valley, Malaysia. Asian Pac J Cancer Prev 9:649-652, 2008.

Adair RK. Constraints of thermal noise on the effects of weak 60-Hz magnetic fields acting on biological magnetite. Proc Natl Acad Sci U S A. 91:2925–2929, 1994.

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

Aksen F, Adkag MZ, Ketani A, Yokus B, Kaya A, Dasdag S. Effect of 50-Hz 1-mT magnetic field on the uterus and ovaries of rats (electron microscopy evaluation). Med Sci Monit 12:BR215-220, 2006.

Al-Akhras MA, Darmani H, Elbetieha A. Influence of 50 Hz magnetic field on sex hormones and other fertility parameters of adult male rats. Bioelectromagnetics 27:127-31, 2006.

Al-Akras MA. Influence of 50 Hz magnetic field on sex hormones and body, uterine, and ovarian weights of adult female rats. Electromagnetic Biology and Medicine 27:155-163, 2008.

American Conference of Government Industrial Hygienists (ACGIH). Documentation of the Threshold Limit Values and Biological Exposure Indices, 7th edition. Publication No. 0100. Cincinnati, OH: American Conference of Government Industrial Hygienists, 2001.

Andel R, Crowe M, Feychting M, Pedersen NL, Fratiglioni L, Johansson B, Gatz M. Work-related exposure to extremely low-frequency magnetic fields and dementia: results from the population-based study of dementia in Swedish twins. Journal of Gerontology [E-Pub ahead of print], 2010.

Anderson LE, Boorman GA, Morris JE, Sasser LB, Mann PC, Grumbein SL, Hailey JR, McNally A, Sills RC, Haseman JK. Effect of 13 week magnetic field exposures on DMBA-initiated mammary gland carcinomas in female Sprague-Dawley rats. Carcinogenesis 20:1615-1620, 1999.

Anselmo CW, Santos AA, Freire CM, Ferreira LM, Cabral Filho JE, Catanho MT, and Medeiros Mdo C. Influence of a 60 Hz, 3 microT, electromagnetic field on the reflex maturation of Wistar rats offspring from mothers fed a regional basic diet during pregnancy. Nutr Neurosci 9:201-6, 2006.

Anselmo CS, Silva TL, Holanda TG, Prado LV, Cabral-Filho JE, Catanho MT, Medeiros MC. Influence of a 60 Hz, microT, electromagnetic field on the somatic maturation of wistar rat offspring fed a regional basic diet during pregnancy. Braz J Biol 68:641-648, 2008.

Astridge PS, Kaye GC, Whitworth S, Kelly P, Camm AJ, Perrins EJ. The response of implanted dual chamber pacemakers to 50 Hz extraneous electrical interference. Pacing Clin Electrophysiol 16:1966-1974, 1993.

Auger N, Joseph D, Goneau M, Daniel M. The relationship between residential proximity to extremely low frequency power transmission lines and adverse birth outcomes. J Epidemiol Community Heath [E-Pub ahead of print], 2010.

Australian Centre for Radiofrequency Bioeffects Research (ACRBR). ACRBR Position Statement on BioInitiative Report. December 18, 2008. http://www.acrbr.org.au/FAQ/ACRBR%20Bioinitiative%20Report%2018%20Dec%202008.pdf

Aydin M, Cevik A, Kandemir FM, Yuksel M, and Apaydin AM. Evaluation of hormonal change, biochemical parameters, and histopathological status of uterus in rats exposed to 50-Hz electromagnetic field. Toxicology and Industrial Health 25:352-158, 2009.

Bankoske JW. The effects of high voltage electric fields on the growth and development of plants and animals. Proceedings of the First National Symposium on Environmental Concerns in Rights-of-Way Management at Mississippi State University, pp. 112-123, 1976.

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

Begall S, Červený J, Neef J, Voljtěch O, Burda H. Magnetic alignment in grazing and resting cattle and deer. PNAS 105:13451-13455.

Bernabò N, Tettamanti E, Pistilli MG, Nardinocchi D, Berardinelli P, Mattioli M, Barboni B. Effects of 50 Hz extremely low frequency magnetic field on the morphology and function of boar spermatozoa capacitation in vitro. Theriogenology 67:801-815, 2007.

Bernard N, Alberdi AJ, Tanguy ML, Brugere H, Helissey P, Hubert C, Gendrey N, Guillosson JJ, Nafziger J. Assessing the potential Leukemogenic effects of 50 Hz and their harmonics using an animal leukemia model. Journal of Radiation Research 49:565-577, 2008.

Bindokas VP, Gauger JR, Greenberg B. Exposure scheme separates effects of electric shock and electric field for honey bees, *Apis mellifera, L.* Bioelectromagnetics 9:275-284, 1988a.

Bindokas VP, Gauger JR, Greenberg B. Mechanism of biological effects observed in honey bees (*Apis mellifera, L.)* hived under extra-high-voltage transmission lines: implications derived from bee exposure to simulated intense electric fields and shocks. Bioelectromagnetics 9:285-301, 1988b.

Bindokas VP, Gauger JR, Greenberg B. Laboratory investigations of the electrical characteristics of honey bees and their exposure to intense electric fields. Bioelectromagnetics 10:1-12, 1989.

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

Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, Kovatch RM, Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. Toxicologic Pathology 27:267-78, 1999b.

Brulfert A, Miller MW, Robertson D, Dooley DA, Economou P. A cytohistological analysis of roots whose growth is affected by a 60-Hz electric field. Bioelectromagnetics. 6:283-291, 1985.

Bullock TH. Electromagnetic sensing in fish. Neurosciences Res Prog Bull 15:17-12, 1977.

Burchard JF, Monardes H, Nguyen DH. Effect of 10 kV, 30 mT, 60 Hz electric and magnetic fields on milk production and feed intake in nonpregnant dairy cattle. Bioelectromagnetics 24:557-563, 2003.

Burchard JF, Nguyen DH, Monardes HG, Petitclerc D. Lack of effect of 10 kV/m 60 Hz electric field exposure on pregnant dairy heifer hormones. Bioelectromagnetics 25:308-312, 2004.

Burchard JF, Nguyen DH, Monardes HG. Exposure of pregnant dairy heifer to magnetic fields at 60 Hz and 30 uT. Bioelectromagnetics 28:471-476, 2007.

Burda H, Begall S, Červený J, Neef J, Němec, P. Extremely low-frequency electromagnetic fields disrupt magnetic alignment of ruminants. PNAS 106:5708-5713, 2009.

Burdak-Rothkamm S, Rothkamm K, Folkard M, Patel G, Hone P, Lloyd D, Ainsbury L, Prise KM. DNA and chromosomal damage in response to intermittent extremely low frequency magnetic fields. Mutation Research 672:82-89, 2009.

Chen C, Ma X, Zhong M, Yu Z. Extremely low frequency electromagnetic fields exposure and female breast cancer risk: a meta-analysis based 24,338 cases and 60,628 controls. Breast Cancer Res Treat 2010 Feb 10 [Epub ahead of print].

Chung M-K, Kim Y-B, Ha C-S, Myung S-H. Lack of a co-promotion effect of 60 Hz rotating magnetic fields on n-ethyl-n-nitrosourea induced neurogenic tumors in F344 rats. Bioelectromagnetics 29:539-48, 2008.

Coble JB, Dosemeci M, Stewart PA, Blair A, Bowman J, Fine HA, Shapiro WR, Selker RG, Loeffler JS, Black PM, Linet MS, Inskip PD. Occupational exposure to magnetic fields and the risk of brain tumors. Neuro Oncol 11:242-249, 2009.

Conti R, Nicolini P, Cerretelli P, Maronato V, Veicsteinas A, Floris C. Enel's research activity on possible biological effects of 50 Hz electromagnetic fields – results and plans of a large research programme. Alta Frequenza 58:395-378, 1989.

Costanzo E. The influence of an electric field on the growth of soy seedlings. Journal of Electrostatics 66:417-420, 2008.

Davanipour Z, Tseng CC, Lee PJ, Sobel E. A case-control study of occupational magnetic field exposure and Alzheimer's disease: results from the California Alzheimer's Disease Diagnosis and Treatment Centers. BMC Neurol 7:13, 2007.

Davanipour Z and Sobel E. Long-term exposure to magnetic fields and the risk of Alzheimer's disease and breast cancer: Further biological research. Pathophysiology 16:149-156, 2009.

Davies MS. Effects of 60 Hz electromagnetic fields on early growth in three plant species and a replication of previous results. Bioelectromagnetics 17:154-161, 1996.

De Bruyn L and De Jager L. Effect of long-term exposure to a randomly varied 5 Hz power frequency magnetic field on the fertility of the mouse. Electromagnetic Biology and Medicine 29:52-61, 2010.

Dell'omo G, Costantini D, Lucini V, Antonucci G, Nonno R, Polichetti A. Magnetic fields produced by power lines do not affect growth, serum melatonin, leukocytes and fledging success in wild kestrels. Comp Biochem Physiol Toxicol Pharmacol 150:372-376, 2009.

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

Dundar B, Cesur G, Comlekci S, Songur A, Gokcimen A, Sahin O, Ulukut O, Yilmaz HR, Sutcu R, Caliskan S. The effect of the prenatal and post-natal long-term exposure to 50 Hz electric field on growth, pubertal development and IGF-1 levels in female Wistar rats. Toxicology and Industrial Health 25:479-487, 2009.

Electric Power Research Institute (EPRI). Electromagnetic Interference With Implanted Medical Devices: 1997-2003. Report No.1005570, 2004. A summary can be found at: http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=221&PageIDqueryComId=0

Elmusharaf MA, Cuppen JJ, Grooten NA, Beynen AC. Antagonistic effect of electromagnetic field exposure on coccidiosis infection in broiler chickens. Poultry Science 86:2139-2143, 2007.

Elwood JM. Childhood leukemia and residential magnetic fields: are pooled analyses more valid than the original studies? Bioelectromagnetics 27:112-118, 2006.

Fadel RAR, Salem A-H, Ali MH, Abu-Saif AN. Growth assessment of children exposed to low frequency electromagnetic fields at the Abu Sultan area in Ismailia (Egypt). Antrop Anz 64:211-226, 2006.

Farkhad SA, Zare S, Hayatgeibi H, Qadiri A. Effects of extremely low frequency electromagnetic fields on testes in guinea pig. Pakistan Journal of Biological Sciences 10:4519-4522, 2007.

Federal-Provincial-Territorial Radiation Protection Committee (FPTRPC). Heath Effects and Exposure Guidelines Related to Extremely Low Frequency Electric and Magnetic Fields - An Overview. Prepared by The ELF Working Group, 2005.

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

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

Feizi AA and Arabi MA. Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines – a risk factor in Iran. Asian Pac J Cancer Prev 8:69-72, 2007.

Feychting M, Jonsson F, Pedersen NL, Ahlbom A. Occupational magnetic field exposure and neurodegenerative disease. Epidemiology 14:413-419, 2003.

Florida Department of Environmental Regulation (FDER). Electric and Magnetic fields. Chapter 17-274. Department of Environmental Regulation Rules, March, 1989.

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

Foliart DE, Pollock BH, Mezei G, Iriye R, Silva JM, Ebi KL, Kheifets L, Link MP, Kavet R. Magnetic field exposure and long-term survival among children with leukaemia. Br J Cancer 94:161-164, 2006.

Foliart DE, Mezei G, Iriye R, Silva JM, Ebi KL, Kheifets L, Link MP, Kavet R, Pollock BH. Magnetic field exposure and prognostic factors in childhood leukemia. Bioelectromagnetics 28:69-71, 2007.

Forssén UM, Lonn S, Ahlbom, Savitz DA, and Feychting M. Occupational magnetic field exposure and the risk of acoustic neuroma. Am J Ind Med 49:112-8, 2006.

Framm J and Lautner S. Electrical signals and their physiological significance in plants. Plant Cell Environm 30: 249-257, 2007.

García AM, Sisternas A, Hoyos SP. Occupational exposure to extremely low frequency electric and magnetic fields and Alzheimer disease: a meta-analysis. Int J Epidemiol 37:329-40, 2008.

Gobba F, Bargellini A, Scaringi M, Bravo G, Borella P. Extremely low frequency-magnetic fields (ELF-EMF) occupational exposure and natural killer activity in peripheral blood lymphocytes. Sci Total Environ 407:1218-1223, 2009.

Greene RW. 60 Hz ultra-high voltage electric field effect on onion root mitotic index: a lack of impact. Environ Exp Bot 23:355-360, 1983.

Greenberg B, Bindokas VP, Gauger JR. Biological effects of a 765-kV transmission line: Exposures and thresholds in honeybee colonies. Bioelectromagnetics 2:315-328, 1981.

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

Groot C and Margolis L. (eds.). Pacific Salmon Life Histories. Vancourver: UBC Press, 1998.

Hardell L and Sage C. Biological effects from electromagnetic field exposure and public exposure standards. Biomedicine & Pharmacotherapy 62:104-109, 2008.

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

Health Council of the Netherlands (HCN). BioInitiative Report. U-5601/EvR/iv/673-L1 Publication nr 2008/17E. September 2008.

Health Council of the Netherlands (HCN). Health Council of the Netherlands; Reports 2008. The Hague: Health Council of the Netherlands. Publication No. A09/02, 2009.

Health Protection Agency (HPA). Power frequency electromagnetic fields, melatonin and the risk of breast cancer: report of an independent advisory group on non-ionising radiation. Doc HPA. Serious B: Radiation, Chemical and Environmental Hazards. RCE-1, 2006.

Her Majesty's Government (HMG) - Department of Health, Department for Communities and Local Government & Department of Energy and Climate Change. Government response to the Stakeholder Advisory Group on extremely low frequency electric and magnetic fields (ELF EMFs) (SAGE) recommendations. 16 October 2009. http://webarchive.nationalarchives.gov.uk/+/www.dh.gov.uk/en/Publichealth/Healthprotection/DH_4089500.

Hilson DW, Noggle JC, Burns ER. Effects of Electric Field on Plants Growing Under High Voltage Transmission Lines. Office of Natural Resources, Air Quality Branch. Tennessee Valley Authority. Chattanooga, Tennessee. 1983.

Hodges TK and Mitchell CA. Influence on High Intensity Electric Fields on Yield of Sweet Corn and Dent Corn-1982. A report for the American Electric Power Service Corporation. North Liberty, Indiana. 1984.

Hodges TK, Mitchell CA, Heydt G. Effect of Electric Fields from 765-kV Transmission Lines on Plant Growth. A report by Purdue University for Indiana and Michigan Electric Company, a Subsidiary of American Electric Power. New York, New York. 1975.

Huang H-H and Wang S-R. The effects of inverter magnetic fields on early seed germination of mung beans. Bioelectromagnetics 29: 649-657, 2008.

Hug K, Grize L, Seidler A, Kaatsch P, Schüz J. Parental occupational exposure to extremely low frequency magnetic fields and childhood cancer: A German case-control study. Am J Epidem 171:27-35, 2010.

Huss A, Spoerri A, Egger M, Röösli M, for the Swiss National Cohort Study. Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population. Am J Epidemiol 169:167-175, 2009.

International Agency for Research on Cancer (IARC). Mechanisms of carcinogenesis in risk identification. No. 116. Lyon, France: IARC Press, 1992.

International Agency for Research on Cancer (IARC). IARC monographs on the evaluation of carcinogenic risks to humans. Volume 80: static and extremely low-frequency (ELF) electric and magnetic fields. Lyon, France: IARC Press, 2002.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys 74:494-522, 1998.

International Commission for Non-Ionizing Radiation Protection (ICNIRP). Review of the epidemiologic literature on EMF and health. Environ Health Perspect 109:S911-S933, 2001.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Exposure to Static and Low Frequency Electromagnetic Fields, Biological Effects and Health Consequences (0-100 kHz) – Review of the Scientific Evidence on Dosimetry, Biological Effects, Epidemiological Observations, and Health Consequences Concerning Exposure to Static and Low Frequency Electromagnetic Fields (0-100 kHz). Matthes R, McKinlay AF, Bernhardt JH, Vecchia P, Beyret B (eds.). International Commission on Non-Ionizing Radiation Protection, 2003.

International Commission on Non-ionizing Radiation Protection (ICNIRP). Draft Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys 96:504-514, 2009.

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

International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz C95. 6-2002. Piscataway, NJ: IEEE, 2002.

Ivancsits S, Diem E, Pilger A, Rüdinger HW, Jahn O. Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts. Mutat Res 519:1-13, 2002a.

Ivancsits S, Pilger A, Diem E, Schaffer A, Rüdinger HW. Vanadate induces DNA strand breaks in cultured human fibroblasts at doses relevant to occupational exposure. Mutat Res 519:25-35, 2002b.

Ivancsits S, Diem E, Jahn O, Rüdiger HW. Age-related effects on induction of DNA strand breaks by intermittent exposure to electromagnetic fields. Mech Ageing Dev 124:847-850, 2003a.

Ivancsits S, Diem E, Jahn O, Rüdiger HW. Intermittent extremely low frequency electromagnetic fields cause DNA damage in a dose-dependent way. Int Arch Occup Environ Health 76:431-436, 2003b.

Johansen C and Olsen JH. Risk of cancer among Danish utility workers--a nationwide cohort study. Am J Epidemiol 147:548-55, 1998.

Johansen C, Raaschou-Nielsen O, Olsen JH, Schuez J. Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up. Occup Environ Med 64:782-4, 2007.

Johansson O. Disturbance of the immune system by electromagnetic fields – A potentially underlying cause for cellular damage and tissue repair reduction which could lead to disease and impairment. Pathophysiology 16:157-177, 2009.

Joosten S, Pammler K, Silny J. The influence of anatomical and physiological parameters on the interference voltage at the input of unipolar cardiac pacemakers in low frequency electric fields. Phys Med Biol 54:591-609, 2009.

Karipidis KK, Benke G, Sim MR, Yost M, and Giles G. Occupational exposure to low frequency magnetic fields and the risk of low grade and high grade glioma. Cancer Causes Control 18:305-13, 2007a.

Karipidis K, Benke G, Sim M, Fritschi L, Yost M, Armstrong B, Hughes AM, Grulich A, Vajdic CM, Kaldor J, and Kricker A. Occupational exposure to power frequency magnetic fields and risk of non-Hodgkin lymphoma. Occup Environ Med 64:25-9, 2007b.

Kavet R and Hooper HC. Residential magnetic fields and measures of neutral-to-earth voltage: Variability within and between residences. Health Physics 97:332-341, 2009.

Khaki AA, Zarrintan S, Khaki A, Zahedi A. The effects of electromagnetic field on the microstructure of seminal vesicles in rat: a light and transmission electron microscope study. Pakistan Journal of Biological Sciences 11:692-701, 2008.

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

Kheifets L, Monroe J, Vergara X, Mezei G, Afifi A. Occupational electromagnetic fields and leukemia and brain cancer: An update to two meta-analyses. JOEM 50:677-88, 2008.

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

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

Kim Y-W, Kim H-S, Lee J-S, Kim Y-J, Lee S-K, Seo J-N, Jung K-C, Kim N, Gimm Y-M. Effects of 60 Hz 14 µT magnetic field on the apoptosis of testicular germ cell in mice. Bioelectromagnetics 30: 66-72, 2009.

Kirschvink, JL; Diaz Ricci, J; Nesson, MH; Kirschvink, SJ Magnetite-based magnetoreceptors in animals: structural, behavioral, and biophysical studies. Palo Alto: Electric Power Research Institute (EPRI), TR-102008, September 1993.

Kirschvink JL, Padmanabha S, Boyce KC, Ogelsby J. Measurement of the threshold sensitivity of honeybees to weak, extremely low-frequency magnetic fields. Journal of Experimental Biology 200:1363-1368, 1997.

Krizaj D and Valencic V. The effects of ELF magnetic fields and temperature on differential plant growth. Journal of Bioelectricity 8:159-165, 1989.

Kroll ME, Swanson J, Vincent TJ, Draper GJ. Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: a case-control study. British Journal of Cancer 103:1122-1127, 2010.

Lai H and Singh NP. Magnetic-field-induced DNA strand breaks in brain cells of the rat. Environ Health Perspect 112:687-694, 2004.

Lee JM and Clark CF. Ecological Effects of EHV and UHV Transmission Lines Current Issues. In: CIRGE Symposium on Transmission Lines and the Environment. June 23-25. Stockholm, Sweden. 223-307, 1981.

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

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

Li P, McLaughlin J, Infante-Rivard C. Maternal occupational exposure to extremely low frequency magnetic fields and the risk of brain cancer in the offspring. Cancer Causes Control 20:945-955, 2009.

Linet MS, Hatch EH, Kleinerman A, Robinson LL, Kaune WT, Friedman DR, Severson RK, Haines CM, Hartsock CT, Niwa S, Wachholder S, and Tarone RE. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. N Engl J Med 337:1-7, 1997.

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

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

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

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

Lowenthal RM, Tuck DM, Bray IC. Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study. Internal Med J 37:614-9, 2007.

Malagoli C, Fabbi S, Teggi S, Calzari M, Poli M, Ballotti E, Notari B, Bruni M, Plazaai G, Paolucci P, Vinceti M. Risk of hematological malignancies associated with magnetic fields exposure from power lines: A case control study in two municipalities of northern Italy. Environ Health 9:16, 2010.

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

Mann, S.; Sparks, N.H.C.; Walker, M.M.; Kirschvink, J.L. Ultrastructure, Morphology and Organization of Biogenic Magnetite from Sockeye Salmon, *Oncorhynchus nerka*: Implications for Magnetoreception. Journal of Experimental Biology 140:35-49, 1988.

Maslanyj M, Simpson J, Roman E, Schüz J. Power frequency magnetic fields and risk of childhood leukaemia: Misclassification of exposure from the use of the distance from power line' exposure surrogate. Bioelectromagnetics 30:183-188, 2009

McBride ML, Gallagher RP, Thériault G, Armstrong BG, Tamaro S, Spinelli JJ, Deadman JE, Fincham S, Robson D, Choi W. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. Am J Epidemiol 149:831-42, 1999.

McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, Pletcher JM, Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice. Toxicol Pathol 27:279-85, 1999.

McElroy JA, Egan KM, Titus-Ernstoff L, Anderson HA, Trentham-Dietz A, Hampton JM, Newcomb PA. Occupational exposure to electromagnetic field and breast cancer risk in a large, population-based, case-control study in the United States. J Occup Environ Med 49:266-74, 2007.

McKee GW, Knievel DP, Poznaniak DT, Bankoske JW. Effects of 60 Hz high intensity electric fields on living plants. IEEE Transactions on Power Apparatus Systems 97:1177-1181, 1978.

McNally RJQ and Parker L. Environmental factors and childhood acute leukemias and lymphomas. Leukemia & Lymphoma 47:583-98, 2006.

Mejia-Arangure JM, Fajardo-Gutierrez A, Perez-Saldivar ML, Gorodezky C, Martinez-Avalos A, Romero-Guzman L, Campo-Martinez MA, Flores-Lujano J, Salamanca-Gomez F, Velasquez-Perez L. Magnetic fields and acute leukemia in children with Down syndrome. Epidemiology 18:158-61, 2007.

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

Mevissen M, Wahnschaffe U, Löscher W, Stamm A, Lerchl A. Effects of AC magnetic field on DMBA-induced mammary carcinogenesis in Sprague-Dawley rats. In: Electricity and Magnetism in Biology and Medicine. Blank M (ed). San Francisco Press, pp. 413-415, 1993b.

Mevissen M, Lerchl A, Löscher W. Study on pineal function and DMBA-induced breast cancer formation in rats during exposure to a 100-mG, 50 Hz magnetic field. J Toxicol Environ Health 48:169-185, 1996a

Mevissen M, Lerchl A, Szamel M, and Löscher W. Exposure of DMBA-treated female rats in a 50 Hz, 50-μT magneticfield: effects on mammary-tumor growth, melatonin levels, and T-lymphocyte activation. Carcinogenesis 17:903-910, 1996b.

Mevissen M, Haussler M, Lerchl A, Löscher W. Acceleration of mammary tumorigenesis by exposure of 7,12-dimethylbenz[a]anthracene-treated female rats in a 50 Hz, 100-microT magnetic field: replication study. J Toxicol Environ Health A 53:401-418, 1998.

Mezei G, Bracken TD, Senior R, Kavet R. Analyses of magnetic-field peak-exposure summary measures. J Expo Sci Environ Epidemiol 16:477-85, 2006.

Mezei G and Kheifets L. Selection bias and its implications for case-control studies: a case study of magnetic field exposure and childhood leukaemia. Int J Epidemiol 35:397-406, 2006.

Mezei G, Gadallah M, Kheifets L. Residential magnetic field exposure and childhood brain cancer: a meta-analysis. Epidemiology 29:424-30, 2008a.

Mezei G, Spinelli JJ, Wong P, Borugian M, McBride ML. Assessment of selection bias in the Canadian case-control study of residential magnetic field exposure and childhood leukemia. Am J Epidemiol 167:1504-10, 2008b.

Mihai R, Cogalniceanu G, Brezeanu, A. Control of *nicotiana tabacum callus* growth by alternating and pulsed electric field. Electro- and Magnetobiology 13:195-201, 1994.

Miller MW, Carstensen EL, Kaufman GE, Robertson D. 60-Hz electric field parameters associated with the perturbation of a eukaryotic system. In: Biological effects of extremely low frequency electromagnetic fields. Proceedings of the Eighteenth Annual Hanford Life Sciences Symposium at Richland, Washington, October 16-18, 1978.

Mostafa RM, Moustafa YM, Ali FM, Shafik A. Sex hormone status in male rats after exposure to 50 Hz, 5 mT magnetic field. Archives of Andrology 52:363-369, 2006.

National Academy of Sciences (NAS), National Research Council. Possible Effects of Electromagnetic Fields on Biologic Systems. Washington, DC: National Academy of Sciences Press, 1997.

National Institute of Environmental Health Sciences (NIEHS). Assessment of health effects from exposure to power-line frequency electric and magnetic fields: working group report. NIH Publication No. 98-3981. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health, 1998.

National Institute of Environmental Health (NIEHS). Health effects from exposure to power line frequency electric and magnetic fields. NIH Publication No. 99-4493. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health, 1999.

National Institute of Environmental Health (NIEHS). EMF Electric and Magnetic Fields Associated with the use of Electric Power: Questions and Answers. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health, 2002.

National Radiological Protection Board (NRPB). Electromagnetic fields and the risk of cancer. Report of an Advisory Group on Non-ionising Radiation. National Radiological Protection Board 3(1):1-138, 1992.

National Radiological Protection Board (NRPB). Electromagnetic fields and the risk of cancer. Supplementary report by the Advisory Group on Non-ionising Radiation. National Radiological Protection Board 4(5):65-69, 1993.

National Radiological Protection Board (NRPB). Electromagnetic fields and the risk of cancer. Supplementary report by the Advisory Group on Non-ionising Radiation. National Radiological Protection Board 5(2):77-81, 1994a.

National Radiological Protection Board (NRPB). Health effects related to the use of visual display units. Report of an Advisory Group on Non-ionising Radiation. National Radiological Protection Board 5(2):1-75, 1994b.

National Radiological Protection Board (NRPB). ELF Electromagnetic Fields and the Risk of Cancer: Report of an Advisory Group on Non-ionising Radiation. National Radiological Protection Board. Volume 12, No 1, 2001a.

National Radiological Protection Board (NRPB). ELF Electromagnetic fields and neurodegenerative disease. National Radiological Protection Board. Volume 12, No 4, 2001b.

National Radiological Protection Board (NRPB). Review of the scientific evidence for limiting exposure to electromagnetic fields (0-300 GHz). National Radiological Protection Board (NRPB). Volume 15, No 3, 2004.

National Research Council; Commission on Life Sciences; Board on Radiation Effects Research; Committee on the Possible Effects of Electromagnetic Fields on Biologic Systems. Possible Health Effects of Exposure to Residential Electric and Magnetic Fields. Washington, DC: National Academy Press. 1997a.

National Research Council. An Evaluation of the U.S. Navy's Extremely Low Frequency Communications System Ecological Monitoring Program. National Academy Press, Washington, D.C. 162 pp. 1997b.

National Toxicology Program (NTP). NTP technical report on the toxicology and carcinogenesis studies of 60 Hz magnetic fields in F344/N rats and B6C3F1 mice. Washington DC, National Toxicology Program. NTP TR 488, NIH Publication No. 99-3979. 1999.

Negishi T, Imai S, Shibuya K, Nishimura I, Shigemitsu T. Lack of promotion effects of 50 Hz magnetic fields on 7,12-dimethylbenz(a)anthracene-induced malignant lymphoma/lymphatic leukemia in mice. Bioelectromagnetics 29:29-38, 2008.

Neutra RR and Li D. Letter to the Editor – Magnetic fields and miscarriage: A commentary on Mezei et al., JESEE 2006. JESEE 18:537-540, 2008.

New York Public Service Commission (NYPSC). Opinion No. 78-13. Opinion and Order Determining Health and Safety Issues, Imposing Operating Conditions, and Authorizing, in Case 26529, Operation Pursuant to Those Conditions. Issued June 19, 1978.

New York Public Service Commission (NYPSC). Statement of Interim Policy on Magnetic Fields of Major Transmission Facilities. Cases 26529 and 26559 Proceeding on Motion of the Commission. Issued and Effective: September 11, 1990.

Okudan B, Keskin AU, Aydin MA, Cesur G, Comlekci S, Suslu H. DEXA analysis on the bones of rats exposed in utero and neonatally to static and 50 Hz electric fields. Bioelectromagnetics 27:589-92, 2006.

Parsch LD and Norman MD. Impact of power lines on crop yields in eastern Arkansas. Arkansas Farm Research (September-October):4, 1986.

Pearce MS, Hammal DM, Tevfik Dorak M, McNally RJQ, Parker L. Paternal occupational exposure to electro-magnetic fields as a risk factor for cancer in children and young adults: A case-control study from the north of England. Pediatr Blood Cancer 49:280-286, 2007.

Poulletier de Gannes F, Ruffie G, Taxile M, Ladeveze E, Hurtier A, Haro E, Duleu S, Charlet de Sauvage R, Billaudel B, Geffard M, Veyret B, Lagroye I. Amyotrophic lateral sclerosis (ALS) and extremely-low frequency (ELF) magnetic fields: a study in the SOD-1 transgenic mouse model. Amyotroph Lateral Sclerosis, 2008 (e-pub ahead of print).

Quinn TP, Merrill RT, Brannon EL. Magnetic field detection in Sockeye salmon. Journal of Experimental Zoology 217:137-142, 1981.

Quinn TP and Brannon EL. The Use of Celestial and Magnetic Cues by Orienting Sockeye Salmon Smolts. Journal of Comparative Physiology 147:547-552, 1982.

Rajaei F, Borhani N, Sabbagh-Ziarani F, Mashayekhi F. Effects of extremely low-frequency electromagnetic field on fertility and heights of epithelial cells in pre-implantation stage endometrium and fallopian tube in mice. Journal of Chinese Integrative Medicine 8:56-60, 2010.

Ray RM, Gao DL, Li W, Wernli KJ, Astrakianakis G, Seixas NS, Camp JE, Fitzgibbons ED, Feng Z, Thomas DB, and Checkoway H. Occupational exposures and breast cancer among women textile workers in Shanghai. Epidemiology 18:383-92, 2007.

Reed DD, Jones EA, Mroz GD, Liechty HO, Cattelino PJ, Jurgensen MF. Effects of 76 Hz electromagnetic fields on forest ecosystems in northern Michigan: tree growth. Int J Biometeorol 37:229-234, 1993.

Reilly JP. An analysis of differences in the low-frequency electric and magnetic field exposure standards of ICES AND ICNIRP. Health Physics 89:71-80, 2005.

Rodriguez M, Petitclerc D, Burchard JF, Nguyen DH, Block E. Blood melatonin and prolactin concentrations in dairy cows exposed to 60 Hz electric and magnetic fields during 8 h photoperiods. Bioelectromagnetics 25:508-515, 2004.

Rodriguez M, Petitclerc D, Burchard JF, Nguyen DH, Block E, Downey BR. Responses of the estrous cycle in dairy cows exposed to electric and magnetic fields (60 Hz) during 8-h photoperiods. Anim Reprod Sci 77:11-20, 2003.

Rodriguez M, Petitclerc D, Nguyen DH, Block E, Burchard JF. Effect of electric and magnetic fields (60 Hz) on production, and levels of growth hormone and insulin-like growth factor 1, in lactating, pregnant cows subjected to short days. J Dairy Sci 85:2843-2849, 2002.

Rogers LE, Warren JL, Gano KA, Hinds NR, Fitzner RE, Gilbert RO. Environmental Studies of a 1100-kV Prototype Transmission Line: An Interim Report. Prepared by Batelle Pacific Northwest Laboratories for Bonneville Power Administration. Portland, Oregon, 1980.

Rogers LE, Warren JL, Hinds NR, Gano KA, Fitzner RE, Piepel GF. Environmental Studies of a 1100-kV Prototype Transmission Line: Annual report for the 1980 Study Period. Battelle Pacific Northwest Laboratories. Portland, Oregon. 1981.

Rogers LE, Warren NR, Hinds KA, Gano RE, Fitzner RE, Peipel GF. Environmental Studies of a 1100-kV Prototype Transmission Line: An Annual Report for the 1981 Study Period. Prepared by Battelle Pacific Northwest Laboratories for Bonneville Power Administration. Portland, Oregon. 1982.

Röösli M, Lörtscher M, Egger M, Pfluger D, Schreirer N, Emanuel L, Locher P, Spoerri A, Minder C. Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees. Occup Environ Med 64:553-9, 2007a.

Röösli M, Lörtscher M, Egger M, Pfluger D, Schreirer N, Lörtscher E, Locher P, Spoerri A, Minder C. Mortality from neurodegenerative disease and exposure to extremely low-frequency magnetic fields: 31 years of observations on Swiss railway employees. Neuroepidemiol 28:197-206, 2007b.

Roushanger L and Soleimani Rad J. Ultrastructural alterations and occurrence of apoptosis in developing follicles exposed to low frequency electromagnetic field in rat ovary. Pakistan Journal of Biological Sciences 10:4413-4419, 2007.

Ruzic R, Jerman I, Jeglic A, Fefer D. Electromagnetic stimulation of buds of *Castanea sativa, mill*. In tissue culture. Electro- and Magnetobiology 11:145-153, 1992.

Saito T, Nitta H, Kubo O, Yamamoto S, Yamaguchi N, Akiba S, Honda Y, Hagihara J, Isaka K, Ojima T, Nakamura Y, Mizoue T, Ito S, Eboshida A, Yamazaki S, Sokejima S, Kurokawa Y, Kabuto M. Power-frequency magnetic fields and childhood brain tumors: A case-control study in Japan. J Epidemiol 20:54-61, 2010.

Santibáñez M, Bolumar F, García AM. Occupational risk factors in Alzheimer's disease: a review assessing the quality of published epidemiological studies. Occup Environ Med 64:723-732, 2007.

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

Savitz DA. The etiology of epidemiologic perseveration: when enough is enough. Epidemiology 21:281-283, 2010.

Savitz DA, Checkoway H, Loomis DP. Magnetic field exposure and neurodegenerative disease mortality among electric utility workers. Epidemiology 9:398-404, 1998.

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

Scarfi MR, Sannino A, Perrotta A, Sarti M, Mesirca P, Bersani F. Evaluation of genotoxic effects in human fibroblasts after intermittent exposure to 50 Hz electromagnetic fields: a confirmatory study. Radiat Res 164:270-6, 2005.

Scholten A and Silny, J. The interference threshold of cardiac pacemakers in electric 50 Hz fields. J Med Eng Technol 25:1-11, 2001.

Schüz J and Ahlbom A. Exposure to electromagnetic fields and the risk of childhood leukaemia: A review. Radiat Prot Dosimetry 132:202-211, 2008.

Schüz J, Svendsen AL, Linet MS, McBride ML, Roman E, Feychting M, Kheifets L, Lightfoot T, Mezei G, Simpson J, Ahlbom A. Nighttime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis. Am J Epidemiol 166:263-269, 2007.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Possible Effects of Electromagnetic Fields (EMF) on Human Health. European Commission. Directorate C – Public Health and Risk Assessment, 2007.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) for the Directorate-General for Health & Consumers of the European Commission. Health Effects of Exposure to EMF. January 2009.

Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE). Possible Effects of Electromagnetic Fields (EMF), Radio Frequency Fields (RF) and Microwave Radiation on Human Health. 2001.

Scientific Steering Committee (SSC). Opinion on possible health effects from exposure to electromagnetic fields (0 Hz- 300 GHz) - Report and opinion adopted at the meeting of the Scientific Steering Committee of 25-26 June 1998.

Schmiedel S and Blettner M. The association between extremely-low frequency fields and childhood leukaemia in epidemiology: enough is enough? Br J Cancer 103:931-932, 2010.

Scholten A and Silny J. The interference threshold of cardiac pacemakers in electric 50 Hz fields, Journal of Medical Engineering and Technology 25: 1-11, 2001.

Seidler A, Geller P, Nienhaus A, Bernhardt T, Ruppe I, Eggert S, Hietanen M, Kauppinen T, and Frolich L. Occupational exposure to low frequency magnetic fields and dementia: a case-control study. Occup Environ Med 64:108-14, 2007.

Seyhan N and Canseven AG. In vivo effects of ELF MFs on collagen synthesis, free radical processes, natural antioxidant system, respiratory burst system, immune system activities, and electrolytes in the skin, plasma, spleen, lung, kidney, and brain tissues. Electromagnetic Biology and Medicine 25:291-305, 2006.

Smith SD, McLeod BR, Liboff AR. Effects of CR-tuned 60 Hz magnetic fields on sprouting and early growth of Raphanus sativus. Bioelectrochem Bioenerg 32:67-76, 1993.

Sobel E, Dunn M, Davanipour Z, Qian Z and Chui HC. Elevated risk of Alzheimer’s disease among workers with likely electromagnetic fields exposure. Neurology 47:1477-81, 1996.

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

Sommer AM and Lerchl A. 50 Hz magnetic fields of 1 mT do not promote lymphoma development in AKR/J mice. Radiat Res 165:343-349, 2006.

Sorahan T and Kheifets L. Mortality from Alzheimer's, motor neurone and Parkinson's disease in relation to magnetic field exposure: findings from the study of UK electricity generation and transmission workers, 1973-2004. Occup Environ Med 64:820–826, 2007.

Svendsen AL, Weihkopf T, Kaatsch P, Schuz J. Exposure to magnetic fields and survival after diagnosis of childhood leukemia: a German cohort study. Cancer Epidemiol Biomarkers Prev 16:1167-71, 2007.

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

Swedish Radiation Protection Authority (SSI). Fifth annual report from SSI's Independent Expert Group on Electromagnetic Fields, 2007: Recent Research on EMF and Health Risks. SSI Rapport 2008:12.

Toivonen L, Metso R, Valjus J, Hongisto M. The influence of 50-Hz electric and magnetic fields on cardiac pacemakers. Imatran Voima Oy Research Reports; Helsinki, 1991.

Ueda H, Kaeriyama M, Mukasa K, Urano A, Kudo H, Shoji T, Tokumitsu Y, Yamauchi K, Kurihara K. Lacustrine Sockeye Salmon Return Straight to their Natal Area from Open Water Using Both Visual and Olfactory Cues. Chemical Senses 23:207-212, 1998.

United Kingdom Childhood Cancer Study Investigators. Childhood cancer and residential proximity to power lines. Br J Cancer 83:1573-1580, 2000.

US Environmental Protection Agency (USEPA). Guidelines for carcinogen risk assessment and supplemental guidance for assessing susceptibility from early-life exposure to carcinogens. EPA/630/P-03/001F, 2005.

US Department of Health and Human Services (HHS), Health Resources and Services Administration, Maternal and Child Health Bureau. Child Health USA 2004. Rockville, MD: US Department of Health and Human Services, 2004.

Walker MM, Quinn TP, Kirschvink JL, Groot C. Production of single-domain magnetite throughout life by sockeye salmon, *oncorhynchus nerka*. J Exp Biol 1988; 140:51-63.

Warren NR, Hinds KA, Gano RE, Fitzner RE, Piepel GF. Environmental Studies of a 1100-kV Prototype Transmission Line: an Annual Report for the 1980 Study Period. Prepared by Battelle Pacific Northwest Laboratories for Bonneville Power Administration. Portland, Oregon. 1981.

Wiltschko W, Wiltschko, R. Orientation by the earth's magnetic field in migrating birds and homing pigeons. pp. 31-43. In: Effects of Atmospheric and Geophysical Variables in Biology and Medicine: Biometeorology. H. Lieth (ed). The Hague: SPB Academic Publishing, 1991.

Wong O, Harris F, Wang Y, Fu H. A hospital-based case-control study of non-Hodgkin lymphoid neoplasms in Shanghai: analysis of personal characteristics, lifestyle, and environmental risk factors by subtypes of the WHO classification. J Occup Environ Med 52:39-53, 2010.

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

World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. WHO, Geneva, Switzerland, ISBN 978-92-4-157238-5, 2007a.

World Health Organization (WHO). Fact sheet No. 322: Electromagnetic Fields and Public Health – Exposure to Extremely Low Frequency Fields. World Health Organization, June 2007b.

Yang Y, Jin X, Yan C, Tian Y, Tang J, Shen X. Case-only of interactions between DNA repair genes (hMLH1, APEX1, MGMT, XRCC1 and XPD) and low-frequency electromagnetic fields in childhood acute leukemia. Leukemia & Lymphoma 49:2344-2350, 2008

Yano AM, Ogura M, Sato A, Sakaki Y, Shimizu Y, Baba N, Nagasawa K. Effect of modified magnetic field on the ocean migration of maturing chum salmon, *Oncorhynchus keta*. Marine Biology 129:523-530, 1997.

Yasui M, Kikuchi T, Ogawa M, Otaka Y, Tsuchitani M, Iwata H. Carcinogenicity test of 50 Hz sinusoidal magnetic fields in rats. Bioelectromagnetics 18:531-540, 1997.

Yao K, Yu Y, Wang KJ, Ye J, Lu DQ, Jiang H. Absence of effect of power-frequency magnetic fields exposure on mouse embryonic lens development. Bioelectromagnetics 28:628-635, 2007.

Zapotosky JE, Gauger JR, Haradem DP. ELF Communications System Ecological Monitoring Program: Final Summary Report. Washington, DC: Space and Naval Warfare Systems Command, Report No. D06214-6. Prepared by IIT Research Institute, Chicago, IL. February. Available through NTIS. 1996

Appendix 1

World Health Organization International EMF Project Summary of Conclusions

Overview

The World Health Organization (WHO) is a scientific organization within the United Nations system whose mandate includes providing leadership on global health matters, shaping the health research agenda, and setting norms and standards. WHO established the International EMF Project in 1996, in response to public concerns about exposures to electric and magnetic fields (EMF) and possible adverse health effects. 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 EMF in the frequency range 0-300 gigahertz (GHz). A key objective is to evaluate the scientific literature and make a status report 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 EMF exposure. This status report was published in June 2007 as part of WHO's Environmental Health Criteria (EHC) Programme.

The Monograph used standard scientific procedures, as outlined in the Preamble, to conduct its weight-of-evidence review.[1] 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 disciplines. The Task Group relied on the conclusions of previous weight-of-evidence reviews, where possible, and (with regard to cancer) mainly focused on evaluating studies published after the IARC review in 2002. Specific terms were used by the Task Group to describe the strength of the evidence in support of causality. *Limited evidence* describes a body of research where the findings are inconsistent or there are outstanding questions about study design or other methodological issues that preclude making strong conclusions. *Inadequate evidence* describes a body of 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.

The following sections describe the conclusions of the WHO by health outcome (cancer, reproductive effects, and neurodegenerative diseases). The conclusions and perspectives of

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[1] 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 Monograph on EMF does not specifically describe their report as a weight-of-evidence review. Rather, they describe conducting a health risk assessment. Although the two terms are similar, a health risk assessment differs from a weight-of-evidence review in that it also incorporates an exposure assessment and an exposure-response assessment.

weight-of-evidence reviews conducted by other scientific organizations are discussed, where appropriate, to highlight consistencies and inconsistencies in conclusions.

Conclusions

Cancer

The overwhelming majority of health research related to EMF has focused on the possibility of a relationship with cancer, including leukemia, lymphoma, breast cancer, and brain cancer. The vast majority of epidemiologic studies in this field enrolled persons with a specific cancer type (*cases*); selected a group of individuals similar to the cancer cases (*controls*); estimated past magnetic or electric field exposures, or both; and compared these exposures between the cases and controls to test for statistical differences. Some of these studies looked for statistical associations of these diseases with magnetic fields produced by nearby power lines (estimated through calculations or distance) or appliances, while other studies actually measured magnetic field levels in homes or estimated personal magnetic field exposures from all sources. In studies of adult cancers, occupational magnetic field exposures were estimated in some studies, as well. *In vivo* studies in this field exposed animals to high levels of magnetic fields (up to 50,000 milligauss [mG]) over the course of their entire lifetime to observe whether exposed animals had higher rates of cancer than unexposed animals. Some of these studies exposed animals to magnetic fields in tandem with a known carcinogen to test whether magnetic field exposure promoted carcinogenesis. Since there is relatively low energy associated with extremely low-frequency (ELF) EMF, researchers believe it is highly unlikely that electric or magnetic fields can directly damage DNA. Therefore, *in vitro* studies in this field have largely focused on investigating whether ELF EMF could promote damage from other known carcinogens or cause cancer through a pathway other than DNA damage (e.g., hormonal or immune effects or alterations in signal transduction).

The International Agency for Research on Cancer (IARC) is the division of the WHO with responsibility to coordinate and conduct research on the causes of human cancer and the mechanisms of carcinogenesis and to develop scientific strategies for cancer control. The IARC convened a scientific panel in 2001 to conduct an extensive review and arrive at a conclusion about the possible carcinogenicity of EMF (IARC, 2002). The IARC has a standard method for classifying exposures based on the strength of the scientific research in support of carcinogenicity.

Categories include (from highest to lowest risk): carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, unclassifiable, and probably not carcinogenic to humans. As a result of two pooled analyses reporting an association between high, average magnetic field exposure and childhood leukemia, the epidemiology data was classified as providing "limited evidence of carcinogenicity"[2] in relation to childhood leukemia. With regard to all other cancer types, the epidemiology evidence was classified as inadequate. The IARC panel also reported that there was "inadequate evidence of carcinogenicity" in studies of experimental animals. Overall, magnetic fields were evaluated as "possibly carcinogenic to humans." The IARC usage of "*possible*" denotes an exposure in which epidemiologic evidence points to a statistical association, but other explanations cannot be ruled out as the cause of that statistical association (e.g., bias and confounding)[3] and experimental evidence does not support a cause-and-effect relationship. Considering recently published epidemiology, *in vivo,* and *in vitro* research, the WHO concluded that the classification of "possible carcinogen" remains accurate (WHO, 2007).

Childhood Leukemia

The issue that has received the most attention is childhood leukemia. Research in this area was prompted by an epidemiology study of children in the United States that reported a statistical association between childhood leukemia and a higher predicted magnetic field level in the home based on characteristics of nearby distribution and transmission lines (Wertheimer and Leeper, 1979). Subsequently, some epidemiologic studies reported that children with leukemia were more likely to live closer to power lines or have higher estimates of magnetic field exposure (compared to children without leukemia), while other epidemiologic studies did not report this statistical association. Of note, the largest epidemiology studies of childhood leukemia that actually measured personal magnetic field exposure (as opposed to estimating exposure through

[2] Each type of evidence is categorized based on the strength of the evidence in support of carcinogenicity. The categories include: sufficient evidence of carcinogenicity, limited evidence of carcinogenicity, inadequate evidence of carcinogenicity, and evidence suggesting lack of carcinogenicity. If a positive association between an exposure and cancer is found (although factors such as chance, bias and confounding cannot be ruled out with reasonable confidence), the epidemiologic evidence is rated as "limited evidence of carcinogenicity." If chance, bias and confounding can be ruled out with reasonable confidence, then the evidence is classified as "sufficient evidence of carcinogenicity." The *in vivo* studies are ranked using a similar system, and the totality of the evidence is then considered to reach a conclusion about a particular exposure's carcinogenicity.

[3] Bias refers to any systematic error in the design, implementation or analysis of a study that results in a mistaken estimate of an exposure's effect on the risk of disease. A confounder is something that is related to both the disease under study and the exposure of interest such that we cannot be sure what causes the observed association - the confounder or the exposure of interest.

calculations or distance) did not report evidence to support a causal relationship, nor did they report a dose-response relationship with exposure to higher magnetic field levels (Linet et al., 1997; McBride et al., 1999; UKCCS, 1999).

In 2000, researchers combined the data from previously published epidemiology studies of magnetic fields and childhood leukemia that met specified criteria (Ahlbom et al., 2000; Greenland et al., 2000). The researchers pooled the data on the individuals from each of the studies, creating a study with a much larger number of subjects and, as a result, greater statistical power to detect an effect (should one exist) than any single study. In both pooled analyses, a weak association was reported between childhood leukemia and estimates of average magnetic field exposures greater than 3-4 mG. The authors were appropriately cautious in the interpretation of their analyses, and noted the uncertainty related to pooling estimates of exposure obtained by different methods from studies of diverse design, as did other researchers (e.g., Elwood, 2006). Because of the inherent uncertainty associated with observational epidemiologic studies, the results of these pooled analyses were not considered to provide strong epidemiologic support for a causal relationship. Furthermore, *in vivo* studies have not found that magnetic fields induce or promote cancer in animals exposed under highly controlled conditions for their entire lifespan, nor have *in vitro* studies found a cellular mechanism by which magnetic fields could induce carcinogenesis. As discussed above, these findings resulted in the classification of magnetic fields as a possible carcinogen (IARC, 2002).

The WHO evaluated two more recently published studies related to childhood leukemia and magnetic fields (Draper et al, 2005; Kabuto et al., 2006). Draper et al. conducted a case-control study of childhood cancer, which included 9,700 children with leukemia (i.e., cases) and an equal number of children that did not have leukemia (i.e., controls). The study compared the distance of birth address to high-voltage transmission lines among cases and controls and reported a weak association between childhood leukemia and birth addresses within 600 feet of high-voltage transmission lines. Kabuto et al. conducted a smaller case-control study in Japan that measured the average weekly magnetic field in the bedrooms of 312 children with leukemia and 603 children without leukemia. The investigators reported that children with leukemia were more likely to have average magnetic field levels >4 mG compared to children without leukemia.

The WHO did not assign a high weight or significance to these studies in their overall evaluation, stating that the low participation rate in Kabuto et al. and the use of distance as a proxy for magnetic field exposure in Draper et al. were important limitations. Less weight should be placed on these studies relative to studies that used good exposure assessment techniques and had high participation rates. The WHO described the results of these two studies as consistent with the classification of limited epidemiologic evidence in support of carcinogenicity and, together with the largely negative *in vivo* and *in vitro* research, consistent with the classification of magnetic fields as a possible carcinogen.

The WHO concluded that several factors might be fully, or partially, responsible for the consistent association observed between high, average magnetic fields and childhood leukemia, including misclassification of magnetic field exposure due to poor exposure assessment methods, confounding from unknown risk factors, and selection bias.[4] The WHO concluded that reconciling the epidemiologic data on childhood leukemia and the negative (i.e., no hazard) 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 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 be low if the association were causal.

Breast Cancer

Research on breast cancer has examined the possible effects of ELF EMF from three sources: workplace exposures, residential exposure from power lines, and electric blankets. Some of the early epidemiology studies in this field reported a weak association between breast cancer and higher magnetic field exposures, while others did not; however, the conclusions that could be drawn from this initial body of research were limited because of study quality issues (e.g., poor exposure assessment, inadequate control for confounding variables, and small sample sizes within subgroups with reported associations). Review panels evaluating this initial body of research

[4] Selection bias arises if there are differences in the persons who participate in a study compared to the persons who do not participate in a study that are related to the exposure and differential by case/control status. For example, if the parents of a child with leukemia were informed that the study was investigating magnetic field exposure and they resided close to a transmission line, they may be more likely to participate than a family that lived far from a transmission line. As a result, children with leukemia that lived closer to transmission lines (and with a presumably higher magnetic field exposure) would be over-represented in the study population compared to the source population. In this scenario, the study may report that children with leukemia are more likely to have higher magnetic field exposure when, if the entire source population of leukemia cases were to be considered, there would be no difference in the exposure levels between leukemia cases and controls.

concluded that the evidence in support of an association was weak, but should be further evaluated with higher quality studies (NRPB, 2001; IARC, 2002; ICNIRP, 2003).

A large number of studies on breast cancer and magnetic field exposure have been conducted since the publication of the IARC review in 2002. These studies were systematically reviewed by the WHO and included seven studies that estimated residential magnetic field exposure, four studies reporting associations with electric blanket usage, and nine studies that estimated occupational magnetic field exposure. No consistent associations between magnetic field exposure and breast cancer were reported in these studies. The WHO concluded that this recent body of research was higher in quality compared with previous studies, and, for that reason, provides strong support to previous consensus statements that magnetic field exposure does not influence the risk of breast cancer. In summary, the WHO stated “With these [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” (p. 9). The WHO recommended no further research with respect to breast cancer and magnetic field exposure.

Breast cancer has received additional attention because of some initial epidemiologic and experimental findings suggesting that magnetic fields may depress levels of the hormone melatonin (which is believed to have anti-carcinogenetic effects), leading to the development of breast cancer. A comprehensive weight-of-evidence review by the Health Protection Agency of Great Britain (HPA) in 2006 concluded that the evidence to date did not support the hypothesis that exposure to magnetic fields affects melatonin levels, or the risk of breast cancer in general (HPA, 2006). The WHO also considered this body of research, concluding “Overall, these data do not indicate that ELF electric and/or magnetic fields affect the neuroendocrine system in a way that would have an adverse impact on human health and the evidence is thus considered inadequate” (p. 186).

Adult leukemia and brain cancer

A large number of studies of variable quality and using a wide range of techniques have been conducted in both occupational and residential settings to explore the possible relationship between EMF exposure and adult brain cancer and leukemia. The scientific committees assembled by the IARC, NRPB, and ICNIRP concluded that the evidence is weak and does not support a role for electric or magnetic fields in the etiology of brain cancer or leukemia among adults (NRPB, 2001a; IARC, 2002; ICNIRP, 2003). The WHO reviewed the body of research published since the time of these reviews, including three studies estimating residential exposure, four cohort studies estimating occupational exposures, and eight case-control studies reported on occupation and brain cancer or leukemia risk. 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" (p. 307). The WHO panel recommended updating the existing European cohorts of occupationally exposed individuals and then pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

***In vivo* and *in vitro* research on carcinogenesis**

It is standard procedure to conduct studies of laboratory animals to determine whether exposure to a specific agent leads to the development of cancer (USEPA, 2005). This approach is used because all known human carcinogens cause cancer in laboratory animals. In the field of ELF EMF research, a number of research laboratories have exposed rodents with a particular genetic susceptibility to cancer to high levels of magnetic fields over the course of their 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 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 acute lymphoblastic leukemia (ALL) currently exists. Some animals, however, develop a type of lymphoma similar to childhood ALL and studies exposing transgenic mice predisposed to this lymphoma to power-frequency magnetic fields have not reported an increased incidence of lymphoma associated with exposure (Harris et al., 1998; McCormick et al., 1998; Sommer and Lerchel 2004). Based on this body of research, the WHO panel concluded that exposure to ELF magnetic fields, does not appear to cause cancer alone, although it is a high priority to identify and perform studies on an animal model that is more directly relevant to childhood ALL.

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/lymphoma, skin tumors, or brain tumors; however, the incidence of DMBA-induced mammary tumors was increased with magnetic field exposure in a series of experiments (Löscher et al., 1993, 1994, 1997; Baum et al., 1995; Löscher and Mevissen, 1995; Mevissen et al., 1993a, 1993b, 1996a, 1996b, 1998), suggesting that magnetic field exposure increased the proliferation of mammary tumor cells. These results were not replicated in subsequent series of experiments in another laboratory (Anderson et al., 1999; Boorman et al.1999; NTP, 1999), possibly due to differences in experimental protocol and the species strain (Fedrowitz et al., 2004). 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.

In summary, the WHO concluded with respect to *in vivo* research, "There is no evidence that ELF exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate." Recommendations for future research include the development of a rodent model for childhood ALL and the continued investigation of whether magnetic fields can act as a co-carcinogen.

In vitro studies are widely used to investigate the mechanisms for effects that are observed in humans and animals. The relative value of *in vitro* tests to human health risk assessment, however, is much less than that of *in vivo* and epidemiology studies. Responses of cells and tissues outside the body may not always reflect the response of those same cells if maintained in a living system, so the relevance of *in vitro* studies cannot be assumed (IARC, 1992).

The IARC and other scientific review panels that systematically evaluated *in vitro* studies concluded that there is no clear evidence indicating how ELF magnetic fields could adversely affect biological processes in cells (IARC, 2002; ICNIRP, 2003; NRPB, 2004). The WHO panel reviewed the *in vitro* research published since the time of these reviews and reached the same conclusion. The WHO noted that previous studies have not indicated a genotoxic effect of ELF magnetic fields on mammalian cells, however a recent series of experiments reported DNA damage in human fibroblasts exposed intermittently to 50-Hz magnetic fields (Ivancsits et al., 2002a, 2002b; Ivancsits et al., 2003a, 2003b). These findings have not been replicated by other laboratories (Scarfi et al., 2005), and the WHO recommended continued research in this area. Research in the field of *in vitro* genotoxicity of magnetic fields combined with known DNA-damaging agents is also recommended, following suggestive findings from several laboratories. As noted by the Swedish Radiation Protection Authority, the levels at which these effects were observed are much higher than the levels we are exposed to in our everyday environments and therefore are not directly relevant to questions about low-level, chronic exposures (SSI, 2007). *In vitro* studies investigating other possible mechanisms, including gene activation, cell proliferation, apoptosis, calcium signaling, intercellular communication, heat shock protein expression and malignant transformation, have produced “inconsistent and inconclusive” results (p. 347, WHO, 2007).

Reproductive Effects

Epidemiology studies have been conducted to observe whether maternal or paternal EMF exposures are associated with adverse reproductive effects, including effects on fertility, reproduction, miscarriage, and prenatal and postnatal growth and development. A body of *in vivo* literature is also available on this topic. Early studies on the potential effect of EMF exposures on reproductive outcomes were limited because the majority of the studies used surrogate measures of exposure (including visual display terminal use, electric blanket use, or wire code data) or assessed exposure retrospectively.

Two recent studies related to miscarriage improved exposure assessment by directly measuring magnetic field exposure. These two studies reported a positive association between miscarriage and exposure to high maximum, or instantaneous, peak magnetic fields (Li et al., 2002; Lee et al., 2002). No consistent associations were reported, however, with high, average magnetic field levels, the typical method for assessing magnetic field exposure. The WHO noted several issues that have been raised by other investigators and scientific review panels concerning the validity of these associations (HCN, 2004; NRPB, 2004; Feychting et al., 2005; Mezei et al., 2005; Savitz et al., 2006). First, the studies had a low response rate, which means that the case and control groups may not be comparable because those who participated in the study may have differed from those who declined (i.e., selection bias). Second, in the study by Lee et al. (2002), magnetic field measurements were taken 30 weeks after a woman's last menstrual period. Some of these women had already miscarried at 30 weeks when magnetic field exposure was measured. This introduces the possibility for bias because pregnancy may alter physical activity levels and physical activity may be associated with magnetic field exposure in pregnant women, as recently confirmed in a study by Savitz et al. (2006). It is possible that the women who miscarried prior to 30 weeks in the study by Lee et al. (2002) subsequently increased their physical activity levels (i.e., returned to work or their normal routine), which resulted in greater opportunities to encounter higher peak magnetic field levels. Furthermore, there is no biological basis to indicate that EMF increases the risk of reproductive effects. *In vivo* studies exposed animals to high levels of electric and magnetic fields and reported no significant, adverse developmental effects. The WHO stated that *in vivo* studies on other reproductive outcomes are inadequate at this time.

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

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) or Lou Gehrig's disease. The inconsistency of the Alzheimer's studies prompted the National Radiological Protection Board of Great Britain (NRPB)[5] to conclude that there is "only weak evidence to suggest that it [i.e., extremely low frequency magnetic fields] could cause Alzheimer's

[5] The NRPB merged with the Health Protection Agency in April 2005 to form its new Radiation Protection Division.

disease" (p. 20, NRPB, 2001b). 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 between ALS and occupational magnetic field exposure. The scientific panels felt that an alternative explanation (i.e., electric shocks received at work) may be the source of the observed association. The NRPB concluded: "In summary, the epidemiological evidence suggests that employment in electrical occupations may increase the risk of ALS, possibly, however, as a result of the increased risk of receiving an electric shock rather than from the increased exposure to electromagnetic fields" (p.20, NRPB, 2001b).

Most recent studies reported 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 (disease status based on death certificate data, exposure based on incomplete occupational information from census data, and no control for confounding factors). There is currently no biological data to support an association between magnetic fields and neurodegenerative diseases. The WHO concluded that there is inadequate data in support of an association between magnetic fields 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.

References

Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, Linet M, Michealis J, Olsen JH, Tynes T, Verasalo PK. A pooled analysis of magnetic fields and childhood leukaemia. British Journal of Cancer 83(5):692-698, 2000.

Anderson LE, Boorman GA, Morris JE, Sasser LB, Mann PC, Grumbein SL, Hailey JR, McNally A, Sills RC, Haseman JK. Effect of 13 week magnetic field exposures on DMBA-initiated mammary gland carcinomas in female Sprague-Dawley rats. Carcinogenesis 20:1615-1620, 1999.

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

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

Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, Kovatch RM, Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. Toxicologic Pathology 27:267-78, 1999b.

Draper G, Vincent T, Kroll ME, Swanson J. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. BMJ 330 (7503):1290, 2005.

Elwood JM. Childhood leukemia and residential magnetic fields: are pooled analyses more valid than the original studies? Bioelectromagnetics 27:112-118, 2006.

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

Feychting M, Ahlbom A, Kheifets L. EMF and health. Annual Review of Public Health 26:165-89, 2005.

Greenland S, Sheppard A, Kelsh M, Kuane W, Poole C, Kelsh MA. Childhood leukemia and power frequency magnetic fields: analysis from pooled data of thirteen epidemiologic studies. Epidemiology 11:624-634, 2000.

Harris AW, Basten A, Gebski V, Noonan D, Finnie J, Bath ML, Bangay MJ, Repacholi MH. A test of lymphoma induction by long-term exposure of E mu-Pim1 transgenic mice to 50 Hz magnetic fields. Radiat Res 149(3):300-307, 1998.

Health Council of the Netherlands (HCN). ELF Electromagnetic Fields Committee. Electromagnetic fields: Annual Update 2003. The Hague: Health Council of the Netherlands. Publication No. 2004/1, 2004.

International Agency for Research on Cancer (IARC). Mechanisms of carcinogenesis in risk identification. No. 116. IARC Press, Lyon, France, 1992.

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

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Exposure to static and low frequency electromagnetic fields, biological effects and health consequences (0-100 kHz) – review of the scientific evidence on dosimetry, biological effects, epidemiological observations, and health consequences concerning exposure to static and low frequency electromagnetic fields (0-100 kHz). Matthes R, McKinlay AF, Bernhardt JH, Vecchia P, Beyret B (eds.). International Commission on Non-Ionizing Radiation Protection, 2003.

Ivancsits S, Diem E, Pilger A, Rudiger HW, Jahn O. Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts. Mutat Res 519(1- 2):1-13, 2002a.

Ivancsits S, Pilger A, Diem E, Schaffer A, Rudiger HW. Vanadate induces DNA strand breaks in cultured human fibroblasts at doses relevant to occupational exposure. Mutat Res 519(1-2):25-35, 2002b.

Ivancsits S, Diem E, Jahn O, Rudiger HW. Age-related effects on induction of DNA strand breaks by intermittent exposure to electromagnetic fields. Mech Ageing Dev 124(7):847-850, 2003a.

Ivancsits S, Diem E, Jahn O, Rudiger HW. Intermittent extremely low frequency electromagnetic fields cause DNA damage in a dose-dependent way. Int Arch Occup Environ Health 76(6):431-436, 2003b.

Kabuto M, Nitta H, Yamamoto S, Yamaguchi N, Akiba S, Honda Y, Hagihara J, Isaka K, Saito T, Ojima T, Nakamura Y, Mizoue T, Ito S, Eboshida A, Yamazaki S, Sokejima S, Kurokawa Y, Kubo O. Childhood leukemia and magnetic fields in Japan: a case-control study of childhood leukemia and residential power-frequency magnetic fields in Japan. Int J Cancer 119:643-650, 2006.

Lai H and Singh NP. Magnetic-field-induced DNA strand breaks in brain cells of the rat. Environ Health Perspect 112:687-694, 2004.

Lee G.M, Neutra RR, Hristova L, Yost M, Hiatt RA. The use of electric bed heaters and the risk of clinically recognized spontaneous abortion. Epidemiology 11:406-415, 2000.

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

Linet MS, Hatch EH, Kleinerman RA, Robinson LL, Kaune WT, Friedman DR, Seversch RK, Haines CM, Hartsock CT, Niwa S, Wacholder S, Tarone RE. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. New England Journal of Medicine 337:1-7, 1997.

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

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

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

Mandeville R et al. Evaluation of the potential carcinogenicity of 60 Hz linear sinusoidal continuous-wave magnetic fields in Fisher F344 rats. FASEB-J, 11:1127-1136, 1997.

McBride ML, Gallagher RP, Thériault G, Armstrong BG, Tamaro S, Spinelli JJ, Deadman JE, Fincham S, Robinson D, Choi W. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. American Journal of Epidemiology 149:831-842, 1999.

McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, Pletcher JM, Sill RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F mice. Toxicologic Pathology 27:279-285, 1999.

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

Mevissen M, Wahnschaffe U, Löscher W, Stamm A, Lerchl A. Effects of AC magnetic field on DMBA-induced mammary carcinogenesis in Sprague-Dawley rats. In: Electricity and Magnetism in Biology and Medicine. Blank M (ed). San Francisco Press. 413-415, 1993b.

Mevissen M, Lerchl A, Löscher W. Study on pineal function and DMBA-induced breastcancer formation in rats during exposure to a 100-mg, 50-Hz magnetic-field. J Toxicol Environ Health 48:169-185, 1996a.

Mevissen M et al. (1996). Exposure of DMBA-treated female rats in a 50-Hz, 50-μT magneticfield: effects on mammary-tumor growth, melatonin levels, and T-lymphocyte activation. Carcinogenesis 17:903-910, 1996b.

Mevissen M, Haussler M, Lerchl A, Löscher W. Acceleration of mammary tumorigenesis by exposure of 7,12-dimethylbenz[a]anthracene-treated female rats in a 50-Hz, 100-microT magnetic field: replication study. J Toxicol Environ Health A 53:401-418, 1998.

Mezei G, Bracken TD, Senior R, Kavet R. 2005. Examination of Magnetic-Field Peak-Exposure Measures. 27th Annual Meeting of the Bioelectromagnetics Society, Dublin, Ireland, June 19-24, 2005.

National Radiological Protection Board (NRPB). Response statement of the NRPB: ELF electromagnetic fields and the risk of cancer. National Radiological Protection Board, Chilton, Dicot, Oxon, Volume 12, No.1, ISNB 0-859951-456-0, 2001a.

National Radiological Protection Board (NRPB). ELF electromagnetic fields and neurodegenerative disease. National Radiological Protection Board. Volume 12, No 4, 2001b.

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

National Research Council (NRC). An Evaluation of the U.S. Navy's Extremely Low Frequency Communications System Ecological Monitoring Program. National Academy Press, Washington, D.C., 1997.

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

Scarfi MR et al. Evaluation of genotoxic effects in human fibroblasts after intermittent exposure to 50 Hz electromagnetic fields: a confirmatory study. Radiat Res 164:270-276, 2005.

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

United Kingdom Childhood Cancer Study Investigators (UKCCS). Exposure to power frequency magnetic fields and the risk of childhood cancer. The Lancet 353:1925-31, 1999.

US Environmental Protection Agency (USEPA). Guidelines for Carcinogen Risk Assessment and Supplemental Guidance for Assessing susceptibility from Early-life Exposure to Carcinogens. EPA/630/P-03/001F, 2005.

Wertheimer N and Leeper E. Electrical wiring configurations and childhood cancer. American Journal of Epidemiology 109:273-284, 1979.

World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. WHO, Geneva, Switzerland, ISBN 978-92-4-157238-5, 2007.

Yasui M, Kikuchi T, Ogawa M, Otaka Y, Tsuchitani M, Iwata H. Carcinogenicity test of 50 Hz sinusoidal magnetic fields in rats. Bioelectromagnetics 18:531-5400, 1997.

Appendix 2

WHO Fact Sheet

Fact sheet N°322
June 2007

Electromagnetic fields and public health
Exposure to extremely low frequency fields

The use of electricity has become an integral part of everyday life. Whenever electricity flows, both electric and magnetic fields exist close to the lines that carry electricity, and close to appliances. Since the late 1970s, questions have been raised whether exposure to these extremely low frequency (ELF) electric and magnetic fields (EMF) produces adverse health consequences. Since then, much research has been done, successfully resolving important issues and narrowing the focus of future research.

In 1996, the World Health Organization (WHO) established the International Electromagnetic Fields Project to investigate potential health risks associated with technologies emitting EMF. A WHO Task Group recently concluded a review of the health implications of ELF fields (WHO, 2007).

This Fact Sheet is based on the findings of that Task Group and updates recent reviews on the health effects of ELF EMF published in 2002 by the International Agency for Research on Cancer (IARC), established under the auspices of WHO, and by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2003.

ELF field sources and residential exposures

Electric and magnetic fields exist wherever electric current flows **-** in power lines and cables, residential wiring and electrical appliances. **Electric** fields arise from electric charges, are measured in volts per metre (V/m) and are shielded by common materials, such as wood and metal. **Magnetic** fields arise from the motion of electric charges (i.e. a current), are expressed in tesla (T), or more commonly in millitesla (mT) or microtesla (μT). In some countries another unit called the gauss, (G), is commonly used (10,000 G = 1 T). These fields are not shielded by most common materials, and pass easily through them. Both types of fields are strongest close to the source and diminish with distance.

Most electric power operates at a frequency of 50 or 60 cycles per second, or hertz (Hz). Close to certain appliances, the magnetic field values can be of the order of a few hundred microtesla. Underneath power lines, magnetic fields can be about 20 μT and electric fields can be several thousand volts per metre. However, average residential power-frequency magnetic fields in homes are much lower - about 0.07 μT in Europe and 0.11 μT in North America. Mean values of the electric field in the home are up to several tens of volts per metre.

Task group evaluation

In October 2005, WHO convened a Task Group of scientific experts to assess any risks to health that might exist from exposure to ELF electric and magnetic fields in the frequency range >0 to 100,000 Hz (100 kHz). While IARC examined the evidence regarding cancer in 2002, this Task Group reviewed evidence for a number of health effects, and updated the evidence regarding cancer. The conclusions and recommendations of the Task Group are presented in a WHO Environmental Health Criteria (EHC) monograph (WHO, 2007).

Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF electric fields at levels generally encountered by members of the public. Thus the remainder of this fact sheet addresses predominantly the effects of exposure to ELF magnetic fields.

Short-term effects

There are established biological effects from acute exposure at high levels (well above 100 µT) that are explained by recognized biophysical mechanisms. External ELF magnetic fields induce electric fields and currents in the body which, at very high field strengths, cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system.

Potential long-term effects

Much of the scientific research examining long-term risks from ELF magnetic field exposure has focused on childhood leukaemia. In 2002, IARC published a monograph classifying ELF magnetic fields as "possibly carcinogenic to humans". This classification is used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals (other examples include coffee and welding fumes). This classification was based on pooled analyses of epidemiological studies demonstrating a consistent pattern of a two-fold increase in childhood leukaemia associated with average exposure to residential power-frequency magnetic field above 0.3 to 0.4 µT. The Task Group concluded that additional studies since then do not alter the status of this classification.

However, the epidemiological evidence is weakened by methodological problems, such as potential selection bias. In addition, there are no accepted biophysical mechanisms that would suggest that low-level exposures are involved in cancer development. Thus, if there were any effects from exposures to these low-level fields, it would have to be through a biological mechanism that is as yet unknown. Additionally, animal studies have been largely negative. Thus, on balance, the evidence related to childhood leukaemia is not strong enough to be considered causal.

Childhood leukaemia is a comparatively rare disease with a total annual number of new cases estimated to be 49,000 worldwide in 2000. Average magnetic field exposures above 0.3 µT in homes are rare: it is estimated that only between 1% and 4% of children live in such conditions. If the association between magnetic fields and childhood leukaemia is causal, the number of cases worldwide that might be attributable to magnetic field exposure is estimated to range from 100 to 2400 cases per year, based on values for the year 2000, representing 0.2 to 4.95% of the total incidence for that year. Thus, if ELF magnetic fields actually do increase the risk of the disease, when considered in a global context, the impact on public health of ELF EMF exposure would be limited.

A number of other adverse health effects have been studied for possible association with ELF magnetic field exposure. These include other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioural effects and neurodegenerative disease. The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukaemia. In some instances (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them.

International exposure guidelines

Health effects related to short-term, high-level exposure have been established and form the basis of two international exposure limit guidelines (ICNIRP, 1998; IEEE, 2002). At present, these bodies consider the scientific evidence related to possible health effects from long-term, low-level exposure to ELF fields insufficient to justify lowering these quantitative exposure limits.

WHO's guidance

For high-level short-term exposures to EMF, adverse health effects have been scientifically established (ICNIRP, 2003). International exposure guidelines designed to protect workers and the public from these effects should be adopted by policy makers. EMF protection programs should include exposure measurements from sources where exposures might be expected to exceed limit values.

Regarding long-term effects, given the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, the benefits of exposure reduction on health are unclear. In view of this situation, the following recommendations are given:

- Government and industry should monitor science and promote research programmes to further reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure. Through the ELF risk assessment process, gaps in knowledge have been identified and these form the basis of a new research agenda.
- Member States are encouraged to establish effective and open communication programmes with all stakeholders to enable informed decision-making. These may include improving coordination and consultation among industry, local government, and citizens in the planning process for ELF EMF-emitting facilities.
- When constructing new facilities and designing new equipment, including appliances, low-cost ways of reducing exposures may be explored. Appropriate exposure reduction measures will vary from one country to another. However, policies based on the adoption of arbitrary low exposure limits are not warranted.

Further reading

WHO - World Health Organization. Extremely low frequency fields. Environmental Health Criteria, Vol. 238. Geneva, World Health Organization, 2007.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. Lyon, IARC, 2002 (Monographs on the Evaluation of Carcinogenic Risks to Humans, 80).

ICNIRP - International Commission on Non-Ionizing Radiation Protection. Exposure to static and low frequency electromagnetic fields, biological effects and health consequences (0-100 kHz). Bernhardt JH et al., eds. Oberschleissheim, International Commission on Non-ionizing Radiation Protection, 2003 (ICNIRP 13/2003).

ICNIRP – International Commission on Non-Ionizing Radiation Protection (1998). Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics 74(4), 494-522.

IEEE Standards Coordinating Committee 28. IEEE standard for safety levels with respect to human exposure to electromagnetic fields, 0-3 kHz. New York, NY, IEEE - The Institute of Electrical and Electronics Engineers, 2002 (IEEE Std C95.6-2002).

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Appendix 3

Comment on the BioInitiative Report

Background

In August 2007, an *ad hoc* group of 14 scientists and public health and policy consultants published an on-line report titled "*The BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields (ELF and RF)*." The group's objective was to "assess scientific evidence on health impacts from electromagnetic radiation below current public exposure limits and evaluate what changes in these limits are warranted now to reduce possible public health risks in the future" (p. 4). The individuals who comprised this group did not represent any well-established regulatory agency, nor were they convened by a recognized scientific authority. The report is a collection of 17 sections on various topics each authored by 1 to 3 persons from the working group. The research on both ELF and radio frequency (RF) EMF was addressed, with major portions of the report focused largely or entirely on RF research. Epidemiologic literature related to ELF EMF and childhood cancers, Alzheimer's disease, and breast cancer was discussed, as well as experimental data for a number of mechanistic hypotheses.

Conclusions and comments

The authors of the BioInitiative Report contended that the standard procedure for developing exposure guidelines—i.e., to set guidelines where adverse health effects have been established by using a weight-of-evidence approach—is not appropriate and should be replaced by a process that sets guidelines at exposure levels where biological effects have been reported in some studies, but not substantiated in a rigorous review of the science or linked to adverse health effects.

Based on this argument, the main conclusion of the BioInitiative Report was that existing standards for exposure to ELF EMF are insufficient because "effects are now widely reported to occur at exposure levels significantly below most current national and international limits" (Table 1-1). Specifically, the authors concluded that there was strong evidence to suggest that magnetic fields were a cause of childhood leukemia based on epidemiologic findings.

The report recommended the following:

> *ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor … While new ELF limits are being developed and implemented, a reasonable approach would be a 1 mG (0.1 µT) planning limit for habitable space adjacent to all new or upgraded power lines and a 2 mG (0.2 µT) limit for all other new construction. It is also recommended that a 1 mG (0.1 µT) limit be established for existing habitable space for children and/or women who are pregnant. (p. 22)*

The recommendations made in the BioInitiative Report are not based on appropriate scientific methods and, therefore, do not warrant any changes to the conclusions from the numerous scientific agencies that have already considered this issue. These organizations are consistent in their conclusions that the research does not support the setting of exposure standards at these low levels of magnetic field exposure.

The World Health Organization (WHO) published the most recent weight-of-evidence review in June 2007 and concluded the following:

> *Everyday, low-intensity ELF magnetic field exposure poses a possible increased risk of childhood leukaemia, but the evidence is not strong enough to be considered causal and therefore ELF magnetic fields remain classified as possibly carcinogenic. (p. 357)*

The report continued:

> *Given the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia and the limited potential impact on public health, the benefits of exposure reduction on health are unclear and thus the cost of reducing exposure should be very low. (p. 372)*

The WHO made no recommendations for exposure standards at the magnetic field levels where an association has been reported in some epidemiologic studies of childhood leukemia. In a fact sheet created for the general public and published on their website, the WHO stated,

> *When constructing new facilities and designing new equipment, including appliances, low-cost ways of reducing exposures may be explored…However, policies based on the adoption of arbitrary low exposure limits are not warranted* (WHO, 2007b).

As stated, the conclusions in the BioInitiative Report deviate substantially from those of reputable scientific organizations because they were not based on standard, scientific methods. Valid scientific conclusions are based on weight-of-evidence reviews, which entail a systematic evaluation of the entire body of scientific evidence in three areas of research (i.e., epidemiology, *in vivo* research, and *in vitro* research), by panels of experts in these relevant disciplines. The report by the BioInitiative working group does not represent a valid weight-of-evidence review for the following key reasons:

1. **Review panels should consist of a multidisciplinary team of experts that reach consensus statements by collaboratively contributing to and reviewing the final work product.** This process ensures that overall conclusions represent a valid and balanced view of each relevant area of research. The document released by the BioInitiative working group was a compilation of sections, with each authored by one to three members of the group. It does not appear that the report was developed collaboratively or reviewed in its entirety by each member.

2. **Valid conclusions about causality are based on systematic evaluations of three lines of evidence—epidemiology, *in vivo* research, and *in vitro* research.** The conclusions in the BioInitiative Report are not based on this multidisciplinary approach. In particular, little attention is provided to the results from *in vivo* studies on cancer and disproportionate weight is given to the results of *in vitro* studies reporting biological effects.

3. **The entire body of evidence to date should be considered when drawing conclusions regarding the strength of evidence in support of a hypothesis.** The BioInitiative Report is not a comprehensive review of the cumulative evidence. Rather, results from specific studies are cited, but no rationale is provided for their inclusion relative to the many other relevant, published studies.

4. **The evidence from each study must be evaluated critically to determine its validity and the degree to which it is relevant and able to support or refute the hypothesis under question.** The significance of the results reported in any study depends on the validity of the methods used in that study, so weight-of-evidence reviews must include an evaluation of the strengths and limitations of each study. In some discussions, the report claimed to use a weight-of-evidence approach, but the individual sections of the report provide little evidence that the strengths and limitations of individual studies (e.g., the quality of exposure assessment, sample size, biases, and confounding factors) were evaluated systematically.

5. **Support for a causal relationship is based on consistent findings from methodologically sound epidemiology studies that are coherent with the results reported from *in vivo* and *in vitro* studies**. The BioInitiative group often arrived at conclusions about causality by considering only a few studies from one discipline, with no consideration of the significance and validity of the study's results.

In summary, the authors of this report largely ignored basic scientific methods that should be followed in the review and evaluation of scientific evidence. These methods are fundamental to scientific inquiry and are not, as the BioInitiative Report states, "unreasonably high."

The policy responses proposed in the report are cast as consistent with the precautionary principle, i.e., taking action in situations of scientific uncertainty before there is strong proof of harm. A central tenet of the precautionary principle is that precautionary recommendations are proportional to the perceived level of risk and that this perception is founded largely on the weight of the available scientific evidence. The BioInitiative Report recommends precautionary measures on the basis of argument, rather than the basis of sound peer-reviewed scientific evidence.

Unlike the BioInitiative Report, the WHO review was the product of a multidisciplinary scientific panel assembled by an established public health agency that followed appropriate scientific methods, including the systematic and critical examination of all the relevant evidence. The recommendations from the WHO report (pp. 372-373) are presented below:

- *Policy-makers should establish guidelines for ELF field exposure for both the general public and workers. The best source of guidance for both exposure levels and the principles of scientific review are the international guidelines.*

- *Policy-makers should establish an ELF EMF protection programme that includes measurements of fields from all sources to ensure that the exposure limits are not exceeded either for the general public or workers.*

- *Provided that the health, social and economic benefits of electric power are not compromised, implementing very low-cost precautionary procedures to reduce exposures is reasonable and warranted.*

- *Policy-makers and community planners should implement very low-cost measures when constructing new facilities and designing new equipment including appliances.*

- *Changes to engineering practice to reduce ELF exposure from equipment or devices should be considered, provided that they yield other additional benefits, such as greater safety, or involve little or no cost.*

- *When changes to existing ELF sources are contemplated, ELF field reduction should be considered alongside safety, reliability and economic aspects.*

- *Local authorities should enforce wiring regulations to reduce unintentional ground currents when building new or rewiring existing facilities, while maintaining safety. Proactive measures to identify violations or existing problems in wiring would be expensive and unlikely to be justified.*

- *National authorities should implement an effective and open communication strategy to enable informed decision-making by all stakeholders; this should include information on how individuals can reduce their own exposure.*

- *Local authorities should improve planning of ELF EMF-emitting facilities, including better consultation between industry, local government, and citizens when siting major ELF EMF-emitting sources.*

- *Government and industry should promote research programmes to reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure.*

Appendix G

Greenhouse Gases

Big Eddy- Knight CO_2 Emissions for 6 months of Transmission Line Construction

Note: Only Vehicle round trips/day or 6 months and distance need to be changed to calculate emissions

CO_2

Vehicle round trips/day	Distance (miles)	Miles/ 6 months	Gallons/year*	*CO_2 Emissions in Metric tons CO_2/year***
16	80	233,600	40,276	**409**

*Gallons/year is calculated using a fuel economy factor of 5.8 mpg for heavy trucks (more than 26,000 lbs)

**CO_2 Emission Factor for Diesel Fuel No 1 and 2 = 10.15 kg CO_2/gallon

CH_4

Vehicle round trips/day	Distance (miles)	Miles/year	Gallons/mile*	CH_4 Emissions in Metric tons	*CO_2e Emissions in Metric tons/year***
16	80	233,600	1,191	0.001	**0.03**

*Gallons/mile is calculated using a CH_4 emission factor of 0.0051 g/mi for all model years of diesel heavy-duty vehicles

**CO_2 equivalent conversion factor for CH_4 is 21 GWP

NO_2

Vehicle round trips/day	Distance (miles)	Miles/year	Gallons/mile*	CH_4 Emissions in Metric tons	*CO_2e Emissions in Metric tons/year***
16	80	233,600	1,121	0.001	**0.35**
				Total CO_2 Emissions over one year of transmission line construction in metric tons/year	***409.38***

*Gallons/mile is calculated using a NO_2 emission factor of 0.0048 g/mi for all model years of diesel heavy-duty vehicles

**CO_2 equivalent conversion factor for NO_2 is 310 GWP

Big Eddy- Knight CO2 Emissions for 6 months for Operations and Maintenance

CO_2				
Vehicle round trips/year	**Distance (miles)**	**Miles/year**	**Gallons/year***	***CO_2 Emissions in Metric tons CO_2/year****
3	80	240	30	**0.3**
Helicopter round trips/year	**Distance (miles)**	**Miles/year**	**Gallons/year*****	***CO_2 Emissions in Metric tons CO_2/year******
2	60	120	44	**0.4**
			Total CO_2	**0.7**

*Gallons/year is calculated using a fuel economy factor of 8.0 mpg for medium trucks (more than 26,000 lbs)

**CO_2 Emission Factor for Motor gasoline = 8.81 kg CO_2/gallon

***Gallons/year is calculated using a fuel economy factor of 2.7 mpg (2.35 Nautical Miles/g) for a helicopter

****CO_2 Emission Factor for Aviation gasoline = 8.32 kg CO_2/gallon

CH_4					
Vehicle round trips/year	**Distance (miles)**	**Miles/year**	**Gallons/mile***	**CH_4 Emissions in Metric tons**	***CO_2e Emissions in Metric tons/year****
3	80	240	0.24	0.000000	**0.000005**
Helicopter round trips/year	**Distance (miles)**	**Gallons/year*****	**Grams/year******	**CH_4 Emissions in Metric tons**	***CO_2e Emissions in Metric tons/year****
2	60	44	313	0.0000	**0.001**
				Total CH_4	**0.001005**

*Gallons/mile is calculated using a CH_4 emission factor of 0.0010 g/mi for model years 1996-2004 diesel light trucks

**CO_2 equivalent conversion factor for CH_4 is 21 GWP

***Gallons used per year = miles per year/2.7 mpg for helicopter

****Grams/year is calculated using an emission factor of 7.04 grams/gallon fuel for aviation gasoline.

N_2O					
Vehicle round trips/year	**Distance (miles)**	**Miles/year**	**Gallons/mile***	**N_20 Emissions in Metric tons**	***CO_2e Emissions in Metric tons/year****
3	160	480	0.72	0.000001	**0.0002**
Helicopter round trips/year	**Distance (miles)**	**Gallons/year*****	**Grams/year******	**N_20 Emissions in Metric tons**	***CO_2e Emissions in Metric tons/year****
2	130	96	11	0.00010	**0.030**
				Total N_2O	**0.0302**
				Total CO_2 Emissions over one year of transmission line operation and maintenance in metric tons/year	***0.7312***

*Gallons/mile is calculated using a N_20 emission factor of 0.0015 g/mi for model years 1996-2004 diesel light trucks

**CO_2 equivalent conversion factor for NO_2 is 310 GWP
***Gallons used per year = miles per year/2.7 mpg for helicopter
****Grams/year is calculated using an emission factor of 0.11 grams/gallon fuel for aviation gasoline.

The following table is a summary of unit conversions and assumptions required to calculate CO_2 emissions associated with tree harvesting.

Coefficient	**Unit**	**Source**
300	Horse power	Assumed
2,545	(British thermal unit/hour)/horse power	---
2	hours/tree	Assumed
138,000	BTU/gallon-diesel	EPA 2005
10.1	kg-$CO_{2\text{-equiv}}$/gallon-diesel	EPA 2005
35%	Efficiency	Assumed

Appendix H

Disclosure Forms

NEPA Financial Disclosure Statement for Preparation of the Environmental Impact Statement for the Proposed Big Eddy-Knight Transmission Project

CEQ regulations at 40 CFR 1506.5(c), which have been adopted by DOE (10 CFR 1021), require contractors who will prepare an EIS to execute a disclosure specifying that they have no financial or other interest in the outcome of the project. The term "financial interest or other interest in the outcome of the project," for the purposes of this disclosure, is defined in the March 23, 1981 guidance "Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations," 46 FR 18026-18038 at Question 17a and b.

Financial or other interest in the outcome of the project 'includes' any financial benefit such as a promise of future construction or design work in the project, as well as indirect benefits the contractor is aware of (e.g., if the project would aid proposals sponsored by the firm's other clients)." 46 FR 18026- 18038 at 18031.

In accordance with these requirements, the offeror and any proposed subcontractors hereby certify as follows: [check either (a) or (b) to assure consideration of your proposal]

(a) ✓ Offeror and any proposed subcontractor have no financial interest in the outcome of the project.

(b) ____________ Offeror and any proposed subcontractor have the following financial or other interest in the outcome of the project and hereby agree to divest themselves of such interest prior to award of this contract.

Financial or Other Interests:

1.

2.

3.

Certified by:

[signature]

Signature

Richard Oestman, Principal, ICF International

Name

1/29/10

Date

NEPA Financial Disclosure Statement for Preparation of the Environmental Impact Statement for the Proposed Big Eddy-Knight Transmission Project

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(a) __X__ Offeror and any proposed subcontractor have no financial interest in the outcome of the project.

(b) ______ Offeror and any proposed subcontractor have the following financial or other interest in the outcome of the project and hereby agree to divest themselves of such interest prior to award of this contract.

Financial or Other Interests:

1.

2.

3.

Certified by:

[signature]
Signature

T. DAN BRACKEN
Name

2/2/2010
Date

NEPA Financial Disclosure Statement for Preparation of the Environmental Impact Statement for the Proposed Big-Eddy-Knight Transmission Project

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Financial or Other Interests:

1.

2.

3.

Certified by:

Kathleen Concannon
Signature

KATHLEEN CONCANNON
Name

2/1/10
Date

NEPA Financial Disclosure Statement for Preparation of the Environmental Impact Statement for the Proposed Big Eddy-Knight Transmission Project

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Financial or Other Interests:

1.

2.

3.

Certified by:

[signature]

Signature

LEROY P. SANCHEZ

Name

JUNE 2, 2010

Date

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(b) ______ Offeror and any proposed subcontractor have the following financial or other interest in the outcome of the project and hereby agree to divest themselves of such interest prior to award of this contract.

Financial or Other Interests:

1.

2.

3.

Certified by:

Kara A Hempy-Mayer

Signature

Kara Hempy-Mayer

Name

1/29/10

Date

Appendix I

Washington Department of Natural Resources Lands Analysis

Appendix I
Washington Department of Natural Resources Lands Analysis

As described in Chapter 6, Washington EFSEC, Oregon DOE, and other state agencies have provided BPA with potentially applicable state substantive standards that they believe apply to the proposed project. Inclusion of these standards in the EIS helps BPA understand these standards and aids state agencies in their review of the proposed project. By identifying and considering these standards as early as possible, the proposed project can be designed to be consistent or compatible with these standards to the maximum extent practicable.

In addition to the incorporation of state standards into the EIS and project design, BPA recognizes that when a state agency owns property that BPA proposes to cross with its proposed transmission line and associated facilities, that agency may need to comply with certain state or local laws or regulations before it can agree to allow BPA use of their property. As discussed in Section 3.1 Land Use and Recreation of the EIS, the Washington Department of Natural Resources (DNR) is a state agency that manages property crossed by the project. To assist DNR in its compliance efforts for DNR lands potentially crossed by the proposed project, BPA has included this Appendix I to provide additional information, where available, for these lands.

Some of the information included in this appendix reflects the expected negotiation of a Washington Statewide Rights-of-Way Memorandum of Agreement (MOA) between BPA and DNR. This MOA will cover certain issues related to all DNR lands that are encumbered with BPA easements. It is the mutual goal of BPA and DNR to address BPA transmission line operations and maintenance compatibility with trust land management and to complete the MOA prior to December 31, 2011. It is expected that this MOA will, at a minimum, address the following elements:

a. Integration of State and Federal Requirements;
b. Danger trees;
c. Vegetation management;
d. Access road management, maintenance, repair, and cost sharing;
e. Dispute resolution;
f. Communications/notification;
g. Liability;
h. Situations where additional right-of-way and/or mitigation is needed for transmission operations, such as safety zones and vegetation removal for clear safe backlines;
i. Third party use (authorized and unauthorized); and
j. Safety.

This appendix also reflects ~~two~~ one other agreement~~s~~ between BPA and DNR: an Appraisal Memorandum of Understanding (Appraisal MOU) ~~and a Land Exchange Agreement~~. The Appraisal MOU was finalized on August 1, 2010 and describes the process BPA would use to appraise DNR lands crossed by the proposed project.

The following sections of this appendix provide more detailed information on DNR lands relevant to the proposed Big Eddy-Knight Transmission Project. Section I.1 describes the specific DNR properties that could be affected by the proposed project, and Section I.2 discusses potential impacts to these properties. Section I.3, at the end of this appendix, lists possible measures that could be undertaken to lessen or avoid these potential impacts.

I.1 DNR Land Parcels Potentially Impacted

In Klickitat County, DNR manages four parcels potentially crossed by the proposed project (see Table I-1 and Maps I-1 thru I-4). BPA's preferred East Alternative with Substation Site 1 would impact Parcel 3 with the proposed line and Parcel 4 with a substation access road. Table I-2 identifies the project components potentially located on the four DNR parcels for all the action alternatives and the possible right-of-way needs. Table I-3 identifies the permanent footprint impacts due to towers and roads as well as the temporary disturbance areas (construction areas around towers, counterpoise and temporary roads).

Table I-1. DNR Land Parcels within the Project Area

Parcel	Township, Section, Range	Land Use	Alternative	Location (Line Mile)
Parcel 1	T03N, R14E, Sections 28, 32, 33	Recreation and Conservation (Columbia Hills Natural Area Preserve) total 3,600 acres	West	W8.5–10.5
Parcel 2	T04N, R14E, Section 36	Washington State Trust Lands – Leased Agriculture and Dispersed Recreation total 633 acres	West	W16–17
Parcel 3	T03N, R15E, Section 36	Washington State Trust Lands – Wind Power Production total 483 acres	East	E15
Parcel 4	T05N, R15E, Section 36	Washington State Trust Lands- Leased Agriculture and Dispersed Recreation total 544 acres	West, Middle, East, Substation 2	WM26, E28, Substation Site 2

Table I-2. Project Components Potentially Located on DNR Parcels

Parcel	Miles of Line	Number of New Towers	New Right-of-Way (acres)	Existing Right-of-Way (acres)	New Roads (miles)	Upgrade Existing Roads (miles)	Substation (acres)
Parcel 1	2	10	13–40	27	~~2~~ 1	2	–
Parcel 2	0.8	3	5–14	9	0.7	0.8	–
Parcel 3	0.5	1	9	0	~~0.04~~ 0.2	0	–
Parcel 4 with Substation	0.7	4	13	15	~~0.7~~ 2	0	30
Parcel 4 without Substation	–	–	–	15	~~0.7~~ 2	– 0	–

Table I-3. Impacts by DNR Parcel

	Permanent Impacts					Temporary Impacts		
Parcel	**Towers (acres)[2]**	**New Roads (acres)**	**Upgrade Existing Roads (acres)**	**Substation (acres)**	**Total Permanent Impacts (acres)**	**Towers (acres)[2]**	**Temporary Roads (acres)**	**Total Temporary Impacts (acres)**
Parcel 1	1–2	~~7~~ 4	8	–	~~17~~ 13–14	4–16	0	4–16
Parcel 2	0.4–0.5	3	3	–	6	1–5	0	1–5
Parcel 3	0.1	~~0.2~~ 0.7	0	–	~~0.3~~ 0.8	0.4	0	0.4
Parcel 4 with Substation	0.5–0.7	~~2~~ 5	0	30	~~32–33~~ 36	2	0.3	2
Parcel 4 without Substation	–	5	– 0	–	– 5	–	–	–

I.2 Resource Impacts

The following discussions focus on the environmental resources that DNR has stated requires additional information to aid the agency in its statutory and regulatory compliance efforts for DNR parcels potentially crossed by the proposed project. General resource impacts that occur due to the project are described in Chapter 3 of this EIS; the information below addresses the site specific impacts on the DNR parcels. Also, Chapter 3 of the EIS provides analysis for the environmental resources not specifically addressed in this appendix, including DNR lands.

I.2.1 Land Use and Recreation

The vicinity of the proposed project, including the general vicinity of the four parcels of DNR lands, is sparsely populated with development mainly limited to rural homes, ranches, and farms. The four DNR parcels are located on gently rolling to moderately hilly plateaus. Parcel 1 is a dedicated preserve under the Washington Natural Area Preserves Act, for the preservation of high quality and rare natural areas, as well as threatened and endangered species as part of the Washington Natural Heritage Program (WNHP) (WNHP 2007, 2009b). While preservation is its primary mission, the preserve is also used for research and education. ~~, and recreation. Recreation~~ Otherwise, public use in the preserve ~~consists primarily of~~ is limited to hiking, wildflower viewing, and wildlife observation along The Dalles Mountain Road. DNR Parcels 2, 3, and 4 are Washington State Trust Lands managed by DNR. Parcels 2 and 4 are leased for agriculture and allow for dispersed recreation (hunting, fishing, etc.), and Parcel 3 is leased for wind production as part of the Windy Flats Energy Production Area and is also used for range and cereal grains/alfalfa production. ~~may also be used for range~~.

Section 3.1 Land Use and Recreation of the EIS provides an analysis of the project's potential impacts on land use along the proposed project, including on the four DNR parcels potentially affected by the project, and identifies measures to lessen or avoid impacts that would also apply to the four DNR parcels.

Impacts to land use would include limitations of use within the right-of-way, removal of land from use due to tower footprints, roads, and Knight Substation, disruption of use due to the presence of the line through properties, and disturbance during maintenance and construction activities.

Use limitation within the right-of-way would include keeping the right-of-way clear of all structures, fire hazards, tall-growing vegetation and any other use that may interfere with the safe operation or maintenance of the line. Buildings could not be constructed within the right-of-way.

While BPA would obtain the right through its easements to keep the right-of-way clear of vegetation and structures, BPA could enter into agreements with DNR for low-growing vegetation that does not interfere with BPA's safe operation and maintenance of its transmission facilities. DNR would coordinate with BPA prior to planting to ensure that the use is safe, compatible and does not create an interference. Most crops could be grown safely under the transmission line. However, orchards, Christmas trees, tall-growing landscape or natural vegetation, and structure–supported crops (i.e., trellises) would require special consideration. For DNR's Parcel 3 specifically, BPA has determined it would be safe to grow non-structure supported vegetation to a mature height not to exceed 10 feet.

Many uses would not be restricted, but certain precautions would need to be taken. For example, no object should be raised higher than 14 feet above the ground within the right-of-way (i.e., when moving irrigation pipes, they should be kept low and parallel to the ground); ground elevation should not be altered (such as piling of dirt within the right-of-way); irrigation spray should not create a continuous stream onto the conductors or towers; fences should be grounded; and installing underground pipes or cables through the right-of-way needs to be coordinated with BPA so as not to interfere with transmission line grounding systems and tower footings. In general, vehicles and large equipment that do not exceed more than 14 feet in height, such as harvesting combines, cranes derricks and booms could be operated safely under the line where it passes over roads, driveways, parking lots, cultivated fields or grazing lands. For DNR's Parcel 3 specifically, line design would accommodate clearance of a 40' crane to cross under the proposed line on Haystack Butte Road.

BPA does not restrict land uses outside the right-of-way. This is true of all lands adjacent to the proposed corridor including DNR lands. Land uses such as growing crops, grazing livestock, state and county roads, electric transmission lines, and outdoor recreational sports and activities would continue. Some temporary impacts may occur during construction of the transmission line as discussed in Section 3.1.2 of the EIS. Placement of the transmission line would not limit development outside the right-of-way including agricultural use, residential development, wind power production, or solar energy or communication sites. Within Klickitat County, private lands crossed by the action alternatives are zoned rural center, open space and extensive agricultural use. Much of the area is in an energy overlay zone. DNR ~~lands, as managed by the State of Washington, are not~~ is subject to state and local zoning laws ~~regulations~~.

The land uses on the DNR parcels include nonirrigated crop land, rangeland (the wind production area appears as rangeland as it is multi use), and Conservation/Recreation. See Table I-4 for acreages of impacts to various land uses, prime farm land, and farmland of statewide importance.

Table I-4. Land Use Impacts and New Right-of-Way by DNR Parcel

Land Use	Permanent Impacts by Parcel (acres)[1]				Temporary Impacts by Parcel (acres)[1]				New Right-of-Way by Parcel (acres)			
	1	2	3	4	1	2	3	4	1	2	3	4
Nonirrigated Cropland	0	0	0	~~32~~ 5–35	0	~~1~~ 0	~~0.4~~ 0	0.04	0	0	0	0–13
Rangeland	0	~~4~~ 6	~~0.3~~ 0.8	0–1	0	~~0~~ 1–5	~~0~~ 0.4	0–2	0	~~4–13~~ 5–14	9	0
Preserve ~~Conservation/ Recreation~~	~~14–15~~ 13–14	0	0	0	~~4–5~~ 4–16	0	0	0	13–40	0	0	0
Totals by Parcel ~~Type of Impact~~	~~14–15~~ 13–14	~~4~~ 6	~~0.3~~ 0.8	~~33~~ 5–36	~~4–5~~ 4–16	1–5	0.4	0–2	13–40	~~4–13~~ 5–14	9	0–13
Prime Farmland	0	0	0	~~31~~ 36	0	0	0	1–2	0	0	0	0–10
Farmland of Statewide Importance	6	2	0.2	0.5	2–4	0.4–1.0	0.4	0.5–0.6	6–19	2–6	6	0–3

[1] Permanent and Temporary Impacts by Parcel include impacts from towers, access roads, and/or substations.

I.2.2 Geology and Soils

Section 3.4 Geology and Soils of the EIS provides an analysis of the potential impacts on geology and soils along the project (routing alternatives and substation sites), and identifies measures to lessen or avoid potential geologic hazards and soil impacts. The analysis in Section 3.4 includes a general assessment of geologic hazards for the four DNR parcels potentially affected by the proposed project, and the identified measures to lessen or avoid potential geologic hazards would also apply to the four DNR parcels. In addition, Map I-5 series of this appendix displays the liquefaction risks and faults found within the project area, including the four DNR parcels.

Additional geology and soils information is continuing to be obtained using geologic hazard assessments, including on-the-ground field assessments. The geologic hazard assessments have included the review of liquefaction hazard mapping, geologic maps for fault locations, and aerial photographs combined with surface condition assessments at proposed tower locations and surrounding terrain for landslide hazard assessment. Geological soil testing will be performed at representative tower locations to help determine appropriate tower footings for a given soil type or hazard. Geologic and soil hazard areas are avoided where possible, and where avoidance is not possible, towers and roads would be designed to address the applicable hazard.

Landslides. In Washington, landslide areas along the project occur along the Columbia Hills (see Map I-5). The West Alternative crosses a large inactive landslide on Washington Parks and DNR lands between line miles W7.6-8.4. Small landslides may also be associated with the headwaters of drainages on the north flank of the Columbia Hills near line mile W9.5.

Landslide areas along the East Alternative in Washington occur in the Wishram area and just south of the DNR Parcel 3.

As discussed in Section 3.4.2 of the EIS, because road development has the potential to cause erosion or landslides, road grades on all lands crossed by the proposed project would be varied depending on the erosion potential of the soil and roads would be rocked where needed for dust abatement, stability, load bearing, and seasons of use. Final design measures would take slopes, soil types, bedrock, the presence of bedrock hollows or inner gorges, and other factors into account based on site-specific information.

Seismic. Various faults are located along the project routes (see Map I-5). Earthquakes occurring in the Northwest could cause ground shaking or ground failure – landslides or liquefaction (severe settling of soil) – in large landslide areas, in floodplain sediments and alluvial fill in the Swale Creek Valley, and in floodplain sediments around Fifteenmile Creek in Oregon and the Little Klickitat River in Washington. All facilities would be built to applicable seismic standards and combined wind- and ice-loading tower design criteria typically exceed earthquake-induced loads.

Liquefaction. Liquefaction hazards occur where the combination of fine-grained cohesionless soils and high water table conditions occur. Generally, transmission towers are likely to survive settlement associated with liquefaction with only minor structural damage. It is BPA's policy to avoid placing towers in areas where liquefaction might occur, such as stream crossings.

Liquefaction hazards were identified where the Middle and East alternatives cross Swale Creek (see Map I-5). Test pits would be excavated at tower sites in these areas to further investigate subsurface conditions and verify no liquefaction hazard exists. If a potential liquefaction hazard is found, the liquefiable soils would most likely be excavated to bedrock and replaced with non-liquefiable backfill.

I.2.3 Vegetation

Section 3.3 of the EIS provides an analysis of the project's potential impacts on vegetation in the project vicinity for all routing alternatives, including on the four DNR parcels potentially affected by the proposed project, and identifies measures to lessen or avoid impacts that would also apply to the four DNR parcels. Table I-5 displays the potential impacts to vegetation at each of the four DNR parcels that could be affected by the proposed project.

Four special-status species associated with high-quality grasslands have mapped occurrences on Columbia Hills Natural Area Preserve Parcel 1; clustered lady's-slipper (*Cypripedium fasciculatum*), Douglas' draba (*Cusickiella douglasii*), hot-rock penstemon (*Penstemon deustus* var. *variabilis*), and obscure buttercup (*Ranunculus triternatus* (ORNHIC 2007 and WNHP 2009c). Vegetation surveys conducted of the proposed transmission line corridors in spring 2010 only found the obscure buttercup. Because of the unusual spring weather (early heat, then a late snow) it is assumed that the field surveys missed the plant flowering times of the other three special species grassland plants and their presence could not be verified. Because both the park and preserve ~~biologists~~ ecologists have recorded their presence, it is assumed that all four of the special-status grassland type species occur in this area and the analysis reflects the previously recorded data. In addition, Parcel 1 has Oregon white oak and ponderosa pine trees.

Table I-5. Vegetation Impacts and Right-of-Way by DNR Parcel

	Permanent Impacts (acres)				Temporary Impacts (acres)				New Right-of-Way (acres)			
Parcel #:	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Vegetation Cover Types												
Shrub-Steppe	0	0	0	0	2–4	0	0	0	0	0	0	0
Grassland	13–14	0	0	0	~~0.04~~ 2–12	0	0	0	12–36	0	0	0
Idaho Fescue-Houndstongue Hawkweed[1]	*3–7*	~~*3–7*~~ *0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Disturbed Shrub-Steppe/ Grassland	0	~~0.4–0.7~~ 6	~~1–2~~ 0.8	~~10.4~~ 0–1	0	~~4~~ 1–5	~~0.3~~ 0.4	~~1~~ 0–2	0–0.01	4–13	9	0

[1] Priority ecosystem associated with grasslands

As discussed in Section 3.3.2, the proposed project could result in the spread of noxious weeds, especially along newly constructed access roads. To control or contain noxious weeds on DNR parcels potentially crossed by the proposed project, BPA would undertake actions in coordination with DNR at four stages of the proposed project: pre-construction, construction, immediate post-construction, and maintenance.

Pre-Construction. The MOA between DNR and BPA and/or easement document for any DNR parcels affected would outline measures for weed control (see Table I-7 for Potential Measures on DNR Parcels). As part of BPA's noxious weed management, BPA contracted with Klickitat County to conduct a noxious weed survey in spring 2010 along the proposed alternatives to help determine infestation locations and appropriate mitigation measures needed for construction. However, because BPA did not have permission to enter the DNR parcels, the inventory in those areas was conducted from public access where available. If noxious weeds are currently on the DNR property, BPA and DNR could decide to apply herbicides prior to construction to help reduce spread during construction. Construction specifications will contain provisions stating how the noxious weeds would be controlled or contained including provisions outlined in the MOA.

All proposed actions to control or eradicate noxious weeds would comply with the Carson-Foley Act (P.L. 90-583), the Federal Noxious Weed Act (P.L. 93-629), ~~and~~ other applicable ~~State and~~ Federal regulations, and all applicable state and county noxious weed control regulations and guidelines to the extent practicable.

Construction. During construction, BPA would implement noxious weed control measures specified in the construction specifications which would include establishing vehicle and equipment washing stations in strategic locations to reduce the possibility of seed being carried to areas that do not have infestations, as well as reseeding disturbed areas with desirable species to limit noxious weed germination. To ensure that the desired level of noxious weed control is being carried out, the BPA field inspector and the land liaison representative would monitor the program. For DNR land, BPA will coordinate these efforts with DNR as specified in the MOA or easement agreement.

Immediate Post-Construction. Upon completion of construction, the maintenance of the transmission line and its associated access roads and rights-of-way would become the responsibility of BPA Transmission Line Maintenance with the assistance of the BPA Regional Natural Resource Specialist. Before the line is released for future maintenance, a detailed post-construction field review would be conducted with DNR, the BPA field inspector, and the BPA Regional Natural Resource Specialist. Specific weed control measures would be agreed upon and responsibilities, including funding, assigned to the participating organization.

Maintenance. Over the long-term, vegetation (including noxious weeds) on DNR land would be managed by the BPA Regional Natural Resource Specialist along the right-of-way as guided by BPA's Transmission System Vegetation Management Program EIS, agreements made with DNR, and input from the Klickitat County weed board.

Noxious weed control on BPA easements across DNR parcels and other lands would be coordinated through the BPA Regional Natural Resource Specialist (NRS). Prior to conducting any such weed control, BPA's usual practice is to develop a noxious weed management plan within an overall Vegetation Management Prescription, followed by preparation of a Supplement Analysis (SA) to BPA's Transmission System Vegetation Management Program EIS. The SA provides a review of the control activities and ensures they are consistent with the vegetation maintenance activities contained in that EIS. BPA would coordinate preparation of the noxious weed management plan on DNR managed trust lands with DNR staff. Examples of maintenance policies that are defined in BPA's Transmission System Vegetation Management Program EIS, and that likely would be included in a noxious weed management plan and considered in SAs relevant to DNR, include the following:

a. Apply herbicides to the rights-of-way.
b. Provide herbicides to landowners.
c. Contract with the owners or county weed control districts to apply herbicides to BPA rights-of-way.
d. Contract with the county weed control district to apply herbicides to specific identified noxious weeds.
e. Initiate additional control measures as recommended by local jurisdictions or responsible governmental agencies.

f. Where required by state or local agencies or in agricultural areas where noxious weeds are present, pressure or steam wash all vehicles used in that location before entering another location.

I.2.4 Wildlife

Section 3.6 of the EIS provides an analysis of the project's potential impacts on wildlife in the project vicinity for all routing alternatives, including on the four DNR parcels potentially affected by the proposed project, and identifies measures to lessen or avoid impacts that would also apply to the four DNR parcels.

DNR parcels 2, 3, and 4 provide common, disturbed grassland/shrub-steppe and cropland habitat (see Table I-4 for acres of the corresponding cropland and rangeland impacts). As described in Section 3.6.1, cropland habitat provides habitat for horned lark, mountain quail, owls, hawks, burrowing owl, and others. The DNR Columbia Hills Natural Area Preserve on Parcel 1 provides high quality grassland/shrub-steppe habitat (see Table I-5) and woodland Oregon white oak-ponderosa pine habitat (see Section I.2.3). These habitats can be frequented by western skink, raccoon, black-tailed deer, mule deer, coyote, various species of rodents, reptiles (such as western rattlesnake, alligator lizard, and western fence lizard), long-billed curlew, prairie falcon, golden eagle, northern harrier, Swainson's hawk, red-tailed hawk, Cooper's hawk, barn owl, downy woodpecker, ash-throated flycatcher, mountain quail, California quail, ring-necked pheasant northern flicker, western meadowlark, horned lark, and many other species.

I.2.5 Water Resources, Wetlands, and Fish

Sections 3.5 and 3.7 of the EIS provides an analysis of the project's potential impacts on water resources, wetlands, and fish in the project vicinity for all three routing alternatives, including on the four DNR parcels potentially affected by the proposed project, and identifies measures to lessen or avoid impacts that would also apply to the four DNR parcels.

There are no perennial water bodies or floodplains located on the four DNR parcels where the proposed transmission line would cross. Proposed access roads would not cross drainages on any DNR parcels and no culverts would be installed.

Wetlands are found on Parcels 1 and 2. On Parcel 1, about 3.2 acres in five different wetlands could be permanently impacted by fill (dirt, rock, or concrete) required for tower footings and upgrading or building new access roads (see Section 3.5, Table 3-19); on Parcel 2 about 1.0 acre in two different wetlands could be permanently impacted. Impacts would vary depending on wetland quality (or "functional level"). Wetlands along Parcel 1 were ranked low or were not ranked because the wetland function could not be assessed and wetlands in Parcel 2 were ranked moderate. There would be no impacts to wetlands on Parcels 3 or 4.

As discussed in Section 3.5.1, if project-generated sediment were to reach an intermittent stream, it would have little effect, if any, and would likely be indiscernible from existing conditions within a few hundred feet. As there are no drainages on DNR parcels, there would be no impacts to fish.

I.2.6 Cultural Resources

Section 3.8 of the EIS provides an analysis of the project's potential impacts on cultural resources in the project vicinity for all three routing alternatives, including on the four DNR parcels potentially affected by the proposed project, and identifies measures to lessen or avoid impacts that would also apply to the four DNR parcels.

The first phase of cultural resource surveys were not conducted on DNR lands due to the lack of permission to enter the properties. Additional surveys of the alternatives, including DNR lands, ~~will be~~ were conducted winter/spring 2011. Cultural resources will be avoided where possible and mitigation measures have been identified to reduce or eliminate adverse impacts (see Table 3.8.2). BPA will coordinate with DNR to avoid and minimize impacts to cultural resources.

I.2.7 Socioeconomics

Section 3.9 of the EIS provides an analysis of the project's potential impacts on socioeconomics and public facilities in the project vicinity for all three routing alternatives, including on the four DNR parcels potentially affected by the proposed project, and identifies measures to lessen or avoid impacts that would also apply to the DNR parcels.

Several of the DNR parcels are Washington State Trust Lands managed by DNR. The State Trust Lands are held in trust by the state and leased to private farmers either on a cash rent or sharecrop basis (McKay 2010), or to a wind developer (i.e., Windy Flats). The primary beneficiaries of State Trust Lands are public schools (kindergarten through 12th grade), which receive over 78 percent of the funds. In 2009, over 5.6 million acres were in State Trust Lands, and provided over $192 million in state revenues (DNR 2010).

As discussed above in Section I.2.2, Land Use and Recreation, DNR Parcels 2, 3, and 4 are Washington State Trust Lands managed by DNR. Parcel 2 is leased for range land and Parcel 4 is leased for range and crop production. Parcel 3 is leased for wind production as part of the Windy Flats Energy Production Area and in the NW ¼ contains 37 acres of leased cropland used for dryland cereal grain and alfalfa production. ~~may also be used for range~~.

As shown in Table I-4, permanent removal of land from use from construction of transmission tower footings and new access roads on DNR land used for grazing leases would be ~~4~~ 6 acres (Parcel 2), ~~0.3~~ 1 acre~~s~~ (Parcel 3) and 0–1 acre (Parcel 4). Parcel 4 is also primarily used for crop production, although there may also be some rangeland, in the area of Substation Site 2, which would permanently remove ~~30~~ 5–36 acres from use. These totals represent a relatively small portion of the DNR parcels (see Section I-1 for total parcel acreages).

It is estimated that cash rents for range land are about $2/acre·year, while crop land rents are between $30 and $40 per acre, per year (acre·year). Sharecrop returns to DNR range from 30 to 35 percent of the crop, which results in $10 to $70 per acre·year.

Based on the maximum potential cash rents and sharecrop returns given above, the amount of DNR revenue that would be lost to towers and access roads is estimated to be $12 per year for Parcel 2 (West Alternative with approach to Knight Substation Site 2) and ~~$0.60~~ $2.60 per year for Parcel 3 (based on the impacts to rangeland; East Alternative with approach to Knight Substation Site 2). The amount of additional DNR revenue lost to Knight Substation Site 1 would be about $322 per year from a substation access road across Parcel 4. Knight Substation Site 2 would result in the loss of about $2,451 in DNR revenue from the substation and substation access road. If any of the alternatives connect to Substation Site 2, they would impact additional State Trust Lands by about $210 per year.

Crops lost to temporary construction activity would result in about $273 annually during construction for the action alternatives; this amount would be compensated in addition to the purchase of the property or easement. If any of the land is held in CRP, federal payments made to the state would be affected if all or a portion of the land had to be taken out of CRP. Placement of transmission lines would not necessarily affect CRP status and no loss in value from construction activities would be expected for CRP land. Because the East Alternative would be routed to avoid conflicts with existing wind turbines already developed on Parcel 3, there would be no additional wind development revenue loss expected.

I.2.8 Transportation

Section 3.10 of the EIS provides an analysis of the project's potential impacts on transportation in the project vicinity for all three routing alternatives, including on the four DNR parcels potentially affected by the proposed project, and identifies measures to lessen or avoid impacts that would also apply to the four DNR parcels.

Table I-2 displays the proposed miles and acres of new access roads and those needing improvement located on the four DNR parcels that could be affected by the proposed project. Table I-6 displays the general characteristics of access road easements proposed to be located on the four DNR parcels that could be affected by the proposed project. This table identifies the type, length, and width of the proposed easements and what type of use is expected (joint or BPA exclusive use).

During construction, unavoidable transportation impacts would consist of minor delays and interruptions to local traffic, with a relatively low increase in daily traffic volume on highways. Operation and maintenance traffic over the life of the line would be only a few maintenance vehicles once a year, and helicopters twice a year.

A discussion of BPA's access road system for the proposed project is included in Section 2.3.4, Access Roads, of the EIS. This discussion includes a general description of the width, location, type of road improvement, and construction equipment that would be used. Use of temporary roads within agricultural fields is also discussed. For the DNR parcels, BPA would acquires rights (easements for line access roads and fee title for substation access roads), and develop and maintain permanent access suitable for travel by wheeled vehicles to each transmission line structure site, substation or other transmission facility. Existing public and private roads and transmission line rights-of-way would be used for access where reasonably possible. See Section 3.1 Land Use and Recreation for a discussion about possible unauthorized access and use of BPA roads.

As part of BPA's Transmission Engineering Manual, BPA has an Access Road Planning and Design Manual (BPA, 1987). This comprehensive manual includes BPA's access road policy and standards regarding the design and construction of access roads that also would be used for proposed access roads on and adjacent to the four DNR parcels.

Environmental, engineering, economic, and maintenance factors are considered in locating and designing access roads. Access road planning, as described in the BPA Manual, takes into account many factors including seasonal constraints for construction, steep slopes, present and potential land uses, soil conditions, soil erosion potential, water quality impacts, visual impacts, and impacts to cultural resources. The BPA Manual also describes erosion and sediment control methods that are implemented. Erosion control is a very important factor in planning, designing, constructing and maintaining access roads. Erosion must be controlled during and after construction to prevent road damage, to avoid undue increases in stream turbidity and sedimentation, and soil deposition outside of the road right-of-way. Well designed and constructed erosion control measures would reduce road maintenance costs and provide a reliable road in the event of emergency work on the transmission line. Drainage structures including culverts, intercepting dips, water bars, and gravel surfacing are elements of erosion control, as is seeding.

Access road planning and design are important elements of transmission project development and to be effective must begin at the earliest stage of project planning. Well developed access road plans and designs minimize construction and maintenance costs, environmental impacts, and costly delays because of late changes in access road routing. Access road plans and designs are developed using landowner, environmental, construction, and maintenance input. For the DNR parcels, access road plans and designs would also be coordinated with the appropriate DNR engineer.

Table I-6. Proposed Access Roads located on DNR Parcels

DNR Parcel	Legal Description	Land Use	Type of Easement	Length of Easement (feet)	Width of Easement (feet)	Anticipated Road Use
Parcel 1	Sec 28 T3N R14E	Columbia Hills Natural Area Preserve	Permanent Road	2,040	50	BPA Use - Road AZH-10-AR-3
Parcel 1	Sec 28 T3N R14E		Permanent Road	1,620	50	BPA Use - Road AZH-11-AR-1
Parcel 1	Sec 32 T3N R14E		Permanent Road	360	50	BPA Use - Road AZH-9-AR-2
Parcel 1	Sec 32 T3N R14E		Permanent Road	1,375	50	BPA Use - Road AZH-9-AR-3
Parcel 1	Sec 32 T3N R14E		Permanent Road	970	50	BPA Use - Road AZH-9-AR-4
Parcel 1	Sec 32 T3N R14E		Permanent Road	1,545	50	BPA Use - Road AZH-9-AR-5
Parcel 1	Sec 32 T3N R14E		Permanent Road	1,775	50	BPA Use - Road AZH-10-AR-1
Parcel 1	Sec 32 T3N R14E		Permanent Road	1,025	50	BPA Use - Road AZH-10-AR-2
Parcel 1	Sec 33 T3N R14E		Permanent Road	1,925	50	BPA Use - Road AZH-10-AR-2
Parcel 1	Sec 32 T3N R14E	Existing Road	None: Existing Road (Stacker Mt Microwave Rd)	5,810	60	Joint Use - Stacker Mt Microwave Rd
Parcel 2	Sec 36 T4N R14E	Agriculture	Permanent Road	330	50	BPA Use - AZH-16-AR-2P1

DNR Parcel	Legal Description	Land Use	Type of Easement	Length of Easement (feet)	Width of Easement (feet)	Anticipated Road Use
Parcel 2	Sec 36 T4N R14E		Permanent Road	1,580	50	BPA Use - AZH-16-AR-2P2
Parcel 2	Sec 36 T4N R14E		Permanent Road	700	50	BPA Use - AZH-16-AR-3
Parcel 2	Sec 36 T4N R14E		Permanent Road	670	50	BPA Use - AZH-17-AR-1
Parcel 2	Sec 36 T4N R14E		Permanent Road	350	50	BPA Use - W17-AR-2
Parcel 2	Sec 36 T4N R14E	Existing Road	None: Existing Road (Ahola Rd)	4,390	60	Joint Use - Ahola Rd
~~Parcel 3~~	~~Sec 36 T3N R15E~~	Windy Flats	~~Permanent Road~~	~~3,035~~	~~50~~	~~BPA Use - Road AZE-15-AR-4~~
Parcel 3	Sec 36 T3N R15E		Permanent Road	105	–	BPA Use - Road AZE-15-AR-3
Parcel 3	Sec 36 T3N R15E		Permanent Road	420	50	BPA Use - Road AZE-15-AR-5
Parcel 3	Sec 36 T3N R15E		Permanent Road	895	50	BPA Use - Road AZE-16-AR-1
Parcel 3	Sec 36 T3N R15E	Existing Road	None: Existing Road (Haystack Butte Road)	1,800	60	Joint Use - Road HAST-SAR-P9 (Haystack Butte Rd)
Parcel 4	Sec 36 T5N R15E	Agriculture	Permanent Easement (Route of Travel)	2,625	50	BPA Use - Tower access E 28/4
Parcel 4	Sec 36 T5N R15E	Agriculture[1]	Permanent Road	2,685	50	BPA Use - Knight-SAR-1
Parcel 4	Sec 36 T5N R15E	Agriculture[2]	Permanent Road	3,900	50	BPA Use - Knight Substation Access

[1] This road would lead to Knight Substation Site 1.
[2] This road would lead to Knight Substation Site 2.

As discussed in the introduction to this appendix, BPA and DNR expect to negotiate a Washington Statewide Rights-of-Way MOA with the goal of addressing BPA transmission line operations and maintenance compatibility with DNR trust land management. Among other things, this MOA is expected to provide mutually agreeable definitions, classifications, and responsibilities for BPA sole and joint use access roads located on DNR lands, in order to provide for mutually agreeable maintenance and operation of these roads. Although a statewide approach to BPA access roads on DNR lands will be addressed in the Statewide MOA, there already has been fairly extensive discussion between BPA and DNR on this issue. While these discussions have not concluded, they provide an indication of the likely language concerning definitions, classifications, and best practices for BPA access roads located on DNR lands that

BPA and DNR expect may be included in the easement documents for the proposed project, as well as in any project-specific maintenance and operation agreement that may be negotiated if the project is approved before the Statewide MOA is negotiated. Based on current, in-progress discussions between BPA and DNR, any such language likely will be similar to, or possibly largely the same as, the following:

DEFINITIONS

1. Road Maintenance: Periodic work performed on a road so that the road prism remains usable and costly repairs are not needed. Activities include but are not limited to shaping the roadway, vegetation control, cleaning catch basins, installation of cross-drain culverts and culvert maintenance, water bars, ditches, roadside brushing, and spot rocking. Includes traffic and non-traffic generated maintenance.

2. Road Improvement: Includes any work that increases the overall value of the road. Activities include but are not limited to: new road and bridge construction, bridge and culvert replacement, significant road surface improvement or changing the surface of a road, widening, ditch construction, abandonment, decommissioning and road realignments or rerouting. It does not include any of the specific activities listed in road maintenance.

3. BPA Sole Use Road: A road on State-managed uplands within and outside the transmission corridor that is used almost exclusively by BPA including roads built for the original line construction, patrol, maintenance, upgrades, emergency repairs, and vegetation management. General characteristics of this type of road include:

    a. Road does not currently, nor in the foreseeable future provide needed access to State-managed lands for the purpose of resource management.
    b. Road is not generally used, identified, or necessary for administrative use by State purchasers, lessees, or permittees.
    c. No additional easement holder user of the road has been identified.
    d. State rarely uses the road administratively. Such State use includes, but is not limited to easement administration.
    e. State does not have a designated recreational trail or promote other authorized recreational use of the road.
    f. State does not consider the road part of the State funded transportation system.

4. BPA/State Joint Use Road: A road on DNR-managed land that is mutually beneficial where BPA is an easement holder. General characteristics of this type of road include:

    a. State uses or has immediate plans to use the road, or a portion of the road, to access DNR-managed lands.
    b. State's purchasers, lessees or permittees require use of the road.
    c. An additional easement holder user of the road may have been identified.
    d. State has designated sections of the road as a recreation trail or has invited recreational use onto the road.
    e. State maintains the road and considers the road part of the State funded transportation system.

BEST PRACTICES TO MAINTAIN AND IMPROVE JOINT AND SOLE USE ROADS ON STATE MANAGED LANDS

DNR and BPA agree to produce and maintain a safe, cost effective, environmentally friendly, and practical road program that is supported by and meets the needs of the sole and joint use roads.

Instead of complying with specific roads standards, the agencies will identify and implement best practices to accomplish the following objectives:

a. Protect water quality and avoid sediment loading into water bodies;
b. Protect sensitive areas and reduce ecosystem impacts;
c. Maintain natural channels, natural stream flow, and maintain passage for aquatic organisms;
d. Control surface water on the road;
e. Stabilize the driving surface;
f. Evaluate unauthorized use that may damage the road and take steps to curtail such use;
g. Implement needed slope stabilization measures and reduce mass wasting;
h. Establish compatible vegetation on disturbed areas; and
i. Avoid and control the spread of noxious weeds.

I.3 Potential Measures on DNR lands

In addition to mitigation measures identified in Chapter 3 of the EIS, the measures outlined in Table I-7 could be implemented to further reduce or avoid potential impacts on DNR lands.

Table I-7. Potential Measures on DNR Parcels

Measure	Implementation
Implement the MOA with DNR that reduces noxious, invasive and undesirable species including tall-growing woody plants and works towards compatible and native low-growing species vegetation on DNR lands. The MOA also will provide coordination between DNR and BPA for the use of herbicides on lands where DNR uses herbicides and minimizes the use of herbicides on lands where DNR does not use herbicides.	Washington Statewide Rights-of-Way MOA/DNR Easement Document
~~Implement the MOA with DNR to jointly maintain mutually beneficial roads that ensures payments by the parties for their joint use and their need for a permanent transportation system.~~	~~Washington Statewide Rights-of-Way MOA/DNR Easement Document~~
~~Commit to coordinating road design with DNR.~~	~~Washington Statewide Rights-of-Way MOA/DNR Easement Document~~
Commit to developing and complying with mutually agreeable definitions, classifications, and responsibilities for BPA sole and joint use access roads for the proposed project that would be located on DNR lands, with the goal of addressing operations and maintenance compatibility of the proposed transmission line with DNR trust land management.	Washington Statewide Rights-of-Way MOA/DNR Easement Document
For any noxious weed management plans prepared for proposed weed control and other vegetation maintenance on DNR managed trust lands as part of future line maintenance activities, coordinate preparation of these management plans with DNR staff.	Noxious Weed Management Plans
Commit to ~~C~~coordinat~~e~~ing with DNR regarding the 1989 DNR Agricultural and Grazing lands Policy Plan and related Resource Management Plans for individual parcels during construction and maintenance of the line and access roads over DNR trust lands. Provide DNR with notice of potential impacts to affected lands enrolled in the Conservation Reserve Program. Request permission to disturb ground cover as needed to complete the project and agree to restore impacted lands outside of lands developed to tower pads and access roads to the same type of cover at no expense to any applicable DNR lessee or to DNR as landowner.	Washington Statewide Rights-of-Way MOA

Measure	Implementation
Implement the Appraisal MOU with DNR to pay fair market value for ~~impacts~~ any easement conveyances granted to BPA ~~to~~ on trust lands.	Appraisal MOU
Utilize the Appraisal MOU with DNR to assess the value for any reduction in CRP acreage due to construction of access roads or towers.	Appraisal MOU
Work with DNR concerning a possible cooperative agreement for the control of unauthorized public access and use on state lands that could result from the proposed project. The agreement could address various provisions related to unauthorized access, such as additional measures to be taken to discourage unauthorized use of the project corridor and associated access roads, periodic inspection for unauthorized access and any resulting damage, and repair of any damage from unauthorized access. BPA will strive to design the corridor to prevent trespass and provide signs that discourage unauthorized use of the corridor.	Washington Statewide Rights-of-Way MOA (see McNary-John Day Maintenance and Operations Agreement) /DNR Easement Document
Mark the easement corridor in strategic locations on DNR land so that BPA, contractors, adjacent landowners and the public can clearly recognize when they are within the corridor to prevent uncompensated corridor expansion, vegetation management conflicts, and to reduce trespass.	Washington Statewide Rights-of-Way MOA (see McNary-John Day Maintenance and Operations Agreement) /DNR Easement Document
Develop a mutually agreeable fire prevention and suppression plan with DNR that addresses managing and controlling the risks associated with wildland fire due to construction, operation, and maintenance of the transmission line.	Washington Statewide Rights-of-Way MOA (see McNary-John Day Maintenance and Operations Agreement) /DNR Easement Document

Appendix J

Geology and Soils

LEGEND

	WEST	MIDDLE	EAST
MILEPOST	8	8	8
ROUTE & BUFFER			
STRUCTURE			

POTENTIAL HAZARDS

GRAVEL PIT

SLIDE OR SLIP

WET SPOT

MINE / QUARRY

ROCK OUTCROP

STONY SPOT

FAULTS*

WA DNR

WA USGS

OR DOGAMI

FOLDS

* WA DNR Version 2.0, 2005 - WA USGS, 2004 - DOGAMI ODGC - Release 5, 2009

SOIL HAZARD

SEVERE

1OO YEAR FLOOD EVENT AREA

WETLAND AREA

LANDSLIDES
(Debris Flow Direction)

LIQUEFACTION

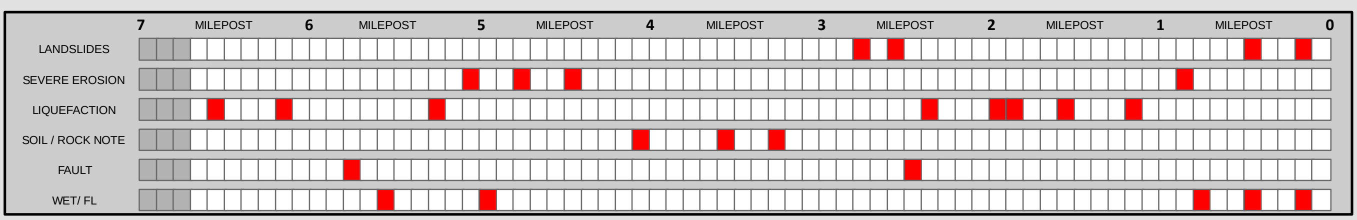
VERY LOW

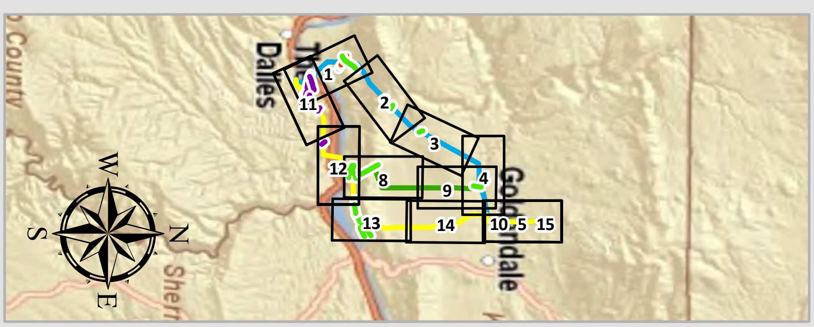
LOW TO MODERATE

MODERATE TO HIGH

POTENTIAL HAZARD KEY BY MILEPOST

Gray = Not Evaluated On This Sheet   Red = Potential Hazard Present Within Corridor   White = Potential Hazard Not Observed





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POTENTIAL HAZARDS STRIP MAP LEGEND

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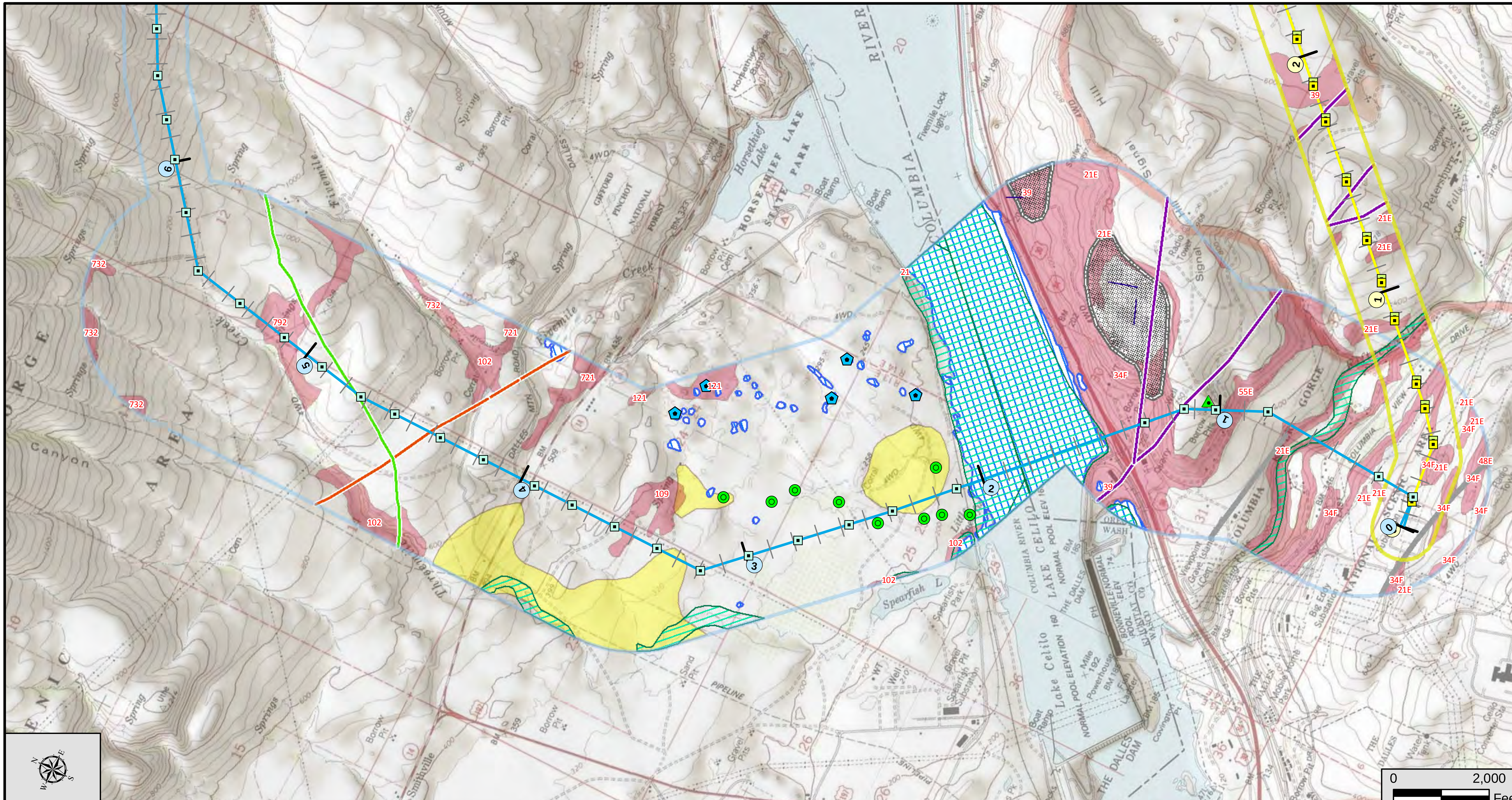
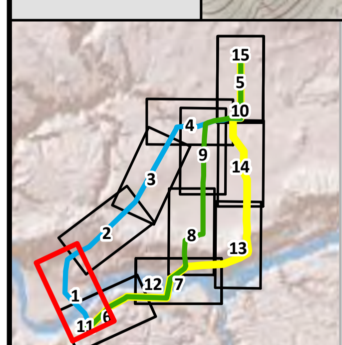
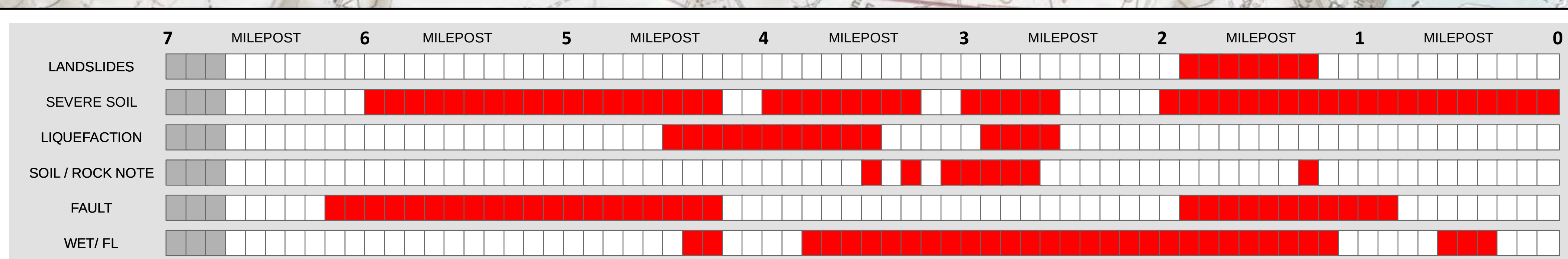
FIG. 6
LEGEND







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POTENTIAL HAZARDS STRIP MAP
WEST
ROUTE

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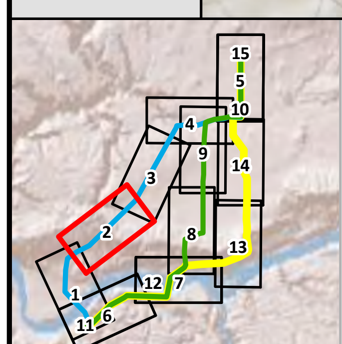

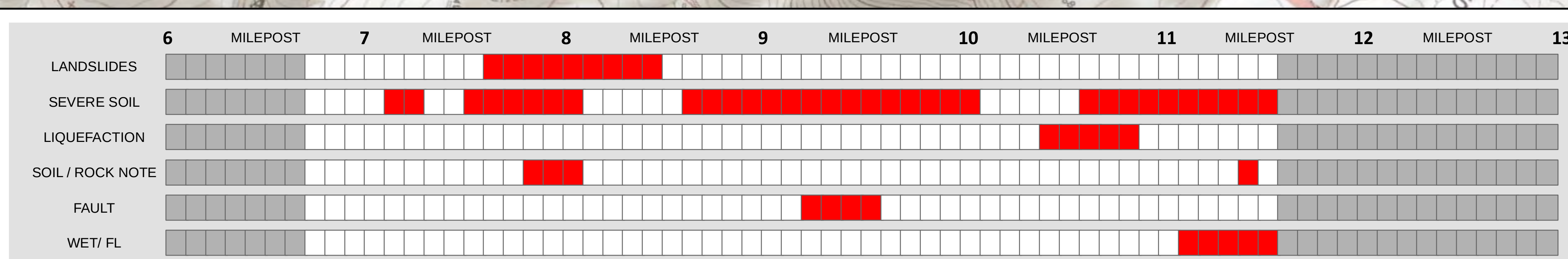

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POTENTIAL HAZARDS STRIP MAP WEST ROUTE

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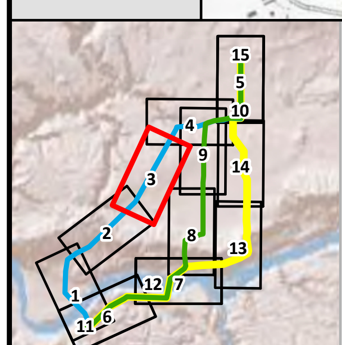

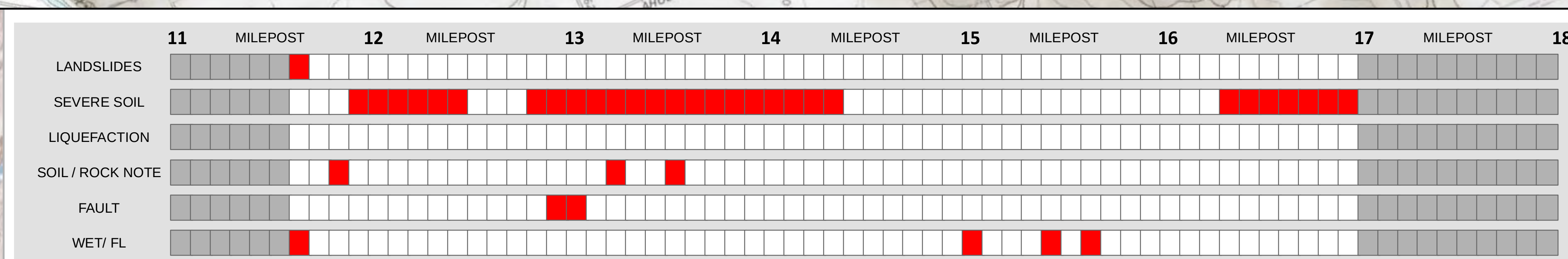

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POTENTIAL HAZARDS STRIP MAP
WEST
ROUTE

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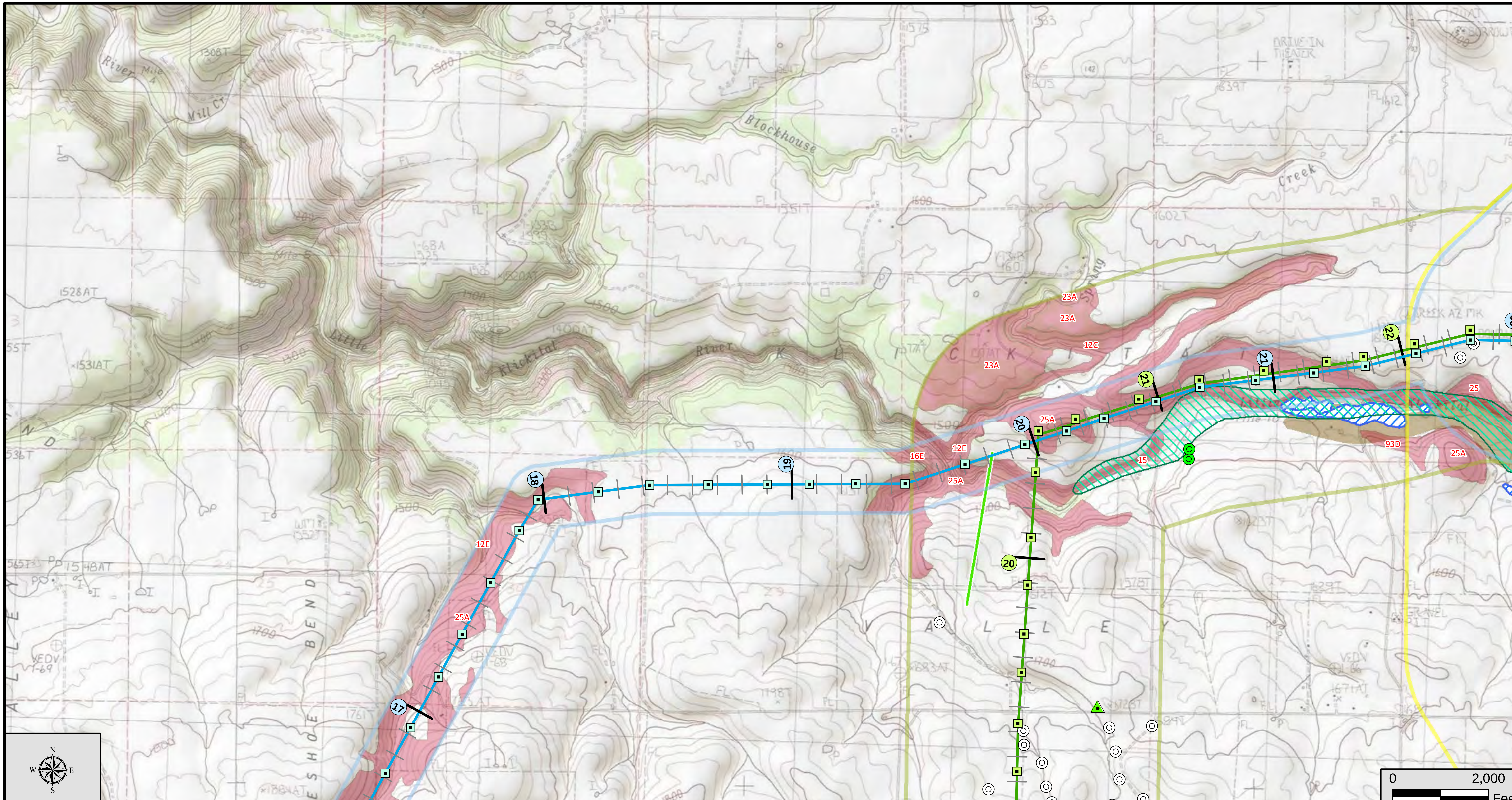

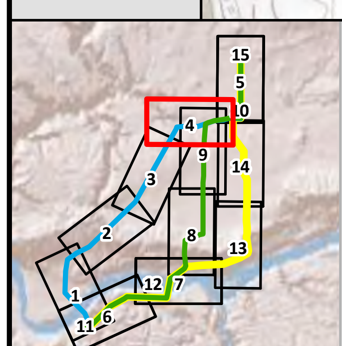

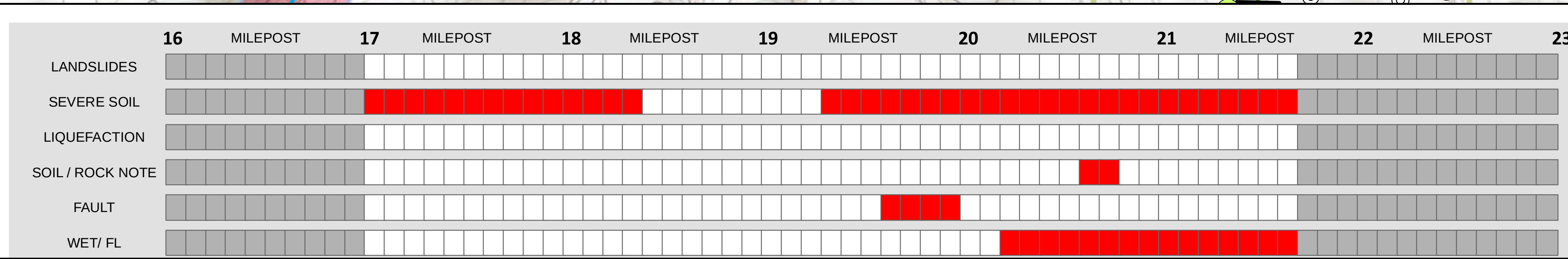

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POTENTIAL HAZARDS STRIP MAP
WEST
ROUTE

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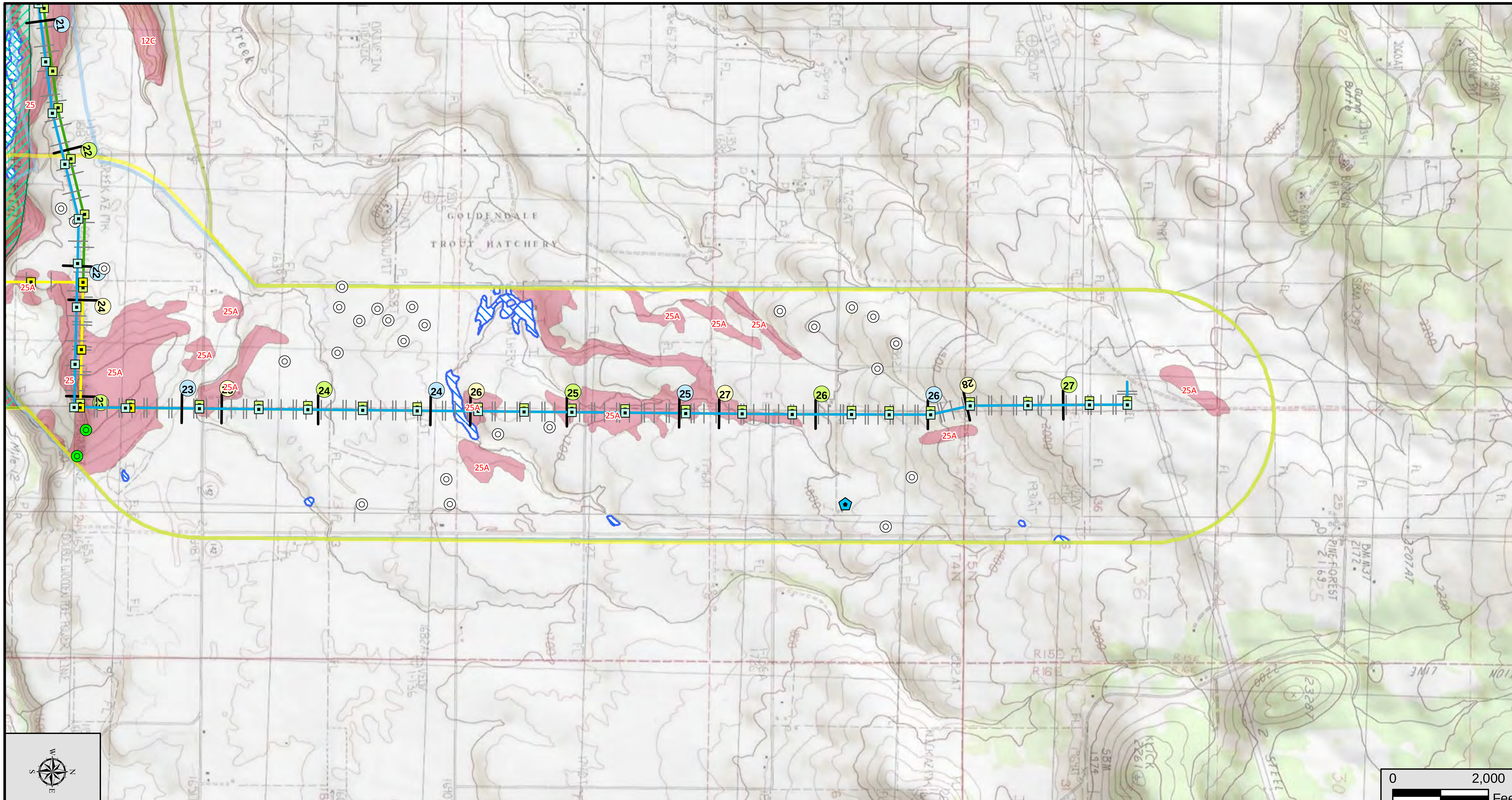

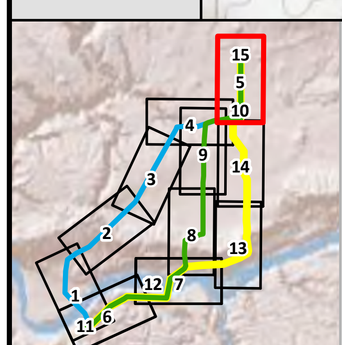

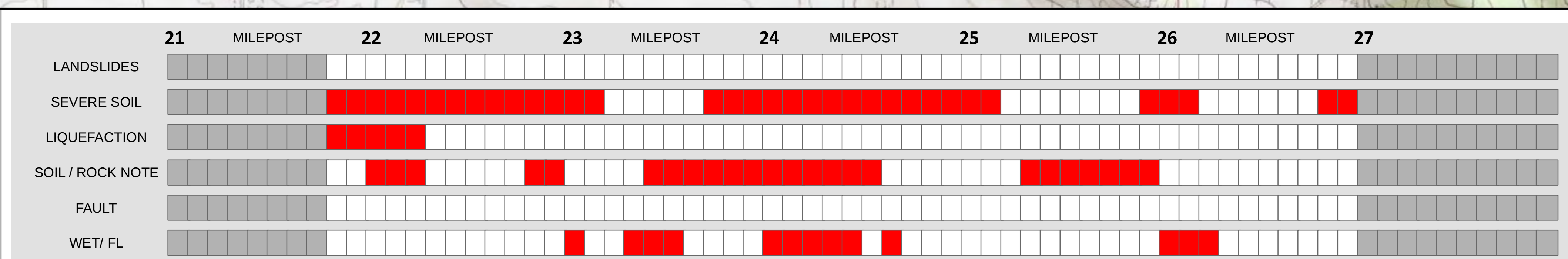

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POTENTIAL HAZARDS STRIP MAP WEST ROUTE

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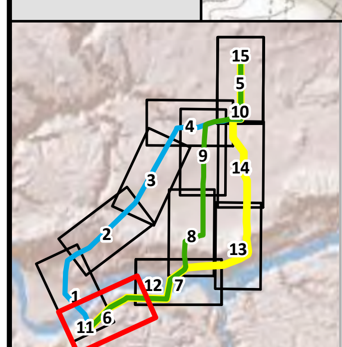

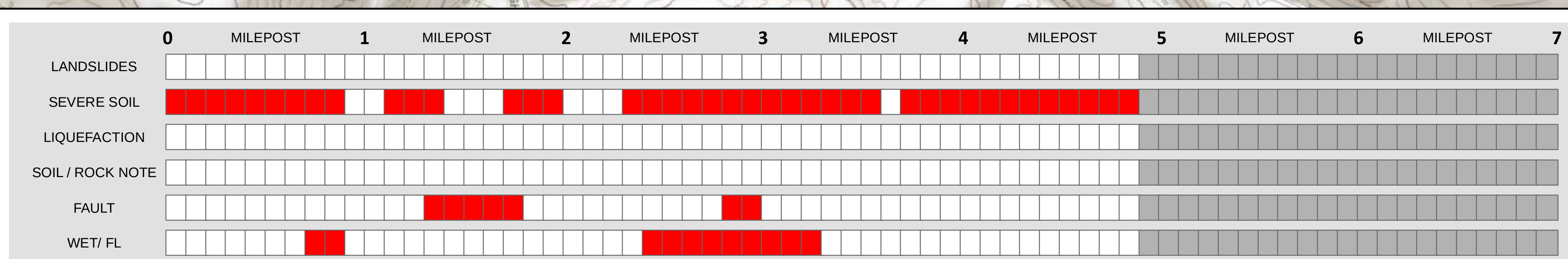

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POTENTIAL HAZARDS STRIP MAP MIDDLE ROUTE

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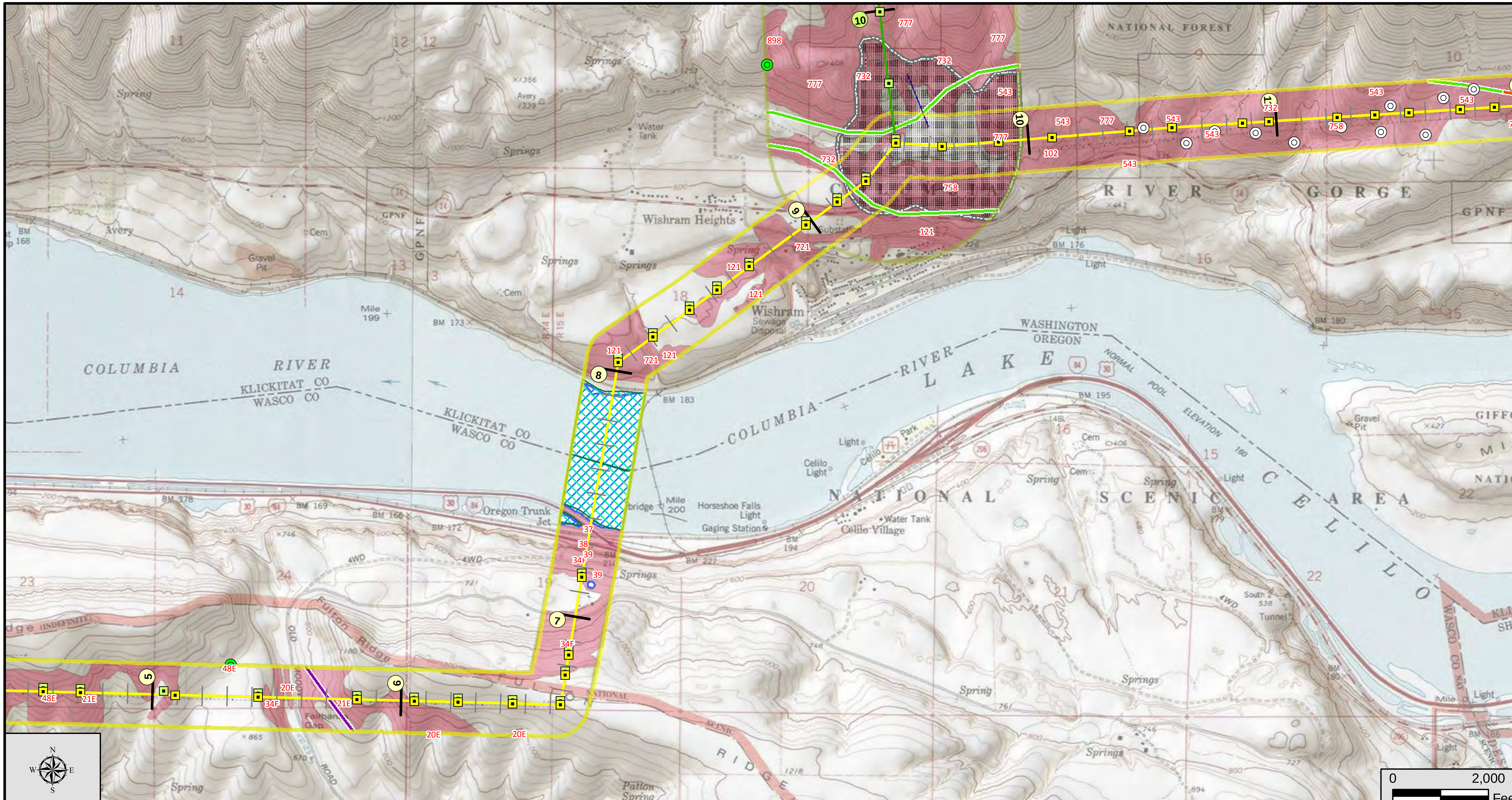

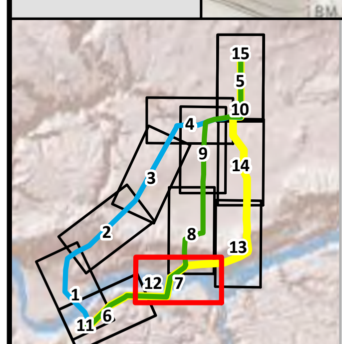

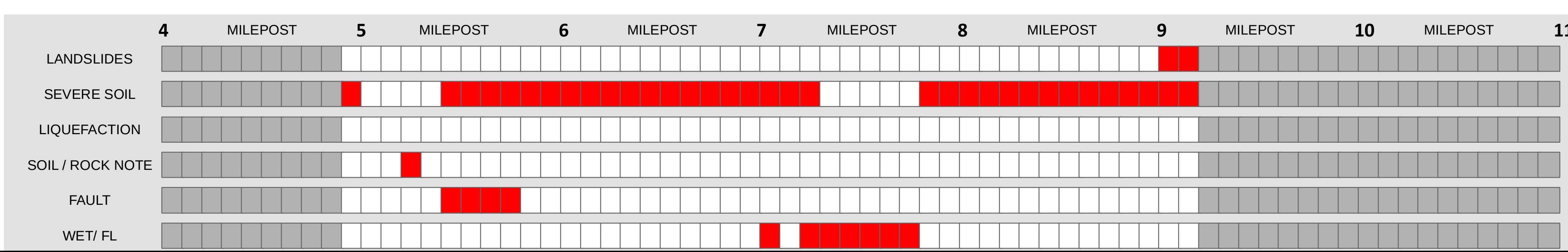

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POTENTIAL HAZARDS STRIP MAP MIDDLE ROUTE

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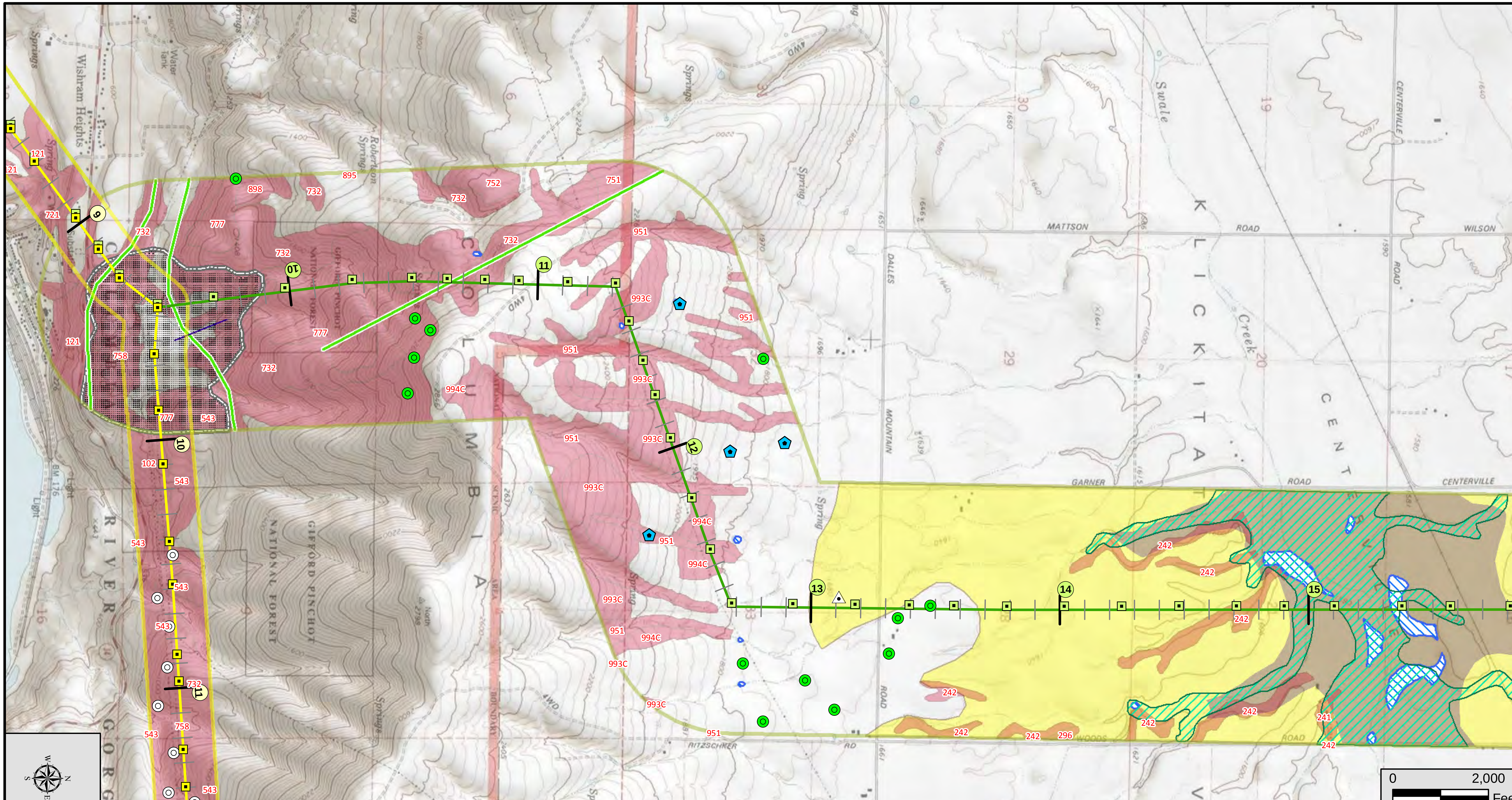

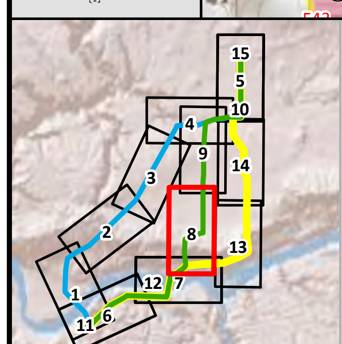

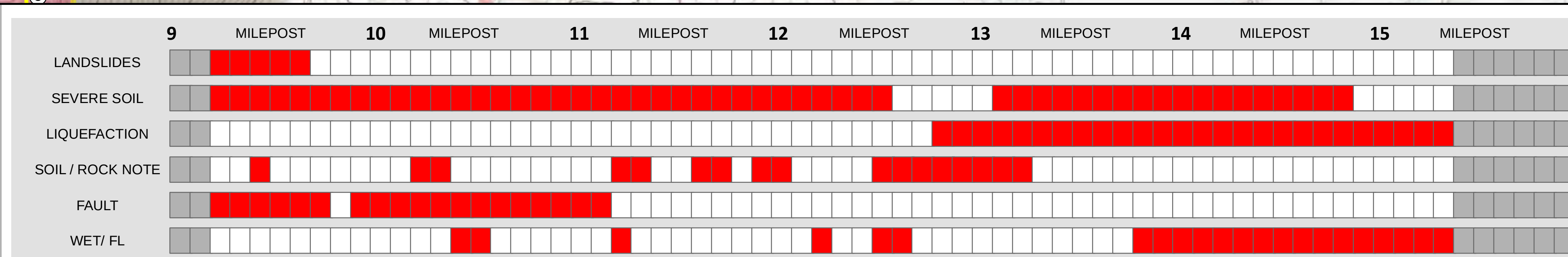

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POTENTIAL HAZARDS STRIP MAP
MIDDLE
ROUTE

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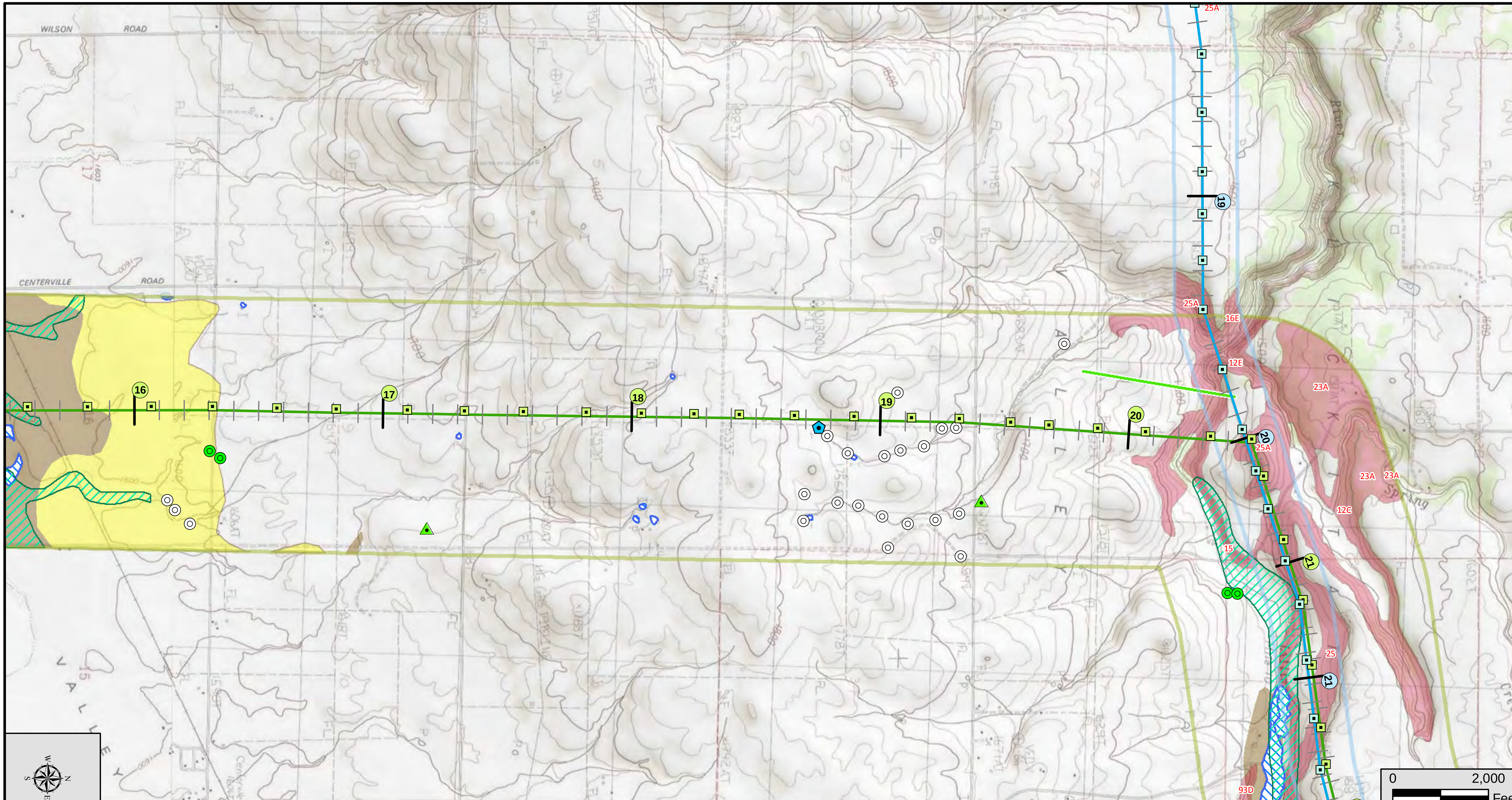

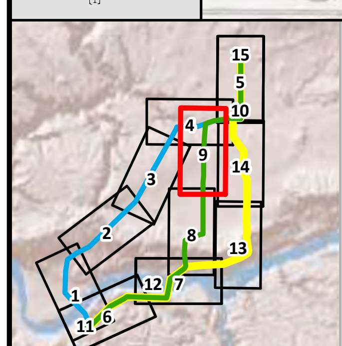

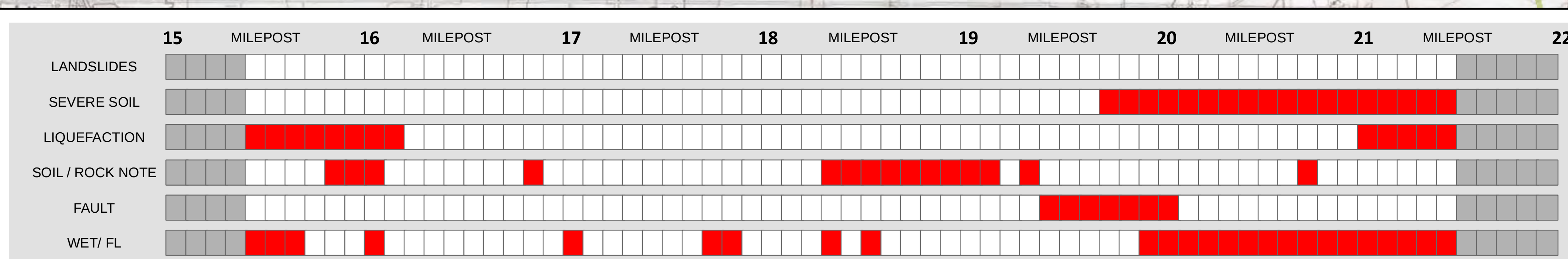

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POTENTIAL HAZARDS STRIP MAP
MIDDLE
ROUTE

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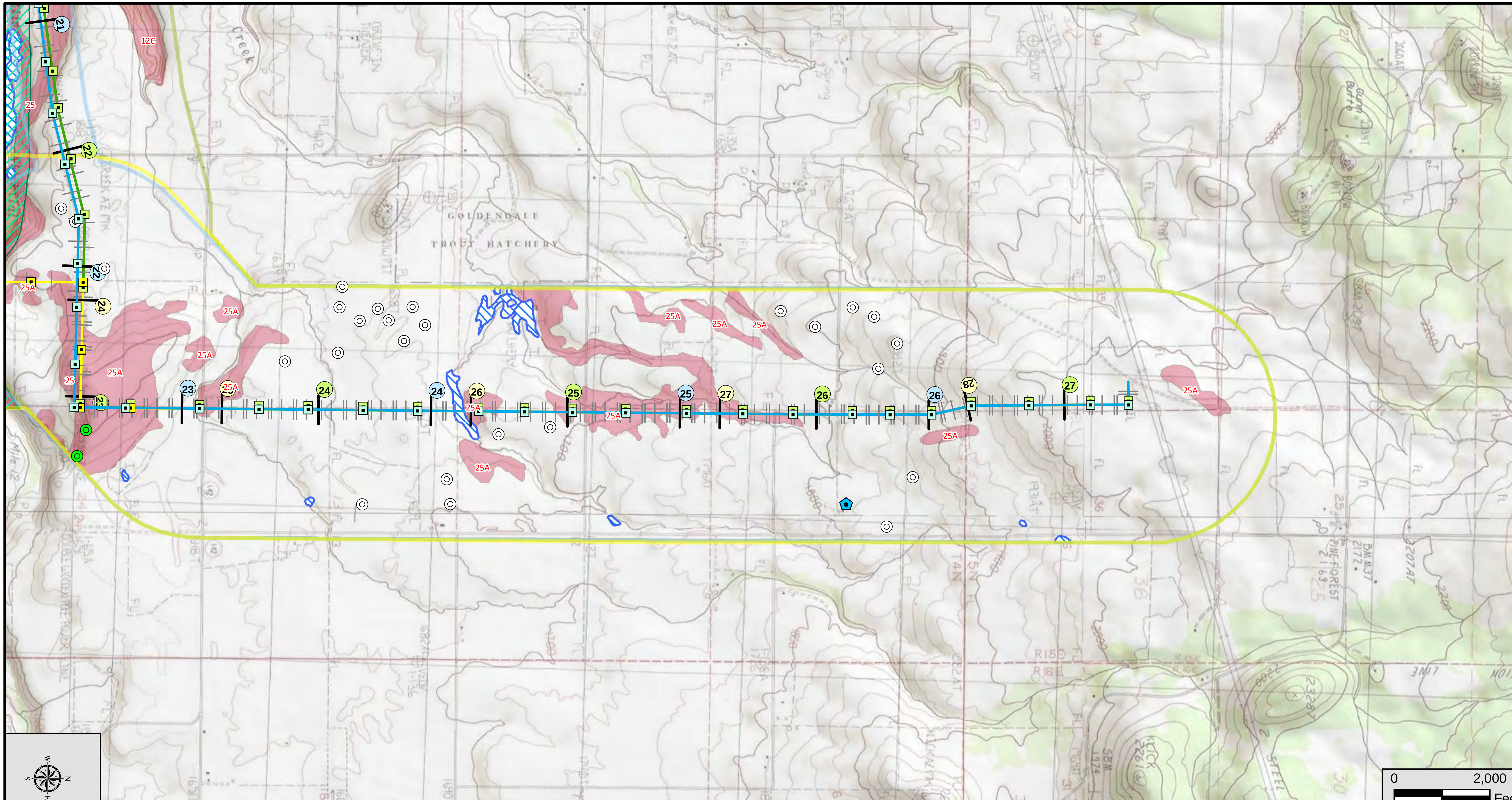

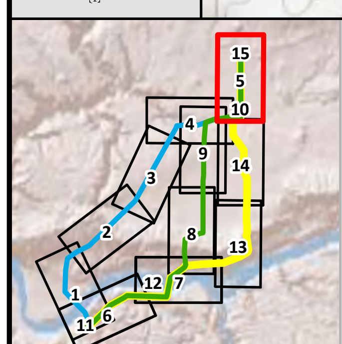

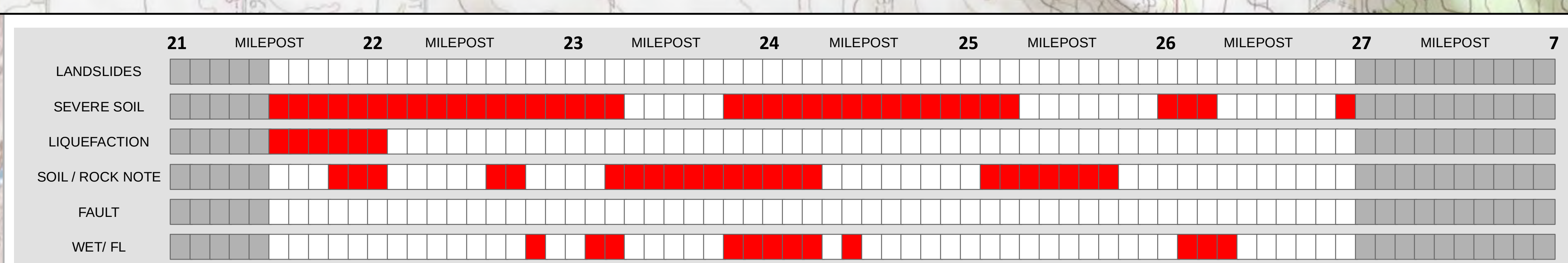

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POTENTIAL HAZARDS STRIP MAP
MIDDLE
ROUTE

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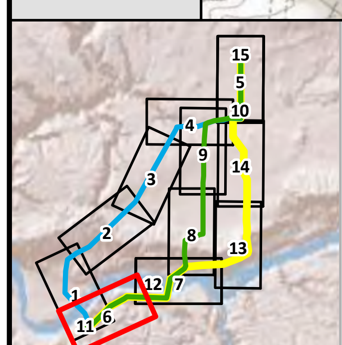

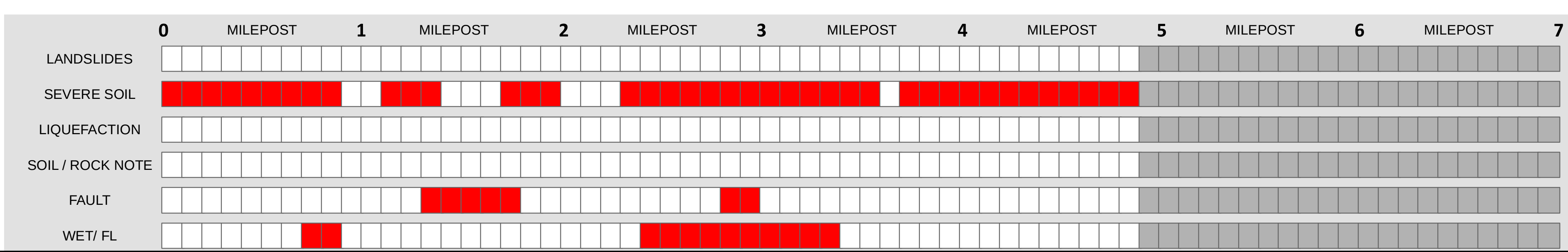

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POTENTIAL HAZARDS STRIP MAP
EAST
ROUTE

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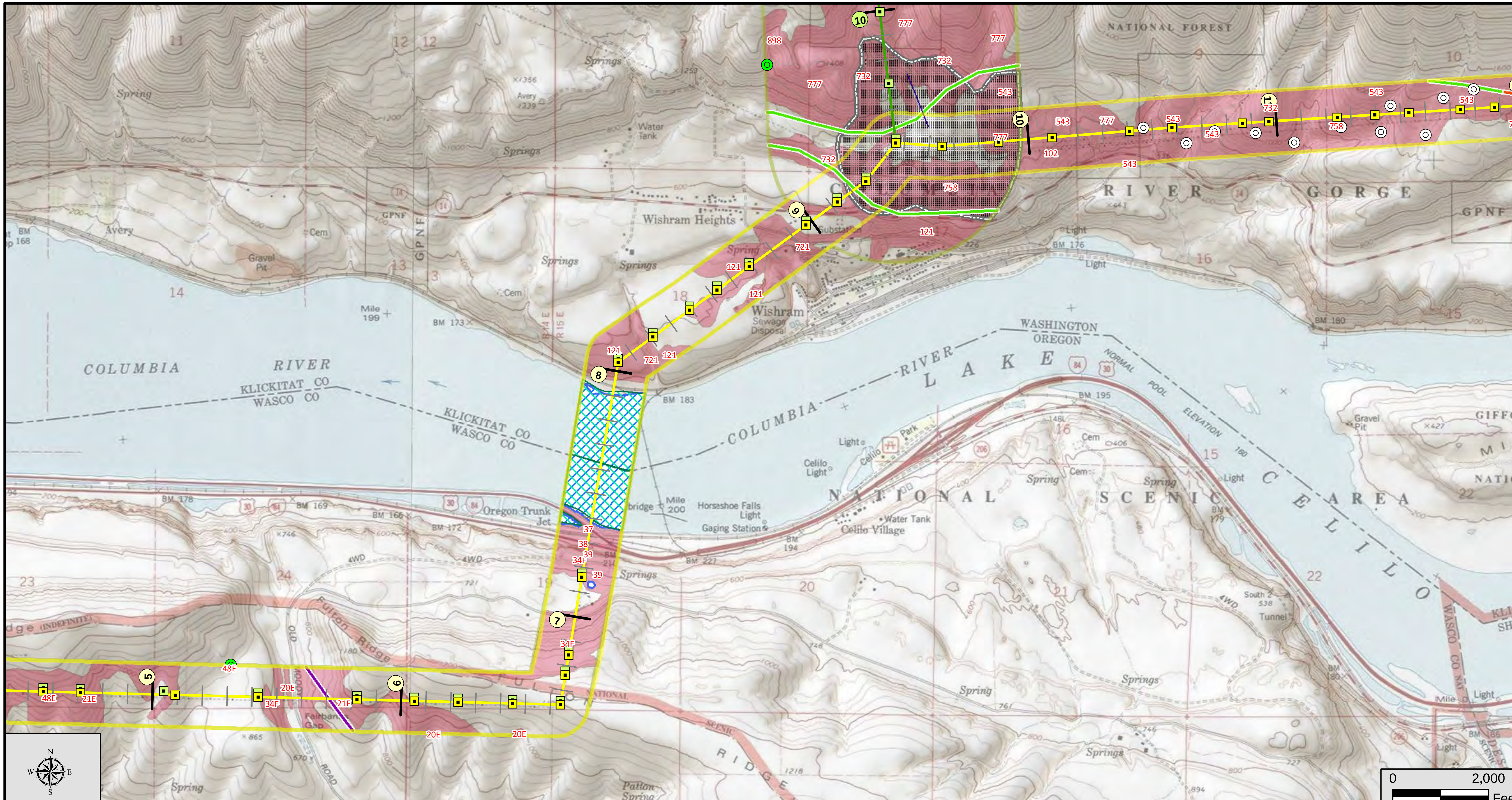

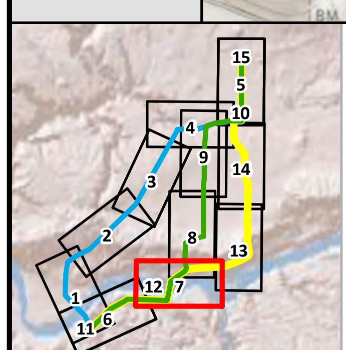

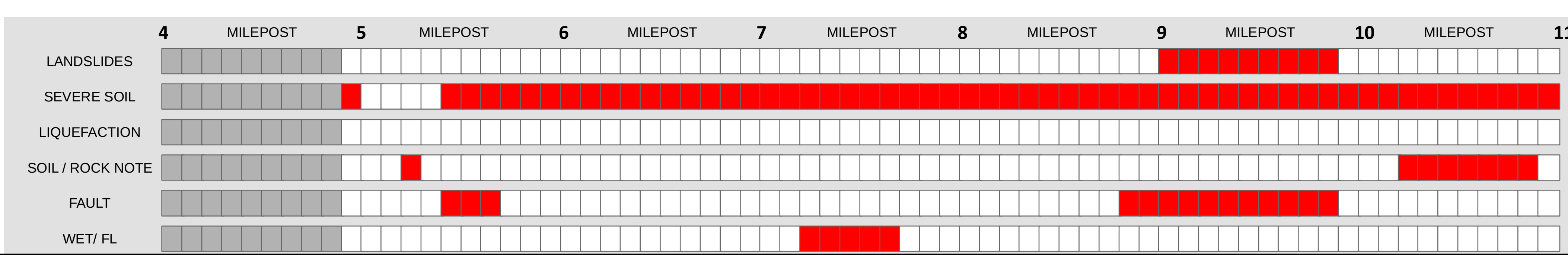

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Big Eddy - Knight 500 kv
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POTENTIAL HAZARDS STRIP MAP EAST ROUTE

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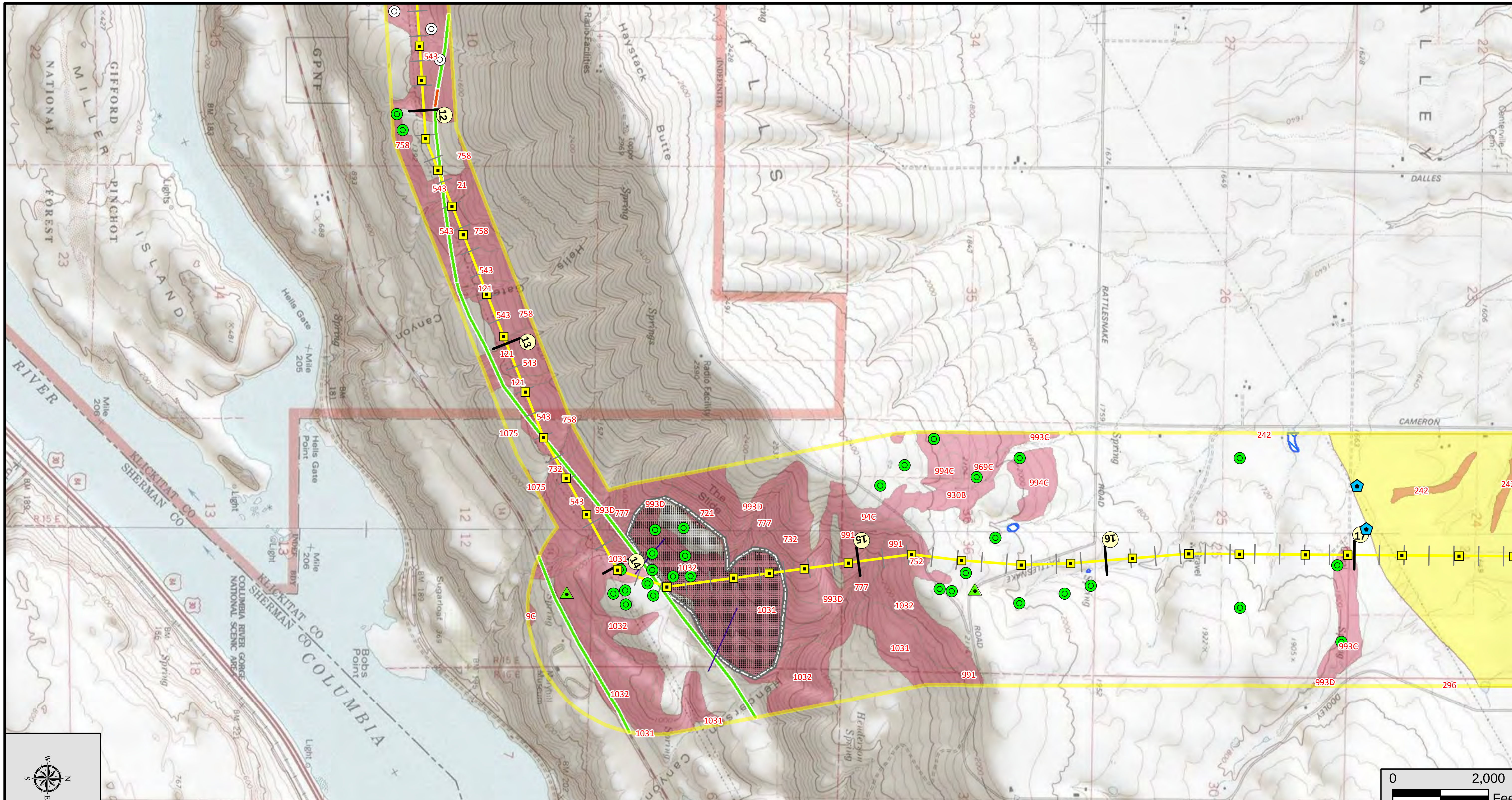

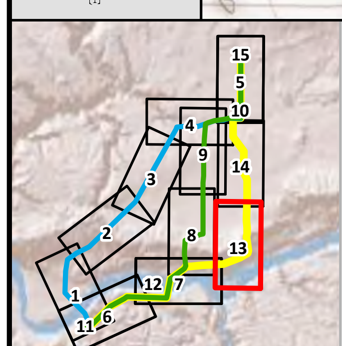

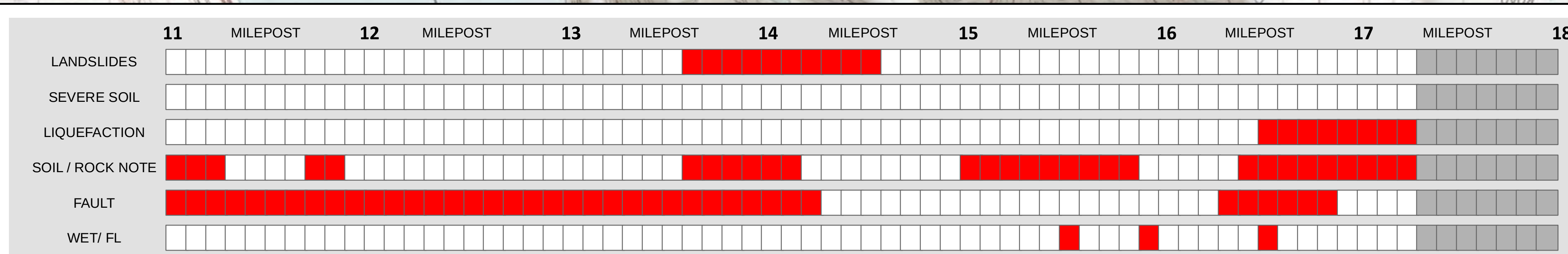

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POTENTIAL HAZARDS STRIP MAP EAST ROUTE

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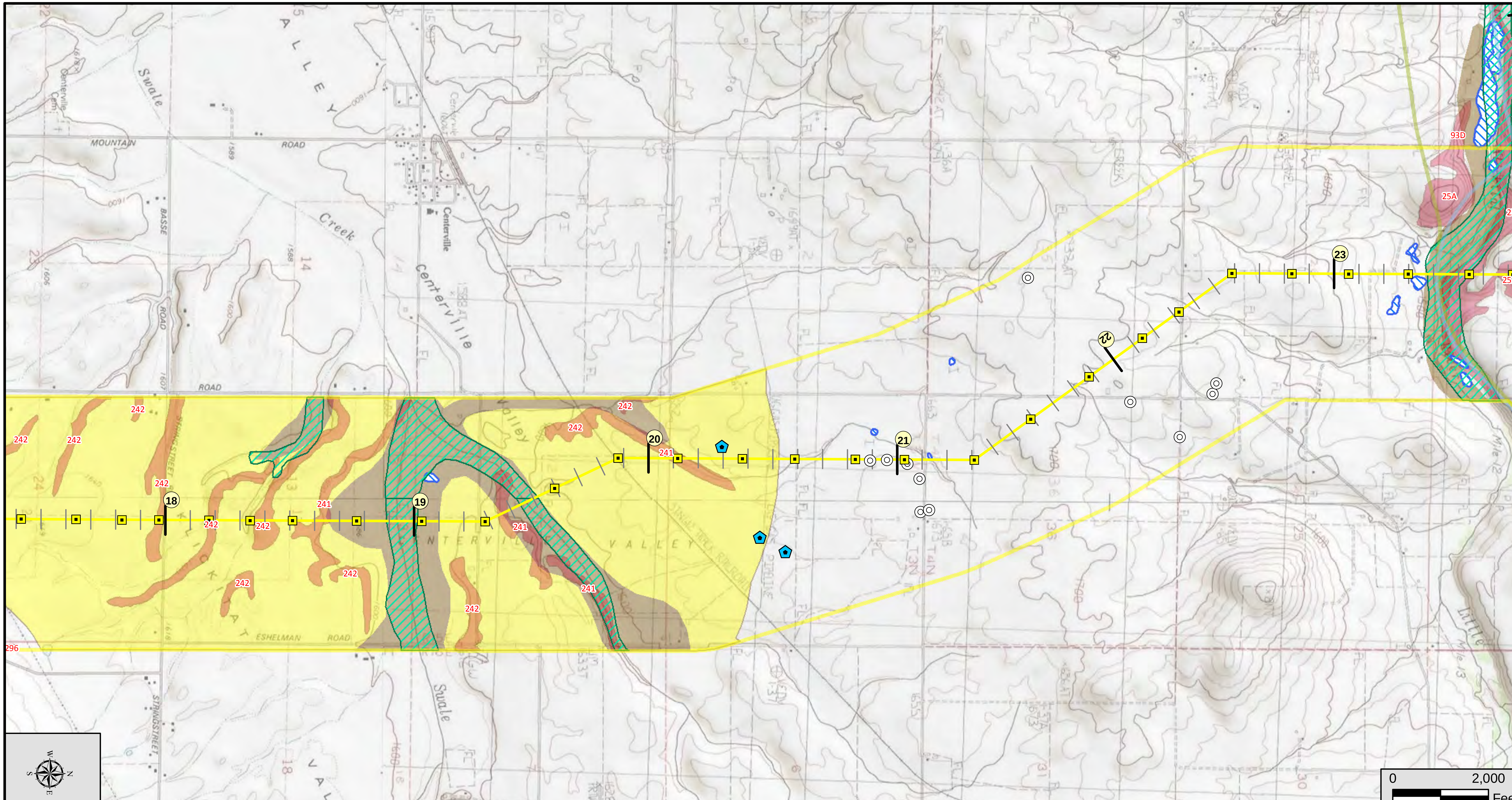

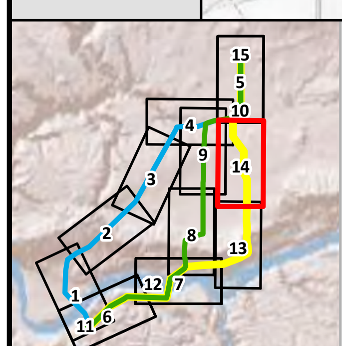

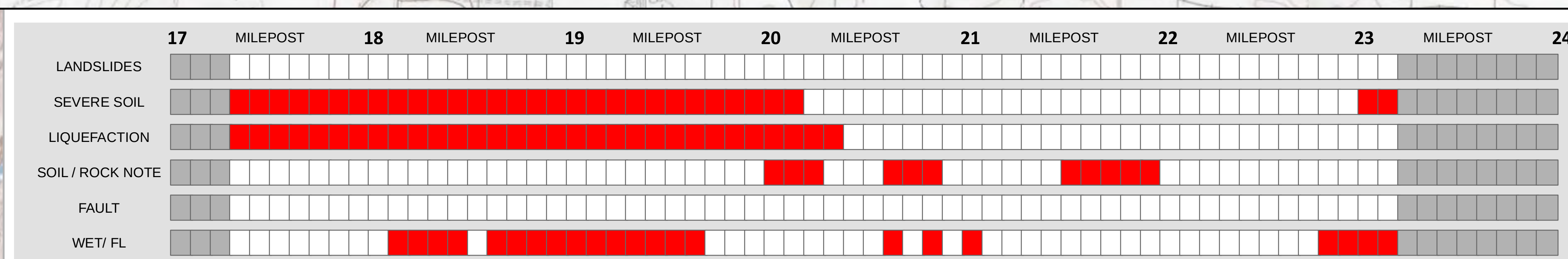

Bonneville Power Administration
Big Eddy - Knight 500 kv
Transmission Line Project

POTENTIAL HAZARDS STRIP MAP EAST ROUTE

March 2011

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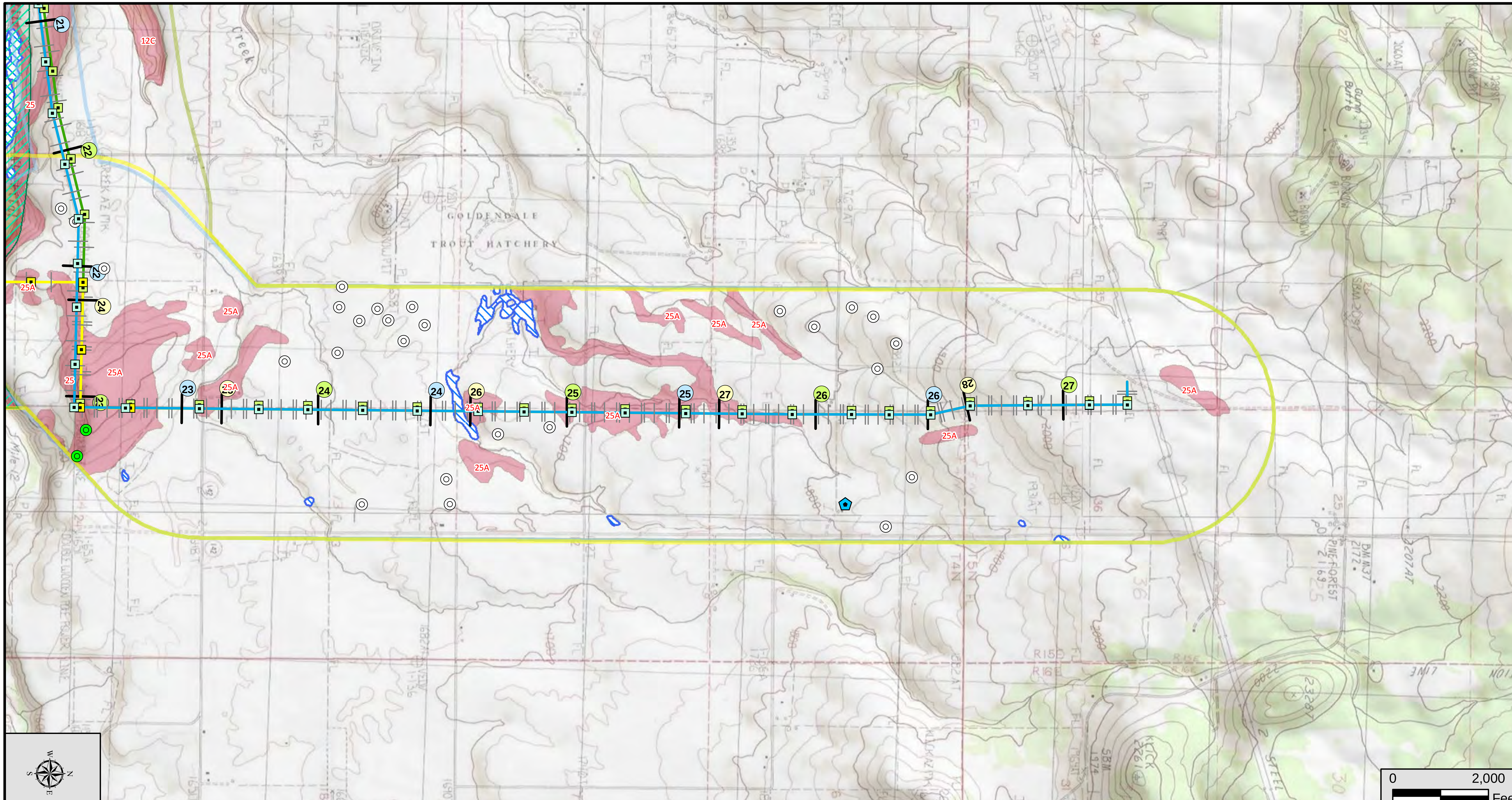

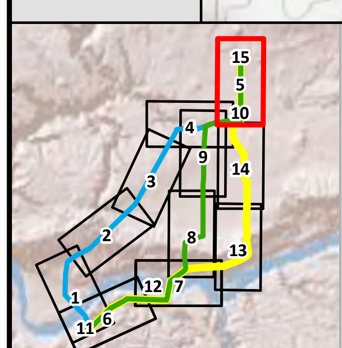

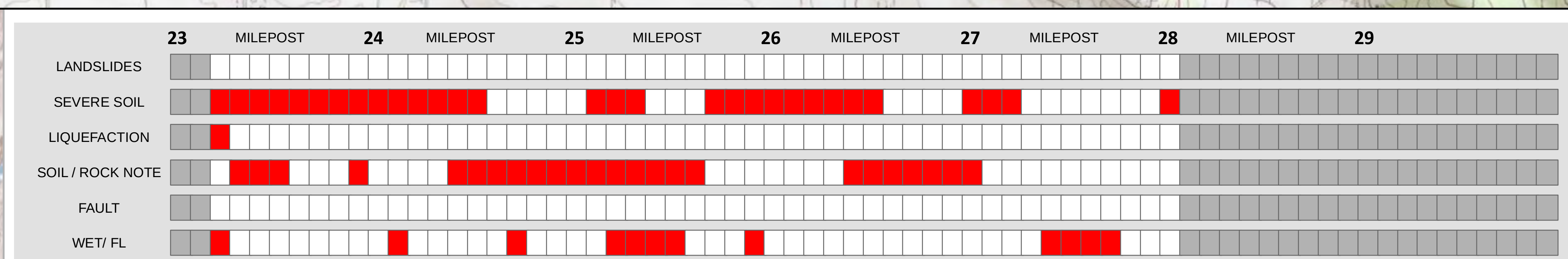

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POTENTIAL HAZARDS STRIP MAP
EAST
ROUTE

March 2011 21-1-21287-001

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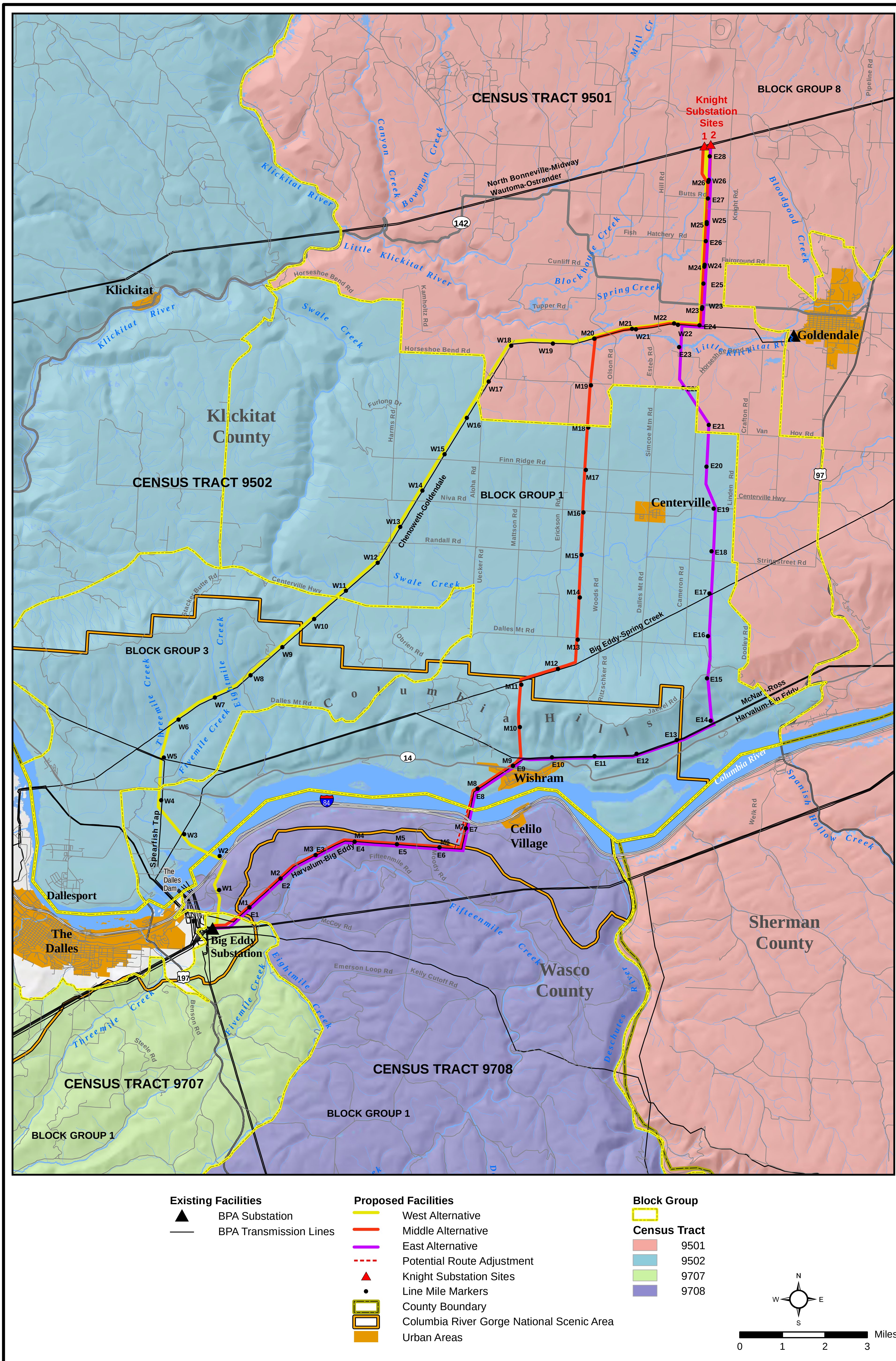
Appendix K

Environmental Justice



K:\Seattle\PROJECTS\BPA\00588_09_BigEddy\2010\MapDocs\Figures\Map K-1 Census Tracts.mxd

Map K-1. Census Tracts and Block Groups

Table Y-1. Minority Populations in ůKŜ .ʎ϶ 9ŘŘèπYyʎ϶Kű tǊƻƨŜŏű !ǊŜl· l·yŘ l·ű ůKŜ /ƻdzyűè l·yŘ {űl·űŜ [Ŝvels

		Total Population	Minority Persons (%)	Black or African American Alone (%)	American Indian and Alaska Native Alone (%)	Asian Alone (%)	Native Hawaiian or Other Pacific Islander (%)	Hispanic (%)
Klickitat County		19,161	896 (4.7)	51 (0.3)	665 (3.5)	139 (0.7)	41 (0.2)	1,496 (7.8)
Washington State		5,894,121	630,456 (10.7)	190,267 (3.2)	93,901 (1.6)	322,335 (5.5)	23,953 (0.4)	441,509 (7.5)
Wasco County		23,791	1,284 (5.4)	71 (0.3)	903 (3.8)	191 (0.8)	119 (0.5)	2,214 (9.3)
Oregon State		3,421,399	210,199 (6.2)	55,662 (1.6)	45,211 (1.3)	101,350 (3.0)	7,976 (0.2)	275,314 (8.0)
Study Area[1]		42,952	2,180 (5.1)	122 (0.3)	1,568 (3.7)	330 (0.8)	160 (0.4)	3,710 (8.6)
Census Tract 9501	Block Group 8	1,480	52 (3.5)	2 (0.1)	45 (3.0)	5 (0.3)	0 (0.0)	44 (3.0)
Census Tract 9502	Block Group 1	898	92 (10.2)	2 (0.2)	85 (9.5)	5 (0.6)	0 (0.0)	34 (3.8)
	Block Group 3	1,350	71 (5.3)	3 (0.2)	43 (3.2)	25 (1.9)	0 (0.0)	64 (4.7)
Census Tract 9707	Block Group 1	731	8 (1.1)	0 (0.0)	2 (0.3)	6 (0.8)	0 (0.0)	113 (15.5)
Census Tract 9708	Block Group 1	1,322	48 (3.6)	2 (0.2)	46 (3.5)	0 (0.0)	0 (0.0)	23 (1.7)

[1] Study Area is comprised of Klickitat and Wasco Counties