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Public Service Commission of Wisconsin
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Appendix E – PSC Publications and Information

Appendix B consists of a reproduction of the PSC's informational material about EMF. This material can also be found on the PSC website at https://psc.wi.gov/Pages/ForConsumers/Publications.aspx.

E1. Electric and Magnetic Fields
E2. Underground Transmission Lines
E3. Integrated Vegetation Management-Framework

EMF
Electric & Magnetic Fields

PUBLIC SERVICE COMMISSION OF WISCONSIN

The Electromagnetic Spectrum

Electricity produces two types of fields, electric and magnetic. These fields are often combined and referred to as electromagnetic fields or EMF. However, the two types of fields are quite different.

Recent scientific studies typically concentrate on the effects of magnetic fields and any potential association with health issues. “EMF” has become the popular short-hand term for magnetic fields.

Electric Fields

Wherever there is electricity, there are electric fields. While magnetic fields are created only when there is a current, electric fields are associated with any device or wire that is connected to a source of electricity, even when current is not flowing or the devise is not turned on.

Electric fields produced by high-voltage electric transmission lines have very little ability to penetrate buildings, or even skin. They are easily shielded by common objects such as trees, fences, and walls. Scientific studies have found no association between exposure to electric fields and human disease.

Magnetic Fields

Magnetic fields are created only when there is an electric current, the motion of electric charges (electrons) in a conductor, such as a wire. The magnitude of a magnetic field is proportional to the current flow through an electric line, not the voltage. As the current increases, so does the magnetic field.

There is no relationship between magnetic field strength and voltage. In the world of electric transmission lines, it is not uncommon for a 69 kilovolt (kV) electric line to have a higher magnetic field than a 115 kV line. High voltage 345 kV lines can carry large currents and as a result may produce relatively high magnetic fields, but primary distribution lines with voltages less than 69 kV can produce fields similar to those measured around a transmission line if they are carrying enough current.

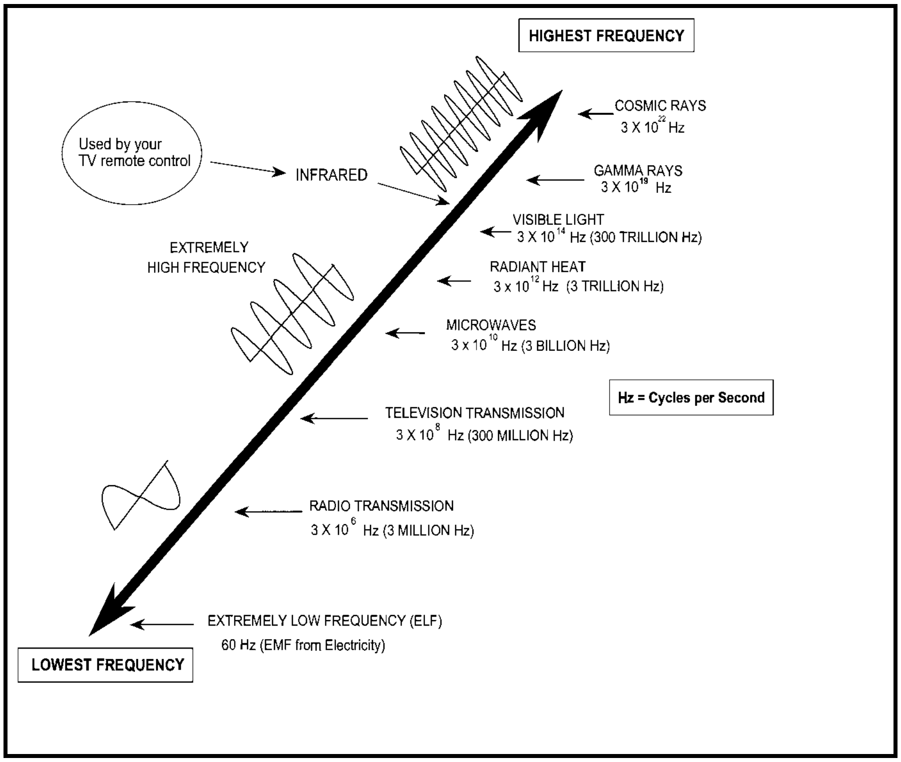
Magnetic fields become weaker rapidly with distance from the source. However, they do pass through most non-metallic materials and are therefore more difficult to shield.

In the literature, magnetic field data are presented in either units of Gauss (G) or Tesla (T). A milligauss (mG) is equal to one-thousandth of a Gauss (G). One Tesla is equal to 10,000 Gauss. A microtesla (μT) is equal to one-millionth of a Tesla or 10 mG.

Types of Radiation

Magnetic fields are part of the electromagnetic spectrum which includes cosmic rays, gamma rays, sunlight, microwaves, radio waves, and heat as illustrated in Figure 1.

Figure 1 Electromagnetic Spectrum



The electromagnetic spectrum is a name given to the range of different types of radiation from low to high frequencies. Radiation is energy that travels and spreads out as it moves away from a source. Visible light that comes from a lamp and radio waves that come from a radio station are two types of electromagnetic radiation. Only the highest frequency electromagnetic radiation, like gamma rays, can break apart DNA and lead to cancer. Low frequency radiations such as microwaves do not have enough energy to break molecular bonds, but can heat food items.

Magnetic fields generated by electric lines are in the extremely-low-frequency (ELF) range of the electromagnetic spectrum. The energy from these magnetic fields is very small. Magnetic fields from appliances and transmission lines cannot break molecular bonds.

Common Levels of Magnetic Fields

Any device that uses electric current creates a magnetic field. Electric appliances such as computers and refrigerators and the wiring that runs through walls and ceilings in homes produce magnetic fields when current is flowing. Table 1 lists sample ranges of magnetic fields for various appliances and tools. For comparison, Table 2 shows typical magnetic fields generated by different types of electric lines. Typical background environmental or ambient magnetic field levels are most often around 1 to 3 mG. Table 3 shows magnetic fields generated by different types of underground transmission lines.

Table 1 Common Sources of Magnetic Fields (mG)[1]

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

* Different makes and models of appliances, tools, or fixtures will produce different levels of magnetic fields. These are generally-accepted ranges.

Table 2 Typical US Magnetic Field Levels Associated with Overhead Transmission Lines[2]

Overhead Transmission Line Voltages	Usage	Typical Magnetic Field Measurements (mG)				
		Maximum in ROW	Approximate Distance From Centerline (Feet)			
			50	100	200	300
115 kV	Average	30	7	2	0.4	0.2
	Peak	63	14	4	0.9	0.4
230 kV	Average	58	20	7	1.8	0.8
	Peak	118	40	15	3.6	1.6
500 kV	Average	87	29	13	3.2	1.4
	Peak	183	62	27	6.7	3.0

NOTE: These values are for general information and not for a specific line.

[1] National Institute of Environmental Health Sciences (NIEHS) and National Institutes of Health, *EMF: Electric and Magnetic Fields Associated with the Use of Electric Power*, June 2002, pp.33-35, <https://www.niehs.nih.gov/health/materials/electric_and_magnetic_fields_associated_with_the_use_of_electric_power_questions_and_answers_english_508.pdf>, accessed on October 12, 2017.

[2] World Health Organization (WHO), *Extremely Low Frequency Fields, Environmental Health Criteria Monograph No. 238,* Geneva, 2007, <http://www.who.int/peh-emf/publications/elf_ehc/en/> modified from Table 6, p. 33.

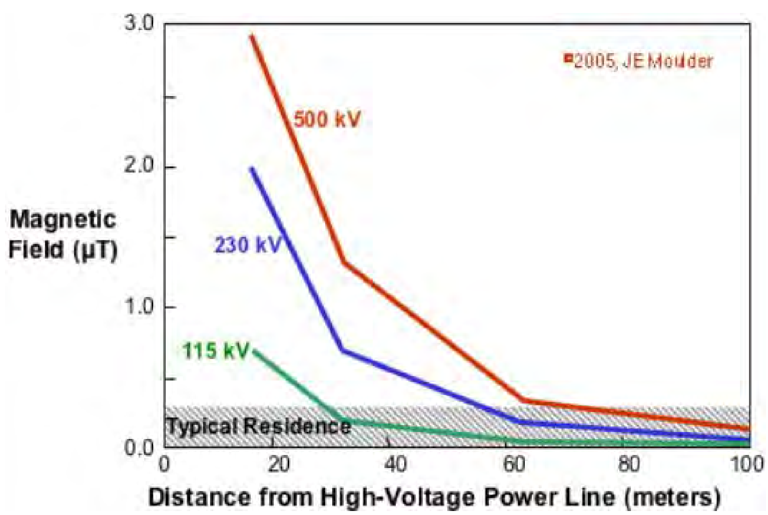
Table 3 Typical Magnetic Field Levels Associated with Underground Transmission Lines in the UK[3]

Underground Transmission Line Voltages	Details	Load	Typical Magnetic Field Measurements (mG) Approximate Distance From Centerline (Feet)			
			0	16	33	66
132 kV	Single cable at a depth of 1 m	Typical	50	17.8	9.4	4.7
275 kV	Direct buried with 0.5 m spacing and at 0.9 m depth	Maximum	962	131	36	9.2
		Typical	241	33	9.0	2.3

NOTE: While the standard voltages of lines in the UK differ from those used in Wisconsin, the information may be used as general background information and as a comparison with overhead transmission lines.

Since magnetic field levels in the vicinity of transmission lines are dependent on the flow of electric current through them, they fluctuate throughout the day as electrical demand increases and decreases. For overhead transmission lines, the magnetic fields typically range from about 5 to 150 mG, depending on current load, separation of the conductors, and distance from the lines. In general, at a distance of about 300 feet from a transmission line, measured magnetic fields are similar to typical ambient background levels found in most homes[4]. Figure 2 shows a generalized graphic view of how magnetic fields quickly diminish with distance.

Figure 2 Magnetic Field Strength and Distances from Overhead Transmission Lines[5]



[3] WHO, 2007, <http://www.who.int/peh-emf/publications/Chapter%202.pdf?ua=1> modified from Table 7 on p.34.
[4] NIEHS, 2002., p. 35, link on previous page, ft1.
[5] Medical College of Wisconsin website by John Moulder, *Power Lines and Cancer FAQs,* archived at <http://large.stanford.edu/publications/crime/references/moulder/moulder.pdf> accessed on October 12, 2017.

Health Concerns

After more than three decades of research, there are still concerns among members of the public regarding exposure to elevated magnetic fields and an increased risk of childhood cancers. The concern about power lines and cancer comes largely from studies of people living near power lines and people working in the electrical occupations. Some of these studies appear to show a weak association between exposure and power-frequency magnetic fields and the incidence of some cancers.

Types of Studies

Medical research is of several different types, including epidemiological studies, laboratory studies, and clinical studies.

Epidemiological studies collect data in the real world and draw inferences from the information collected. For medical research, epidemiological studies observe and compare groups of people who have had or have not had certain diseases or exposures to see if the risks to the groups differ. Usually when epidemiological studies show a consistent and strong association to a risk factor, scientists will develop a plausible theory for how such an exposure might cause the disease. This is called a biological mechanism.

Epidemiological studies alone are not sufficient to verify a theory of cause and effect because the results are statistical associations and not direct evidence. To get beyond epidemiological studies and evaluate whether exposure to magnetic fields actually causes health effects, laboratory studies of cells and animals and clinical studies with human volunteers are necessary.

Controlled laboratory studies are conducted at the cellular level and on lab animals to test the hypothesis. In medical laboratory studies, the researchers take total control over study conditions to try to determine the actual biological mechanisms of how potential agents like magnetic fields can cause disease.

Clinical studies make use of the theories of biological mechanisms, and perhaps the laboratory testing results, to try to quantify effects on persons. In clinical studies, human volunteers are tested with different treatments to measure the actual effects on them accurately. For studies of EMF effects, medical researchers use controlled exposure rates on volunteers to look for measurable changes such as brain activity and hormonal levels.

Epidemiological Studies

In 1979, an epidemiology study by Wertheimer and Leeper[6] reported a statistical association between "wire codes" and childhood cancers in certain neighborhoods of Denver, Colorado. The term, "wire code" referred to the physical size of the power line which was assumed to be related to current flow of the line and thus a good surrogate measurement for the magnetic field. No magnetic field measurements were ever conducted for this study. Because the size of a line is not related to the magnetic field, subsequent studies have been tried to determine if there is any validity to the relationship stated in the Wertheimer/Leeper study. A multitude of increasingly sophisticated laboratory and correlative studies have investigated the potential association for more than 30 years.

[6] N.W. Wertheimer and Leeper, E., "Electric Wiring Configurations and Childhood Cancer", *Am. J. Epidem.*, Vol. 109, 1979, pp. 273-284. <https://www.ncbi.nlm.nih.gov/pubmed/453167> accessed October 12, 2017.

Epidemiological studies are field studies. Unlike laboratory research where investigators have total control over study conditions, epidemiologists observe the world as it is. They draw inferences from information observed or collected about a study population's life, habits, and exposure to environmental factors. Because of this limitation, epidemiological studies suffer from a number of inherent weaknesses which may include issues associated with sample size, sample biases, and confounding factors. It is not uncommon for published studies to be criticized for weaknesses in study design or faulty conclusions. Additionally, particularly in regard to the study of EMF impacts, there is a problem with the lack of unexposed populations (control group) that can be compared to exposed populations. Everyone is exposed to some level of magnetic fields from household appliances and existing electric lines.

Most public and scientific attention has focused on childhood leukemia with lesser attention given to adult leukemia, childhood and adult brain cancer, lymphoma, and overall childhood cancer. Some epidemiological studies used a combination of the type of wiring and the distance to a residence as means of quantifying exposure, as the Wertheimer/Leeper study did, to see if level of exposure varied with the occurrence of cancer. Other studies used distance from transmission lines or substations as measures of exposure, and some studies have used contemporary measured fields or calculated fields. In general, the different methods of exposure assessment do not agree with each other, and there is no one method of exposure assessment common to all the major studies.

One set of epidemiological studies has involved research of potential links between the occurrence of adult cancers and EMF exposure in electrical workers. The assumption is that electrical workers present a larger population than children with leukemia and they may be routinely exposed to higher levels of magnetic fields for longer periods of time. However in some of these studies, there were no consistent dose-response relationships. They were studies based on job titles and not on measured exposures.

Laboratory Studies

Laboratory studies have been conducted to look at the possibility of genetic mutations from magnetic fields because genetic mutations are at the root of the development of cancers like leukemia.

Cellular genotoxicity studies look at the properties of an agent that might damage the genetic information within a cell and cause mutations, which may lead to cancer. There have been many published cellular studies, examining many types of cells from plasmids and bacteria to human cells. A wide range of exposure conditions and field intensities have been assessed looking for a plausible biological mechanism to explain how EMF might cause disease in the human body.

Whole-animal laboratory studies are used to determine whether or not exposure does indeed lead to disease. Animals can be exposed to elevated levels of an agent under strictly controlled conditions for long periods of time and then carefully examined for an increase in tumors, pre-cancerous effects, and cancer. The usefulness of laboratory animal work for assessing toxicity depends on how well the work is done, what care is given to the animals, and whether the results are reproducible.

Clinical Studies

Clinical studies with human individuals rely on volunteers in a last step toward determining the degree of an agent's ability to cause disease. Clinical studies have varying degrees of rigor and can depend in part of how the volunteer study participants cooperate with the researchers as well as the researchers' control over the volunteer participants.

Participating Organizations

More than 25,000 scientific epidemiological, occupational safety, laboratory animal and cellular studies have been published. In addition there have been numerous reviews of the available research from various respected national and international organizations. A short list of the countries and organizations that have participated include:

American Cancer Society (ACS)
American Industrial Hygiene Association (AHA)
American Medical Association (AMA)
British Columbia Center for Disease Control
European Union
Health Canada
Institute of Electrical and Electronics Engineers (IEEE)
International Agency for Research on Cancer (IARC)
International Commission on Non Ionizing Radiation Protection (ICNIRP)
National Cancer Institute (NCI)
National Institute of Environmental Health Sciences (NIEHS)
Netherlands Health Council (NHC)
World Health Organization (WHO)

A list of all EMF studies to-date would be too numerous for our purposes, but a list of useful links to studies and organizations can be found at the end of this publication. There is also a summary of the findings from scientific organizations on EMF and its potential health effects.

The Results

Childhood leukemia is a relatively rare disease and its causes are not well understood despite decades of research. On average, 1 to 2 children develop the disease each year for every 10,000 children in the United States.[7] Overall though, it is still the most common type of childhood cancer, amounting to 30 percent of all cancers diagnosed in children younger than 15 years. Because the disease is very serious, researchers continue to study a wide range of subjects looking for causes and for the most effective treatments.

In order to have confidence that an exposure agent is actually linked to human disease, scientists look for strong and consistent associations from epidemiological research. In the cases of electric and magnetic fields, the studies have found only weak association, or no association, between exposure and the incidence of some cancers. In addition, study outcomes are not consistent. A large number of studies show no association between transmission lines and cancers. In contrast, the vast majority of epidemiological studies on cigarette smoking have showed a strong positive association between cigarette smoking and lung, neck, and throat cancer.

Science cannot prove a negative, so magnetic fields cannot be proven to have no effect and be safe. However, so far, science has not been able to prove the positive either, that magnetic fields do have an effect -- no published power-frequency exposure study has shown a statistically-significant dose-

[7] National Cancer Institute at the National Institutes of Health, National Cancer Institute Factsheet, Childhood Cancers, <http://www.cancer.gov/cancertopics/factsheet/Sites-Types/childhood>, accessed October 12, 2017.

response relationship between measured magnetic fields and cancer rates, or between distances from transmission lines and cancer rates.

Overall, most scientists are convinced that the evidence that power line fields cause or contribute to cancer is weak to nonexistent. The biological studies conducted to-date has not been able to establish a cause-and-effect relationship between exposure to magnetic fields and human disease. Scientists have been unable to identify any plausible biological mechanism by which EMF exposure might cause human disease. There is a general consensus within the scientific community that exposure to EMF is not responsible for human disease. In summary:

- There is no mechanism identified that would explain how EMF could cause cancer.[8]
- There is little evidence that magnetic fields cause childhood leukemia, and there is inadequate evidence that magnetic fields cause other cancers in children.[9]
- Studies of adults' magnetic field exposure from power lines show little evidence of an association with leukemia, brain tumors, or breast cancer.[10]
- Whole animal exposure studies have not shown evidence that long-term exposure to EMF causes cancer, and no link has been found to leukemia, brain cancer, and breast cancer.[11]
- For power line magnetic fields below 500 mG, no plausible mechanisms have been identified by which biological effects can be caused in living systems. [12]

Regulation of Magnetic Fields

Public Service Commission of Wisconsin

The Public Service Commission of Wisconsin (PSCW or Commission) actively monitors research on EMF and its potential for causing human health effects. Consideration of magnetic field exposures is a regular part of the review process for electric utility construction cases. Transmission and substation construction applications must contain several types of information that relate to magnetic fields.

A utility must provide estimates of magnetic fields that would be generated by a proposed transmission line. The estimates are specific to the proposed voltage, line configuration and peak power flows during the first year of operation and after ten years of operation. In its application, a utility must report the number and type of buildings within 300 feet of a proposed centerline, including schools, hospitals, and daycare centers.

Commission staff checks and verifies the utility's calculations of the estimated magnetic fields. This information is then available to the public and considered by the Commission in its route selection decisions.

[8] National Cancer Institute Factsheet, <http://www.cancer.gov/cancertopics/factsheet/Risk/magnetic-fields>, accessed October 12, 2017.

[9] Ibid.

[10] Ibid.

[11] Boorman et.al, 1999, <https://www.ncbi.nlm.nih.gov/pubmed/10356702>, accessed October 12, 2017.

[12] Robert K. Adair, "Constraints on Biological Effects of Weak Extremely-Low-Frequency Electromagnetic Fields," *Phys Rev A*, January 1991, Vol. 43, Issue 2, pp. 1039-1048 <https://journals.aps.org/pra/abstract/10.1103/PhysRevA.43.1039#fulltext>, accessed October 12, 2017.

Other Regulations and Guidelines

Limits established by national and international professional organizations are well beyond the range of magnetic fields typically generated by transmission lines. In 2002, the Institute of Electrical and Electronics Engineers (IEEE), a professional group, published a public exposure guideline of 9,040 mG.[13] In 2010, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) revised its reference levels for public exposure for magnetic fields in the 60 Hz range, and recommended that magnetic fields to not exceed 2,000 mG[14]. In the US, there are no federal standards at all limiting occupational or residential exposure to power line EMF.

Some other states, particularly Florida and New York, have standards or guidance documents related to magnetic fields produced by transmission power lines. Florida limits magnetic fields at the edge of the ROW to 150 mG for transmission lines with voltages of 69 kV through 230 kV. For lines greater than 250 kV, the limit is 200 mG. Double-circuited 500 kV lines and lines greater than 500 kV may not exceed 250 mG, also at the edge of the ROW.[15] New York has a policy that requires transmission lines to be designed, constructed and operated so that magnetic fields at the edges of the ROW will not exceed 200 mG.[16]

The California Public Utility Commission requires utilities to apply no- or low-cost EMF reduction techniques to new or upgraded transmission facilities.[17]

Mitigation of Magnetic Fields

One method to lower the public's exposure to the magnetic fields generated by transmission lines is to increase the distance of the conductors from the public. The fields decrease drastically with distance. The magnetic field level at 300 feet or more from a transmission line centerline should be similar to local ambient, or background, levels. Increasing the height of any transmission structure thus lowers any resulting exposure levels.

Another common method to reduce magnetic field exposure to the public is to bring the lines (conductors) closer together. The magnetic fields interfere with one another, producing a lower overall magnetic field level. The conductors can be brought closer together by using different types of structures or double-circuiting two lines on the same structures (see Figure 3). However, there are electrical safety limits to how close together conductors can be placed. Conductors must be far enough apart so that arcing cannot occur and so that utility employees can safely work around them.

[13] Institute of Electrical and Electronics Engineers (IEEE), *C95.6-2002 IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz*. New York, IEEE, 2002 <http://standards.ieee.org/findstds/standard/C95.6-2002.html>, accessed on October 12, 2017.

[14] International Commission on Non-Ionizing Radiation Protection (ICNIRP), *Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz)*. Health Physics, Vol. 99, No. 6, November 2010, p. 3, <https://www.icnirp.org/cms/upload/publications/ICNIRPLFgdl.pdf>, accessed on October 12, 2017.

[15] Florida Administrative Code 62-814.450. <https://www.flrules.org/gateway/ruleno.asp?id=62-814.450>

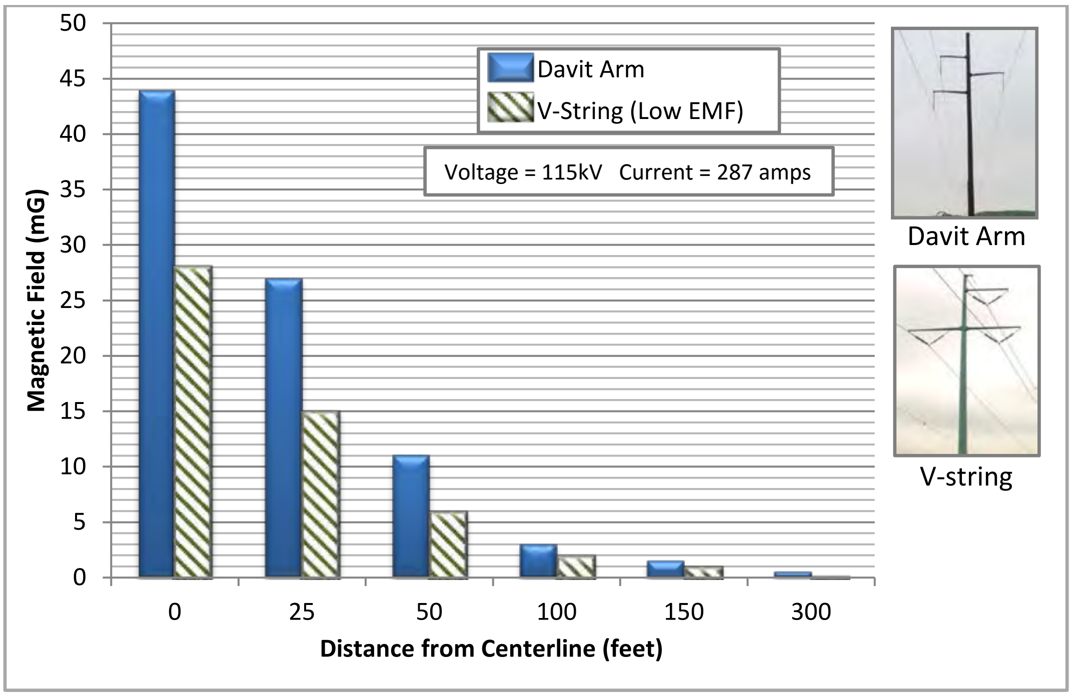
[16] State of New York Public Service Commission, *Statement of Interim Policy on Magnetic Fields of Major Electric Transmission Facilities, Cases 26529 and 26559*, Issued and Effective September 11, 1990. <http://www3.dps.ny.gov/pscweb/WebFileRoom.nsf/0/9C381C482723BE6285256FA1005BF743/$File/26529.pdf?OpenElement>.

[17] California Public Utility Commission, CPUC Decision D.93-11-013. <http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/53181.pdf>

Additionally, the closer conductors are to one another, the closer together poles must be constructed. Increasing the number of poles per mile increases private property land impacts and costs.

Burying transmission lines can also reduce magnetic fields because the underground lines can be installed closer together than overhead lines. Overhead lines need to be further apart because air is used as an insulator, but underground cables be insulated with rubber, plastic, or oil. Underground transmission lines are typically three to five feet below ground. While magnetic fields can be quite high directly over the line, magnetic fields on either side of an underground line decrease more drastically with increased distance than magnetic fields from an overhead line.

Figure 3 Sample EMF for Two Types of Transmission Structures



Sources of Information

The following organizations and websites contain detailed information about EMF and transmission lines along with links to published research.

International Commission on Non Ionizing Radiation Protection
http://www.icnirp.de/PubEMF.htm

National Cancer Institute (NCI)
http://www.cancer.gov/cancertopics/factsheet/Risk/magnetic-fields

National Institute of Environmental Health Sciences (NIEHS)
http://www.niehs.nih.gov/health/topics/agents/emf/

US EPA
http://www.epa.gov/radtown/power-lines.html

World Health Organization (WHO)
http://www.who.int/peh-emf/en/

Summaries of Scientific Consensus Group Assessments of EMF and Health Effects[18]

Scientific Group	Endpoints Considered	Overall Conclusions	Level of Concern
American Cancer Society (ACS)	cancer	[EMF] not proven to cause cancer	low
American Conference of Governmental Industrial Hygienists (ACGIH)	health	insufficient information on human responses and possible health effects of magnetic fields in the frequency range of 1 Hz to 30 kHz to permit the establishment of a threshold limit value for time-weighted exposures	low
American Industrial Hygiene Association (AIHA)	health	insufficient evidence of human health risk at EMF levels below ICNIRP guidelines	low
American Medical Association (AMA)	cancer/health	no scientifically documented health risk associated with the usually occurring levels of electromagnetic fields	low
American Physical Society (APS)	cancer/health	conjecture relating cancer to power line fields has not been scientifically substantiated	low
Australian Radiation Protection and Nuclear Safety Agency (ARPNSA)	health	no evidence that prolonged exposures to weak EMF result in adverse health effects	low
British Columbia Center for Disease Control (BCCDC)	health	no evidence yet to support the assumption that adverse health effects from exposure to current residential and occupational levels pose a risk to human health	low
British National Radiation Protection Board (NRPB), now health Protection Agency (HPA)	health	recommend ICNIRP EMF limits; apparent increased incidence of childhood leukemia at >4 mG, but weak evidence does not justify causality; no evidence of other health effects	low
Committee on Man and Radiation	health	balance of evidence is against the fields encountered by the public being a cause of cancer or any other disease	low
European Union (EU)	cancer/health	overall evidence for EMF to produce childhood leukemia is limited; no suggestions of any other cancer effects	low
Health Canada (HC)	health	no conclusive evidence of any harm caused by exposures at levels normally found in residential and work environments	low
Institution of Electrical Engineers (IEE)	health	not enough scientific evidence to indicate that harmful effects occur in humans due to low-level electromagnetic field exposure	low
Institute of Electrical and Electronics Engineers (IEEE)	health	the low-frequency standard IEEE C95.6 is leading standard worldwide on protection against ELF exposure to human beings; basic restrictions based on current biological knowledge; IEEE standards also adopted by the International Committee on Electromagnetic Safety (ICES)	low
International Agency for Research on Cancer (IARC)	cancer	limited convincing evidence in humans for childhood leukemia; inadequate evidence in humans for all cancers	low / med
International Commission on Non Ionizing Radiation Protection (ICNIRP)	health	no convincing evidence for carcinogenic effects of EMF; data cannot be used to set guidelines; ICNIRP guidelines are not based on cancer risks	low
Medical College of Wisconsin (MCW)	health	evidence that power line fields cause or contribute to cancer seen by most scientists as weak to nonexistent	low
National Academy of Sciences / National Research Council (NRC)	cancer/health	body of evidence has not demonstrated that exposures to EMF are a human-health hazard	low
National Cancer Institute (NCI)	cancer (breast)	no association between exposure to EMF and breast cancer in Long Island	low
National Cancer Institute (NCI)	cancer (leukemia)	little support for hypothesis that EMF is related to risk of childhood leukemia	low

[18] State of Connecticut, Connecticut Siting Council, "*Current Status of Scientific Research, Consensus, and Regulation Regarding Potential Health Effects of Power-Line Electric and Magnetic Fields (EMF)*", January 2006, http://www.ct.gov/csc/lib/csc/emf_bmp/emf_report.pdf. Modified from Appendix A.

Summaries of Scientific Consensus Group Assessments cont'd

Scientific Group	Health Endpoints Considered	Overall Conclusions	Level of Concern
National Institute of Environmental Health Sciences (NIEHS)	health	weak evidence for possible health effects from EMF; but they cannot be ruled out, especially epidemiological associations with childhood leukemia	low
National Toxicology Program (NTP)	cancer	no increased neoplasm incidences at sites in highly exposed rats and mice for which epidemiology studies have suggested an association with EMF	low
Netherlands Health Council (NHC)	cancer	adheres to its previously expressed view that, on the basis of the current level of knowledge, there is no reason to take action to reduce EMF levels	low
Occupational Safety and Health Administration (OSHA)	health	no specific OSHA standards address ELF fields; however, there are national consensus standards which OSHA could consider (ACGIH and ICNIRP)	low
World Health Organization(WHO)	health	cause-and-effect link between ELF field exposure and cancer has not been confirmed	low
California Department of Health Services	health	concern about possible health hazards - childhood leukemia, adult brain cancer, Lou Gehrig's disease and miscarriage, but evidence is incomplete, inconclusive and often contradictory	low
California Public Utilities Commission (CPUC)	health	interim measures adopted because of the lack of scientific or medical conclusions about potential health effects from utility electric facilities and power lines	low / med
Connecticut Department of Public Health	health/cancer	health risk caused by EMF exposure remains an open question; some studies show a weak link between EMF exposure and a small increased risk of childhood leukemia at average exposures above 3 mG; for cancers other than childhood leukemia, none of the studies provide evidence of an association	low
Florida Department of Environmental Protection	health	no convincing evidence for carcinogenic effects of ELF fields	low
Maryland Department of Natural Resources	health	EMF exposures remain suspect, but remaining unknowns are the reason for continued lack of firm affirmation of health risks from EMF exposures	low
Massachusetts - Energy Facilities Siting Board	health	informally adopt edge of ROW permissible levels of 85 mG for magnetic fields	
Minnesota Department of Health	health	body of evidence insufficient to establish a cause and effect relationship between EMF and adverse health effects	low
New Jersey Department of Environmental Protection	health	not known at this point whether exposure to magnetic fields from power frequency sources constitutes a health hazard	low
New York Department of Environmental Protection	health	interim policy requires transmission lines to be designed, constructed and operated such that magnetic fields at the edges of their ROWs will not exceed 200 mG	
Utah Department of Environmental Quality	health	no convincing evidence in the published literature to support the contention that exposures to extremely low frequency electric and magnetic fields (ELF-EMF) generated by sources such as household appliances, video display terminals, and local power lines are demonstrable health hazards	
Vermont Department of Health	health	data insufficient to establish a direct cause and effect between EMF exposure and adverse health effects	low
Virginia Department of Health	health	scientific proof of a causal association has not been satisfied for the implicit adverse effects of power-line frequency EMF	low

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natural gas, electricity, heat, steam, water and telecommunication services.

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Electric 12 (10/12/17)

Underground Electric Transmission Lines

Introduction

This overview contains information about electric transmission lines which are installed underground, rather than overhead on poles or towers. Underground cables have different technical requirements than overhead lines and have different environmental impacts. Due to their different physical, environmental, and construction needs, underground transmission generally costs more and may be more complicated to construct than overhead lines. Issues discussed in this pamphlet include:

- Types of Underground Electric Transmission Cables
- Ancillary Facilities
- Construction and Operation Considerations
- Costs
- Repairs

The design and construction of underground transmission lines differ from overhead lines because of two significant technical challenges that need to be overcome. These are: 1) providing sufficient insulation so that cables can be within inches of grounded material; and 2) dissipating the heat produced during the operation of the electrical cables. Overhead lines are separated from each other and surrounded by air. Open air circulating between and around the conductors cools the wires and dissipates heat very effectively. Air also provides insulation that can recover if there is a flashover.

In contrast, a number of different systems, materials, and construction methods have been used during the last century in order to achieve the necessary insulation and heat dissipation required for undergrounding transmission lines. The first underground transmission line was a 132 kV line constructed in 1927. The cable was fluid-filled and paper insulated. The fluid was necessary to dissipate the heat. For decades, reliability problems continued to be associated with constructing longer cables at higher voltages. The most significant issue was maintenance difficulties. Not until the mid-1960s did the technology advance sufficiently so that a high-voltage 345 kV line could be constructed underground. The lines though were still fluid filled. This caused significant maintenance, contamination, and infrastructure issues. In the 1990s the first solid cable transmission line was constructed more than one mile in length and greater than 230 kV.

Underground Transmission in Wisconsin

There are approximately 12,000 miles of transmission lines currently in Wisconsin. Less than one percent of the transmission system in Wisconsin is constructed underground. All underground transmission lines are 138 kV lines or less. There are no 345 kV lines constructed underground, currently in Wisconsin.

Types of Underground Electric Transmission Cables

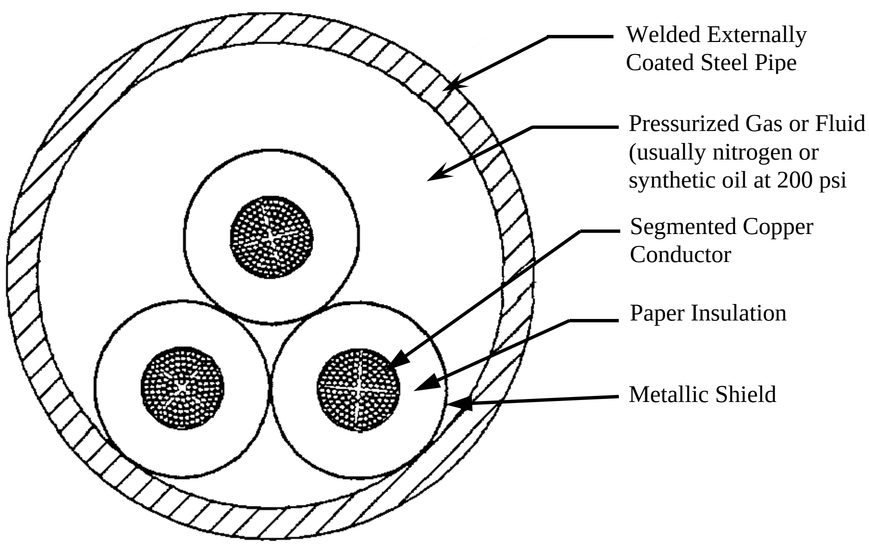
There are two main types of underground transmission lines currently in use. One type is constructed in a pipe with fluid or gas pumped or circulated through and around the cable in order to manage heat and insulate the cables. The other type is a solid dielectric cable which requires no fluids or gas and is a more recent technological advancement. The common types of underground cable construction include:

- High-pressure, fluid-filled pipe (HPFF)
- High-pressure, gas-filled pipe (HPGF)
- Self-contained fluid-filled (SCFF)
- Solid cable, cross-linked polyethylene (XLPE)

High-Pressure, Fluid-Filled Pipe-Type Cable

A high-pressure, fluid-filled (HPFF) pipe-type of underground transmission line, consists of a steel pipe that contains three high-voltage conductors. Figure 1 illustrates a typical HPFF pipe-type cable. Each conductor is made of copper or aluminum; insulated with high-quality, oil-impregnated kraft paper insulation; and covered with metal shielding (usually lead) and skid wires (for protection during construction).

Figure 1 HPFF or HPGF Pipe-Type Cross Section



Inside steel pipes, three conductors are surrounded by a dielectric oil which is maintained at 200 pounds per square inch (psi). This fluid acts as an insulator and does not conduct electricity. The pressurized dielectric fluid prevents electrical discharges in the conductors' insulation. An electrical discharge can cause the line to fail. The fluid also transfers heat away from the conductors. The fluid is usually static and removes heat by conduction. In some situations the fluid is pumped through the pipe and cooled through the use of a heat exchanger. Cables with pumped fluids require aboveground pumping stations, usually located within substations. The pumping stations monitor the pressure and temperature of the fluid. There is a radiator-type device that moves the heat from the underground cables to the atmosphere. The oil is also monitored for any degradation or trouble with the cable materials.

The outer steel pipe protects the conductors from mechanical damage, water infiltration, and minimizes the potential for oil leaks. The pipe is protected from the chemical and electrical environment of the soil by means of a coating and cathodic protection.

Problems associated with HPFF pipe-type underground transmission lines include maintenance issues and possible contamination of surrounding soils and groundwater due to leaking oil.

High-Pressure, Gas-Filled Pipe-Type Cable

The high-pressure, gas-filled (HPGF) pipe-type of underground transmission line (see Figure 1) is a variation of the HPFF pipe-type, described above. Instead of a dielectric oil, pressurized nitrogen gas is used to insulate the conductors. Nitrogen gas is less effective than dielectric fluids at suppressing electrical discharges and cooling. To compensate for this, the conductors' insulation is about 20 percent thicker than the insulation in fluid-filled pipes. Thicker insulation and a warmer pipe reduce the amount of current the line can safely and efficiently carry. In case of a leak or break in the cable system, the nitrogen gas is easier to deal with than the dielectric oil in the surrounding environment.

Self-Contained, Fluid-Filled Pipe-Type

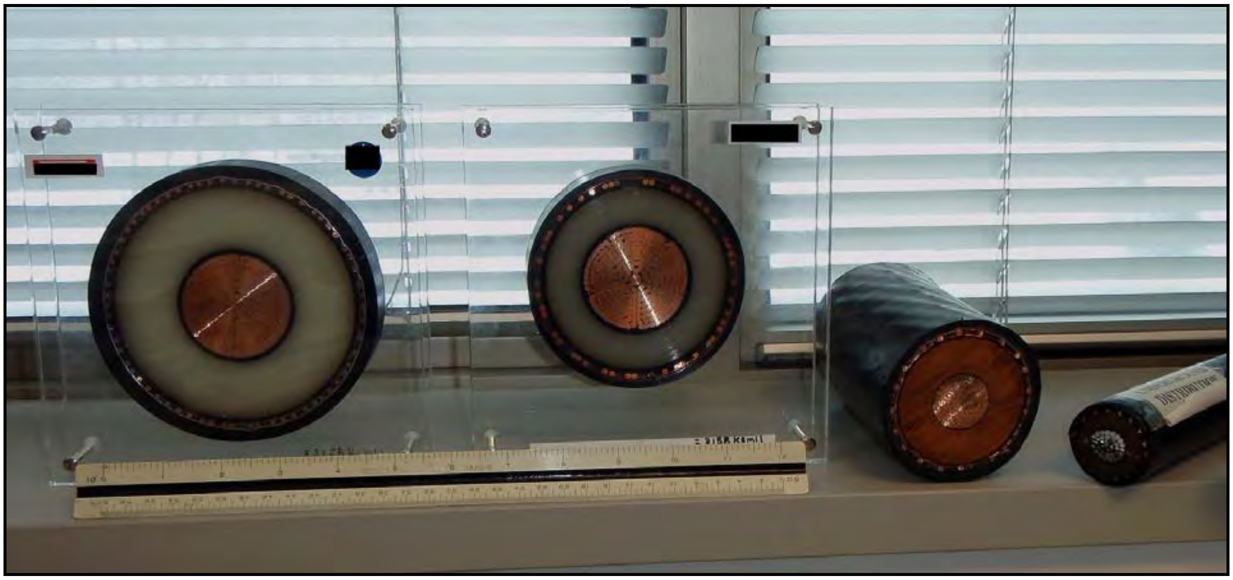
The self-contained, fluid-filled (SCFF) pipe-type of underground transmission is often used for underwater transmission construction. The conductors are hollow and filled with an insulating fluid that is pressurized to 25 to 50 psi. In addition, the three cables are independent of each other. They are not placed together in a pipe.

Each cable consists of a fluid-filled conductor insulated with high-quality kraft paper and protected by a lead-bronze or aluminum sheath and a plastic jacket. The fluid reduces the chance of electrical discharge and line failure. The sheath helps pressurize the conductor's fluid and the plastic jacket keeps the water out. This type of construction reduces the risk of a total failure, but the construction costs are much higher than the single pipe used to construct the HPFF or HPGF systems.

Solid Cable, Cross-Linked Polyethylene

The cross-linked polyethylene (XLPE) underground transmission line is often called solid dielectic cable. The solid dielectric material replaces the pressurized liquid or gas of the pipe-type cables. XLPE cable has become the national standard for underground electric transmission lines less than 200 kV. There is less maintenance with the solid cable, but impending insulation failures are much more difficult to monitor and detect. The diameter of the XLPE cables increase with voltage (Figure 2).

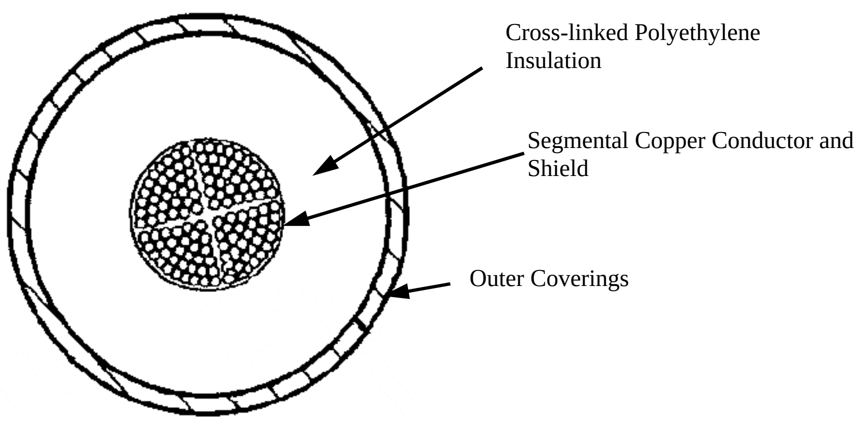
Figure 2 XLPE Cables with Different Voltages



Underground XLPE cables left to right: 345 kV, 138 kV, 69 kV, and distribution

Each transmission line requires three separate cables, similar to the three conductors required for aboveground transmission lines. They are not housed together in a pipe, but are set in concrete ducts or buried side-by-side. Each cable consists of a copper or aluminum conductor and a semi-conducting shield at its core. A cross-linked polyethylene insulation surrounds the core. The outer covering of the cable consists of a metallic sheath and a plastic jacket (Figure 3).

Figure 3 XLPE Cable Cross-Section



For 345 kV XLPE construction, two sets of three cables (six cables) are necessary for a number of reasons, primarily so that the capacity of the underground system matches the capacity of the overhead line. This design aids in limiting the scope of any cable failure and shortens restoration time in an emergency situation. Most underground transmission requires increased down time for the repair of operating problems or maintenance issues compared to overhead lines. The double sets of cables allows for the rerouting of the power through the backup cable set, reducing the down time but increases the construction footprint of the line.

Ancillary Facilities

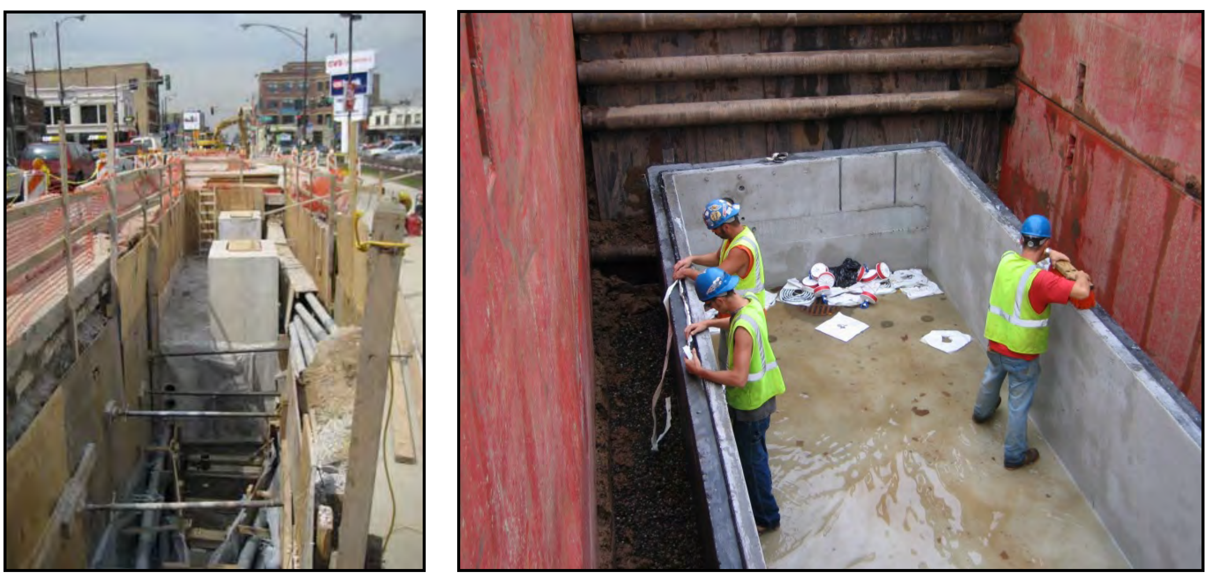
Different types of cables require different ancillary facilities. Some of these facilities are constructed underground, while others are aboveground and may have a significant footprint. When assessing the impacts of underground transmission line construction and operation, the impacts of the ancillary facilities must be considered, as well.

Vaults

Vaults are large concrete boxes buried at regular intervals along the underground construction route. The primary function of the vault is for splicing the cables during construction and for permanent access, maintenance, and repair of the cables. The number of vaults required for an underground transmission line is dictated by the maximum length of cable that can be transported on a reel, the cable's allowable pulling tension, elevation changes along the route, and the sidewall pressure as the cable goes around bends. XLPE cable requires a splice every 900 to 2000 feet, depending on topography and voltage. Pipe-type cables need a splice at least every 3,500 feet. The photos in Figure 4 show examples of vault construction.

Vaults are approximately 10 by 30 feet and 10 feet high. They have two chimneys constructed with manholes which workmen use to enter the vaults for cable maintenance. Covers for the manholes are designed to be flush with the finished road surface or ground elevation. Vaults can be either pre-fabricated and transported to the site in two pieces or constructed onsite. Excavations in the vicinity of the vaults will be deeper and wider. Higher voltage construction may require two vaults constructed adjacent to each other to handle the redundant set of cables.

Figure 4 Vault Construction



Left: 345 kV XLPE project – Cement vault visible with two chimneys extending up to be level with the future road surface.
Right: 138 kV XLPE project – Bottom half of pre-constructed vault positioned in trench.

138 kV XLPE project – Pre-fabricated top half of vault being lowered into trench.

Transition Structures

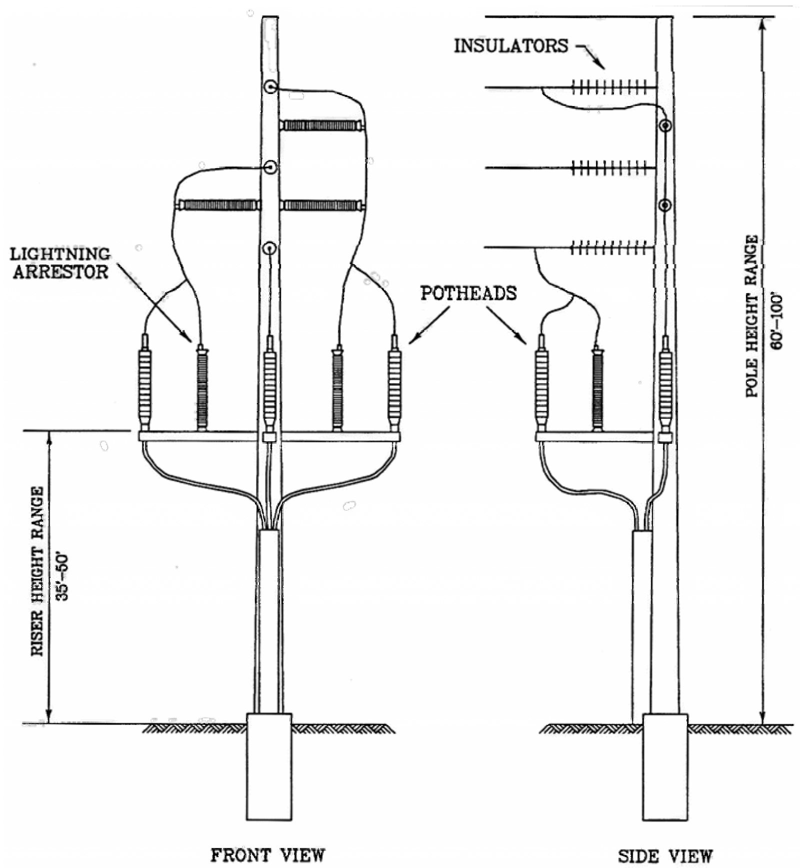
For underground cables less than 345 kV, the connection from overhead to underground lines require the construction of a transition structure, also known as a riser. Figures 5 and 6 depict sample transition structure designs. These structures are between 60 and 100 feet tall. They are designed so that the three conductors are effectively separated and meet electric code requirements.

The insulated conductor of the overhead line is linked through a solid insulator device to the underground cable. This keeps moisture out of the cable and the overhead line away from the supporting structure.

Figure 5 138 kV Underground to Overhead Transition Structures

Lightning arrestors are placed close to where the underground cable connects to the overhead line to protect the underground cable from nearby lightning strikes. The insulating material is very sensitive to large voltage changes and cannot be repaired. If damaged, a completely new cable is installed.

Figure 6   Diagram of a Typical Transmission Riser Structure



Transition Stations

High voltage (345 kV or greater) underground transmission lines require transition stations wherever the underground cable connects to overhead transmission. For very lengthy sections of underground transmission, intermediate transition stations might be necessary. The appearance of a 345 kV transition station is similar to that of a small switching station. The size is governed by whether reactors or other additional components are required. They range in size from approximately 1 to 2 acres. Transition stations also require grading, access roads, and storm water management facilities. Figure 7 is a photo of small transition station.

Figure 7 Small Transition Station

Pressurizing Sources

For HPFF systems, a pressurizing plant maintains fluid pressure in the pipe. The number of pressurizing plants depends on the length of the underground lines. It may be located within a substation. It includes a reservoir that holds reserve fluid. An HPGF system does not use a pressurizing plant, but rather a regulator and nitrogen cylinder. These are located in a gas-cabinet that contains high-pressure and low-pressure alarms and a regulator. The XLPE system does not require any pressurization facilities.

Construction of Underground Transmission

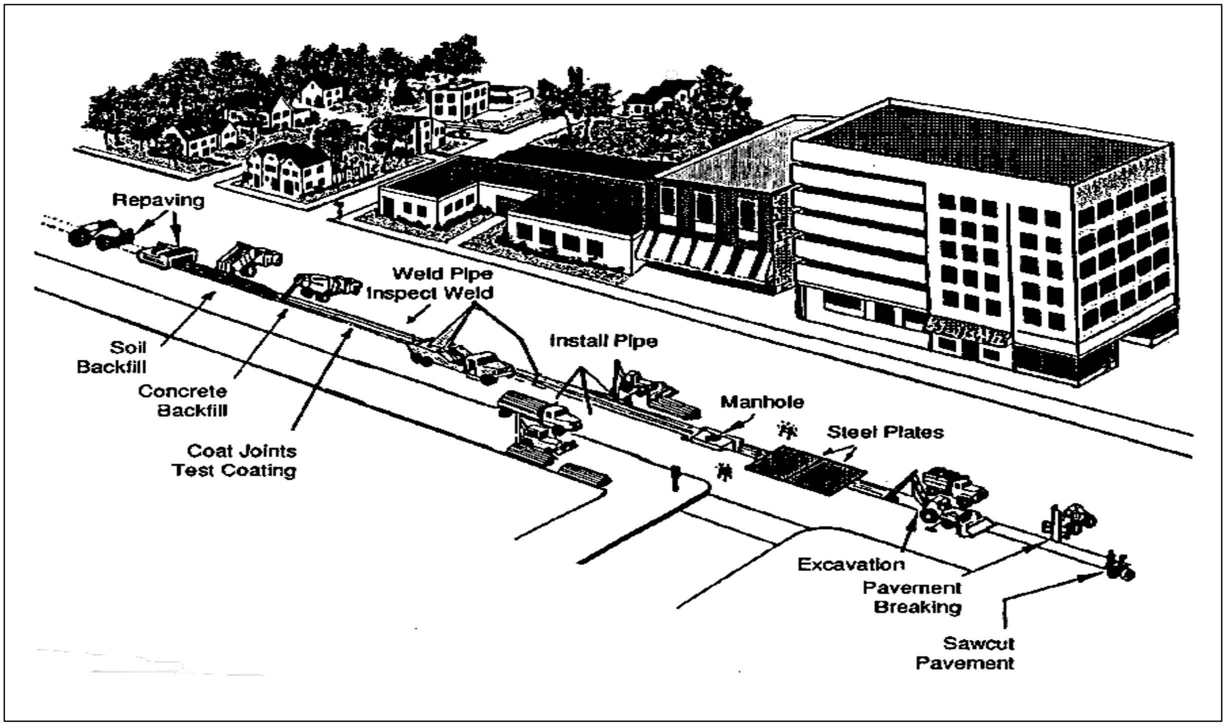
Installation of an underground transmission cable generally involves the following sequence of events: 1) ROW clearing, 2) trenching/blasting, 3) laying and/or welding pipe, 4) duct bank and vault installation, 5) backfilling, 6) cable installation, 7) adding fluids or gas, and 8) site restoration. Many of these activities are conducted simultaneously so as to minimize the interference with street traffic. Figure 8 shows a typical installation sequence in a city street.

Right-Of-Way Construction Zone

Similar to overhead transmission construction, underground construction begins by staking the ROW boundaries and marking sensitive resources. Existing underground utilities are identified and marked prior to the start of construction.

If the transmission line is constructed within roadways, lane closures will be required and traffic control signage installed. Construction activities and equipment will disrupt traffic flow. On average, several hundred feet of traffic lane are closed during construction. When materials and equipment are delivered, additional lengths or lanes of traffic may be closed. Construction areas need to be wide and level enough to support the movement of backhoes, dump trucks, concrete trucks, and other necessary construction equipment and materials. Undeveloped portions of the road ROW may require excavation or fill deposited on hillsides so that the surface is leveled and compact enough for support of the construction equipment. Construction areas in road ROWs are typically 12 to 15 feet wide with an additional 5 to 8 feet for trench construction.

Figure 8 Typical Work Sequence for Pipe-Type Installation in an Urban Area



If the transmission line is to be constructed in unpaved areas, all shrubs and trees are cleared in the travel path and in the area to be trenched. Temporary easements would be necessary during construction and permanent easements for the life of the transmission line.

Trenching and Blasting

Most commonly, a backhoe is used to dig the trench (see Figure 9). The excavation starts with the removal of the top soil in unpaved areas or the concrete/asphalt in paved areas. Large trucks haul away excavated subsoil materials to approved off-site location for disposal, or if appropriate, re-use. In accordance with OSHA requirements, trenches of a certain depth may require additional shoring. Trench size will vary depending on the cable type and the line's voltage. Most commonly, trenches are at least 6 to 8 feet deep to keep cables below the frost line. The trench dimensions will be greater in places where vaults are located. In many instances, groundwater will be encountered during the trenching. In accordance with DNR permits, groundwater may be pumped from the excavation to a suitable upland area or pumped directly into a tanker truck for transport to a suitable location for release.

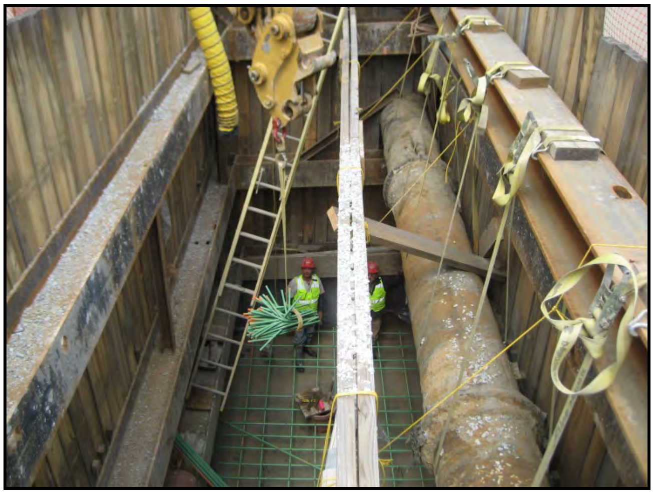
Figure 9 Examples of Trench Construction

Urban road ROWs often contain a wide variety of underground obstacles, such as existing utilities, natural features, topography, major roadways, or underpasses. The dimensions of the trench might need to be deeper and wider to avoid underground obstacles. Every effort should be made to prevent impacts to existing utilities such as making minor adjustment to the alignment of the duct bank, relocating the existing utility, or putting the duct bank below the existing infrastructure.

When trenches are excavated deeper than anticipated, the width of the trench must be widened for purposes of stability. Figure 10 shows a greatly enlarged trench so that the transmission cables and could be located below the exposed storm sewer (sewer located along the right side of the photo).

When bedrock or subsoils primarily consisting of large boulders are encountered, blasting may be required.

Figure 10 Example of Trench with Storm Sewer Obstacle



Jack and Bore

Jack and bore construction is used in areas where open trench construction is obstructed by existing features such as railroads, waterways, or other large facilities or utilities. It can be used for most types of underground cable construction. Entrance and exit pits are excavated to accommodate the boring equipment and materials. Typical boring pits are around 14 by 35 feet, and deep enough to accommodate the boring equipment. An auger is used in the entrance pit to excavate a hole and remove spoils. A jack pushes a reinforced pipe in sections behind the auger head. When the pipe is installed, the conduit is surrounded by bore spacers and the conduit is pushed into the casing pipe. The casing pipe is then backfilled with a material that optimizes thermal radiation. Lastly, the entrance and exit pits are restored to their original condition.

The amount of disturbed construction area required for a jack and bore is usually proportional to the diameter of the bore, its maximum depth, and the length of the bore. Typically construction lay down areas are equal to the length of bore to facilitate the welding of the pipe that is installed into the bore hole. The bore entry site may be as much as 150 feet long to handle the drilling equipment and management of the slurry.

Conduit Assembly for XLPE Construction

The assembly of conduits and direct-buried method of XLPE construction are illustrated in Figures 11, 12, and 13. Underground XLPE cable systems can be direct-buried or encased in concrete duct banks. For duct bank installation, the trench is first excavated a couple hundred feet. Then the duct bank is assembled using polyvinyl chloride (PVC) conduit and spacers. Even though using concrete duct banks is more expensive than direct-bury, it is the most common method of installation for higher voltage lines. This is because the construction technique provides more mechanical protection, reduces the need for re-excavation in the event of a cable failure, and shorter lengths of trench are opened at any one time for construction and maintenance activities.

Figure 11 Examples of XLPE Conduit Assembly

Figure 12 Sample Configuration of an XLPE Duct Bank

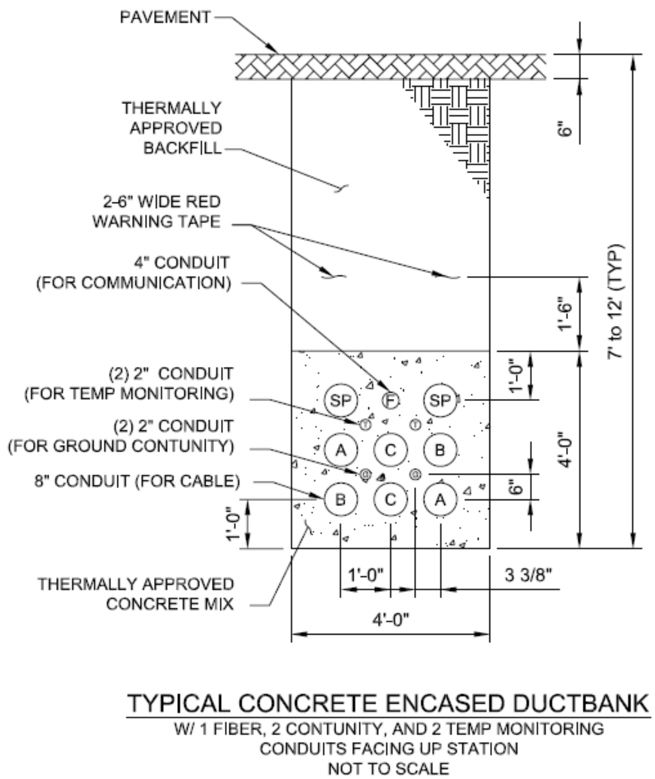
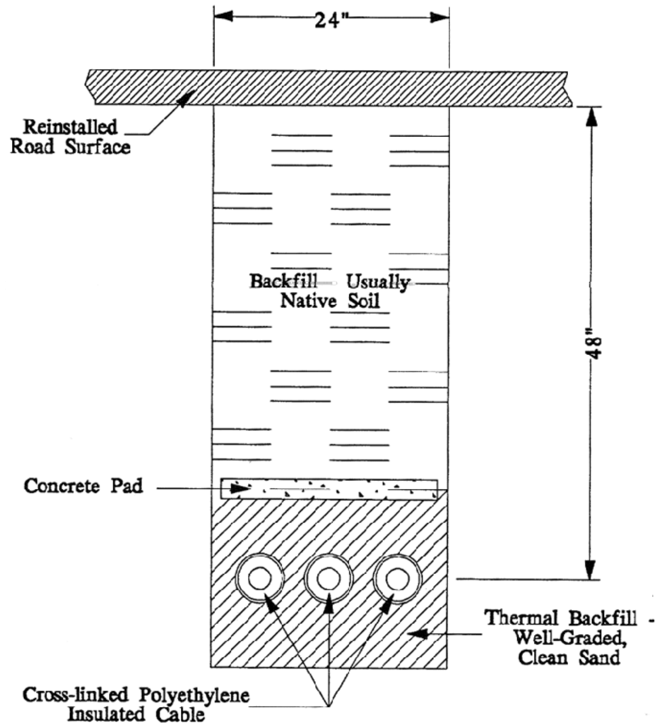


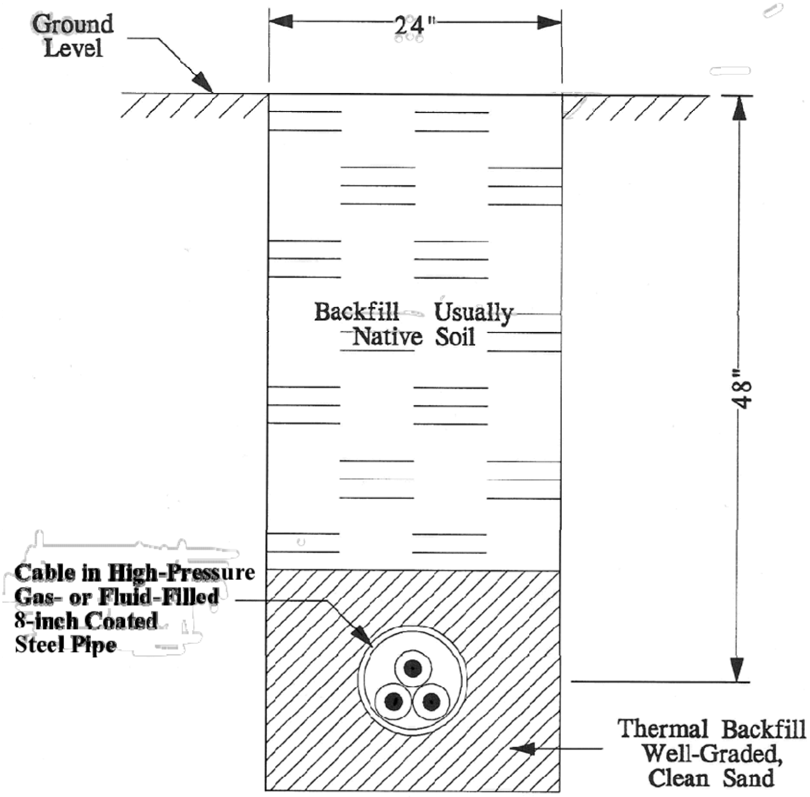
Figure 13 Installation of XLPE Underground Cable Directly Buried



Pipe Installation

HPFF and HPGF pipe-type installation requires the construction of welded steel pipe sections to house the cables. The welding of pipe sections takes place either in or over the trench. Pipe welds are X-rayed, and then protected from corrosion with plastic coatings. When the pipe is completely installed, it is pressure tested with either air or nitrogen gas. It is then vacuum-tested, vault to vault, which also dries the pipe. Figure 14 show the cross-section for an HPFF or HPGF pipe-type underground transmission line.

Figure 14 Installation of HPFF or HPGF Pipe-Type Underground Cable



Cable Installation

Cable pulling and splicing can occur any time after the duct banks and vaults are completed. Prior to installation of the cable, the conduit is tested and cleaned by pulling a mandrel and swab through each of the ducts. A typical setup is to lace the reel of cable at the transition structure or at one of the vaults and the winch truck at the next vault (see Figure 15). The cable is then pulled from the transition structure to the nearest vault. Direction of pull between vaults is based on the direction that results in the lowest pulling and sidewall tensions. Cable lengths are spliced within the vaults.

Figure 15 Cable Pulling

Backfilling

Pipe-type conductors operate at about 167 to 185 °F with an emergency operating temperature of 212 to 221 °F. XLPE conductors operate at about 176 to 194 °F with an emergency operating temperature of about 266 °F. Heat must be carried away from the conductors for them to operate efficiently. The air performs this function for overhead lines. The soils in and around the trench do this for underground lines.

All of the heat generated from direct buried cables must be dissipated through the soil. The selection of backfill type can make a strong difference on the capacity rating. Different soils have different abilities to transfer heat. Saturated soils conduct heat more easily than for instance, sandy soils. For this reason, the design needs to determine the type of soil nearest the line. A soil thermal survey may be necessary before construction to help determine the soil's ability to move heat away from the line. In many cases, a special backfill material is used instead of soil in the trench around the cables to ensure sufficient heat transfer to the surrounding soils and groundwater.

Site Restoration

Site restoration for underground construction is similar to overhead transmission line construction restoration. When construction is completed, roadways, landscaped areas, and undeveloped areas are restored to their original condition and topography (Figure 16). Highway lands and shoulders are re-constructed so as to support road traffic. Roadside areas and landscaped private properties are restored with top soils that was previously stripped and stockpiled during construction or with new topsoil. Any infrastructure impacted by the construction project such as driveways, curbs, and private utilities are restored to their previous function, and yards and pastures are vegetated as specified in landowner easements. Similar to overhead lines, all landowner protections listed in Wisconsin statute (Wis. Stat. § 182.017(7)(c)) must be met.

Figure 16 Backfilling and Street Restoration

Underground Construction Considerations

Underground construction could be a reasonable alternative to overhead in urban areas where an overhead line cannot be installed with appropriate clearance, at any cost. In suburban areas, aesthetic issues, weather-related outages, some environmental concerns, and the high cost of some ROWs could make an underground option more attractive.

Underground transmission construction is most often used in urban areas. However, underground construction may be disruptive to street traffic and individuals because of the extensive excavation necessary. During construction, barricades, warning and illuminated flashing signs, are often required to guide traffic and pedestrians. After each day's work, steel plates will cover any open trench. All open concrete vaults will have a highly visible fence around them. When the cable is pulled into the pipe, the contractor should cordon off the work area. There may be time-of-day or work week limitations for construction activities in roadways that are imposed for reasons of noise, dust, and traffic impacts. These construction limitations often increase the cost of the project.

The trenching for the construction of underground lines causes greater soil disturbance than overhead lines. Overhead line construction disturbs the soil mostly at the site of each transmission pole. Trenching an underground line through farmlands, forests, wetlands, and other natural areas can cause significant land disturbances.

Many engineering factors significantly increase the cost of underground transmission facilities. As the voltage increases, engineering constraints and costs dramatically increase. This is the reason why underground distribution lines (12 - 24 kV) are not uncommon; whereas, there is just over 100 miles of underground transmission currently in the state. There are also no 345 kV underground segments in Wisconsin.

Construction Impacts in Suburban and Urban Areas

The construction impacts of underground lines are temporary and, for the most part, reversible. They include dirt, dust, noise, and traffic disruption. Increased particles in the air can cause health problems for people who live or work nearby. Particularly sensitive persons include the very young, the very old, and those with health problems, such as asthma. If the right-of-way is in a residential area, construction hours and the amount of equipment operating simultaneously may need to be limited to reduce noise levels. In commercial or industrial areas, special measures may be needed to keep access to businesses open or to control traffic during rush hours.

Construction Impacts in Farmland and Natural Areas

Most underground transmission is constructed in urban areas. In non-urban areas, soil compaction, erosion, and mixing are serious problems, in addition to dust and noise. During construction, special methods are needed to avoid mixing the topsoil with lower soil horizons and to minimize erosion. The special soils often placed around an underground line may slightly change the responsiveness of surface soils to farming practices. Post-construction, trees and large shrubs would not be allowed within the right-of-way due to potential problems with roots. Some herbaceous vegetation and agricultural crops may be allowed to return to the right-of-way.

Costs

The estimated cost for constructing underground transmission lines ranges from 4 to 14 times more expensive than overhead lines of the same voltage and same distance. A typical new 69 kV overhead single-circuit transmission line costs approximately $285,000 per mile as opposed to $1.5 million per mile for a new 69 kV underground line (without the terminals). A new 138 kV overhead line costs approximately $390,000 per mile as opposed to $2 million per mile for underground (without the terminals).

These costs are determined by the local environment, the distances between splices and termination points, and the number of ancillary facilities required. Other issues that make underground transmission lines more costly are right-of-way access, start-up complications, construction limitations in urban areas, conflicts with other utilities, trenching construction issues, crossing natural or manmade barriers, and the potential need for forced cooling facilities. Other transmission facilities in or near the line may also require new or upgraded facilities to balance power issues such fault currents and voltage transients, all adding to the cost.

While it may be useful to sometimes compare the general cost differences between overhead and underground construction, the actual costs for underground may be quite different. Underground transmission construction can be very site-specific, especially for higher voltage lines. Components of underground transmission are often not interchangeable as they are for overhead. A complete in-depth study and characterization of the subsurface and electrical environment is necessary in order to get an accurate cost estimate for undergrounding a specific section of transmission. This can make the cost of underground transmission extremely variable when calculated on a per-mile basis.

Underground Operating Considerations

Post-construction issues such as aesthetics, electric and magnetic fields (EMF), and property values are usually less of an issue for underground lines. Underground lines are not visible after construction and have less impact on property values and aesthetics.

Apart from cost and construction issues, there are continued maintenance and safety issues associated with the right-of-way. The right-of-way must be kept safe from accidental contact by subsequent construction activities. To protect individual ducts (for SCFF and XLPE lines) against accidental future dig-ins, a concrete duct bank, a concrete slab, or patio blocks are installed above the line, along with a system of warning signs ("high-voltage buried cable").

Additionally, if the cables are not constructed under roads or highways, the ROW must be kept clear of vegetation with long roots such as trees that could interfere with the system.

Cable Repairs

Repair costs for an underground line are usually greater than costs for an equivalent overhead line. Leaks can cost $50,000 to $100,000 to locate and repair. A leak detection system for a HPFF cable system can cost from $1,000 to $400,000 to purchase and install depending on the system technology.

Molded joints for splices in XLPE line could cost about $20,000 to repair. Field-made splices could cost up to $60,000 to repair.

A fault in a directionally drilled section of the line could require replacement of the entire section. For example, the cost for directional drilling an HPGF cables is $25 per foot per cable. The cables in the directional drilled section twist around each other in the pipe so they all would have to be pulled out for examination.

The newer XLPE cables tend to have a life that is one half of an overhead conductor which may require replacing the underground every 35 years or so.

Easement agreements may require the utility to compensate property owners for disruption in their property use and for property damage that is caused by repairing underground transmission lines on private property. However, the cost to compensate the landowner is small compared to the total repair costs. Underground transmission lines have higher life cycle costs than overhead transmission lines when combining construction repair and maintenance costs over the life of the line.

Potential Fluid Leaks

Although pipe-type underground transmission lines require little maintenance, transmission owners must establish and follow an appropriate maintenance program, otherwise pipe corrosion can lead to fluid leaks.

Both HPFF and SCFF lines must have a spill control plan. The estimate for potential line leakage is about one leak every 25 years. Soil contaminated with leaking dielectric oil is classified as a hazardous waste. This means that contaminated soils and water would have to be remediated. The types of dielectric fluid used in underground transmission lines include alkylbenzene (which is used in making detergents) and polybutene (which is chemically related to Styrofoam). These are not toxic, but are slow to degrade. The release and degradation of alkylbenzene could cause benzene compounds, a known carcinogen, to show up in plants or wildlife.

A nitrogen leak from a HPGF line would not affect the environment, but workers would need to check oxygen levels in the vaults before entering. Fluid leaks are not a problem for solid dielectric cables.

Electric and Magnetic Fields

Electric fields are created by voltage. Higher voltage produces stronger electric fields. Electric fields are blocked by most objects such as walls, trees, and soil and are not an issue with underground transmission lines. Magnetic fields are created by current and produced by all household appliances that use electricity. Magnetic field strength increases as current increases so there is a stronger magnetic field generated when an appliance is set on “high” than when it is set on “low”. Milligauss (mG) is the common measurement of magnetic field strength. Typically, a hair dryer produces a magnetic field of 70 mG when measured one foot from the appliance. A television produces approximately 20 mG measured at a distance of one foot.

The strength of the magnetic field produced by a particular transmission line is determined by current, distance from the line, arrangement of the three conductors, and the presence or absence of magnetic shielding. Underground transmission lines produce lower magnetic fields than aboveground lines because the underground conductors are placed closer together which causes the magnetic fields created by each of the three conductors to cancel out some of the other’s fields. This results in reduced magnetic fields. Magnetic fields are also strongest close to their source and drop off rapidly with distance (Table 1). Pipe-type underground lines can have significantly lower magnetic fields than overhead lines or other kinds of underground lines because the steel pipe has magnetic shielding properties that further reduce the field produced by the conductors.

Table 1 shows sample magnetic field measurements at different distances from underground and overhead lines. Maximum magnetic field strengths of underground transmission lines typically do not exceed a few mG at a distance of 25 feet.

Table 1 Sample Magnetic Field Strength of Various Transmission Lines

Voltage	Construction	Amperes	Distance	mG
69 kV	Underground - XLPE	252	Centerline at surface	34.20
			50 feet from Centerline	0.90
69 kV	Underground - Pipe-type	204	Centerline at surface	0.80
			50 feet from Centerline	0.10
69 kV	Overhead	167	Centerline	23.00
			40 feet from Centerline	7.00
138 kV	Underground - Pipe-type	467	Centerline at surface	0.21
			50 feet from Centerline	0.05
138 kV	Overhead	710	Centerline at surface	190.00
			50 feet from Centerline	46.00

Heat

Heat produced by the operation of an underground transmission cable raises the temperature at the above the line, a few degrees. This is not enough to harm growing plants, but it could cause premature seed germination in the spring. Heat could also build up in enclosed buildings near the line.

Transmission routes that include other heat sources, such as steam mains, should be avoided. Electric cables should be kept at least 12 feet from other heat sources, otherwise the cable's ability to carry current decreases.

Reliability of Service

In general, lower voltage underground transmission lines are very reliable. However, their repair times are much longer than those for overhead lines.

Repair Rates – Pipe-Type Transmission Cables

For pipe-type lines, the trouble rates historically, for about 2,536 miles of line correspond to about:

- One cable repair needed per year for every 833 miles of cable.
- One splice repair needed per year for every 2,439 miles of cable.
- One termination repair needed per year for every 359 miles of cable.

These trouble rates indicate that there would be, at most, a 1:300 chance for the most common type of repair to be needed in any one mile of pipe-type underground line over any one year.

Repair Rates - XLPE lines

There is less available documentation regarding XLPE trouble rates and very little information for 345 kV transmission lines. However, the following estimates are generally accepted.

- One cable repair needed per year for every 1,000 miles of cable.
- One splice repair needed per year for every 1,428 miles of cable.
- One termination repair needed per year for every 1,428 miles of cable.

These trouble rates indicate that there would be, at most, a 1:1,000 chance for the most common type of repair to be needed in any one mile of XLPE underground line over any one year.

Outage Duration

The duration of outages varies widely, depending on the circumstances of the failure, the availability of parts, and the skill level of the available repair personnel. The typical duration of an HPGF outage is 8 to 12 days. The duration of typical XLPE outages is 5 to 9 days. The repair of a fault in a HPFF system is estimated to be from 2 to 9 months, depending on the extent of the damage.

The outage rate would increase as the number of splices increases. However, the use of concrete vaults at splice locations can reduce the duration of a splice failure by allowing quick and clean access to the failure. The outage would be longer if the splice were directly buried, as is sometimes done with rural or suburban XLPE lines.

To locate a leak in a pipe-type line, the pipe pressure must be reduced below 60 psi and the line de-energized before any probes are put into the pipe. For some leak probes, the line must be out of service for a day before the tests can begin. After repairs, pipe pressure must be returned to normal slowly. This would require an additional day or more before the repaired line could be energized.

To locate an electrical fault in an underground line, the affected cable must be identified. To repair a pipe-type line, the fluid on each side of the electrical failure would be frozen at least 25 feet out from the failure point. Then, the pipe would be opened and the line inspected. New splices are sometimes required and sometimes cable may need to be replaced and spliced. Then, the pipe would be thawed and the line would be re-pressurized, tested, and finally put back in service.

In contrast, a fault or break in an overhead line can usually be located almost immediately and repaired within hours or, at most, a day or two.

One problem that increases emergency response time for underground transmission lines is that most of the suppliers of underground transmission materials are in Europe. While some of the European companies keep American-based offices, cable and system supplies may not be immediately available for emergency repairs.

Line Life Expectancies

While the assumed life of underground pipe-type or XLPE cable is about 40 years, there are pipe-type cables that has been in service for more than 60 years. Overhead lines in northern Wisconsin last 60 plus years. There are some overhead lines that have lasted more than 80 years.

Choosing Between Underground and Overhead

There are different advantages and disadvantages for underground transmission lines. When compared with overhead transmission lines, the choice to build an underground transmission line instead of an overhead line depends on a number of factors.

The most non-debatable reason for choosing underground is in highly urban areas, where acquiring ROW that meets National Electrical Safety Code requirements is difficult or impossible. This makes the added cost of undergrounding acceptable to not being able to route the new line at all.

Choosing underground for reasons of aesthetics, may be justified because it is assumed that following the disruption of construction, the entire line would be out-of-sight. However, considerations must be made for the disruption caused by the trench construction and the ancillary facilities that would be above ground, such as transition structures (risers), pressurizing stations, and transition stations.

In general, underground lines are significantly more expensive than overhead lines. There are operational limitations and maintenance issues that must be weighed against the advantages. For some projects only a portion of a line may be constructed underground to avoid specific impacts. Every project must be assessed individually to determine the best type of transmission line for each location segment.

Role of the Public Service Commission

For most large underground or overhead transmission lines, the utility must apply to the Public Service Commission (PSC) for approval prior to building the line. An applicant must receive a Certificate of Public Convenience and Necessity (CPCN) from the Commission for a transmission project that is either:

- 345 kV or greater; or,
- Less than 345 kV but greater than or equal to 100 kV, over one mile in length, and requiring new right-of-way (ROW).

All other transmission line projects must receive a Certificate of Authority (CA) from the Commission if the project's cost is above a certain percent of the utility's annual revenue. The requirements for these certificates are specified in Wis. Stat. §§ 196.49 and 196.491.

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Electric 11 (05/11)

A FRAMEWORK FOR APPLYING INTEGRATED VEGETATION MANAGEMENT ON RIGHTS-OF-WAY

By Christopher A. Nowak[1] and Benjamin D. Ballard[2]

Abstract. Integrated Vegetation Management, or IVM, is purportedly being used by many right-of-way management organizations across the United States. In many cases, IVM is just a name applied to old management approaches. Yet IVM is more than just a name. It is an in-depth and sophisticated system of information gathering, planning, implementing, reviewing, and improving vegetation management treatments. IVM is used to understand, justify, choose among, selectively apply, and monitor different types of treatments, with an overall goal of eliciting site-specific, ecosystem-sensitive, economically sensible, and socially responsible treatment effects that lead to refined achievement of management objectives. We propose a six-step system to IVM that can act as a framework of activities to aid managers and other related stakeholders in communicating, organizing, and conducting IVM business. Each step produces information that must be integrated into the management system. Our six-step system is consistent with Integrated Pest Management and other IVM-like systems developed in forestry and agriculture. We present an IVM system with some unique perspectives and ideas from the literature, and incorporate information from and experience with the electric utility industry.

Key Words. Right-of-way; vegetation management; management systems; powerline corridors; electric transmission lines; pipelines; highway; railroad.

Rights-of-way (ROWs) can be generally defined as units of land used for transportation. As such, ROWs provide many goods, values, and services important to society. Production of values and services can occur from the ROW itself via the act of transport, such as with the movement of people in cars, trucks, and trains. Benefits of ROWs can accrue from the movement of goods, such as gas, oil, and electricity—these goods hold the benefit, and ROWs are a means of transmitting or distributing them to a place where the direct benefit is secured.

All ROWs are managed with a general goal of providing safe and reliable transport. Managers endeavor to meet this goal by creating corridors that exist in narrowly defined technical and environmental states. In almost all ROW scenarios, active management is needed to create specific vegetation and related environmental conditions. On electric transmission line ROWs, the selective removal of tall-growing trees and promotion of low-growing, relatively stable plant communities composed of grasses, forbs, and shrubs is the common approach to vegetation management. Tall-growing trees can cause unsafe conditions and shortfalls in reliability by growing into or near the wire conductors. These trees act as conduits for electricity, causing ground-fault disruptions in transmission. ROWs fully occupied by low-growing plants have been shown to produce safe, reliable, cost-effective transmission of electricity, primarily because, over the long-term, they result in a minimal amount of undesirable trees (Egler 1953; Niering 1958; Nowak and Abrahamson 1993; Finch and Shupe 1997; Jackson 1997).

Tree seeds and seedlings are consumed by small mammals that find suitable cover in the low-growing plants. When trees do become established, their growth and development are minimized by interference from the low-growing plant community (Bramble and Byrnes 1983; Hill et al. 1995; Bramble et al. 1996). Reduced and minimized tree populations lead to a reduction in management inputs. Herbicide use can be halved when this selective vegetation management approach is used, compared to other less-discriminate approaches such as broadcast spraying (Nowak and Abrahamson 1993; Finch and Shupe 1997). In addition to providing desirable corridor conditions for the transport of electricity and minimization of management costs, ROWs managed for complex, low-growing plant communities provide a wide variety of environmental values, benefits, and services, particularly associated with wildlife (Nowak 2002; Yahner 2004).

The idea of selective tree removal to manage powerline ROWs was first proposed 50 years ago (Egler 1953; Niering and Egler 1955; Niering 1958), with numerous, subsequent re-propositions (Niering and Goodwin 1974; Dreyer and Niering 1986; Niering et al. 1986; Bramble et al. 1990; Nowak and Abrahamson 1993). Over the past five decades, herbicides have been presented as both the optimum way of controlling the pest (the tall-growing trees) and a treatment that minimizes its own use in the long run, as explained above.

The selective vegetation management approach has been a part of New York State regulations since 1980 (Nowak and Abrahamson 1993; Jackson 1997; McLoughlin 2002). Other states and regions have also adopted this approach to vegetation management (Van Bossuyt 1987; Daar 1991; Bramble and Byrnes 1996; Wells et al. 2002).

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In the 1980s, the selective vegetation management approach was first compared to Integrated Pest Management (IPM), as it was clear that the selective control of tree pests followed the core precepts of IPM—"prevention" and "integrated control" (*sensu* Stern et al. 1959). Because it was not clear that all of the precepts and principles of IPM applied to vegetation management on powerline corridors, and, given that for many people it is difficult to view trees as "pests," the phrase "Integrated Vegetation Management" was coined (Jackson 1997; McLoughlin 2002). Efforts to apply IPM in other plant systems have resulted in similar phrases to describe vegetation management systems, such as "Integrated Weed Management" in agriculture (Swanton and Weise 1991) and "Integrated Forest Vegetation Management" in forestry (Wagner 1994).

Within IVM, various key elements of IPM systems have only recently been developed or recognized. Some examples include (after McLoughlin 1997, 2002) the following:

- managing a pest with integrated control measures, including prevention and an emphasis on biological control (liken to the use of low-growing plant communities to naturally control pest tree populations);
- a growing emphasis on monitoring and assessment (including refined efforts to document a pest problem);
- decisions based on tolerance levels;
- professional-grade prescriptions of treatments; and
- formalized efforts to determine long-term efficacy and effectiveness of treatments.

Our paper presents the next evolution in IVM along an IPM path: development of a full systems approach. We present a refined system for guiding the assessment and application of IVM on ROWs as an adaptation of an Integrated Pest Management model developed by Witter and Stoyenoff (1996) for insects in urban systems. In our system, IVM is viewed as a series of six steps that formalize the relationships among critical phases of vegetation management (Figure 1):

1. understanding pest and ecosystem dynamics;
2. setting management objectives and tolerance levels;
3. compiling treatment options;
4. accounting for economic and environmental effects of treatments;
5. site-specific implementation of treatments; and
6. adaptive management and monitoring.

These steps are not the same as those in Witter and Stoyenoff (1996); we have tailored them to better match application of IVM on ROWs.

We have found our IVM system to be useful in organizing research programs on pipeline, roadside, and electric transmission ROWs. Through interacting with various ROW vegetation managers over the past few years, we have

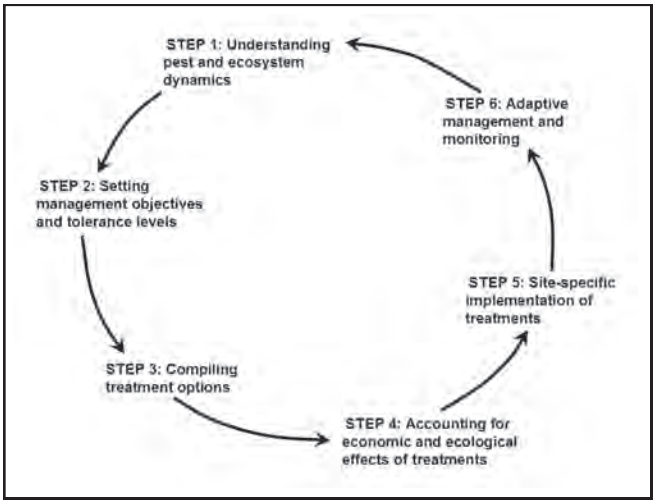

Figure 1. Component steps of Integrated Vegetation Management, a system for managing rights-of-way vegetation (adapted from Nowak and Ballard 2001, and Nowak 2002, from Witter and Stoyenoff 1996).

received favorable comments on the "utility" (no pun intended) of our IVM system framework for vegetation management operations. Recently, a variation of our system was used to describe wildlife considerations on ROWs (Nowak 2002).

Examples of system-level frameworks for vegetation management do exist. A stepwise framework similar to ours was described by IPM Associates (1996) as a model for vegetation management, as follows:

1. Gather background information and conduct weed inventories.
2. Set management objectives.
3. Establish monitoring programs to inventory weed growth stages, locations, and acreage infested.
4. Set treatment action levels and thresholds to determine whether treatment is necessary.
5. Use weed prevention measures and revegetation in management plans.
6. Apply effective, least-toxic management methods.
7. Educate the public.
8. Evaluate the program.

There is some similarity between our steps and those developed by IPM Associates (1996), but, given that most management systems involve patterns of information gathering, planning, implementing, reviewing, and improving vegetation management treatments, the similarity is not surprising.

Our system-level framework differs from other frameworks of IPM/IVM in two main ways:

- We present the system as a series of cyclical steps rather than a linear progression. A cyclic portrayal

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underscores integration of steps and emphasizes continual self-improvement.

- We focus on the elements and information that are to be integrated into the system with each step. This idea of "integration" is critical, yet it seems to be overlooked in most portrayals of IPM and IVM. Each of our steps provides information that needs to be integrated into the system. Failure to integrate any one element in a step could prevent the development of a fully functioning management system.

In this paper, we present a working framework for an IVM system using a cyclical series of six steps. Each step and its accompanying description are meant to promote broad considerations for ecological, environmental, economic, and social opportunities and constraints for vegetation management.

We outline general concepts and cite key references for each step. Specific methods for each step should be developed by the reader through further study and practice. Also, the reader should recognize that the steps are a simplification of what is an extremely complex system. It is, after all, this complexity that requires professionals to conduct IVM.

Because the electric utility industry has led the development of IVM and is rich with documented effort in all steps, we provide references that are mostly related to vegetation management on electric transmission line ROWs. More general references are provided when ROW experience is lacking. While we focus the paper on the electric utility industry, it must be recognized that this systematic approach of IVM is applicable to all systems, including ROWs, where plants are pests.

Our goal with this paper is to provide a useful framework to foster assessment and application of IVM. Organizations and people may then better assess their actions and understand how to more fully apply and communicate about IVM.

A STEPWISE SYSTEM TO INTEGRATED VEGETATION MANAGEMENT ON ELECTRIC TRANSMISSION LINE RIGHTS-OF-WAY

Step 1: Understanding Pest and Ecosystem Dynamics

A first step to conducting IVM is to develop a working knowledge of the organisms in the managed system and how they interact with each other and the environment, with or without vegetation management, to produce ecosystem conditions. ROW vegetation management necessarily puts a focus on controlling vegetation conditions, but all organisms affected by management should be considered. Basic knowledge of plants and animals is critical, starting with species identification through to understanding life histories (reproduction, growth, and longevity), plant strategies, and responses to disturbance (Wagner and Zasada 1991).

In plant-dominated systems, changes in distribution and abundance of plants through time and space (referred to as plant succession for communities) must be understood (Niering 1958; Bramble 1980; Niering 1987; Luken 1990). Plants and plant communities are manipulated to control the rate and direction of plant succession via control of various mechanisms, such as interference and herbivory. Vegetation management affects these and other mechanisms by changing plant community composition and structure through type, timing, intensity, and scale of disturbance, which affect interference patterns and wildlife habitat. Models that describe these interactions and outcomes (e.g., see Bramble et al. 1991) are useful in portraying vegetation dynamics with different types of management, and in planning and communicating with stakeholders.

Step 2: Setting Management Objectives and Tolerance Levels

Step 2 is where people first fully enter the cycle of IVM. Although IVM is challenging and potentially complex, managers must articulate objectives and tolerance levels of a multitude of stakeholders, as well as ecological and engineering constraints. Transmission of electricity exacts very specific requirements so that safety and reliability of service is maintained—no tall-growing trees under or near the conductors. The type of vegetation or other land uses that can occur may vary considerably from one location to the next. People, or, more specifically, stakeholders, can participate in deciding what type of ROW condition is satisfactory to them.

Stakeholders include vegetation management professionals responsible for management decisions on a particular ROW, landowners of the ROW or adjacent properties, governmental regulators responsible for administering state and federal policies and laws, and nongovernmental organizations with a general concern for the environment. In addition to viewing powerline corridors for the transport of electricity, stakeholders value these types of ROWs for wildlife habitat, recreation opportunities, and conservation (Niering 1958; Glaholt et al. 1995; Hay and Mohrman 1995). All stakeholders need to be engaged in the process of developing management objectives, framing the issues, and providing perspectives and opinions (Buchanan 1995; Clark et al. 1995; Johnstone 1995; Shupe et al. 1997).

Stakeholders are often concerned with risks to human health and well-being associated with treatment of ROW vegetation, particularly with herbicides (Wagner 1994; Norris et al. 2002). ROW vegetation managers must learn to recognize and acknowledge needs of other interested parties and adjust management to accommodate where possible. However, it is rare that all parties can be satisfied in

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a specific situation. Ultimately, the decision on how to compromise, or not, and best manage any one section of a ROW lies in the hands of the professional vegetation manager.

An important aspect of communication with stakeholders revolves around the concept of "tolerance levels" (see Stern et al. 1959). Tolerance levels are specific descriptions of vegetation condition—individual plant and plant community size, abundance, and composition—that, if exceeded, trigger a need to intervene. Inventory and monitoring are a part of IVM (see Steps 5 and 6). Pests are not treated unless they exceed the critical threshold. Well-defined thresholds are an important element of IVM (McLoughlin 1997, 2002) that can be useful in communicating management needs to various stakeholders; for example, thresholds and tolerance levels can be used to demonstrate the cyclic nature of vegetation dynamics, which supports a need to control vegetation on a regular basis.

Step 3: Compiling Treatment Options

Singular use of any one treatment method across all sites and conditions is not an IVM approach. ROW vegetation managers can conduct IVM only if multiple treatment options are available for application to any one site and in any one setting. Different treatment options may be needed to match variable environmental and site conditions on a ROW (see Step 5) or to address other stakeholder concerns and interests (see Step 2).

Vegetation treatments can be grouped into categories, such as mechanical, chemical, cultural, physical, biological, and ecological (McLoughlin 1997, 2002). It is most common to use two or more of these categories of treatment on any one site at any one time (e.g., the cut-stump method of killing trees combines mechanical and chemical treatments and leads to the biological/ecological control associated with removing individual trees on ROWs, as explained at the beginning of this paper). IVM does focus on integrating biological/ecological control into all treatment schemes. Such control prevents the buildup of pest populations, which is a critical element of the integrated control concept (Stern et al. 1959) and IPM (McLoughlin 1997, 2002). A primary objective of vegetation management in an IVM system on powerline corridors should be to create stable, low-growing plant communities, which leads to a reduction in pest (tree) populations (Niering and Goodwin 1974). This biological/ecological control produces a long-term reduction in treatment efforts and a reduction in herbicide use (Nowak and Abrahamson 1993; Finch and Shupe 1997).

Step 4: Accounting for Economic and Environmental Effects of Treatments

Choice of treatment must be made with an understanding of potential socioeconomic and environmental impacts. Approaches to this can be unique to each person and company. A useful metric is cost effectiveness (see Nowak et al. [1992] and Abrahamson et al. [1995] for details on use and application, based on research and development studies). Cost effectiveness is a measure of the success of a treatment in terms of economics, plant community dynamics, and related environmental considerations. It can be defined by its two component parts: cost and effectiveness. Cost for ROW vegetation management can be viewed as including direct costs and indirect costs. Direct costs pertain to the actual outlay of money made to treat ROW vegetation. Labor, equipment, and materials are commonly reported as direct costs. Indirect costs are the loss or nonproduction of values or service that can result from a treatment. These are often associated with water quality, wildlife habitat, and aesthetics, or other ways that the environment can be degraded. They are sometimes referred to as "environmental externalities," though environmental externalities can be either positive or negative, depending on whether they are a benefit or a cost. Other indirect costs are associated with risk of treatment to human health, and related pollution of soil, air, and sound (noise). Actual dollar amounts are difficult to ascribe to indirect costs.

Effectiveness pertains to production of desired vegetation conditions and associated benefits and values, including safe and reliable transmission of electricity, promotion of diverse plant and animal communities, protection of riparian areas and water quality, creation of visual attributes fashioned to minimize negative impacts to aesthetic appeal or quality, and enhancement of opportunities for recreational endeavors.

Time frames for consideration of cost effectiveness can be short- or long-term. Because vegetation management and the IVM process is a long-term affair, efforts must be made to balance short-term savings with long-term costs. For example, it may be less costly, monetarily, to mow a ROW today than use herbicides. Mowing may produce higher costs over the long-term because of short-term control of vegetation conditions and shorter treatment cycles than can be achieved with other treatments (e.g., see Johnstone 1990; Nowak et al. 1995).

Vegetation managers need to select the most cost-effective treatment for each ROW management scenario. Because no two situations are alike, different treatments are often needed to maximize cost effectiveness (see Step 5). In general, we expect that treatments will lead to a reduction in the pest organism (trees) and will minimize (prevent) further development of a problem, which will lead to a reduction in management inputs and a reduction in both direct and indirect costs. IVM equates to using treatments that are least costly in terms of dollars, produce minimal risks for human health and the environment, and create the desired vegetation conditions and associated positive values or externalities associated with these conditions over the long-term.

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Said differently, IVM is used to maximize cost effectiveness of management efforts.

Step 5: Site-Specific Implementation of Treatments

A key element of IVM is the use of prescriptions to describe and document decisions on treatment methods for different circumstances of vegetation management. Prescriptions include a presentation of desired future conditions of the ROW area to be treated, description of the treatment as a function of current vegetation conditions, and justification of treatments as a function of ecological, socioeconomic, and administrative considerations (Florence 1977; Beaufait et al. 1984; Province of British Columbia 2000). Treatment recommendations are the crucial part of the prescription. After developing a suite of treatment options (Steps 2, 3, and 4) and weighing the effects of those treatments on long-term production of vegetation conditions and associated benefits and values, a treatment is chosen by the professional vegetation manager.

Blanket prescriptions should not be written for whole ROWs but instead developed for specific sections of any one ROW. There are many examples of site-specific treatment needs in ROW vegetation management. Water resources (e.g., streams and wetlands) are protected by the use of edge buffers where specific treatments may be applicable. Buffer widths may vary as a function of the type of treatment (Environmental Consultants 1991). Site-specific management may also occur across and along ROWs via a two-zone concept. In the "wire zone/border zone" two-zone approach, the edges or border zone of the ROW are treated differently than the center or wire zone of the ROW (Niering 1958; Bramble et al. 1985; Ballard et al. 2004). Vegetation along the centerline can be kept in herbaceous plant and short shrub communities to allow ready access to transmission facilities, whereas the edges of the ROWs are kept in taller shrubs and short trees. Both conditions are produced using different vegetation management treatments and have been shown to produce diverse elements of wildlife habitat (Bramble et al. 1985, 1992, 1997; Yahner et al. 2001).

It is critical to have well-educated and trained professionals making these decisions, because of the complexity in doing so in the context of IVM (Abrahamson et al. 1995). It is important to base treatment choices on inventory and analysis of existing site and vegetation conditions (Dykes 1980; Alkiewicz et al. 2002), particularly because these data will be critical in monitoring outcomes of treatments (see Step 6).

Step 6: Adaptive Management and Monitoring

Adaptive management is formalization of the process of learning from experience (Baskerville 1985). Effects of treatments are monitored over successive cycles. Amount of materials used in treatment, treatment costs, and vegetation conditions before and after treatment are quantified. System performance (reliability) is documented. A wide variety of system elements can be monitored, such as tree populations (Johnstone 1990; Nowak et al. 1995; Finch and Shupe 1997), herbicide use in conjunction with plant community changes with management over time (Finch and Shupe 1997), herbicide residuals with chemical treatments (Norris 1997), water quality (Peterson 1993; Garant et al. 1997), and wildlife populations (Doucet and Brown 1997; Doucet and Garant 1997; Ricard and Doucet 1999). Data collection and record keeping that produce credible, factual information is a requirement of effective monitoring, as is skilled analysis of the data (Norris 1997). Vegetation conditions are compared to the desired condition set during the "management objectives and tolerance levels" step (Step 2) and described in prescriptions during the "site-specific implementation of treatments" step (Step 5). Any disparities between "desired" and "achieved" results are investigated, and future treatment options are adjusted accordingly. Monitoring in an IVM program assures stakeholders that treatment effects are gauged and shortfalls are corrected by improving management schemes to better accomplish management objectives.

SUMMARY AND CONCLUDING REMARKS

IVM is a complex of basic and applied knowledge, coupled with high-intensity management effort. It is used to understand, justify, choose among, selectively apply, and monitor different types of treatments, with an overall goal of eliciting site-specific, ecosystem-sensitive, economically sensible, and socially responsible treatment effects that lead to refined achievement of management objectives.

IVM is described in this paper as a system based on a continuous cycle of information gathering, planning, implementing, reviewing, and improving vegetation management treatments and the related actions that a utility or other management organization could undertake to meet its business and environmental needs. Systematic steps of IVM can be used to frame efforts by utilities to manage vegetation based on science but also with artistry that comes from experience and a sense of the management situation from site-specific inventories and awareness of socioeconomic constraints and opportunities.

IVM differs from past management approaches to managing vegetation on ROWs in its greater breadth and complexity of management considerations and in its higher level of sophistication and effort in evaluating management choices. In this paper, we portray how the basic steps of IVM relate to each other. Applying all IVM steps is the only way to derive full system benefits. Critical information (categorized below in italics) is being produced at each step:

Step 1: *Basic knowledge*—rudimentary ecological understanding of the biotic (plants and animals) and abiotic components of the managed system, with an aim to under-

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standing why and how individuals and ecosystems function certain ways and variably respond to disturbance (e.g., management);

Step 2: *Stakeholder perspectives*—input from affected people with regard to objectives for, and objections to, management;

Step 3: *A "toolbox" full of treatments*—development of a cadre of methods to produce desired plant or plant system effects;

Step 4: *Applied knowledge*—an accounting of all direct and indirect costs and benefits, usually via measures of cost effectiveness and applied research that serves to address how treatments affect ROW ecosystems and socioeconomics;

Step 5: *Prescriptions*—expectations of treatment needs and responses on a site- and pest-specific basis; and

Step 6: *Experience*—monitoring treatment effects as a basis for adaptation and improvement.

Elements of information acquired from each step can be used to support subsequent steps (see Figure 1), or information from any one step can be integrated into other steps (Figure 2). The steps are not necessarily used in sequence. Many steps can occur simultaneously.

IVM focuses on continual improvement. It is the sense of improvement that draws the circle of steps to close in the form of a self-improving cycle (Figures 1 and 2). With new knowledge gained from completing an IVM cycle, the process is begun anew with heightened understanding of the ROW system and awareness of the opportunities and potential shortfalls of management. Each cycle of management builds on the previous cycle to build a rising, expanding spiral of accomplishment and professional development (Figure 3).

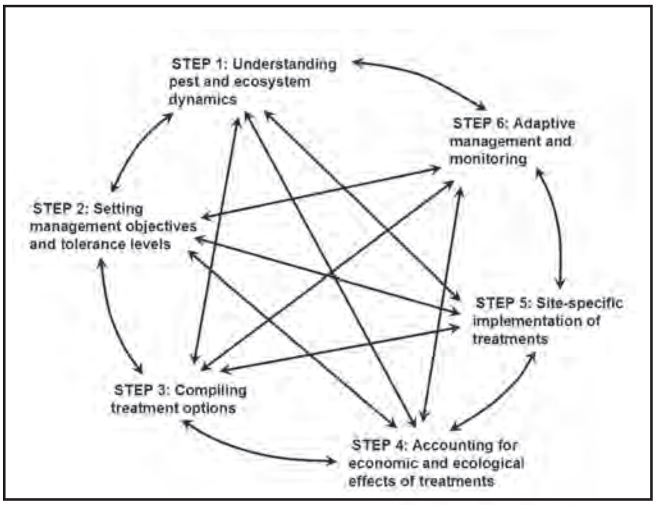

Figure 2. Component steps of Integrated Vegetation Management showing the cross-linkages among steps.

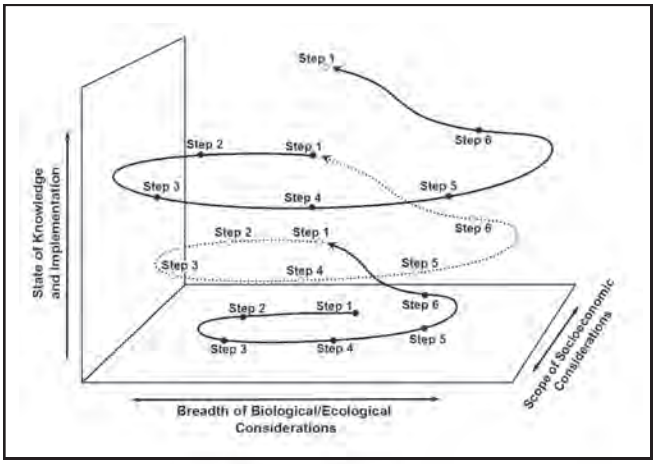

Figure 3. Three complete iterations of the six-step Integrated Vegetation Management system demonstrating the self-improving nature of IVM. Each complete iteration expands the scope of the management considerations, elevates the level of knowledge, and increases success of implementation.

To conduct IVM according to our six step system, managers must fully consider the following questions (these numbers correspond to the step numbers associated with our IVM system):

1. Do you have a detailed, basic knowledge of the managed ecosystem?

2a. Do you actively and broadly involve stakeholders in vegetation management decisions?

2b. Do you consider tolerance levels when determining the need to treat vegetation (positive approach), or do you take a rote approach and treat vegetation only routinely (negative approach)?

2c. Are you proactive in vegetation management (e.g., treat vegetation in concert with tolerance levels, with decisions based on inventory and planning) or reactive (e.g., "hot spotting," where vegetation is treated after thresholds are soon to be, or already, exceeded)?

3a. Do you maintain a broad range of vegetation treatments—mechanical, chemical, cultural, and biological—in your "toolbox" and apply a variety of treatments depending on the site and vegetation conditions?

3b. Do you foster the use of biological/ecological controls to prevent pest populations from building beyond economic thresholds?

4. Do you use broad considerations of cost effectiveness in selecting a treatment for a specific site?

5. Do you prescribe treatments in a site-specific manner, based on a contemporary inventory of ROW resources?

6. Do you monitor the results of treatments to compare actual conditions to desired future conditions, and look to improve the system based on that comparison?

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Answers to these questions are the crux to a systems approach to IVM and to the application of IVM itself. However, it is important to recognize that these steps do not represent the only way of going about the ROW management business. There may be other steps appropriate for any one organization, and how the steps are woven together in the larger ROW management plan may differ among organizations. We do feel that all IVM programs should include our steps, and we challenge practitioners to recognize that it is only with the integration of information from all steps that IVM can be claimed as a management approach.

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Résumé. La gestion intégrée de la végétation est une terminologie qui est utilisée par plusieurs organisations qui ont à gérer des emprises de lignes électriques à travers l'ensemble des États-Unis. Dans plusieurs cas, cette expression (gestion intégrée de la végétation) est juste un nom appliqué en regard de vieilles approches de gestion. Cependant, la gestion intégrée de la végétation est plus qu'un simple nom. C'est un système poussé et sophistiqué de collecte d'informations, de planification, d'implantation, de révision et d'amélioration des traitements liés à la gestion de la végétation. Cette expression est utilisée pour comprendre, justifier, sélectionner, appliquer sélectivement et suivre différents types de traitement, et ce avec l'objectif global que les effets des traitements tiennent compte des caractéristiques spécifiques des sites et des écosystèmes sensibles tout en tenant compte de variables économiques et en étant socialement responsables afin de pouvoir améliorer les objectifs de gestion. À cet effet, on propose un système en six étapes de gestion intégrée de la végétation afin de donner un cadre d'activités pour aider les gestionnaires et autres intervenants à communiquer, organiser et mener les activités liées à l'entreprise de la gestion intégrée de la végétation. Chaque étape permet de produire des informations qui doivent être intégrées à l'intérieur du système de gestion. Ce système en six étapes est semblable à ceux de gestion intégrée des insectes et des maladies et autres systèmes de gestion similaire développés en agriculture et en foresterie. Nous y présentons un système intégré de gestion de la végétation avec certaines perspectives et idées originales tirées de la littérature auquel nous y incorporons de l'information et des expériences tirés de l'industrie du transport de l'électricité.

Zusammenfassung. Das Integrierte Vegetationsmanagement oder IVM wird inhaltlich von vielen Organisationen mit dem Pflegeauftrag für Überlandleitungen in den Vereinigten Staaten verwendet. In vielen Fällen ist IVM nur ein neuer Name für bereits verwendete Managementmethoden. Dennoch ist IVM mehr als ein Name. Es ist ein detailliertes und umfangreiches System zur Sammlung von Informationen, Planung, Rückschau und Verbesserung der Pflegemaßnahmen. IVM wird verwendet, um zu verstehen, anzupassen, zu wählen, selektiv anzuwenden und verschiedene Behandlungstypen zu überwachen, alles mit einem übergeordneten Ziel, standortspezifische, ökologisch und ökonomisch sensible und sozialverträgliche Behandlungen herauszubekommen, die dazuführen können, die Managementziele zu verbessern. Wir schlagen ein 6-Schritte-System vor, welches als Rahmenwerk Managern und anderen Verantwortlichen dienen kann, miteinander zu kommunizieren, organisieren und IVM-Projekte zu steuern. Jeder Schritt produziert Informationen, die in das ganze System integriert werden. Unser 6-Schritt-System ist ausgestattet mit Integriertem Pflanzenschutz und anderen IVM-ähnlichen Systemen, die für Land- und Forstwirtschaft entwickelt wurden. Wir stellen ein IVM-System vor mit einigen besonderen Perspektiven und Ideen aus der Literatur und fügen Informationen aus und Erfahrungen mit der Elektroindustrie ein.

Resumen. El Manejo Integrado de la Vegetación, o IVM, es utilizado principalmente por muchas organizaciones de manejo de derecho de vía a través de los Estados Unidos. En muchos casos, IVM es solo un nombre aplicado a las tradicionales aproximaciones de manejo. Aún así, IVM es más que un nombre. Es un profundo y sofisticado sistema de información para obtención, planeación, implementación, revisión y mejoramiento de los tratamientos de manejo de vegetación. IVM es usado para entender, justificar, escoger, aplicar selectivamente y monitorear diferentes tipos de tratamientos, con el objetivo de extraer los efectos de estos tratamientos de una manera social, económica y ecológicamente responsable y de esta forma refinar los objetivos del manejo. Se propuso un sistema de seis pasos a IVM que pueda actuar como una estructura de actividades para ayudar a los manejadores en la organización y conducción de sus negocios en IVM. Cada paso produce información que puede ser integrada en el sistema de manejo. Nuestro sistema de seis pasos es consistente con el Manejo Integrado de Plagas y otros sistemas parecidos a IVM desarrollados en forestería y agricultura. Presentamos un sistema IVM con algunas perspectivas e ideas de la literatura, e información incorporada de la experiencia propia en la industria de servicios eléctricos.

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