ELECTRIC POWER RESEARCH INSTITUTE

Best Management Practices for Vegetation Management at Electric Utility Facilities

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NOTE

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ABSTRACT

Controlling vegetation inside key electric utility facilities is a necessary maintenance activity for a utility's safe and reliable operation. Substations, switchyards, and other facilities require perpetual maintenance to maintain a vegetation-free environment. At a minimum, vegetation-maintenance treatment needs to be conducted annually; in some climatic regions, multiple treatments may be required. The objective of this research paper was to define current industry practices by means of a literature review; seek out nonherbicidal methods to control vegetation within utility facilities; and use Integrated Pest Management (IPM) principles to develop an outline of best-management practices for total vegetation control. Through this study, EPRI is seeking to provide information about methods to achieve sustainability in the total control of vegetation in and around utility facilities—especially substations. Alternative methods to the annual application of herbicides are explored, and the viability of these methods for the cost-effective control of vegetation is assessed. The study found that the vast majority of North American utilities use herbicides as the predominant method for total vegetation control at substations and other utility sites. Europe is leading the way in identifying alternatives to herbicide use for total vegetation control. Worldwide, utilities are seeking and experimenting with environmentally responsible and cost-effective alternatives to herbicides. One of the most notable recent changes is the adoption of IPM principles for total vegetation control at utility facilities. Consideration is being given to off-site damage caused by herbicide drift, runoff, and groundwater contamination.

Keywords

Alternative weed-control methods
Best-management practices (BMPs)
Herbicide
Integrated Pest Management (IPM)
Integrated Vegetation Management (IVM)
Substations

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INTRODUCTION AND LITERATURE REVIEW

Introduction

Controlling vegetation inside key electric utility facilities (substation, switch yards, switch points, equipment and wood pole storage sites, fuel storage areas, communication sites, etc.) is a necessary maintenance activity for their safe and reliable operation. These facilities, containing ground surfaces often covered by rock or stone, require perpetual maintenance to maintain a vegetation-free condition. Vegetation maintenance is, at a minimum, an annual activity and in some climatic regions multiple treatments may be required. The goal is to achieve a vegetation-free or bare-ground condition for as long as practical within financial and environmental constraints.

Maintaining a vegetation-free area is important for the electric utilities for the following reasons:

- Reduces the potential for fire inside the station or facility due to collection of organic debris.
- Eliminates habitat for rodents, snakes, etc. as well as predators that would use these as a food source, thus, reducing the potential for animals getting into buss work, crossing phases and causing equipment faults.
- Improves worker safety by reducing habitat for venomous snakes as well as providing clear line of site to avoid tripping and slipping hazards.
- Aids in equipment cooling by allowing air circulation thereby preventing heat build-up due to vegetation in close proximity to the equipment.
- Provides ventilation around equipment to reduce equipment corrosion due to moisture build-up or high humidity near the equipment.
- Provides clear line of site for equipment inspection and maintenance.
- Eliminates the potential for vegetation to cause a power outage by interfering with electrical equipment.
- Prevents vegetation from covering or hiding fences, reducing the risk of unauthorized entry and theft.

In addition, the surface of clean, crushed rock provides an insulating layer between the grounding grid and the surface. Crushed rock has many features that contribute to electrical and engineering safety. In particular, it has a high level of electrical resistivity i.e. it does not conduct electricity, thereby reducing the risk of electrocution over the ground grid. If weeds and organic debris become established in the crushed rock, its function as an insulating layer is reduced. Weeds in the crushed rock interfere with the ground grid, seriously compromising the safety functions of the grid and posing an electrical hazard to workers.

In addition to previously listed concerns, many municipalities have weed ordinances that require the control of noxious weeds as well as specific height requirements at which the vegetation must be maintained.

Maintaining a weed-free environment is often limited to one growing season and relies primarily on herbicide applications. This project will identify control alternatives for a vegetation free environment in critical utility facilities. A literature search and a selective industry review were used to determine current herbicide and non-herbicide practices for maintaining a vegetation-free zone inside critical utility facilities (electric and gas industry, fuel storage facilities and other industrial sites). The project report will provide guidance for vegetation management where bare ground conditions are required.

Herbicides have proven to be the most cost effective means of controlling unwanted vegetation in and around utility equipment. Herbicides are still the predominant method of controlling unwanted vegetation in North America. To better understand the types of herbicides and how and when they are used, residual and non-residual herbicides are defined to provide a better understanding of various treatment options.

Residual herbicides

Residual herbicides (i.e. pre-emergent or soil applied herbicides) remain active in the soil for an extended period of time (months). They are applied to bare soil or crushed rock surfaces to prevent germination of seeds. These herbicides depend on light rainfall to carry them into the soil and root zone. Residual herbicides, depending on the soil type, may pose a risk of running off site or entering the ground water. Residual herbicides are generally limited to one application per site per year.

Non-residual herbicides

Non-residual herbicides (i.e. foliar or contact herbicides) have little or no soil activity and are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They are active only on growing plant tissue, and kill vegetation either through leaf/stem contact (desiccation) or by translocation through the plant's vascular system to the roots and growing points. The action of these herbicides can be very fast, within a few days to a week. They are of limited effectiveness in preventing reestablishment from seed or invasion by plants from outside the treated area. The use of a species-specific herbicide product may be needed for difficult to control species such as knapweed or horsetail. Non-residual herbicides may require multiple applications within the same growing season, depending on the geographic location of the treatment site and weed species present.

Literature Review

ECI conducted a literature search, using peer-reviewed published research and technical articles from current trade publications. Topical articles related to bare ground vegetation management practices in strategic locations such as substations, switch yards, fuel storage areas, gas valve locations, and other critical utility infrastructures. The literature search included non-herbicide methods/techniques being currently utilized to maintain a vegetation-free environment around critical utility infrastructures. The literature search includes: practices for utility bare ground vegetation management; methods and materials and alternatives for reducing the need for herbicides in vegetation management, and pre-construction considerations.

Successful control of vegetation starts by establishing a long-range management plan that considers the economics, effectiveness, environmental issues, and public relations. In addition, potential control methods need to be identified with minimal risk to workers, non-target organisms, and natural resources. Brennan, et al. [13] in their published article provides fundamental information on the use of herbicide and other methods to control weeds.

Herbicides have been a key method for controlling vegetation within electric utility facilities; however, as policies change and vegetation management techniques continue to advance, alternative techniques are being implemented. Culture, economics, and politics have a large influence on what is considered acceptable techniques for weed management [65]. One of the major reasons for the increased push for alternative methods to control unwanted vegetation is the publics' concern for the environment. Another concern is the potential negative side-effects observed in research from herbicide residues. Herbicide residues are being found on a regular basis in storm, ground, and stream water resulting in increased exposure to humans and the natural environment [19].

Policies and regulations are being implemented in seven European countries to limit the use of pesticides and require other control methods to be used when practical. The reason for such policy change is that research has shown that herbicides are being transported offsite from rain water when applied to hard surfaces before sufficient time has occurred for the herbicide to decompose. The amount of pesticides reaching the streams from non-agricultural uses is a factor of ten times higher than from agricultural use. Examining the regulations for herbicide in other countries and how public opinion and research has influenced those regulations can help utilities understand what to expect in the future [45].

The literature review summary is separated into six categories. The categories are: herbicide and chemical techniques, non-chemical (heat and cold treatment) techniques, biological controls, surface materials, and environmental issues.

Herbicide and Chemical Techniques

Herbicide and chemical techniques have been used for the past century and continue to be used as a tool to control unwanted vegetation. Methods used to treat weeds with herbicides and the different types of herbicides used, continue to evolve along with the safety measure used to protect applicators and the environment. EPRI [34] published a survey to identify herbicide use, safety issues, controlling practices and procedures working with contractors. From the survey, more than 40 different herbicide mixes were reported as being used for ROW maintenance. EPRI reported that 60 percent of the utilities assessed had contractors without the necessary personal protective equipment. Proper management of weeds to effectively and efficiently reduce the risks requires knowledge of new management techniques including safety precautions.

When using herbicides the applicators should understand target species plant morphology, the chemical mechanism of the herbicide and the different factors that will influence the effectiveness of foliar herbicide application [13]. Successful utility vegetation management and the delivery of safe reliable electricity become more costly to achieve without the use of herbicides. Hance and Holly [30] provide a detailed overview of weed biology to help explain the factors to consider when applying herbicides. Their book was developed to be a reference for recent developments in weed science and technology up to 1990. In addition to understanding weed biology and the action mechanisms for different herbicides, vegetation management requires a knowledge of which weeds have a tendency to develop herbicide resistance. Beckie [10] provides an overview of different techniques for herbicide application to minimize the creation of resistant weeds.

Best management practices (BMPs) have been developed to reduce the development of herbicide resistant weeds. Those BMPs include understanding weed biology; identification of weeds that are susceptible to herbicide resistance; the use a diversified approach to minimize weed seed production and reducing the amount in the seed bank; and implement multiple herbicides with different mechanisms of action (MOA), the use of non-herbicide methods, etc. [54]. Herbicide sequence, rotation and mixture are methods to help reduce the development or delay weed resistance. Herbicides are developed to target a specific site of action (i.e. contact or systemic). Combining herbicides with different mechanisms of action to kill weeds can increase effectiveness. Researching weeds and their propensity to develop resistance to specific herbicides will allow for better management [10].

As research and development continue to improve methods of weed prevention and alternative weed control techniques, herbicide use will decrease [40]. Research performed in Sweden measured the viability of acetic acid as a natural chemical to be used for weed control. A reduction of 90 percent in the number of weed plants was achieved on one site by the application of 12 percent acetic acid concentration at a rate of 0.21L m-2. While these products can be used as a substitute for herbicides, they have little to no direct effect for pre-emergent application. Therefore a site may require additional treatments to address seeds that have not germinated at the time the product was applied [33].

The article summarizes different alternative techniques for weed control. The authors mention the use of ASOLFIL to prevent the establishment of weeds. ASOLFIL is a liquid that can be sprayed on the soil that hardens to form a weed suppressive layer. Another concept called Minimum Lethal Herbicide Dose, developed by the Dutch, is the technique of using photosynthesis inhibiting herbicides for weed control. The technique uses portable sensing equipment to determine the minimum dosage required to kill the weeds [40].

Non-Chemical

The push to decrease herbicide use has increased over the past few decades and as a result, public authorities in various countries have become proactive in minimizing herbicide application and transition to non-chemical weed control [31, 32]. Thermal weed control methods can be separated into either direct heating or indirect heating [5]. Direct heating methods would include flaming, infrared, hot water and steaming. Indirect heating methods included electrocution, microwave, laser radiation, and UV-light [57]. Thermal weed control methods may be viable for utilities when herbicides cannot be used in substations or other facilities, even though the majority of research has been conducted on agriculture fields to test effectiveness. The different thermal weed control methods include prescribed burns, flame weeding, infrared radiation, hot water, steam, electrical energy, microwave radiation, ultraviolet radiation, lasers, and freezing. Electric energy, microwave radiation, UV, and lasers are fairly new methods for control weeds and additional research is being performed to further develop these methods and to determine method validity.

While the methods listed are alternatives to herbicide techniques and address the concern to reduce herbicide residues, these methods consume larger amounts of energy to achieve the same level of effectiveness with herbicides [5]. The use of non-chemical methods to control weeds will result in a large increase in cost and may require site prioritization or specific treatment regimens to address economic constraints [31]. Cost can be reduced when using non-chemical thermal weed control during earlier stages of plant development. When treatment was applied early during the growing season, propane could be applied at a rate of 20 to 30 kg ha-1 to achieve up to 90 percent reduction in plant numbers. When treatments were applied later in the growing season, the amount of propane increased 500 percent to achieve the same reduction in the number of plants [4]. Success of different thermal treatments is dependent upon the species and the efficiency of various treatment periods. Hoyle [35] observed increased efficiency in thermal treatment when the application occurred in the fall versus summer application.

While the data shows that treating weeds shortly after emergence requires a smaller dose, that data does not provide the amount needed on a per plant scale for spot applications. A limited number of smaller scale studies (non-agriculture sites) have been performed such as the one published by Burnham et al. [14]. The authors conducted a study in Alaska along railroad rights-of-way with heated water treatments to target weeds. The research revealed that a moist surface absorbs the heat better, allowing the heat to be transmitted to the vegetation more efficiently. Even after treatment, the plant surface continues to be affected by heated water on the plant surface. In addition, the research revealed that thermal weed control had a higher success of surface seed mortality as the metric volume of water content increased in the soil [36].

Biological

Interest in the application and study of biological control of weeds has also increased as a result of economic, social, and environmental forces pushing for more alternative methods [17]. Biological control of weeds can be separated into either classical methods or inundative (bio-herbicides) methods [12]. The classical method consists of using natural enemies from a plants place of origin for control. The inundative method is the use of microorganisms that are natural plant pathogens that can be applied to the target weed in high doses and not persist longer than a single growing season.

Research and development of bio-herbicides has increased as the number of resistant weed species continue to increase. Bio-herbicides will eventually become a tool used to enhance integrated pest management. One of the benefits of using naturally occurring microorganism is that weeds can be suppressed over the entire spectrum of growth stages [39].

Surface Materials

The previous categories were focused on direct treatments that can be used to achieve desired levels of weed control. Different industries are beginning to include indirect weed control techniques by altering surface material to further hinder vegetation development by removing access to a substrate acceptable for germination. One published article provides a review of three different physical barriers used for preventing the establishment of weeds. The barriers listed were ForeverMulch (shredded tires used as mulch), Weed-Ender (a non-woven material made of synthetic fibers), and PolyPavement (a liquid soil solidifier) [55].

BC Hydro developed a pest management plan for secured facility grounds that describes the different processes to keep the area weed-free. In the plan developed by BC Hydro, the use of geotextile under crushed asphalt and concrete is discussed as an alternative ground cover to further reduce susceptibility of weed intrusion. Asphalt and concrete should be used with caution because these materials conduct electricity and can spread oil further than spills over crushed rock. Asphalt and concrete can be used for access roads or for storage areas within facilities. Geotextiles are porous materials that can be laid under crushed rock in areas with little to no traffic to limit damage from puncturing or tearing [38]. Grass seeding was also discussed in a separate publication as a method to reduce the establishment of broadleaf weeds [1].

An alternative to surface materials in new substation designs are being used in Sweden to increase reliability in rural areas. The compact design allows for the substation to be built inside of an enclosed build leading to a greatly reduced level of vegetation maintenance. A 15-year maintenance interval is required for the secondary substations with fully insulated switch gear. This is a much longer maintenance cycle when compared to the unprotected insulation design of many older substations [46].

Environmental

Over the past several decades the concern for the environment has steadily increased, which has influenced the type of laws being enforced, research objectives being studied, public opinion, etc. The concern for the environment includes the long term side effect of herbicide use on the ecosystem and the contamination of public drinking water. Countries are beginning to implement programs to decrease herbicide use and incorporate alternative weed control techniques [25]. Even though non-residual herbicides begin to decompose the moment they are applied to plants and soil, there are many factors that influence the rate of decomposition (i.e., temperature, soil moisture content, soil microbial activity, general weather conditions, etc.) [28, 44]. Herbicide decomposition on hard surfaces is slower than when it is applied directly to soils (i.e., urban vs. agricultural environments). As a result of slower decomposition, the amount of herbicides being transported off site by surface water is tenfold high than the amount of herbicides being transported from agricultural fields.

Even though research has shown that using herbicides can result in long term side effects that range from off-site leaching into streams to herbicide resistant weeds, the large scale influences on the environment should be considered as well as for each of the alternative weed control techniques as well. DiTomaso [22] discusses the risk associated with mechanical, cultural, biological, and herbicide techniques used to control weeds. The amount of energy used by alternative methods (i.e. flaming weeding, thermal weed control, etc.) requires a substantial amount of gas or fuel source to achieve the same level of weed control as herbicides. While the alternative methods of weed control may be environmentally acceptable, carbon emissions should be considered when comparing the risk of herbicides to alternative control methods. Research in the Netherlands has shown that the cost of non-chemical weed control is 4.5 times higher than herbicide treatment [42]. However, the difference between cost estimates do not account for the external costs such as treating city water that has been contaminated with herbicides or the impact from carbon emissions. Kempenaar and Saft discuss the Environmental Life Cycle Assessment model to analyze the impact on the environment in a “cradle-to-grave” approach. Herbicide treatments resulted in the greatest environmental burden whereas flame weeding was the least in the methods analyzed. Kempenaar recommends not using herbicides where hard surfaces are within 10 km of a stream used for drinking water, specifically glyphosate and MCPA[1] (pure compound is a brown-colored powder). Another recommendation was to limit herbicide application when the weather conditions (i.e., probability of rain greater than 40 percent) could result in run off. The results of implementing these recommendations showed that the concentrations of glyphosate and MCPA (degradation product of glyphosate) in

[1] MCPA - 2-methyl-4-chlorophenoxyacetic acid is a powerful, selective, widely used phenoxy herbicide.

surface waters were much lower than the maximum permissible concentration level by tenfold [41].

Conclusion

Integration of alternative weed control techniques has become a requirement in some countries to decrease negative side effects that have been observed from the use of herbicides to control weeds. Research continues to improve methodologies used to implement alternative weed control techniques, which will result in a decreased reliance on herbicides and will ultimately add another factor in integrated pest management. Integrated pest management has begun to include analysis of environmental impacts on a much boarder scale when determining which technique to apply for controlling weeds along rights-of-way and in secured facilities. When determining the cost effectiveness of different weed control techniques the analysis should include considerations for administrative, social, economic, and environmental factors [20].

2
INDUSTRY SURVEY OF CURRENT VEGETATION CONTROL METHODS BEING UTILIZED

Utility Survey

In the second phase of the project, the ECI Project Team conducted a selective review of the industry at utilities throughout North America, including a utility in the Caribbean and South America. The industry review identified vegetation management principles considered for bare ground vegetation management such as:

- The predominant methods and techniques utilized to maintain vegetation-free substations.
- In addition to control with herbicides, alternative methods and practices utilized to maintain vegetation-free facilities.
- Special problems and concerns related to substation weed control including: environmental concerns, wetland issues, endangered plants/animals, public concern, etc.
- Engineering considerations that affect vegetation control in substations.

Utilities Participating in Survey

The following utilities participated in a phone survey and were gracious enough to share information about their substation bare-ground programs:

AEP
Alliant Energy
ComEd
FirstEnergy
Florida Power and Light
LIPA
PECO
PG&E
PEPCO
KCP&L
XcelEnergy
Progress Energy
Cemig (Brazil)
Jamaica Public Service (JPS-Caribbean)
BC Hydro

Utility Survey Overview

The predominant method for total vegetation control in substations utilized by the vast majority of utilities surveyed is pre-emergent herbicide treatment. The primary goal expressed by the majority of utilities is to select the best method and products that provide vegetation-free conditions for the longest possible time at the lowest cost. Regardless of control method selected, with rare exception, utilities contract this work to licensed herbicide applicators.

In addition to control with herbicides, alternative methods and practices utilized to maintain vegetation-free facilities

Virtually all the utilities surveyed were utilizing herbicide techniques to control vegetation in substation areas. A few utilities have experimented with non-herbicide treatment techniques in the past. These techniques included steam, fire and boiling water. These techniques proved ineffective in providing season-long vegetation free conditions and the cost were several times that of conventional herbicide treatments.

In one test site where steam was utilized, the vegetation present on the site at time of treatment was killed, but, shortly after treatment prolific regeneration was noted on the treated sites as compared to the control areas. The hypothesis on why this occurred centered on providing added moisture and heat to germinate the seeds in the gravel substrate. The steam produced enough heat to kill the existing plant; however, the heat produced by the steam was inadequate to kill the seeds in the gravel substrate. Due to the poor short- and long-term control, this technique of total vegetation control was not repeated.

PEPCO is one exception to utilities using herbicides as their main control method. PEPCO has several transmission substation sites covered in grasses. The grass is mowed six times per year as part of routine grounds maintenance at that these sites. These were formerly 69kV substations converted to 230kV substations in the late 1950's. The reason as to why these stations were left in grass and not converted to the more traditional crushed stone base is unknown and grass mowing at these sites is the historically accepted maintenance technique. The cost of periodic mowing on a per acre basis is significantly higher than the comparable per acre cost of herbicide application.

Special problems and concerns related to substation weed control include: environmental concerns, wetland issues, endangered plants/animals, public concern, etc.

Utilities do have exceptional circumstances where pre-emergent herbicide vegetation control may not be permitted. These situations are rarely encountered, but include the following circumstances: concern for herbicide runoff from the treated substation site, substations located in or near a wetland areas, endangered plans/animals near area to be treated, soils that readily transport herbicides into the ground water, local laws/regulations prohibiting the use of herbicides, state restrictions on approved herbicides for total vegetation control (due to concern for ground water contamination, i.e. Long Island in New York state).

When circumstances prevent the use of pre-emergent herbicides, herbicides for post-emergent vegetation treatments are selected. Products such as glyphosate are used multiple times during the growing season (as local growing conditions dictate) along with manual cutting and removal of vegetation and debris as necessary to reduce the potential for fire.

Engineering and maintenance considerations that affect vegetation control in substations

Currently, new substation construction takes into account the site when making selection decisions. This may not always be possible as open space for new substations may be limited to those sites undesirable for more conventional building projects. In the construction process, provisions are made to contain any oil leaks or spills within the substation site and prevent runoff or ground water contamination. Many times a non-pervious material is used on the graded site prior to the stone/gravel being applied to further ensure the containment of any leakage from substation equipment. These new sites constructed in this manner would also provide protection from herbicide runoff or ground water contamination.

The following are six engineering/construction techniques that can minimize or eliminate the need for herbicide treatments [1].

Crushed Rock

The most effective way to prevent the establishment of weeds is to maintain a layer of clean, crushed rock to engineered standards, around areas that have zero tolerance for weeds:

- The crushed rock must completely cover the site, since any areas of exposed soil will serve as sources for weed infestation.
- The rocks must be about 4 to 20mm in size, evenly graded, layered to a depth of 15cm, and fractured on at least two faces. Round rocks reduce drivability.
- The crushed rock must be free from sand, silt, clay, and organic matter.
- The crushed rock surfaces should extend 2 metres outside the facility fence line to maintain an even layer over the grounding grid, which extends 1.5m outside the fence line.

Crushed rock has many features that contribute to electrical and engineering safety. In particular, it has a high level of electrical resistivity, which means it does not conduct electricity, thereby reducing the risk of electrocution over the ground grid. Other functions and advantages of crushed rock include:

- impedes vegetation from establishing
- finished, aesthetically pleasing surface
- rapid drainage
- low cost and readily available
- non-flammable and helps to control oil fires in areas around oil-filled equipment
- reduces the spread of oil from a spill, unlike a paved surface where the oil would rapidly spread
- provides a suitable surface for the movement of equipment and vehicles
- controls dust

Over time, the resistivity and effectiveness of crushed rock surfaces will be reduced due to construction activity, traffic, and organic matter build-up that encourage the establishment of weeds. BC Hydro as well as some utility sites in the United Kingdom [56] have programs to assess sites for condition of the crushed rock and add new material when it is required. In addition, sites may be scheduled for spreader grader work, a process that cleans the existing crushed rock surface layer. This specialized spreader grader removes all organic matter, including plants, soil, seeds, leaves, and twigs via raking and vacuuming the site.

Crushed rock over geotextile

In areas where there is limited vehicle traffic and away from oil-filled transformers, the effectiveness of crushed rock for excluding weeds can be enhanced with a geotextile layer. Geotextile is porous sheeting that is laid underneath the crushed rock or staked to the soil surface in areas without crushed rock. Geotextile allows drainage but effectively prevents the growth of weeds. It works particularly well for annuals, but less so for longer-lived perennials, such as trees or shrubs. Together with crushed rock, geotextile is very effective at preventing the growth of weeds. Geotextile is not normally used in drivable areas because it may become damaged, or around oil-filled equipment, because it will cause the oil to spread during a spill. It is also not practical over larger tracts of land. This technique is being slowly implemented on newly constructed substation site in the United Kingdom [56].

Spreader grader

A spreader grader is a unique tractor-pulled device that tumbles crushed rock and other aggregates. It works by inverting the top layer of crushed rock (contaminated with organic matter) with the cleaner rock just underneath it, similar to how a soil tiller works. This effectively controls any vegetation or weeds that were established on the top layer and can result in improved control over the long-term. The spreader grader is effective on large to medium flat areas accessible by tractor. It has some limitations under some electrical equipment or in compact areas.

Asphalt and concrete

Asphalt and concrete can also be used within electrical facilities, but are not as favorable as crushed rock. The use of asphalt and concrete is generally limited to access roads and storage areas inside facilities, or for new facilities especially designed to use asphalt or concrete.

The benefits and limitations of asphalt and concrete include:

- Asphalt is highly weed-resistant and makes an excellent driving surface.
- It has high resistivity, only slightly less than crushed rock.
- Both concrete and asphalt cost more than crushed rock.
- They cannot be used around oil-filled equipment because they will cause oil to spread in the event of a spill.
- They provide no drainage.
- Underground work is difficult to carry out.
- Concrete conducts electricity more readily than crushed rock.
- Asphalt will burn at high temperatures.

Grass seeding

Grass seeding is the manual planting of turf or agricultural grasses or the seeding of large areas of bare soil with grass-seeding machines. This method is used to reduce the establishment of broadleaf weeds with rapidly spreading airborne seeds. It can be used on large undeveloped sites or disturbed areas within the facility, or around the fence line. Required equipment may include cyclone spreaders, belly grinders, seed drills, and hydro-seeding machines. New varieties of grass have been developed that have very slow and limited height growth. These grasses were developed for use on airport runways to minimize the need for mowing. Such grass may have application at some utility locations [43].

The benefits and limitations of grass-seeding are:

- It must be mowed regularly to remove the seed heads any broadleaf weeds growing in the turf to prevent the spread of broadleaf weeds. Low-maintenance, slow growing grasses and legumes are recommended.
- It provides good drainage and is fairly inexpensive to install.
- It prevents erosion.

- It promotes aesthetics.
- The seeded area may have to be irrigated to establish and maintain it.
- There may be safety concerns using equipment around electrical wires and equipment.
- In wetter climates, there are problems with drivability.
- Its ability to exclude weed species is inferior to that of most other methods, especially crushed rock or geotextile.

Non-Herbicide treatments - Manual and mechanical methods

Herbaceous plants, grasses, tree seedlings, and mosses or liverworts and woody weeds both inside and outside facilities are controlled using the following physical or mechanical methods:

- mowing
- weed trimming
- raking
- hand-pulling
- slashing (manual tree removal)

Weeds just outside the facility must be controlled to prevent them from spreading into the site and to protect the ground grid if it extends outside the fence line.

Mowing

Mowing can be used in undeveloped areas within facilities, especially if they are not covered in crushed rock. Areas around the site are mowed to reduce the spread of windborne seeds into the site. Commercial lawnmowers, garden tractors, or industrial tractors with rotary or flail cutters can be used.

Mowing has the following benefits and limitations:

- Mowing helps control weeds before they go to seed, thereby reducing spread into areas where there is low weed tolerance.
- Mowing promotes aesthetics.
- Mowing is economical, but requires repeated treatments.
- There are some safety risks due to flying debris.

Weed trimming

Weed trimming removes weeds using power tools such as weed trimmers. Trimming removes seed heads and is a useful method when immediate action is needed. It works best on annuals. It is not useful on species that propagate from stem pieces and it does not remove roots. As part of weed trimming, organic matter including dead weeds leaves, and branches that could degrade the crushed rock layer are raked up and removed from the facility to reduce the accumulation of organic matter.

The benefits and limitations of weed trimming include:

- It is convenient and economical.
- Flying rocks and debris propelled by the spinning thread or blade may damage windows and equipment.
- It can be a safety hazard to the operator and other staff.

Hand Pulling

Hand-pulling of weeds inside facilities is not a preferred method because it degrades the crushed rock surface. Excessive hand-pulling increases organic matter in the crushed rock, which encourages subsequent weed establishment. Hand-pulling is not viable as a control measure for many species, because roots are difficult to remove, and if left in the soil, the weed will regrow. Root extraction cultivates the soil, stimulating dormant seeds to germinate, and introduces mineral and organic soils to the stone/gravel surface.

There are also serious safety hazards connected with hand-pulling of weeds within electrical facilities. If roots are in contact with the ground grid, workers pulling weeds are at risk of electrocution.

However, hand-pulling is an important treatment option for areas within facilities where herbicides cannot or should not be used. Weeds will be hand pulled as soon as they are established at any time of the year. This method is only recommended for larger, established weeds that can be easily uprooted, such as tree seedlings. It is only effective if there are few weeds on the site (100 or less). Weed seedlings and grass species are too small and numerous to hand-remove.

The benefits of hand-pulling are:

- In certain areas, effective at reducing bulk vegetation to a manageable level, allowing use of other control methods to complete the work.
- Effective for larger, established weeds that can be easily uprooted.
- Effective if there are only a few weeds on the site (e.g., 100 or less).

The limitations of hand-pulling are:

- Roots regenerate because many species snap off at ground line.
- Degrades the crushed rock surface and increases organic matter.
- Exposes soil and seeds.
- Safety risks to weed-pullers where weeds are in contact with the ground grid.
- Extremely labor-intensive and very costly.

Manual Tree Removal

Trees may need to be removed if they are unhealthy and could fall into the facility, causing damage, or if they pose a hazard to nearby electrical equipment. In addition, all tall-growing species that could grow within limits of approach to power lines crossing the site must be removed. Trees that could interfere with microwave signals must be removed. Branches hanging over the fence line that will drop debris into the site should be pruned. Trees may also be removed to reduce potential fire hazard. Required equipment includes chain saws, circular brush saws and axes.

The benefits and limitations of manual tree removal are:

- Selective (only cuts undesirable species).
- Assures electrical safety requirements are met.
- Very expensive and labor intensive.
- Deciduous stumps must be removed, ground down, covered, or treated with herbicide to prevent resprouting.
- Chainsaws, hand tools, and falling trees pose safety hazards.
- Negative aesthetics unless costly clean-up is completed.

3

CONCLUSIONS AND RECOMMENDATIONS

Herbicides are currently a key technique to control vegetation within electric utility facilities; however, as policies change and vegetation management techniques continue to advance alternative techniques are being implemented. Such things as culture, economics, and politics have a large influence on what is considered acceptable techniques for weed management. The driving force behind the increased push for alternative methods to control unwanted vegetation is public concerns for the environment and potential negative side effects from herbicide residues. Herbicide residues are being found on a regular basis in storm, ground and stream water resulting in increased exposure to humans and the ecosystems.

The Clean Water Act is enforced by the U.S Environmental Protection Agency (EPA). The EPA is proposing strengthening the National Pollutant Discharge Elimination System (NPDES) through proposed national rule making. These standards will be increased and the issue of herbicide residue in runoff is addressed (updated on September 10, 2013, URL:http://cfpub.epa.gov/npdes/stormwater/const.cfm). Depending on the final outcome of this rule making and the interpretation of these new rules, it is anticipated that there will be a direct impact on how and where herbicides are used. This will further influence the need to find alternatives to herbicides.

The policies and regulations being implemented in seven European countries are limiting the use of pesticides and require other control methods to be used when practical. Pending rule interpretation of existing U.S regulations (NPDES) may also require alternatives to herbicides in certain locations. The reason for such policy changes in Europe and the U.S. is that research has shown that herbicides are commonly being transported off site from rain water. Utilities in the U.S. need to examine the regulations for herbicide in other countries and how public opinion and research has influenced those regulations. This can help utilities understand what to expect in the future regarding pesticide use to manage secured facilities.

Research into Alternative Methods

Utilities are looking for and testing new and innovative ways to prevent the growth and spread of weeds. The cost-benefits, efficiency, and safety of various preventive and control methods have been researched, including:

- Burning weeds with a torch. Limitation - does not kill roots, and risk of fire too high for use around electrical equipment and oil-filled equipment.
- Steaming weeds or spraying hot water over weeds. Limitations - only controls shallow rooted annuals, not deep-rooted weeds or perennials; requires a lot of water which many facilities do not have; hot water machines have also proven unreliable and expensive.
- Mycoherbicides. Limitations - limited effect; works well on alder species and some aspen, but not on birch and maple.
- Infrared light to control seeds and weeds. Limitations - does not control roots; very expensive.

Utility Survey

A formal phone survey of 14 utilities indicated that almost all secured utility facilities still rely on herbicides for total vegetation control. Some modify particular herbicides used to meet specific requirements if the facility is situated in or near an existing wetland. However, there is not a sense of urgency on the part of vegetation managers to switch to non-herbicide vegetation control. As can be expected from an operations point of view, utilities are looking for long lasting control that is cost effective, easy to implement and meets current environmental regulations. The rule making associated with NPDES may have a direct affect on total vegetation control in utility facilities using herbicides. Utility vegetation managers need to be aware of the NPDES as it currently exists as well as the proposed changes and begin to consider how they can best meet the new rules and what alternatives will be available should the use of herbicides not be permissible under the new regulations. It remains to be seen what the final outcome on NPDES will be regarding the use of herbicides, however, utility vegetation managers need to be ahead of the curve and begin to develop alternative strategies now so that the best alternatives to herbicides can be field tested to determine the most cost effective and efficient methods prior to any significant negative findings in the use of herbicides.

Interviews with Manufacture Technical Representatives, Herbicide Suppliers and Application contractors

In addition to utility vegetation management personnel, the author interviewed herbicide technical representatives (Dow and DuPont), herbicide suppliers (Arborchem, CWC) and several application contractors (DeAngelo Brothers, Osmose, Lentzscape, Weeds Inc., Asplundh) to gain a different perspective on total vegetation control at secured utility facilities. As could be expected, there was no breaking news on non-herbicide treatment methods or technologies that they were aware of or recommending to the utilities. The emphasis for these companies is providing products and application technology that meets existing environmental regulations that is cost effective and which provides high efficacy (good control) on the target vegetation. The innovations within this group is providing herbicides and herbicide combinations that target hard to control vegetation, invasive species and species that may be resistant to herbicide treatment. One applicator was aware of test using alternatives to herbicides (steam) and was very knowledgeable in some of the non-herbicide research taking place. New innovative non-herbicide methods and technologies most likely will not be coming from this group. It will be up to the end user, the utility, to be the innovator of non-herbicide practices through experimenting or collaborative efforts with contractors, manufactures and suppliers. There may be new business opportunities for these groups in meeting future needs for non-herbicide treatment.

IPM not IVM

As defined in ANSI A300 Part 7, Integrated Vegetation Management (IVM) is a system of managing plant communities in which managers set objectives; identify compatible and incompatible vegetation; consider action thresholds; and evaluate, select, and implement the most appropriate control method or methods to achieve those objectives.

IVM has its origins in Integrated Pest Management (IPM). IVM consist of the overt retention and fostering of all the lower growing desirable compatible plant species. IVM is designed to develop (or maintain) low-growing plant communities primarily comprised of early successional/sun-loving woody shrubs and vines, all herbaceous plants including the forbs, various grasses, sedges, rushes, and reeds along with ferns and related fern allies such as horsetails and club mosses. They all act collectively to inhibit the growth of the trees making future ROW maintenance efforts less intensive and intrusive as well as much more economic. As defined, IVM is truly only able to be fully implemented on transmission rights-of-way (ROW). Total vegetation control in and around substations and other secured utility facilities does not fit within the IVM definition. However, concepts of Integrated Pest Management (IPM) can be utilized in total vegetation control.

"Integrated Pest Management is a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks" (SOURCE-Pub. L. 104-170, title III, Sec. 303, Aug. 3, 1996, 110 Stat.1512. USC Title 7 – AGRICULTURE, CHAPTER 6 - INSECTICIDES AND ENVIRONMENTAL PESTICIDE CONTROL, SUBCHAPTER II - ENVIRONMENTAL PESTICIDE CONTROL, Sec. 136r-1. Integrated Pest Management).

The total control of vegetation at utility substations and other critical secured sites does not fall within IVM; however, it does fit within the definition of IPM. What is important is that the concepts of IPM are extremely useful in developing and implementing a sound total vegetation control program.

The key steps of IPM include:

- Prevention - cultural practices that prevent the re-introduction of vegetation.
- Identification of pests - it is critical to know the plant species present to prescribe the most effective herbicide.
- Monitoring for pests - this is on-going as invasive and resistant species can appear at any time and an effective program monitors for these problematic species so the appropriate control can be prescribed.
- Identification and use of injury threshold levels - for substations and other critical utility facilities there is zero tolerance for any vegetation at most sites.
- Treatment - selecting the best herbicide, application technique or non-herbicide control method to achieve total vegetation control.
- Evaluation of treatment - post treatment site evaluation to determine the efficacy and effectiveness of the herbicide or non-herbicide treatment technique in meeting the goal of a vegetation free site.

Best Management Practice (BMP) Considerations for Total Vegetation Control.

Using the definition of IPM (key steps for implementing IPM), interviews with utility vegetation managers, herbicide application contractors, chemical suppliers, and technical representatives, several best management practices (BMP's) have been identified for total vegetation control. They include:

- Technical requirements – have strong, clear technical specifications for the application contractor to follow.
- Contracts and special considerations – contracts should be multiyear, three years being minimum and five year the maximum. This provides "ownership" of the site by the application contractor and can provide for better long term pricing as the contractors have secured the work and can avoid the bid process and pre-purchase herbicides. Contracts must

be flexible enough to provide for changes to meet changing field conditions. This is especially important in longer term contracts.

- IPM – utilize the steps of IPM to maximize effectiveness of program:
  - Identification of problematic vegetation - particular species that are resistant, persistent, late season germination, invasive, etc.
  - Know the site history – past treatment methods and timing, past problems, soil conditions, proximity to residences, streams, wetlands, possibility of runoff from site, impervious surfaces under stone that would result in severe runoff issues, etc.
- Selection of Control methods – determination of vegetation control methods (herbicide or non-herbicide method) and if controlling with herbicide, what herbicides will provide the best results, be economical and meet environmental regulations.
- Engineering and pre-construction considerations – for new sites, consider alternative to traditional construction. Consideration should be given to final surface treatment (stone with geotextile underlayment, grass, etc.) to minimize or eliminate the need for herbicides.

A
ANNOTATED BIBLIOGRAPHY

1. Arthur, Joyce. BC Hydro Secured Facilities Pest Management Plan for Control of Weeds. British Columbia Hydro & Power Authority (2010).

   BC Hydro developed a pest management plan for secured facility grounds that describe the different processes to keep the area weed free. Secured facilities would include substations, switch yards, capacitor stations, etc. Vegetation control within these facilities is done to mitigate fire hazards, the risk of power outages from interference with electrical components, risk of unauthorized entry and theft from covered fences, reduce corrosion of steel equipment, tripping and slipping hazards, etc. In the plan developed by BC Hydro, the use of geotextile under crushed, asphalt and concrete is discussed as alternative ground cover in the appropriate areas to further reduce susceptibility of weed intrusion. Grass seeding is also discussed as a method to reduce the establishment of broadleaf weeds. Herbicides and non-herbicide use is outlined in the plan as well to manage the vegetation at a desired threshold. Non-herbicide techniques are to be used largely in the surrounding area of the facility to help prevent encroachment of vegetation.

2. Ascard, J. *Comparison of Flaming and Infrared Radiation Techniques for Thermal Weed Control*. Weed Research 38, no. 1 (1998): 69–76. doi:10.1046/j.1365-3180.1998.00073.x.

   Research was performed to measure the effectiveness of two different heat treatments for weeding. Flame weeding can reach temperatures of 1900ºC while the infrared radiation weeding achieves temperatures at 900ºC. When treating plants at the four-leaf stage there was not a significant difference in performance (i.e., speed and fuel consumption) between the two methods. However, when treating plants during the cotyledon or up to the two-leaf stage, the flaming method performed slight better than the infrared radiation methods. The results from this study are different than previous studies that concluded flaming resulted in better control. However, the author provides possible explanations for the differences observed between the two methods and possible short-comings of the other studies.

3. Ascard, J. Dose–response Models for Flame Weeding in Relation to Plant Size and Density. Weed Research 34, no. 5 (1994): 377–385.

   Three models, developed from previous research, were used to analyze the relationship between the amount of propane (kg ha-1) and Sinapis alba density and size. The data, collected from three field experiments, was used to validate the accuracy of the models and showed that the plant size had a larger influence than plant density to achieve a 95 percent control effect. The amount of propane required for smaller plants was approximately 40 kg ha-1 whereas plants with more than two true leaves needed about 70 kg ha-1. While the data shows that by treating weeds shortly after emergence requires a smaller dose, the data does not provide the amount needed on a per plant scale for spot applications. While the experiment is conducted using agricultural fields, the use of flame treatment would be a viable option for weed control in substations.

4. Ascard, J. Effects of Flame Weeding on Weed Species at Different Developmental Stages. Weed Research 35, no. 5 (1995): 397–411.

The research examines the influence of various flame treatments to six different plant species (Capsella bursa-pastooris, Chamomilla suaveolens, Chenopodium album, Poa annua, Senecio vulgaris, Stellaria media, and Urtica urens). The effects to other plant species were observed but those additional species were not identified. The susceptibility to flame weeding varied among the plant species. When treatment was applied early during the growing season, propane could be applied at a rate of 20 to 30 kg ha-1 to achieve up to 90 percent reduction in plant numbers. When treatments were applied later in the growing season, the amount of propane increased 500 percent to achieve the same reduction in the number of plants. The research is useful in that it provides the response to flame weeding for seven different species, which could be extrapolated to other plant species with similar phytomorphology.

5. Ascard, J., P. E. Hatcher, B. Melander, M. K. Upadhyaya, M. K. Upadhyaya, and R. E. Blackshaw. *10 Thermal Weed Control Methods*. Non-Chemical Weed Management: Principles, Concepts and Technology (2007): 155–175.

Ten thermal weed control methods are described by the authors as alternative methods to applying herbicides. Even though the research that has been conducted to analyze the effectiveness of these alternative methods have been performed largely in agriculture fields, these methods may be viable for utilities when herbicides cannot be used in substations or other facilities. The alternative methods described are prescribed burns, flame weeding, infrared radiation, hot water, steam, electrical energy, microwave radiation, ultraviolet radiation, lasers, and freezing. Electric energy, microwave radiation, UV, and lasers are fairly new methods for control weeds and additional research is being performed to further develop these methods and to determine method validity. While the methods listed are alternatives to herbicide use and address the concern to reduce herbicide residues, these methods consume much larger amounts of energy to achieve the same level effectiveness as herbicides. The author provides an example from previous research that flaming requires ten times more energy than mechanical or chemical weed control.

6. Ascard, Johan. *Thermal Weed Control by Flaming*. Swedish University of Agricultural Sciences, 1995. http://pub.epsilon.slu.se/3853/.

The dissertation focused on studying the biological and technical factors that influence the effectiveness of flame weeding to further reduce energy consumption and increase the speed of treatment. Fuel consumption and speed of treatment can be adjusted to achieve the desired levels of control on weeds. Open flamers were less effective than flamers with covered burners in killing larger plants and tolerant species. Smaller plants required less time for treatment. In general, the research found that flame weeding can be effective but the method could be improved upon.

7. Bainbridge, David A. *Soil Solarization for Restorationists*. Ecological Restoration 8, no. 2 (December 21, 1990): 96–98. doi:10.3368/er.8.2.96.

Soil solarization is the process of covering the ground with clear polyethylene sheeting for at least four weeks to kill weeds, seeds, and soil pathogens. The soil is to be cultivated to allow for higher temperatures at lower levels and to help increase the effect on deep rooted plants. While this technique maybe be useful for bare soil and in areas with no structures, these methods for controlling weeds may not be practical in substations or other utility facilities due to the length of time and cultivation.

8. Battaglin, W.A., E.T. Furlong, M.R. Burkhardt, and C.J. Peter. *Occurrence of Sulfonylurea, Sulfonamide, Imidazolinone, and Other Herbicides in Rivers, Reservoirs*. The Science of the Total Environment 248 (2000): 123–133.

   The authors discuss new herbicides in 1998 that were relatively new classes of chemical compounds. The MOA was achieved by inhibiting the action of a plant enzyme, stopping plant growth, and eventually killing the plant. These compounds generally have low mammalian toxicity, but plants demonstrate a wide range in sensitivity to these herbicides, with over a 10,000-fold difference in observed toxicity levels for some compounds. When these herbicides are applied either pre- or post-emergence the rate is commonly at 1/50 or less compared to other herbicides. Little is known about their occurrence, fate, or transport in surface water or ground water in the US. To obtain information on the occurrence of SU, SA, and IMI herbicides in the Midwestern United States, 212 water samples were collected from 75 surface-water and 25 ground-water sites in 1998. Samples were also analyzed for 47 pesticides or pesticide degradation products. At least one of the 16 SUs, SAs or IMIs was detected above the method reporting limit of 0.01 μg/L. The sum of the concentration of acetochlor, alachlor, atrazine, cyanazine and metolachlor exceeded 50 μg/L in approximately 10 percent of stream samples.

9. Battaglin, W, and J. Fairchild. *Potential Toxicity of Pesticides Measured in Midwestern Streams to Aquatic Organisms*. Water Science and Technology 45, no. 9 (2002): 95–103.

   Society is becoming increasingly aware of the value of healthy aquatic environments and as a result many sources of contamination have been reduced or eliminated in recent years. Even though the agricultural industry has worked towards reducing off-site movement of chemicals, an estimate of less than one to two percent of the pesticides applied are lost and enter nearby streams during rainfall events. In many cases aquatic organisms are exposed to mixtures of chemicals, which may lead to greater non-target risk than that predicted based on traditional risk assessments for single chemicals. The authors evaluated the potential toxicity of environmental mixtures of 5 classes of pesticides using concentrations found in water samples collected from approximately 50 mid-western stream sites during late spring or early summer runoff events in 1989 and 1998. Results indicate that some samples had probable toxicity to duckweed and green algae, but few are suspected of having significant toxicity to bluegill, sunfish, or chorus frogs.

10. Beckie, Hugh J. Herbicide-Resistant Weeds: Management Tactics and Practices. Weed Science Society of America 20, no. 3 (2009): 793–814. doi:http://dx.doi.org/10.1614/WT-05-084R1.1.

   Herbicide resistance in weeds has become more common as the use of herbicides continue to increase. The author provides an overview of different techniques for herbicide application to minimize resistant weeds. Herbicide sequence, rotation and mixture are methods to help reduce the development or delay weed resistance. Herbicides are developed to target a specific site of action (i.e. contact or systemic). Combining herbicides with different mechanisms of action to kill weeds can increase effectiveness. Researching weeds and their propensity to develop resistance to specific herbicides will allow for better management.

11. Borggaard, Ole, and Louise Gimsing. Fate of Glyphosate in Soil and the Possibility of Leaching to Ground and Surface Waters. Pest Management Science 64 (2008): 441–456.

Glyphosate is a very common herbicide used throughout the world and should be given special attention for its potential to be transported from terrestrial to aquatic environments. The authors discuss sorption, degradation and leachability as it pertains to glyphosate in soils. The natural variation within and between soils make it difficult to draw clear and unambiguous conclusions as to how glyphosate is transported from terrestrial to aquatic environment. Even still the authors claim the risk of ground and surface water contamination by glyphosate seems limited because of the ability for soil sorption and microbial degradation. The mobility of glyphosate through soils is mainly determined by soil structure and rainfall. Glyphosate was observed to be more mobile in a structured soil with preferential flow in macro pores when high rainfall followed application of the herbicide. Even though glyphosate may be transported in drainage water and then into surface waters, the herbicide does not necessarily reach groundwater because of soil sorption in deeper soil layers. Additional research is needed to gain an understanding about subsurface leaching and transport as related to ground and surface water quality for glyphosate and other herbicides.

12. Boyetchko, Susan M, Karen L Bailey, and Rosemarie A De Clerck-Floate. *Current Biological Weed Control Agents-their Adoption and Future Prospects*. Prairie Soils & Crops Journal 2 (2009): 38–45.

Biological control of weeds can be separated into either classical methods or inundative (bio-herbicides) methods. The classical method consists of using natural enemies from a plants place of origin for control. Bio-herbicides entail the use of microorganisms applied to the target weed in high does. These microorganisms are naturally occurring plant pathogens that are not expected to persist for more than one growing season at the time of application. An example of a bio-herbicide would be Sarritor® which is a fungus that infects broadleaf plants. The information presented is an overview of current research being performed to further expand the use of biological weed control agents and may be a viable option in the future for utilities.

13. Brennan, Barry M, Sabina F Swift, and Charles Nagamine. *Rights-of-Way Weed Control–A Guide for Commercial Pesticide Applicators*. College of Tropical Agriculture and Human Resources (CTAHR), 2007. http://www.ctahr.hawaii.edu/freepubs.

This publication provides fundamental information pertaining to the use of herbicides and other methods to control weeds. Successful vegetation control starts by establishing a long-range management plan that considers the economics, effectiveness, environment, and public relations. In addition, potential control methods need to be identified to select options that minimize risk to workers, non-target organisms, and natural resources. When using herbicides the applicators should understand target species, plant morphology, the chemical mechanism of the herbicide, and the different factors that will influence the effectiveness of foliar herbicide application.

14. Burnham, Doug, Greg Prull, and Karro Frost. *Non-Chemical Methods of Vegetation Management on Railroad Rights-of Way*. Vermont Agency of Transportation, 2003. www.aot.state.vt.us.

The project was conducted to evaluate non-chemical methods to control vegetation in the rights-of-way of railroads. In the field trial, the project limited the scope to only evaluate

a single non-chemical method that had been develop for use in Alaska, “wet infrared”. Temperatures greater than 1300ºF are required to sufficiently damage the biological process in order to cause plant mortality. A thin film of water is applied to the vegetation to facilitate impact of thermal energy. A moist surface absorbs the heat better than a dry surface allowing the heat to be transmitted to the vegetation more efficiently. In addition, the heated water on the surface of plant continues to transmit heat to the plant after the infrared treatment has been applied.

15. Cedergreen, Nina, Jens Streibig, and Niels Spliid. *Sensitivity of Aquatic Plants to the Herbicide Metsulfuron-methyl*. Ecotoxicology and Environmental Safety 57 (2004): 153–161.

    The sensitivity of 12 aquatic plant species to the herbicide metsulfuron-methyl was tested in microcosm experiments under two growth conditions. Fast-growing species with a small exposed leaf area proved to be more sensitive to the herbicide than slow growing species with a large exposed leaf area, which was believed to be primarily due to variations in growth rates rather than to variations in exposed leaf area. The aquatic plants displayed high tolerances in growth to metsulfuron compared with the sensitive crop oil-seed rape. Hence, possible spray-drift events and leaching of the herbicide applied at agricultural rates are not considered to have a large impact on the growth of the aquatic flora tested.

16. Cederlund, Harald. *The Microbiology of Railway Tracks*. Vol. 2006. 44, 2006. http://pub.epsilon.slu.se/id/eprint/1096.

    Swedish railways are regularly treated with herbicides in order to keep the track beds free from weeds. The author’s thesis provides details into the investigation of some fundamental aspects of the microbiology in response to the use herbicides on railway tracks. Degradation of diuron in fine material of railway ballast followed first-order kinetics and thus did not support growth of degrading microorganisms. The metabolites DCPMU and DCPU were formed in all samples and accumulated in most of them. The mineralization of MCPA followed growth-linked degradation kinetics and was enhanced where the railway track had been previously treated with MCPA. This enhancement was related to higher numbers of MCPA-degraders and higher specific growth rates (μ) of these in the previously treated track. These findings indicate that it would be sensible to use metabolically degradable herbicides and to apply them using weed-seeker techniques in order to decrease potential contamination of groundwater beneath the railroad.

17. Charudattan, Raghavan. Biological Control of Weeds by Means of Plant Pathogens: Significance for Integrated Weed Management in Modern Agro-ecology. BioControl 46, no. 2 (2001): 229–260.

    Interest in the application and study of biological control of weeds has increased due to economic, social and environmental forces pushing for more alternative methods. A table is included in the publication providing examples of biological pathogens that have been used on specific weeds. The pathogens are grouped into seven categories ranging from verifiable success to additional research required to biological agents that could be further developed. With each pathogen list in the table, a reference is provided for additional information. The author provides a good outline of how the biological control of weeds have progressed over the past several decades and where further development will progress.

18. Cisneros, Juan Jose, and Bernard H Zandstra. *Flame Weeding Effects on Several Weed Species.* Weed Technology 22, no. 2 (2008): 290–295.

    The technique of flame weeding generates temperature up to 1900ºC. The use of this technique is not designed to burn the plants but to rapidly raise the temperature in the leaves to denaturize the plant proteins resulting in the loss of cell function which ultimately kills the plant within two to three days. Flame weeding has been shown to be the most efficient at the early stages of the growing season. Flame weeding was applied to both grasses and broadleaf plants. The ability to control grasses (barnyard grass, green foxtail, crabgrass) using flame weeding resulted in moderate to no control in stem count 14 days after treatment. The use of flame weeding was much more effective with broadleaves because the growing point is above ground whereas for grasses the growing point is below ground.

19. Colborn, Theo, and Polly Short. *Pesticide Use in the US and Policy Implications: a Focus on Herbicides.* Toxicology and Industrial Health 15, no. 1–2 (1999): 241–276.

    The overview of pesticide use provides information that may be helpful for utilities concerning toxicity of active and inert ingredients, weed resistance, and occurrence of herbicides in the environment. The article should be treated as a source to find additional articles pertaining to the subjects listed. The herbicides that have been determined to affect the endocrine or reproductive systems or inhibit acetolactate synthase are provided in a table format with a list of reference to find additional information. Secondly, the author makes the point that even though the MSDS for an herbicide may list an ingredient as inert does not mean that the inert ingredient is not toxic or pose any health risk.

20. Cost-effectiveness of Different Herbicide and Non-herbicide Alternative for Treating Transmission Rights of Way Vegetation. EPRI, Palo, CA: 1025379. 2012.

    Cost effectiveness is a technique to assist with making a decision between different options to apply in management. The monetary cost and expected outcomes produced from actions performed by management are used for cost-effectiveness analysis. The author provides a ten step process for cost-effectiveness analysis: 1) Set the framework for the analysis; 2) Decide what costs and outcomes should be recognized; 3) Identify and categorize costs and outcomes; 4) Cost and outcomes over the duration of a project, or the life of a program; 5) Monetize (place a dollar value on costs); 6) Quantify outcomes in terms of units of effectiveness; 7) Discounting costs to obtain present values; 8) Computing cost-effective rations; 9) Perform sensitivity analysis; 10) Make a recommendation. Each step listed is thoroughly described and an illustration is provided on how the process is used. In section four of the report, Nowak provides an example of cost-effectiveness analysis that includes consideration of the administrative, social, economic, and environmental factors to be used to make sound management decisions about vegetation management.

21. Cotey, Angela. *Pulling Out All the Stops*. Progressive Railroading 51, no. 2 (2008). http://www.arscorp.com/assets/pr%200208.pdf.

    The short article provides an overview of the vegetation management practices implemented by railroad companies. In the USA, railroad companies control vegetation by using either herbicides or mechanical methods. Many of the railroads cut through urban settings or along the edge of private property. When treating the vegetation with herbicides the contractors have been instructed to limit treatment to rights-of-way and to be conscious of weather conditions that either will result in drift or ineffectiveness of the herbicides.

22. DiTomaso, Joseph M. *Risk Analysis of Various Weed Control Methods*. In Proc. Calif. Exotic Pest Plant Council Symposium, 3:34–39, 1997.

The article provides a brief description of various weed control methods and the associated risk. Weed control methods discussed are split into four categories: mechanical control strategies, cultural control methods, biological control, and herbicides. In addition to the methods discussed in this article, other methods (i.e., flame weeding or chemical treatment) are being researched and are not described. The main focus of the article is on herbicides and provides a starting point for the risk associated with the use of this method to control weeds.

23. Ecological and Wildlife Risk Assessment of Chemical Use in Vegetation Management on Electric Utility Rights-of-Way. EPRI, Palo, CA: 2004, 1009445.

The assessment analyzes the ecological and wildlife risk that accompany the use of eight herbicides (2,4-D, Fosamine Ammonium, Glyphosate, Imazapyr, Metsulfuron Methyl, Picloram, Sulfometuron Methyl and Triclopyr) and various other herbicide carriers (diesel oil, mineral oil, kerosene, etc.). The report separates the assessment of each herbicide into chemical-physical properties, environmental behavior, wildlife risk assessment and environmental risk assessment. The limitation of the reports is that the assessment is based upon a specific geographical area; however, the information can to some degree be extrapolated to other area with similar climate, soil series, ecological environment, etc. The report is useful to gain general information about the behavior of different herbicides.

24. Evans, G. J., R. R. Bellinder, and R. R. Hahn. *Integration of Vinegar for In-Row Weed Control in Transplanted Bell Pepper and Broccoli.* Weed Technology 25, no. 3 (July 1, 2011): 459–465. doi:10.1614/WT-D-10-00167.1.

Organic farmers are constantly using non-herbicidal weed control practice to control unwanted vegetation in agricultural fields. Non-herbicidal products would include vinegar or citric acid. The results from the experiment showed that vinegar resulted in 100 percent control in two treatment plots and 96 percent in the other two treatment plots. During the time of treatment, weeds ranged from cotyledon to six-leaf stage. The down side of vinegar is the short time span for residual control after application. Vinegar has little to no direct effect for pre-emergent application. While the research demonstrates that vinegar is a viable alternative to post-emergent herbicide, a site may require additional treatment to address seeds that had not germinated at the time the vinegar was applied.

25. Fagot, M, B De Cauwer, A Beeldens, E Boonen, R Bulcke, and D Reheul. *Weed Flora in Paved Areas in Relation to Environment, Pavement Characteristics and Weed Control.* Weed Research 51, no. 6 (2011): 650–660. doi:10.1111/j.1365-3180.2011.00878.x.

The concern when applying herbicide to hard surfaces is the potential for the chemical to be transported by surface water, ultimately entering into streams. This concern for the environment has led several European countries to impose restriction on herbicide use. Public authorities agreed to a regiment that would decrease the use of herbicide and begin

to use mechanical and thermal treatment methods to control weeds. It was observed that continual applications of any weed control method cause a shift in weed flora composition. Thermal weeding resulted in a shift to annual monocotyledonous species. It was found that a single approach method using only one method allows the flora to evolve into a state that is more difficult to control. Combining treatments with different modes of action resulted in a sustainable weed control.

26. Ferrell, J. A. *Weed Management in Rights-of-Way and Non-Cropped Areas*. University of Florida, January 20, 2012. http://edis.ifas.ufl.edu/wg068.

    The article provides a list of 45 herbicides with the recommend rate per acre. Remarks are included for each herbicide listed to explain the target weeds, application technique and area of application.

27. Geoffroy, Laure, Cecile Frankart, and Philippe Eullaffory. Comparison of Different Physiological Parameter Responses in Lemna minor and Scenedesmus obliquus Exposed to Herbicide Flumioxazin. Environment Pollution 131 (2004): 233–241.

    The authors compared the sensitivity of selected physiological parameters in Scenedesmus obliquus and Lemna minor after being exposed to frequently used herbicides. Flumioxazin, a non-selective herbicide, flumioxazin appeared to be a very strong inhibitor of cell growth that was observed by a reduction in the rate of cell division. In fact, flumioxazin, like other herbicides such as oxyfluorfen is a strong inhibitor of chlorophyll synthesis.

28. Gillespie, William E, George F Czapar, and Aaron G Hager. *Pesticide Fate in the Environment: A Guide for Field Inspectors*. Contract Report. University of Illinois at Urbana-Champaign, 2011. http://webh2o.sws.uiuc.edu/pubdoc/CR/ISWSCR2011-07.pdf.

    The purpose of the report is to help applicator and inspector to better understand what occurs to herbicide once it has been applied to a site. Immediately after application the herbicide begins to decompose but the rate of decomposition depends on physical and chemical properties of the herbicide, site characteristics, and environmental conditions. The report provides information for 35 herbicides and how long each persists in soil, water, and plant tissue. This report would be a useful guide to reference when discussing how long different herbicides remain in the environment.

29. Giudice, Ben D, Arash Massoudieh, Xinjiang Huang, and Thomas M Young. *A Stochastic* Simulation Procedure for Selecting Herbicides with Minimum Environmental Impact. Environmental Science & Technology 42, no. 2 (2007): 354–360.

    A model is presented to estimate the amount of runoff from 33 different herbicides in three geographical areas in California and to estimate the amount of water quality impact. While the model presented by the authors is useful, it should be viewed only as an estimate because there are many factors of uncertainty that were identified. Some of the factors for uncertainty are site specific weather verse regional weather and how long after application herbicide runoff may be observed. While the article does not fully explain the model, the author provides a reference to Huang et al. (2005) for an extensive explanation of the model.

30. Hance, R. J., and Keith Holly. *Weed Control Handbook: Principles*. Ed. 8. Blackwell Scientific Publications, 1990. http://www.cabdirect.org/abstracts/19901139435.html.

The book provides a detailed overview of weed biology to help explain the factors to consider when applying herbicides. Even though the book was written to outline principles for weed control in the United Kingdom, the information could be applied in other regions with a temperate climate. The book was developed to be a reference guide for recent developments in weed science and technology up to 1990. Each of the 22 chapters in the book was written by scientists who have performed extensive research on the topic specific to their individual chapter.

31. Hansen, Preben K, Palle Kristoffersen, and Kristian Kristensen. *Strategies for Non-chemical Weed Control on Public Paved Areas in Denmark*. Pest Management Science 60, no. 6 (2004): 600–604. doi:10.1002/ps.853.

    The push to decrease herbicide use has increased over the past decades, resulting in the public authorities in Denmark to become proactive in minimizing herbicide application and transition to non-chemical weed control. The use of non-chemical methods to control weeds will result in a large increase in cost. The public authority minimized the cost increase by prioritizing paved areas by type and location. The research revealed that in order to achieve the desired percent cover for areas where weeds are well established would require a thermal treatment every two weeks starting in mid-April. While the data reported the effectiveness of different treatment regimes, secured facilities managed by utilities may not require such an intense treatment regime.

32. Hansson, D, and J Ascard. I*nfluence of Developmental Stage and Time of Assessment on Hot Water Weed Control.* Weed Research 42, no. 4 (2002): 307–316. doi:10.1046/j.1365-3180.2002.00290.x.

    Thermal weed control using flames or hot water has increased in use as an alternative to herbicide treatment in European countries. In some countries, flame weed is no longer used because of the fire risk. The goal of the research project was to determine the effective dose amount required to kill weeds at different developmental stages. In order to achieve a 90 percent reduction in plant numbers, the energy dose was 2.7 times higher in Experiment One to kill Sinapis alba at the six-leaf stage than at the two-leaf stage. In order to achieve the desired level weed control, six treatments were required within a single growing season (March 27 through September 30).

33. Hansson, D., S. E. Svensson, J. E. Mattsson, J. E. Englund, and H. Schroeder. *Acetic Acid for Weed Control on Hard Surface Areas.* DIAS Report (2006): 35.

    Research was performed in Sweden to measure the viability of acetic acid as a natural chemical to be used for weed control. The project measured the concentration of acetic acid that would be required to achieve a reduction of 90 percent in the number of weed plants. One site that was used for the experiment was a disused railway embankment that had not been maintained for an unknown number of years. An application of 12 percent acetic acid at a rate of 0.21 L m-2 was sufficient to achieve the desired reduction in weed count.

34. Herbicide Use Safety for Vegetation Management on Power Line Corridors: Improvement of Work Practices Between Utilities and Their Contractors. EPRI, Palo, CA: 1023752. 2012.

    In 2012, EPRI issued a survey created by the author to determine herbicide use, safety issues, controlling practices, and procedures used by contractors. Only eleven surveys were returned representing 48 percent of the companies that received the survey. From the survey, more than 40 different herbicide mixes were reported as being used for ROW maintenance. Even though the respondent reported that seldom do safety issues arise, between 2006 and 2009 EPRI reported that 60 percent of the utilities assessed had contractors without the necessary personal protective equipment. The question is then whether it is the utility's responsibility to ensure the contractor is working safely. The key to the question is in the contract between the utility and contractor. The contractor should be allowed to control the techniques used to complete the work, but the utility has the responsibility to address anything performed incorrectly which should include safety.

35. Hoyle, Jared A., J. Scott McElroy, and J. Jack Rose. *Weed Control Using an Enclosed Thermal Heating Apparatus.* Weed Technology 26, no. 4 (November 1, 2012): 699–707. doi:10.1614/WT-D-12-00057.1.

    The research examined the effectiveness of seven different treatment methods to control eight different weed species common to managing turf grass. The effectiveness of flame weeding increased when the flaming apparatus was enclosed to better control and direct the heat from the flames. The research was conducted to determine if thermal weeding was a viable method to control weeds on turf grass. While the study was conducted specifically on turf grass, the information present further supports the use of flaming as an alternative method of weed control.

36. Hoyle, Jared Adam. Factors Affecting Thermal Weed Control. Auburn University, 2012. http://etd.auburn.edu/etd/handle/10415/2980.

    The dissertation of the author provides a thorough examination of factors affecting the efficiency of thermal weed control. The factors discussed are seed heat tolerance, seed depth, thermal conductivity, soil moisture, and timing. Dependent upon the species the author observed increase efficiency in thermal treatment when the application occurred in the fall versus summer time frames. Temperature and exposure time have an indirect relationship for achieving weed mortality. Less time is required to treat an area when using increased thermal temperatures. There is a direct relation between the combination of these two factors and percent of weed mortality, as temperature and time increase the percentage of weed and seed mortality increases. In addition, the research revealed that thermal weed control had a higher success of surface seed mortality as the volume metric water content increased in the soil.

37. Human Health Risk Assessment of Chemicals Encountered in Vegetation Management on Electric Utility Rights-of-Way; EPRI, Palo Alto, CA: 2003. 1005367.

    The report provides basic concepts and methods used in human health risk assessment and summary of how each chemical reacts in the environment in relation to human exposure. The human health risk assessment was based upon guidelines and procedures that were developed by and for the United States Department of Agriculture Forest Service, Environmental Protection Agency, United States Department for Health and Human Services, and California Department of Pesticide Registration. Basing the human health risk on maximum exposure frequency does not provide a margin of safety due to chronic exposure to the skin. Maximum exposure frequency is sufficient when referring to large spills but not to the minor exposure that occurs frequently. The strength of the report is that it provides guidance for mitigating inadequate margins of safety by explaining the importance of different techniques used to minimize the amount of exposure.

38. Hydro, B. C. Pest Management Plan for Management of Vegetation at BC Hydro Facilities. Surrey, BC. BC Hydro Reference TBD Page (2009): 12–2.

    The pest management plan for BC Hydro discusses different methods of weed prevention and control. The utility company examined the use of four different surface materials to control weeds with secured facilities. Asphalt and concrete should be used with caution because these materials conduct electricity and can spread oil further than if a spill occurs over crush rock. Asphalt and concrete can be used for access roads or for storage area within facilities. Geotextiles are porous materials that can be laid under crushed rock in areas with little to no traffic to limit damage from puncturing or tearing. Crushed rock was found to be the best overall material because it greatly impedes the encroachment of weeds, retards soil evaporation and allows for better conduction of fault or lightning current, rapid surface drainage, is non-flammable, etc. BC Hydro monitors and tracks weed occurrence, density and site condition by location to better develop site specific plans. Dependent upon many factors described in the pest management plan, BC Hydro will use either chemical, physical, and/or cultural/biological methods for weed control. The plan describes seven different techniques for applying herbicides that are herbicide and weed dependent. Grass seeding and parasitic insects are the two non-chemical methods used by BC Hydro for weed control.

39. Kao-Kniffin, Jenny, Sarah M. Carver, and Antonio DiTommaso. *Advancing Weed Management Strategies Using Metagenomic Techniques.* Weed Science 61, no. 2 (April 1, 2013): 171–184. doi:10.1614/WS-D-12-00114.1.

    Research and development of bioherbicides has increased as the number of resistant weed species continue to increase. Bioherbicides will eventually become a tool used to enhance integrated pest management. Naturally occurring microorganism can suppress the weeds across the spectrum of growth stages. Research has been done to isolate the microbial strains responsible for the decay of weed seeds. Very few commercial products are available because isolating a single strain out of a 1,000+ strains requires a significant amount of time and resources. Metagenomics is a technique used to isolate DNA and RNA directly from the environment circumventing the isolation process that has been used in the past. The use of metagenomics leads to a greater potential to isolate natural compounds excreted by microorganisms that can be used to control weeds.

40. Kempenaar, C., and L. A. Lotz. *Reduction of Herbicide Use and Emission by New Weed Control Methods and Strategies.* Water Science and Technology: a Journal of the International Association on Water Pollution Research 49, no. 3 (2004): 135.

    The article summarizes different alternative techniques for weed control. As research and development continues to improve alternative methods of weed prevention, chemical weed control and herbicides use will decrease. The authors mention the use of ASOLFIL by Groenevald et al. (2000) to prevent the establishment of weeds. ASOLFIL is a liquid that can be sprayed on the soil that hardens to form a weed suppressive layer. A concept called Minimum Lethal Herbicide Dose, developed by the Dutch, is the technique of using photosynthesis inhibiting herbicides for weed control. The technique uses portable sensing equipment to determine the minimum dosage required to kill the weeds.

41. Kempenaar, C., L. A. P. Lotz, C. L. M. Van Der Horst, W. H. J. Beltman, K. J. M. Leemans, and A. D. Bannink. *Trade Off Between Costs and Environmental Effects of Weed Control on Pavements.* Crop Protection 26, no. 3 (2007): 430–435.

Herbicides had the largest environmental impact on aquatic and sediment ecotoxicology when compared to three other non-chemical methods. The authors provide a list of five recommendations to minimize the potential transport of herbicides to surface waters. If the hard surface is within 10 km of a stream used for drinking water then herbicide was should not be used, specifically glyphosate and MCPA. Another recommendation is that herbicides should not be sprayed when the weather conditions (ea. probability of rain greater than 40 percent) could result in runoff. The results of implementing the recommendation showed that the concentrations of glyphosate and AMPA in surface waters were much lower than the maximum permissible concentration level by tenfold.

42. Kempenaar, Corné, and R. J. Saft. Weed Control in the Public Area: Combining Environmental and Economical Targets. DIAS Report (2006): 17.

The article combines the results from multiple studies on the cost and side effects of various weed control methods. Research in the Netherlands showed that cost of non-chemical weed control cost up to 4.5 times more than herbicide treatment. However, the cost estimate does not account for the external costs such as treating city water that has been contaminated with herbicides. The authors also discuss the Environmental Life Cycle Assessment model to analyze the impact on the environment in a "cradle-to-grave" approach. Herbicide treatment resulted in the greatest environmental burden whereas flame weeding was the least in the methods analyzed. Sustainable Weed Control on Pavements (SWEEP) is a new management concept to help establish cost-effective and environmentally sound weed control that integrates non-chemical methods with herbicides.

43. Kobland, C. *Flight Turf® Grass.* Accessed 8/9/2013. www.flightturf.com.

Since 2008, Native Return® has studied the economic, safety and environmental benefits of replacing traditional turf grass with lower-maintenance, wildlife-deterring FlightTurf® within airport operations areas. As an initiative of the City of Philadelphia Division of Aviations' (DOA) toward Environmental Stewardship and Sustainability, the Northeast Philadelphia Airport (PNE) was the site of the research. FlightTurf®, meeting FAA specifications, grows to a height averaging seven inches. Reduced maintenance with FlightTurf® has resulted in significant cost savings. Independent analysis shows an airport with 1,000 mowable acres would save on average $800,000 in mowing costs per year, or $8M over 10 years (in 2010 dollars). This calculation does not include the additional potential reduction in wildlife management expenses, and perhaps more significantly, the costs of runway interruptions.

44. Kristoffersen, P, A. M Rask, and S U Larsen. *Non-chemical Weed Control on Traffic Islands: a Comparison of the Efficacy of Five Weed Control Techniques*. Weed Research 48, no. 2 (2008): 124–130. doi:10.1111/j.1365-3180.2007.00612.x.

The purpose of the study was to compare the effectiveness of five non-chemical weed control methods when used on a hard surface on a round-about to direct traffic flow. The five methods were flames, hot air, steam, hot water, and brushes. Controlling weeds using non-chemical methods requires more treatment throughout the growing season than herbicides. The reason for the increase in treatment is because non-chemical methods effect above ground plant parts whereas systematic herbicides are able to kill the below ground portion of weeds. The use of hot water showed the greatest reduction in weed cover and required only four treatments.

45. Kristoffersen, Palle, Anne Merete Rask, A. C. Grundy, I. Franzen, C. Kempenaar, J. Raisio, H. Schroeder, J. Spijker, A. Verschwele, and L. Zarina. *A Review of Pesticide Policies and Regulations for Urban Amenity Areas in Seven European Countries*. Weed Research 48, no. 3 (2008): 201–214.

    The article provides a review of the policies and regulations being implemented in seven European countries regarding pesticide use. Herbicides when applied to hard surfaces are being transported off-site from rain water before sufficient time has occurred for the herbicide to decompose. Even though non-agricultural use of pesticides are but a fraction of the amount used in agricultural settings, the amount of pesticide reaching the streams from non-agricultural uses is a factor of ten-times more than from agricultural use. The survey from the authors revealed great difference in the regulation imposed upon herbicide use in the seven countries. Examining the regulations for herbicide use in other countries and how public opinion and research has influenced those regulations can help utilities understand what to expect in the future regarding pesticide use to manage secured facilities and rights-of-way.

46. Larsson, Arne, Alex Pikkert, and Stefan Konsberg. *New Criteria for Insulated Substations in Rural Areas in Medium Voltage Cable Networks in Sweden*. In Electricity Distribution-Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition On, 1–4, 2009. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5255453.

    The article is a summary of the new substation designs that are being used in Sweden to increase reliability in rural areas. The compact design allows for the substation to be built inside of an enclosed build leading to a greatly reduced level of vegetation maintenance. A 15 year maintenance interval is required for the secondary substations with fully insulated switch gear. This is a much longer maintenance cycle when compared to the unprotected insulation design of many older substations.

47. McLoughlin, Kevin. Traditional IPM Background in Agriculture as it Pertains to IVM. 10^{th} ROW Symposium. Phoenix, AZ. 2012.

    The paper presents a thorough history of Integrated Pest Management (IPM) in the United States and how it led to Integrated Vegetation Management (IVM). There is a detailed description of how IVM is to be implemented and specifically develops a history of IPM and IVM as practiced by the New York Power Authority (NYPA) in New York. NYPA was a pioneer in implementing IVM in the early 1990’s and the article sites the changes that IVM has undergone over the years.

48. Michael, Jerry, and Daniel Neary. *Herbicide Dissipation Studies in Southern Forest Ecosystems.* Environmental Toxicology and Chemistry 12 (1993): 405–410.

    The authors researched the movement of hexazinone, imazapyr, picloram, and sulfometuron in small watersheds in the southern United States. The level of herbicides contaminates in surface waters varied because of application rate, method of application, product formulation, and site-specific characteristics. Highest concentrations of the herbicides were observed in streams after the first three storm events following application. Streamside management zones greatly reduced the amount of herbicide entering streams from forestry applications. The persistence of the different herbicides in the soils was highly variable due the many localized site characteristics. The herbicides had a half-life less than 40 days.

49. Moffitt, L. J., L. K. Tanigoshi, and J. L. Baritelle. *Incorporating Risk in Comparisons of Alternative Pest Control Methods*. Environmental Entomology 12, no. 4 (1983): 1003–1011.

    The stochastic dominance method uses the effectiveness, risk, and cost of different pesticides to evaluate the best method. The authors use the stochastic dominance method to analyze different methods to control Scirtothrips citri (Moulton). Stochastic dominance was used to determine that the soil application of insecticide, FMC35001, was most efficient when considering the expected return in profit and the ability for risk-aversion when accounting for reduced cost from subsequent treatments. Even though the analysis is used for an insecticide, the methodology explained in the article could be used to evaluate herbicide and non-herbicide methods to control weeds in secured facilities managed by utilities.

50. Mojzis, M. *Energetic Requirements of Flame Weed Control*. Research in Agricultural Engineering 48 (2002): 94–97.

    Even though the objective of the article is to examine the effectiveness of flaming for agricultural purpose, the author includes results from the research that explains the significance in the relationship between gas consumption on the weed developmental stage and percent decrease in the number of weeds. The research showed that changing gas consumption resulted in approximately a 31percent change in treatment effectiveness for wild radish (Raphanum raphanistrum L.). Changing gas consumption when treating wild oats (Avena fatua L.) resulted in a 33 percent change in effectiveness. The influence to effectiveness resulting from different developmental stages for the two species mentioned was much less.

51. Monaco, Thomas J, Steve C Weller, and Floyd M Ashton. *Weed Science: Principles and Practices*. Wiley-Blackwell, 2002.

    The book discusses old weed control tactics that were reliable and how these methods can be integrated with new techniques to develop a multiple-factor weed management program. The author provides background information to assist practitioners in understanding all aspects of weed control. The book is split into three sections: principles of weed science, herbicides and herbicide mechanism, weed control practice in specific crops or situations. While most of the last third of the text book has little information on practices that may be used to control weeds in secured facilities managed by utilities, the first two sections provide useful background information that may be used as reference material when explaining how different herbicides work.

52. Moncada, Adriana. *Environmental Fate of Diuron*. Environmental Monitoring Branch, Department of Pesticide Regulation, 2004.

    Diuron is a systemic substituted phenylurea herbicide. The herbicide is easily absorbed from the soil by plant roots and then translocated into stems and leaves. The primarily MOA is by inhibiting the reaction of photosynthesis. Diuron has a low tendency to adsorb to soils and sediments causing the herbicide to be both mobile and relatively persistent, and is therefore prone to off-site movement in surface runoff, and migration to ground water. Diuron is typically applied in winter or early spring during rainy season to control weeds. This practice, coupled with relatively high use and mobility, is one reason why diuron is a commonly detected pesticide in surface water. In California, the herbicide was detected in more than half of 955 surface water samples.

53. Norris, Logan. Determination of the Effectiveness of Herbicide Buffer Zones in Protecting Water Quality. EPRI, Palo Alto, CA and ESEERCO, Schenectady, NY: 1999. TR-113160.

    The report presents the results from a research project used to test the effectiveness of a buffer zone in protecting stream water quality and to provide a factual basis for creating water quality goals and standards. The methodology of the research project was designed to examine the buffer zone width and vegetation density, the influence of different buffer zone strategies in protecting water quality, and determine water quality criteria sufficient to protect aquatic organisms and human health. The results from the research project showed differences in decomposition patterns with different application methods, vegetation density, and buffer zone width. The majority of the water samples did not have detectable amounts of herbicides. The report helps with establishing guidelines for water quality and buffer zones that may be used by rights-of-way managers.

54. Norsworthy, Jason K., Sarah M. Ward, David R. Shaw, Rick S. Llewellyn, Robert L. Nichols, Theodore M. Webster, Kevin W. Bradley, et al. Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations. Weed Science 60, no. sp1 (August 1, 2012): 31–62. doi:10.1614/WS-D-11-00155.1.

    Herbicide resistant weeds are increasing in number and research/methods have been developed to employ best management practices (BMPs). Those BMPs include understanding weed biology, identification of weeds that are susceptible to herbicide resistance, use of a diversified approach to minimize weed seed production and reducing the amount in the seed bank, implementing multiple herbicides with different mechanisms of action (MOA), use of non-herbicide methods, etc. Herbicide MOA can be further promoted by creating a labeling system and an awareness campaign to educate the applicators. The integration of BMPs can help to reduce future cost by decreasing the establishment of herbicide resistant weeds. While much of the article is focused on crop management, some of the BMPs identified may be applicable for utility management of weeds in secured facilities.

55. Nowak, Christopher A. *New Alternatives to Synthetic Herbicide Techniques for Treating Roadside Vegetation.* University Transportation Research Center, Region II, 2005. http://www.utrc2.org/sites/default/files/pubs/herbicides-final-5_4.pdf.

    The report provides a brief description of eight alternative techniques to synthetic herbicides. Three of the alternatives are physical barriers that can be used to prevent the establishment of weeds. The barriers are ForeverMulch (shredded tires used as mulch), Weed-Ender (a non-woven material made of synthetic fibers), and PolyPavement (a liquid soil solidifier). The other techniques are natural herbicides: Finale (Bayer CropScience), Burnout II (St. Gabriel Laboratories), EcoEXEMPT (EcoSMART Technologies, Inc.), ScyThe (Mycogen Corporation), and Chrondrostereum purpureum (MycoLogic Incorporated).

56. O'Callaghan, Dealga. *Non-herbicide Vegetation Control in the United Kingdom.* Interview by E.L Cunningham, ECI. August, 2013.

57. Rask, Anne Merete, and Palle Kristoffersen. *A Review of Non-chemical Weed Control on Hard Surfaces*. Weed Research 47, no. 5 (2007): 370–380.

Thermal weed control uses either direct heating methods or indirect heating methods. Direct heating methods would be flaming, infrared, hot water, and steaming. Indirect heating methods included electrocution, microwave, laser radiation, and UV-light. As mentioned in other publications, the developmental stage of the weeds impact the effectiveness of non-chemical weed control. Thermal weed control has been found to be more effective when applied to weeds during early developmental stages (zero to two-leaf stage). The authors provide a list of experiments that have been conducted since 1994. The list includes experimental dose-response results, weed species targeted, developmental stage of the plants, and the control level achieved. Along with describing the results from the different thermal weed control methods, the authors provide some discussion about mechanical weed control that includes brushing, sweeping, hand hoeing, and harrowing on gravel surfaces.

58. Shrimpton, Gwen. *Herbicides Keep Weeds Out of Substations*. Accessed May 16, 2013. http://tdworld.com/vegetation-management/herbicides-keep-weeds-out-substations.

BC Hydro created a research and development program to determine which alternative options to herbicide use were viable to control weeds within substations. The utility company tested alternative surface material and found that crush rock was the best overall option. While limestone was thought to be an effective alternative because the high pH should deter growth of some weeds, after the field experiments the limestone did not reduce the number of weeds better than crushed rock. Geotextile laid underneath crushed rock increased the effectiveness to deter weed establishment. Even though geotextile increased the effectiveness, BC Hydro determined that the material should be limited to areas of little or no traffic use because it can be easily damaged. Asphalt and concrete are highly weed-resistant but should not be used near oil filled equipment because the oil will have the ability to spread and will potentially burn when in contact with high temperatures. In addition to these alternative surface materials, BC Hydro created a device to be pulled by a tractor to remove organic material from the crushed rock. The size of the tractor and device limits its use to large flat-areas that are absent of electric equipment. Non-chemical methods were also tested but were found to be effective only for shallow rooted plants. BC Hydro came to the conclusion the best option was to use herbicides and that utilities can use these finds to support herbicides in their vegetation management program.

59. Sivesind, Evan C, Maryse L Leblanc, Daniel C Cloutier, Philippe Seguin, and Katrine A Stewart. *Weed Response to Flame Weeding at Different Developmental Stages*. Weed Technology 23, no. 3 (2009): 438–443.

The author provides additional research supporting the influence that plant developmental stages have on the dose requirement for flaming to achieve a desired level of plant mortality. The dose requirements for five different stages of development are combined into a single graph for easy comparison. In addition, formulas are included to estimate the percent mortality by developmental stage by propane dose amount for common lambs' quarters (Chenopodium album) and redroot pigweed (Amaranthus retroflexus L.). The formulas could be used by utilities to estimate the amount of propane required on a per site basis to help budgeting requirements.

60. Thompson, D.G., B Staznik, D.D. Fontaine, T. Mackay, G.R. Oliver, and J. Troth. *Fate of Triclopyr Ester in a Boreal Forest Stream*. Environmental Toxicology and Chemistry 10 (1991): 619–632.

The authors investigate the fate of triclopyr butoxyethyl ester after direct aerial application to study sites in boreal forest watersheds. Diminishing pulses of the herbicide in the streams were observed after treatments were applied upslope from the stream banks. The average concentrations of one form of the herbicide residue in stream water ranged from 0.05 to 0.11 mg/L during the first 12 to 14 hours after application and began to decline below the limits of quantification (0.001 mg/L) within three days. Other forms herbicide residues were observed in stream water. Results indicate that natural dissipation mechanisms reduce both the period and the concentrations to which aquatic organisms would be exposed.

61. Thompson, D.G., L.M. MacDonald, and B Staznik. *Persistence of Hexazinone and Metsulfuron-methyl in a Mixed-Wood Boreal Forest Lake.* Journal of Agriculture and Food Science 40, no. 8 (1992).

The authors researched the persistence of hexazinone and metsulfuron-methyl herbicides in an experiment using in situ enclosures in a mixed-wood/boreal forest lake. The dissipation rate of hexazinone differed based upon initial concentrations (1044 and 103 µg L-1); however, the differences were of little significance. Concentration played a much larger role in the dissipation of metsulfuron-methyl with 103 µg L-1 decay time below 84 days and 10 µg L-1 decay time of 29.1 days. The authors hypothesized that the unexpectedly slow dissipation of hexazinone observed in this study resulted from the influence of low light intensity and short day length. They concluded that further study was required of hexazinone dissipation and impact in relevant northern aquatic systems subject to photolytic inhibition.

62. Tu, Mandy, Callie Hurd, and John M Randall. *Weed Control Methods Handbook: Tools & Techniques for Use in Natural Areas*. All U.S. Government Documents (Utah Regional Depository), 2001. http://digitalcommons.usu.edu/govdocs/533/.

While the focus of the book was on vegetation management in natural areas, there are some aspects that may be beneficial for utilities to reference. The book is split into eight chapters. Chapters five through eight discuss different aspects of herbicide application that would be applicable for utility guidance, such as detailed description of different herbicides and the mechanism of action to kill targeted plants. Even though protective equipment may not be required for some herbicides, authors include a list of PPE that should be worn by applicators.

63. Upadhyaya, Mahesh K., and Robert E. Blackshaw. *Non-Chemical Weed Management: Principles.* Concepts and Technology. CABI, 2007.

The book provides a comprehensive examination of non-chemical weed control management that includes an evaluation of techniques that were thought to be uneconomical and impractical. In addition, the text provides a good source for an overall review and discussion of non-chemical weed control practices.

64. Vegetation Management in Electric Transmission Rights-of-Way and Potential Impacts on Groundwater. EPRI, Palo, CA: EPRI: 1020323. 2010.

Public concerns for the ground water quality and potential contamination resulting from various industry activities has resulted in increased research on these topics. Pesticide use has become a widespread management tool to control unwanted vegetation and as in the case for utilities, herbicides are applied in a linear fashion over long distance that may include areas used by others for various purposes. Understanding the potential impacts herbicides may have to ground water requires the ability to predict how the chemical may respond to the environment. The report discusses the different management techniques where herbicides are used on the ROW and evaluate different mitigation measures for protecting ground water sources.

65. Zimdahl, Robert L. *Fundamentals of Weed Science*. Academic Press, 2007.

The text provides detailed information about herbicides and how they provide crucial weed management. Herbicides become an ecological framework when used correctly. Successful utility vegetation management weed control programs to ensure the delivery of safe reliable electricity are becoming more costly to achieve acceptable levels. Culture, economics, and politics have a large influence on what is considered acceptable techniques for weed management.

B
IVM DECISION MAKING

IVM – Integrated Vegetation Management

- The steps for IVM include:
- Set Objective [initial prevention]
- Evaluate Site [identification of pests; evaluation of site conditions (soil type, wetlands, runoff potential, etc.)]
- Define Action Thresholds [identification of risk (pest to be controlled); establish injury threshold levels]
- Evaluate Site/Conditions and Select method of Control
- Implement IVM (the treatment)
- Monitor treatment and QA

There may be a variety of treatment methods that may differ depending on the type of vegetation to be controlled. The best method will be chosen by considering the type and density of weeds, the physical locations of the target weeds, and the control objectives. Treatment timing is especially important if herbicides will be used. The effectiveness of many products depends on the growth stage of the plant. For example, residual herbicides (soil-applied) should be applied before weeds germinate. Ensuring that herbicide applications are as effective as possible will help reduce the need for future herbicide use.

The following flowchart (ANSI A300 Part 7 – IVM) shows the decision-making process that personnel should utilize when choosing a vegetation management technique. Specific conditions may exist on the site that lends them to a particular method. Using the flowchart will help ensure that where an herbicide is used, the product will provide effective vegetation control.

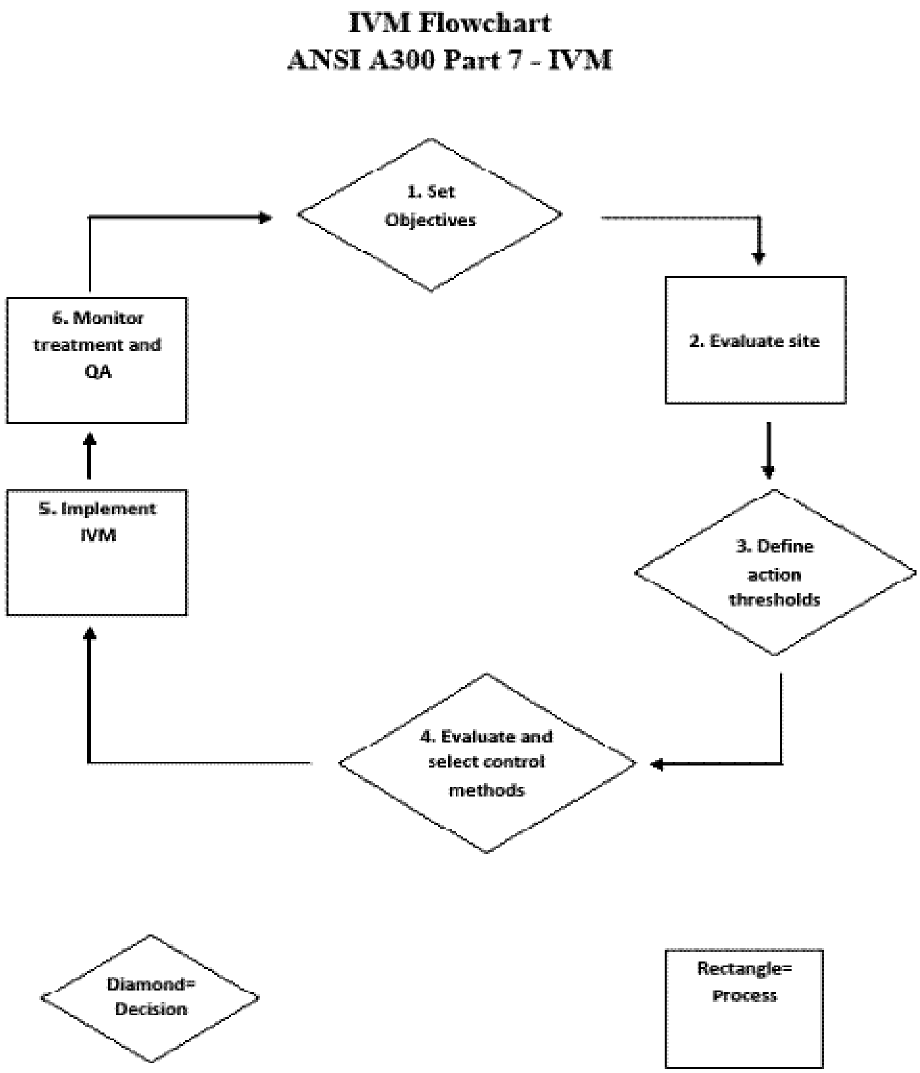

Figure B-1
IVM Flow Chart

Export Control Restrictions

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