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Non-Chemical Methods of Vegetation Management on Railroad Rights-of Way

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Office of Research, Demonstration and Innovation

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13. ABSTRACT (Maximum 200 words)

The goal of this project was to evaluate non-chemical alternatives to vegetation control in railroad rights-of-way primarily through a demonstration project. The current status of alternative railroad weed control technology implementation in Europe and North America was reviewed

A vegetation control demonstration project was implemented during the 2001 growing season on 30 miles of track, located in northeastern Vermont, owned and operated by the Saint Lawrence and Atlantic Railroad, Auburn, ME. Wet infra-red thermal technology designed and built by Sunburst Corp., Eugene, OR, was demonstrated within the context of an experimental implementation plan that included multiple treatment scenarios to evaluate optimal treatment intensity, and quantitative vegetation assessments to evaluate effectiveness in controlling vegetation. The prototype ballast weed control equipment was highly effective at killing treated vegetation, easy to operate, and adaptable to a variety of application platforms. As environmental, water quality, and human health concerns continue to add constraints on routine use of pesticides, other forms of vegetation management must be developed. Sunburst's technology offers an opportunity to incorporate an additional and effective tool to important resource management systems.

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* Member of Steering Committee
** Project Manager

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Photographs courtesy of Greg Prull, Integrated Pest Management Associates and Sunburst, Inc.

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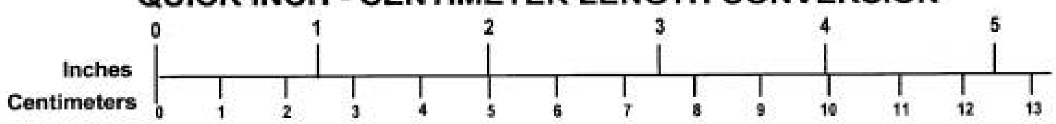
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE)	**LENGTH** (APPROXIMATE)
1 inch (in) = 2.5 centimeters (cm)	1 millimeter (mm) = 0.04 inch (in)
1 foot (ft) = 30 centimeters (cm)	1 centimeter (cm) = 0.4 inch (in)
1 yard (yd) = 0.9 meter (m)	1 meter (m) = 3.3 feet (ft)
1 mile (mi) = 1.6 kilometers (km)	1 meter (m) = 1.1 yards (yd)
	1 kilometer (km) = 0.6 mile (mi)
AREA (APPROXIMATE)	**AREA** (APPROXIMATE)
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)	1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)	1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)	1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)	10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)	
MASS - WEIGHT (APPROXIMATE)	**MASS - WEIGHT** (APPROXIMATE)
1 ounce (oz) = 28 grams (gm)	1 gram (gm) = 0.036 ounce (oz)
1 pound (lb) = 0.45 kilogram (kg)	1 kilogram (kg) = 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)	**VOLUME** (APPROXIMATE)
1 teaspoon (tsp) = 5 milliliters (ml)	1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp) = 15 milliliters (ml)	1 liter (l) = 2.1 pints (pt)
1 fluid ounce (fl oz) = 30 milliliters (ml)	1 liter (l) = 1.06 quarts (qt)
1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
1 pint (pt) = 0.47 liter (l)	
1 quart (qt) = 0.96 liter (l)	
1 gallon (gal) = 3.8 liters (l)	
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)	1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)	**TEMPERATURE** (EXACT)
[(x-32)(5/9)] °F = y °C	[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Executive Summary

Activities were conducted under a cooperative agreement with the Federal Transit Administration with the Vermont Agency of Transportation and collaborators, including: the Saint Lawrence and Atlantic Railroad (SL&A) of Auburn, Maine; the Vermont Agency of Agriculture, Food and Markets; Vermont Pesticide Advisory Council; citizen activists; and representatives of the Vermont railroad industry. The goal of the project was to evaluate non-chemical alternatives to vegetation control in railroad rights-of-way primarily through a demonstration project.

A Steering Committee composed of representatives from various stakeholder groups was formed to provide oversight for the project. This group brought a diversity of interests together in a mutually respective atmosphere to address a common goal – the search for an economically feasible alternative to the use of herbicides for controlling vegetation in railroad rights-of-way.

The current status of alternative railroad weed control technology implementation in Europe and North America was reviewed. Several very informative compilations have been published in the European literature, including a brochure published by the Swiss Agency for the Environment, Forests and Landscapes in collaboration with the Swiss Federal Railway and other federal agencies. This brochure compares the advantages, disadvantages and costs of a wide range of vegetation management technologies. Integrated vegetation management using a variety of techniques, including use of herbicides, appears to be commonplace among the European railroad industry. No similar commitment to non-chemical alternative implementation or integrated vegetation management in general was noted in North America. The Alaska Railroad Corporation has conducted demonstrations of non-chemical alternatives for many years, and uses no herbicides in its pesticide management program. The Canadian Pacific Railway has built and implemented hot water technology as a primary management tool on a portion of its track in the Pacific Northwest. In the mid-1990's, Asplundh, Corporation in collaboration with Aqua Heat Technology Inc. built a hot water vegetation control apparatus. Asplundh conducted extensive demonstrations of this technology across North America, including Burlington, VT. Despite a recognized need for some sort of non-chemical alternative, incentives for utilizing available methods that have been demonstrated to be effective at reducing dependency on herbicides have not overcome what apparently are primarily cost disincentives within the North American railroad industry.

A vegetation control demonstration project was implemented during the 2001 growing season on 30 miles of track, located in northeastern Vermont, owned and operated by the Saint Lawrence and Atlantic Railroad. Wet infra-red thermal technology designed and built by Sunburst Corp., Eugene, OR, was demonstrated within the context of an experimental implementation plan that included multiple treatment scenarios to evaluate optimal treatment intensity, and quantitative vegetation assessments to evaluate effectiveness in controlling vegetation. Technical support for the demonstration was provided by Integrated Pest Management Associates of Eugene, OR. Thermal units provided by Sunburst Inc were retrofitted onto a ballast regulator owned by SL&A. Retrofitting and accessory installation (e.g gas and water delivery systems, equipment vehicle) was done by SL&A mechanics. SL&A staff performed all equipment operation.

The SL&A personnel adapted the ballast regulator as an effective platform for carrying and using Sunburst's weed control equipment. The regulator was stable and rugged; carrying the 3 thermal units with ease while the telescoping arms provided more than adequate strength, flexibility, and reach for manipulating the 4-foot units for treatments along the side of the ballast. Development of the lorry car to carry propane and water supplies and equipment was an excellent innovation that worked well, although additional propane tank capacity would be needed when treating an extensive length of track.

The wet infra-red technology offers advantages not found with any other thermal weed control systems. It is highly effective, and efficient with respect to propane and water use. The combined use of pre-watering and 3 forms of intense heat for weed control (turbulent hot air, infrared energy, and direct flame), with simultaneous and selective application of water for fire prevention, all in a single treatment pass, is a unique technology. The prototype ballast weed control equipment was highly effective at killing treated vegetation, easy to operate, and adaptable to a variety of application platforms. As environmental, water quality, and human health concerns continue to add constraints on routine use of pesticides, other forms of vegetation management must be developed. Thermal technology, such as demonstrated here offers an opportunity to incorporate an additional and effective tool to important resource management systems.

Logistical considerations related to equipment, weather, and staff resources resulted in only partial implementation of the original work plan. Thus, a full evaluation of the potential of this technology to provide effective weed management was precluded. However, there were many observations made and lessons learned from the project that could significantly advance the state of knowledge regarding the feasibility of implementing practical and cost-effective alternative technologies in regular railroad vegetation maintenance programs.

Depending on the degree of treatment required, annual costs per mile for vegetation management using the demonstrated technology (propane at $1.75/gal; labor at $40/hr) could reasonably be expected to range from $70 - $500 per mile. Of that cost, 65-80% would be labor. If labor costs are internalized within the railroad maintenance budget, significant savings over external expenditures could be realized.

New England Environmental, Inc., Amherst, MA, conducted vegetation monitoring. Quantitative sampling consisted of estimates of percent cover by plant type in square meter plots on 50 transects (3 plots on each transect) located at points along the track. Transects were located within treatment areas (treatment effect), outside treatment areas (non-treatment controls), and within a herbicide-treated area (herbicide control). Vegetation was monitored four times: spring and fall 2000 with no treatments occurring; and spring and fall 2001, bracketing the treatment period. The significance of observed changes in vegetation cover could be statistically described.

The vegetation monitoring data analyses did not yield conclusive results on the success of using wet infra-red treatments to control vegetative growth on the railroad ballast area. The pre-treatment baseline sampling found that vegetational percent cover had increased significantly during 2000 in all transects except those on which track maintenance was performed. From June to October, 2001, statistically significant decreases in vegetation were observed within all transects, including ones which received no infra-red treatments, herbicides, or track maintenance. The significant decrease in vegetation within transects that did not receive infra-red treatments indicates that other factors, including the drought, may be responsible for the decrease in vegetation recorded between the two sampling periods.

Key Findings:

* Sunburst's prototype thermal equipment worked well and was effective; the tops of treated weeds were killed when the equipment was utilized as intended. The units were readily adapted to the ballast regulator and were easy to use on the ballast, although rapid height adjustment of the center unit will be necessary for working effectively over switches and grade crossings. The units could be maneuvered well and were effective where obstacles impeded their use on the sides of the ballast (e.g. rails, ties, buckets of spikes left on the side of the ballast). However, treatments can be implemented more easily, efficiently, with better impact, and less hazard to the equipment without obstacles on the ballast.

* This project and other similar tests have shown clearly that Sunburst's equipment works well and is effective for controlling vegetation - in particular, young vegetation on sites where growing conditions are adverse or challenging.

* Fires were not a problem and ties were not damaged when the equipment was used, although a few pieces of rotted wood and small, dried twigs developed embers when one of the working units passed over them. Had the perimeter systems been fully operational, it is unlikely that these materials would have ignited.

* In the project, propane use per mile was within the range experienced during similar applications *(5-10* gal/ mile/4-foot unit) and represented a cost of approximately *$56* per mile when using all units continuously (@ 8 gal per 4-foot unit and *$1.75/gal).*

* A minimum crew of two is needed to operate the equipment. Treatment speed averages 2 mph, therefore approximately 1 person-hour per mile of track treated is required.

* The thermal units were purchased at a cost of $29,000. It is estimated that a similar investment was made by SL&A in retrofitting and accessorizing the ballast regulator used as a platform for the thermal units.

* Treatments were not started until well after the start of the growing season, allowing weeds to become well developed and hardy before any control applications were implemented. However, the applied treatments were very effective on the tops of existing weeds. Treatment impact was more effective on smaller, scattered weeds than on tall dense plants since underlying vegetation is somewhat protected by the tall thick vegetation on top.

*   Treatment intervals were extremely extended, negating the impact and benefits of the initial treatments. Once the first treatments had been completed between June 27 and July 18, 2001 no treatments were implemented until the second week in September, 2001, allowing any surviving weeds to fully recover before the 2nd treatments were started. This greatly affected results of the vegetation survey at the end of the growing season.

*   Undoubtedly the evaluation project was an additional workload for the railroad and may have influenced preparations for the field trials as well as treatment implementation, especially given the treatment plot lengths, number of plots, and the number of treatments. New projects may benefit from having equipment preparations and treatment applications undertaken by contractors to ensure the work plan is implemented as designed and provides the type of data needed for accurate assessment of thermal methods.

*   Although the proper implementation of a rigorous experimental demonstration may benefit from independent implementation, use of railroad equipment and staff for implementing routine vegetation management can result in cost savings when those costs are considered as internal operation and maintenance costs rather than external costs.

*   Platforms to carry Sunburst Units: while the ballast regulator and a hi-rail truck employed in similar trials in Alaska have both worked to carry and operate Sunburst's units, each entails conditions that make them less than perfect for this use. Better options may exist or be developed; exploration of additional ways and means to carry and utilize Sunburst's units should continue.

Figure 1: Thermal vegetation control equipment in action on the Saint Lawrence and Atlantic Railroad in Northeastern Vermont

I. Introduction and Background

In 1986, Vermont Governor Madeleine Kunin issued a "pesticide policy statement for the State of Vermont" with several proposals directed at the overall goal of pesticide use reduction. This policy has resulted in a wide range of regulatory (including the current regulations for right-of-way pesticide permitting) and non-regulatory actions that have contributed to increased awareness of and overall reduction in pesticide use in Vermont. The Vermont Agency of Agriculture, Food, and Markets (AAFM) regulates vegetation management of railroad rights-of-way (ROWs) in Vermont. Application of pesticides to ROWs requires a permit issued by the Commissioner of AAFM pursuant to *"Vermont Regulations for the Control of Pesticides in Accordance with 6 V.S.A. Chapter 87, Section IV.4 (Rights-of-way clearing and maintenance)"*. Applicants for a permit are required to submit to the Commissioner a "long-term vegetation management plan". ROW permits issued by the Commissioner identify specific products and application rates to be used, establish buffers for the protection of surface and ground waters, identify "no spray" zones as appropriate, and require full compliance with any other applicable rules and regulations. Current regulations limit chemical use to the ballast area, an area approximately 16 feet wide (8 feet on each side of the track centerline) with some exceptions for line-of-site, signal structure and yard maintenance. The Commissioner of AAFM is advised on matters concerning the issuance of ROW permits by the Vermont Pesticide Advisory Council (VPAC), established in 1967 (6 V.S.A. Chapter 87) and charged with advising state government on the use of "economic poisons". VPAC members are appointed by the Governor of Vermont and by statute include representatives from a wide range of constituencies including State agencies, the general public, academia, and the agricultural industry.

In February of 1998, in response to public request, the VPAC held a public hearing to take comment on the use of herbicides for the control of vegetation in railroad ROWs. In response to comments received, the VPAC initiated an effort to evaluate environmental and health risks associated with current practices and to study alternatives to chemical vegetation control methods that could be reasonably implemented and result in long-term reductions in the use of pesticides in railroad ROW vegetation management. This effort resulted in the formation of a multi-stakeholder work group. This group held several meetings during the summer and fall of 1998 to discuss strategies for moving forward with an investigative agenda. A meeting was held in Island Pond, VT on November 4, 1998 to discuss the specifics of a possible demonstration project on the Saint Lawrence and Atlantic Railroad in Vermont. The US Congress authorized an FY 1999 appropriation of $250,00 requesting the U.S. Department of Transportation, Federal Transit Administration (FTA), to "work with the Federal Railroad Administration (FRA) to conduct demonstration testing of vegetation control technologies in cooperation with commuter or freight carriers that express interest in participating in the research project". The results of the Island Pond meeting were used to develop a proposal for submission to the FTA in response to this funding opportunity. The FTA subsequently funded the proposal.

Statement of need:

The current regulatory program for railroad ROW vegetation management control in Vermont requires that surface and groundwater be protected by observing buffers around sources of drinking water and adjacent to surface waters within which chemical applications are not allowed or are otherwise restricted. A significant portion of the rail system in Vermont is impacted by these regulations protecting "sensitive areas" from the environmental and human health risks associated with the use of pesticides. As a result, vegetation management on significant portions of track cannot be implemented with chemicals. Alternative methods must be employed to ensure that standards related to operational safety can be achieved and maintained. There are no alternative methods of vegetation control other than control realized by routine ballast and track maintenance (e.g. ballast regulation, surfacing and tamping, and rail and tie replacement), that are currently implemented on a routine basis by the Vermont railroad industry. This clearly identified need combined with the public concern over the environmental and health risks associated with pesticide use prompted the VPAC, working collaboratively with the public and the railroad industry, to seek effective alternatives to pesticide use that can be reasonably implemented, and will contribute to the goal of reduced pesticide use.

II. Goals and Objectives

The overall goal of this project as originally conceived was to identify and demonstrate non-herbicide (non-toxic) technologies and practices for vegetation management on railroad rights-of-way (ROW) that could be effectively incorporated into comprehensive integrated vegetation management programs for the railroad industry. Potential benefits to accrue from this project include: potential reduction in overall herbicide use with resultant reduction in associated risks; improved understanding through collaboration between the public and the railroad industry of issues and concerns related to railroad ROW vegetation management; development of practices that have potential for implementation on a broad scale; and serve as a model program for evaluating the effectiveness of vegetation management control using non-chemical methods. The overall goal was broken down into sub-goals and subsequent objectives aimed at identifying tasks that would address the achievement of those sub-goals. These sub-goals and objectives are listed below.

Goals:

1. Provide recommendations regarding the potential to reduce overall herbicide use associated with railroad right-of-way vegetation management with resultant reductions in environmental health risks;

2. Improve, through collaboration, understanding between the public and the railroad industry of issues and concerns related to right-of-way vegetation management;

3. Assist in the development and demonstration on non-chemical vegetation management alternatives and practices that have the potential for broad-scale implementation within the railroad industry;

4. Develop a model program for evaluating the effectiveness of vegetation management and control using non-chemical methods;

Principal objectives for this project are:

1. Provide a project management structure that: ensures sound financial management and accounting; ensures collaboration of public, regulatory, and industry interests; ensures adequate coordination and collaboration with technical experts as required to assure project validity; provides adequate participation in the process to maximize the validity of the finding across a broad range of affected interests.

2. Review historical and current non-chemical ROW vegetation management alternatives, including implementation experiences in North America and world-wide.

3. Plan and implement a full-scale demonstration project of one or more non-chemical vegetation management technology (technologies) or practice alternative(s) that will provide for a reasonable opportunity to fully evaluate the effectiveness of the demonstrated "treatment" technique(s).

4. In association with #2 above, conduct scientifically sound vegetation surveys within the "treatment" ROWs in order to establish sampling protocols, evaluate treatment effectiveness and the influence of species distribution and density on effectiveness, and provide baseline data for future considerations of integrated pest management planning.

5. Complete a final project report of findings and provide other reports as appropriate.

The remainder of this report, which constitutes fulfillment of Objective 5, will describe and discuss the results of activities conducted pursuant to Objectives 1-4 above.

Figure 2: Saint Lawrence and Atlantic track in Northeastern Vermont

III. Project Description

The following section of this report provides a description of the project in the context of the five objectives outlined in Section II. It was originally anticipated that the project would be conducted over a two-year period beginning in April of 1999. Due to a number of organization and implementation issues, the project period was extended to almost 5 years with completion in December 31, 2003, a total project period of 57 months.

Objective I: Project management:

Task 1.1 - Establish project steering committee. Under the auspices of the Vermont Pesticide Advisory Council (VPAC), a working group was established to study herbicide alternatives. This group consisted of six members: 2 members of the VPAC, 2 representatives from the railroad industry in Vermont, and 2 members from the public at large. The group was expanded to include a representative from the Vermont Agency of Transportation (VTrans), Vermont Agency of Agriculture, Food and Markets (VAFM - the agency responsible for the regulation of pesticide use in the State of Vermont), and the Federal Transit Administration (FTA), the sponsor agency. The expanded group became the project Steering Committee. The Steering Committee (SC) was to designate a project manager who would oversee all aspects of this project, and who would be responsible for assuring that the project met its goals objectives in a timely manner. The project manager, in conjunction with the Steering Committee, would be responsible for all work plans and reports and would report to the VPAC. Ex-officio participation in the business of the Steering Committee would include but not be limited to representatives of the Alaska Railroad, Federal Railroad Administration (FRA) and American Public Transit Association (APTA). It was the intent of the SC to strive to ensure that all affected interests would have adequate opportunity for comment on implementations plans as generated.

It was originally anticipated that a project manager, reporting to the SC, would be hired to coordinate and administer work plan implementation and to coordinate and assist in reporting requirements. The Steering Committee believed that project management would be more efficiently served by one of its own, and hence designated a project manager and Steering Committee chairperson from within its membership.

Task 1.2 - Financial administration. Financial administration was managed by the Vermont Agency of Transportation (VTrans) in coordination with the Steering Committee.

Task 1.3 - Technical advisors. The SC did not formally identify appropriate technical experts and collaborators as necessary to ensure that the project was implemented using technologically appropriate methods and procedures. However, the project manager and SC informally sought out the advice and input of experts in the field of railroad vegetation management in order to take advantage of current expertise to the greatest extent possible.

Objective II: Review of current and historical methods and experiences

Task 2.1 - Alternatives information review. It was originally anticipated that the task of compiling and reviewing information on current and historical alternative methods and experiences would be a contract effort. The contractor would make a valid effort to obtain all information related to the implementation of non-chemical vegetation management alternatives primarily from the North American and European experience. It would be the responsibility of the contractor to review compiled information and augment that information in order to assure that the compilation was complete and accurate. To the extent possible, this review would include cost estimates of the methods reviewed in a standardized format that would allow equivalent comparisons to be made between all methods of vegetation management.

Because workgroup members had already accomplished much of this effort, the Steering Committee decided to implement and complete this task within its own membership rather than through a contractor.

Objective III: Demonstration Project

Task 3.1 - Demonstration project(s). A Vermont railroad freight carrier, the Saint Lawrence and Atlantic Railroad Company (SL&A), offered 30 miles of track in Vermont to be used as a test site for a demonstration. This section of track traverses through a wide range of eco-systems and land-use classes including wetlands and farmland as well as areas with diverse forest cover types. It was the intent of the project to conduct a demonstration on this 30-mile track section using a single non-chemical technology in combination with a variety of mechanical ballast and track maintenance procedures. The design of the demonstration was to include a variety of combination treatment scenarios using the selected technology, mechanical procedures (e.g. ballast regulation), and treatment controls. While the SC originally discussed the possibilities of demonstrating multiple technologies (i.e., infra-red plus steam/hot water) at multiple sites, the VPAC working group on alternative technology expressed concerns that, given the anticipated multiple treatment scenario, an attempt to conduct multiple technology demonstrations on this section of track would compromise the ability to fully assess the effectiveness of any one technology. It also became evident that logistical considerations would limit the ability to conduct additional demonstrations at other sites in Vermont. It has been a priority of the project to be able to provide a full opportunity to evaluate the effectiveness of a demonstrated technology. To this end, it became the intent of this project to focus its limited resources on the single most appropriate technology as determined by the SC for a demonstration on the SL&A track.

Contracts and agreements were developed and implemented for the planned demonstration.

Objective IV: Vegetation Surveys

Task 4.1 - Vegetation surveys. Vegetation surveys were to be conducted within and adjacent to the railroad track throughout the treatment area. Scientifically sound surveys of the species present and their respective densities would be conducted at appropriate time intervals before, during, and after the test. This vegetation database would be the primary basis for determining the effectiveness of the treatment tests. This task was to be implemented by a qualified contractor. Contracts and agreements were developed and implemented for the planned vegetation monitoring.

Task 4.2 - Establishment of vegetative indicators of success. Prior to demonstration implementation, the SC, in consultation with technical advisors, was to establish vegetation measurement endpoints to evaluate the effectiveness of the demonstration treatment in controlling track vegetation. Factors to be considered were to include but not be limited to: ability to provide compliance with FRA safety regulations related to track inspection; and post-treatment re-growth characteristics.

Objective V: Reporting

Task 5.1 - Financial reporting. Financial status reports were generated by VTrans and submitted to FTA as required by the terms of the cooperative arrangement between VTrans and FTA.

Task 5.2 - Progress reports. Activity progress reports were generated by the project manager, in coordination with VTrans and the Steering Committee, and submitted to FTA as required by contractual agreement between VTrans and FTA.

Task 5.3 - Final Report. The project manager would submit a final report to the FTA. The final report would describe and summarize all activities, project findings and conclusions. This report constitutes fulfillment of that obligation.

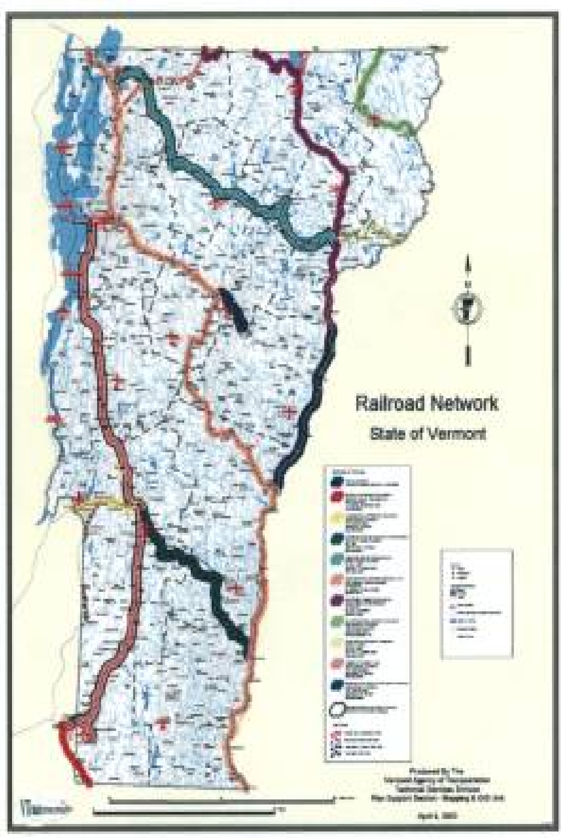


Figure 3: Location of Saint Lawrence and Atlantic Railroad (green) in Northeastern Vermont.

IV. Overview of Non-Chemical Alternatives for Vegetation Management of Railroad Rights-of-Way

At a Congressional hearing on the "Relationship Between Estrogenic Pesticides, Breast Cancer and Other Health Effects" held on October 21, 1993, Theo Colborn, Ph.D. stated:
"Humans are now carrying burdens of both industrial and agricultural chemicals at concentrations at which adverse endocrine, immune, and reproductive effects have been reported in affected wild life and laboratory animals. There is growing evidence that some of these humans also have been affected as a result of their parent's exposure to endocrine disrupting chemicals... Because so many chemicals of this nature already exist in the environment, it is cavalier to think that the global environment can assimilate more and not suffer dire consequences... Our goal should not be to replace old chemicals with new chemicals, but rather to seek non-chemical alternatives..."

A 1997 National Cancer Institute report found that the incidence of cancer in children has increased over the past 20 years. In excess of 8,000 new cases a year are occurring in children under 15. According to the National Cancer Institute and the Center for Disease Control, the following increases have occurred between 1973 and 1995.

Children from the ages of 0-4 years:
- 18% increase in leukemia
- 32% increase in kidney and renal pelvis cancer
- 37% increase in soft tissue cancers
- 53% increase in brain and nervous system cancers

Teenagers between the ages of 15-19 years
- 29% increase in thyroid
- 128% increase in Non-Hodgkin Lymphoma
- 78% increase in ovarian cancer
- 65% increase in testis cancer
- 39% increase in bone and joint cancer

A 1996 study of the correlation between herbicide appliers and birth defects found the rate of birth defects increased in children born to the appliers and in children in the general population living in high use herbicide areas and in infants conceived in the spring when most herbicides are applied.'[1] Other independent studies have shown an increase in cancer in children exposed to herbicides.[2]

There is an alarming rise in the incidence rate of brain cancer, non-Hodgkins lymphoma, Wilms' Tumor, breast cancer and leukemia in adults.[3] The incidence of all types of cancer increased by 49.3 percent between 1950 and 1991 in America. Excluding lung cancer, there was a 35 percent increase. Brain cancer in all Americans has risen 25 percent between 1973 and 1991. "Researchers at the U.S. National Cancer Institute (NCI) have concluded that "Exposure to pesticides has been associated with cancers of the lymphatic and hematopoietic system and brain."

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[1] 'Garry, V., D Schreinemachers, M. Harkins, and J. Griffith. 1996. "Pesticide Appliers, Biocides, and Birth Defects in Rural MinnesOta". *Environmental Health Perspectives* Vol. 104, No 4 (April 1996)

[2] Zahrn, Shelia and Susan Devesa. 1995. "Childhood Cancer: Overview of Incidence Trends and Environmental Carcinogens". *Environmental Health Perspectives* Vol. 103, Supplement 6 (September 1995)

[3] Repetto, Robert, Sanjay S. Baliga. 1996. *Pesticides and The Immune System: The Public Health Risks.* World Resources Institute.

A recent textbook, *Immunotoxicology and Immunopharmacology*, reviewed over 100 primary experimental studies that found suppression of the immune system by many classes of pesticides. Health effects associated with immune suppression are increased risks of infectious diseases, cancers of the immune system, and immune system disorders. Because of this growing body of research linking pesticides with health effects, state and federal agencies and a number of other countries are investigating non-herbicide based methods for vegetation control.[4,5]

The Swiss Agency for the Environment, Forests, and Landscapes (2001) compiled information on options for managing vegetation in railroad rights-of-way: "Vegetation Control on Railway Tracks and Grounds", BAV/SAEFL/SBB 2001. The full report provides an excellent overview of issues and options related to railway vegetation management. Another excellent review of vegetation management options for railroads was recently reported by the International Union of Railroads as part of a broad-based "Vegetation Control Project". The reader is referred to these publications for extensive information on vegetation control alternatives. The following is a general summary of experiences with alternatives to chemical methods of vegetation control.

ALASKA

In 1978, Alaska Governor, Jay Hammond, issued a directive that banned the use of herbicides by state agencies. This directive was influenced by significant public opposition to the "use of public funds by a state agency to apply herbicides". Residents of the railbelt brought suit against the Alaska Railroad to stop herbicide use. In 1983, a Federal judge "determined that herbicides could not be used without preparation of an Environmental Impact Statement (EIS) as required by the National Environmental Policy Act". When the state took over control of the railroads in 1985, Hammond's ban on herbicides was applied and has continued to apply to the present.

Some of the reasons cited for Alaskans intolerance of herbicide-based vegetation control include: the large number of Alaskans who "participate in the harvest and consumption of various wild plants, game, and fish"; the dependence of "several of Alaska's major industries such as commercial fishing and tourism.., on the image, as well as the reality, of a pristine, non-toxic environment"; and the "unique environmental conditions inherent in (the) sub-arctic and arctic environment". A University of Alaska (Fairbanks) study conducted in 1990/91 on railroad test sites "found a greater persistence of the parent (herbicide) compounds and far more extensive downward migration of the herbicides than had been anticipated based on the available scientific literature."

The Alaska Railroad Corporation (ARRC) has intermittently applied for permits since then, but these permits have been denied on the "basis that no data on herbicide persistence and migration under Alaskan conditions existed", supported by public opposition to herbicide use, as determined in hearings held in railbelt communities.

[4] Steingraber, Sandra. 1997. *Living downstream An Ecologist Looks at Cancer and the Environment.* Addison Wesley

[5] Repetto, Robert, Sanjay S. Baliga. 1996. *Pesticides and The Immune System: The Public Health Risks.* World Resources Institute.

Since the discontinuation of herbicide based vegetation management, the tracks have been maintained by brush-cutting the right-of-way areas and manual and mechanical ballast clearing. Ballast regulation has also been used and experimentation in modifying ballast regulators to enhance their weed control effect has been initiated. In 1993, a demonstration project was conducted on portions of Alaskan railroads using Canadian National's prototype steam machine. "The treated areas showed excellent vegetation die-off, particularly where given 2 treatments within the season."

In 1998, ARRC conducted trials with three thermal technologies: open flame burning; hot water; and wet infra-red. The results of these trials, previous trials involving hand labor and hot water, as well as a review of other alternative methods, were published in an undated report, "Controlling Unwanted Vegetation that Impacts Railroad Infrastructure: A critique of the trials of five potential solutions and review of seven other potential control strategies". Additional trials using a hy-rail mounted version of the wet infra-red technology developed by Sunburst, Inc. have been conducted by ARRC. It is our understanding at this time that ARRC has returned to manual and mechanical vegetation control methods in favor of the wet infra-red technology, primily due to cost rather that effe4ctiveness issues.

UNITED STATES

Asplundh, Inc. has been very active in attempting to market a hot water vegetation control system developed in collaboration with Aqua-Heat Inc. In addition to the recent trial in Alaska, Asplundh conducted extensive demonstrations of its equipment and hot water technology for many railroads across North America in the mid-1990's. Included was a demonstration in Burlington, VT in 1996. The single treatment was shown to be effective in killing weeds present. Asplundh was very astute to recognize the need for such an alternative to chemicals. However, despite successful demonstrations and some longer-term implementation projects, an extensive sustainable market has not developed. Costs are the most likely barrier to sustained implementation A lack of appropriate incentives to the rail industry is most likely a contributing factor for the lack of the development of a sustainable market for proven non-chemical vegetation control implementation. Scattered small-scale attempts by individual railroads to implement non-chemical alternatives have taken place, but this project did not find any sustained efforts that were successfully being implemented in regular vegetation management programs

CANADA

In response to major environmental problems created by herbicide use and public concern, Canadian Pacific Railroad (CP Rail),established a task force in 1988 to evaluate herbicide programs and to develop both short and long-term vegetation management policies as part of an environmental program. CP Rail presented a paper titled "Alternative Methods of Vegetation Management: An Ecological Approach to Vegetation Management CP Rail System" at a seminar in 1993 detailing its findings. Their approach included the use of steam, competing vegetation, timely mowing and vegetation replacement. CP Rail has also experimented with Borax as a weed killer. and have developed a prototype steam machine that is used on sensitive areas. In some areas, CP Rail seeded its rights-of-ways with grasses that can then be mowed by local farmers for their own use. Shoulders of some stretches of track have been leveled and seeded to grass to facilitate mowing. The mowed grasses along the ballast contribute no weed seeds or roots for invasion into the ballast areas. In contrast, they point out that “herbicides create a bare strip which invites invasive weeds.” CPRial is currently proposing to discontinue this program, citing costs and lack of effectiveness.

GERMANY

Germany has banned all herbicides on railroad rights-of-way, with the exception of glyphosate, a “leaf” herbicide. Diuron, a “soil” herbicide, was banned in 1996. Because glyphosate was unable to provide satisfactory control of vegetation and because of “public interest of an environmental friendly weed control” process, an ongoing investigation into alternatives has developed. Some of the methods investigated to date are thermal infrared methods, a vacuum cutter which sucks weeds off the ballast along with the top two to three inches of ballast material, mowing and geotextile applications.

An Integrated Vegetation Management Project has been established, with a core group meeting regularly to exchange information on new methods and measures. In addition, a vegetation assessment system has been initiated, including the establishment of a data-base to document the identification of plant species and the geological, hydrological and environmental protection aspects on different areas of the track. Also included will be the management systems used. Among these are a method termed undercutting, which involves removing the old ballast, cleaning and reusing or replacing it and placing a geotextile underneath the recycled ballast, which has been used successfully for vegetation control and remains effective for 5 to 7 years. They have found that not only does this provide weed control, but that the rebuilt railbed can handle heavier loads at higher speeds with less possibility of derailments. Since 1992, the German Federal Railway has been using an infrared method of control which covers the ballast and shoulders up to about 17 feet on either side of the centerline. Although initially, up to four applications a year are needed, the number decreases with every following season. The German machine that administers this technique is fueled with a soybean-based fuel, making this alternative even more environmentally significant. Infrared is considered the most successful and cost effective of the non-chemical alternatives.

NETHERLANDS

In 1991, the Netherlands’ Ministry for Agriculture, Nature Conservation and Fisheries produced a plan for the reduction of the use of herbicides for both agriculture and public spaces. This plan included a list of herbicides to be eliminated in response to “the continued pollution of ground and surface water by excess herbicides.” Glyphosate is the remaining herbicide for vegetation control on railroad rights-of-way.

“In reply to NS Railinfrastructure’s desire to reduce the use of herbicides on railway tracks, inspection paths and platforms” they have participated in a “diffuse discharges” project. This project was instituted by the Association of Operators of Waterworks in the Netherlands, which views the project as a first step toward its goal of “no herbicides in the ground and surface water." Participants include NS Railinfrastructure, VEWIN, Eindhoveri Council, The Ministry of Defense's Buildings, Roads and Land Department, DuPont, Douven BV and Ijzerman BV.

In 1995, a spraying technique using an optical sensor to detect leaf green was developed. "Information received by the detector is subsequently fed into a computer which then decides which spraying nozzles on the spray boom are to be opened." This spraying method uses 36% less herbicide than manual spraying with a knapsack sprayer and as much as 57% less herbicide than full-field spraying (e.g. over the entire area)." Another advantage is better control through spraying only "when three-quarters of the weeds have reached a height of 10 centimeters instead of periodic annual spraying." "During the tests, the average speed was between 3km/h and 10km/h. Taking depreciation into account, the costs per square meter vary between *2.5* and 5 cents", about half as much as selective manual spraying."

Since this is a first generation technology, the possibilities of further reduction in herbicide use is possible. Highly selective weed control where the sensors identify both beneficial and undesirable plant species would allow only the undesirable species to be eradicated.

Since the "Belgian political and environmental authorities have been made conscious of the problem pesticide use raises", the surfaces the railway is allowed to treat has been limited. In 1985, the use of herbicides on railway "side slopes" was forbidden. In 1996 an ecotax was levied on a "number of radicular weed-killers, including duiron", resulting in additional costs.

SWEDEN

In 1994, the Swedish National Rail Administration (SNRA) financed a report prepared by the Department of Agricultural Engineering at the Swedish University of Agricultural Science: "Vegetation Control on Railway Embankment – A review of preventative measures and non-chemical methods." "This report is considered to be a preparatory study and throws a light upon problems and conditions, alternative non-chemical methods and equipments on the market..." The SNRA "is in charge of approximately 10,000 km of railroad track, of which 750 km are restricted sections where chemical weed control may not be used... this study shows that for certain methods there is not enough material to evaluate their practical usefulness (for example UV-light). In other cases, the fundamental theoretical knowledge of the methods is fairly good, whereas the practical experience is inadequate as a basis for deciding to try them out on a large scale. The report gives suggestions for continued R&D activities on both a long-term and a short-term basis in order to attain a more efficient exploitation of resources in a development phase." The summary includes a list of questions that need further research, including: How much vegetation can be tolerated without seriously affecting the road beds?" and , To what extent is it possible to reach economical and environmental advantages by replacing gravel ballast with a growth restraining macadam ballast?

Herbicide uses on Sweden's railway rights-of-way have been restricted in water resource areas, nature reservations and protected sections. "Also there are often local deals between communities and Sweden's National Rail Administration about on which railway lines chemical weed control isn't allowed."

SWITZERLAND

The Swiss Federal Railway (SBB) has chaired a workgroup made up of representatives from the SBB, private railways, agricultural research centers, the Swiss Federal Transport Office, the Swiss Federal Office for Public Health, and the Swiss Agency for the Environment, Forests and Landscapes. The workgroup was to investigate methods of vegetation control in an effort to find alternatives to chemicals, with emphasis on constructional, biological, mechanical and thermal measures. The group makes the point that “to optimize vegetation control from an economical and ecological point of view, it is essential for all the technical departments of a railway company to be aware of the problems associated with railway vegetation and to have some basic knowledge of the subject” and that the “main concern today is to bring vegetation under control through the use of a combination of different measures appropriate to the specific situation.” The SBB currently uses a variety of prevention and maintenance methods as appropriate to individual situations to manage vegetation on its rail system. SBB has found the structural and biological measures implemented at the time of track construction are the most effective at preventing vegetation from encroaching into the right-of-way to the extent that regular maintenance is required.

Figure 4: Hy-Rail infra-red platform tested in Alaska.

V. Field Trials of a Thermal Weed Control Technology

One of the primary goals of this project was to "plan and implement a full-scale demonstration project of one or more non-chemical vegetation management technology (technologies) or practice alternative(s) that will provide for a reasonable opportunity to fully evaluate the effectiveness of the demonstrated "treatment" technique(s)". While it was originally anticipated that there was potential to demonstrate multiple technologies in conjunction with this project, the Steering Committee expressed concerns that, given the anticipated multiple treatment scenario, an attempt to conduct multiple technology demonstrations would compromise the ability to fully assess the effectiveness of any one technology. To this end it was the intent of this project to focus its limited resources on the single most appropriate technology, as determined by the Steering Committee, for a primary demonstration on the SL&A track. For the technology demonstration, the Steering Committee selected a thermal technology developed by Sunburst, Inc. of Eugene, Oregon. The technology, described as "wet infrared", is being tested simultaneously in field trials in Alaska.

Site selection:

To facilitate project implementation, the Vermont Agency of Transportation (VTrans) invited railroads within the state of Vermont to participate by providing a rail segment where Sunburst's thermal weed control technology could be evaluated.

Several of Vermont railroads expressed an interest in participating in the project. The Steering Committee selected the Saint Lawrence and Atlantic Railroad Company (SL&A), a "shortline" railroad freight carrier with 30 miles of track in Vermont, as the primary demonstration site primarily because: (a) the SL&A was committed to not using chemicals to control vegetation on its Vermont track and made a strong commitment to participate in this project; and (b) considerable work had already been done on the track to characterize conditions and vegetation growth.

Site Description:

The SL&A operates on 30 miles of track that passes through Vermont's "Northeast Kingdom" from Bloomfield, near the New Hampshire border, to Norton near the Canadian border. This section of rail traverses through a wide range of eco-systems and land-use classes including wetlands and farmland as well as areas with diverse forest cover types. This track segment is part of a larger network operated by SL&A that includes sections in Maine, New Hampshire, and Canada. Outside of Vermont, SL&A uses herbicides as its primary ballast weed control tool to the extent allowed by local regulatory programs. SL&A also provided a short section of track outside of North Stratford, NH as an example of track ballast where herbicides were used on a bi-annual basis to control vegetative growth in the ballast. Weed growth here would be compared with development in the ballast where the thermal treatments were applied along the Vermont track.

While herbicides were used historically to control vegetation in the ballast, no herbicides have been applied to the Vermont portion of the SL&A right-of-way since 1997. Control of vegetation in the right-of-way outside the ballast perimeter is conducted by manual and mechanical means. Regular maintenance activities conducted before and during this demonstration include: surfacing and regulating of ballast; rail replacement; tie replacement; and brushing. All of these activities have a secondary effect on ballast vegetation.

Surface water is abundant in the SL&A corridor through the Northeast Kingdom. Wetlands, streams, rivers and lakes are found on either or both sides of the track for many miles and numerous culverts intersect the rail bed. In some instances, water features lay upland of the track corridor and “seeps” from these features as well as surface water runoff during storm events and from melting snow and ice moves down slope where it is intercepted by the track structure. There are multiple grade crossings along the right-of-way, many involving steep unpaved roads providing a ready source of sediment discharge to the adjacent ballast during storm events.

Weeds are present in many areas of the track ballast, varying in species, age class and density from: annuals to perennials; native species to exotic invasive species; seedlings to well established plants; and scattered to dense. To a large extent, plant distribution seems to be affected primarily by ballast condition and management activities and the availability of soil and moisture in the ballast: where fines are abundant and/or where ballast depth is shallow, weed growth is aggressive; where fines are absent and ballast depth is near or exceeds what is commonly considered adequate (e.g. 9-12 inches below the ties) weeds are absent, scattered or occasionally in small groups. Vegetation characteristics will be discussed in more detail later.

Figure 5: Light (left) and moderate to heavy (right) vegetation

Along some areas of the track, brush and trees are encroaching on the edge of the ballast. All vegetation outside of the ballast prism is controlled by non-chemical means.

Demonstration Objectives:

- The project was designed was to examine the potential to use Sunburst’s thermal weed control technology for cost-effective management of vegetation invading track ballast in Northeast Vermont.

- Of primary interest was the potential to use Sunburst's technology for routine maintenance of acceptable ballast conditions (i.e., where ballast weed control was currently adequate, could Sunburst's technology be used effectively to maintain these conditions?).

- Secondarily, because extensive areas of the SL&A track included ballast with well-established weeds, it was also of interest to examine whether Sunburst's technology could be effectively applied to remediation of such sites.

- In addition, developing estimates of propane and water use and treatment speed were needed to help assess application costs and productivity. Records of treatment distance, time, and the amount of materials for each application were to provide this information.

- The impact on specific vegetation types (i.e., species, age class) would also be monitored to help characterize the response of various types of plants to thermal control.

"Wet Infra-red" Thermal Treatment Theory:

Wet Infra-red thermal treatment exposes weeds to high temperatures, coagulating proteins and rupturing cell walls, which disables normal plant functions and destroys their tops. This forces weeds to rely on their capacity to develop new shoots and leaves to recover and survive. When sufficiently damaged (i.e., after 1-3 treatments), any plants that cannot re-sprout are killed. With weeds that can regenerate after treatment, repeated loss and regeneration of new growth consumes their root reserves. When these reserves are depleted, the weeds perish because they can no longer recover.

Effective treatment impact (i.e., death of leaves and stems) requires that weeds be subjected to damaging temperatures (>1300-1350 F°) for several seconds at least (e.g., 3 seconds at minimum temperatures).

Effective treatment does not involve heating weeds to the extent that they are singed or burned; rather, ruptured cell walls within the plant causes plants to wilt, but they remain entirely green. This effect is usually immediate and very evident, although slightly wilted leaves may not exhibit a clear impact when first observed. However, they will be imprinted when pressed between the fingers.

Site and environmental conditions influence treatment impact since they affect the transference of thermal energy from the equipment to the weeds (e.g., weed characteristics/species, age class, height, and density; ambient temperatures - air, ground, and plant).

Application speed that will subject weeds to an effective thermal "dose" is determined by equipment size (i.e., length of effective treatment area), operating temperature, and site conditions. Operators can adjust treatment speed to match existing conditions to help ensure effective impact on weeds. Maintenance of heat close to the ground and circulating around plant

structures facilitates maximum transference of heat to target weeds.
Temperature under Sunburst's equipment varies, but has been estimated at between 1000-2000^{0}F (based on infrared readings of the unit shroud; no temperature measurements were made during the project). A covering hood helps trap and immerse plants fully in intense heat. Flames from the burners create turbulent hot air that helps penetrate dense and overlying vegetation, intense infrared energy is radiated by the surrounding metal shroud and special grid under the roof of the unit, and, tall weeds are often momentarily impacted by the flames generated by the propane burners. During treatment, the equipment is kept close to the ground surface to help contain heat and maximize temperatures at ground level, which facilitates effective impact on low growing and small weeds.

Sunburst's prototype equipment used for the project has an application area approximately 4.3 feet in length and provides an effective impact on vegetation at ½ - 3 miles per hour, depending on ballast site conditions.

Sunburst's unique technology applies a thin film of water to weed leaf and stem surfaces just prior to heating them intensely; this water facilitates the impact of the applied thermal energy:

- Water absorbs heat more efficiently than dry plant surfaces.
- Hot water transmits heat to weeds more efficiently than hot air.
- Hot water remaining on plants surfaces after thermal equipment has passed by continues to transmit heat to the plant, effectively prolonging treatment.

The application of water also has a very useful supplementary impact: it helps prevent unwanted ignition of flammable materials under the unit and adjacent to the treatment area. Optimum use of Sunburst's equipment requires simultaneous operation of both the heating and watering systems.

If weeds have little resistance to the intense heat of a thermal weed control treatment and a poor capacity to regenerate, they perish after 1-3 applications, particularly when trying to survive in an adverse, challenging environment (e.g., 9- 12" of dry, clean, rock ballast).

Seedling and juvenile plants of most species, even biennials and perennials, are generally very susceptible to thermal treatments, however some do exhibit resistance. These include plants with insulated sites where stems emerge (e.g., grasses that form clumps), some prostrate weeds thst, due to their small size and low growing position, receive the least amount of intense heat during treatment, and in some instances, plants with thick leaf surfaces or dense hairs that insulate the leaf surface.

As plants mature, not only are their leaves and stems hardier and more resistant to adverse growth factors, including intense heat, but their root systems are also better developed and contain more carbohydrate reserves to support recovery after being damaged. In addition, depending on species, many mature plants have a capacity to grow new shoots either from the original root or from spreading rhizomes or stolons (e.g., blackberries).

Where weed growth is dense or tall, overtopping vegetation can act as a physical barrier to the effects of thermal treatments, protecting lower growing or underlying vegetation and reducing treatment impact (e.g., a dense community of short grass; layers of creeping vines; tall weeds bent over by the application equipment during treatment). Also, vigorous plants are able to resist treatment and regenerate more effectively than weakened plants, such as those damaged during a mechanical ballast treatment, such as regulating.

Reducing weed growth and even density and vigor if feasible prior to thermal treatment for example by mowing, scarification, or tilling, can facilitate control impact and effectiveness.

Some variations in morphology between and within weed species can influence the impact of thermal treatments, for example:

- Many grasses are well adapted to fire, even young plants, having a protective root crown or clump at ground level that is developed by the continual formation of upright branches within the lower sheaths of the stems where they emerge from the roots. This root crown insulates the inner stems, which sprout after their tops have died back from exposure to intense heat.

- Some plants have protective leaf and stem structures such as dense hairs, thickened surfaces, waxy cuticles (e.g. mullein) that help insulate the plant from the effects of heat.

Treatment effectiveness may be optimized by identifying resistant target vegetation types and applying modified control techniques, such as adjusted application schedules and/or practices, e.g., timing of initial and/or subsequent treatments; extending treatment length or intensity; coordinating thermal treatments with other track maintenance operations that are damaging to weeds.

Figure 6: Vegetation in Plot 12.14 west before (left) and after (right) treatment.

Equipment:

The equipment used for the project tests was a combination of fabricated thermal units retrofitted on to pre-existing equipment owned by the SL&A and fabricated accessory equipment to support thermal unit accessories.

Thermal Units – IPM Associates Inc. provided three Sunburst prototype thermal units for this project: two 4-foot wide 5-foot long units to treat the sides of the ballast; one 8-foot wide, 5-foot long unit to treat the center of the ballast between the tie ends. With all units active, the effective treatment area would be eight feet on either side of the centerline – a sixteen-foot wide swath. The prototype units were fabricated in Portland, OR and shipped to the SL&A at Berlin, NH, for attachment to the regulator.

Ballast Regulator – The thermal units were retrofitted on to a BEB 17 ballast regulator. The 4-foot thermal units were fitted onto the hydraulic arms on the side of the ballast regulator. The units could be lowered onto the shoulder of the ballast with a great deal of flexibility for adjusting to changes in the form and structure of the ballast shoulder in order to maximize treatment effectiveness. Similarly, the 8-foot unit was mounted on the central hydraulic unit, allowing the unit to be raised and lowered from the center area of the ballast over the rails. The hydraulic systems were operated from the cab of the regulator. Propane and water lines were fabricated in order to provide appropriate feeds to the burners and peripheral watering systems respectively. Propane and water supplies were carried on a "lorry" which was attached as a trailer to the regulator.

Figure 7: Infra-red units in the shop (left) and in the field (right**)**

Accessory equipment – Mechanics at SL&A fabricated a "lorry" to carry propane and water tanks to support the operation of the thermal units. The lorry carried a water tank and propane tanks, as well as a water pump to pressurize the wetting system and to provide the means for refilling the water tank.

Figure 8: Regulator and lorry in the field

The propane burners are supplied by liquid propane to produce intense heat. For this project, each 4-foot wide unit included 4 burners that together use about 5-10 gallons per hour when operating at 20-30 psi. Two 100 gallon tanks carried on the lorry car pulled by the ballast regulator supplied propane. Valves, tubing and regulators were manually operated to bring fuel to the units. Water was supplied to the units from a tank on the lorry car. A gas-powered portable water pump generated water pressure. The water tank was re-filled as needed from water sources adjacent to the tack. A standard garden hose was attached to the water distribution system for the purpose of maintaining fire control following treatment.

Demonstration Experimental Design:

An experimental design was developed that would evaluate various treatment intensities under a variety of existing vegetation density conditions.

New England Environmental, Inc., the project's vegetation monitoring and assessment contractor, completed initial monitoring of vegetation on the SL&A in Vermont during May and November, 2000, describing the vegetation coverage along the track at the beginning and end of a growing season where no thermal treatments occurred. Using this information, four treatment plots, each approximately four miles in length, were established on the SL&A in May, 2001. The number of infra-red treatments each plot was to receive was based on the vegetation percent cover within the plot. The light vegetation plots (Plots A and C) were to receive 2 and 3 treatments, respectively with the infra-red equipment; the medium vegetation plot (Plot D) was to receive 4 treatments, and Plot B, with the heaviest vegetational growth, was planned to have 6 treatments. Additional vegetation monitoring was to be conducted at the beginning and end of the 2001 growing season in order to assess the effectiveness of the treatments. Results would be compared with the herbicide control segment in New Hampshire.

Identification of typical weed problems and areas where vegetation survey transects might be located was undertaken in May 2000 during a hi-rail review of the track. Attending were VTrans and VT Department of Environmental Conservation staff, members of the Vermont Pesticide Advisory Council, and staff from the SL&A, New England Environmental vegetation monitoring contractor), and IPM Associates Inc (demonstration implementation contractor).

Following the site review, the group affirmed an earlier decision that both survey and treatment plots should be established in areas of the track corresponding to 3 different levels of existing ballast weed cover: those with light, moderate, and heavy densities of established vegetation. These levels of weed development were initially estimated by observation and were intended to correspond to approximately <5% cover; >5% - 25% cover; and >25% cover.

Characterizing existing ballast weed development using 3 levels of percent cover was done in an attempt to organize the thermal control applications into two types of treatment:

(1.) *Extensive* treatment —2 and 3 treatments would be applied to areas where existing vegetation in the ballast was very limited and scattered — i.e., where there were extensive areas of ballast with few if any weed control requirements.

Productivity on such sites can be high due to minimum treatment requirements: i.e., application requirements are scattered — treatments are implemented only where weeds are growing — areas without weeds can be skipped, allowing equipment to maintain a high average working speed and cover large areas per unit of time. When routine treatment practices are applied, extensive weed development seldom occurs; also, most weeds appearing are susceptible due to their young age class. Where present, established or otherwise resistant weeds on side ballast areas can be treated more intensively by a momentary ‘‘hovering’’ of the equipment over the site, ensuring maximum treatment effect, or, through an integrated treatment strategy using complimentary treatment practices, e.g., ballast regulating.

“Extensive” treatment conditions correspond to: (1) those typically found on ballast in good condition where weed control has been an on-going practice (especially routine herbicide use), and (2) those for which Sunburst’s thermal weed control equipment was designed and has performed most effectively. As illustrated earlier, several miles of the SL&A’s track through Vermont had only light weed cover predominantly in those areas without ballast drainage problems.

Figure 9: Typical "extensive treatment" track condition

(2.) *Intensive* treatment — 4 and 6 treatments would be applied to areas where established weeds were common or abundant.

Treatment efficiency in such areas is usually low due to demanding treatment requirements; while applications can be site specific, i.e., only where weeds are found growing, conditions require reduced treatment speed to achieve effective results.

Where patches of weeds involve dense and/or tall weed growth, treatment speed must be minimized to provide effective impact; if weed growth is wide spread, treatments will involve both slow speeds and large areas, resulting in minimum productivity. These conditions are atypical of most railroads and are usually found where few or no vegetation management treatments have been applied for a while, in some cases for an extended period of time.

Such conditions are challenging for all types of weed control methods, including herbicides, (i.e., repeated treatments with a variety of chemicals are often required, frequently for more than one growing season), but they are particularly difficult for non-chemical treatment methods, including thermal technologies, especially where perennial weeds have become well established, notably those that are resistant to heat treatments (e.g., grasses, protected by clump development) and those that propagate by underground rhizomes, stolons, and/or tip layering (e.g., willow, blackberry).

These conditions are beyond those for which Sunburst's equipment was designed, although with repeated applications, control of perennial weeds has been achieved in some management settings. Such efforts are usually not cost-effective, since without eradication, perennial species frequently rebound vigorously, requiring an on-going intensive treatment program to maintain a satisfactory level of control. However, in some instances, non-chemical methods may be the only available treatment option (e.g., environmentally sensitive areas)

Figure 10 Typical "intensive treatment" track condition.

Extensive and Intensive treatment strategies were included in the project to reflect two distinct types of weed control programs, and significantly, in an effort to support evaluation of Sunburst's equipment based on the different operational requirements of these two programs:

(3) Routine Maintenance Operations: i.e., vegetation management programs where routine treatments are performed at regular, timely intervals to eradicate or control unwanted vegetation using a "prevention" strategy. In such programs, control applications are made when weeds are young, small, and scattered — i.e., when susceptible to thermal treatments. Pre-existing, established plants can be managed by use of a "hovering" technique to intensify treatment (where feasible), through routine "harassment" (applying control techniques regularly to force plants to use up their root reserves), and by integrating several maintenance practices together, making it difficult for even perennial weeds to thrive and expand. These pre-existing plants may include perennial, well-established weeds growing along the edge of the ballast that send out underground rhizomes or stolons each year. Shoots from these stems emerge in the ballast and must be killed back to control their expansion; some may need thermal treatment beyond the edge of the ballast to ensure good control. Mowing or brushing should be applied to any "mother" plant(s) when the right-of-way along that portion of the ballast is being treated.

Similarly, areas where these types of weeds are known to be a consistent problem should also be subjected to ballast regulation when such equipment is working in the vicinity. Even a minimal treatment will help weaken these weeds, making them more susceptible to thermal control. Regulators can also be fitted with a tine along their outside edge (hydraulically controlled) for added spot scarification capacity. Indeed, a routine ballast vegetation management program should integrate thermal treatments with all ballast maintenance practices to take advantage of synergistic impacts that can help optimize weed control.

Routine maintenance programs help minimize costs while maintaining optimum site conditions. Non-chemical methods may be as cost-effective as using herbicides, particularly when treatments are integrated and all environmental impacts (e.g., movement of application materials off-site) and program administrative costs are fully accounted for. These costs may include: insurance; application equipment purchase; maintenance storage; tools and facilities for cleaning application equipment, including proper disposal of rinsates and disposal of hazardous containers; material purchase and storage; annual personnel training and licensing; posting requirements; sampling requirements; public relations, etc.

(4) Remediation or Corrective Operations: vegetation management programs where treatments have been infrequent or delayed for an extended period of time and site conditions have deteriorated to the extent that treatments to restore even minimally acceptable conditions are often imperative for safe operations and/or other important reasons (e.g., practical purposes — to avoid complicating the implementation of other operations, like ballast regulating; protection of investment in facilities). Conditions on several miles of SL&A's track through Vermont exhibit this type of weed growth.

In such situations, weeds are not treated until their development has become widespread, often dense, and plants are well established, making control difficult. Intensive treatment is then required to achieve even satisfactory results. Sometimes, eradication cannot be accomplished despite extraordinary effort. These programs are costly, even when using herbicides, due to the amount of material needed and the fact that repeated applications are often necessary. Additional effort and cost is usually required with non-chemical methods, and frequently with reduced results, particularly when perennial species that propagate by rhizomes, stolons, and/or tip layering are involved. If full control of unwanted vegetation is not achieved, maintenance of acceptable site conditions may require a routine management program that is more intensive and more costly than would normally be required. These programs underscore the idea that "an ounce of prevention is worth a pound of cure".

VI. Vegetation Monitoring and Assessement

Quantitative vegetation sampling was an integral component of the demonstration project. The primary objective of the monitoring was to be able to determine whether or not the treatments had an effect on ambient vegetation and to be able to describe the significance of the effect statistically. New England Environmental, Inc. (NEE) of Amherst, MA. was awarded a contract to conduct the pre- and post-treatment monitoring. In collaboration with the Steering Committee and Integrated Pest Management Associates (the demonstration contractor), NEE developed and implemented a monitoring plan, as described below, designed to quantify the effectiveness of the treatments.

Sampling Methods:

Pre-treatment sampling of plant percent-cover occurred during both May and November of 2000, and during June 2001. Post-treatment sampling of plant percent cover was completed during October 2001. Four treatment plots, each four miles in length, were established along the 30 miles of SL&A track in Vermont. Within each of these plots,.NEE established a minimum of 10 transects with three 1 meter square quadrats each, for a minimum of 30 quadrats per treatment area. The location of each of the transects was determined through a sub-meter Trimble *G.P.S.* unit and mapped onto a base map from the State of Vermont GIS system.

In addition to the four treatment plots, to serve as a control, NEE established 10 transects of three 1 square meter quadrats (30 quadrats) in New Hampshire in a section that is maintained with herbicide on a biennial basis. The initial vegetative sampling of these sites occurred prior to the application of herbicide in May 2000. These quadrats were re-sampled in June and October 2001.

<u>Plot Descriptions</u>

The 4 treatment plots were established by a team from IPM Associates, the State of Vermont, the SL&A, and NEE., to cover a variety of vegetative conditions on the track. A recommended number of infra-red treatments for each plot was developed by Greg Prull of IPM Associates. Each treatment plot consisted of a four-mile stretch of railroad track: two were lightly vegetated, one was moderately vegetated, and one was heavily vegetated. Two "Control Plots," each 100 feet long, were established by State of Vermont personnel within each of the larger treatment plots, and received no infra-red treatments. The locations of each of the control plots were determined with the G.P.S. unit by NEE. Plot A (light vegetation) was established from railroad track mileage 137.8 to 141.95, between the two Route 105 grade crossings, just west of the Vermont/New Hampshire state line; Plot B (heavy vegetation) extends from railroad track mileage *145.5* to mile post 0 in the center of Island Pond, Vermont; Plot C (light vegetation) was established from mile post 5 to mile post 9, north of Island Pond and Plot D (moderate vegetation) was established between railroad mile posts 11 and 15.

Prior to the establishment of the treatment plots, NEE had established 50 vegetative transects along the entire 30 miles of SL&A track within Vermont to determine the vegetative cover on the track. When the boundaries of the infra-red treatment plots were established in May, 2001, all but 9 transects were within plots. NEE continued to monitor the vegetation within these transects which are located outside of the infra-red treatment plots (27 quadrats). There were no infra-red treatments on any of these transects, and none of these transects received either track maintenance measures or herbicide during 2001. These data were used as a comparison to the data collected from the four treatment plots. These transects were lightly to moderately vegetated.

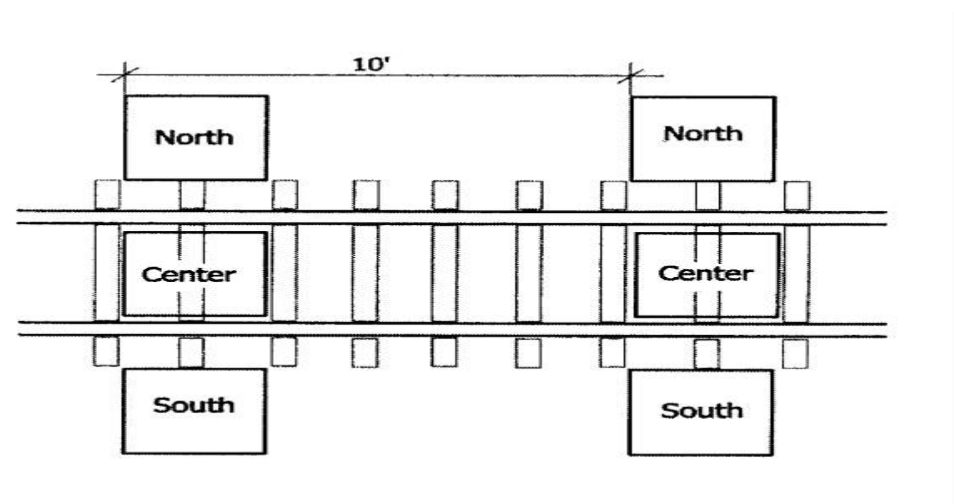
<u>Treatments</u>

Each of the 4 treatment plots was to have a different number of treatments during the summer. Originally, lightly vegetated Plot A was scheduled to have 2 treatments, heavily vegetated Plot B was to have 6 treatments, Plot C, also lightly vegetated, was to have 3 treatments, and Plot D, moderately vegetated, was to be treated 4 times. Proposed dates for treatments were recommended by IPM Associates, Inc. A number of conditions led to this not being the case. Northern Vermont had an extremely hot and dry summer, and entered into drought conditions early on. There was concern of fires being started by the infra-red treatments. Secondly, the railroad had a problem with scheduling the treatments on a regular basis. Only 2 treatments were completed during the 2001 growing season on all plots, one during the week of June 25, 2001 and a second one during September 24, 2001.

Vegetative Sampling

Within each of the 4 treatment plots, a minimum of 10 transects was established. During June 2001, when fewer than 10 of the original transects were located within the treatment plots, additional transects were added adjacent to the original transects. Each transect extends over the track and included the ballast on both sides, as well as any growth between the tracks. The transects were marked in the field with pink spray paint on the top of the ties outside of the rails and on the side of the rails immediately above the marked tie. The paint was refreshed during each vegetative sampling at the particular transect. Three 1 square meter quadrats were located along each transect. A schematic drawing of the transects with the quadrat locations is shown in Figure 6, below.

Figure 11: Vegetation monitoring plot layout design.



The sampling quadrat consisted of a foldable light-weight aluminum frame with an interior area of one square meter. This was used to sample the ballast on either side of the track. So that no tools were actually laid on or between the tracks (a potential railroad safety hazard), NEE used the area bounded by three ties and the rails as the middle quadrat, which approximates one square meter. As vegetation did not typically grow on the ties, the vegetated area was slightly less than one square meter even though the total area sampled was slightly larger.

For each of the quadrats, a list of species was compiled and percent cover was estimated for each species using the following scale:

Cover Class	Rate of Percent Cover	Midpoint
1	<1%	0.5
2	1 to 5%	3.0
3	6 to 25%	15.5
4	26 to 50%	38.0
5	51 to 75%	63.0
6	76 to 100%	88.0

Figure 12: Vegetation monitoring quadrat.

The total percent cover for each quadrat is the sum of percent cover of all the species found within the quadrat. The midpoint was used for each range of percent cover for the data analysis. For each of the 4 treatments, and the New Hampshire control transects, there is a minimum of 30 quadrats, so that statistical analysis of the data can be completed. Unfortunately, not all of the transects outside of the treatment plots were re-sampled regularly, so the use of these will not be statistically valid.

Pre-treatment vegetative sampling in 2001 occurred June 11 - 14, and post-treatment vegetative surveys were completed October 23 - 25. Data from sampling in May and November 2000 were included in the data analysis when these were available. Some of the transects were only established in June 2001.

VII. Results and Discussion

A. The Thermal "Wet Infra-red" Demonstration Evaluation

The implementation of this demonstration project turned out to be challenging. The primary source of the challenge was the expectation that a rigorous experiment (Section V – *Demonstration Experimental Design*) could be interjected into the day-to-day maintenance schedule of a railroad company.

The Steering Committee felt that incorporating these treatments into the routine maintenance schedule of the railroad would be less costly than having that service supplied by a contractor. It became clear fairly early on that trying to overlay a rigorous experimental design with a need for specific actions to be implemented at specific times was not entirely realistic. It should be pointed out that the demands of implementing an experimental plan are probably greater than the demands of routine vegetation control. Practical vegetation management activities can be directed to where and when they are needed while the experimental plan requires action regardless of actual need. This lack of need was a factor during the 2002 growing season, when weather conditions and track maintenance activities reduced the need to actively control vegetation. While the project design called for treatments to be taking place at specific places and times, meteorological conditions as well as the vegetation control effected by extensive track maintenance activities eliminated to a great extent the practical need to treat vegetation, and thus railroad priorities were directed elsewhere. Given the multiple demands on railroad staff, there was little time for the luxury of applying effort merely for the sake of experimental rigor with no practical benefit. Thus, despite the best of intentions, pragmatism ruled when limited resources were available and daily work plans for track maintenance were developed. Similar conditions prevented the implementation of treatments in 2003. The ability of the railroad to implement the plan was routinely diverted by conflicting demands on limited staff.

In any case, the full experimental demonstration plan proved to be much too aggressive to be implemented in its entirety. As a result, the original expectations of a comprehensive evaluation of the technology under a range of conditions were significantly lowered. The following table summarizes the "planned" vs "actual" treatment scenario.

Table 1: Planned vs Actual Treatments

Plot	Planned # of Treatments	Actual # of Treatments	First Treatment
A – Light growth	3x	2x	6-27-01
B – Heavy growth	6x	2x	7-3-01
C – Light growth	2x	2x	7-12-01
D – Moderate growth	4x	2x	7-16-01

In addition, the experimental plan called for initial treatments to begin very early in the growing season. Treatment of early growth stages is an important factor for treatment efficacy as intervention of early growth stages of plants provides a much more efficient treatment than does later intervention when plants are larger and more firmly established and resistant to treatment (see previous discussion – Part V). Because treatments didn't start until well into the growing season, this aspect of the experimental design was lost. The treatments that did take place, however, provided excellent opportunities for observing the operational characteristics of the technology as well as the immediate effects of the treatment.

While the project encountered difficulties, some of which were critical with regard to planned implementation, it was successful in illustrating the potential for thermal methods to be effective for controlling ballast vegetation. In particular, project results suggest that thermal methods have very good potential for cost-effective management of weeds invading ballast that is in good condition (not fouled; with standard or greater depth), is consistently well maintained (routinely regulated and tamped), and overlies a stable, well-drained sub-grade. These conditions by themselves are not only good for railroad operations, they also make the ballast an undesirable and challenging place for weeds to grow, thereby supporting use of thermal methods for eliminating new weeds attempting to colonize the ballast, as well as controlling the expansion of perennial weeds that occupy the verge.

The regulator was stable and rugged, carrying the 3 thermal units with ease while the telescoping arms provided more than adequate strength, flexibility, and reach for manipulating the 4-foot units for treatments along the side of the ballast. From their position over the rails, the operators had very clear visibility of the track and target vegetation, making it easy to determine optimum use of the equipment as the regulator moved along the ballast. Operators also had excellent visibility of the side units and could see the rear unit easily to make needed adjustments while applying treatments. Development of the lorry car to carry propane and water supplies and equipment was an excellent innovation that worked well, although additional propane tank capacity would be needed when doing extensive amounts of track. Water filters were not installed on the water system, contributing to dysfunction of the perimeter spray nozzles used to wet target vegetation and prevent ignition of flammable materials.

Unlike a hi-rail platform, the ballast regulator cannot get off the track at grade crossings; it must go to sidings to get out of the way of passing trains or for storage. It also cannot get off the track to travel by road to distant work sites. This may not only be inconvenient, but could also involve significant amounts of lost work time. Similarly, because it can't get off the track to go to the nearest supplier, propane must be brought to the regulator to provide fuel for the thermal equipment. In addition, while excellent at operating at speeds appropriate for applying thermal treatments, the ballast regulator is not particularly well suited to traveling long distances for work (i.e., to, from or between treatment sites) or getting out of the way of oncoming trains. Because the Vermont track had speed limits and work sites were relatively close together, this was not a significant problem. However, if working on high-speed track, the regulator would be less efficient than platforms that can travel more quickly.

Two treatments were completed on each of the thermal application plots in 2001. The applied treatments were very effective on the tops of existing weeds. Treatment impact was more effective on smaller, scattered weeds than on tall dense plants (since underlying vegetation is somewhat protected by the tall thick vegetation on top).

Treatments were not started until well after the start of the growing season, allowing weeds to become well developed and hardy before any control applications were implemented. Originally, the first treatments were to begin in late May to control weeds early when they were small and tender. This was changed to the end of the first week in June and then the last week of the month when equipment preparation delays occurred. As a result, plot A, the first to receive an application, was not treated until June 27, 2001; Plot D, the last plot to receive its first application, was not treated until July 12, 2001. This situation made it very difficult for the thermal treatments to eliminate even new weeds or to be efficient. More resistant weeds required slower treatment speeds and increased propane use to achieve an effective impact.

The center thermal unit was frequently not utilized, even where weeds were present, as constant attention was required to adjusting side units to avoid materials in the side-path. In addition, the fact that ignition of the units could not be remotely controlled by the equipment operators may have influenced how they were used. Without installation of the safety control modules, the units had to be turned on and off manually, which is very inconvenient and would have increased the time needed to complete plot treatments. These factors may have affected material use data and may have negatively impacted vegetation survey data.

Planned treatment frequencies ranged from 2-6 (depending on weed cover); the ballast regulator crew submitted treatment records for only 1 treatment for each plot; the SL&A reported that 2 treatments were applied in each plot, although no field records were supplied. Treatment intervals were extremely extended, negating the impact and benefits of the initial treatments. Once the first treatments had been completed between June 27 and July 18, 2001, no treatments were implemented until the second week in September, allowing any surviving weeds to fully recover before the 2nd treatments were started, which greatly affected results of the vegetation survey at the end of the growing season.

The treatment plots were 4 miles in length to provide operational conditions sufficient for realistic assessment of treatment productivity and costs. Future projects evaluating thermal vegetation treatments should continue using plots of this or greater length since experience has shown that short plots do not provide an adequate cross section of operational conditions.

Undoubtedly the demonstration project was an additional workload for the railroad and may have influenced preparations for the field trials as well as treatment implementation, especially given the treatment plot lengths, number of plots, and the number of treatments. Future demonstration projects may benefit from having equipment preparations and treatment applications undertaken by contractors to ensure the work plan is implemented as designed, and which should provide the type of data needed for accurate assessment of thermal methods.

Limiting any further evaluations to track with clean ballast would be useful since these conditions are representative of most rail beds in the U.S. and those to which thermal methods can be cost-effectively applied. Remediation sites, particularly extensive areas of track with such conditions, are unlikely to be managed with thermal tools unless there are no other options since costs would almost certainly be high due to low productivity and the need for repetitive treatments.

B. Capital and Operating Costs:

Capital costs: The capital costs associated with this demonstration include: the materials and labor involved with the building and construction of the burners; the materials and labor involved in rebuilding and retrofitting the ballast regulator platform; the materials and labor involved in building the support "lorry" vehicle which was pulled behind the ballast regulator and carried operating materials (e.g., propane and water).

Infra-red thermal units - Three units, as previously described, were manufactured by Sunburst, Inc of Eugene, OR and shipped to the project as whole units. The total cost, including shipping and handling, was approximately $30,000.

Ballast regulator - The ballast regulator to which the infra-red thermal units were retrofitted was a piece of equipment already in the possession of SL&A and was in "surplus" status. As such, there were no initial capital costs to the project associated with the acquisition of the platform vehicle. (A reasonable market value for a similar piece of used equipment may be $25-35,000.) SL&A invested time and materials to rebuild the diesel engine, refurbish the general operational mechanics of the regulator, purchase and install propane and water systems. SL&A estimates that $25-30,000 in labor and materials were invested in equipment development.

Lorry vehicle - The lorry vehicle was built from scratch by SL&A mechanics. Costs are included in the estimated $25-30,000 cited above.

Operating costs: Operating expenses include materials and labor associated with conducting treatments on the track.

Materials - Materials consisted primarily of fuel (propane, diesel fuel for the ballast regulator and gasoline for the water pump) and water. There was essentially no cost associated with water as it was obtained from natural sources adjacent to the right-of-way.

Operating costs are estimated based on data collected by treatment crews in the field at the time work was conducted. Crews recorded: the time spent on the track; the distance covered; the length of time that thermal units were lit and operating; the amount of propane and water used (estimated); the identity of crew members. The intent of the operational data gathering was to be able to estimate the costs per areal unit of ballast (e.g acre, m^2) in order to facilitate comparisons with other methods of vegetation control that estimate costs on a similar basis.

Propane use during the project averaged about 7.8 gal/hour for each 4-foot thermal unit (twice that for the 8-foot unit). This value is within the range experienced in other trials conducted by Sunburst, Inc. with similar equipment. Based on that figure, maximum propane use per mile of track, assuming both 4-foot side units plus the 8-foot center unit in operation, and an average speed of 2 mph, would be approximately 16 gal/mile. Assuming approximately 2 acres per treated mile (16'x5280'=84,480ft^2 = 1.94 acres), propane use would be at a rate of 8 gal/acre or 0.001 gal/m^2. In actuality, it was seldom that all thermal units were operated at the same time so actual material consumption was less than the maximum estimate. The common mode of operation during this project was to operate the two side units together and leave the center untreated, or treat the center only.

Because the vehicle was track-bound, fuel tanks had to be carried to and from the demonstration site from the supplier location. While this presented no problems for the project, In some instances, changing of propane tanks may be more convenient with a support vehicle that is not track-bound (e.g. hy-rail).

Water demand, estimated from nozzle configuration and an operating pressure of 40 psi was calculated to be in the range of 135-186 gallons/hour with all units in operation. Actual water consumption, as estimated from field records, ranged from 0 gals/h (treatments during light rain when no water was used) to 380 gals/hr with only the two side units in operation. Greater than anticipated water use was most likely a result of enlargements to the nozzle pores made to compensate for the lack of a filtration system in the water distribution, resulting in the clogging of small nozzle pores. It is likely that the installation of filtration in the water system would result in a more efficient use of water. Costs for water were minimal and will not be factored into the overall operating costs.

Similarly, fuel costs for the diesel regulator engine and the water pump were minimal and will not be calculated into the overall operating costs.

A minimum of two staff were required to operate the equipment. Labor costs normalized to track length or areal unit treated are, as is propane use, dependent upon average treatment speed: 2

person-hours/mile at 1 mph; 1 person-hour/mile at 2 mph; 0.66 person-hour/mile at 3 mph. Some additional labor is involved in filling the water tank and changing propane tanks.

Table 2: Operating costs per treatment mile. For annual treatment costs, these numbers are multiplied by the number of treatments required.

	Propane Use [a]				Labor [b]
	All Units	Center+1 side	2 Sides OR Center	1 Side Only	Person-hours per Mile
1 mph	24g-$42	18g-$31.50	12g-$21	6g-$10.50	2hrs-$80
2 mph	16g-$28	12G-$21	8g-$14	4g-$7	1hr-$40
3mph	8g-$14	6g$10.50	4g-$7	2g$3.50	0.66hr-$27

[a] = propane cost $1.75/gal [b] = labor cost $40/hr.

A reasonable range of expected costs would be $70 - $500 per track mile for an annual maintenance program, with 65-80% of the cost associated with labor and 20-35% materials.

Estimating costs for the 30 miles of SLA track (or any other track) would involve a combination of calculations assuming that some track may not require any treatment and some sections may require up to 6 treatments. It is likely that under a maintenance scenario, 2-4 treatments would be required over a portion of the track. For example if 20 miles of track needed 3 treatments on the sides only, 5 miles need 4 treatments on all portions, and 5 miles needed no treatment, an annual total of 800 gallons of propane and 80 person-hours would be required. Total cost would be approximately $5,000 for an annual maintenance program on the 30 miles of track. Clearly an evaluation of cost-effectiveness is dependent upon how the railroad company accounts for labor costs when activities are conducted by existing track crews as part of regular internal maintenance activities rather than a contractual line-item..

C. Vegetation Monitoring

Statistical analysis of the data was completed through 2-tailed T-tests. The mean vegetative percent cover for 10 different parameters was calculated for each of the plots: total percent cover, perennials, annuals, biennials, herbaceous, woody, monocots, dicots, mosses and ferns, and gymnosperms. Each of these parameters was compared for May and October 2001 (pre- and post-treatment) as well as compared to May and November 2000 when data allowed. New transects were established in Plot A and Plot C in June 2001, and previous plot data were insufficient for statistical analysis in these Plots.

Plot A

Plot A was one of two lightly vegetated plots. Ninety percent of the sampling transects for this plot were established in June 2001; only 3 transects were located in this plot prior to that date. As a result, data were only compared between June 2001 and October 2001. Decreases in percent cover were noted in all but one of the cover types: biennials had low percent cover in June 2001 with a mean of only 0.35 %; in October 2001, the mean had remained essentially the same at 0.33 %. A statistically significant decrease was noted in the percent cover from June 2001, to October 2001, in total percent cover (all plants combined) (p=0.001), perennials (p=0.001), herbaceous species (p=0.002), woody species (p=0.019), dicot percent cover (p=0.002) and gymnosperm percent cover (p=0.023). Table V1 shows the percent cover means for Plot A for the various vegetation types over time. Bolded names indicate that a statistically significant change was noted between the two dates. No statistical difference was noted in the percent cover of annual species, biennials, woody species, monocot species, gymnosperms or mosses and ferns, all of which had percent covers less than 1% in June 2001.

Table 3: Vegetation Cover Plot A – Lightly Vegetated.

	May 2001	October 2001
Total % Cover [a]	**4.93**	**1.15**
Perennials [a]	**4.36**	**0.73**
Annuals	0.18	0.08
Biennials	0.35	0.33
Herbaceous [b]	**4.42**	**1.05**
Woody [c]	**0.55**	**0.10**
Monocot	0.32	0.18
Dicots [b]	**4.47**	**0.97**
Moss/Ferns	0.10	0
Gymnosperms [d]	**0.08**	**0**

[a] p=0.001 [b] p=0.002 [c] p=0.019 [d] p=0.023

Plot B

Plot B was the heavily vegetated plot. Vegetative response over time in shown graphically in Table V2 over the four sampling periods: May 2000, November 2000, June 2001 and October 2001. Plot B consists of 22 transects, and all but 1 have been sampled during all 4 of the sampling periods. This has yielded 66 quadrats (except for comparisons to November 2000, which has only 63 quadrats) for the paired sample two-tailed t-tests.

A review of the May to November 2000 data show increases in all percent cover parameters, and statistically significant increases in total percent cover, perennials, biennials, herbaceous, monocots and dicots percent cover ($p<0.001$ for all the above). May 2000, compared to June 2001, shows similar results: increases in all percent cover measurements, and there were statistically significant increases in total percent cover, perennials, biennials, herbaceous, monocots, dicots and gymnosperm percent cover ($p<0.001$ except $p=0.024$ for biennial percent cover and $p=0.018$ for gymnosperm percent cover).

During 2001, all plots were sampled in June prior to the two infra-red treatments and then sampled in October after treatments were completed. Decreases were observed in all parameters for percent cover. Statistically significant decreases were observed in the total percent cover, perennials, annuals, herbaceous, monocots, dicots, and gymnosperms were noted ($p<0.001$ except $p=0.042$ for annuals percent cover, $p=0.008$ for monocot percent cover and $p=0.001$ for gymnosperms percent cover).

A comparison between May 2000 and October 2001, indicates the two infra-red treatments administered during the Summer of 2001 were insufficient to bring the vegetation percent cover levels below those observed in May 2000. The total percent cover observed was a statistically significant increase from May 2000 to October 2001 ($p<0.001$). Statistically significant increases were also observed in perennials ($p<0.001$), biennials ($p=0.002$), herbaceous ($p<0.001$), and dicots ($p<0.001$). An increase was also observed in monocots, though this was not significant. Decreases were observed in the other cover types including annuals, woody species, mosses/ferns and gymnosperms, though none of these were statistically significant.

Table 4. Vegetation Cover Plot B – Heavily Vegetated.

	May 2000	November 2000	May 2001	October 2001
Total %Cover [abei]	12.02	32.45	30.78	18.72
Perrenials [abei]	7.99	23.08	27.14	15.99
Annuals [f]	3.59	5.85	2.21	1.14
Biennials [adj]	0.19	1.65	1.19	1.14
Herbaceous [abei]	11.91	31.76	30.63	18.62
Woody	0.11	0.16	0.16	0.10
Monocots [abg]	2.49	7.87	5.24	3.08
Dicots [abei]	9.34	23.42	24.6	15.54
Moss/Ferns	0.16	0.62	0.88	0.09
Gymnosperms [ch]	0.02	0.01	0.07	0.01

[a] $p<0.001$ from May to November 2000
[b] $p<0.001$ from May 2000 to May 2001
[c] $p=0.018$ from May 2000 to May 2001
[d] $p=0.024$ from May 2000 to May 2001
[e] $p=0.001$ from May 2000 to October 2001;
[f] $p=0.001$ from May to October 2001
[g] $p=0.042$ from May to October 2001
[h] $p=0.008$ from May to October 2001
[i] $p=0.010$ from May to October 2001
[j] $p=0.002$ from May 2000 to October 2001

<u>Plot</u> <u>C</u>

Plot C is also a lightly vegetated plot (see Sheet 4). This plot is similar to Plot A in that the majority of the transects were established in June, 2001. Only 12 quadrats were sampled during 2000, a sample size too small to yield valid statistical results, so results are available only for June to October, 2001. An analysis of the available data yielded mixed results. Of the 10 cover types analyzed, most experienced decreases, while 2, annuals and monocots, actually increased in percent cover between June and October 2001 despite the infra-red treatments. Statistically significant decreases were not as great as in the other plots, but were noted for the total percent cover ($p=0.028$), perennials ($p=0.042$), herbaceous ($p=0.046$). and dicot percent cover ($p=0.025$). These four had the largest initial percent covers in June 2001. Four other cover types also showed decreases, though none were significant. See Table V3 for a presentation of the vegetational change over time.

Table 5. Vegetation Cover Plot C – Lightly Vegetated.

	May 2001	October 2001
Total %Cover [a]	**8.60**	**3.98**
Perrenials [b]	**7.53**	**3.30**
Annuals	0.05	0.08
Biennials	0.82	0.48
Herbaceous [c]	**7.65**	**3.53**
Woody	0.97	0.45
Monocots	0.43	0.55
Dicots [d]	**8.13**	**3.42**
Moss/Ferns	0.03	0.02
Gymnosperms	0.02	0

[a] p=0.028 [b] p=0.042 [c] p=0.046 [d] p=0.025

Plot D

This plot has medium vegetational cover, and included 30 to 36 quadrats over the sampling period. Like the other transects, Plot D transects experienced an increase in vegetational growth from May to November 2000. Of the 10 cover types analyzed, 7 had statistically significant increases (p<0.001 for all but p=0.006 for annuals percent cover). Both monocots and moss/fern percent cover increased but neither was significant, and gymnosperms were not found in the plot during 2000. Plant growth continued to increase from November 2000 to June 2001, with statistically significant increases in total percent cover (p=0.023), biennials (p=0.008), woody species (p=0.001), dicots (p=0.027), and gymnosperms (p=0.0l2). In comparing May 2000 to June 2001, statistically significant increases were observed in all cover types expect monocots and moss/fern percent cover; of these, only annuals (p=0.021) and gymnosperms (p=0.012) were less than p<0.001. From June 2001 to November 2000, decreases in vegetation were observed in all ten cover types, with statistically significant decreases (p<0.001, except as noted) observed for total percent cover, perennials, biennials, herbaceous, woody, dicots, moss/fern (p=0.047), and gymnosperm percent cover (p=0.023).

During the period from May 2000 (initial pre-treatment monitoring) to October 2001, (post-treatment monitoring), all cover types experienced statistically significant increases with the exception of the moss/ferns percent cover which decreased slightly, monocots percent cover which increased slightly, and gymnosperms percent cover(which were not found during either sampling period. Although the 2 infra-red treatments did decrease the vegetation percent cover during 2001, they were not reduced to levels seen during the initial vegetation monitoring in May 2000.

Table 6. Vegetation Cover Plot D – Medium Vegetation.

	May 2000	November 2000	May 2001	October 2001
Total %Cover [achk]	3.57	27.64	36.29	10.73
Perrenials [ahk]	2.33	14.53	18.72	5.97
Annuals [bi]	0.15	3.81	1.29	0.62
Biennials [adhk]	0.39	8.33	15.64	3.47
Herbaceous [ahk]	3.17	18.90	17.13	6.85
Woody [aehk]	0.40	8.39	19.14	3.88
Monocots	1.07	2.25	2.35	1.67
Dicots [afhi]	2.39	23.51	31.71	9.03
Moss/Ferns [l]	0.11	1.57	2.13	0.03
Gymnosperms [gjm]	0	0	0.08	0

[a] $p<0.001$ from May to November 2000
[b] $p=0.006$ from May to November 2000
[c] $p=0.023$ from November 2000 to May 2001
[d] $p=0.008$ from November 2000 to May 2001
[e] $p=0.001$ from November 2000 to May 2001
[f] $p=0.027$ from November 2000 to May 2001
[g] $p=0.012$ from November 2000 to May 2001
[h] $p<0.001$ from May 2000 to May 2001
[i] $p=0.021$ from May 2000 to May 2001
[j] $p=0.012$ from May 2000 to May 2001
[k] $p<0.001$ from May to October 2001
[l] $p=0.047$ from May to October 2001
[m] $p=0.023$ from May to October 2001

New Hampshire Controls

The New Hampshire control plots were established to compare the traditional herbicide treatments to the infra-red treatments. These are a series of 10 transects that in May 2000, were moderately vegetated. They were originally sampled a day before the Railroad applied herbicide to the track in New Hampshire. These transects were not re-sampled in November 2000, but were re-sampled in both June and October 2001. In comparing May 2000 to October 2001, all cover types have decreased with statistically significant decreases noted for total percent cover ($p=0.002$), perennials ($p=0.005$), woody species ($p=0.011$) and dicots ($p=0.005$).

Table 7. Vegetation Cover New Hampshire Plot – Herbicide Control
Treated with herbicide after May 2000 vegetation sampling.

	May 2000	November 2000	May 2001	October 2001
Total %Cover [a]	7.60	N/S	0.10	0.02
Perrenials [b]	5.12	N/S	0.10	0.02
Annuals	1.85	N/S	0	0
Biennials	0.27	N/S	0	0
Herbaceous	3.15	N/S	0	0
Woody [c]	4.45	N/S	0.10	0.02
Monocots	2.47	N/S	0	0
Dicots [b]	5.12	N/S	0.10	0.02
Moss/Ferns	0.02	N/S	0	0
Gymnosperms	0	N/S	0	0

[a] p=0.002 from May 2000 to October 2002 [b] p=0.005 from May 2000 to October 2001
[c] p=0.011 from May 2000 to October 2001

No Treatment Ouadrats

The treatment plot boundaries were not established until June 2001. NEE established sampling transects along the entire 30 miles of track in Vermont. The treatment plots did not include all of the original transects, and some of these transects have been re-sampled during each of the sampling periods. Unfortunately, only during June 2001 were 30 quadrats sampled; during the other sampling periods, fewer quadrats were sampled: in May 2000, 27 quadrats were sampled; in November 2000 only 12 quadrats were sampled; and in October 2001 only 21 quadrats were sampled. Unfortunately, these data were insufficient to yield any statistically significant results. If the State of Vermont plans to continue vegetative monitoring after infra-red treatments in the future, NEE recommends that all 30 quadrats which have received no treatments be sampled for analysis.

Although the data are not yielding statistically valid results because the sample size is too small, there are some interesting trends. A similar pattern in vegetative cover is observed for the No-Treatment quadrats as was observed in the Treatment Plots. From the baseline sampling in May 2000, vegetation percent cover increased until June 2001, and then decreased again in October 2001, almost to percent cover levels observed in May 2000. This is the same pattern that was observed in the Treatment Plots: an increase in the vegetative percent cover from May 2000, to June 2001, and then a decrease in percent cover to October 2001.

Table 8. Vegetation Cover – No Treatment Plots.

	May 2000 (N=27)	November 2000 (N=13)	May 2001 (N=30)	October 2001 (N=21)
Total %Cover	13.39	22.96	23.13	12.57
Perrenials Annuals Biennials	6.76 2.89 0.43	6.73 10.73 0.31	12.00 6.73 1.03	6.48 5.17 0.62
Herbaceous Woody	12.52 0.89	22.96 0	22.45 0.254	12.29 0.26
Monocots Dicots Moss/Ferns Gymnosperms	3.43 9.91 0.06 0	5.39 17.54 0.04 0	5.08 17.35 0.15 0.1	2.52 9.79 0.14 0.10

At this time, there is no conclusive evidence the infra-red treatments have successfully reduced vegetation percent cover on the SL&A in Vermont. Vegetation growth patterns were similar for all plots and quadrats, even for ones that had received no treatments, herbicide or track maintenance.

A first assessment of these data seems to indicate the infra-red treatments were successful in reducing the percent cover of the vegetation on the railroad tracks in Vermont. However, the vegetative pattern observed in the No Treatment Quadrats (though not statistically analyzed due to the sample size) follows the same pattern seen within the Treatment Plots, indicating other factor(s) were impacting the growth of vegetation during the summer of 2001. In 2000, all quadrats, except those which received track maintenance, had a significant increase in vegetative cover. In 2001, all transects, even those without any treatments, herbicides, or track maintenance, had a substantial decrease in vegetative cover. The drought that occurred during the summer of 2001 is a potential factor for the noted decrease in vegetative percent cover recorded across all transects.

A second indicator that drought may be the cause of vegetative decline along the railroad tracks is the data from the New Hampshire Control plots. When these plots were monitored in May 2000, they had not received an herbicide treatment for 2 growing seasons. They were re-sampled in October 2001, and had not received any herbicide treatments for 2 growing seasons, yet the vegetation percent cover was significantly less than in May 2000. Under typical weather conditions (not drought), the vegetation in October 2001 would be expected to have similar percent cover to May 2000 (compare October 2000 to June 2001 for all treatment plots).

Unfortunately NEE could not state conclusively that the infra-red treatments were successful in reducing vegetation percent cover on the railroad ballast. A second year of treatments following the recommended treatment protocol designed by Greg Prull of IPM, Associates, (with more treatments on the plots that are more heavily vegetated) followed by vegetative monitoring in the fall, would yield more conclusive results. An important aspect of the treatment protocol is the infra-red treatments be administered only within the 4 treatment plots so the No-Treatment plots, which are scattered along the 30 miles of track in Vermont outside of the Treatment Plots, can be used as controls, as well as the herbicide treated plots in New Hampshire.

Vegetation Summary: NEE completed initial monitoring of vegetation on the SL&A in Vermont during May and November 2000, establishing the vegetation coverage along the track. Using this information, 4 treatment plots, each approximately 4 miles in length, were established on the SL&A in northeastern Vermont in May 2001. During June and October 2001, NEE sampled a minimum of 10 transects within each of the 4 plots, 10 transects on a section of track in New Hampshire that had received herbicide, and 9 pre-existing transects outside of the treatment plots on the track within Vermont.

The number of infra-red treatments each plot was to receive was based on the vegetation percent cover within the plot. The light vegetation plots (Plots A and C) were to receive 2 and 3 treatments, respectively, with the infra-red equipment; the medium vegetation plot (Plot D) was to receive 4 treatments and Plot B, with the heaviest vegetation growth, was planned to have 6 treatments.

During the summer of 2001, Northeastern Vermont experienced a severe drought, and vegetation growth was not a major maintenance concern for the railroad. As a result, all treatment plots received only 2 treatments, one in June, after the vegetative monitoring, and one in September.

VIII. Conclusions and Recommendations

Conclusions:

In general, the European railroad industry appears to be much more committed to the concept of integrated vegetation management than the North American railroad industry. This most likely is a result of a combination of cultural perceptions, regulatory restrictions and administrative differences related to public (European) vs. private (North America) ownership. The European experience has shown that the technology to implement integrated vegetation management programs is available and achievable given the proper incentives. Those incentives are not in place in North America.

Control of vegetation in railroad rights-of-way is an important maintenance function for railroads to help maintain integrity of the track structure, provide for safety of railroad personnel, and to help prevent fires. However, vegetation control is becoming increasingly challenging due to a growing number of environmental rules and regulations and public concerns about the routine use of herbicides. An integrated vegetation management program can help railroads address these issues through the development of specific strategies and plans for effective utilization of a variety of tools to control weeds in railroad ballast. This project demonstrated that thermal weed control treatments could be one of these tools. However, work yet remains to determine more definitively how, where, and to what extent these methods can be cost effectively applied.

The timing, interval, and frequency of thermal treatments are critical to their efficacy. Implementation of the project work plan was late and incomplete, detracting from the potential value of the project for evaluating the utility of the equipment. Control treatments were started well after they were originally scheduled and treatment intervals were so extended they negated the impact of earlier treatments by allowing weeds to fully recover, and treatment frequencies did not approach planned levels, particularly for the 2 sites with the highest percent weed cover and most established plants. Defining the potential to use thermal equipment for cost effective control of weeds in railway ballast is dependent on appropriate implementation of treatments.

The vegetation monitoring data did not yield conclusive results on the success of using infra-red treatments to control vegetative growth on the railroad ballast area. The pre-treatment baseline sampling found that vegetation percent cover had increased significantly during 2000 in all transects except those on which track maintenance was performed. From June to October 2001, statistically significant decreases in vegetation were observed within all transects, including ones which received no infra-red treatments, herbicides, or track maintenance. The significant decrease in vegetation within transects that did not receive infra-red treatments indicates that other factors, including the drought, may be responsible for the decrease in vegetation recorded between the two sampling periods.

Costs can be controlled by incorporating vegetation management into a railroad's regular maintenance work, using its own equipment and personnel. However, despite their interest in effective weed control as a maintenance requirement, railroads must generally focus on service and equipment maintenance functions to succeed as a business. Therefore, reliance on railroads for implementation of field trials may result in less than optimum performance. Unless vegetation management is given adequate priority within a railroad's maintenance plan, effective vegetation management may be precluded by the diversion of available resources to higher priority activities. When resources and priorities are directed away from vegetation management, the use of contractors to prepare equipment and implement thermal treatments should be considered as an option to ensure work plans are completed as designed and vegetation management objectives are achieved.

This project illustrated that a ballast regulator could be readily adapted to carrying and utilizing thermal equipment for effective right-of-way weed control, primarily within the ballast prism. Further work on this platform will develop its utility for this purpose. However, there are drawbacks and constraints to its use. Additional platforms should be considered and evaluated to help determine an optimum system for employing thermal equipment for railroad right-of-way weed control.

Recommendations:

1. Continue to evaluate platforms for deploying thermal technology to the track right-of-way: This project relied on a ballast regulator to carry and deploy thermal weed control equipment. Other platforms and/or configurations for thermal equipment application may be feasible, more productive, and more cost-effective. Since it is likely that the future will see further limits on the use of chemicals for weed control in railroad ballast and that other methods will be needed to replace those tools in some instances, exploration of additional ways and means to implement the use of thermal equipment for ballast weed control should be considered. Since developments in this regard could have wide application, public funding sources may support such efforts.

Additional platforms should be considered and evaluated to help determine an optimum system for employing thermal equipment for railroad right-of-way weed control. For example: single purpose hi-rail trucks - i.e., installation of a single side or center unit on a small truck that hauls propane and water supply for the unit they carry. Each truck would be able to operate at a range of speeds for work or travel and would be highly mobile: able to travel quickly and to get on and off the rails at many locations to get out of the way of oncoming traffic, for storage or service (e.g., repairs, fuel, water), or to move to other work sites. Each vehicle would be responsible for treating a specific portion of the ballast (left or right side or the center) and could move quickly along the track from one treatment site to the next, making work on that portion of the ballast very focused and productive. A second small truck would accompany the application vehicle for safety and to provide support, including fire watch. These service trucks would carry tools to supply propane or water to the work truck as well as fire control tools in the event of an emergency. This approach would provide great flexibility for treatment applications, likely be more productive than other platforms that have been used to date, not require set-up and transition costs from one type of equipment to another or tie up use of important equipment when it is needed for other operations (as with the ballast regulator), and perhaps cost less for purchase, operation, maintenance, and replacement than the large truck used by the Alaska Railroad.

2. Evaluate ways to assist railroads in Vermont to implement integrated vegetation management activities in their work plans: The Vermont Agencies of Transportation and Agriculture and the Vermont Pesticide Advisory Council should consider ways to encourage and make resources available to Vermont railroads to develop and implement alternative vegetation control plans and methods that would help reduce the use of herbicides by railroads, consistent with state policy, without creating an undue burden on the railroads. Current regulations limiting the use of herbicides have created a real need for the development of cost-effective alternatives.

3. The equipment developed for this project should be utilized for further implementation of field trials and regular vegetation management activities: Additional tests should be scheduled to evaluate the most effective and efficient use of the technology developed under this project. VTrans and SL&A should investigate ways to make the equipment available to other railroads in Vermont for vegetation control.

4. Railroads should be encouraged to develop and implement comprehensive integrated vegetation management plans. Opportunities to provide business incentives to railroad companies to pursue non-chemical alternatives would appear to be a significant requirement in order to develop acceptance by the railroad industry in Vermont and elsewhere.

Figure 13: Thermal vegetation control equipment in action on the Saint Lawrence and Atlantic Railroad in Northeastern Vermont.

IX. Related Literature

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* Report produced pursuant to contracts let by this project.
** Highly recommended reading