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FINAL REPORT

ALASKA RAILROAD CORPORATION INTEGRATED VEGETATION MANAGEMENT RESEARCH PROJECT

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FOREWORD

This project initially focused on an investigation of herbicide persistence and migration in Alaska. The scope was later broadened to include alternative methods of vegetation control.

Completion of this research investigation required the efforts of numerous individuals. Four students completed Master of Science theses on subjects associated with this project, and as required for their graduate degrees in the Environmental Quality Engineering and Science Program, Department of Civil Engineering, University of Alaska Fairbanks. The four students were Ms. Jill S. Chouinard, Mr. Darren F. Mulkey, Mr. Adam H. Owen and Ms. Tracey L. Preston.

The report that follows is in large part from the theses prepared for the respective students' University of Alaska thesis requirements. Those students are recognized and acknowledged for their efforts without which this project would not have been completed. The report reflects their efforts and those of others spanning more than two years of study.

An Executive Summary is included with this report to provide the reader with an overview of the project and its findings.

Timothy Tilsworth and Lawrence A. Johnson
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Mr. Ralph Chiperno - Roadmaster
Ms. Debby Davis - Secretary
Mr. Walter Earl - Logistics
Mr. Mike Fretwell - Surveying
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Ms. Phyllis Johnson - Legal
Ms. Steve Love - Roadmaster
Ms. Donna Rulien - Finance
Ms. Juanita Stewart - Secretary
Ms. Cheryl Sautel - Secretary
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EXECUTIVE SUMMARY

**NOTE: This executive summary has been prepared for the purpose of providing the reader a summary of the major findings of this study. It is not intended to be a stand-alone document. Therefore, the reader is cautioned to interpret information in the context in which it was intended.

This project consisted of field testing to determine persistence and migration of herbicides on the Alaska Railroad Corporation (ARRC) right-of-way, literature reviews of vegetation control methods used by railroads, a survey of operating railroads in the U.S. and Canada, cost analyses of vegetation control methods used by railroads in general and the Alaska Railroad in particular, laboratory testing under controlled conditions, and an evaluation of vegetation control methods along the ARRC right-of-way.

The herbicide portion of the project was designed to address the persistence and migration of two herbicides in the field. This was accomplished through laboratory determination of residual levels of the chemicals in soil applications. Analyses were done by taking soil samples and performing pesticide extraction and cleanup procedures on the soils so that the extracts could be analyzed by gas chromatography.

Concentrations of the herbicides were determined at four depths in the soil: surface (0 ft), 1 ft, 2 ft, and 3 ft. Soil samples were taken at intervals of approximately 0, 7, 49, and 365 days after initial application of the herbicides.

Persistence was evaluated by analysis of the parent compound through time, which was then compared to the original application concentration. Migration was tracked through analysis of samples at progressive depths through time and soil outside of the application zone.

The herbicides that the Alaska Railroad Corporation chose for the study were Velpar (active ingredient, hexazinone), which is sold in powder form, and Garlon 3A (active ingredient, triclopyr), which is sold as a liquid concentrate. Velpar is produced by Du Pont De Nemours & Co. and is used primarily for the control of grasses and broadleaf and woody plants (USEPA, 1988a). Garlon 3A is produced by Dow Chemical Co. and is used primarily for the control of brushy plants (Dow Chemical Co., 1989). In combination, these two herbicides can control a broad spectrum of vegetation.

Eight herbicide treatments at six sites were chosen for this study. A mixture of Velpar and Garlon 3A was applied to six of the treatments, while the remaining two treatments consisted of Garlon 3A at one plot and Velpar at another plot. The site locations were at the ARRC Seward Rail Yard, Fire Creek siding near Birchwood, ARRC Birchwood Rail Yard, Chulitna Wye, ARRC mainline gravel pit near Clear Air Force Station, and the Eielson Branch next to Fort Wainwright. Each treatment plot was 24 feet by 105 feet, resulting in a total combined herbicide application area of less than 0.5 acre.

The literature review utilized extensive references in both railroad technical reports and journals as well as reports in scientific journals, particularly relating to chemical control of vegetation. In addition, a survey was mailed during May 1989 to 174 railroads in the United States and Canada. All railroads listed with 50 miles or more of track were contacted. After the original survey form was mailed, a second form was distributed in an attempt to increase the response rate. To determine what methods other countries were practicing for vegetation control, the survey was also sent to a selected group of railroads in foreign countries.

Of the 174 railroads contacted, 106 responded to the survey, a 60 percent response rate. The survey form requested a description of the vegetation management control methodology in both the roadbed and the wider right-of-way. The use of herbicides, their application rates, costs, and application times were also requested, along with a description of the costs and techniques for physical, thermal/burning, and other methods used to eliminate vegetation along the right-of-way. Vegetation management reports and cost effectiveness data were also requested.

Ninety-four percent of the railroads responding to the survey use herbicides in their vegetation control programs. Most railroads did not restrict themselves to one chemical, but used several products simultaneously.

Most railroads also reported using another form of vegetation control in conjunction with herbicides. Physical methods, such as mowing and brush cutting, were common control strategies.

The cost analyses of vegetation control methods examined both railroads outside Alaska and the Alaska Railroad. An independent cost estimate for railroads outside of Alaska was developed for each method of vegetation control applicable in the ballast area or trackbed. Data were obtained through a review of the pertinent literature and by personal communications. When possible, estimates were prepared using a range of data to account for varying conditions.

Each estimate is divided into equipment costs (including maintenance and fuel), labor costs (including base pay, benefits, and per diem), mobilization and demobilization costs, overhead and indirect costs, and profit. Materials costs were also included where applicable. The costs are reported in dollars per track mile for a specified width of control. All costs were converted into a 1991 average U.S. city dollar base using the United States Consumer Price Index (CPI-US).

Economic analyses were also performed for those vegetation control alternatives appropriate for the trackbed of the Alaska Railroad. Six main alternatives for vegetation control within the trackbed were examined: herbicide application, reballasting, ballast regulating, undercutting, brushcutting and hand clearing. The cost per track mile, as well as a normalized cost, are given for each alternative.

These costs are based on data obtained from the Alaska Railroad and other sources. Where no information was available, assumptions were made. Engineering economic principles were applied to adjust costs to an Anchorage, Alaska 1991 dollar base and to express costs on an annual basis.

The vegetation control methods portion of the project evaluated the effectiveness of methods for eliminating and preventing reestablishment of all vegetation within the Alaska Railroad roadbed. Seven different treatments (herbicide mixture, hand weeding, hand cutting, multiple hand cutting, ballast regulation, reballasting, and a combination of ballast regulation and reballasting) were evaluated at four sites (Fort Wainwright, Clear, Birchwood, and Seward) along the Alaska Railroad during the 1989 and 1990 growing seasons.

Treatment effectiveness was measured by plant abundance as indicated by 1) percent cover and 2) stem counts of woody species. Additional field studies included evaluation of plant abundances at two sites where the track structure had been rebuilt during the last decade, ballast particle size analyses at the six sites, and excavation of plant root systems at each of the four intensive study sites.

CONCLUSIONS

1. No single type of vegetation treatment was most effective for all cases in reducing total vascular cover (TVC) or the number of (woody) stems at 10 cm and 50 cm. However, the herbicide treatment had the highest frequency of any single treatment for being among the group of most effective after one year (37%) and after two years (47%).

2. Any single method of vegetation control has limitations. For example: a) the ballast regulator may not be able to remove vegetation more than five feet beyond the ends of the ties and can only control vegetation between the ties by means of a broom, b) herbicides should be restricted in their use when applied adjacent

to water bodies, c) hand weeding cannot effectively remove large diameter or deeply rooted woody species, and d) mechanical brush cutting is not presently done between the ties.

3. For railroads outside Alaska, the three least expensive control methods on a per-mile basis were using the ballast regulator every second year, applying herbicides every year, or brushcutting annually. These results are based upon both an independent economic analysis and a survey of railroads.

4. Engineering analyses suggest that herbicides are one of the most cost effective vegetation control methods. However, these analyses do not include intangibles or externalities, nor do they incorporate monitoring requirements. Should herbicides contact groundwater in significant concentrations, considerable liability could result from cleanup requirements. Even though there was little indication from this field evaluation that groundwater contamination could occur, there is substantial evidence from past use of pesticides in the U.S. that contamination has occurred. It is unknown if this contamination was due to improper use or was caused by improper application of pesticides or if it occurred in proximity to railroads. A recent national survey of pesticides in water wells reported that they were unable to find hexazinone in concentrations above minimum reporting limits (MRL).

5. Unexplained results from the Chulitna site indicate that herbicides will not be uniformly effective, necessitating a second application or an alternate control method.

6. Under some conditions, physical/mechanical control methods are cost competitive for controlling vegetation, particularly when the costs of monitoring of herbicides are considered.

7. Difficulty is encountered in comparing alternative control methods based on the short term nature of results from this research

project. Extrapolation of the project information is not possible without continued evaluation.

8. Use of high quality ballast, as required by present ARRC specifications, could reduce vegetation control problems, but for an unknown period of time.

9. Vegetation control between the ties is readily accomplished through the use of chemicals. It is also possible to control vegetation using mechanical and manual methods. Factors such as convenience, safety, cost and effectiveness should be considered when selecting a method.

10. This project evaluated the efficacy of Velpar and Garlon 3A at controlling vegetation. It did not evaluate the efficacy of other herbicides. New generation herbicides are available that may be more effective, have a higher LD_{50}, be less toxic, less susceptible to leaching/migration, less persistent and more environment friendly.

11. Velpar and Garlon 3A were both found to persist up to one year at all of the sites tested. Therefore, it is probable that they could persist in detectable quantities for periods beyond one year.

12. Velpar was detected at the three-foot depth at all study sites. Garlon 3A was detected at the three-foot depth at all sites except Fort Wainwright. It is not known if the herbicides migrated deeper than three feet, as no testing occurred beyond that depth.

13. Regulatory agencies may require monitoring of herbicides in addition to other safeguards to reduce or eliminate environmental impacts of chemicals based on the results of this project. Significant vertical movement of both Velpar and Garlon 3A occurred.

14. No lateral or horizontal migration of Velpar or Garlon 3A from the application zone was detected at any of the sites evaluated.

15. The herbicide treatments had off-site effects upon mature trees at two of the six sites tested. There was no evidence of drift during the application, and the off-site effects are believed to have resulted from translocation of the herbicides through plant root structures.

16. Public opposition exists to the use of chemicals for vegetation control in Alaska and other parts of the country.

17. Adoption and implementation of integrated vegetation management (IVM) could enhance vegetation control, reduce cost, lessen environmental impact and produce favorable public opinion.

RECOMMENDATIONS

1. Adopt and implement an integrated vegetation management philosophy.

2. Conduct a vegetation survey of the ARRC trackbed to determine species, density, and frequency. The IVM plan would draw upon this survey to assist in selection of vegetation control alternatives.

3. Continue monitoring, at a reduced level, herbicide persistence and migration, impact on off-site vegetation, and vegetation recovery on treatment plots for a period of at least two years to include the summer seasons of 1991 and 1992.

4. Continue the use of a Vegetation Advisory Committee.

5. Initiate and develop IVM that incorporates public participation.

6. Continue to evaluate new alternative control strategies for vegetation management, such as steam, new generation herbicides, and other methods.

7. Improve railroad record-keeping to more accurately determine vegetation control costs and to define vegetation recovery rates.

INTRODUCTION

This report reflects two years of research conducted by the Institute of Northern Engineering, University of Alaska Fairbanks (UAF) on integrated vegetation management (IVM) along the Alaska Railroad right-of-way (ROW). It examines the persistence and migration of two herbicides selected by the Alaska Railroad Corporation (ARRC) and the cost and effectiveness of various methods of vegetation management including, but not limited to, herbicides.

JUSTIFICATION

Vegetation management on the roadbed and right-of-way is essential for safe railroad operation. Within the roadbed, vegetation control enhances visibility and maintains side clearance for railcars, reduces wheel slippage, prevents uncontrolled fires, maintains drainage of the track roadbed, and satisfies United States Department of Transportation Federal Railroad Administration Track Safety standards. Beyond the roadbed, vegetation control prevents interference with signals, communications and power lines, maintains visibility, and meets Federal Track Safety Standards.

PROJECT HISTORY

In January 1988, the ARRC applied to the Alaska Department of Environmental Conservation (ADEC) for a permit to use herbicides on their right-of-way. Governor Cowper intervened in the process and denied the permit until data on herbicide persistence and migration under cold Alaskan conditions were gathered. Previously, Governor Hammond on May 11, 1978 had issued a directive to state agencies that halted the applications of herbicides by the State of Alaska. Subsequent governors, Sheffield and Cowper, upheld the Hammond directive.

The ARRC applied to use two herbicides: Garlon 3A (active ingredient triclopyr), manufactured by Dow Chemical Company, and Velpar (active ingredient hexazinone), manufactured by E.I. DuPont Corporation. Following denial of their permit application, they contracted with the University of Alaska Fairbanks (UAF) to study the persistence and migration of these two herbicides under field conditions (Mulkey, 1990) and in controlled lab experiments (Owen, 1991). To supplement the herbicide study, the project was expanded to include research on integrated vegetation management (IVM). The IVM study had three goals: (1) to evaluate ARRC's past vegetation management program (Preston, 1991); (2) to investigate the methods used by other railroads to control vegetation on their rights-of-way (Chouinard, 1990); and (3) to assess the effectiveness of the most promising vegetation control methods along the ARRC roadbed over the course of two growing seasons--1989 and 1990.

OBJECTIVES

The overall objective of this project was to evaluate alternatives for integrated vegetation management within the roadbed of the Alaska Railroad. The two major portions of the study concerned 1) the persistence and migration of the two herbicides, Velpar and Garlon 3A, under Alaskan conditions and 2) the cost and effectiveness of vegetation control methods in Alaska.

The specific objectives of the persistence and migration portion were:

1. to determine the persistence of Garlon 3A and Velpar in Alaskan soils under field conditions;

2. to determine the migration of Garlon 3A and Velpar in Alaskan soils under field conditions; and

3. to conduct leaching and degradation studies of Garlan 3A and Velpar under controlled laboratory conditions.

The specific objectives of the cost and effectiveness portion of this study were:

1. to identify pertinent vegetation control methods from the literature for the ARRC;

2. to survey vegetation control methods used by the ARRC and other railroads;

3. to estimate costs for vegetation control methods by railroads outside of Alaska and by ARRC;

4. to evaluate the effectiveness of methods for eliminating vegetation along the ARRC roadbed, allowing for variabilities due to plant growth form, climatic conditions, and ballast type;

5. to estimate short term control of vegetation regrowth and reestablishment along the ARRC roadbed; and

6. to make recommendations for future ARRC vegetation research and management.

Figures and tables for this report are included at the end of each chapter for ease of access.

HERBICIDE PERSISTENCE AND MIGRATION

INTRODUCTION

Vegetation control is a necessary part of maintaining the integrity of railroad rights-of-way. Federal Track Safety Standards require safe walkways and access for inspection of the track and railcars. Vegetation control prevents interference with signals, communications, power lines and visibility. It also relates to structural stability, primarily the track roadbed drainage. This is important in order to maintain the track's load carrying capacity and to reduce frost action in the roadbed. Other significant benefits of vegetation control include fire prevention and the reduction of wheel slippage.

When discussing vegetation control, plants are usually referred to as weeds. From this a weed can be defined as any plant that is in a place where it is unwanted.

METHODS OF WEED CONTROL

There are several methods or categories of weed control: preventative, physical, cultural (crop management and competition), biological, and chemical. In practice, the major emphases and efforts are placed on mechanical and chemical methods (Ross and Lembi, 1985). This section of the report deals with chemical methods, including herbicides.

Chemical weed control has been widely used because it is effective at a reasonable cost. Nonselective methods have been practiced for centuries through the application of salt, ashes, smelter wastes, and other chemicals. The discovery of the herbicidal properties of 2,4-Dichlorophenoxy-acetic acid (2,4-D) during the 1940s triggered the development of hundreds of pesticides. Herbicides have provided many advances in weed control during the past three decades and will likely do so in the near future (Ross and Lembi, 1985). An example of an ideal herbicide would be one that is effective at low rates, is economical to manufacture, has a broad spectrum of uses, is safe and easy to handle and apply, and has little adverse effect on the environment.

TOXICITY

A substantial portion of the cost of herbicide development is devoted to assessing its effects on human health. These effects are commonly expressed in terms of toxicity and hazard. Toxicity is the amount of compound that is harmful or lethal, whereas hazard is the probability of encountering a harmful dose of a compound. Hazard includes both the extent of exposure and its toxicity. An extremely toxic compound used in small amounts may be less hazardous than a less toxic compound used in large quantities.

Adverse effects on humans are estimated from toxicology studies on experimental animals such as rats, rabbits, and dogs. Chemicals may also be evaluated for possible oncogenic (tumor producing), carcinogenic (cancer producing), teratogenic (deformity producing), and mutagenic (genetic abnormality producing) properties. Those that are carcinogenic are not approved for use.

Potential toxicity to the user is generally expressed in terms of the acute (short term) oral dosage as measured by the 50% lethal dose (LD_{50}). The acute oral toxicity is the single dose in milligrams of compound per kilogram of body weight taken by mouth or ingested that will kill 50% of the population of test animals. Toxicology data for fish species are expressed in terms of 50% lethal concentration (LC_{50}), the concentration (mg/l) that causes mortality to 50% of the population tested.

Oral LD_{50} values (rat) for selected chemicals and pesticides, in mg/kg, are given in Table 3.1. Dosages may vary according to source and test procedures. The higher the LD_{50}, the less toxic the chemical.

PERSISTENCE AND MIGRATION

Persistence and migration of herbicides play major roles in their effectiveness. The amount of time that plants are exposed to herbicides affects the degree to which the chemicals will be able to act upon target vegetation.

Persistence, as used for this report, is the length of time a herbicide, when applied at the recommended rate, interferes with the regrowth of native vegetation (Ross and Lembi, 1985). Persistence of herbicides in soil can be affected by degradation, or the chemical breakdown of the original (parent) compound, and movement or migration from the application site.

Herbicides can be degraded by a combination of environmental factors, including temperature, ultraviolet light, and microbial action. The degradation products are called metabolites. Once an herbicide has entered the soil column, microorganisms are the primary degraders. When conditions favor the growth and reproduction of microbes, degradation rates are likely to be correspondingly high. Factors that may affect the growth of microbes include temperature, availability of oxygen, soil pH, moisture, and nutrients.

Migration from an application site can affect the persistence of an herbicide. The migration rate is influenced by the herbicide's solubility, and by precipitation, soil pH, soil organic content, soil composition, and particle size distribution (Barring and Torstenssen, 1983; Feng, 1987; Harrington et al., 1982).

Infiltrating precipitation is probably the most important factor controlling herbicide transport from the initial application site. Highly soluble herbicides move with the water that percolates down through the soil during a precipitation event. The percolation rate through a soil column is directly related to soil permeability.

Physiochemical interactions of an herbicide with soil particles also influence the migration rate. Highly organic soils retard herbicide movement by binding it to the organic matter. Hygroscopic and ionic forces also play a significant role in the movement of herbicides (Feng, 1987).

HERBICIDES

Herbicide classification is based on two features: the pathway of herbicide movement in plants and the mechanisms by which herbicides control plant growth. Herbicides are symplastic (phloem translocated), apoplastic (xylem translocated), or contact (no translocation). Herbicide types, according to their mode of action, include auxin type growth regulators, photosynthetic inhibitors, disrupters of cell permeability, disrupters of mitosis, seedling root or shoot inhibitors, general metabolic inhibitors, and pigment inhibitors (Ross and Lembi, 1985).

Herbicides are also classified according to their common chemistry, such as the phenoxy acids, benzoic acids, aliphatics, dinitroanilines, biphenyl ethers, ureas, triazines, and thiocarbamates. The chemical structure and characteristics of a compound determine how the herbicide will act in biological and physical systems. Velpar and Garlon 3A are the two herbicides of interest to the Alaska Railroad Corporation; Velpar (active ingredient (a.i.) hexazinone) is a triazine herbicide and Garlon (a.i. triclopyr) is a phenoxy herbicide.

Phenoxy Herbicides

Phenoxy herbicides are widely used for controlling broadleaved weeds in grass crops such as corn, small grains, sorghum, rice, sugarcane, pasture, rangeland, and turf. They are also used for controlling woody plants in forest management, noncropland sites, and aquatic weeds (Ross and Lembi, 1985).

The phenoxy acids are primarily foliar applied and symplastically translocated, that is, carried in the plant's nutrient distribution network. They can be soil applied and absorbed by the roots, but symplastic movement in plant roots is limited. Also, they are susceptible to microbial degradation and thus are relatively short-lived in the soil. Those with a third chlorine atom in their ring are longer lived than two-chlorine phenoxy acids, but none of them accumulate significantly in soil, even as a result of continued usage. Their characteristic chemical structure is noted in Figure 3.1.

Garlon, the trade name for the herbicide triclopyr, [(3,5,6-trichloro-2-pyridinyl) oxy]acetic acid, was developed by The DOW Chemical Co. Figure 3.2 shows its chemical structure. It is available in two formulations: the water soluble triethylamine salt (Garlon 3A) or an oil soluble butoxy ethyl ester (Garlon 4). Garlon 3A has 44.4% active ingredient.

Garlon has been found to be more effective than the well-known pesticide 2,4,5-T (2,4,5-trichlorophenoxy-acetic acid) against many woody plants and broad-leafed weeds (Byrd et al., 1974), and it has potential for use on rights-of-way (Reynolds et al., 1983). It is a systemic herbicide that is rapidly absorbed by foliage and roots and is translocated throughout the plant (Worthing, 1979).

Triclopyr mimics an auxin, a plant growth hormone. It is a selective herbicide that does not injure established grasses when applied at ratios required for brush control, as its use in grass crops indicates. It provides superior control of ash, oaks, and other root-sprouting species in comparison to other auxin type herbicides (Weed Science Society of America, 1983). Its physical and chemical properties are listed in Tables 3.2 and 3.3. It has a relatively low solubility in water.

Triclopyr has a low mammalian toxicity (acute oral LD_{50}, rats, 713 mg/kg), as noted in Table 3.4, and is moderately toxic to trout and bluegills with a 96-hr LC_{50} of 117 and 148 ppm, respectively, as presented in Table 3.5 (Weed Science Society of America, 1983). Some LD_{50}s of TCP, triclopyr's aerobic metabolite, and TMP, its anaerobic metabolite, are presented in Table 3.4 as well.

Subacute toxicity tests with rats fed triclopyr at 30 mg/kg/day for a 90 day period showed no effect. Technical grade triclopyr is nonirritating to skin. Garlon 3A concentrate may cause mild irritation or a mild burn to skin if in contact for prolonged periods, such as by contaminated clothing.

Triclopyr is relatively nontoxic and is normally applied at dilute concentrations. Assuming the highest concentration of triclopyr at an application site is about three ppm, the LC_{50} values of triclopyr to fish, notably trout and bluegill, are still from 1 to 3 orders of magnitude higher (Weed Science Society of America, 1983; Gersich et al., 1984). Even if bare pure quartz sand near a fish-bearing water was treated with an unrealistically high dose of triclopyr and it leached from the sand into the water, disaster for fish and invertebrates would be improbable because of a high dilution factor.

TCP (3,5,6-trichloro-2-pyridinol), the triclopyr aerobic metabolite found in soils, is relatively nontoxic to mammals (McKeller et al., 1982; Roberts and Marshall, 1978). Its toxicity to fish is not known. Methylation of TCP in soils yields 2-methoxy-4,5,6-trichloropyridine (TMP), an anaerobic metabolite whose biological activities are unknown, as reported by Roberts and Marshall (1978). Neither TCP or TMP have herbicidal properties (Hamaker and Goring, 1976).

Degradation of pesticides in soil is accomplished through biological reactions. Microorganisms are responsible for most of this activity, which indicates that a microbiologically active soil usually has good capacity to mineralize most organic compounds supplied to the soil.

Triclopyr degrades rapidly in soil, having an average half-life of approximately 46 days, and is readily degraded by microbes. The rate of degradation is dependent on soil and climatic conditions (Lee et al., 1986). The degree to which Garlon will adsorb to soil particles depends on the organic content and pH. Leaching may occur in low organic soils under high precipitation conditions. Loss from photodecomposition results in a half-life of 10 hr in water at 25°C.

Temperature and moisture conditions control microbial activity. Under laboratory conditions, 50 percent breakdown (half-life) occurs in 10 to 46 days at 35°C. Field tests yielded degradation rates between that of 2,4,5-T and picloram (Haagsma, 1975).

Laboratory experiments found residues of triclopyr in two different U.S. soils at a temperature of 35°C for up to one year (Hamaker & Goring, 1976). A study in Sweden showed longer persistence under field conditions, where soil temperature is lower and consequently the rate of decomposition is also lower. Triclopyr had a residual persistence of at least 1-2 years, and in some cases, more than 2 years under cold conditions (Torstenssen and Stark, 1982).

The triclopyr metabolites TCP (aerobic) and TMP (anaerobic) in soil may have half-lives less than or greater than that of the parent compound. The reported half-lives of TCP and TMP are 30-60 days and 5-90 days, respectively.

Triclopyr can be retained by vegetation with delayed migrations into the soil. Analysis of early spring samples often show higher values than samples from the prior autumn because of wash off. Accumulation of triclopyr in the uppermost soil layer occurs during the winter when the rate of degradation is low. Triclopyr can be found in the soil for an extended period following application because of organic and/or vegetation binding.

Laboratory soil column studies of triclopyr found that water equivalent to 2.5 cm of precipitation percolated through the column every other day. Residues were found only in the top 10-cm layers of loam soils after 54 days (Lee, 1985). This indicated that the triclopyr residues were held in the soil by sorptive forces that did not permit desorption by water and thus inhibited a downward movement through the soil profile. Moreover, the soil's sorptive capacity was high enough for all residues to be held at, or near, the point of application.

Both clay mineral particles and organic matter in soil have large specific surfaces that absorb herbicides (Bailey and White, 1970). Sorbed pesticides resist displacement from organic soil by water, but not desorption from clay minerals (Harris, 1973; Oloffs, 1975). Desorption from organic soil fractions is mainly prevented by shielding of sorbed molecules, held by hydrophobic interactions inside non-polar, hydrophobic areas and attractive sites in the soil and soil water; e.g., ionic bonds or cooperative hydrogen bonding (Lehninger, 1982).

Another factor influencing triclopyr's limited leaching in soil is low pH, because the pH at the surfaces of soil particles is usually considered to be about two units below that of the soil in bulk solution. Triclopyr has a pK_a of 2.68 (Spencer, 1982), which results in a significant fraction of it not being ionized at low pH.

Triazine Herbicides

The active ingredient in Velpar is hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione). Hexazinone is a triazine herbicide that is primarily soil applied. Triazines are used widely for the selective control of annual grasses and broadleaved weeds in crops.

The chemical structure of the triazine molecule is a ring composed of nitrogen and carbon atoms as shown in Figure 3.3. Most triazines are symmetrical; that is, the carbons and nitrogens alternate in the ring. In hexazinone (Figure 3.4), however, the ring structure is asymmetrical due to radicals attached to the ring.

Triazines are photosynthetic inhibitors that are activated by light, resulting in chlorosis and desiccation of green tissues. They move apoplastically (carried in the plant's water and mineral salt distribution network), whether taken in through the roots or shoots, and movement is up and out of the plant. When soil applied, they are readily taken up by seedling roots and move into emerging foliage.

Triazines are relatively persistent in soils and can cause carry-over problems in susceptible crops. The amount of precipitation, soil type, pH, and other factors all affect persistence. They are more persistent under arid conditions and high pH soils.

Velpar - the trade name for the herbicide hexazinone manufactured by E.I. DuPont DeNemours and Company - is sold in four formulations: Velpar weed killer, a 90% hexazinone soluble powder; Velpar L weed killer, a 25% hexazinone miscible liquid; Velpar Gridball brush killer, a 10% hexazinone pellet; and Velpar K products, which contain wettable powders of hexazinone and diuron. The type of Velpar weed killer used in this study was the 90% hexazinone soluble powder form.

The active ingredient in Velpar is 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione (hexazinone). The chemical structure is shown in Figure 3.4. Hexazinone is a triazine herbicide that controls grasses and broadleaved weeds for both preplanting and postplanting applications in forest vegetation management. Velpar weed killer is an effective herbicide for the control of many annual and perennial broadleafed weeds, grasses, herbaceous vines, and woody plants. It is used for site preparation and conifer release in forest renewal and production operations. The herbicide hexazinone received temporary forestry registration for ground application beginning in 1984 (USEPA, 1988a).

Hexazinone is commonly applied to the soil surface by either a spotgun or broadcast spraying. It is water soluble and soil mobile and thus is transported by soil water to the roots of the target species. Root uptake is the principal absorption mechanism. Hexazinone is translocated to the foliage, where it blocks the photosynthetic process. It is dissipated in soil by photodegradation, biodegradation and leaching. Weed control increases for moist soils but, if the site is continuously wet, off-site movement can occur. Rainfall of one-quarter to one-half inch within two weeks of application provides the best weed control by moving the herbicide to the root zone.

Site specific environmental conditions, including soil moisture, soil temperature, rainfall and snowmelt regimes as well as soil texture and organic matter content, are important to achieve maximum benefit from hexazinone and minimize risks to nontarget species. Application is subject to specific use recommendations for different soil textures based on efficacy, leaching (soil texture), and organic matter in the soil.

Hexazinone has a solubility in water of 33 g/kg at 25°C (Worthing, 1979) and thus is easily mobile in soil unless it is mineralized. It is susceptible to off-site movement in storm runoff and leaching. However, lateral or vertical movement in soil may be slowed because of high organic matter or clay cation exchange capability. As a result, hexazinone is moderately to strongly adsorbed in most soils. Its solubilities and properties are summarized in Tables 3.6 and 3.7.

Hexazinone has very low toxicity in animals. The concentrations commonly applied for weed control are two or more orders of magnitude lower than the LD_{50} concentrations found to affect animals (USEPA, 1988b). LD_{50}s and LC_{50}s are summarized in Table 3.8. The toxicity of the metabolites of hexazinone have oral Approximate Lethal Doses (ALDs) for rats as reported in Table 3.9.

Hexazinone persistence, leaching and lateral mobility have been highly variable, depending on the soil types and climatic conditions (Miller and Bace, 1980; Harrington et al., 1982; Barring and Torstenssen, 1983; Neary, 1983).

Half-life times for hexazinone under field conditions are reported to be 1-6 months (Riggleman, 1978; Rhodes, 1980). The wide variability is due to soil types and climatic conditions. Hexazinone was found at the 50-60 cm level one year after application in Sweden (Barring and

Torstenssen, 1985). Precipitation and temperature data were not presented for that study. The concentrations at which it was found ranged from 0.03-3.0 ppm. The higher values were attributed to increased clay contents, which created anaerobic conditions that discouraged the degradation of the herbicide (Rhodes, 1980).

A high soil organic content to which the herbicide can be bound favors retention in the surface layers of the soil. For soils having organic matter greater than 10%, the intended effect on brush will not be achieved because the herbicide may not be transported to the roots (Barring and Torstenssen, 1983). Binding of the herbicide in the soil is then too strong for the roots to take up sufficient amounts. Therefore, a soil with moderate organic material is a condition for successful treatment because it results in large amounts of herbicide penetrating down to the mineral soil where it is easily transported away by roots. However, the finer the soil material, the longer the vertical transport delay. Nonetheless, it can still result in a considerable amount of the applied hexazinone penetrating to soil depths of one meter or more (Barring and Torstenssen, 1985).

Rhodes (1980) found that the leaching potential for hexazinone is greatest soon after application and then diminishes with time, based on a soil column study. Another study, with a slope of 12-15 degrees, used biological tests that revealed the herbicide had moved at least two m down slope and had penetrated the soil to a depth of at least 30 cm (Neary et al., 1986). Some field studies have not shown lateral or downslope movement of hexazinone or its metabolites in leached or runoff water even though lab experiments have demonstrated the potential (Neary et al., 1986).

The U.S. Environmental Protection Agency recently completed its 5-year National Survey of Pesticides in Drinking Water Wells (USEPA, 1990). The agency sampled some 1300 community and rural domestic wells for the presence of 101 pesticides, 25 pesticide degradates, and nitrate. Hexazinone, a triazine, was one of the pesticides analyzed but was not found at concentrations above minimum reporting limits (MRL) for the survey. The most frequently found pesticides were DCPA (dacthal) and atrazine (atrizine). Statistical estimates project 61,500 rural and community wells nationally contain at least one pesticide detection above the Minimum Contaminant Level (MCL) or Health Advisory Level (HAL). The total number of wells was estimated to be about 10.6 million, including 94,600 community wells and 10.5 million rural domestic wells.

In a Corps of Engineers study of hexazinone on the Chena River Lakes Flood Control Project in Alaska, after 298 days, 98.5 percent of hexazinone had dissipated from surface soil samples (0-4 inches). Hexazinone was detected in day-40 surface water samples at the dam toe at 0.001 ppm. Hexazinone was detected in two samples collected the following spring, day 298, in the surface runoff pond (snow melt) at 0.0049 ppm and 0.0039 ppm. Hexazinone was not detected in any of the piezometer wells used to detect groundwater contamination by the herbicides (U.S. Army Corps of Engineers, 1988).

Retention or persistence of a chemical pesticide in soil is dependent on how the substance is bound to the soil particles, how it is transported, and how it is degraded. Binding is largely due to the organic fraction of the soil or to its clay fraction. The strength of the bonds and the total capacity of the soil to bind, or adsorb, the pesticide in question is important in how it will be transported in the soil profile. The transport downward is also dependent on soil water movement. The difference in binding capacity of hexazinone between the humus layer and an underlying mineral soil has a great influence on the transport of the herbicide down through the soil profile.

Greenhouse soil metabolism tests conducted by E.I. Du Pont De Nemours & Company using ^{14}C-labeled hexazinone demonstrated that hexazinone can be degraded by soil microorganisms under both aerobic and anaerobic conditions. The rate of degradation is somewhat slower under anaerobic conditions (Rhodes, 1975). Under aerobic conditions, the half-life of extractable ^{14}C in both Fallsington sandy loam and Flanagan silt loam was about 25 weeks. The major metabolites present at 25 weeks included metabolites A, B and D. Hexazinone has eight different metabolites but only A, B, C, and D are considered major products. Their chemical structures, except for metabolite C, are shown in Figure 3.4.

Hexazinone on a soil surface is subject to photodegradation. The half-life of the parent compound on a soil surface when exposed to artificial sunlight was estimated to be 37 days, with 40 percent of the parent compound remaining at six weeks (Rhodes, 1975). The major photodegradation product was metabolite B, and minor photodegradation products included metabolites A and D. The minor metabolites do not usually occur in significant amounts. Sung et al. (1985) reported that metabolite B is the only phytotoxic metabolite of hexazinone.

The major routes of hexazinone degradation in soil involve both demethylation and hydroxylation of the four position of the cyclohexyl ring. Biological activity decreases rapidly with increasing soil depth, and the potential for the degradation of hexazinone decreases. The herbicide metabolites have also been shown to be degradation products in rats (Rhodes and Jewell, 1980) and in water (Rhodes, 1980).

According to a study conducted in Canada, 66 percent of hexazinone was degraded at the end of 104 days of monitoring, decreasing from 7.12 $\mu g/g$ (ppm) at nine days to 2.09 $\mu g/g$ (ppm) at 104 days. The amount of metabolite A (30-50% of hexazinone detected) compared to metabolite B (0-12%) indicated more hydroxylation than demethylation in the silt loam soil. Leaching of hexazinone and its metabolites from the surface organics to the underlying 0-15 cm mineral soil layer was found only in the 55-day sample. No residues of hexazinone or its metabolites were detected at deeper (15-30 cm) soil horizons (Feng, 1987).

Degradation of hexazinone in greenhouse-treated soils was similar to the degradation in field-treated soils. The half-life determined was less than four months in sandy loam and silt loam soils (Rhodes and Jewell, 1980). The major metabolites in the greenhouse soils included A, B, and D in contrast to the field studies, where compound C was the major metabolite (Rhodes, 1980). This difference of metabolite production between the field study and the greenhouse study is not clearly understood.

Under field conditions, the half-life of hexazinone in soil treated at 3.7 kg/ha (1.5 kg/ac) was one month in Delaware, two months in Illinois, and six months in Mississippi. The major degradation product at all locations was metabolite C. Greenhouse soil degradation tests for both silt loam and sandy loam soil showed a half-life of hexazinone of less than four months (Rhodes, 1980).

Laboratory experiments with hexazinone indicated that herbicide degradation in soil takes place microbially under aerobic conditions. Under anaerobic conditions no herbicide degradation could be demonstrated during a period of 60 days (Rhodes, 1980).

SUMMARY - PERSISTENCE AND MIGRATION

Data on the two herbicides used in this project are summarized in Table 3.10. Characteristics for hexazinone are normally higher than triclopyr. A major difference between the two herbicides is the solubility in water. It should also be noted that LD_{50}s for Garlon 3A (44.4% a.i.) are considerably higher than triclopyr (Table 3.4) but LD_{50}s for Velpar (90% a.i.) are approximately the same as hexazinone.

HERBICIDE METHODS AND MATERIALS

Field Testing

The field sampling and testing for this project were developed to standardize the processes. Many of the methods were developed specifically for this project because of circumstances involved with the logistics and field testing in Alaska. The plots used for testing and part of the testing program were selected in cooperation with ARRC, the Alaska Department of Environmental Conservation (ADEC), and other State and Federal agencies. The sites were located at ARRC mileposts (MP) as noted:

Seward ARRC Rail Yard at MP 2.6
Fire Creek ARRC Siding at MP 131.2
Birchwood ARRC Rail Yard at MP 135.5
Chulitna ARRC Wye at MP 273.7
ARRC Mainline near Clear at MP 388.1
ARRC Eielson Branch near Ft. Wainwright at MP G7.7

Site Description

Each herbicide treatment area was approximately 105 feet long by 24 feet wide. They were each divided into 7 sectors, A-G (see Figure 3.5). Railroad north on the sites is defined as the direction in which the tracks go toward Eielson Air Force Base. Sector A was at the beginning (railroad south end) of the application zone and sector G was at the terminal end (railroad north end) of the application zone. Release of herbicide mixtures were synchronized with the vehicle speed in order to distribute the entire volume uniformly within the 105 foot length. Sectors B, D, and F were selected for collection of soil samples. Sectors A, C, E, and G were used for alternative integrated vegetation studies and comparisons.

Site Preparation

Sectors B, D, and F were prepared prior to herbicide application as follows: where the ballast extended to the four foot test area, at the left or right limit of the 24 foot spray zone, it and larger rocks were raked off of the soil for each of five strips in each sector (see Figure 3.6).

Removal of rocks from the soil surface was done in order to obtain even application of the herbicide mixture directly to the soil and to minimize herbicide being applied directly to the vegetation. This removal of rocks and vegetation was considered to result in a worst case scenario of the amount of herbicide available for soil degradation and migration, and it also facilitated the obtaining of a representative sample.

The strips, located eight feet from the track centerline, were four feet long by one foot wide and located on both sides of the tracks. Strip one was used to collect the samples immediately after application and the consecutive strips were used for sampling with time as noted in Table 3.11.

Herbicide Application

Garlon 3A and Velpar were applied to the study sites at concentrations of 64 fluid ounces per acre and 10 pounds per acre, respectively. The herbicides were prepared for application by measuring the specified quantities and dissolving them into a water base solution. The water temperature was maintained at approximately 70°F to facilitate solubility. A surfactant, drift inhibitor, and a coloring agent were then added to the mixture. The surfactant, Ortho X-77 (Chevron Chemical Co.), was used to reduce surface tension and assist with even application. The drift inhibitor, NalControl (Nalco Chemical Co.), was used to reduce drift of the herbicide to non-target areas. The coloring agent, Hi-Lite (Becker-Underwood), was added as a visual indicator of where the mixture of chemicals was applied. Amounts and concentrations of chemicals used are included in Appendix A.

Drift targets were placed at two feet inside and two feet outside of the application zone prior to chemical application in order to determine off-site transport of the herbicide by drift. The drift targets used were made of yellow water-sensitive paper that turns blue when moisture comes in contact with it. Detectable drift did not occur during any of the applications. Three- by five-inch white cards were substituted for water-sensitive drift paper at Seward and Birchwood where light precipitation was occurring during herbicide application. The blue dye in the herbicide mixture (Hi-Lite) was used to indicate drift, but none was detected.

A custom-made spraying rig was used for the herbicide application. It was a 24-foot boom, made by ARRC, mounted on a flat bed trolly that was pulled by motorized railcar. The boom was fitted with a series of nine nozzles (No. 8006), which were arranged three feet apart from one another. Each nozzle was fed by Tygon tubing and connected to the distribution control device. The chemical mixture was delivered to the distribution device from a stainless steel container that was pressurized to about 90 psi using nitrogen gas and using a boom pressure of 15 psi. The total time to apply the herbicide mixture to a treatment area was about 31 seconds with a vehicle speed of approximately 2.31 mph. This allowed the complete and uniform distribution of the herbicide mixture across the 105 foot test plot.

The application of the herbicides to treatment areas followed strict procedures in order to minimize contamination of non-target areas, and to ensure safe conditions for the individuals involved in the application. Safety gear included goggles, gloves, respirators, Tyvek coveralls, and rubber boots with plastic booties. This equipment minimized exposure to the herbicides or adjuvants. The herbicide mixture was not applied unless the wind was less than or equal to nine mph, as prescribed by ADEC. In actuality, applications occurred with winds ranging between zero to six mph.

It was desirable that herbicides be applied during dry conditions and at least four hours before precipitation. That was not the case at Seward and Birchwood where light rainfall occurred during application. Rainfall is desirable a short time after application to facilitate the herbicide activity.

Herbicide Soil Sampling

The field sampling schedule was planned as: prior to treatment, immediately after treatment, seven days after treatment, 49 days after treatment, random after break-up, and 365 days after treatment. These times were chosen to obtain a reasonable number of samples while meeting schedule constraints and other environmental concerns. Due to logistics, the sampling schedule diverged slightly from Table 3.11 as regards days 7, 49, and 365 after treatment. Actual days of sampling are presented in Table 3.12.

Soil was collected at various depths prior to treatment, composited and then sent to an independent laboratory for background residual testing for Bromicil, Picloram, 2,4-D, hexazinone and triclopyr. These analyses verified that the soil was free of the herbicides used in this study and also established the levels of herbicides still present from past applications. The ARRC stopped herbicide use in 1983. Herbicides detected in these analyses should have been residual amounts that persisted for at least six years (1983-1989). Positive results for this background testing were found for Bromicil only, at the Clear, Birchwood, Firecreek, and Seward sites. Refer to Appendix B for the background analyses performed by Analytical Resources, Inc., the contracted laboratory used for this study.

Surface (0-2 inches) samples were taken immediately after application. At seven, 49, and 365 days following application, samples were taken at the surface (0-2 inches or 0-5.1 cm), 1-foot (30.5 cm), 2-foot (61.0 cm), and 3-foot (91.4 cm) depths below the surface. A 3-foot depth sample was taken at the random sampling time following break-up.

Sampling depths, following application, were selected to obtain chemical concentrations in the soil column within project constraints.

Soil samples from the strips were collected according to the following procedure: the top two inches of soil, including the vegetative mat and organic layer, were collected in surface sampling. The two inch depth was chosen in order to ensure that all of the herbicide applied was measured in the initial sample. Twenty portions (aliquots) of soil were collected perpendicular to the tracks along the centerline of each four foot strip. These were combined into a single composite sample. Each of the 20 portions was taken with a clean, acetone washed stainless steel scoop to avoid cross contamination. Samples that were taken at the 1-, 2-, and 3-foot depths were obtained by drilling 8-inch holes using a gas powered auger and then using a previously cleaned long handled spoon, scraping soil from the appropriate depths. The sampling spoon was also acetone rinsed to prevent contamination. Soil at the immediate edge of each hole was scraped away and discarded prior to collecting a sample in the event it may have been contaminated by the auger. Composite samples representing sectors B, D, and F, for both the left and right side of the tracks, were used for gas chromatographic (GC) analyses.

Samples were also collected about five feet outside the zone of application on both sides of the track in order to detect lateral movement of the herbicides. Water samples were collected at the Seward and Firecreek sites to assess if leaching or surface runoff of the herbicides into the standing water adjacent to each plot was occurring. All samples were collected in pre-cleaned 1-liter amber glass wide mouth jars with Teflon lids. Samples were labeled appropriately and placed immediately in an iced cooler for transport to the laboratory for processing and storage in a refrigeration unit.

Samples were assigned a laboratory number corresponding to their field location and date. They were then prepared for chemical analyses by a homogenization procedure, which included sieving of the samples through a U.S. Standard Sieve Series #4 to remove large rocks, followed by blending of the sieved soil. A high speed Osterizer kitchen blender with stainless steel container and blades was used for blending. The container, blades and sieves were acetone rinsed between samples to prevent contamination. Following preparation, samples were stored at -20°C until the extraction procedure was performed.

Hexazinone Extraction and Analysis

A summary description of a modification of the method for determination of hexazinone is included here (Holt, 1981; Feng, 1987). Refer to Appendix C for the complete method. The modification occurred in the initial extraction of herbicide from the soil and prior to the partition into chloroform.

Extraction - Ten grams of soil (wet weight) are extracted a total of three times by shaking vigorously for two minutes in 30 ml acetone:water (4:1). The solution is then centrifuged at 2000 RPM for five minutes and filtered. The filtrate is transferred to a rotary vacuum evaporator to remove the acetone under vacuum. The aqueous solution is cleaned with a total of three 20 ml extractions of hexane and the herbicide is extracted from the aqueous solution three times with 30 ml of chloroform. The chloroform is then dried with 10 g of anhydrous sodium sulfate, evaporated, and the residue dissolved in 20 ml acetonitrile. The acetonitrile is cleaned with 20 ml hexane, evaporated to approximately two ml, transferred to a two ml conical vial and evaporated under nitrogen to dryness. Esterification is achieved by adding one ml trifluoroacetic anhydride to the residue in the conical vial and heating for 30 minutes at 60°C. The trifluoroacetic anhydride is then evaporated to dryness under nitrogen and the residue dissolved to one ml with ethyl acetate. The solution is then transferred to a gas chromatography (GC) vial for analysis. All extractions were performed under a fume hood. The time required to extract one sample was approximately six hours. An average recovery of 79.3 ± 6.3 percent for the soil samples was achieved using this procedure.

Gas Chromatography - A Hewlett-Packard Model 5890A gas chromatograph with an N-P (nitrogen phosphorous) detector and a Model 7673A Autosampler were used. The chromatographic column was a 30 m J&W fused silica DB-5 column (0.325 mm i.d., 1.5 micron film thickness). The chromatographic conditions were as follows: (1) temperature: injection port, 315°C; detector, 300°C; oven temperature, 220°C (isothermal); (2) gases: carrier gas, helium, 5.0 ml/min; head pressure, 50 psi; make-up gas, helium, 30 ml/min; plasma gases, air, 175 ml/min, hydrogen, 4.5 ml/min. Hexazinone chromatograms were integrated by a Hewlett-Packard Model 3396A Data System and quantified by comparison with a series of standards of analytical grade hexazinone, which were supplied by Du Pont De Nemours and Company, Inc. Standards were analyzed in random order with the samples. A detection limit of 0.04 ppm, or 40 ppb, was established using this method, which compares with the Feng method, which reports a 30 ppb detection limit.

Triclopyr Extraction and Analysis

Phenoxy herbicides have a high polarity and a low volatility, which prevents the use of a direct GC method for their determination. Thus, they are subjected to GC or GC-MS (gas chromatograph-mass spectrophotometer) after conversion into more volatile compounds; i.e., alkyl esters, halogenated esters, or halogenated aromatic esters.

Chlorophenoxy acids and esters along with some other herbicides, are neither stable nor volatile enough to be analyzed by gas chromatography without conversion to their derivatives. Triclopyr is a chlorophenoxy acid. There are several methods for preparing derivatives from herbicides. Some derivitizing agents that have been used successfully are H_2SO_4/n-propanol, H_2SO_4/methanol, pentafluorobenzyl, diazomethane, H^+/n-butanol, H^+/2,2,2-trichloroethanol, and various solutions of boron trifluoride (Cochrane, 1979). The limit of detection for triclopyr using derivitizing agents range from: 50 ppb for fuming sulfuric acid-ethanol esterification; 20 ppb for diazomethane esterification; and 50 ppb for Iodoethane esterification (Siltanen and Rosenberg, 1978). Triclopyr has been extracted from acidified aqueous samples with recoveries ranging from 90-93% and coefficients of variation of less than 4%. Recoveries in a soil matrix are less than aqueous solutions and are approximately 75% (Lee et al., 1986).

Extraction - The extraction process is a minor modification of the Tsukioka, method (Tsukioka et al., 1986) utilizing the safer, boron trifluoride, esterification procedure instead of the more dangerous, diazomethane esterification procedure. Refer to Appendix C for the complete method. The modification occurs in the esterification procedure where boron trifluoride in methanol was substituted for diazomethane, which is highly explosive. Five grams of soil (wet weight) is weighed into an erlenmeyer flask and mixed with two ml of a 37% potassium hydroxide solution, 15 ml deionized water, and 50 ml of ether. The ether is evaporated in a steam bath at 60°C. The basic solution is then filtered, cleaned by adding 20 ml ether and shaken for one minute. Next, the ether is decanted off and the aqueous solution acidified with sulfuric acid. The herbicide is extracted from the acidified aqueous solution using three successive ether washes. The ether is dried with anhydrous sodium sulfate and reduced to a volume of about two ml in a 60°C steam bath. The ether is next transferred to a conical two ml vial and dried under a stream of nitrogen. Esterification is achieved by using boron trifluoride in methanol and heating to 80°C for one hour. The residue is transferred to a separatory funnel with a 10% sodium chloride solution and extracted two times with 30 ml of hexane. The hexane extract is reduced to one ml and prepared for analysis by gas chromatography. Extractions are performed under a fume hood. The extraction required for each sample was approximately seven hours. An average recovery of 73.6 ± 6.9 percent for the soil samples was achieved using this method.

Gas Chromatography - A Hewlett-Packard Model 5890A gas chromatograph was used with an electron capture detector and a Model 7673A Autosampler. The chromatographic column was a 30 m J&W fused silica DB-17 column (0.325 mm i.d., one micron film thickness). The gas chromatographic conditions were as follows: (1) temperature: injection port, 210°C; detector, 300°C; oven temperature, 150°C for two minutes, ramp 10 degrees/minute, 170°C for 36 minutes; (2) gases: carrier gas, nitrogen (ultra-pure), 5.0 ml/min; head pressure, 50 psi; make-up gas, nitrogen (ultra-pure), 35 ml/min. Triclopyr chromatograms were integrated by a Hewlett-Packard Model 3396A Data System and quantified by comparison with a series of standards of analytical grade triclopyr, supplied by Dow Chemical Co. Standards were analyzed in random order with the samples. A detection limit of 0.01 ppm, or 10 ppb, was established for this method. The Tsukioka method reports a 25 ppb detection limit for environmental waters (Tsukioka et al., 1986).

Percent Solids Determination

Soil samples were prepared prior to extraction by weighing two separate 10 g portions of soil and then drying in a 104°C oven overnight. The samples were cooled in a dessicator and weighed. The dry weight divided by the wet weight multiplied by 100 gives the percent solids. This dry weight is then applied to the concentration determined on a wet weight basis samples and in the GC analysis to give a concentration on a dry weight basis. Data are presented on a dry weight basis.

Quality Assurance and Quality Control

Replicate studies were performed for the two extraction methods on a series of 10 augmented samples to establish reproducibility. For triclopyr, the ten samples had an average concentration of 0.143 ppm with a standard deviation of 0.021 ppm. The hexazinone samples had an average concentration of 0.384 ppm with a standard deviation of 0.055 ppm.

Herbicide percent recoveries were performed on a routine basis on one of a group of samples that were extracted each day. The average recovery for each method is presented with the extraction procedure previously described.

Throughout this project, replicate samples were periodically sent to Analytical Resources, Inc. (Seattle, Washington) for confirmation testing. These data are presented in Appendix B. The analyses performed by Analytical Resources resulted in consistently lower concentrations of triclopyr and hexazinone. The percent recoveries that this firm reported are highly variable, 12 to 148 percent, due to the quality assurance methods they employed for their analyses. The large variation is the result of using surrogate standards with percent recoveries rather than using internal standards and recoveries as used for this project. It is also mentioned that Analytical Resources, Inc. used different extraction and gas chromatographic methods (EPA methods 8140 and 8150) for their determinations of hexazinone and triclopyr. The difference in results between the samples analyzed for this project as compared to those of Analytical Resources, Inc. could have been expected. The analytical equipment for this research project was dedicated solely to the analyses of triclopyr and hexazinone, while Analytical Resources, Inc. performs numerous different analyses on their equipment.

Quality control for this research project was achieved through the care in sample gathering, processing, and analyses as described in this chapter. These procedures were standardized and applied to all samples that were subsequently analyzed for herbicide concentrations. This uniform and consistent treatment of samples through the life of the project ensured quality control with respect to laboratory analysis.

HERBICIDE DATA AND DISCUSSION

Introduction

Environmental factors influence the persistence of herbicides as noted previously in the literature reviewed. Ground temperature, soil type and precipitation have a significant impact on herbicide persistence.

Ground temperature influences solubility of herbicides and the rate of microbial action. In general, the solubility of a chemical is directly proportional to the temperature of water. Temperature affects microbial growth in that as the temperature is increased, so is the rate of microbial growth, within limits.

Soil type is significant due to its sorptive capacity, organic content, and permeability. In general, a soil comprised of small particles will have a lower permeability than one with large particles. Organics and clay in a soil tend to absorb herbicides. Therefore, herbicides in clay or organic soils will tend to persist longer. Herbicide degradation may be delayed as a sorbed chemical may not be available to the microorganisms. Migration will also be hindered because of soil binding.

Precipitation greatly influences the persistence of an herbicide. Most herbicides are soluble to some degree in water. Regions with substantial precipitation could expect migration of the herbicide from the site of application. Moisture content of a soil influences microbial action, and areas of low annual precipitation may have a reduced rate of microbial action.

Weather Stations

Weather stations for this project were placed at each herbicide application site to collect data that could affect the behavior of the herbicides in the field. Environmental factors monitored included precipitation, air temperature, ground temperature, and solar activity. The data were collected using Campbell Scientific, Inc. model CR10 data loggers. These data loggers were removed from the sites prior to freeze-up in 1989 and subsequently returned to the field sites the following spring (1990). The data collected from each site are presented in the following sections of this report.

Ground Temperature

Ground temperature was monitored through the use of thermocouples placed 12 inches below the ground surface. Temperature is an important environmental factor influencing the growth and survival of organisms.

As temperature increases, chemical and enzymatic reactions in the microbial cell proceed at more rapid rates and growth becomes faster. As temperature decreases, chemical and enzymatic reaction rates slow until a minimum temperature is reached, below which no growth occurs. Alaskan soil temperatures are lower than most soils of temperate climates (Russell, 1988). This in turn decreases solubility and microbial activity, thereby favoring persistence.

Microorganisms can be grouped according to their optimal growth temperature range: psychrophiles, with low temperature optima, mesophiles, with mid-range temperature optima, thermophiles, with high-temperature optima, and extreme thermophiles. These temperature distinctions are not strictly defined. In general, soil microorganisms can be considered to belong to the mesophiles because of the relatively wide range of temperature variation found in soils (Brock and Madigan, 1988). The van Hoff rule for mesophilic (5°C-35°C) biological activity states that the activity rate approximately doubles for every 10°C of rise in temperature (Viessman and Hammer, 1985).

Ground temperature data from the summers of 1989 and 1990 are summarized in Tables 3.13 and 3.14. The average ground temperature at one foot depth in the first summer following application (1989) ranged from 13.1°C to 15.3°C, a difference of 2.3°C , for all of the sites except the Chulitna site. No weather data were collected at Chulitna because of instrument failure.

Weather data for 1990 were collected after breakup in the spring and continued until the final samples for day-365 at each site were collected. The ground temperatures for 1990 are slightly lower than the temperatures reported for the summer of 1989. The data for Firecreek are absent due to the theft of the data logger at that location. No ground temperature data are available for the Birchwood and Chulitna sites due to programming and retrieval difficulty.

Soil Characteristics

Characteristics of a soil directly influence the behavior of an herbicide. Samples were taken from each site prior to herbicide application to characterize each site's soil type (see Appendix D). The data are summarized in Table 3.15 and soil types are identified in Table 3.16.

Soil types were comprised of mostly sand, silt, and gravel as noticed in Table 3.15. These types of soils have relatively high permeabilities that would favor leaching of the herbicides (see Table 3.17). It is also noted that organic content of the soils is at the high end of a typical range for common mineral soils, which range from one-half to six percent.

Precipitation

Precipitation was monitored using a Rainwise Raingauge. Data from the summers of 1989 and 1990 are presented in Tables 3.18 and 3.19. Two sites, Birchwood and Seward, received more than ten inches of precipitation during the observation periods (12.6 and 18.9 inches, respectively). The 0.0 value for Clear during the 1990 time period is due to a data logger failure.

Major precipitation events can cause increased migration depths of the herbicide. This is caused by the chemical dissolving in water and percolating down through the soil column. A precipitation event of 0.2 inch or greater in a 24-hour period was considered a significant precipitation event for the purpose of this analysis.

Significant 1989 precipitation events are summarized in Tables 3.20-3.24. Precipitation versus the days after application is graphed in Figures 3.7-3.11. These graphs facilitate comparison between major precipitation events and migration of the herbicide through the soil column.

Four separate significant precipitation events occurred at Fort Wainwright during the data collection period, as shown in Table 3.20. Figure 3.7 shows that the majority of precipitation occurred on days 19 and 20. This high amount of precipitation would have a tendency to leach the herbicide through the soil column by day 49 when herbicide soil samples were collected.

Table 3.21 identifies five separate significant precipitation events at Clear during the data collection time period. Over one inch of precipitation was measured on days 38 and 39. It is illustrated in Figure 3.8 that some 21 days had measureable precipitation, with days 12 and 39 being the time of main precipitation. Most of this occurred after day seven and before day 49. This should result in transportation of the herbicide to deeper depths during this period. Thus, the transport rate of the herbicide should be greater during the major precipitation events. The relatively constant precipitation would, however, aid in microbial degradation through provision of soil moisture, which is needed for microbial growth.

As noted in Table 3.22, 12 separate significant precipitation events occurred at Birchwood during the data collection time period. During the period of day 25 through 30, significant amounts of precipitation occurred each day, with 5.80 inches accumulating.

Figure 3.9 shows that precipitation occurred at Birchwood during 29 days out of the 49-day time period. This high frequency of precipitation would tend to greatly influence the depth to which the herbicide will travel.

Table 3.23 indicates that eight separate significant precipitation events occurred at Firecreek during the data collection time period. It should be noted that significant precipitation occurred each day of days 11 through 15. Days 11 and 12 accounted for over three inches of precipitation. Firecreek is relatively close to Birchwood, and it can be observed that the major precipitation events coincided by comparing Figures 3.9 and 3.10. The time period is different because the application date at Firecreek was 14 days later than the Birchwood application.

Table 3.24 indicates that ten separate significant precipitation events occurred at Seward during the data collection time period. Over seven inches of precipitation were measured on days 50 and 51.

Figure 3.11 shows heavy precipitation occurring after the day 49 sampling time at Seward. While a significant amount of precipitation occurred prior to day 49, the high amount immediately after day 49 should significantly influence migration of the herbicide at the Seward plot.

__Field Data__

The data presented in this section are the concentrations of herbicides as analyzed in the laboratory, adjusted to a dry weight basis, for the samples that were taken at each site. Tables 3.25-3.38 are the results for hexazinone (Velpar), Tables 3.39-3.52 are the results for triclopyr (Garlon 3A), and Figures 3.12-3.25 are graphical representations of the average concentrations for each depth at each site.

Organic content, as mentioned earlier, plays a major role in the resistance to migration of a herbicide through the soil column. The migration rate is dependent on the adsorbing and desorbing characteristics of the herbicide onto the organic material. Precipitation must occur to drive the herbicides into the soil column and, therefore, is the dominating factor with respect to migration.

Hexazinone - The hexazinone field data are presented in Tables 3.25-3.38. Metabolites A, B, and D are the only major metabolites that were detectable using the extraction method previously described. Their presence in the soil is indicated in the tables noted.

In all cases, detectable residues (> 0.04 ppm) of hexazinone were present, for all depths sampled one year after application. This indicates that hexazinone is persistent and that it will even migrate in regions with relatively low annual precipitation (i.e., Fairbanks' annual precipitation averages about 10 inches).

Hexazinone residues were found at the three foot (91.4 cm) level, on the approximate 49th day of sampling at the Seward, Birchwood (combination), and Firecreek sites only. This is in contrast with the literature in that the maximum migration was generally found at the 60 cm level (see Table 3.10). However, one source noted penetration to a depth of one meter (Barring and Torstenssen, 1985). Hexazinone was not found at the three foot level at the Ft. Wainwright, Clear and Chulitna sites for the 49 day time period. This is significant in that the Seward, Birchwood and Firecreek sites received the most precipitation over the 49 day period with 6.05, 9.28 and 8.02 inches, respectively. Fort Wainwright and Clear received 3.28 and 3.38 inches of precipitation, respectively. The weather station at Chulitna failed and thus no precipitation data were collected there. The migration data indicate that precipitation played a major role in the movement of hexazinone.

The literature indicates that hexazinone is susceptible to migration because of its high solubility in water. The persistence of hexazinone in the soil of the ARRC right-of-way is about that of the reported average of one to two years (refer to Table 3.10). However, data collection for this project stopped after one year. Thus, it is unknown how long hexazinone will persist in Alaskan soils.

The project sampling design did not allow calculation of a half-life for hexazinone in the soil. Determination of a half-life requires a mass balance of the herbicide in the soil column. To do this, an undisturbed column of soil must be extracted from the application site and analyzed. This was not feasible under the project constraints (time, budget, ability to collect *in situ* soil column samples, multiple analyses, etc.)

The presence of hexazinone metabolites indicates that degradation was occurring and was responsible, in part, for the dissipation of the herbicide. The quantities of metabolites present were not determined but the presence of the metabolites is noted for each site. Their presence is indicative that degradation is occurring at all levels where the herbicide is present. Degradation of the metabolites in the soil indicates that the soil microorganisms are using the herbicides for an energy source.

The Ft. Wainwright and Clear sites show an apparent anomaly with respect to the day seven surface concentration. The surface concentration is higher than at the day zero. An explanation for this is that during the application the herbicide may have accumulated on vegetation and large rocks, neither of which were analyzed, thereby giving an artificially low soil concentration. Precipitation that occurred after application and prior to the day seven sampling time may then have washed the herbicide residues into the soil, yielding higher values than the application rate concentrations. The literature gives evidence of this anomaly occurring in other herbicide studies (Neary, 1983).

Triclopyr - Field data for triclopyr are presented in Tables 3.39-3.52. It is noted that both triclopyr metabolites, TCP (the aerobic metabolite) and TMP (the anaerobic metabolite), are converted to TMP during the esterification of the samples. TMP was present in all cases where triclopyr was detected because of the analytical procedure. This implied that triclopyr was degradable by the microorganisms present in the soil and that TCP is probably the major metabolite in the samples that were collected. This finding is consistent with the literature. It is unlikely that TMP was present at any of the sample sites due to the probable absence of anaerobic activity. Anaerobic activity could have been prevalent but septic conditions were not evident.

Data presented in Tables 3.39-3.52 indicate that triclopyr is both persistent and susceptible to migration. In all cases, detectable residues (> 0.01 ppm) of triclopyr were present one year after application. In only one instance did residue of triclopyr exceed one part per million after one year. This occurred at the Clear site on day 365, right side of the track, and on the surface (0-2 inches). Triclopyr residues were detected at the three foot level at all sites except the Ft. Wainwright and Birchwood (triclopyr only) sites after one year.

Three of the sites had detectable triclopyr levels at the three foot (91.4 cm) level at the approximate 49 day sampling time. This finding conflicts with the literature presented in Table 3.10 where typical migration depths were about 10 cm (Lee, 1985). Triclopyr was not detected in this study at three feet (91.4 cm) at the Fort Wainwright site.

Triclopyr persists in the Alaskan environment and this is not unexpected based on the literature of studies conducted in Sweden. The studies conducted by Torstenssen and Stark (1982) in Sweden did not report soil temperatures. Due to the similar latitudes of Alaska and Sweden, a similarity of soil temperatures can be assumed. The migration of triclopyr in this study to the three foot level however, was unexpected because of its relative low solubility in water and its reported high affinity for absorption to organics in the soil.

It appears that triclopyr degraded more rapidly than did hexazinone, as noted in Figures 3.12-3.25. The rate of degradation is not conclusive, however, because half-life was not determined and the actual herbicide loss could have been due to migration or wash through the soil column. It is likely that detectable triclopyr will persist longer than one year and that it migrated beyond the three-foot depth.

Summary

It is evident that precipitation has a major influence in the migration of both triclopyr and hexazinone. From the precipitation tables it can be seen that within the approximate 49 day period after application, Birchwood, Firecreek and Seward received precipitations of 9.28, 8.02 and 6.05 inches respectively. The Ft. Wainwright and Clear sites received less than 3.5 inches each.

As mentioned previously, the Birchwood, Firecreek and Seward sites all had detectable residues of hexazinone at the three foot level at the approximate 49 day time period. The Birchwood, Seward and Chulitna sites all had detectable residues of triclopyr at the approximate 49 day time period at the three foot level.

It is apparent that herbicide degradation is taking place from the detectable levels of metabolites present during all of the sampling time periods. The hexazinone metabolites B and D are major metabolites, and their presence indicates hydroxylation rather than methylization is the predominant degradation pathway for hexazinone. While the indication of triclopyr metabolites include both TCP and TMP, the TCP (aerobic) metabolite is probably the major metabolite for triclopyr due to the apparent absence of anaerobic soils.

There was no evidence of lateral movement in any of the soil or surface water samples collected outside of the application site. Soil samples were collected at each site on both sides of application for each sampling period. Surface water samples of adjacent water bodies were also taken at the Seward and Firecreek sites.

Since the other environmental factors studied, that affect herbicide persistence and migration (namely soil organic content and ground temperature), varied only slightly from site to site, it would appear that precipitation played a dominant role with respect to the environmental fate of herbicides in Alaskan soils. This is not surprising since precipitation appears to be the main variable of emphasis of migration in laboratory studies reviewed in the literature.

A graphical summary of the average concentration versus depth for each site is presented in Figures 3.12-3.25. Note that the y-axis is not constant for each graph, in order to facilitate presentation. In general, these figures approximate typical decay curves. This is illustrated by the initial rapid decline of concentration, followed by a more gradual decline of concentration as a function of time. This type of decay is what would be expected from herbicides in the field.

LABORATORY INVESTIGATIONS

Laboratory studies were conducted to establish relationships with the field portion of the project. The results were used to determine the potential for migration and persistence of the two herbicides in an Alaskan soil system (Wentz, 1989; Racke, 1984).

Introduction

It was necessary to simulate environmental field conditions for this portion of the study, and therefore it was based on field data and information from the literature. The soil used for the laboratory study was a natural soil with zero percent organic matter. Soil samples taken in the field indicated an average soil organic matter content of about three percent and therefore, the laboratory soil was augmented with three percent organic matter. Soils used for the microbiological degradation study were incubated at temperatures of 2, 10, and 20°C. Soil column studies were designed to investigate the leaching potential of triclopyr and hexazinone in the soil system. A sandy-silt soil was used having a hydraulic conductivity corresponding to a medium-coarse sand. The volume of equivalent rainfall applied to each column simulated a worst case scenario with respect to actual field precipitation events. An equivalent of 2.2 inches (5.6 cm or 400 ml) of rainfall was applied to the column every hour for ten hours. This section of the report details methods which were used for experiments and quantification of samples. Chromatographic methods were identified and discussed earlier in this chapter. Additional information is presented for soil microorganism counts, microbial degradation experiments and soil column leach studies (Bohn et al., 1979; Krauskopf, 1979).

Microbiological Degradation

Microbial degradation studies were conducted using a natural soil which was classified as a silty-sand (Unified Soil Classification SM). This soil was analyzed and classified by the Alaska Department of

Transportation and Public Facilities Soils Testing Laboratory (Appendix D). The soil was divided into two portions, one of which was not altered. The second portion was augmented with three percent organic matter in the form of canadian sphagnum peat. Moisture of the samples was adjusted to forty percent holding capacity which provided a favorable environment for microbial activity (Stark, 1982; Ghassemi et al., 1981; Meikle et al., 1974; Weber and Weed, 1974; Weber et al., 1974; Sethunathan and Yoshide, 1973; Watanabe and Hayashi, 1972; Upchurch and Mason, 1962).

Five hundred gram soil samples were placed in acetone rinsed amber glass jars. These samples consisted of six natural soil samples and six which were augmented with organic matter. Three of each type were then dosed with hexazinone to achieve an approximate concentration of eight ppm and three were dosed with triclopyr to achieve an approximate concentration of two ppm. Dosages chosen were selected to approximate concentrations expected in the field investigations of this study.

Following preparation, four treated soil samples were stored at each of 2, 10 and 20°C. Samples were then subjected to herbicide analyses at time equal to 0, 14, 30, 49, 70, 105 and 145 days. Moisture in the soil samples was maintained at an average of about 14% during the study period. Soil samples were mixed once a week to provide aeration.

Triclopyr - Laboratory microbial degradation data were collected for a total of 145 days. Tables 3.53 and 3.54 present the concentrations of triclopyr in the soil augmented with three percent organic content and with the soil with no organic content. Data presented represent averages of replicate determinations. Figure 3.26 shows the concentrations of triclopyr in soil augmented with three percent organic matter. All of the plots show similar trends with some unexpected deviations at day 30 and day 105. Figure 3.27 is a plot of triclopyr concentration versus time for soil containing no organic matter. Possible explanations for the variations include: (1) the sample used for extraction may have contained a higher/lower mass of triclopyr than the overall soil sample, or (2) contaminated glassware might have caused a relatively high concentration in the day 30 sample, or (3) quality control was not at the expected level for those particular test days.

Even with these fluctuations, the concentrations are statistically equivalent based on a confidence interval of 0.86 ppm, as discussed later. The data indicates that between 2°C and 20°C, microbial degradation did not occur or occurred so slowly it was unmeasurable with the techniques used. The addition of three percent organic matter to the soil seems to have had no significant influence on the rate of microbial degradation of triclopyr within these temperature ranges. However, analysis of chromatograph peaks indicate that metabolite TMP was present in all samples analyzed between day zero and day 145. This correlates to field results which also showed triclopyr metabolite TMP being present from day zero through day 365 and is indicative of triclopyr degradation. Nevertheless, an insignificant decrease in the parent compound concentrations, based on the statistical analysis, suggests little degradation (USDA, 1988; Washington State, 1978; USDA, 1984b; DOW, 1983; McKeller et al., 1982; Sheets et al., 1962).

Percent recoveries of herbicides were measured for each extraction run. They were determined by "spiking" a duplicate sample with a known concentration of triclopyr, typically two times higher than the expected concentration in the unspiked sample. Concentrations of the unspiked versus the spiked sample were compared to determine the percent recovery following analysis. The statistical mean of these recoveries was 64.6 percent.

A significance test was conducted to determine the confidence interval associated with the results. The test was based on a 95 percent confidence interval and a 2.45 critical value (Freund, 1982). The results are presented in Tables 3.55 and 3.56. The statistical analysis revealed that the average concentration of triclopyr in these soils at 2°C was 0.93 ppm with a standard deviation of 0.16 ppm. The confidence interval was 0.75 ppm for 95 percent confidence meaning that the concentrations at any one time could be 0.75 ppm above or below the average triclopyr concentration (0.08 to 1.68 ppm). This implies that between day 0 and day 145, all measured concentration values were relatively the same and that little degradation of triclopyr occurred in either soil, organic versus nonorganic, at their respective temperatures.

Inspection of Figures 3.26 and 3.27 does show a slight downward trend with time. However, review of Table 3.10 indicates the half-life of triclopyr to range from 10-46 days, presumably at warmer soil temperatures. Thus, for a temperature of 20°C, the initial concentration of approximately one ppm should decrease to about 0.5 ppm in 46 days, assuming a half-life of 46 days. It does not. Using the general rule of thumb that the reaction rate decreases for each 10°C decrease, then one would expect a concentration of about 0.75 ppm at 10°C and 0.88 ppm at 2°C for a 46 day half-life. These decreases are not evident (Deli and Kish, 1974).

It is apparent that these studies were not continued for a long enough period of time and that acclimation of soil organisms could have been a factor. Further, more replicate number of samples would have been desirable. It is also evident that the initial analyses, at time equal zero, may have been flawed as the proposed concentration was two ppm but the concentration measured was less than one ppm.

Hexazinone - Microbial degradation of hexazinone was studied for 145 days with two soils using the same procedure as which triclopyr was evaluated. Tables 3.57 and 3.58 summarize the concentrations of hexazinone in both soil types over the 145 day testing period. Figure 3.28 shows the concentration of hexazinone in soil with no organic matter, whereas Figure 3.29 is for soil with organic matter. Hexazinone concentrations did not vary significantly from day zero to day 145 for all temperatures evaluated. A small amount of degradation occurred in the soil incubated at 20°C, however, the reduction was statistically insignificant. Hexazinone metabolites A, B, and D were detected in some of the soil samples which was an indication of degradation. Table 3.59 describes the metabolites detected, soil type, temperature and sampling time (USDA, 1988; USDA, 1984a).

As can be seen from Figure 3.28 and 3.29, hexazinone concentrations decrease rapidly between days 30 and 70 and then increase between days 70 and 145, for all three temperatures. There was no significant degradation evident due to the organic content or temperature differences. However, the presence of hexazinone metabolites indicates that some degradation may have occurred in the samples even though the statistical evaluation suggests otherwise.

A significance test was conducted to determine whether or not the hexazinone concentrations were statistically different. Table 3.60 reports the average, standard deviation and confidence interval of hexazinone for soil with three percent organic matter while Table 3.61 reports information for zero percent organic matter. All values fall within the average, plus or minus the confidence interval, and the test indicates that they are not significantly different from each other. Significant microbial degradation of the hexazinone parent compound did not occur in this soil at the three temperatures. However, the presence of metabolites indicated that some degradation may have been occurring.

Inspection of Figures 3.28 and 3.29 also shows a slight downward movement with time for hexazinone, as did triclopyr. In the case of hexazinone, however, the half-life ranges from 30-180 days, presumably at warmer soil temperatures. This is in comparison to the half-life of triclopyr which ranges from 10-46 days. Therefore, for hexazinone, at 20°C the concentration would be expected to decrease from the planned initial concentration of 8 ppm to about 4 ppm in 180 days. Again, making the assumption that the reaction rate doubles for each 10°C increase, then this concentration should have fallen to 6 ppm and 7 ppm in 180 days at 10°C and 0°C, respectively. These decreases are not apparent.

It is concluded, as with triclopyr, that the length of the study should have been extended and more replicate analyses conducted. Microbial acclimation may also have been a consideration. Further, the targeted initial concentration of hexazinone was eight ppm but the actual concentration was only six ppm.

Soil Microbial Population Counts

Soil bacteria population counts were performed to determine populations in the soils used for the degradation experiments. The plate count technique, as described by Benson (1978), was utilized to determine the bacterial population in the soil. Petri dishes were used along with serial dilutions in order to achieve representative plate counts. Samples were incubated at 30°C and plates with more than 30 colonies but less than 300 colonies were counted in triplicate. Table 3.62 includes the average concentration (organisms/gram) of bacteria in the samples. The average values were multiplied by the respective dilution factor to determine the number of bacteria per gram of soil. These values were then averaged to establish the number of bacteria per gram of soil which was 2.81×10^7.

Russell (1988) indicates that most microbiologically active soils contain an average of 10^7 to $10x^9$ bacteria per gram of soil. The bacteria counts were conducted at approximately day 150 and there were apparently sufficient numbers of organisms present to degrade the herbicides. Initial soil bacteria counts were not conducted because natural aerobic soils normally contain a high and diverse population of organisms for organics degradation. It is possible that sufficient numbers of organisms were not initially present when the degradation studies commenced or that the organisms were not acclemated to the substrate (the herbicides). It is also possible that there was a source of nutrients in the soil other than the herbicides which was more efficiently utilized for energy. If any of these conditions were prevalent, a reduced rate of degradation could have been expected. Nevertheless, the results about degradation rates are inconclusive based on these tests.

Soil Leaching Columns

Soil column studies were performed to investigate the leaching potential in triclopyr and hexazinone. Four columns containing a sand-silty soil mixture were used for the experiment. Two of the four columns were augmented with three percent organic matter (Canadian sphagnum peat) to determine its effect on the leachability of the two herbicides. The soil depth in the column was approximately 30 cm with a column diameter of 9.5 cm. The glass column design is shown in Figure 3.30. The method described by Lee et al. (1986) was followed with some modifications for the purpose of this study. The contents of the columns were supported by a wire mesh screen and pea gravel. Water (leachate) was collected in 500 ml amber glass jars which had been acetone rinsed. Deionized water was applied to the top of the columns with a 500 ml Erlenmeyer flask and all columns were preconditioned by continuous application of deionized water for eight hours. 100 gram portions of soil which had been treated with triclopyr or hexazinone were placed on top of the soil in the columns (Helling, 1971; Chohen and Pinkerton, 1966).

Triclopyr - Two 100 gram samples of soil were treated with 10 ml of the standard which consisted of triclopyr dissolved in acetone at a concentration of 0.35 mg/ml. Therefore, each treated sample received 3.5 mg of triclopyr while tumbling in a glass roto-vapor distillation flask. Tumbling continued for 30 minutes to ensure mixing and evaporation of the solvent and then the treated sample was added to the top of a column, covering the nontreated soil. Fiberglass was placed on top of the treated layer followed by one cm of sand to prevent channeling of the applied water. 400 ml of water (equivalent to 5.6 cm or 2.2 inches of rainfall) was applied to each column every hour for ten hours. The resulting eluates, collected every hour in amber glass jars, were stored at zero °C until analyzed. Ten eluates were collected during one day of leaching.

Table 3.63 summarizes the concentration of triclopyr in the eluates after the equivalent of 56.1 cm of rainfall was applied to the columns. For the column without the addition of organic matter (0 percent O.C.) the highest percentage of triclopyr was leached within an equivalent of 16.5 cm of rainfall which corresponds to 88.84 percent of the triclopyr applied to the column. A total of 97.10 percent of applied triclopyr eluted through the column after the equivalent of 56.1 cm of rainfall. Figure 3.31 illustrates the cumulative percent triclopyr leached from the soil columns. Figure 3.32 depects concentration versus cumulative rainfall. Leaching occurred more rapidly in the column without organic matter than in the column with the addition of organic matter.

Leaching was less intense in the column augmented with three percent organic matter (3% O.C.). Triclopyr leached through the column, as seen in Figure 3.32, until a maximum concentration of 0.988 ppm occurred at approximately 28 cm of equivalent rainfall. The concentrations in the eluates gradually decrease after this peak.

The peak concentration at 28 cm of rainfall may have been attained due to the effect of an organic "layer" within the column. The high specific surface area associated with organic matter would tend to retain triclopyr longer than a soil with a lower specific surface area.

As seen in Figure 3.31, the retention time of triclopyr was greater in the column augmented with three percent organic matter due to the higher specific surface area. Only 0.90 percent of the applied triclopyr was retained within the column containing organic matter compared to 2.90 percent retained in the column without organic matter.

Hexazinone - Two 100 gram samples of soil were treated with 10 ml of standard solution which consisted of hexazinone dissolved in acetone to a concentration of one mg/ml. Therefore, each treated sample received 10 mg of hexazinone. The preparation of the soil, application of water to the columns and sample collection and storage were the same as the procedure for triclopyr, described previously.

Table 3.64 summarizes the concentration of hexazinone in the eluates collected from the soil column leach studies. In the column without organic matter, the highest concentration of 3.65 ppm leached through within the first 11.2 cm of equivalent rainfall which was 36.5 percent of the total hexazinone applied. As seen in Figure 3.31, the majority of the hexazinone (approximately 60 percent) leached through the column within the first 22 cm of equivalent rainfall. A total of 76.15 percent of the applied hexazinone leached through the column after 56.1 cm of equivalent rainfall.

In the column augmented with three percent organic matter, a total of 90.09 percent of the hexazinone applied was eluted after 56.1 cm of equivalent rainfall. The peak concentration of 2.27 ppm was eluted within 33.7 cm of equivalent rainfall as shown in Figure 3.33.

More hexazinone leached from the column augmented with organic matter than from the column without organic matter. As with triclopyr, the high specific surface area associated with organic matter increased the retention time of hexazinone in the column. Figure 3.34 shows that the addition of three percent organic matter did not significantly affect the cumulative percent hexazinone leached from the soil column.

For both hexazinone and triclopyr, the addition of organic matter to the soil slowed the rate at which these herbicides leached through the column (Figures 3.31 and 3.34).

Hydraulic Conductivity - Studies were conducted to determine the hydraulic conductivity of the soil used in the columns. The hydraulic conductivity was determined experimentally to be 0.0181 cm/sec for the soil containing no organics and 0.0145 cm/sec for the soil with three percent organic content. These values are averages of six replicate tests per soil column. The constant head method described by Das (1985) was used for these determinations. Table 3.65 summarizes typical values of hydraulic conductivity for various soils. The average hydraulic conductivity determined from this study placed both soil types, natural and augmented, in the coarse sand classification. Results from this study are included in Table 3.66

Distribution Coefficient - The method commonly referred to as the "slurry" or "batch" method was used to determine the distribution coefficient of the herbicide between solids and aqueous solution. In the method described by Weber (1977), known weights of solids are mixed with a given quantity of herbicide in solution, allowed to equilibrate at a given temperature, and the remaining concentration of the herbicide in the liquid determined. The method assumes that no loss of the herbicide occurs and that the herbicide not in the water is on the soil.

Adsorption of an herbicide can occur when soil particles are placed in a solution and the slurry is agitated or mixed to give adequate contact until equilibrium is reached. Contact time must be long enough to allow the organics (herbicide) in the solute to adsorb to the soil surface and equilibrium achieved between the adsorbent and the solvent. The herbicide concentration decreases from an initial level to an equilibrium value if the contact time is sufficient. A relationship between the equilibrium concentration and the amount of organic substance adsorbed per unit mass of soil can be obtained by performing a series of slurry tests. The results were used to compare the relative adsorption of triclopyr and hexazinone by the soil used in the column studies.

The herbicide concentration in the equilibrated solution was subtracted from the concentration of the initial herbicide added to the columns. Karickhoff and Brown (1979) suggest an equilibration time of 4-8 hours, so to insure complete equilibration of the herbicide solution to the soil particles, a time of 24 hours was employed. The result of this equilibration was that the herbicide apparently absorbed to the soil particles. That concentration was multiplied by the volume (40 ml) of equilibrated solution used for the extraction analysis to obtaion the mass of herbicide, in micrograms. This value was divided by 2.5 grams, the mass of soil used in the study, to determine the mass of herbicide adsorbed per gram of soil.

Adsorption Isotherm Study - Adsorption studies were conducted to determine the soil's ability to hold herbicide to the soil surface. The method used was the "batch" method where known weights of soil are mixed with the herbicide liquid solution, allowed to equilibrate at a selected temperature, and the change in concentration calculated.

The adsorption coefficients determined in this study are used to predict the movement of triclopyr and hexazinone in the field and the laboratory. Adsorption isotherms are generally linear at equilibrium aqeuous solute concentrations. The sediment/water distribution coefficient (K_d) is the slope of the linear portion of the adsorption isotherm (Karickhoff and Brown, 1979).

The partition coefficients for triclopyr and hexazinone determined in this study are specific only for the particular conditions to which they were subjected. Karickhoff and Brown (1979) state that sorption may be affected significantly by pH, the redox potential (Eh), exposure time, and the cation exchange capacity of the sediment. Therefore, any of these factors, if changed, could alter the results of this study by either increasing or decreasing the adsorptions of the herbicides onto the soil (Nicholls, 1988; Saltzman and Yaron, 1986; Morrill et al., 1982; Weber, 1977; Carringer et al., 1975; Doherty and Warren, 1969; Bailey and White, 1964).

Triclopyr - Table 3.67 summarizes the preparation of solutions for studying of adsorption of triclopyr.

The results of this experiment are included in Table 3.68 which notes the calculated amount of triclopyr adsorbed from five different triclopyr concentrations. The amount of triclopyr adsorbed per gram of adsorbent versus the concentration of herbicide in the equilibrium solution for each sample was plotted to obtain an adsorption isotherm (Figure 3.35). A linear regression analysis was performed for the triclopyr adsorption data of this experiment and yielded an r^2 value of 0.997. For triclopyr, the partition coefficient was computed to be 356.18.

Hexazinone - Figure 3.36 is a plot of hexazinone adsorbed per gram of adsorbent versus the concentration of hexazinone in the equilibrium solution. The partition coefficient of hexazinone for this soil was computed to be 77.62. Linear regression analysis of the hexazinone standards resulted in an r^2 value of 0.96.

Table 3.69 summarizes the results obtained for the adsorption of hexazinone on a silt-sand soil. As with triclopyr, the contact time was 24 hours at approximately 25°C. After 24 hours, the sample jars were stored in an incubator at 0°C. The contact time of the herbicides in the soil column study was approximately 30 minutes.

Summary and Conclusions

At all three temperatures, the data indicated that significant microbiological degradation of triclopyr and hexazinone did not occur for both soil types during the 145 day testing periofd. However, the presence of triclopyr and hexazinone metabolites does suggest that some degradation may have been occurring.

Three percent organic matter influenced the retention time only slightly of triclopyr and hexazinone which was probably due to the higher specific surface area associated with organic matter. It should be noted that actual field precipitation events would most probably be less dramatic than those used in the laboratory column studies, thus increasing adsorption and persistence.

The results of this study indicate that hexazinone and triclopyr are mobile in the soil types used. Furthermore, the presence of only three percent organic matter had some but relatively little influence on the leaching potential of these herbicides. This observation adds credence to the discovery of triclopyr and hexazinone at a depth of three feet in the field study.

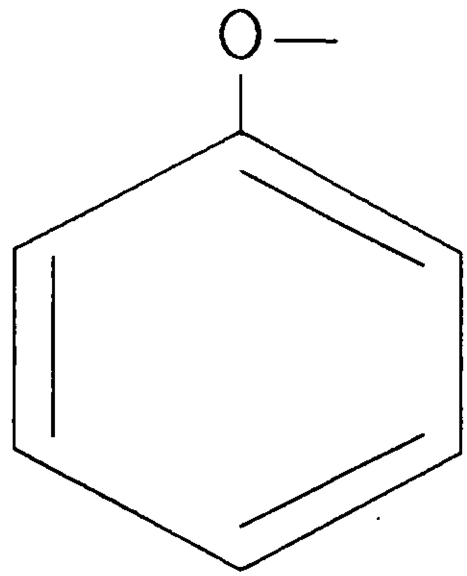


Figure 3.1. Phenoxy chemical structure.

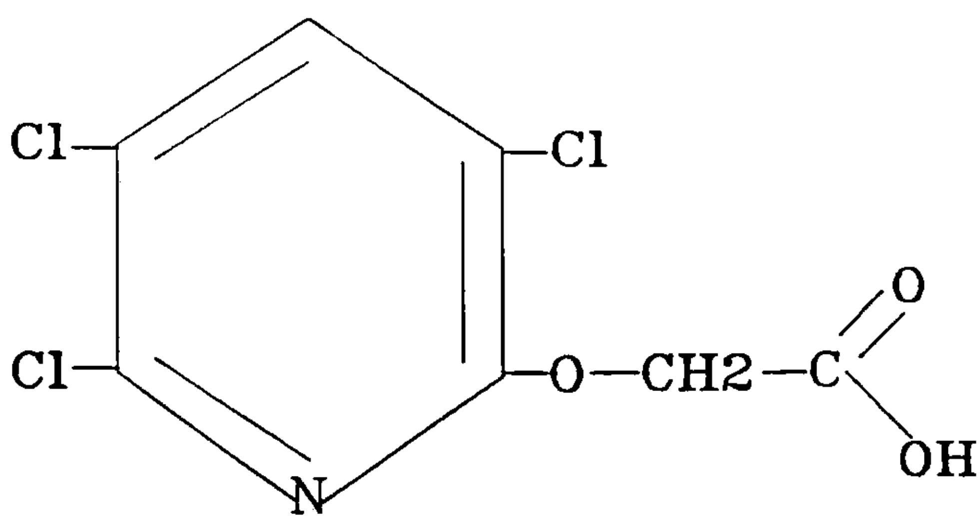


Figure 3.2. Triclopyr: [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid

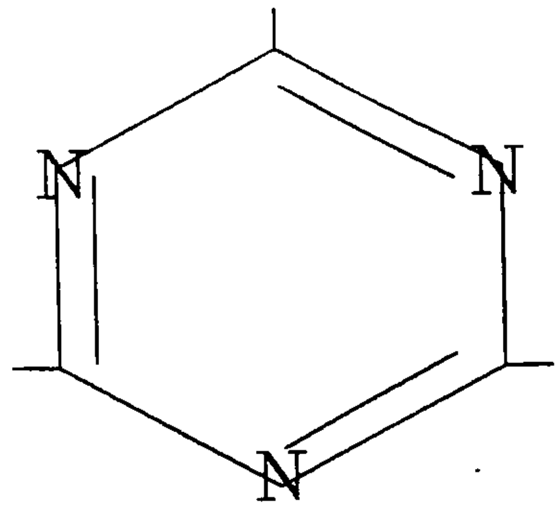


Figure 3.3. Typical triazine molecule.

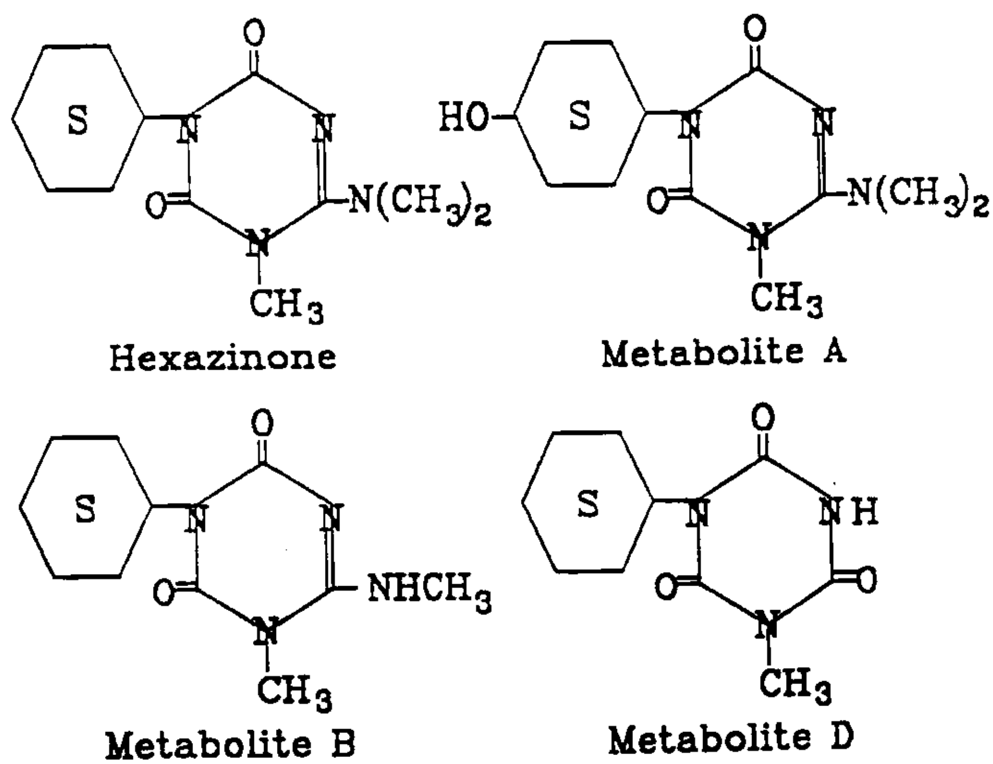


Figure 3.4. Structures of hexazinone and its major degradation products (Rhodes, 1980).

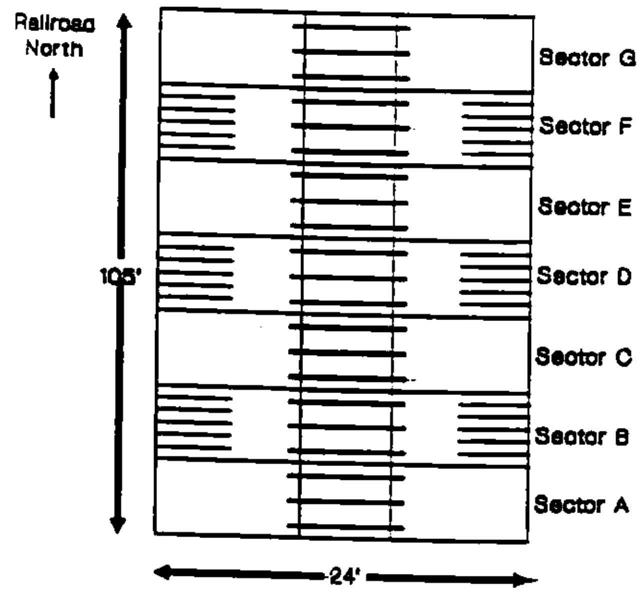


Figure 3.5. Herbicide application site (not to scale).

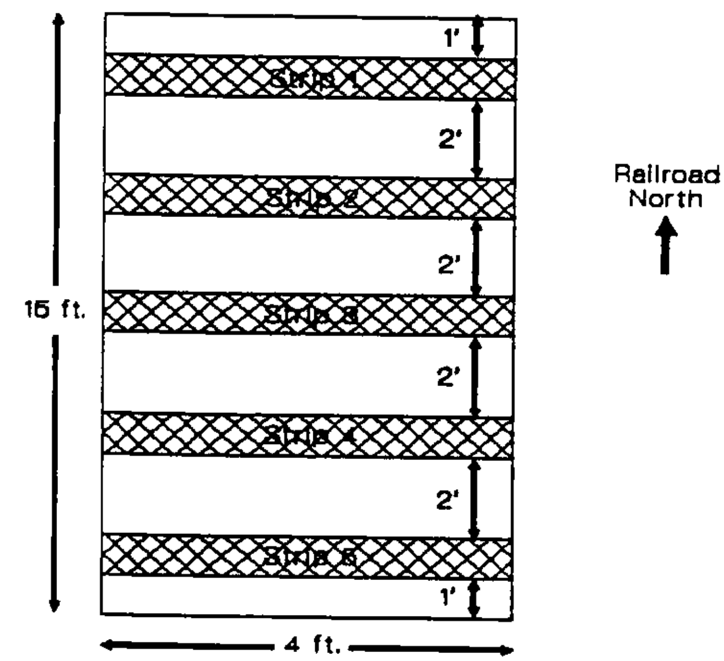


Figure 3.6. Sector dimensions (not to scale).

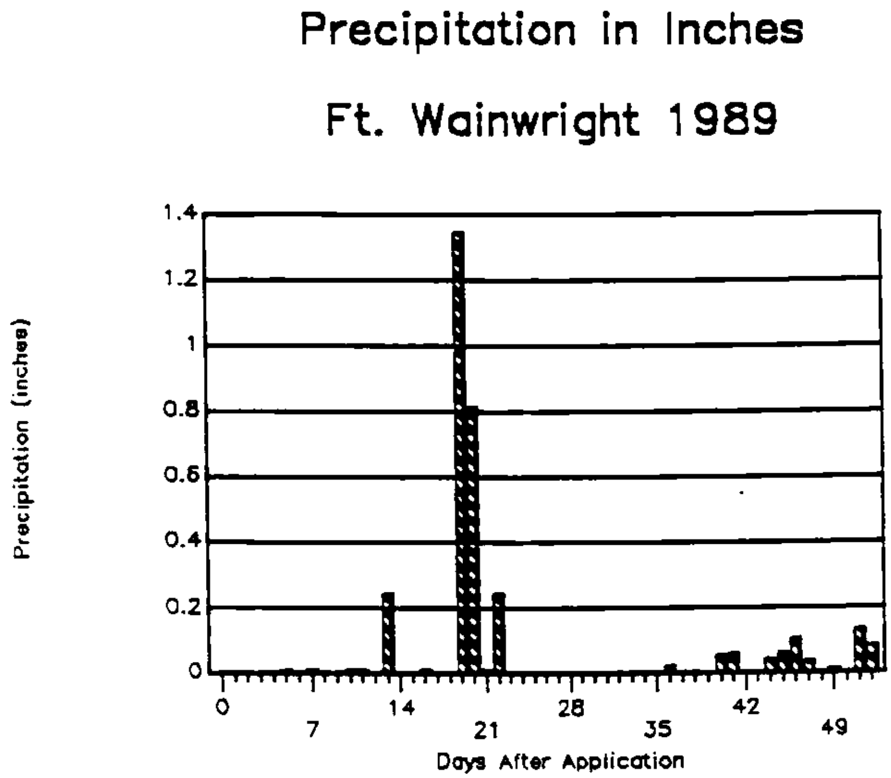


Figure 3.7. Precipitation at Ft. Wainwright for 1989.

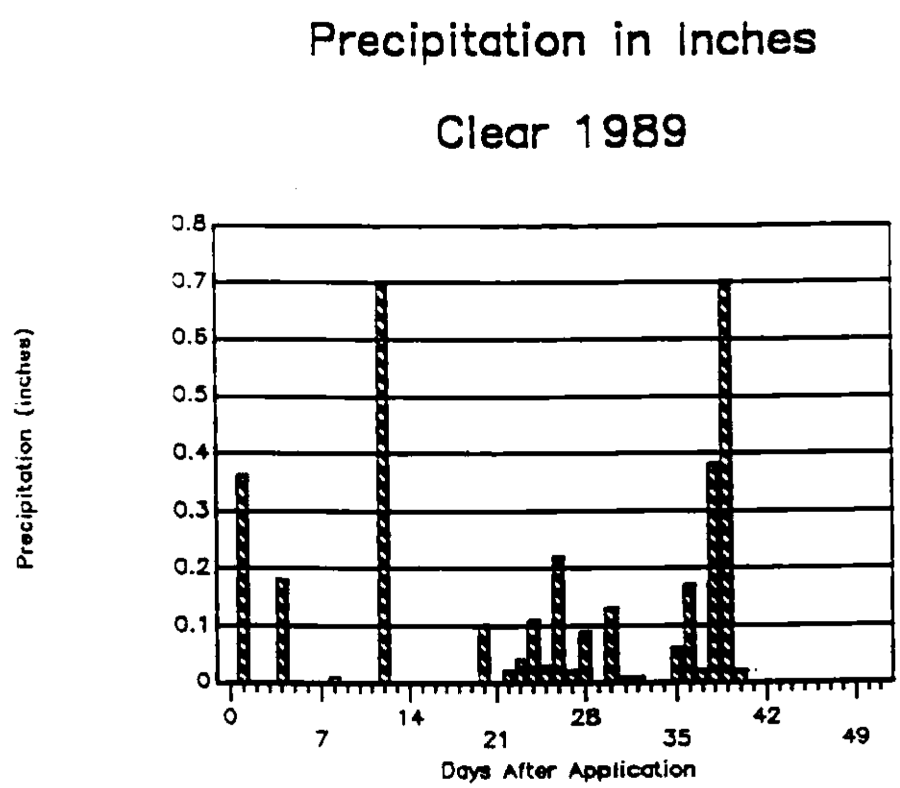


Figure 3.8. Precipitation at Clear for 1989.

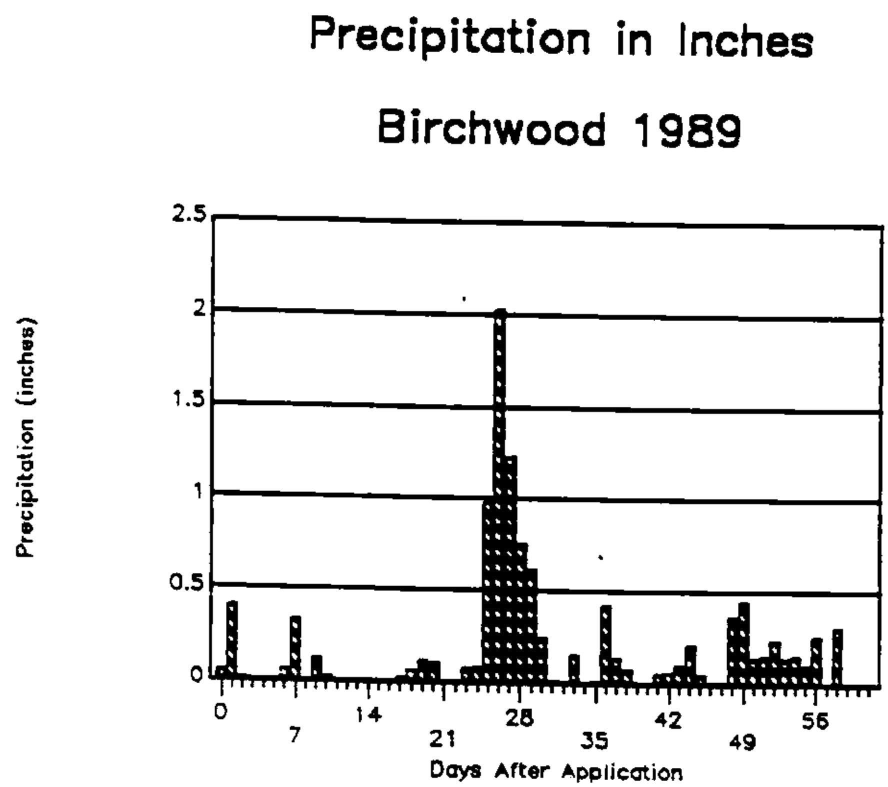


Figure 3.9. Precipitation at Birchwood for 1989.

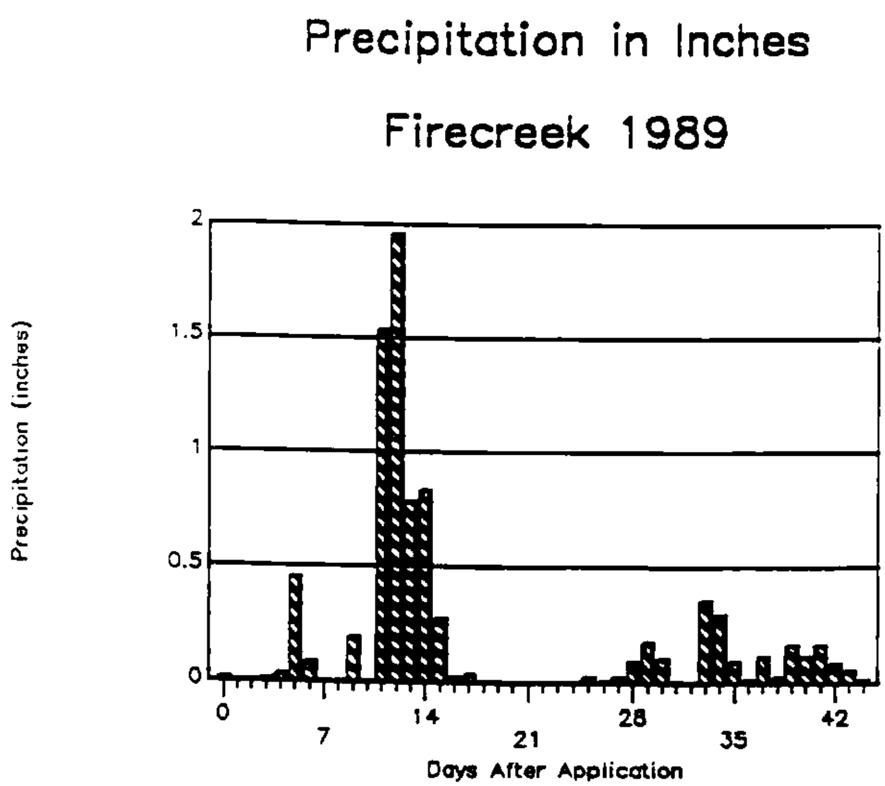


Figure 3.10. Precipitation at Firecreek for 1989.

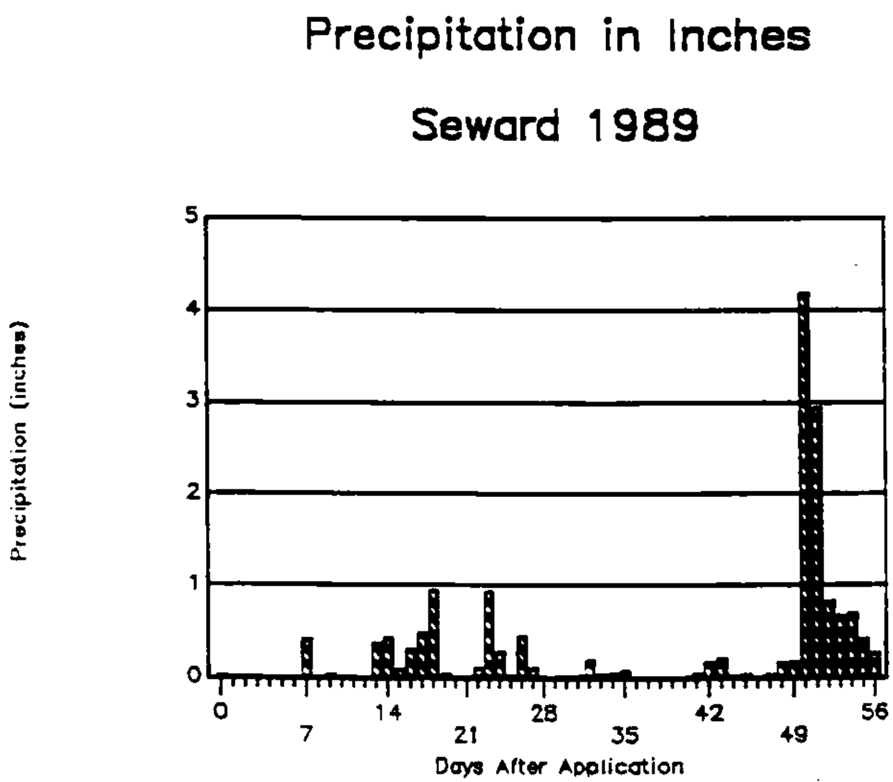


Figure 3.11. Precipitation at Seward for 1989.

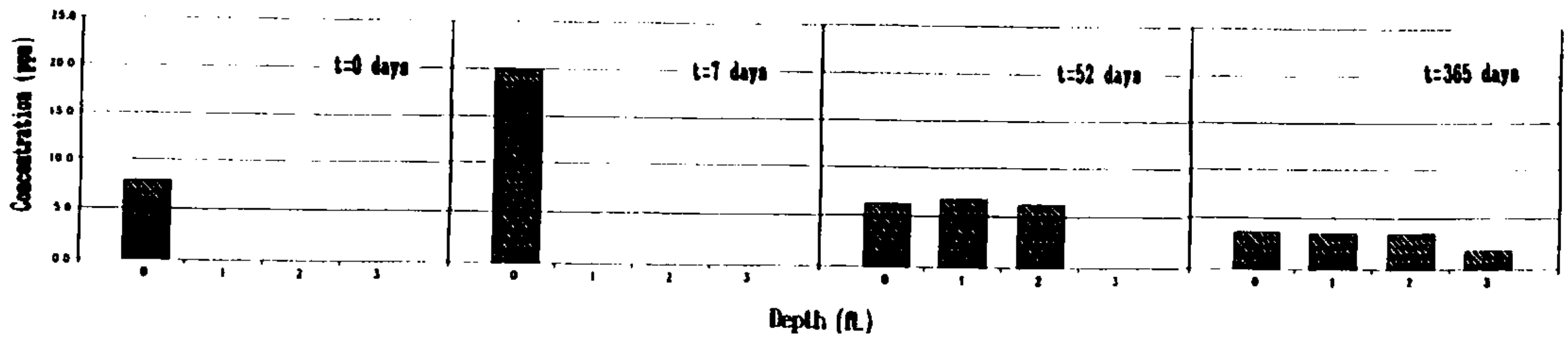


Figure 3.12. Hexazinone Concentration vs. Depth for Ft. Wainwright Plot.

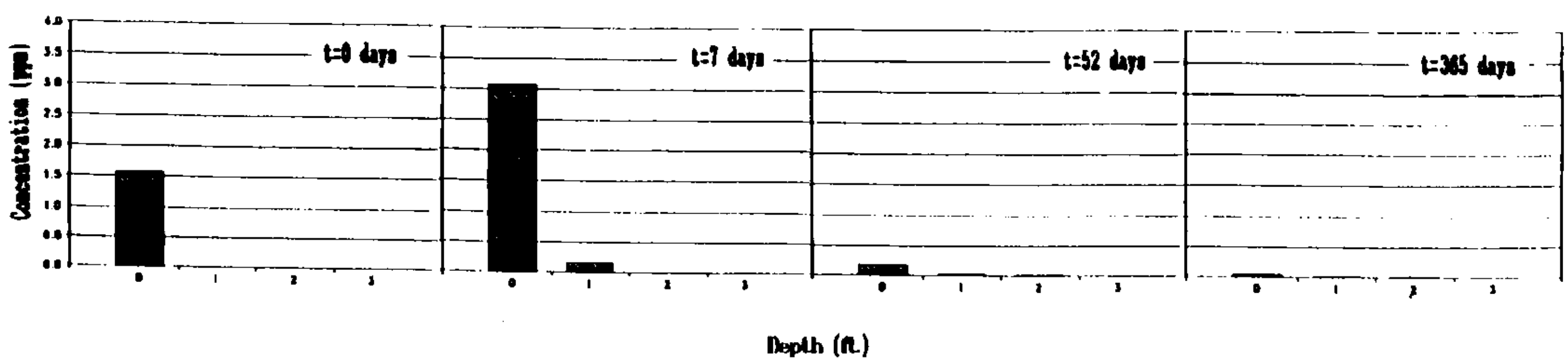


Figure 3.13. Triclopyr Concentration vs. Depth for Ft. Wainwright Plot.

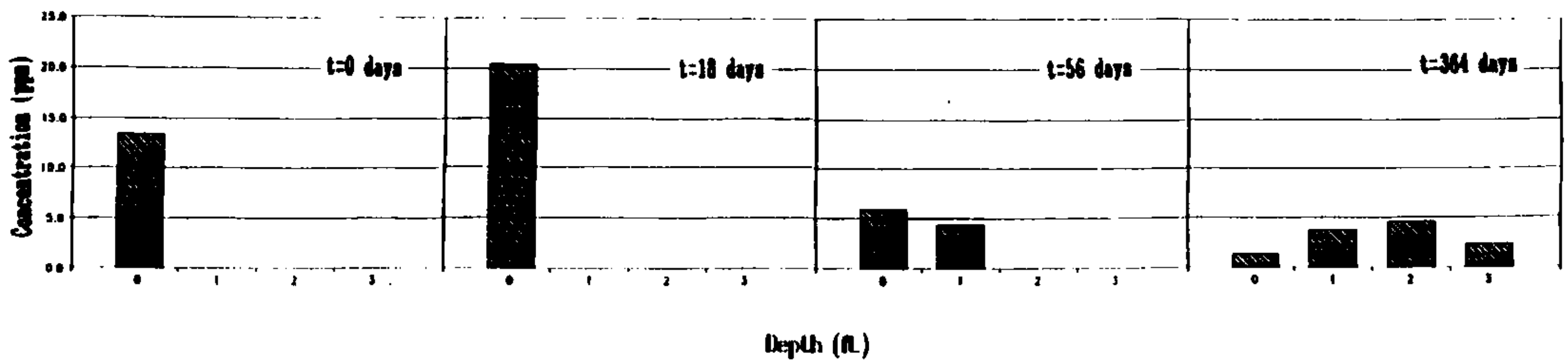


Figure 3.14. Hexazinone Concentration vs. Depth for Clear Plot.

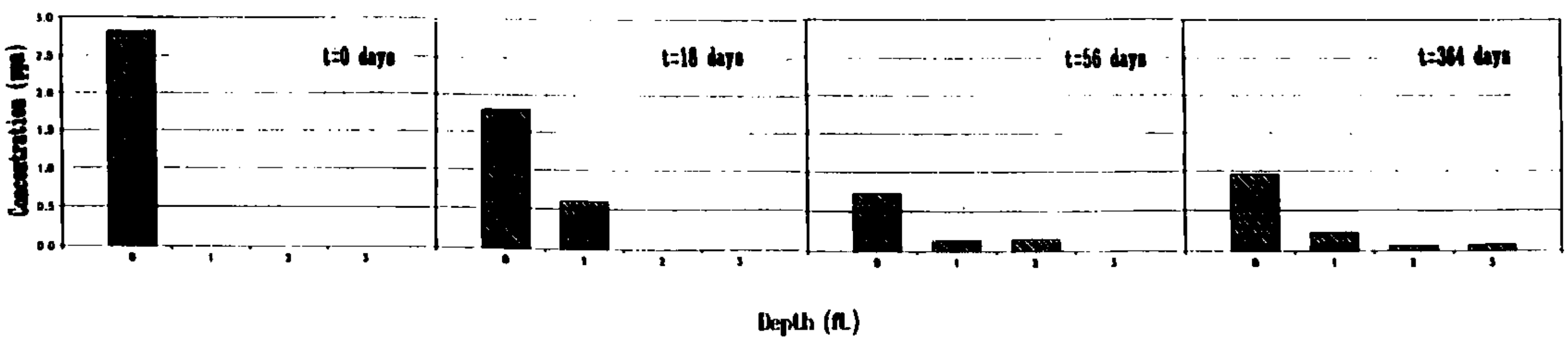


Figure 3.15. Triclopyr Concentration vs. Depth for Clear Plot.

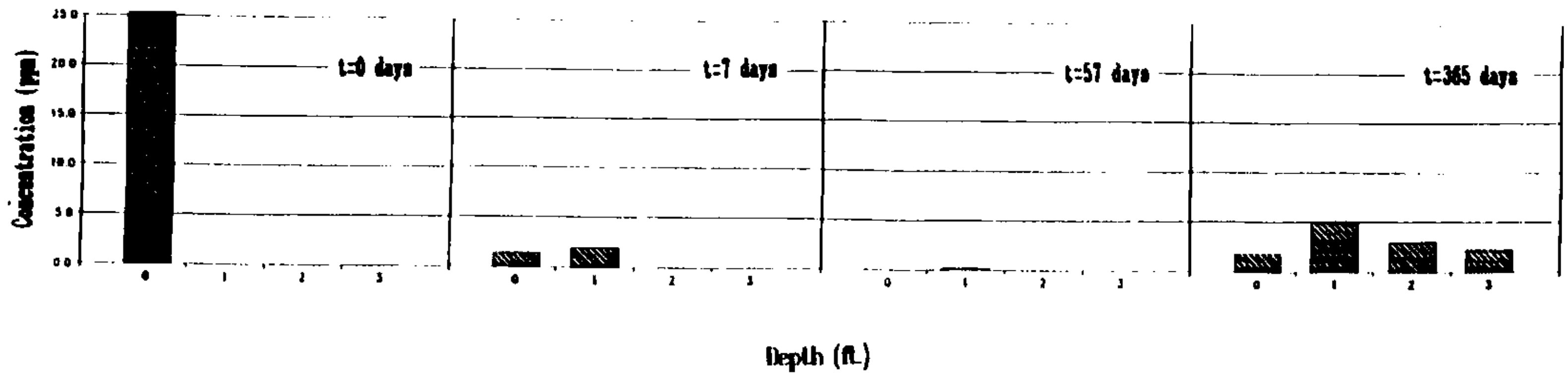


Figure 3.16. Hexazinone Concentration vs. Depth for Chulitna Plot.

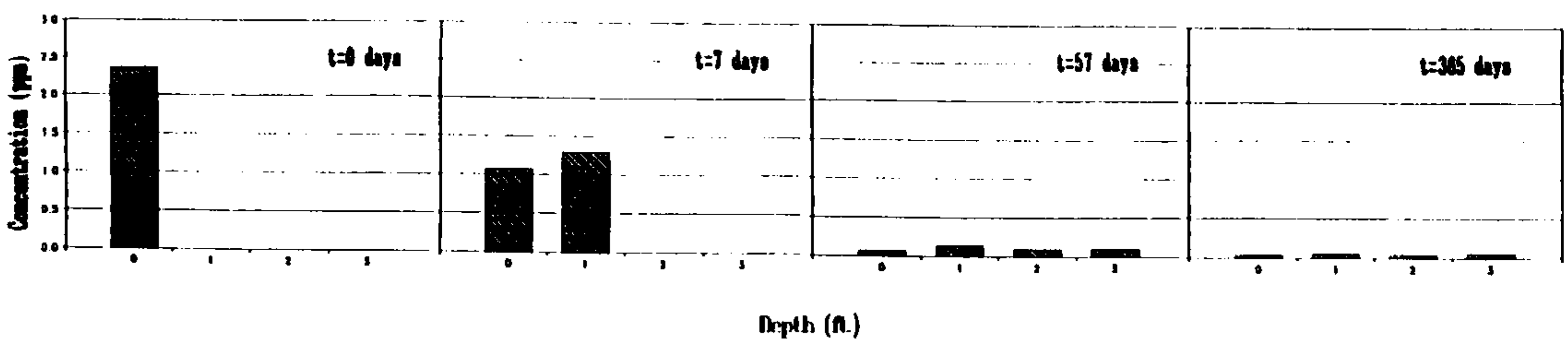


Figure 3.17. Triclopyr Concentration vs. Depth for Chulitna Plot.

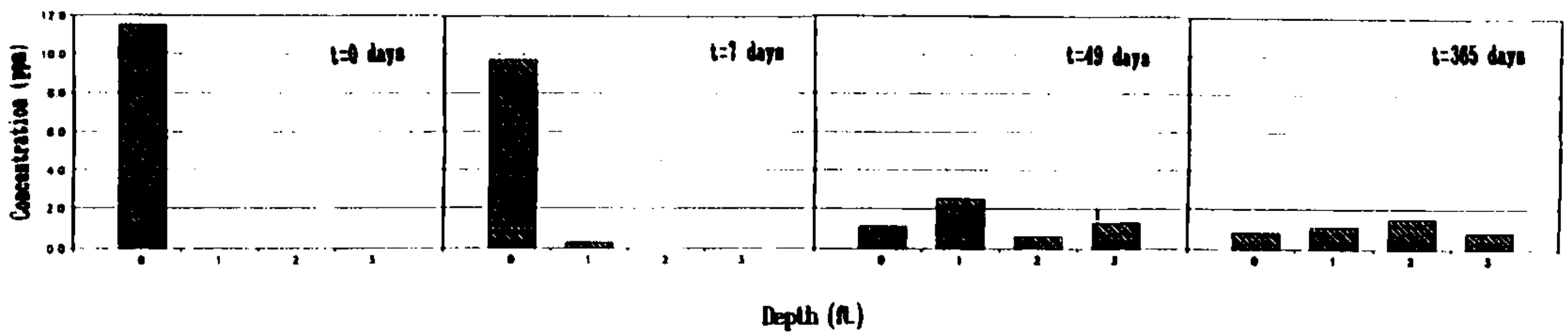


Figure 3.18. Hexazinone Concentration vs. Depth for Birchwood Combination Plot.

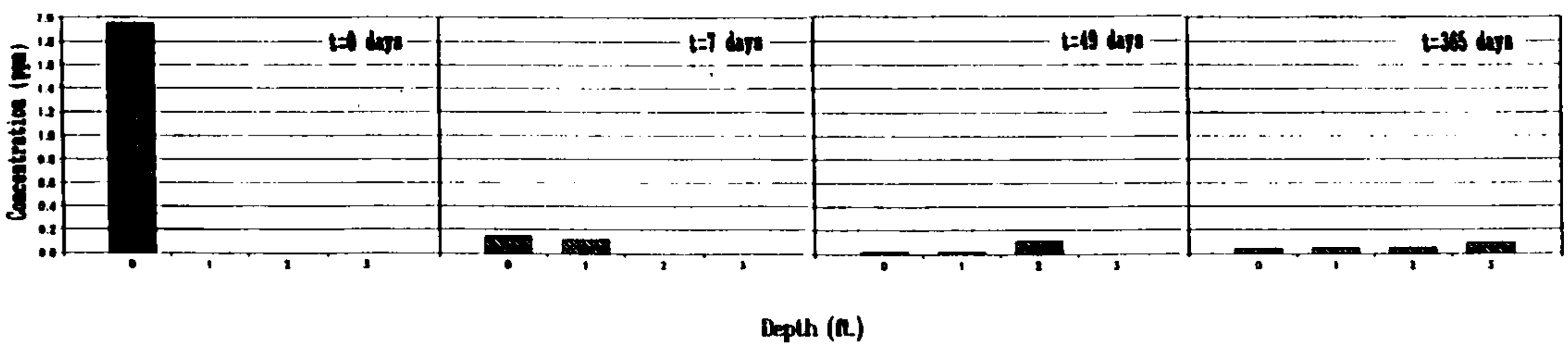


Figure 3.19. Triclopyr Concentration vs. Depth for Birchwood Combination Plot.

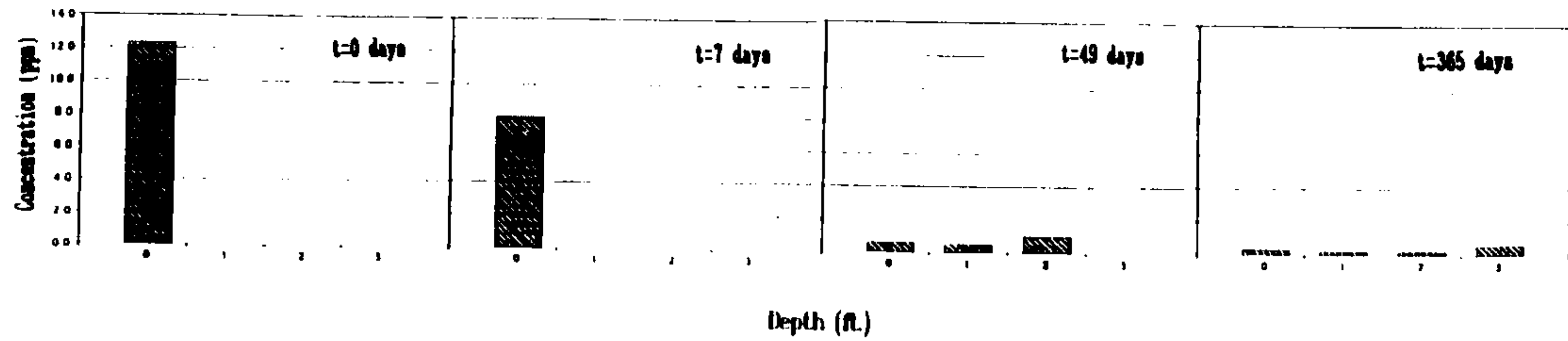


Figure 3.20. Hexazinone Concentration vs. Depth for Birchwood Hexazinone Plot.

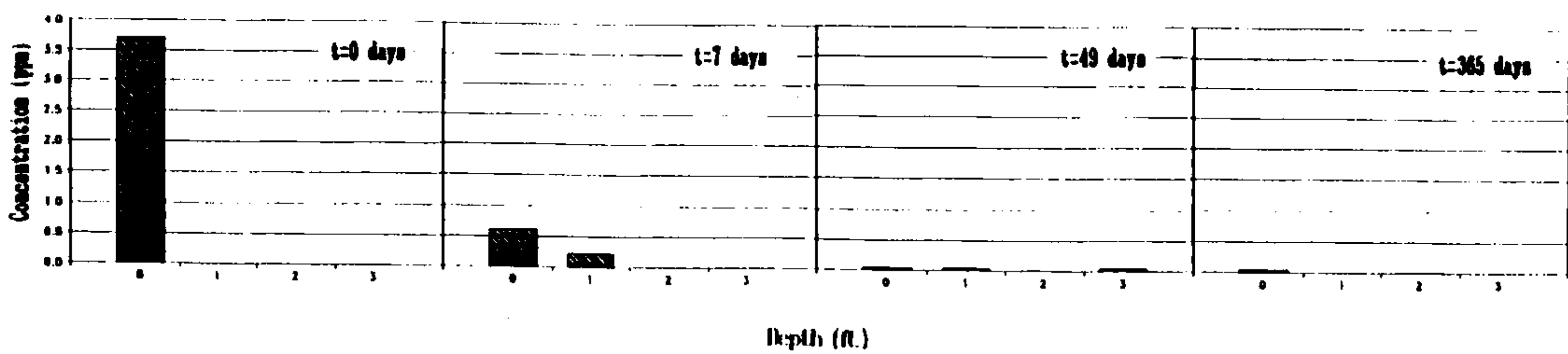


Figure 3.21. Triclopyr Concentration vs. Depth for Birchwood Triclopyr Plot.

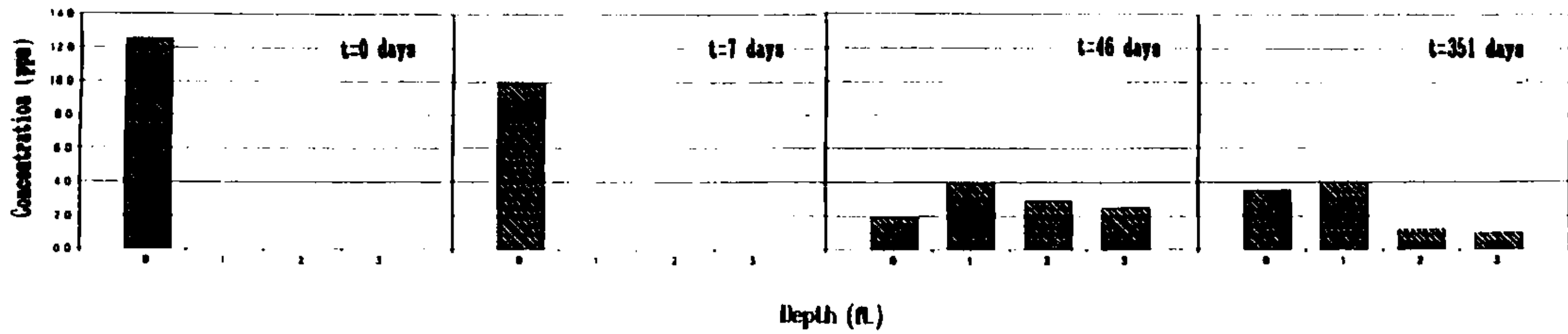


Figure 3.22. Hexazionone Concentration vs. Depth for Firecreek Plot.

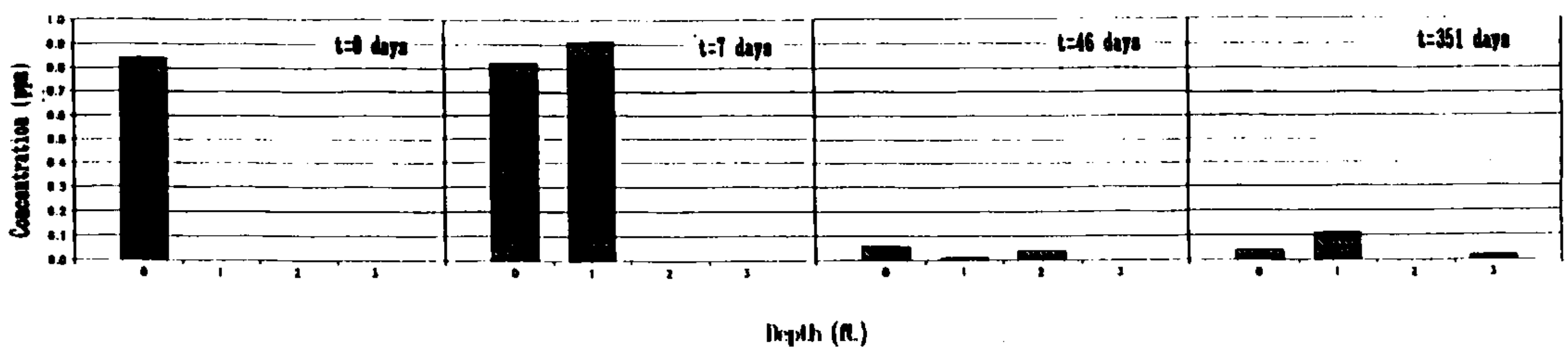


Figure 3.23. Triclopyr Concentration vs. Depth for Firecreek Plot.

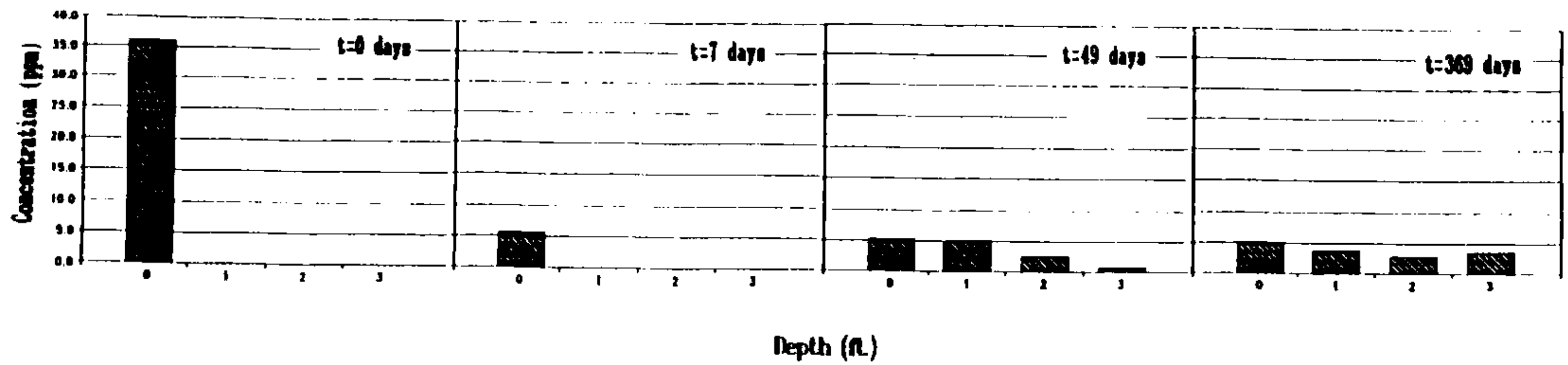


Figure 3.24. Hexazinone Concentration vs. Depth for Seward Plot.

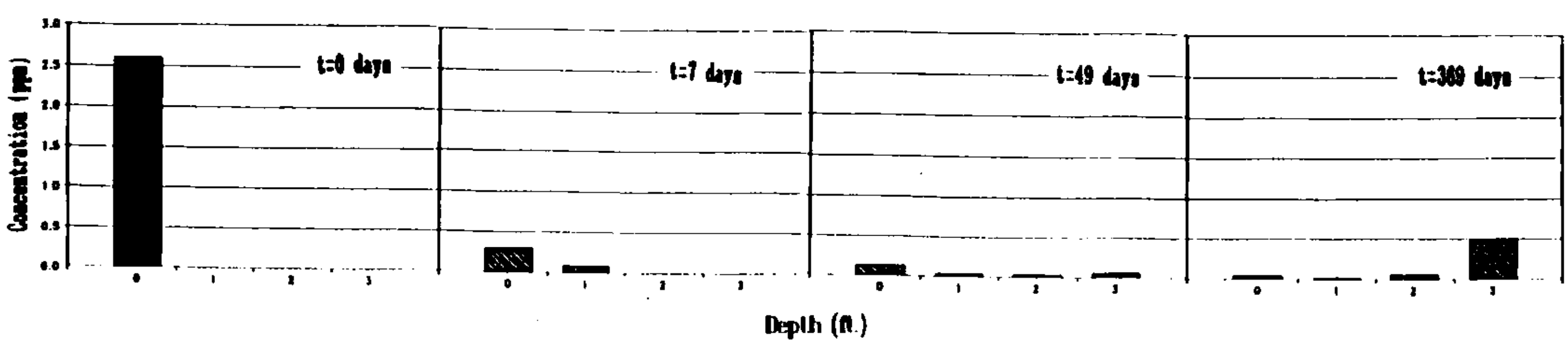


Figure 3.25. Triclopyr Concentration vs. Depth for Seward Plot.

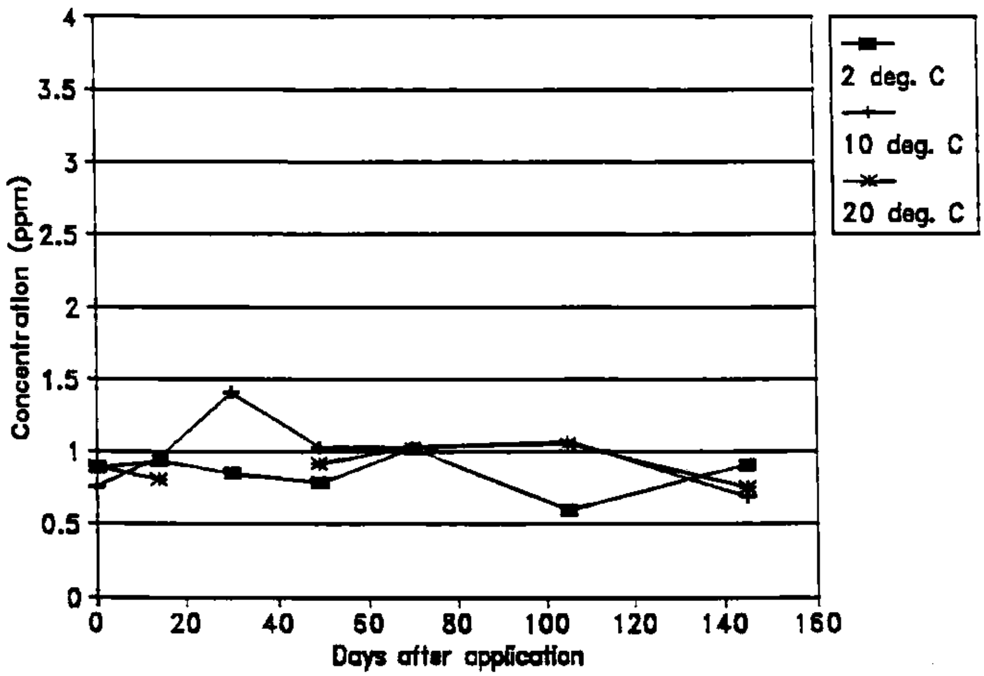


Figure 3.26. Microbial Degradation of Triclopyr in Soil Augmented With 3% (By Weight) Organic Matter.

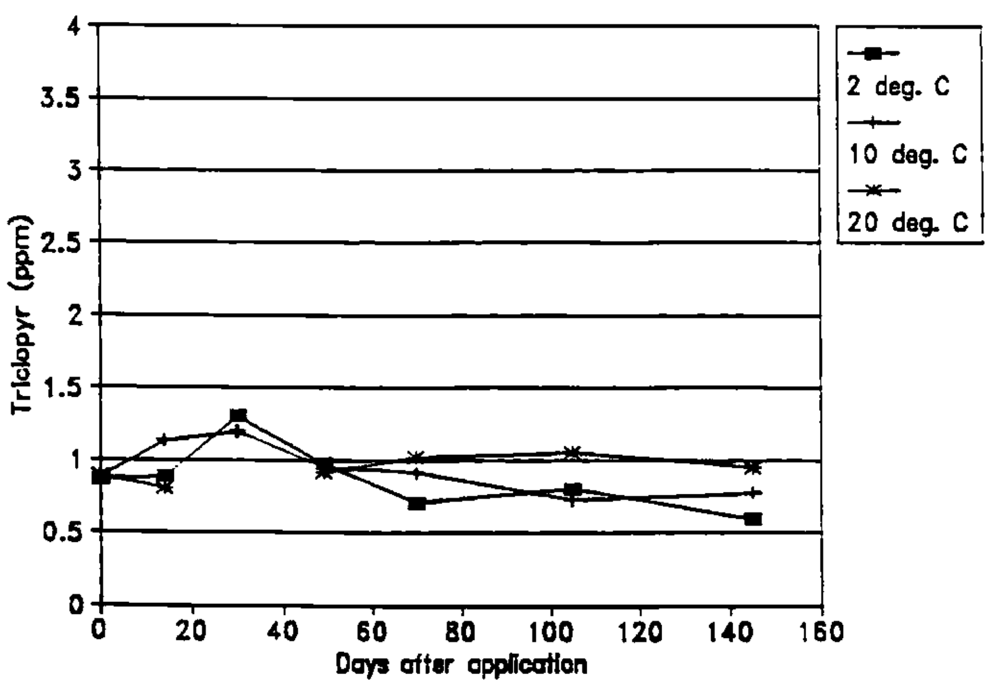


Figure 3.27. Microbial Degradation of Triclopyr in Soil With Zero Percent Organic Matter.

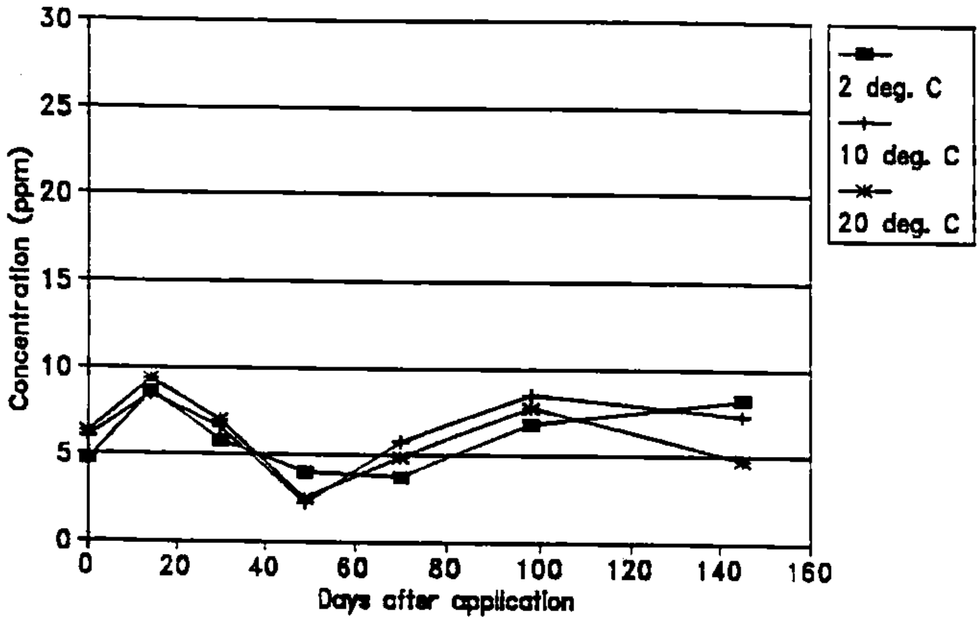


Figure 3.28. Microbial Degradation Curve of Hexazinone in Soil With Zero Percent Organic Matter.

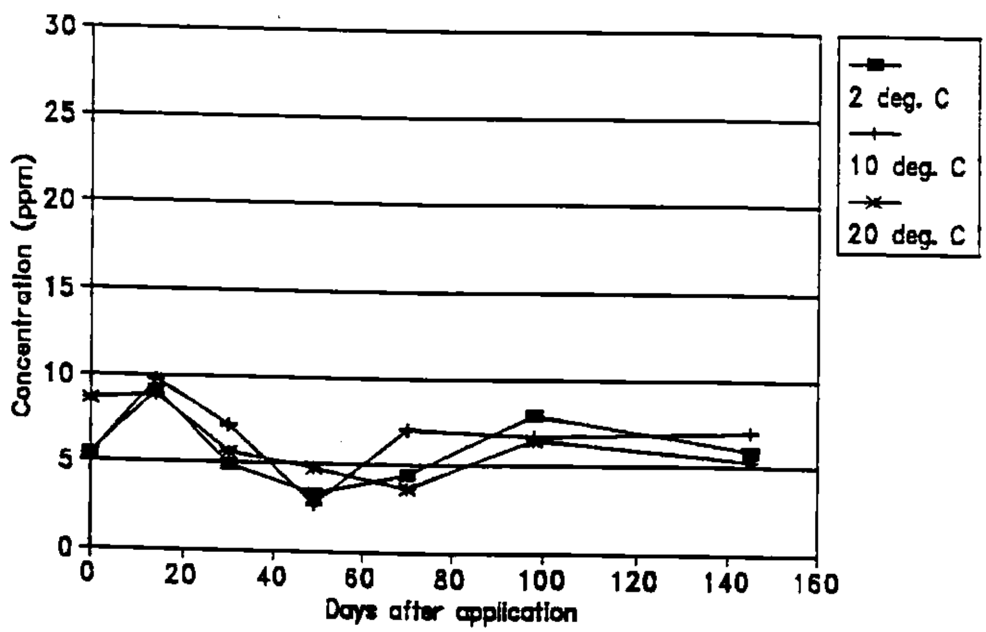


Figure 3.29. Microbial Degradation of Hexazinone in Soil Augmented With 3% (By Weight) Organic Matter.

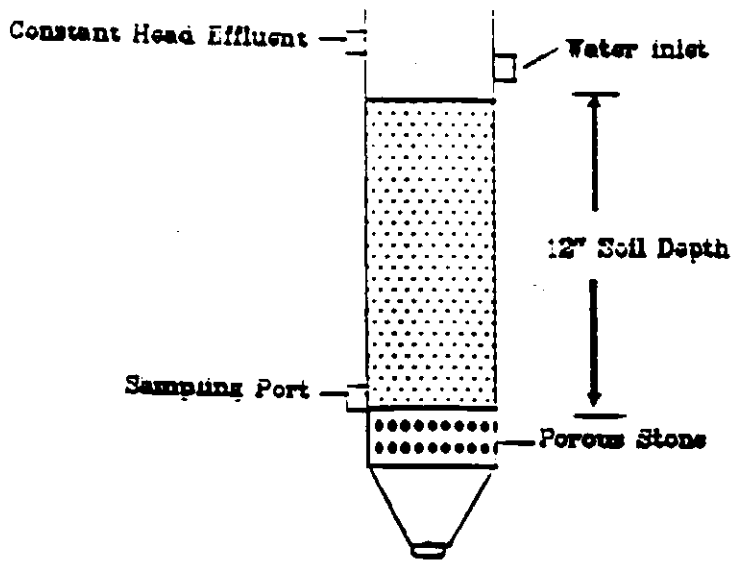


Figure 3.30. Soil Column.

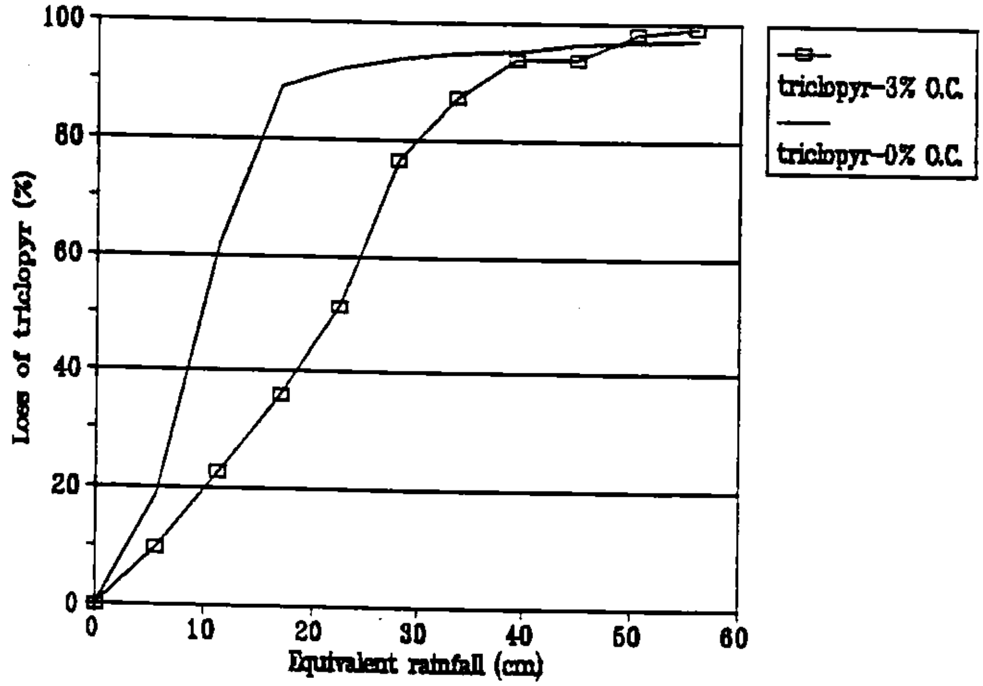


Figure 3.31. Cumulative Percent Triclopyr Leached From Soil Columns.

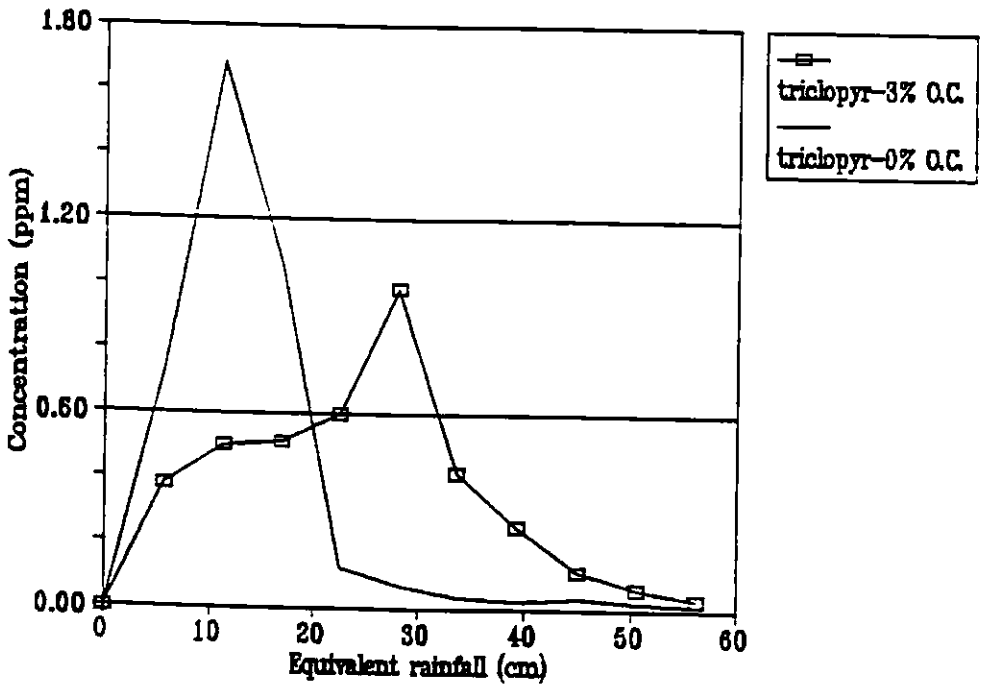


Figure 3.32. Concentration of Triclopyr in Eluates.

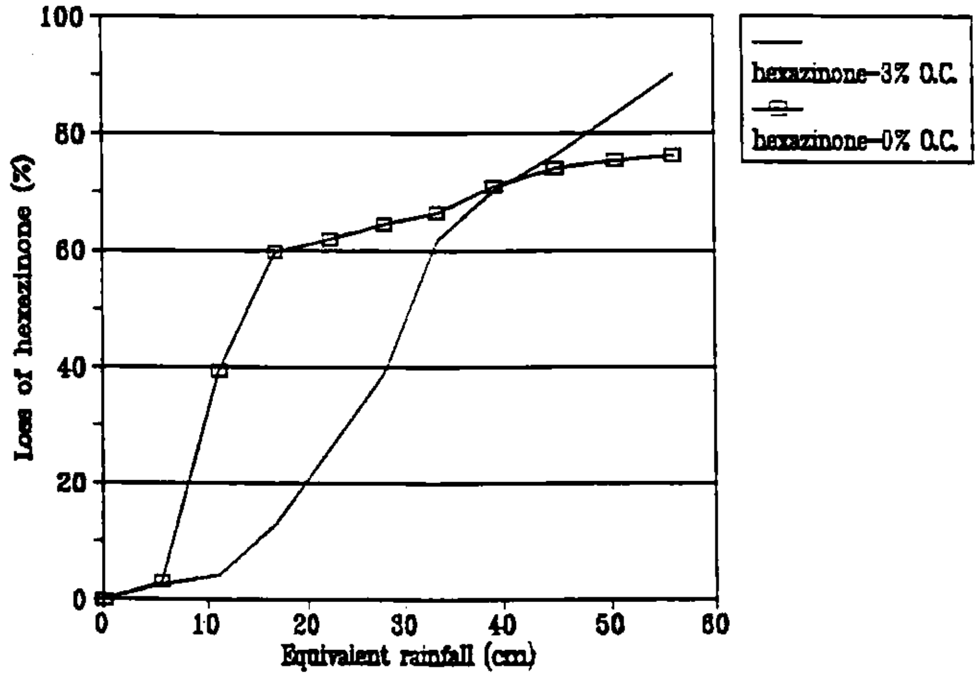


Figure 3.33. Cumulative Percent Hexazinone Leached From Soil Columns.

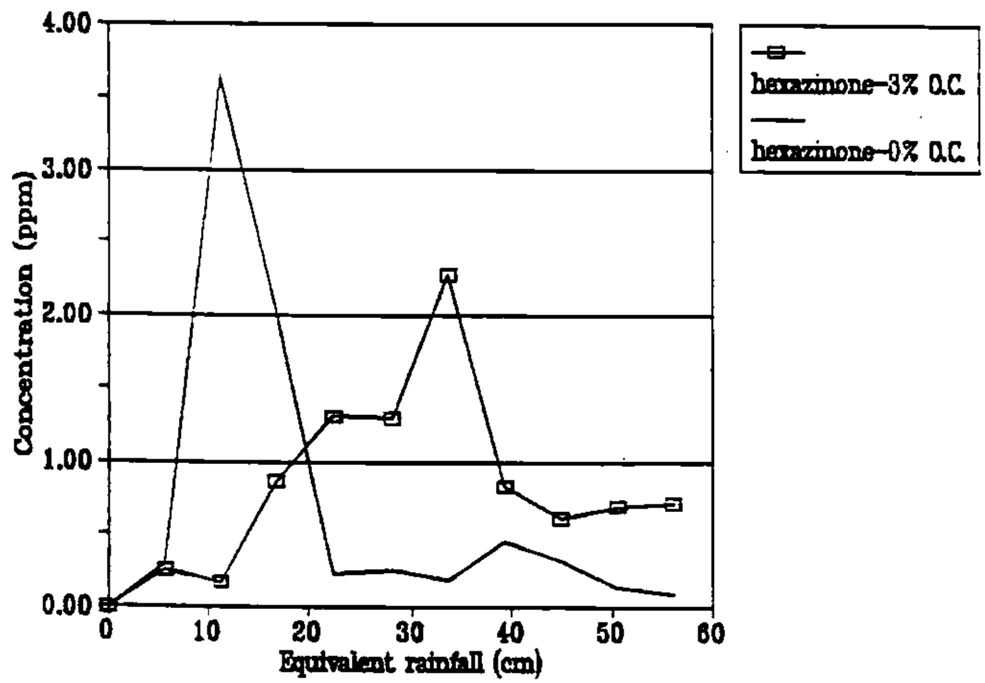


Figure 3.34. Concentration of Hexazinone in Eluates.

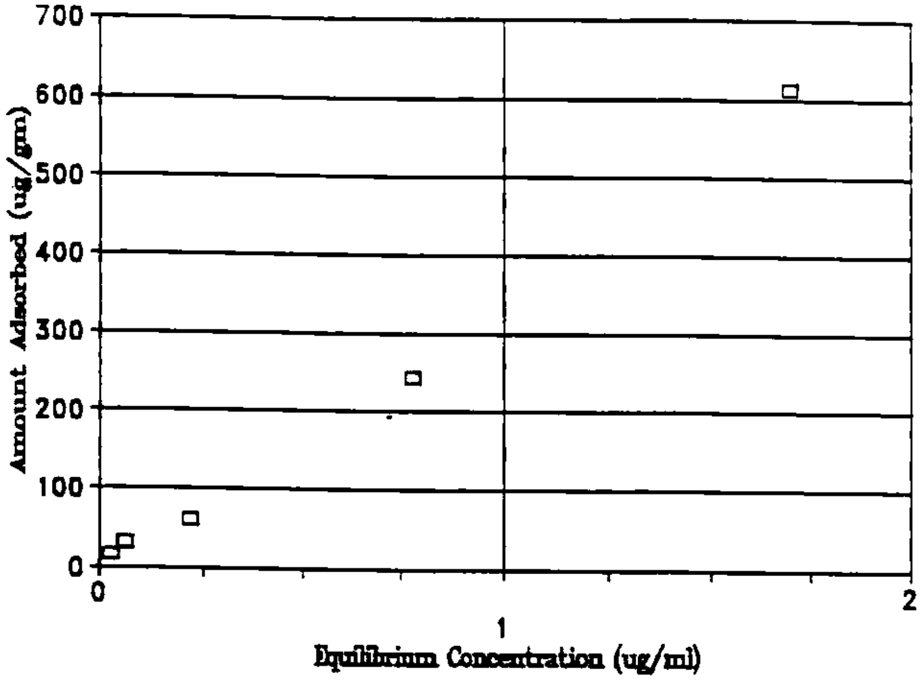


Figure 3.35. Adsorption Isotherm for Triclopyr in Sand-Silt Soil With 0% Organic Content.

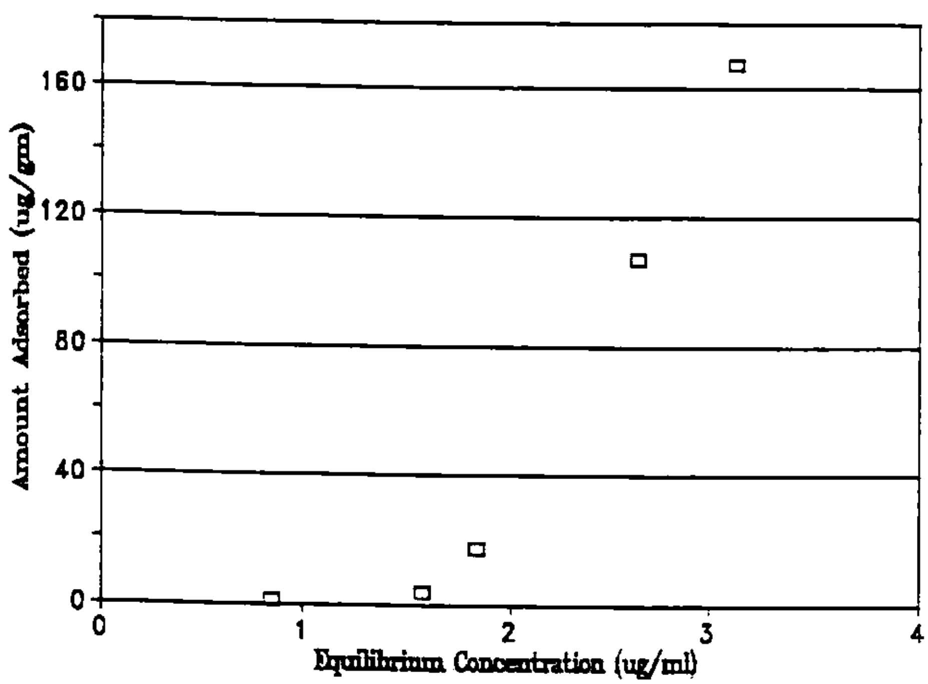


Figure 3.36. Adsorption Isotherm for Hexazinone in Sand-Silt Soil With 0% Organic Content.

Table 3.1. LD_{50}s (rats) for various chemicals and pesticides

mg/kg body weight	chemical or pesticide
0.93	Aldicarb
3	Endrin (banned)
8	Carbofuran
10	Aldrin (banned)
22	Paraquat
24	Nicotine
30	Diquat
100	2,4,5-T (restricted dioxin)
113	DDT (restricted)
200	Caffeine
260	Formaldehyde
375	2,4-D
470	Glyphosate
670	EDC
1000	Aspirin
1040	Dicamba
1100	Aminotriazole (Amitrol)
2000	Vitamin A
2000	Picloram
2460	Isobutanol
2660	Boric acid
2800	Carbon tetrachloride
2860	Garlon (a.i. triclopyr)
3000	Table salt (sodium chloride)
3080	Tordon 101 mix
5000+	Tordon 101R
5000+	Rodeo (a.i. glyphosate)
5200	Bromacil (Hyvar X)
6880	Velpar (a.i. hexazinone)

NOTE: a.i. = active ingredient

Table 3.2. Triclopyr physical properties

Common Name	triclopyr, DOWCO 233
Product Name	GARLON - DOW
Molecular Formula	$C_7H_4Cl_3NO_3$
Molecular Weight	256.5
Melting Point	148 to 150°C
Subject to photodecomposition	

Weed Science Society of America, 1983

Table 3.3. Solubilities of Triclopyr @ 25°C

Solvent	g/100 ml
Acetone	98.9
Acetonitrile	12.6
Benzene	2.73
Chloroform	2.73
N-hexane	0.041
N-octanol	30.7
Xylene	2.79
Water	0.043

Weed Science Society of America, 1983

Table 3.4. Triclopyr Toxicological Properties (LD_{50}s)

Animal	Acute LD_{50} (mg/kg)			
	Triclopyr (a.i., Garlon)	Garlon 3A	TCP	TMP
Mallard Duck	1698	3176	--	--
Rat (F)	713	2140	870	--
Rat (M)	713	2830	794	>2000
Rabbit (mixed)	550	--	--	--
Guinea Pig (M)	310	--	--	--
Teratogenicity	negative	--	--	--
Mutagenicity	negative	--	--	--

Weed Science Society of America, 1983

Table 3.5. LC_{50}s (for various fish and wildlife)

Animal	LC_{50}	Triclopyr	Garlon 3A
Trout	96 hr	117 ppm	240 ppm
Bluegill	96 hr	148 ppm	471 ppm
Shrimp	96 hr	--	895 ppm
Oyster	48 hr	--	>56,<87 ppm
Crab	96 hr	--	>1000 ppm
Mallard Duck	8-day dietary	>5000 ppm	>10000 ppm
Bobwhite Quail	8-day dietary	2935 ppm	11622 ppm
Japanese Quail	8-day dietary	3272 ppm	--

Weed Science Society of America, 1983

Table 3.6. Solubilities of Hexazinone

Solvent	g/100g solvent at 25°C
Water	3.3
Chloroform	388
Methanol	265
Benzene	94
Dimethylformamide	83.6
Acetone	79.2
Toluene	38.6
Hexane	0.3

USEPA, 1988a

Table 3.7. Chemical Properties of Hexazinone

Chemical Formula	$C_{12}H_{20}O_2N_4$
Molecular Weight	252
Physical State (25°C)	white crystalline solid
Melting Point	115-117°C
Vapor Pressure(86°C)	6.4×10^{-5} mm Hg
Water Solubility (25°C)	33000 mg/L

USEPA, 1988b

Table 3.8. Toxilogical Properties of Hexazinone

Oral LD_{50} (Rat)	6887 mg/kg
Oral LD_{50} (Beagle)	>3400 mg/kg
Oral LD_{50} (Guinea Pigs)	825 mg/kg
Oral LD_{50} (Bobwhite)	>5000 mg/kg
Oral LD_{50} (Mallard Duck)	>10000 mg/kg
96 hour LC_{50} (Bluegill)	505 ppm
96 hour LC_{50} (Rainbow Trout)	370 ppm
Teratogenicity	negative
Mutagenicity	negative
Carcinogenicity	negative

USEPA, 1988b

Table 3.9. Toxilogical Properties of the Hexazinone Metabolites in Rats

Oral ALD, Metabolite A	>4686 mg/kg
Oral ALD, Metabolite B	>5000 mg/kg
Oral ALD, Metabolite C	>7500 mg/kg
Oral ALD, Metabolite D	>7500 mg/kg
Oral ALD, Metabolite E	>7500 mg/kg

U.S. Forest Service , 1984

Table 3.10. Summary of triclopyr and hexazinone general characteristics

Parameter	Units	Triclopyr (a.i., Garlon)	Hexazinone (a.i., Velpar)
Toxicity LD_{50} (rat)	mg/kg	713	1690
Half-life (in soil)	days	10-46	30-180
Migration (in soil)	cm	± 10	± 60
Persistence (in soil)	years	1-2	1-2
Major Metabolites	#	2	4
Solubility in Water	mg/L @ 25°C	430	33000
Application Rate	kg/ac	0.954	4.082

Table 3.11. Strip identification for sampling events.

Strip No.	Approximate time period of sampling event
1	T = 0 days
2	T = 7 days
3	T = 49 days
4	T = random after breakup
5	T = 365 days

Table 3.12. Sampling dates of herbicide application for each site and times (days) of follow-up sampling.

	Sampling times in order of collection (days)				
Site	Initial	7	49	Random	365
Ft. Wainwright	6/05/89	7	52	343	365
Clear	6/26/89	18	56	324	364
Seward	7/06/89	7	49	316	369
Chulitna	7/17/89	7	57	303	365
Birchwood	7/31/89	7	49	290	365
Firecreek	8/14/89	7	46	276	351

Table 3.13. Ground temperature data for 1989.

Site I.D.	Date	Julian Days	Ground Temperature (°C @ 1') Low	High	Avg.
Ft. Wainwright	6/1-8/31	184-221	---	14.5	13.4
Clear	6/22-8/16	173-228	10.5	16.3	13.9
Chulitna	---	---	---	---	---
Birchwood	7/3-9/18	184-261	9.8	21.4	15.3
Firecreek	8/14-9/27	226-270	8.5	21.6	13.1
Seward	6/1-8/24	152-236	8.7	20.9	14.9

--- Denotes no data available for that time period.

Table 3.14. Ground temperature data for 1990.

Site I.D.	Date	Julian Days	Ground Temperature (°C @ 1') Low	High	Avg.
Ft. Wainwright	5/11-5/22	131-142	5.8	15.3	11.9
Clear	5/17-7/17	137-198	7.7	16.0	12.3
Chulitna	---	---	---	---	---
Birchwood	---	---	---	---	---
Firecreek	---	---	---	---	---
Seward	5/19-7/10	139-191	7.8	16.3	12.2

--- Denotes no data available for that time period.

Table 3.15. Site Soil Characteristics

Site	UCS Type	% Organics
Ft. Wainwright	GW-GM	4.2
Clear	SW-SM	4.8
Chulitna	SM	6.5
Birchwood	SM	7.9
Firecreek	SM	4.9
Seward	SW-SM	NA
Average		5.7

DOT&PF, 1989

Table 3.16. Unified Classification Designations

Group Symbols	Typical Names
GW	Well-graded gravel and gravel-sand mixtures, little or no fines
GM	Silty gravels, gravel-sand-silt mixtures
SW	Well-graded sands and gravelly sands, little or no fines
SM	Silty sands, sand-silt mixtures

Das, 1985

Table 3.17. Typical values of permeability coefficients.

Soil type	k (cm/sec)	k (ft/min)
Clean gravel	1.0-100	2.0-200
Course sand	1.0-0.01	2.0-0.02
Fine sand	0.01-0.001	0.02-0.002
Silt	0.001-0.00001	0.002-0.00002
Clay	Less than 0.000001	Less than 0.000002

Das, 1985

Table 3.18. Precipitation data for 1989.

Site I.D.	Date	Julian Days	Days After Application	Total Precip. (inches)
Ft. Wainwright	6/1-8/31	152-243	91	3.6
Clear	6/22-8/16	173-228	55	5.2
Chulitna	---	---	---	---
Birchwood	7/3-9/18	184-261	77	12.6
Firecreek	8/14-9/27	226-270	44	8.0
Seward	6/1-8/24	152-236	84	18.9

--- Denotes no data collected for that time period.

Table 3.19. Precipitation data for 1990.

Site I.D.	Date	Julian Days	Days After Application	Total Precip. (inches)
Ft. Wainwright	5/11-6/24	131-205	344-418	4.6
Clear	5/17-7/17	137-198	329-390	0.0
Chulitna	---	---	---	---
Birchwood	---	---	---	---
Firecreek	---	---	---	---
Seward	5/19-7/10	139-191	352-404	2.5

--- Denotes no data collected for that time period.
Note: The Clear value of 0.0 is due to a data logger failure.

Table 3.20. Summary of significant precipitation events at Ft. Wainwright - 1989.

Day of Precipitation Event	Inches of Precipitation Per Event	Cumulative Precipitation (Inches)
13	0.24	0.29
19	1.34	1.64
20	0.81	2.45
22	0.24	2.70
52	---	3.28

Table 3.21. Summary of significant precipitation events at Clear - 1989.

Day of Precipitation Event	Inches of Precipitation Per Event	Cumulative Precipitation (Inches)
1	0.36	0.36
12	0.70	1.25
26	0.22	1.77
38	0.38	2.66
39	0.70	3.36
51	---	3.38

Table 3.22. Summary of significant precipitation events at Birchwood - 1989

Day of Precipitation Event	Inches of Precipitation Per Event	Cumulative Precipitation (Inches)
1	0.40	0.45
7	0.33	0.86
25	0.97	2.41
26	2.02	4.43
27	1.22	5.65
28	0.74	6.39
29	0.61	7.00
30	0.24	7.24
36	0.42	7.83
44	0.20	8.44
48	0.36	8.84
49	0.44	9.28

Table 3.23. Summary of significant precipitation events at Firecreek - 1989.

Day of Precipitation Event	Inches of Precipitation Per Event	Cumulative Precipitation (Inches)
5	0.45	0.50
11	1.53	2.30
12	1.95	4.25
13	0.78	5.03
14	0.83	5.86
15	0.27	6.13
33	0.35	6.93
34	0.29	7.22
44	---	8.02

Table 3.24. Summary of significant precipitation events at Seward - 1989.

Day of Precipitation Event	Inches of Precipitation Per Event	Cumulative Precipitation (Inches)
7	0.41	0.42
13	0.37	0.82
14	0.42	1.24
16	0.29	1.61
17	0.48	2.09
18	0.94	3.03
23	0.92	4.08
24	0.26	4.34
26	0.43	4.79
43	0.20	5.64
49	---	6.05

Table 3.25. Amount of hexazinone in different soil layers at Fort Wainwright.

Layer	Amount of hexazinone (ppm) at different times after application (days)				
	0	7	52	343	365
Left of track					
0-2 inches	4.7	15.8	5.8	---	2.9
1 foot	---	*	8.5	---	3.1
2 foot	---	---	1.3	---	3.3
3 foot	---	---	---	---	1.7
Right of track					
0-2 inches	11.1	23.9	6.9	---	4.3
1 foot	---	*	5.1	---	4.0
2 foot	---	---	*	---	3.7
3 foot	---	---	---	1.4	1.9
Average					
0-2 inches	7.9	19.8	6.3	---	3.6
1 foot	---	*	6.8	---	3.5
2 foot	---	---	6.3	---	3.5
3 foot	---	---	---	---	1.8

--- no sample taken
* less than 0.04 ppm (none detected)

Table 3.26. Qualification of hexazinone metabolites in different soil layers at Ft. Wainwright.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	7	52	343	365
Left of track					
0-2 inches	BD	ABD	BD	---	B
1 foot	---	D	BD	---	*
2 foot	---	---	BD	---	*
3 foot	---	---	---	---	*
Right of track					
0-2 inches	BD	BD	BD	---	B
1 foot	---	D	BD	---	*
2 foot	---	---	BD	---	D
3 foot	---	---	---	BD	*

Table 3.27. Amount of hexazinone in different soil layers at Clear.

Layer	Amount of hexazinone (ppm) at different times after application (days)				
	0	18	56	324	364
Left of track					
0-2 inches	13.7	17.8	7.4	---	2.9
1 foot	---	*	4.9	---	6.2
2 foot	---	---	*	---	4.8
3 foot	---	---	*	---	2.9
Right of track					
0-2 inches	13.4	23.0	4.4	---	*
1 foot	---	*	4.0	---	1.3
2 foot	---	---	*	---	4.5
3 foot	---	---	*	1.4	1.9
Average					
0-2 inches	13.5	20.4	5.9	---	1.4
1 foot	---	*	4.4	---	3.8
2 foot	---	---	*	---	4.6
3 foot	---	---	*	---	2.4

--- no sample taken
* less than 0.04 ppm (none detected)

Table 3.28. Qualification of hexazinone metabolites in different soil layers at Clear.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	18	56	343	364
Left of track					
0-2 inches	BD	BD	BD	---	BD
1 foot	---	BD	D	---	*
2 foot	---	---	*	---	*
3 foot	---	---	B	---	*
Right of track					
0-2 inches	BD	BD	BD	---	*
1 foot	---	BD	*	---	*
2 foot	---	---	*	---	*
3 foot	---	---	*	BD	*

Table 3.29. Amount of hexazinone in different soil layers at Seward.

Layer	Amount of hexazinone (ppm) at different times after application (days)				
	0	7	49	316	369
<u>Left of track</u>					
0-2 inches	38.1	4.8	5.7	---	4.7
1 foot	---	*	5.0	---	3.7
2 foot	---	---	1.4	---	0.6
3 foot	---	---	*	---	2.4
<u>Right of track</u>					
0-2 inches	34.1	6.4	4.6	---	5.6
1 foot	---	*	2.1	---	5.8
2 foot	---	---	3.6	---	4.9
3 foot	---	---	1.0	*	4.7
<u>Average</u>					
0-2 inches	36.1	5.6	5.2	---	5.1
1 foot	---	*	5.0	---	3.7
2 foot	---	---	2.5	---	2.8
3 foot	---	---	0.7	---	3.5

--- no sample taken
* less than 0.04 ppm (none detected)

Table 3.30. Qualification of hexazinone metabolites in different soil layers at Seward.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	7	49	316	369
<u>Left of track</u>					
0-2 inches	BD	BD	BD	---	*
1 foot	---	BD	BD	---	*
2 foot	---	---	BD	---	*
3 foot	---	---	BD	---	*
<u>Right of track</u>					
0-2 inches	BD	BD	*	---	*
1 foot	---	BD	BD	---	*
2 foot	---	---	BD	---	*
3 foot	---	---	BD	ABD	*

Table 3.31. Amount of hexazinone in different soil layers at Chulitna.

Layer	Amount of hexazinone (ppm) at different times after application (days)				
	0	7	57	303	365
Left of track					
0-2 inches	22.9	3.1	*	---	2.6
1 foot	---	1.4	*	---	4.2
2 foot	---	---	*	---	2.9
3 foot	---	---	*	*	1.9
Right of track					
0-2 inches	28.8	*	*	---	1.0
1 foot	---	2.7	*	---	5.9
2 foot	---	---	*	---	3.0
3 foot	---	---	*	---	2.7
Average					
0-2 inches	25.9	1.5	*	---	1.8
1 foot	---	2.0	*	---	5.1
2 foot	---	---	*	---	3.0
3 foot	---	---	*	---	2.3

--- no sample taken
 * less than 0.04 ppm (none detected)

Table 3.32. Qualification of hexazinone metabolites in different soil layers at Chulitna.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	7	57	303	365
Left of track					
0-2 inches	BD	BD	*	---	B
1 foot	---	BD	BD	---	AB
2 foot	---	---	BD	---	B
3 foot	---	---	AB	BD	*
Right of track					
0-2 inches	BD	BD	BD	---	BD
1 foot	---	BD	BD	---	B
2 foot	---	---	AB	---	AB
3 foot	---	---	A	---	B

Table 3.33. Amount of hexazinone in different soil layers at Birchwood (Combination plot).

Layer	Amount of hexazinone (ppm) at different times after application (days)				
	0	7	49	290	365
<u>Left of track</u>					
0-2 inches	6.5	10.0	1.7	---	0.9
1 foot	---	*	2.6	---	1.1
2 foot	---	---	0.6	---	0.5
3 foot	---	---	1.1	---	1.5
<u>Right of track</u>					
0-2 inches	16.5	9.3	*	---	0.6
1 foot	---	0.6	2.3	---	1.0
2 foot	---	---	0.7	---	2.5
3 foot	---	---	1.5	*	*
<u>Average</u>					
0-2 inches	11.5	9.7	1.1	---	0.8
1 foot	---	*	2.5	---	1.1
2 foot	---	---	0.6	---	1.5
3 foot	---	---	1.3	---	0.8

--- no sample taken
* less than 0.04 ppm (none detected)

Table 3.34. Qualification of hexazinone metabolites in different soil layers at Birchwood Combination plot.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	7	49	290	365
<u>Left of track</u>					
0-2 inches	*	*	*	---	*
1 foot	---	BD	B	---	BD
2 foot	---	---	B	---	B
3 foot	---	---	BD	---	BD
<u>Right of track</u>					
0-2 inches	*	*	B	---	*
1 foot	---	BD	BD	---	BD
2 foot	---	---	B	---	BD
3 foot	---	---	B	BD	B

Table 3.35. Amount of hexazinone in different soil layers at Birchwood Hexazinone Only plot.

Layer	Amount of hexazinone (ug) at different times after application (days)				
	0	7	49	290	365
Left of track					
0-2 inches	12.9	9.5	0.5	---	*
1 foot	---	*	0.5	---	0.4
2 foot	---	---	1.0	---	*
3 foot	---	---	*	*	0.6
Right of track					
0-2 inches	11.7	6.4	0.7	---	*
1 foot	---	*	*	---	*
2 foot	---	---	0.9	---	*
3 foot	---	---	*	---	0.6
Average					
0-2 inches	12.3	7.9	0.6	---	*
1 foot	---	*	0.5	---	*
2 foot	---	---	1.0	---	*
3 foot	---	---	*	---	0.6

--- no sample taken
* less than 0.04 ppm (none detected)

Table 3.36. Qualification of hexazinone metabolites in different soil layers at Birchwood Hexazinone Only plot.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	7	49	290	365
Left of track					
0-2 inches	BD	*	*	---	B
1 foot	---	BD	B	---	BD
2 foot	---	---	*	---	B
3 foot	---	---	BD	*	BD
Right of track					
0-2 inches	D	BD	BD	---	BD
1 foot	---	BD	B	---	BD
2 foot	---	---	B	---	B
3 foot	---	---	BD	---	BD

Table 3.37. Amount of hexazinone in different soil layers at Firecreek.

Layer	Amount of hexazinone (ug) at different times after application (days)				
	0	7	46	276	351
<u>Left of track</u>					
0-2 inches	13.2	11.4	1.0	---	4.8
1 foot	---	*	4.1	---	4.1
2 foot	---	---	3.8	---	1.1
3 foot	---	---	2.9	2.8	1.3
<u>Right of track</u>					
0-2 inches	11.9	8.3	2.8	---	2.1
1 foot	---	*	3.7	---	3.9
2 foot	---	---	2.1	---	1.3
3 foot	---	---	2.1	---	0.7
<u>Average</u>					
0-2 inches	12.5	9.9	1.9	---	3.5
1 foot	---	*	3.9	---	4.0
2 foot	---	---	2.9	---	1.2
3 foot	---	---	2.5	---	1.0

--- no sample taken
* less than 0.04 ppm (none detected)

Table 3.38. Qualification of hexazinone metabolites in different soil layers at Firecreek.

Layer	Metabolites present at different times after application (only metabolites A, B, and D)				
	0	7	46	276	351
<u>Left of track</u>					
0-2 inches	BD	BD	BD	---	BD
1 foot	---	D	BD	---	BD
2 foot	---	---	BD	---	BD
3 foot	---	---	BD	BD	BD
<u>Right of track</u>					
0-2 inches	BD	BD	BD	---	B
1 foot	---	D	BD	---	BD
2 foot	---	---	BD	---	BD
3 foot	---	---	BD	---	BD

Table 3.39. Amount of triclopyr in different soil layers at Fort Wainwright.

Layer	Amount of triclopyr (ppm) at different times after application (days)				
	0	7	52	343	365
Left of track					
0-2 inches	1.07	2.65	0.09	---	0.09
1 foot	---	0.14	0.05	---	0.05
2 foot	---	---	*	---	*
3 foot	---	---	*	---	*
Right of track					
0-2 inches	2.08	3.52	0.26	---	0.02
1 foot	---	0.18	*	---	*
2 foot	---	---	0.04	---	0.04
3 foot	---	---	*	*	*
Average					
0-2 inches	1.57	3.08	0.17	---	0.05
1 foot	---	0.16	0.03	---	0.02
2 foot	---	---	0.02	---	0.02
3 foot	---	---	*	---	*

--- no sample taken
 * less than 0.01 ppm (none detected)

Table 3.40. Qualification of triclopyr metabolites in different soil layers at Ft. Wainwright.

Layer	Metabolites present at different times after application.				
	0	7	52	343	365
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.41. Amount of triclopyr in different soil layers at Clear.

Layer	Amount of triclopyr (ppm) at different times after application (days)				
	0	18	56	324	364
Left of track					
0-2 inches	2.85	1.55	0.69	---	0.80
1 foot	---	0.57	0.15	---	0.45
2 foot	---	---	0.16	---	0.06
3 foot	---	---	*	---	0.13
Right of track					
0-2 inches	2.79	2.06	0.77	---	1.12
1 foot	---	0.62	0.12	---	0.03
2 foot	---	---	0.13	---	0.06
3 foot	---	---	*	0.04	0.03
Average					
0-2 inches	2.82	1.80	0.73	---	0.96
1 foot	---	0.60	0.13	---	0.24
2 foot	---	---	0.15	---	0.06
3 foot	---	---	*	---	0.08

--- no sample taken
* less than 0.01 ppm (none detected)

Table 3.42. Qualification of triclopyr metabolites in different soil layers at Clear.

Layer	Metabolites present at different times after application.				
	0	18	56	324	364
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.43. Amount of triclopyr in different soil layers at Seward.

Layer	Amount of triclopyr (ppm) at different times after application (days)				
	0	7	49	316	369
Left of track					
0-2 inches	2.44	0.28	0.19	---	0.05
1 foot	---	0.10	0.04	---	0.02
2 foot	---	---	0.03	---	0.05
3 foot	---	---	*	---	0.98
Right of track					
0-2 inches	2.76	0.32	0.08	---	0.04
1 foot	---	0.09	0.04	---	0.02
2 foot	---	---	0.02	---	0.09
3 foot	---	---	0.12	0.01	*
Average					
0-2 inches	2.60	0.30	0.13	---	0.05
1 foot	---	0.09	0.04	---	0.02
2 foot	---	---	0.03	---	0.07
3 foot	---	---	0.06	---	0.49

--- no sample taken
* less than 0.01 ppm (none detected)

Table 3.44. Qualification of triclopyr metabolites in different soil layers at Seward.

Layer	Metabolites present at different times after application.				
	0	7	49	316	369
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.45. Amount of triclopyr in different soil layers at Chulitna.

Layer	Amount of triclopyr (ppm) at different times after application (days)				
	0	7	57	303	365
Left of track					
0-2 inches	2.94	0.89	0.09	---	0.04
1 foot	---	1.50	0.21	---	*
2 foot	---	---	0.02	---	0.06
3 foot	---	---	*	*	0.09
Right of track					
0-2 inches	1.78	1.24	0.06	---	0.03
1 foot	---	1.07	0.06	---	0.09
2 foot	---	---	0.16	---	0.02
3 foot	---	---	0.20	---	*
Average					
0-2 inches	2.36	1.07	0.07	---	0.03
1 foot	---	1.29	0.14	---	0.05
2 foot	---	---	0.09	---	0.04
3 foot	---	---	0.10	---	0.05

--- no sample taken
* less than 0.01 ppm (none detected)

Table 3.46. Qualification of triclopyr metabolites in different soil layers at Chulitna.

Layer	Metabolites present at different times after application.				
	0	7	57	303	365
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.47. Amount of triclopyr in different soil layers at Birchwood (Combination plot).

	Amount of triclopyr (ppm) at different times after application. (days)				
Layer	0	7	49	290	365
Left of track					
0-2 inches	1.60	0.24	0.03	---	0.05
1 foot	---	0.19	*	---	0.10
2 foot	---	---	0.06	---	*
3 foot	---	---	*	---	*
Right of track					
0-2 inches	2.30	0.05	*	---	0.04
1 foot	---	0.06	0.05	---	*
2 foot	---	---	0.16	---	0.10
3 foot	---	---	*	0.02	0.18
Average					
0-2 inches	1.95	0.15	0.02	---	0.04
1 foot	---	0.12	0.02	---	0.05
2 foot	---	---	0.11	---	0.05
3 foot	---	---	*	---	0.09

--- no sample taken
* less than 0.01 ppm (none detected)

Table 3.48. Qualification of triclopyr metabolites in different soil layers at Birchwood (Combination plot).

	Metabolites present at different times after application.				
Layer	0	7	49	290	365
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.49. Amount of triclopyr in different soil layers at Birchwood Triclopyr Only plot.

Layer	Amount of triclopyr (ppm) at different times after application (days)				
	0	7	49	290	365
Left of track					
0-2 inches	3.83	0.96	0.09	---	*
1 foot	---	0.32	*	---	*
2 foot	---	---	*	---	0.02
3 foot	---	---	*	---	*
Right of track					
0-2 inches	3.59	0.25	*	---	0.08
1 foot	---	0.14	0.10	---	*
2 foot	---	---	0.03	---	*
3 foot	---	---	0.10	0.01	*
Average					
0-2 inches	3.71	0.61	0.04	---	0.04
1 foot	---	0.23	0.05	---	*
2 foot	---	---	0.01	---	0.01
3 foot	---	---	0.05	---	*

--- no sample taken

* less than 0.01 ppm (none detected)

Table 3.50. Qualification of triclopyr metabolites in different soil layers at Birchwood Triclopyr Only plot.

Layer	Metabolites present at different times after application.				
	0	7	49	290	365
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.51. Amount of triclopyr in different soil layers at Firecreek.

Layer	Amount of triclopyr (ppm) at different times after application (days)				
	0	7	46	276	351
Left of track					
0-2 inches	0.02	1.45	0.06	---	0.07
1 foot	---	1.70	0.02	---	0.01
2 foot	---	---	0.08	---	*
3 foot	---	---	*	0.06	*
Right of track					
0-2 inches	1.67	0.19	0.06	---	*
1 foot	---	0.12	*	---	0.20
2 foot	---	---	*	---	0.01
3 foot	---	---	*	---	0.04
Average					
0-2 inches	0.84	0.82	0.06	---	0.04
1 foot	---	0.91	0.01	---	0.11
2 foot	---	---	0.04	---	*
3 foot	---	---	*	---	0.02

--- no sample taken
* less than 0.01 ppm (none detected)

Table 3.52. Qualification of triclopyr metabolites in different soil layers at Firecreek.

Layer	Metabolites present at different times after application.				
	0	7	46	276	351
Left of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP
Right of track					
0-2 inches	TMP	TMP	TMP	---	TMP
1 foot	---	TMP	TMP	---	TMP
2 foot	---	---	TMP	---	TMP
3 foot	---	---	TMP	---	TMP

Table 3.53. Triclopyr Microbial Degradation Data in Soil With Three Percent Organics (mg/kg as dry weight basis)

Temperature (Celsius)	Days after application						
	0	14	30	49	70	105	145
2	0.89	0.94	0.85	0.79	1.02	0.60	0.91
10	0.76	0.96	1.41	1.03	1.03	1.07	0.69
20	0.90	0.81	nd	0.92	1.03	1.06	0.75

nd = no data

Table 3.54. Triclopyr Microbial Degradation Data in Soil With 0% Organics (mg/kg as dry weight basis).

Temperature (Celsius)	Day after application						
	0	14	30	49	70	105	145
2	0.87	0.89	1.31	0.98	0.71	0.81	0.59
10	0.89	1.14	1.20	0.95	0.92	0.73	0.78
20	0.90	0.81	nd	0.92	1.02	1.06	0.95

nd = no data

Table 3.55. Statistical Analysis of Triclopyr Concentrations in Soil Augmented With 3% Organic Content (mg/kg).

	Temperature (Celsius)		
	2	10	20
Average Concentration	0.85	1.04	0.79
Standard Deviation	0.13	0.19	0.36
Confidence Interval	0.73	0.86	0.45

Table 3.56. Statistical Analysis of Triclopyr Concentrations in Soil Augmented With 0% Organic Content (mg/kg).

	Temperature (Celsius)		
	2	10	20
Average Concentration	0.93	0.97	0.79
Standard Deviation	0.19	0.16	0.36
Confidence Interval	0.75	0.85	0.45

Table 3.57. Hexazinone Microbial Degradation Data in Soil With 3% Organics (mg/kg as dry weight basis).

Temperature (Celsius)	Day after application						
	0	14	30	49	70	105	145
2	5.46	9.13	4.90	3.25	4.41	7.93	5.88
10	5.35	9.75	7.15	2.72	7.01	6.67	6.96
20	8.58	8.89	5.59	4.77	3.63	6.44	5.29

Table 3.58. Hexazinone Microbial Degradation Data in Soil With 0% Organics (mg/kg as dry weight basis).

Temperature (Celsius)	Day after application						
	0	14	30	49	70	105	145
2	4.74	8.60	5.82	4.02	3.74	6.79	8.27
10	5.97	8.50	6.57	2.22	5.76	8.46	7.33
20	6.27	9.33	6.95	2.49	4.88	7.71	4.77

Table 3.59. Qualification of Hexazinone Metabolites in Laboratory Microbial Degradation Study.

Day after application	Metabolite	Soil Type*	Temperature (degree C)
14	B	O, N.O.	10, 20
30	B	O, N.O.	10, 20
49	B,D	N.O.	20
	B	O, N.O.	10, 20
70	B	O	20
98	A,B,D	O, N.O.	2
	A,B,D	O	10
	B,D	O, N.O.	10, 20
145	none		

* O = 3% organic content
N.O. = 0% organic content

Table 3.60. Statistical Analysis of Hexazinone Concentrations in Soil Augmented With 3% Organic Content (mg/kg)

	Temperature (Celsius)		
	2	10	20
Average Concentration	5.85	6.44	6.32
Standard Deviation	2.04	2.12	1.91
Confidence Interval	5.73	6.67	5.33

Table 3.61. Statistical Analysis of Hexazinone Concentrations in Soil With 0% Organic Content (mg/kg)

	Temperature (Celsius)		
	2	10	20
Average Concentration	5.62	6.25	6.27
Standard Deviation	1.69	2.11	2.16
Confidence Interval	4.48	5.87	6.90

Table 3.62. Soil Bacteria Population Counts

Petri Plate	Number of Colonies Counted			
	Count #1	Count #2	Count #3	Avg.
(A) 1:10,000	>300	---	---	---
(B) 1:100,000	208	216	211	212
(C) 1:1,000,000	29	37	39	35
(D) 1.10,000,000	<30	---	---	---

Table 3.63. Concentration of Triclopyr in Soil Column Eluates and Percent Triclopyr Leached

Equivalent railfall (cm)	Triclopyr concentration (ppm		Percent Triclopyr leached through	
	(0% O.C.)	(3% O.C.)	(0% O.C.)	3% O.C.)
0.0	0.0	0.0	0.0	0.0
5.6	0.732	0.379	18.77	9.74
11.2	1.681	0.501	43.11	12.86
16.5	1.052	0.514	26.96	13.17
22.5	0.124	0.599	3.17	15.36
28.0	0.071	0.988	1.81	25.34
33.7	0.036	0.416	0.92	10.66
39.3	0.024	0.253	0.62	6.50
44.9	0.035	0.117	0.89	3.00
50.5	0.019	0.062	0.49	1.60
56.1	0.014	0.034	0.36	0.87
Total percent leaching through =			97.10	99.10
Percent retained in column =			2.90	0.90

Table 3.64. Concentration of Hexazinone in Soil Column Eluates and Percent Hexazinone Leached

Equivalent rainfall (cm)	Hexazinone Concentration (ppm) (0% O.C.)	(3% O.C.)	Percent Hexazinone Leaching Through (0% O.C.)	(3% O.C.)
0	0.0	0.0	0.0	0.0
5.6	0.296	0.255	2.96	2.55
11.2	3.647	0.166	36.47	1.66
16.5	2.015	0.867	20.15	8.86
22.5	0.231	1.308	2.31	13.08
28.0	0.254	1.293	2.54	12.93
33.7	0.179	2.274	1.79	22.74
39.3	0.452	0.834	4.52	8.34
44.9	0.319	0.608	3.20	6.08
50.5	0.132	0.693	1.32	6.93
56.1	0.089	0.711	0.89	7.12
Total percent leaching through =			76.15	90.09
Percent retained in column =			23.85	9.91

Table 3.65. Typical Values of Hydraulic Conductivity in Different Soils

Soil type	Hydraulic conductivity (cm/sec)	(ft/min)
Clean gravel	1.0 - 100	2.0 - 200
Coarse sand	1.0 - 0.01	2.0 - 0.02
Fine sand	0.01 - 0.001	0.02 - 0.002
Silty	0.001 - 0.00001	0.002 - 0.00002
Clay	Less than 0.00001	Less than 0.00002

Table 3.66. Average Hydraulic Conductivity in Soil Columns

Soil Column	Average Hydraulic Conductivity	Soil Type (Das, 1985)
(A) Tri. - 3% O.C.	0.012223 (cm/s)	Coarse Sand
(B) Tri. - 0% O.C.	0.016808 (cm/s)	Coarse Sand
(C) Hex. - 3% O.C.	0.016723 (cm/s)	Coarse Sand
(D) Hex. - 0% O.C.	0.019325 (cm/s)	Coarse Sand

Table 3.67. Preparation of Solutions for Studying the Adsorption of Triclopyr*

Desired concentration (ug/gm)	Amount of 20 ppm stock soln. (ml)	Amount of water (ml)	Amount of adsorbent (mg)
0 (blank)	0	40.00	0
4 (std.)	0.50	39.50	0
0 (bkgd.)	0	40.00	2.5
1	0.15	39.85	2.5
2	0.25	39.75	2.5
4	0.50	39.50	2.5
16	2.0	38.00	2.5
40	5.0	35.00	2.5

* Temperature = 24 degrees Celsius
Exposure time = 24 hours

Table 3.68. Adsorption of Triclopyr

Trial	Conc. added (ppm)	Equil. conc.* (ppm)	Conc. adsorbed** (ppm)	Amt. adsorbed (ug/gm)
A	1	0.026	0.97	15.58
B	2	0.059	1.94	31.05
C	4	0.218	3.78	60.52
D	16	0.778	15.22	243.56
E	40	1.696	38.30	612.87

* Concentration of herbicide in the water at equilibrium
** Concentration of herbicide which disappeared from solution and was assumed to have been adsorbed.

Table 3.69. Adsorption of Hexazinone

Trial	Conc. added (ppm)	Equil. conc.* (ppm)	Conc. adsorbed** (ppm)	Amt. adsorbed (ug/gm)
A	1	0.852	0.15	1.184
B	2	1.567	0.43	3.460
C	4	1.839	2.16	17.29
D	16	2.640	13.36	106.88
E	24	3.130	20.87	166.96

* Concentration of herbicide in the water at equilibrium

** Concentration of herbicide which disappeared from solution and was assumed to have been adsorbed.

VEGETATION MANAGEMENT METHODS EVALUATION

LITERATURE REVIEW

The primary purpose for eliminating unwanted vegetation is to assure the safety of passengers, crew and goods. According to the Federal Railroad Administration Track Safety Standards, vegetation along the track or in the track structure, which consists of the railroad ties and the ballast in the immediate area surrounding the ties, must be controlled. Vegetation must not present a fire hazard, obstruct visibility, interfere with normal employee duties, prevent proper functioning of railroad signal and communication lines, or prevent visual inspections of moving equipment (Archdeacon and Ellsworth, 1985; Federal Government, 1988; Swan et al., 1988; Anonymous, 1989a).

The American Railway Engineering Association (AREA) lists areas in which vegetation should be controlled: the ballast; shoulders and ditches; around bridges, buildings and other structures; in railroad yards; around signal appurtenances and wayside signs; and under signal, communication and power lines (AREA, 1988). Some states have laws that require railroads to control noxious weeds in their right-of-way. A noxious weed is one that is considered sufficiently harmful to the environment, cropland, or waterway to make its control essential. One-hundred-thirty-seven plant species have been declared by state laws as noxious weeds in the continental United States (Anderson, 1983). The railroads must keep the noxious weeds from spreading onto pasture or cropland adjacent to the railroad right-of-way in such cases (Anonymous, 1987a).

Vegetation control may keep water from accumulating in the ballast by maintaining good drainage in the track structure. Adequate control also facilitates maintenance of bridges, buildings and structures and helps provide a safe walkway along the track. When vegetation control is inadequate, the sight distance around curves and at crossings may become obstructed, and objects can be hidden from view by vegetation growth, increasing the possibility of an accident (Hoover, 1986; Lacey, 1985).

Vegetation may cause poor drainage in the ballast area (the railroad ties, the area between the ties, and the side slopes of the track structure). Increased moisture in the ballast may cause uplift of the ties when heavy loads travel over the track. This uplift produces a suction effect or "pumping" of soft fine soils into the ballast (Hay, 1982; Moehren, 1983). Uneven settling and heaving of the track may occur during freeze-thaw cycles because of moisture and fine soil particles present in the ballast. This can lead to accelerated wear on the track.

For safety reasons, train speeds may have to be lowered in these areas, reducing the amount of traffic and resulting in potential loss of revenues. Settling also breaks up the track structure and causes uneven track wear and instability, which can lead to accidents (Hay, 1982). However, no studies have specifically quantified the degree and type of track degradation associated with vegetation. No data are available about the effect of vegetation upon moisture retention in the ballast, nor on the effect of different species or types of vegetation upon track wear.

Ballast without fine soil grains can more readily form an interlocking structure that supports the tie and track geometry. The tighter the interlocking of the ballast particles, the longer the track structure will remain intact. When fine particles invade the ballast, they wear it down and act as a lubricant, so that proper compaction, a tight interlocking of the particles, is impeded (Moehren, 1983).

Ballast may be fouled by subgrade intrusion ("pumping"), internal abrasion of ballast particles, or by external intrusion of fine particles carried into the ballast. Internal and external intrusion have been cited as the most common method of ballast fouling, but all three mechanisms work simultaneously to foul the ballast (Hay, 1982). By deferring right-of-way maintenance, railroads have found that uncontrolled vegetation growth is associated with deterioration of all structural components of the system (the subgrade, ballast, ties, hardware, and adjacent drainage ditches) that are essential to successful operation (Archdeacon and Ellsworth, 1985; Anonymous, 1985a; Anonymous, 1989a). However, it is not clear whether vegetation is a primary cause or merely a symptom associated with this deterioration.

Recent studies by Selig (Chrismer, 1988) suggest that the ballast particles do not experience an intrusion of fine particles from below, but rather the ballast itself breaks down. The addition of water in this situation increases the likelihood that the ballast particles will abrade and thus create more fine particles. "Pumping" of ballast has been cited as the symptom rather than the cause of ballast failure because it indicates that the ballast is in its final stages of breakdown.

Integrated Vegetation Management

Integrated pest management (IPM) is a system of management for all types of pests. Integrated vegetation management (IVM) is a more specific kind of IPM that refers to the control of unwanted vegetation. Generally, IVM is the practice of making use of all feasible control methods to obtain the most practical, effective, and economic results for vegetation control in order to form an optimal program (Anonymous, 1980; Caswell et al., 1981-1982). Another aspect of IVM is that the vegetation population is kept to a level below that which causes economic injury (Matthews, 1984; Hatfield and Thomason, 1982). Railroads have not yet established this level.

The average yearly state roadside vegetation budget for U.S. highway transportation agencies in 1986 was seven million dollars (Johnson, 1988). Railroads also spend large sums of money to control vegetation that invades their rights-of-way. The average railroad maintenance-of-way-and-structures budget, from a broad survey of U.S. railroads, was three-thousandths of a dollar (1982) per gross ton-mile of rail travel (Tennyson, 1983). Track maintenance and vegetation control may enhance each other because some track maintenance procedures provide vegetation control and, conversely, adequate vegetation control facilitates efficient track maintenance.

Right-of-way maintenance may be undertaken by railroad personnel or by contract. In practice, most railroads contract some work and do other maintenance in-house. Right-of-way maintenance is labor intensive, subject to funding fluctuations, and slow to change (Borzo, 1988). The trend has been toward contract work, especially for herbicide application programs. The growing restrictions imposed upon herbicide applications, the cost of employing and licensing the necessary skilled personnel, and the expense of purchasing and maintaining the required equipment all favor contract work (Hoover, 1986). In addition to economic concerns, most railroads perform vegetation control programs as part of safety programs. There is no quantitative information about the influence of preventive or corrective maintenance on track deterioration (Markow, 1985).

One important aspect of a vegetation control program is to establish what constitutes a weed so that an appropriate control plan can be devised. A species of plant that normally is not considered a weed may be a pest in some circumstance and thus a weed (Archdeacon and Ellsworth, 1985). Weeds are plants that grow in the wrong place, in the wrong quantity, or at the wrong time (Lacey, 1985) and interfere with human activities or welfare (Anonymous, 1989a).

A variety of vegetation, both woody and herbaceous, grow along railroad rights-of-way. Depending on the geographical location, some plants may be classified as noxious weeds, such as Johnsongrass.

Woody plants are perennials that have hard stems composed mainly of wood tissue, while herbaceous plants (herbs) are soft stemmed (Viereck and Little, 1972; Swan et al., 1988). Grasses are herbaceous, have a single seedleaf, and their mature leaves have parallel veins. Broadleaf plants have two seedleaves, and their mature leaves are generally broad with net-like patterned veins. Broadleaf species may have woody or herbaceous stems (Cole et al., 1987).

Each of these plant growth forms presents unique vegetation control problems. Another way to categorize vegetation is by the length of time it takes to complete a life cycle. All woody plants are perennials, while herbaceous plants may be annuals, biennials, or perennials.

Annuals grow from seeds, complete a life cycle in one growing season and can be classified as summer or winter annuals, depending on when they germinate. Summer annuals germinate in the spring and die by winter, while winter annuals usually germinate in the late summer or fall and die by the summer (Stewart, 1986; Cole et al., 1987). Annuals produce an abundance of seeds that germinate during the subsequent growing seasons. To effectively control annuals, the plants need to be destroyed before they have a chance to produce seed (Archdeacon and Ellsworth, 1985; Swan et al. 1988), preferably in the seedling stage of growth (Stewart, 1986).

Biennials generally require two growing seasons to complete their reproductive cycle. This type of plant also reproduces by seeds, and the most effective way to control them is to eliminate the plants before they are well established, in their first year of growth (Swan et al., 1988). Common examples of biennials are wild carrot and teasel (Cole et al., 1987).

Plants that grow back yearly are referred to as perennials. They can develop extensive root systems in addition to producing seeds. New plants are sometimes produced from the root system. For herbaceous species, the above ground component of the plant dies each fall, and in the spring new shoots are produced by the root system. They are the most costly type of plant to control, as the underground root system must frequently be destroyed to prevent reproduction (Archdeacon and Ellsworth, 1985; Swan et al., 1988). Perennials may reproduce by seed, crown buds, and cut root systems or they may spread by underground root and creeping above ground systems. Examples of herbaceous perennials are dandelion, wild barley, Canada thistle, toadflax, and leafy spurge (Stewart, 1986).

Most control methods for perennials are more effective when adapted to the growth cycle of the specific species. Plants are most susceptible in the fast growth period prior to flowering or during regrowth following fruiting or cutting (Stewart, 1986; Cole et al., 1987; Swan et al., 1988). Annuals present the biggest vegetation control problem in most of the contiguous United States, but are more limited in Alaska. Perennials are the most prevalent class of plant life in Alaska, where there are a relatively short growing seasons and harsh winters.

The state of Alaska encompasses 365.5 million acres with a high habitat diversity. Eight main regions of woody vegetation have been identified (Viereck and Dyrness, 1980; Viereck and Little, 1972), and the Alaska Railroad passes through five of them.

The general trends are: from Seward to Anchorage, alpine tundra and coastal spruce-hemlock forests; on the Whittier branch line, coastal spruce-hemlock forests; from Anchorage to Talkeetna, open, low-growing spruce forests; and from Talkeetna to Fairbanks, predominantly closed spruce-hardwood forests with some open, low-growing spruce forests and treeless bogs.

Many vegetation control problems are due to woody plants. Troublesome species include balsam poplar, willows, aspen and alder. Most problematic of the herbaceous plants are generally species that grow tall or are particularly difficult to eradicate. These include fireweed (*Epilobium angustifolium*), horsetail (*Equisetum arverse*) and bluejoint (*Calamagrostis canadensis*).

The degree and frequency of vegetation control are factors that need to be established for a successful control program. The amount of vegetation control chosen usually depends both on economic factors and on engineering concerns. Some methods inherently contain a fixed measure of control, while others vary the amount of control. For example, with chemical control applications the dosage of herbicide used can be varied to obtain different degrees of control, while in mechanical brush cutting procedures the amount of control is fixed, as the shrubs are cut to the same level each time.

The most expensive degree of control is to completely remove all vegetation (AREA, 1988). The other extreme is to not control any vegetation; this is also an expensive alternative when the cost of the structural damage to the track, and the decrease in traffic efficiency are considered. The majority of vegetation control programs for the track structure fall between the two extremes, and aim for short term control of most plant species.

Railroads should evaluate the extent of vegetation infestation that appears in their rights-of-way. Such evaluation is critical to developing adequate control programs. In the 1970s Burlington Northern (BN) developed a numerical ranking system to describe the degree of vegetation growth in a particular area (Anonymous, 1973a). On the same date each year BN evaluates their right-of-way. They use a numbered ranking system, from one to ten, where one represents an area with zero to ten percent coverage by vegetation, two represents an area ten to twenty percent covered with vegetation, etc. A vegetation ranking number is determined for a stretch of track and the number of miles that contain this vegetation ranking are recorded. Next, the number of miles are multiplied by the vegetation ranking number to establish the number of points for an area. To find an average scoring of a certain number of miles, the points for each section in the area are added together and then divided by the total number of miles. The scores are then mapped for easy reference, and the areas with the greatest vegetation control problems (highest point values) are easily distinguished.

Vegetation monitoring is the first in a five-step approach developed as a total vegetation control program (Smith, 1987). Next, the railroad determines the vegetation infestation level that causes damage. Third, an action level is established to avoid injurious vegetation levels. Treatment methods then should be chosen to combat different types of vegetation infestation. Finally, the results are evaluated to provide feedback to the vegetation control program.

Railroad rights-of-way may be divided into two general problem areas in terms of vegetation control, on-track and off-track. The track area, or roadbed, consists of the track and its support system. Generally, the bed is made up of a subgrade layer of compacted soil; a layer of ballast, stone aggregate conforming to specifications of hardness, angularity, and purity; and the ties, rails and other hardware that make up the track proper and that rest on the ballast. Ballast also lies between the ties, normally to the surface of, but sometimes covering, the ties. For the purpose of vegetation management, the track right-of-way encompasses all of the structure and the sideslopes, up to a horizontal distance of 12-15 feet from track centerline (Figure 4.1). The wider right-of-way, often 100 feet or more from track centerline, is considered the off-track or greater right-of-way. Railroads deal with the two portions of the right-of-way separately because the degree of control required varies (Archdeacon and Ellsworth, 1985; Gangstad, 1982).

The most critical sections of the track, with regard to performance, maintenance and intrusion of vegetation, are the ballast and subgrade of the trackbed. Track stability is obtained through the interlocking capability of the ballast. Contaminants, generally fine soil particles, act as a lubricant to reduce this interlocking capability. The fines also impede drainage, therein trapping water and softening the underlaying subgrade, which may permit the structure to settle. Trapped water may cause frost heaving or act as an abrasive medium, in conjunction with the fines, to wear the cross ties and ballast. High pressure loads of passing trains and the movement induced among the ballast particles accentuate this abrasion. Ballast that is adequately drained and contains no fine soils will not readily support plant life (Anonymous, 1975a; Anonymous, 1987a; Archdeacon and Ellsworth, 1985).

There are many other organizations and groups that have established vegetation control programs. Agricultural vegetation control programs differ from that of railroads because the aim is to remove specific plant species, while railroads ideally would like to remove all plant species within the ballast area.

Boroughs, counties, states and other political subdivisions also establish vegetation control programs for their rights-of-way along highways, roads, and freeways. Their primary focus is to provide adequate sight distance for curves, signs, and intersections. Ground cover in the form of low-growing species is acceptable in their rights-of-way. In the outer right-of-way, railroads have similar vegetation control goals, primarily to provide adequate sight distance.

Utility companies control vegetation that grows under their power and communication lines; railroads may have vegetation control programs that match those needs because trees and shrubs must also be kept to an acceptable height under their power and communication lines. This is important because vegetation can interfere with wires and cause breakage during storms (Hay, 1982).

Dams and other flood control projects control vegetation to maintain the integrity of their structures, and to reduce the amount of moisture that is held in the system. Railroad vegetation control programs aimed at the roadbed area have similar objectives in eliminating all plant species.

Methods of Vegetation Control

A wide variety of techniques have been and are in use to eliminate undesirable vegetation. Methods employed are influenced by many factors including growing season, climate, plant species, available resources, political pressures, and economics. Vegetation control techniques can be categorized into chemical, physical, and other methods.

Chemical Vegetation Control- Since the 1950s, chemical applications have grown increasingly popular for use in controlling unwanted vegetation along highway, utility and railroad rights-of way. Chemicals are often used because they are considered less costly than other methods, requiring less time and labor to complete treatment.

The timing and method of chemical applications are important to the success of a vegetation management program. They may be applied in many diferent ways, before or after seasonal growth has begun.

Pre-emergent chemicals are applied to soil prior to the emergence of weeds. Biologically, this method is advantageous because the chemicals are already in place on the ground when the first plant growth develops and the plant is most susceptible. Dosages for pre-emergent applications are relatively high and timed so that a residual can be expected to remain on the soil until growth does begin (Archdeacon and Ellsworth, 1985).

Post-emergent chemicals can be applied at any time in the growing season after emergence. The specific timing is dependent on vegetation type and the management program. Since the post-emergence treatment is made after the above-ground growth is visible, there is less need for a residual portion of the chemical. Lower chemical dosage rates are feasible, making the post-emergent method less expensive than pre-emergent treatment (Archdeacon and Ellsworth, 1985).

There are seven general methods of applying chemicals:

1. Broadcast applications spray chemicals evenly and indiscriminately over an area.

2. Band applications spray chemicals over a limited area.

3. Directed applications apply liquid chemicals in a narrow stream toward the base of individual plants.

4. Spot applications treat individual plants or clusters of plants.

5. Basal bark treatments apply liquid chemicals in a water or oil base over the lower 8-10 inches of individual brush or trees.

6. Dormant stem applications use a liquid chemical in a water or oil base to treat individual tree trunks and woody stems during the winter season, when the plant is dormant.

7. Cut stump treatments apply liquid chemicals in a water or oil base to brush and tree stumps immediately after cutting, to prevent sprouting.

(AREA, 1988; Cole et al., 1987; Klingman et al., 1982; Swan et al., 1988).

Railroads most often employ both pre- and post-emergent techniques in conjunction with physical methods in their vegetation control programs to provide the greatest degree of control with a minimum cost.

Pre-emergent treatments offer the most effective control, but since a larger volume of chemical is required, the cost is increased. An additional consideration in choosing the application method is the political and social attitude within the nearby communities toward chemical applications. Since post-emergent treatments require less chemical, this technique may be more acceptable in socially sensitive regions (Archdeacon and Ellsworth, 1985).

For the railroad bed, chemical treatments are generally broadcast or band applications. For a well maintained trackbed exhibiting a low percentage of ground cover, directed or spot treatments may be applicable. For the wider right-of-way, any and all of the application methods may be utilized.

Herbicides are a subset of chemical control alternatives. The term herbicide generally refers to any chemical that affects or kills plant life (Watterson, 1988). Use of herbicides on roadway, railroad, utility, pipeline and firebreak rights-of-way came into practice about 1950 (Gangstad, 1982). A broad array of herbicides has been used on railroad rights-of-way in the past. The general rise in environmentalism within the last two decades (Arnold, 1982) has led to increased public concerns and subsequent tighter restrictions (Anonymous, 1989b; USEPA, 1990). A 5-year survey conducted by Mead Data Control via its NEXIS News Monitor found that pesticides was the top environmental issue among 80,980 news stories and accounted for 29% of them (Anonymous, 1989b). There are some areas of the right-of-way that generally should not be treated with chemicals, including waterways and narrow rights-of-way that are adjacent to sensitive private properties (Cole et al. 1987). In such areas, an integrated vegetation management approach (IVM) is often practiced.

Herbicide use is controlled by state and federal agencies. The federal regulations are established by the Federal Insecticide, Fungicide, and

Rodenticide Act (FIFRA) and its amendments. Clauses within FIFRA allow individual states the jurisdiction to enforce FIFRA's regulations.

Herbicides are available in several forms, both liquid and dry powder. The form influences the type of application and the equipment that is required to apply it. Liquids are sold in wettable powder, water soluble powder, or in liquid suspension form. The dry forms may come in grains or pellets that can be spread on the ground.

Herbicides are classified according to how they are utilized for weed control as either selective or non-selective. Selective herbicides are chemicals that kill specific unwanted plants but leave desirous plants uninjured. Selective herbicides are often used for roadside and utility rights-of-way. For railroad vegetation control, selective herbicides can be used to maintain the wider right-of-way but do not usually offer the degree of control necessary for the trackbed (Gangstad, 1982; Swan et al., 1988).

Non-selective herbicides are chemicals that are generally toxic to plants without regard for the species. Non-selective herbicides are meant to kill all vegetation and may leave the soil barren for a year or more, depending on the chemical and the dosage (Swan et al., 1988).

For highway and utility rights-of-way, complete vegetation control is desirable beneath guardrails, around bridge abutments, and near signposts (Cole et al., 1987; Doll, 1988). For railroad situations, complete vegetation control is desired in railroad yards and in railroad ballast (Gangstad, 1982; Klingman et al., 1982; Ross and Lembi, 1985; Swan et al., 1988).

Herbicides are also grouped, on the basis of mode of action, as contact, systemic hormone or systemic residual. Contact herbicides affect only that portion of the plant with which they come in contact. They primarily penetrate the protective layers on leaf surfaces, so they are often called foliage active. They are applied as water- or oil-based sprays. Oil-based applications are avoided when practical because they are more costly (Archdeacon and Ellsworth, 1985; Swan et al., 1988).

Contact herbicides are effective only on the treated plants, and soil activity is usually very limited. It is important not to apply them during periods of rainfall, since the chemical activity depends upon contact duration (Anonymous, 1989a).

Systemic hormone herbicides, also referred to as growth regulator compounds, are synthetic chemicals similar to naturally occurring plant hormones. This class of herbicides is highly selective, being particularly effective on broadleaf plants, especially when the plants are in an active growth stage (Archdeacon and Ellsworth, 1985; Swan et al., 1988).

Systemic residual, or soil sterilant, herbicides are considered bare ground chemicals. These herbicides generally kill all vegetation when applied in sufficient concentration, leaving the ground barren. Even though systemic residuals are called soil sterilants, they do not destroy all life in the soil. When applied at high rates, most microorganisms, such as fungi and bacteria, are not killed, but all higher plants are. This is important because the bacteria gradually degrade the chemical into less toxic components (Archdeacon and Ellsworth, 1985; Cole et al., 1987; Swan et al., 1988). Both classes of systemic herbicides, systemic hormone and systemic residual, have little or no contact effect on the plant. These products are absorbed through plant roots and are translocated through the vascular system of the plant to the growing points, where they interfere with photosynthesis, resulting in the death of the plant (Swan et al., 1988).

Systemic herbicides may be applied at any time except when the ground is frozen or during heavy rainfall periods. Excessive rainfall may wash the herbicide away from the target area before the chemical can leach into the soil and penetrate to the plant roots. A prolonged period of several weeks without rainfall will also generally reduce treatment effectiveness beause vertical movement of the herbicide to the root zones will be inhibited (Anonymous, 1989a).

In general, the most practical and cost effective application programs use a combination of contact, systemic hormone and systemic residual herbicides (Anonymous, 1989a; Archdeacon and Ellsworth, 1985; Swan et al., 1988). For railroad herbicide spray programs, various mixes may be specified for use, e.g., along the mainline, the branch lines, industrial tracks, yards, bridges and crossings. Other mixes can be used for brush control and for followup applications against perennial weeds. Dry pellet mixes are often used for switches, signals, material piles, buildings, bridges or for general cleanup (Hoover, 1986). Chemicals may also be used on the wider right-of-way to retard plant growth and reduce mowing costs, to kill undesirable or noxious species, and to encourage revegetation with desirable species (Anonymous, 1987b).

Application is done by hi-rail truck or spray train. Hi-rail refers to vehicles equipped to ride on the track, regardless of size and purpose. The trucks are flexible but limited in capacity. Some contractors have 3,000-5,000 gallon units with divided containment tanks, but more commonly they have 1,500-3,000 gallon capacities. These smaller trucks are less efficient because of the down-time required for refilling, however, smaller lines may be able to undertake their own spray programs with them (Archdeacon and Ellsworth, 1985; Hoover, 1986).

In contrast, spray trains are capable of hauling 20,000 gallons or more, which allows them to travel for extended times. These specialized trains can apply a number of mixes simultaneously and can target a variety of different weed species (Archdeacon and Ellsworth, 1985; Hoover, 1986).

As technology has increased, herbicides have been developed that require smaller and smaller doses to provide effective weed control. New synthetic formulas have application rates of less than two grams per acre have been developed (Riggleman, 1986). Older formulations may require up to twenty pounds (9,079 grams) per acre (Bullington, 1987). At a two gram per acre application rate, the herbicide is spread over an acre at a depth of only one molecule (Riggleman, 1986).

Environmental concerns have caused the Environmental Protection Agency (EPA) to impose strict regulations on herbicide registration and testing. Organizations, such as the Audubon Society and the Sierra Club, have applied pressure to the government agencies in order to force pesticide manufacturers and users to limit risk to wildlife, prevent crop contamination, and to limit the possibility of pesticide residue entering into milk and flesh of livestock (Anonymous, 1973b). The cost of health and safety aspects of regulating herbicides has more than doubled during the last five years (Riggleman, 1986). In 1953, to develop and test a new pesticide would have cost approximately $1.2 million dollars, and would have required the testing of 10,000 different compounds. The cost listed in 1973 for research and development of a pesticide is between six and twelve million dollars with a research time of up to ten years (Anonymous, 1973b) In 1987, development and testing a new pesticide averaged seven years, cost approximately $45 million dollars, and required the analysis of 20,000 or more chemicals (Watterson, 1988). When the inflation between 1973 and 1987 was considered, the cost to develop a pesticide almost doubled.

A working knowledge of soil variations, plant species, climate conditions, and biological processes are also needed to develop an effective herbicide application program (Anonymous, 1975c). Soil type, temperature, rainfall, and microorganisms may enhance or reduce the amount of vegetation that an herbicide is able to destroy (Table 4.1). The soil type does not affect contact or systemic hormone herbicides, but it does influence the action of systemic residual herbicides.

Because these types of herbicides are dependent on action through plant root systems, the physical adsorption of the herbicide is important. Minerals, organics, and soils with high clay contents have numerous electrically charged sites. These readily bind herbicides and make them unavailable to the plants (Cole et al., 1987; Swan et al., 1988; U.S. Department of Agriculture, no date). Sand and silt have fewer charged sites to attract herbicides, so they allow them to move quickly to the root systems. However, since sand and silt are unable to bind herbicides in the soil, they are effective for a shorter duration than if they remained in contact longer with the plant root system (Archdeacon and Ellsworth, 1985; Swan et al., 1988).

Soil and air temperatures influence the effectiveness of an herbicide because plant growth and herbicide degradation are functions of temperature. At high temperatures, herbicides will readily degrade in soil, but the plants can actively adsorb them. Increased temperature, if there is adequate moisture, may speed weed control because of greater plant activity (Cole et al., 1987; Swan et al., 1988). Conversely, when it is cold and plants are in a dormant stage, systemic hormone herbicides may have little effect.

Some contact herbicides have reduced effect when they are applied at temperatures lower than 75°F or 80°F (Archdeacon and Ellsworth, 1985). They are more effective when applied at 70°F or greater. The 10°F increase from 60°F to 70°F generally doubles the chemical reaction rate (Cole et al., 1987).

Rainfall promotes plant growth, making them susceptible to chemical treatment. Residual herbicides, which enter plants through the root zone, require very little moisture to mobilize them. A heavy dew can provide adequate soil moisture to facilitate good plant uptake (Swan et al., 1988). The longer the herbicide remains on the soil surface, the greater degradation it experiences due to evaporation and possibly photodegradation. If the chemical application is followed by three weeks without rain, all vegetation control from the herbicide may be lost (Cole et al., 1987).

Excessive rainfall can cause problems since the herbicide may leach rapidly through the soil and be unavailable for uptake by the plants (Cole et al., 1987; Swan et al., 1988). This may also result in infiltration of the herbicide into groundwater. A heavy rain may even cause overland runoff, which transports the chemicals out of the target area and can damage non-targeted vegetation. Foliar-applied herbicides are more effective when an eight hour period without rain follows the application so that the herbicides are absorbed into the leaves (Cole et al., 1987).

Soil microorganisms contribute to the breakdown of herbicides. They absorb and metabolize herbicides, using the organic matter as an energy source. This affects residual herbicides because the majority of the product is either absorbed by the plant or used by microorganisms after the first growing season. Application rates that are high enough to perform for more than one season are not economically feasible (Archdeacon and Ellsworth, 1985).

The cost of herbicide application to railroad rights-of-way is influenced by a variety of factors, including the chemical formula that is used, the amount of the chemical needed to control vegetation, and the timing and frequency with which it must be applied. Railroads must determine the degree of vegetation control desired, the pattern of herbicide coverage, and the portion of the railroad line to be treated with herbicide (Anonymous, 1975b). In recent years chemicals have become the dominant means to address vegetation management problems on railroads (Archdeacon and Ellsworth, 1985; AREA, 1988). This is primarily because they have been viewed as the most economical method to obtain satisfying vegetation control (Brauer, 1983).

Annual spray costs vary greatly among railroads, but they tend to be lower in the western United States, compared to the south. During 1983 the cost ranged from $25 to $125 per acre, depending on the vegetation species and the weather conditions (Brauer, 1983).

In 1988, ARRC requested contractor bid proposals to apply herbicides to the trackbed. Although ARRC was denied a permit to spray, the bid that was selected provides cost data in 1988 dollars.

The total contractor charge depended on the number of days required to spray the entire track as needed. The costs established by the chosen bid were: $7,750 for mobilization and demobilization; $2,500 daily charge per working day, applied only after the fifth working day; $500 per standby day; and $245 application charge per acre sprayed. These costs do not include ARRC administrative, overhead and permitting costs.

Measures should be used to reduce potential problems with the use of herbicides. When herbicides are applied the chemical may drift outside of the zone of application. Drift, due to improper application of herbicides, may cause damage to or destruction of non-targeted vegetation that is not on the railroad's property.

Drift can be reduced by using a low pressure spray nozzle, by not spraying when temperatures exceed 75°F (Cole et al., 1987), or by using low-drift adjuvants (drift inhibitors) that can be added to the herbicide mixture (Bandoni, 1987). State regulations may specify a maximum wind speed and/or maximum applicator speed at which herbicides can be applied (Holt and Osburn, 1985).

There are also the possibilities of air and water pollution when herbicides are applied. If there is a heavy rainfall before adsorption of herbicides occurs, the herbicide can run off in the rainwater. Aquatic organisms may be damaged by the herbicide if it reaches a water body, or it may leach into the drinking water supply and potentially be consumed. Occasionally herbicides have been detected in water, but they are usually in low concentrations and occur infrequently (McWhorter and Chandler, 1982; U.S. Department of Agriculture, no date).

A number of chemical methods that are not typically thought of as herbicides have been used to eliminate vegetation. Two examples of these are salt and oil. Salt in solid form or as ocean water has been tried, but there is little research on the effectiveness of this method. Generally, high concentrations are needed to eliminate vegetation. The method poses high groundwater contamination threat and may attract wildlife to the railroad roadbed.

Oil and grease have been used as a means to control vegetation. Usually waste oil and grease are poured over troublesome plant species in spot applications. Unfortunately, this practice may allow hydrocarbons to enter the environment. Non-herbicide chemicals that are used for weed control are not used on a wide scale basis.

Physical Vegetation Control - There are a number of ways to remove unwanted vegetation mechanically from the right-of-way. Shrub or grass cutting machines can be used along with bulldozers that scrape away the vegetation layer. Traditional railroad maintenance equipment, such as a ballast regulator, an undercutter/cleaner, or a spreading and ditching machine, can also play a role in eliminating vegetation. The practice of cutting vegetation along the right-of-way was the original method of vegetation control used by railroads. Hand labor was employed to cut vegetation until the shortage of an inexpensive work force made the practice uneconomical.

After World War II, railroads started using tractor mowers, and much railroad right-of-way was still being mowed until recently. Brush cutting, or other mechanical methods, is widely used in conjunction with or as an alternative to chemical treatment because of its immediate results (Brauer, 1983).

Timing is an important aspect when using mechanical means to control vegetation (DeVault, 1987). If the vegetation is cut at a time when it has expended most of its reserve energy by producing above ground shoots, then cutting may serve to kill the plant. If the plant has enough reserve energy stored within the root system and young points (buds) remain, it will survive the cutting. For example, cutting winter broadleaf vegetation works well in the springtime after leaf emergence when these plants experience their maximum growth and have little reserve energy left to resprout (Lee, 1985; Swan et al., 1988).

With mechanical cutting methods, there is a possibility of rapid regrowth of suckering and sprouting species because the root system of the plant is not eliminated. Cutting shrubs may produce a more dense secondary growth than that which existed prior to cutting (Archdeacon and Ellsworth, 1985; Brauer, 1983). No control is provided for vines, and this process may actually encourage their growth (Brauer, 1983). In the outer right-of-way, the goal is often to reduce the height of the growth, so the sprouting may be acceptable. Within the roadbed, though, increased density from regrowth of the woody species is detrimental.

Clipping or mowing is a method of vegetation control that is used in the outer right-of-way but not in the immediate roadbed area of the track. It is commonly used along roadways and has been found to control broadleaf plants more effectively than grasses. Best results are achieved when the vegetation is 30 to 45 inches in height at cutting time.

Mowing controls weeds by removing the tops before seed production, by depleting underground food reserves, and by favoring the growth habits of desirable vegetation. The difficulty with mowing to control vegetation is that many plants send out seedstalks from the base of the plant. Therefore, mowing is relatively ineffective on species that can grow and produce seed below the normal cutting height of the mower. For mowing to prevent seed production, the plant must have a relatively tall growth habit and treatment must be initiated before pollination and fertilization (Crafts, 1975; Ross and Lembi, 1985).

Mowing may kill tall annuals with one or two treatments if the buds on the stems are above the cutting height. However, the plants may respond to cutting by sending up new shoots from buds below the cut, which may then produce seeds. Repeated close mowing of perennials may drain the food reserves in the roots and rootstalks and gradually eliminate the plant (Crafts, 1975; Ross and Lembi, 1985).

As mowed plants generally do survive one cutting and generate new tops, repeated treatment is necessary to prevent seed formation. Most species require three to six mowings per year if good control is desired. Annuals should be cut when the first flowers appear because some weed seeds will germinate even though the plant is cut soon after pollination. Perennials should be cut when the underground root reserves are at a minimum. For many species, this is between full leaf development and flowering (Klingman et al., 1982; Ross and Lembi, 1985).

Vegetation along the right-of-way can be controlled using either on- or off-track brush cutting equipment. Brush cutters cut trees and shrubs with a rotating head at the end of an extendable arm (Hay, 1982).

Track mounted brush cutters are self-propelled, can reach 22 to 30 feet from the track centerline, and remove trees with six to eight inch diameters (Archdeacon and Ellsworth, 1985; Brauer, 1983). A special brush cutter for removing shrubs under transmission line wires was used on Burlington Northern in southern Illinois (Anonymous, 1970a). It had a 52 foot reach and was capable of a 45 to 110 degree arm swing to accommodate rough terrain. The productivity rate for a 1970 prototype was 1.12 miles of right-of-way, an average width of 28 feet, cut per day.

A 1986 productivity estimate of CSX Transportation Incorporated's Chessie System component reported that 0.89 miles of track, total width of 24 feet, was cut per day by their on-track brush cutter. Their time was 44 percent production time and 56 percent delays, including 15 percent maintenance and repair, with the remainder of the delays due to train delay, crew travel, and miscellaneous items (Sheahan, 1988). The efficiency of on-track brush cutters varies with a given situation and is limited by the lateral reach of the equipment and by the density of other rail traffic (AREA, 1988).

Railroads tend to use this type of equipment to remove vegetation in areas beyond the chemically treated swaths, which are commonly twenty feet on each side of the track centerline (Anonymous, 1989a). By removing the shrubs, brush cutters help reduce barriers for blowing and drifting snow and improve visibility along the track (Archdeacon and Ellsworth, 1985).

Equipment that operates beyond the railroad track can also be used to control unwanted vegetation. Off-track equipment can adequately eliminate vegetation but may be unable to operate in wet areas (Brauer, 1983). The right-of-way should be prepared to allow operation of off-track equipment, as the equipment must travel on a relatively smooth, unobstructed surface. Preparation increases the costs of using off-track equipment, reducing its desirability (Anonymous, 1989a).

In areas where brush has been allowed to grow unchecked for a number of years, an on-track brush cutter has been cited as the most economical and practical way to begin a cleanup program (Archdeacon and Ellsworth, 1985), but the cost of mechanical brush control is usually greater than that of chemical brush control once the brush has been removed initially (AREA, 1988). The cost of the initial vegetation control effort for any means of control is greater than the cost of maintaining the vegetation at acceptable levels. There are experimental programs in progress to

help recover the cost of brush cutting by shredding the brush in the right-of-way and selling the chips as fuel or paper pulp (Brauer, 1983).

There is some information on brush cutting costs available in the literature. The Chessie System component of CSX Transportation reported (Sheahan, 1988) the cost to brush the trackbed with an on-track cutter for a span of 24 feet, 12 feet each side of track centerline. Total cost, in 1986 dollars, was $921 per mile of track or $307 per acre. The average productivity rate was 0.25 miles per hour.

Brushcutting expenditures reported by ARRC do not include maintenance, operation and capital recovery cost of the machine nor fuel costs. In 1988, the railroad brushed 74 miles of track at an average cost for labor, in 1988 dollars, of $384.97 per mile. In 1989, the railroad brushed 50 miles of track by July 30 at an average cost for labor, in 1989 dollars, of $237.80 per mile. The average productivity rate was one mile per day (Leggett, 1989a).

Vegetation along the track, but not directly under the ties, can be eliminated with bulldozers, ballast regulators or other scraping equipment. Disturbing the soil by removing the top surface layer is one of the oldest methods of non-chemical weed control. This process eliminates weeds but also may bring buried seeds to the surface to germinate.

In many cases, the majority of the seed pool is buried in the upper three inches of soil, so that scraping to this depth removes most of them (Lanini, 1987). This method of "shallow cultivation" is used in many crop applications in the arid west (McEachern, 1985). Disturbing the soil in the early spring should be avoided, as it helps to warm the soil and causes the weeds to develop shoots earlier in the season (Klor and Klor, 1987). Bulldozers that are used to scrape away vegetation are able to clear shrubs under wires and in other difficult areas, but it is a costly method. The increased cost is at least partly offset since vegetation control with bulldozing usually lasts longer than vegetation control from cutting methods (Brauer, 1983).

The Alaska Railroad uses a dozer for limited brush control. Dozing is done primarily to improve sight distance along the track in areas with high moose populations (Leggett, 1989a).

Vegetation may be removed by hand cutting or pulling out the vegetation. Hand cutting is similar to cutting using mechanical equipment, except that it is more labor intensive and can be accomplished in the area between the ties where mechanical cutting machines cannot reach. This type of vegetation control is most applicable in the roadbed area, where removal of all vegetation is desired, and in areas where dense vegetation is not present.

Hand cutting is most effective on annuals and on woody species that do not readily resprout, especially conifers. Pulling out the vegetation by hand is an effective means of control if the soil is loose enough or the roots are shallow enough to allow the majority of the root system to be removed with the plant shoots. In some plant species, for example horsetail, it is very difficult to remove enough of the root to prevent regrowth. Younger plants are much easier to completely uproot by hand. Some states use convict labor or youth corps for hand cutting or weeding programs. The work crew poses potential safety problems along the track, especially if they are working in the roadbed area, and measures must be taken to ensure their safety. Access may also be a problem. Much of the ARRC right-of-way is inaccessible, except by rail. This increases the time and expense of transporting laborers and equipment to a site for vegetation control. This type of vegetation program has more flexibility than on-track mechanical cutting programs, as the workers can easily move off the track ahead of traffic, whereas on-track mechanical equipment must pull into a siding to clear the railway.

Maintaining the structural integrity of the track structure requires a variety of mechanical techniques. Concurrently, many track maintenance operations provide some vegetation control benefit. This is important from the vegetation management standpoint, as some vegetation control costs may be born by the track maintenance operations.

Physical techniques that offer vegetation control benefits include reballasting, ballast regulating, and undercutting. The common railroad track maintenance technique called surfacing is discussed first because it is essential to track maintenance. Most reballasting and ballast regulating occurs as part of the surfacing operation. Reballasting and ballast regulating costs available in the literature are reported within surfacing, or undercutting, costs.

Track surfacing and alignment are fundamental to the maintenance of ballasted track. Determination of need is done according to Federal Railroad Administration requirements, data provided from a track geometry car, and through standards imposed by respective railroads. The frequency of surfacing depends principally on the track geometry with respect to crosslevel, profile, and warp. It also influenced by desired riding quality, traffic density, train speed and operations such as tie and rail renewals. The surfacing cycle is dictated by the ability of the various track, ballast and subgrade combinations to resist track geometry deterioration (Archdeacon and Ellsworth, 1985).

Surfacing involves reballasting, followed by tamping, aligning, and regulating of trackbed. Reballasting is the overlaying of new ballast on previously placed ballast. The crushed rock is dumped from rail ballast cars onto the track and distributed by the ballast regulator blades. The track is then groomed, or dressed, by the ballast regulator (Anonymous, 1975a; Archdeacon and Ellsworth, 1985). The amount of ballast is dictated by the desired track raise. Most modern tampers then align the track with the aid of electronics. Aligning is the process of picking up the track and moving it in a horizontal plane (Archdeacon and Ellsworth, 1985; Leggett, 1989b).

Although an integral part of track maintenance, tamping must not be done too frequently, as the tamping tines significantly abrade the ballast. The most important factor in determining the surfacing cycle, and indirectly the ballast life, is the subgrade quality. High quality subgrade can prevent the intrusion of fine particles into the ballast and therefore extend its life, strength and drainage ability. This will result in a superior trackbed that will maintain its geometry longer and decrease the frequency of surfacing operations. Additionally, when surfacing is required, the ballast will be in better condition and thus the tamping will not affect it as adversely (Archdeacon and Ellsworth, 1985; Zarembski, 1989).

The cost to surface track may depend on the equipment available, the amount of ballast required, the ballast cost, the transport distance, and the labor cost.

A few authors (Anonymous, 1988; Burns, 1987a) report surfacing costs. One article lists average surfacing costs, in 1986 dollars, as $8,826 per mile. Burns (1987a) details surfacing costs in 1987 dollars. The total cost ranged from $2,751 to $24,134 per mile, averaging $7,822 per mile. The average productivity rate was one mile per 6.5 hour shift.

ARRC's accounting procedure allows only for the reporting of partial costs for their surfacing operations. The operation costs recorded do not include maintenance, operation and capital recovery costs of the equipment or fuel costs. The partial cost for ARRC to surface in 1988 was $1,391.24 per mile. The average productivity rate was 0.7 miles per day (Leggett, 1989a).

Reballasting may retard vegetative cover due to the physical disturbance of the plants and burial or removal of the substrate and plant growth.

This control would be most effective on species with shallow root zones and low growing, above-ground portions. Unfortunately, there is a dearth of information dealing with reballast operations in the literature and no cost data disassociated from surfacing costs.

The Alaska Railroad uses reballasting as part of their track maintenance. Generally, one rail car of rock can cover about 500 feet of track, depending on the condition of the trackbed and how much ballast was in place in the crib, the area between the ties. The productivity rate for their Kershaw Ballast Regulator averages 900 to 1,000 feet per hour.

The ballast regulator is used to groom the ballast so that the top of the ties and tie plates are visible to facilitate inspections and maintenance. Grooming, or dressing, the ballast is necessary to ensure that the ballast maintains adequate longitudinal, lateral and vertical track stability. Track maintenance operations that require the application of additional ballast or that disturb the existing ballast require dressing with the regulator (Anonymous, 1984; Archdeacon and Ellsworth, 1985; Brauer, 1983; Leggett, 1989b).

Although ballast regulators are not marketed as tools for vegetation control, they are occasionally used for that purpose. Regulating kills vegetation by ballast removal on the shoulder and by disturbing the above ground growth between the rails by brooming. Because regulating normally removes not more than several inches, it is most effective on species with shallow root zones or seed banks. The disadvantages to using a ballast regulator for vegetation control are that seed banks may be exposed, encouraging revegetation, and providing colonization sites. Ballast regulating is limited to areas of excess material unless reballasting is also performed.

Relative cost data in the literature consider the use of the ballast regulator for surfacing or undercutting operations, as opposed to the use for vegetation control. Consequently, costs are not reported outside of total surfacing or undercutting costs. The machine is often used in the winter to plow snow from the track, and the year around use makes it a more cost effective tool (Anonymous, 1984).

The Alaska Railroad performs routine ballast regulating as part of their surfacing operations and uses the regulator to plow snow in winter months. No records on cost are kept disassociated from surfacing costs.

Ballast undercutters are machines that remove ballast to a depth of 6-18 inches below the tie, as desired, by means of a cutting chain. The equipment is expensive and complex, and the operation time is consuming. However, undercutting is utilized by some railroads for track rehabilitation, removing and replacing contaminated ballast.

Some undercutters are equipped with conveyor belts to lift the old ballast to a screening apparatus. Such machines are called ballast undercutter-cleaners. After screening the ballast, the portion that still meets quality standards is returned to the track. New material is used to replace the unacceptable ballast. Recycling of ballast makes the operation more economical (Anonymous, 1975a; Anonymous, 1975b; Anonymous, 1976; Anonymous, 1985b; Anonymous, 1987b; Anonymous, 1987c; Archdeacon and Ellsworth, 1985).

Although probably never undertaken explicitly as a vegetation control measure, the undercutter may provide excellent results. Undercutting removes the fines and vegetation contaminating the ballast to a greater depth than can be achieved by other means. Undercutting also reduces or eliminates the need for most normal track maintenance since the ballast is cleared, poor ties are replaced, the track is aligned, and shoulders are reshaped. Additionally, geosynthetic membranes are commonly used in undercutting operations. When placed on the subgrade before filling the trackbed with clean ballast, the membrane inhibits ballast contamination from the subgrade, maintaining proper drainage through the track structure.

Although there have been quite a few articles written on undercutting operations, none report any cost data. Productivity rate depends upon the depth of cut and the condition of the track. Manufacturers estimate it at 1,000 to 1,200 feet per hour (Anonymous, 1987b), but actual railroad estimates range from 450 to 754 feet per hour (Anonymous, 1975b; Anonymous, 1985b; Anonymous, 1987c).

In 1986, the Alaska Railroad sustained severe flood damage to some track sections. The next season, ARRC leased a Kershaw Undercutter for track renovation. The reported costs include the six month lease and shipping, maintenance, operation, ballast, labor and administration. They totaled $463,040 (1987 dollars). Productivity rate is unknown. The ARRC undercut 3.15 miles in 1987 at an average cost of $147,000 per mile (Weeks, 1991).

One theory for vegetation control is that not only should existing vegetation should be removed, but the likelihood of vegetative regrowth should be reduced. Replacing old ballast with cleaner ballast, adding a geotextile to the track structure, and asphalting the ballast area are all methods that reduce the amount of vegetative regrowth.

Over the years ballast tends to wear, and the amount of fine particles in the ballast increases. These fine particles, as previously noted, tend to increase the moisture carrying capacity and improve the growing environment for plants. If the new ballast is free from fine particles and seed, then the amount of vegetation able to grow is reduced. New ballast should be of good quality to meet both the strength and gradation specifications so that it does not easily degrade and produce fine particles (Zarembski, 1989). For example, ARRC specifies that less than 1% of ballast by weight pass number 200 sieve. This eliminates the vast majority of fine particles (ARRC, 1989). Studies have developed an accurate procedure that determines how fast a specific type of ballast will degrade under repeated loadings (Chrismer, 1988).

In areas of little excess ballast, new ballast is dumped onto the old ballast in order to raise the track. Depending on the depth of the new layer, this eliminates existing vegetation by reducing the amount of light it receives. Some vegetation is able to grow through the rock and resprout on the new ballast surface.

The addition of geotextiles underneath the ballast area helps control plant growth and maintains ballast integrity. It stops the upward movement of fine soil particles. Water can pass through the semipermeable membrane but soil particles cannot.

Another option to limit vegetation growth in the right-of-way is to apply hot-mix asphalt on the ballast area (Figure 4.2). This procedure was first used in 1968 by the Cleveland Transit Authority, which experimented with two 1,000-foot test sections. The Santa Fe Railway developed some 700-foot test sections in 1969. In both cases, the asphalt layer was 2.5 to 7.5 inches thick, and the primary purpose was to determine if asphalt would add strength to the track structure. Testing this procedure was resumed in 1981 by the University of Kentucky. There are now over thirty different installations of hot-mix asphalt in place (Huang et al., 1986).

The asphalt applications have proven to be excellent water blocks, and the experimental sections have consistently been drier than similar non-asphalted sections (Huang et al., 1986). The costs make it prohibitive for use exclusively as a vegetation control technique, but it is an economic control of herbaceous and grassy species when applied for increasing ballast structural strength.

The most common uses of asphaltic ballast at this time are in areas where developing adequate drainage is costly and raising the track is also expensive. For example, the ballast is often asphalted at the entrances of stations, in tunnels, on platforms, at highway crossings, and on open-floored bridges (Hay, 1982).

Other Methods - Another method to eliminate unwanted vegetation is to employ a thermal technique such as burning or steam. In the past, fire was used extensively in crop and railroad applications. Burning is still considered an economic and efficient way to remove undesirable vegetation species in some areas (Swan et al., 1988), although increased costs of fuel and labor have greatly decreased the use of this method (McWhorter and Chandler, 1982; Archdeacon and Ellsworth, 1985). When weeds are burned, a crew needs to be present to prevent the fire from spreading. Burning for weed control also contributes to air pollution (Archdeacon and Ellsworth, 1985; AREA, 1988) and may require a permit (Gangstad, 1982; Hay, 1982). Optimal use of burning as a means of vegetation control requires several burns in a season to prevent regrowth (Archdeacon and Ellsworth, 1985).

The Alaska Railroad does very little burning. Dead vegetation is burned in the spring, when the trackbed is exposed but snow still covers the wider right-of-way, reducing the fire hazard (Leggett, 1989a; Tryck, Nyman & Hayes, 1985).

Another thermal method is the use of steam to wilt and kill plants. In comparison with common vegetation control methods, thermal methods have not been widely used among railroads (AREA, 1988). Steam is not well documented and can be expensive because it is an energy intensive process.

Canadian Pacific (CP) Rail's British Columbia Division has been testing the applicability of steam for vegetation control on the ballast area for two years. Laboratory tests showed that steam effectively breaks down the plant leaf structures, inhibiting photosynthesis. Typically, three days after treatment the foliage turns brown and dies.

Co-Principal Investigator, Johnson, was able to observe the CP steam train in operation in November 1990 and made the following observations:

1. Although the steam train can operate at speeds up to 15 mph to give a minimum contact time of 1.5 seconds, the effective speed varies with the vegetation density and type, as well as the weather conditions. In dense, wet vegetation, speeds down to 2 mph may be necessary.

2. CP has spent considerable time and money to develop a sophisticated railcar-mounted steam machine prototype. Steam is super heated (700 to 800°F) and released through banks of steam jets under the specially designed car. It is able to treat both between the rails and along the roadbed shoulders to kill vegetation eight feet on either side of the centerline.

3. CP treated between 1,000 and 2,000 miles of track during the summer of 1990.

4. Although the steam treatments appear to be very effective in killing all aboveground foliage within three days, the rate and degree of regrowth is not known. CP is attempting to determine at what frequency to treat different types of vegetation to kill both above and below structures.

5. CP has pursued steam as a vegetation management technique both in response to public opposition to herbicides and because alternative treatments are required for special situations, such as adjacent to water bodies.

6. The steam train is part of an overall vegetation management policy developed by the entire CP Rail (CP Rail, 1989).

A final alternative is biological control. This primarily applies to the wider right-of-way, where selective revegetation, species competition, and natural predators may be useful in establishing and maintaining desireable vegetation, such as a low-growing grass cover (Zak, 1983; Hay, 1982). However, there also is the potential to use pathogens, such as fungi or viruses, to ensure that vegetation on the roadbed remains below deleterious levels.

All vegetation control methods have pros and cons. Table 4.2 summarizes this discussion.

SURVEY OF MANAGEMENT ALTERNATIVES AND COSTS

Methods

A survey (Appendix E) was mailed during May 1989 to 174 railroads in the United States and Canada. The railroads selected to participate in the survey were obtained from the Pocket List of Railroad Officials (Todor, 1988) for freight and passenger railroads. All railroads listed with 50 miles or more of track were contacted. After the original survey form was mailed, a second form was distributed in an attempt to increase the response rate. To determine what methods other countries were practicing for vegetation control, the survey was sent to a selected group of railroads in foreign countries. A list of all railroads contacted is located in Appendix F.

One hundred six railroads responded to the survey, which is a 60 percent response rate. Five of the responding railroads indicated that they were no longer in operation or otherwise unable to answer the survey.

The initial survey form requested a description of the vegetation management control methodology in both the roadbed and the wider right-of-way. The use of herbicides, their application rates, costs, and application times were also requested, along with a description of the costs and techniques for mechanical, thermal/burning, and other methods used to eliminate vegetation along the right-of-way. Vegetation management reports and cost effectiveness data were also requested.

The second survey form requested information similar to the first form, but was greatly condensed. Every participant that did return a response to the first form by a designated time was mailed a second "short form" survey. The focus of this second request was to determine if methods other than herbicides were used for right-of-way vegetation management.

Results

A summary of the railroad survey responses was compiled in order to analyze the data, and that list is located in Appendix G. The results are summarized in Table 4.3 and Figure 4.3. Specific railroads may be referred to by name, but in general the brand of herbicide used and the use of other vegetation control methods will remain anonymous in order to respect the confidentiality of the participants.

Ninety-four percent of the railroads responding to the survey use herbicides in their vegetation control programs. The types varied widely. Most of the railroads did not restrict themselves to one, but used several products simultaneously. The herbicides most commonly used were Roundup, Arsenal, and Oust. This finding is consistent in that new generation herbicides are being developed which are more effective and designed to be less toxic, less susceptible to leaching/migration, less persistent and more environment friendly (Newton, 1990). The application zone varied from 14 to 62 feet in width, with the most common being 16 and 24 feet.

Both spray trains and hi-rail vehicles were used for application. One railroad used both types of application vehicles. Tank sizes of hi-rail vehicles varied between 500 gallons and 2,000 gallons.

Contractor labor was more popular than internal labor forces for herbicide application. Twenty-three percent of the railroads reported contractor labor usage, while four percent used internal labor forces. Two percent of the herbicide users used both contractor and in-house labor, but 71 percent did not specify the type of labor used.

Herbicide form varied, but included pre- and post-emergence, pellet applications, soil sterilization, selective herbicides, and residual and translocated herbicides.

Yearly application was the most popular frequency reported by the railroads. Several have programs with herbicide application every three to four years, and one reported that application was necessary twice yearly.

Most railroads (85 percent) reported using another form of vegetation control in conjunction with herbicides (Table 4.3, Figure 4.3b). Physical methods, such as mowing and brush cutting, were common control strategies. Mechanical cutting and mowing are usually used in the wider right-of-way and not in the ballast area. Twelve percent reported that they mowed their rights-of-way for vegetation control.

Of the railroads that mow, 25 percent use off-track equipment, eight percent use on-track equipment, and 67 percent did not specify.

Fifty percent used some form of mechanical brush control. This is usually done in the wider right-of-way unless shrubs have been allowed to encroach on the roadbed because of poor maintenance.

Of the railroads that reported brush cutter usage, 30 percent use on-track models, four percent use off-track models, 14 percent use both, and 52 percent did not specify which type they use. Four percent reported that they lease their brush cutting equipment. One company responded that brush was cut on a yearly basis, while another said that they cut brush in three- to four-year cycles.

Hand clearing of vegetation was reported by 32 percent of the railroads. Hand held "weedeaters" and chainsaws are used for spot applications of vegetation control. Thirteen percent said they used laborers with chainsaws, and nine percent said they used laborers with weedeaters.

Hand pulling weeds was reported by one railroad. Another stated that it used hand clearing in conjunction with plowing, discing, and grading in order to remove all vegetation in areas of high fire hazard. Several respondents use convict labor for hand clearing programs, and one railroad uses a government-funded youth corps. The productivity rate for hand clearing was listed by one railroad as eight person-days per mile. It is likely that this is for clearing trees and shrubs with power hand tools, which is commonly done, and not for eliminating all vegetation by hand weeding. Another reported that a track gang for hand clearing one acre costs twice as much as herbicide application on the acre and takes ten times the amount of time.

The use of a ballast regulator for vegetation control was reported by 25 percent of the railroads (Table 4.3). A number pointed out that vegetation control was not the primary use of the ballast regulator. Ballast regulators were reported to be used during ballasting, surfacing, and track dressing operations or during tie renewal and track maintenance operations to churn up the vegetation.

Several railroads stated that the ballast regulator controls vegetation adequately on the shoulders, while others pointed out that it is not effective in the area between the rails. A few reported using the broom attachment on the regulator to beat down vegetation there, but one railroad stated that it pushes down only 50 percent of the growth. A ballast regulator is used by another railroad to clear small trees and vegetation by pulling ballast back into the track structure.

Ditchers, dozers and spreaders are used for vegetation control by 14 percent of the railroads. One reported that ballast regulators, undercutters, spreaders, and ditchers together provide 15 to 30 percent of their total yearly vegetation control as a side product of other work.

Burning vegetation along rights-of-way was used in ten percent of the railroads, and in Virginia it is required by state law. Canadian Pacific Ltd. is experimenting with steam to control vegetation on their right-of-way.

One railroad plants grass after their construction projects in order to develop a low vegetation cover. Another is developing competing vegetation techniques to inhibit undesirable vegetation growth. Geotextiles are routinely used by one company in reconstruction projects to inhibit vegetation growth.

Analysis of Reported Vegetation Control Costs

The following sections contain a summary of the cost information obtained from railroads participating in the survey. A description of how the data were compared is also included.

In order to compare information that was gathered in different states and areas of the country, the data were converted to average United States city values. This was accomplished by using conversion factors found in City Cost Indexes from the Means Building Construction Cost Data text. The construction indexes reflect the cost of construction projects for a variety of trades, including wages, materials, and equipment, in 30 major cities in the United States. These cities are used to develop an average data base, which equals 100 points, and other cities are compared to this value. Selected Canadian cities are included in the index, so they can be compared to U.S. cities by using an exchange rate of $1.00 Canadian to $.80 American.

To convert data from one city to another, a ratio of the city indexes for the two cities is multiplied by the value to be converted. Table 4.4 demonstrates a sample calculation for converting a city cost to a national average cost.

To convert the cost data reported by the different railroads to a common data base, a base city was established for each railroad. The selection of a base city for conversion was difficult as most of the railroads covered more than one state. The city from where the data were reported was chosen as the base city because, in most cases, it is the railroad's headquarters and thus most of their business transactions are based out of that city. In some cases, that city was not on the data base, so a city of similar size in the same state was used instead.

Costs Reported From Survey - The costs from the survey recipients are reported, as gathered, in 1989 dollar base. All the costs in the following sections have been converted to an average U.S. city dollar base.

A variety of vegetation control methods are applicable to the roadbed area and also the wider right-of-way. For the data obtained by the survey, the roadbed area will be considered because this is the area where vegetation control is crucial.

It was assumed that the prices reported were comparable to those incurred by a contractor. Costs included the amortized cost of the equipment, maintenance and operation costs for equipment, and wages and benefits for the workers.

The data from the survey responses, reported on a per mile basis, were converted to a cost per acre figure so that different herbicide spray widths could be compared. The data were converted to national average values and to an Anchorage, Alaska data base for comparison. Seventeen railroads submitted herbicide application cost data, and the cost per mile (Average U.S. City Costs, 1989 Dollar Base) ranged from $57 to $1,130, with an average value of $188 per mile. The per acre spray costs ranged from a low of $15 to a high of $454 with a median value of $74. Table 4.5 summarizes the 17 responses, showing the city and state where the headquarters is located and the per mile herbicide application cost. Some railroads reported more than one cost to apply chemicals. This reflected the fact that different chemicals are used in the spray program and/or the herbicide application zone may vary with the application area. For example, the railroad may have one program for applying herbicides to dual lines or in the rail yard, and another program for single mainline track. One railroad had a wide disparity between two herbicide application costs ($63.40 per mile and $179 per mile); this can be attributed to two different application programs and the differing chemical costs.

The railroad that reported a $1,130 per mile herbicide application cost was well above the norm. Two cost values per mile, $7.80 and $4.50, were excluded from the analysis, as they were anomalously low, and probably included only chemical costs and not equipment and labor costs.

Excluding the abnormally high ($1,130/mile) and two unusually low costs ($7.80 and $4.50/mile), the herbicide costs reported were split into three ranges. The average per mile low-range application cost was $95, the average mid-range per mile application cost was $195, and the average high-range per mile application cost was $340.

Several physical methods of vegetation control were reported by railroads, including brush cutting, using the ballast regulator, and hand clearing.

Brush cutting , either by mechanical or by hand, is a vegetation control option practiced in both the inner and outer rights-of-way. Of railroads specifying the type, on-track brush cutters were the most popular.

The per mile reported costs for brush cutting (Average U.S. City Values, 1989 Dollar Base) ranged from $21.50 to $1,940. Excluding the anomalously low $21.50 figure, the average per mile value was $720 (Table 4.6).

A number of railroads reported cost data for using the ballast regulator for vegetation control, but most were quick to point out that ballast regulating is not commonly used for that purpose.

The costs (Average U.S. City Values, 1989 Dollar Base) ranged from $49.70 per mile to $317 per mile, with an average of $219/mile (Table 4.7).

Most commonly, hand clearing is the use of a chain saw to eliminate large trees in the right-of-way. It is practiced by 13 percent of the railroads. One reported a cost of $1,030 per acre or $2,490 per mile a 20-foot width. The others reported $1,720 and $2,870 per mile for their hand clearing programs, without specifying a treatment width.

Only one railroad reported a cost for burning their right-of-way. This method seemed to be unpopular. The reported cost was $1,110 per mile, but no treatment width was specified.

The data vary greatly for each method of vegetation control. Although some are no doubt due to varying work efficiencies, field conditions, equipment productivity and the like, it is also likely that not all railroads reported total costs in their survey responses. For example, some railroads may be reporting only the labor and fuel costs of an operation, while another may be including the amortized equipment cost and maintenance costs. When contractor prices are reported, markup or profit is included. When a railroad reports its internal cost for performing an operation, no profit margin is included.

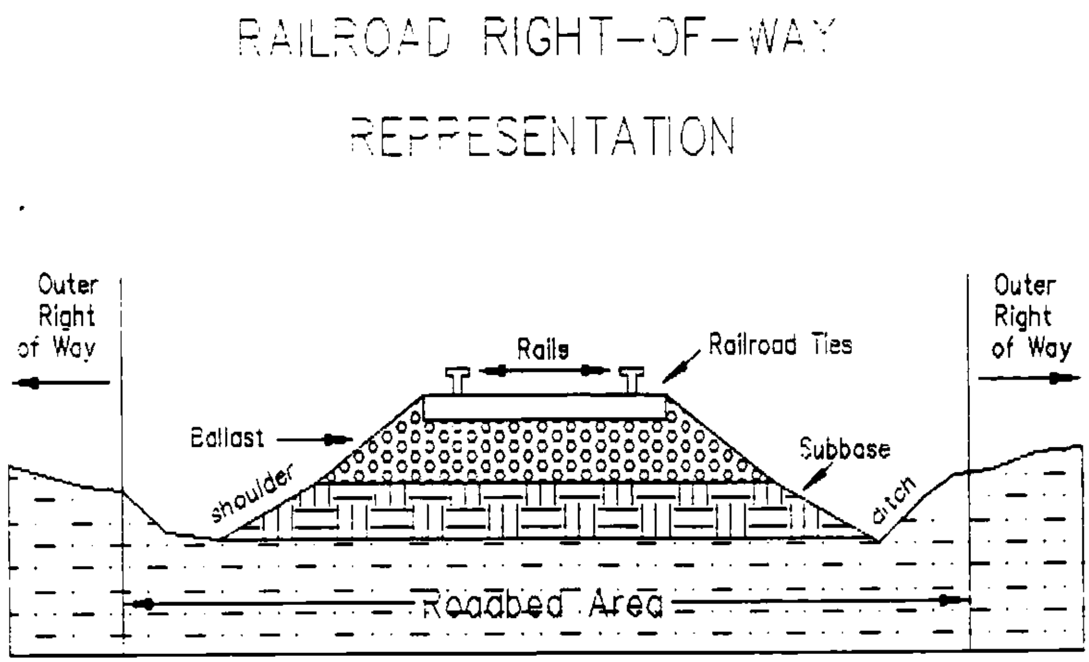
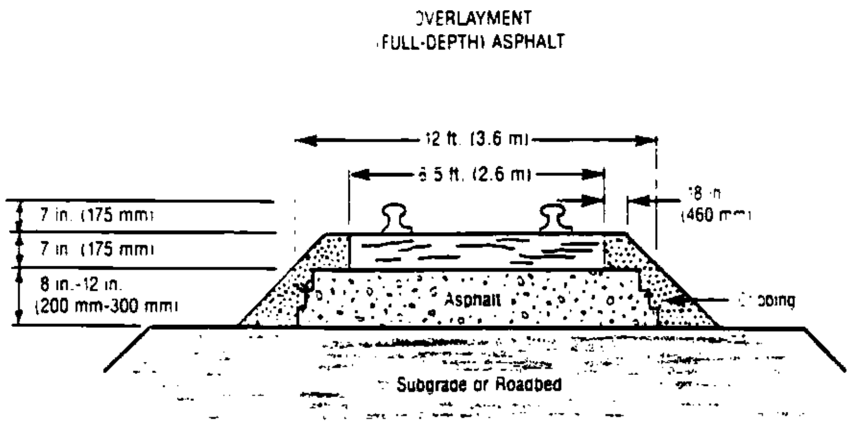


Figure 4.1. Railroad Right-of-way Representation.



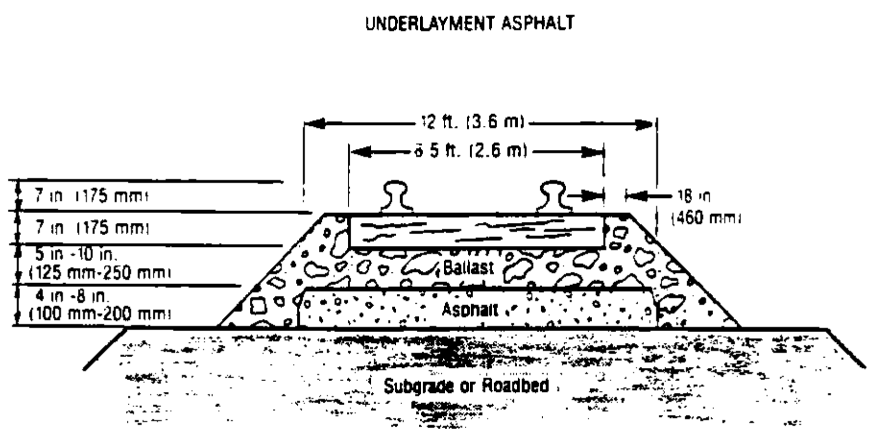
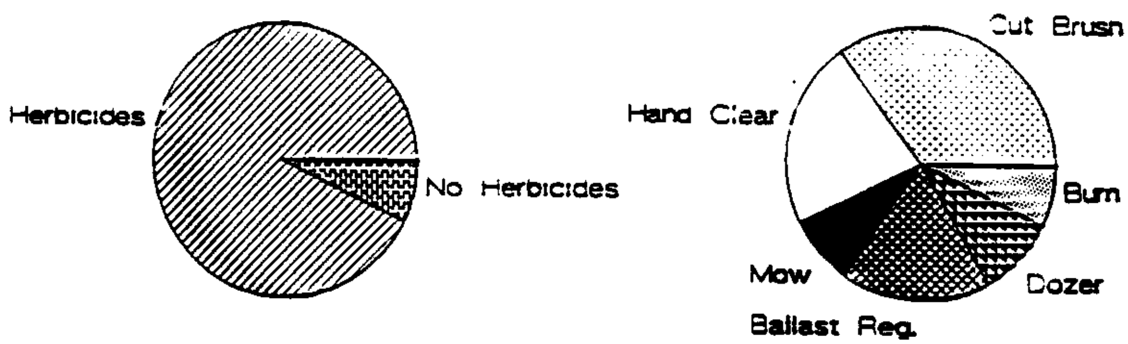


Figure 4.2. Typical Hot Mix Asphalt Trackbed Cross-Sections (J.G. Rose, 1989).



A. Herbicide Usage

B. Other Vegetation Control Methods

Figure 4.3. Railroad Vegetation Control, 1989 Survey Results.

Table 4.1. Summary of Environmental Influences

Key:
+ Positive Influence
- Negative Influence
* Depends on Rainfall Conditions

Environmental Factor	Translocated Herbicide	Contact Herbicide
Temperature < 70°F	-	-
Temperature 70 - 80°F	+	+
Temperature > 80°F	*	-
No Rainfall	-	+
Moderate Rainfall	+	-
Excessive Rainfall	-	-
Wind > 5 mph	-	-

Table 4.2. Summary of Vegetation Control Methods

METHOD: Chemical, Herbicide Application
- ADVANTAGES:
  - Efficient vegetation removal
  - Many programs already in place
- DISADVANTAGES:
  - Public Opposition
  - Potential for environmental harm

METHOD: Chemical, Non-Herbicide Chemical Application
- ADVANTAGES:
  - Materials readily available
- DISADVANTAGES:
  - May not be effective
  - Expensive
  - Potential environmental problems at effective dosage rates

METHOD: Physical, Mowing and Brush Cutting
- ADVANTAGES:
  - Leaves aesthetically pleasing right-of-way
- DISADVANTAGES:
  - Labor intensive
  - May require more than one treatment per year

METHOD: Physical, Bulldozers and Scraping Equipment
- ADVANTAGES:
  - Removes all vegetation
- DISADVANTAGES:
  - May cause erosion problems in outer right-of-way if not reseeded
  - Labor intensive

METHOD: Physical, Hand Clearing
- ADVANTAGES:
  - Selected plant species easily removed
  - Vegetation can be removed between ties of track
- DISADVANTAGES:
  - Potential safety problem for crew on tracks
  - Very labor intensive
  - May require large crew to cover enough area
  - May not remove enough of the plant root system to prevent regrowth

METHOD: Physical, Undercutting
- ADVANTAGES:
  - Benefits other than vegetation control
- DISADVANTAGES:
  - Requires a certain maintenance level to be efficient
  - Equipment may not be readily available

METHOD: Physical, Ballast Regulator

ADVANTAGES:

- Benefits other than vegetation control

DISADVANTAGES:

- Equipment may not be readily available
- May waste ballast

METHOD: Thermal, Burning Vegetation

ADVANTAGES:

- Complete removal of vegetation
- Lessens fire hazards

DISADVANTAGES:

- Causes air pollution
- Potential to get out of control

METHOD: Thermal Steam

ADVANTAGES:

- Compact
- Publically acceptable

DISADVANTAGES:

- Requires specialized equipment
- Still in test stage
- May require multiple treatments

METHOD: Biological Control

ADVANTAGES:

- Established cultures fluctuate in population as needed to control vegetation

DISADVANTAGES:

- Requires trained professional to develop program
- May be difficult to establish an effective program
- Potential to harm desirable vegetation

Table 4.3. Summary of Vegetation Control Methods Used by Survey Respondents

Herbicide Use	94%
Contractor Labor	23%
In-house Labor	4%
Both Types Labor	2%
Unspecified Labor	71%
No Herbicide Use	6%
Physical Methods	85%
Mowing	12%
On-track Equipment	8%
Off-track Equipment	25%
Unspecified Equipment	67%
Contract Labor	2%
Unspecified Labor	98%
Brush Cutting	50%
On-track Equipment	30%
Off-track Equipment	4%
Both Types Equipment	14%
Unspecified Equipment	52%
Leased Equipment	4%
Ballast Regulator	25%
Hand Clearing	32%
Chainsaw Use	13%
Weedeater Use	9%
Ditcher, Dozer or Spreader	14%

Table 4.4. Sample Calculation of Cost Conversion For Changes in Geographic Location

Given: Omaha, Nebraska Index = 90.2
Cost of Project = $1,000

Find: Cost of the Project in an Average U.S. City

Calculation:
National Average Cost = (Cost in Omaha) * 100/(Omaha City Index)
= ($1,000) * 100/(90.2) = $1,110

Table 4.5. Herbicide Cost Data, Reported in 1989 Dollar Base.

Headquarters Location	As-Reported Local Cost ($/mi)	Average U.S. City Cost (calculated,$/mi)	Anchorage Cost (calculated,$/mi)
Jacksonville FL	75 100	86 115	108 145
Montgomery, AL	153	131	238
Vancouver British Columbia	288 283	265 261	322 329
Pittsburgh PA	88 120	87 119	114 156
Jacksonville FL	200 250	229 287	300 376
Chicago, IL	130	128	161
Quebec City, PQ	1,100	1,130	1,420
Boise ID	53.6 58.9	56.7 62.2	71.5 78.4
Winnipeg, Manatoba	320	317	400
Des Moines, IA	287	315	413
Jackson MS	291 335 339	349 402 407	458 527 458
New Orleans, LA	191	213	269
Norfolk, VA	100	119	156
Omaha NE	72.5 75	80.4 83.1	105 109
Pittsburgh PA	88 102	87 101	115 133
Milwaukee WI	61.4 173	63.4 179	83.2 235
Tacoma WA	150 200	145 193	190 254

Table 4.6. Brush Cutting Cost Data, Reported in 1989 Dollar Base.

Headquarters Location	As-Reported Local Cost ($/Mi)	Average U.S. City Cost (Calculated, $/mi)	Anchorage Cost (Calculated, $/mi)
Vancouver British Columbia	$200	$230	$302
Chicago Illinois	$200	$197	$258
Jacksonville Florida	$1,000	$1,150	$1,500
Jackson Mississippi	$327	$393	$515
Omaha Nebraska	$1,750	$1,940	$2,250
Madison Wisconsin	$20	$21.5	$28.2
Rochester New York	$420	$414	$543

Table 4.7 Ballast Regulator Cost Data, Reported in 1989 Dollar Base.

Headquarters Location	As-Reported Local Cost ($/mi)	Average U.S. City Cost (calculated, $/mi)	Anchorage Cost (Calculated, $/mi)
Boise Idaho	$47	$49.7	$65.2
Winnipeg Manitoba	$320	$317	$400
Jackson Mississippi	$242	$291	$381

ENGINEERING COST ANALYSES

RAILROADS OUTSIDE ALASKA

Methods

An independent cost estimate for railroads outside of Alaska was developed for each method of vegetation control applicable in the ballast area or trackbed. Data were obtained through a review of the pertinent literature and by personal communications. When possible, estimates were prepared using a range of data to account for varying conditions.

Each estimate is divided into equipment costs (including maintenance and fuel), labor costs (including base pay, benefits, and per diem), mobilization and demobilization costs, overhead and indirect costs, and profit. Materials costs were also included where applicable. The costs are reported in dollars per track mile for a specified width of control.

All costs were converted into a 1991 average U.S. city dollar base using the United States Consumer Price Index (CPI-US). The index reflects the price consumers must pay for goods and services, as well as their wage rates during a specified year. For the CPI-US index (Dole, 1990) the baseline was developed by averaging the indexes from the years 1982 to 1984 and making this value 100. The 1991 index was estimated by straight-line extrapolation. Figure 5.1 shows a graph of the index values. A sample calculation of the conversion from one year to another is included as Table 5.1.

To distribute the costs over a period of years a conservative interest rate of ten percent was chosen. Burns (1987b) used an eight percent interest rate for economic evaluations, and a ten percent interest rate was used in a 1985 study of vegetation management for the Alaska Railroad Corporation (Tryck, Nyman & Hayes, 1985).

A capital recovery factor (A/P) corresponding to the interest rate and service life of the equipment was selected from a standard compound interest table (Grant et al., 1990) and multiplied by the value. Table 5.2 shows a sample interest rate calculation for a product with a $50,000 purchase price, a ten year product life, an interest rate of ten percent, and an assumed zero salvage value.

Standard values for interest rate, overhead, indirect and profit calculations, as well as those for the cost of equipment maintenance, mobilization and demobilization are assumed as noted. A standard wage rate table used to determine labor costs is also included as Table 5.3.

Yearly maintenance costs for most railroad equipment range from 10 to 30 percent of the purchase cost. For some types of equipment a standard maintenance ratio has been established (Cataldi and Elkaim, 1980). Where this ratio was not available, a mid-range value of 20 percent was chosen for this study. It is common that track maintenance (including vegetation control) equipment operates for 150 to 300 shifts per year for railroads operating in the contiguous United States (Cataldi and Elkaim, 1980). When the number of yearly operating shifts for a specific piece of machinery was unknown a value within this range, 200 shifts per year, was chosen.

United States average daily wage rates for railroad workers of different job classifications were adopted from Cataldi and Elkaim (1980) and used to determine the labor costs for each vegetation control estimate. Table 5.3 depicts wage rates based on Cataldi and Elkaims's assumptions of an eight hour work day, including 41 percent benefits and a fixed value for daily expenses. The wages were modified from a 1980 dollar base to a 1991 dollar base using the CPI-US as demonstrated in the Dollar Base Conversion section. In order to standardize the data gathered from different cities to national average values, it was converted to an Anchorage, Alaska data base.

Each vegetation control method employed a different support staff, but the wage rates on which the labor cost was based for different labor classifications (laborer, general foreman, etc.) remained constant for all types of operations. These values are shown in Table 5.3.

Costs are incurred for each project when equipment and personnel are taken to and from a particular job site. In some cases this cost is included in the overhead and indirect project costs, but in others it is calculated separately. For railroad projects mobilization and demobilization may involve considerable expense because of delays associated with other traffic on the rails. An estimate of the cost for mobilization and demobilization was calculated using a report by Tryck, Nyman & Hayes, for the Alaska Railroad in August of 1985 (Tryck, Nyman & Hayes, 1985). Mobilization and demobilization ranged from two percent to three percent of the total vegetation control cost in their analyses. To account for the uncertainty of the productivity rates in the Tryck, Nyman & Hayes estimates a conservative value of five percent of the equipment and labor costs was chosen as the mobilization and demobilization estimate for the present study.

Overhead costs are those costs which are not associated directly with any particular work item but are necessary for project completion such as insurance costs, permit fees, and a project manager (Clough, 1986).

Indirect costs, e.g. telephone charges, secretarial support, etc., encompass the daily expenses of running a business and are not only incurred by a specific project but are shared by all projects within an organization. To account for these expenses it is common to increase the project cost by a fixed percentage.

The profit or markup taken on a job, in some instances, is included with the overhead and indirect costs. The amount of profit varies from job to job and depends on the existing market conditions and the desirability of the job. Engelsman's General Construction Cost Guide

(Engelsman, 1985) states that the overhead, indirect and profit on construction projects range from 20 to 40 percent of the total project cost. Godfrey (1974) suggests that 25 percent is a reasonable figure for overhead, indirect and profit. Currently, the Fairbanks North Star Borough (Fairbanks, Alaska) allows a ten percent overhead and indirect, and a 15 percent profit markup for all of their change orders on construction projects. It was assumed that railroad projects are similar to other types of construction projects, and an overhead and indirect cost of 10 percent and a profit of 15 percent (totaling approximately 25 percent) of the total project costs was chosen.

Table 5.4 summarizes the general assumptions. An average value was chosen when specific data were unavailable.

Results

Estimates were compiled for herbicide application, brushcutting operations, ballast regulator use, reballasting, undercutting operations, and hand weeding.

Herbicide Application Costs - Herbicides are applied in the ballast area for this form of vegetation control, using an herbicide spray unit. Herbicide sprayers are able to reach a variety of widths on each side of the track centerline, but twenty feet is the most common (Anonymous, 1989a). Field tests done in conjunction with this study (Mulkey, 1990) used an herbicide application width of 24 feet.

The chemical cost, equipment and fuel cost, labor cost, mobilization and demobilization cost, spill cleanup equipment cost, profit, indirect costs, and overhead costs, all influence the cost of applying herbicides. Herbicides are normally applied at rates of 50 to 80 gallons per acre (Caswell et al., 1981-1982), and the application equipment may have a tank that ranges in size from 1,000 to 10,000 gallons in capacity (Holt and Osburn, 1985; Anonymous, 1986).

Herbicide application productivity has been recorded from one source as 200 miles in three days (67 miles per day) of dual treatment of the track (Anonymous, 1986) and as 33 miles per day (Sheahan, 1988) from another source. Different tank holding capacities may influence productivity.

It is assumed that herbicide application equipment is devoted solely to applying herbicides and it is not used for other tasks. Tank capacity influences the efficiency of application systems. Small tanks (about 1,000 gallons in capacity) require frequent stops to refill with water and chemicals. Larger systems can have the capacity to treat the right-of-way with more than one type of chemical. Very large systems with tank sizes in the 10,000 gallon range are cost prohibitive in areas where large volumes of herbicide application are not needed.

For the present analysis, a 2,000 gallon capacity dual treatment herbicide applicator was chosen. It has an estimated 1991 (average U.S. city dollar base) purchase cost of roughly $150,000 (Hag, 1990). A single spray system reduces the cost, and the cost may double for large spray train systems. For this exercise, a moderate cost figure was chosen. With an estimated life of ten years, the yearly cost for this equipment, using the capital recovery factor as demonstrated previously and a ten percent interest rate, is $24,400 (average U.S. city, 1991 dollar base).

The yearly maintenance for this machine, using Cataldi and Elkaim's guidelines, is assumed to be 20 percent of the purchase price. The calculated maintenance cost is $30,000 per year. Table 5.5 demonstrates a sample calculation for maintenance costs.

The fuel cost for this equipment is estimated as $30 per shift (Cataldi and Elkaim, 1980). Translated into a 1991 dollar base using the CPI-US, as demonstrated above, this per shift fuel cost is $46. An average amount of equipment usage based on Cataldi and Elkaim's guidelines of

200 shifts per year is assumed, and the yearly fuel price is $9,110. A sample calculation for the annual fuel cost is demonstrated in Table 5.6. The yearly herbicide application equipment costs are summarized in Table 5.7.

When applying chemicals to control vegetation, there is the possibility that a chemical spill may occur. Basic safety equipment should be available to protect workers and to facilitate containment and cleanup operations. For this estimate it is assumed that safety equipment is needed for three additional workers along with the two person crew already with the herbicide apparatus. Equipment to protect the workers such as gloves, coveralls, respirators, goggles, and an eye wash station are included in the cleanup/safety equipment kit, along with shovels and spill absorbent. For this estimate extra amounts, approximately one years use, of disposable worker protection items such as tyvex suits and respirator cartridges were included so they would be available for more than one incident.

Eight rolls of a blanket spill absorbent 150 feet long, 36 inches wide, and $^{1}/_{4}$-inch thick per roll were selected. This is capable of soaking up a 7,200 square foot area of spilled material. Eighteen cans of a spill absorbent that is capable of containing 55 gallons of water-based liquid per 2.5 gallon can were included in the safety equipment kit. Assuming a 2,000 gallon herbicide tank capacity, the solid spill absorbent is capable of absorbing about 50 percent of the total volume if a full tank was spilled. The amount of cleanup and containment materials is limited by the supply storage capacity on the herbicide application vehicle. Some of the materials may be stored at a location near the herbicide application area for dispatch in case of a spill.

Basic first aid equipment was not included in the estimate, as it was assumed that those items are also needed for other jobs and will be included in the overhead and indirect expenses. Table 5.8 contains a list of the equipment needed and their associated costs. The price estimates were taken from current (1989) catalogs of Forestry Suppliers, Inc. and Direct Safety Company, who are two of the many suppliers of this type of equipment, and they include freight costs.

The cost of the items were converted to a 1991 dollar base using the CPI-US conversion factor, and the total was $2,460 annually. This cost may vary on a yearly basis as some items may have to be replaced and others can be used for a number of years.

Although additional personnel may sometimes be required, a two person crew is assumed for herbicide application with one laborer and one operator. The daily cost of labor (average U.S. city values, 1991 dollar base) as shown in Table 5.3 is $153 for a laborer and $255 for an operator. An average equipment usage of 200 shifts per year, as specified by Cataldi and Elkaim (1980), results in a total yearly labor of $81,600. One shift per day is considered with the labor cost calculated only for the 200 shifts when the equipment is working. Table 5.9 is a sample calculation of the yearly wage calculation.

The actual herbicide costs and their transport costs are included in the chemical costs for herbicide application. The transportation cost for the chemicals was not computed directly for this estimate, but rather the cost was considered a function of the productivity of the process. For example, the more times an application unit has to refill, the less acreage of herbicide it is able to apply. It is assumed that all chemicals for one application day can be carried directly on the herbicide application apparatus, and that the application rate is 65 gallons per acre, within the 50 to 80 gallon range discussed previously. A 2,000 gallon tank capacity is also assumed, with a twenty-foot herbicide application zone.

Chemical cost and the application concentration varies with the particular product. Chemical costs were gathered from Forestry Suppliers (1989 catalog) for several types of herbicides (Table 5.10).

These costs are conservative (high) estimates because they may be bought directly from the chemical company at a lower cost.

Each of the herbicides has a different application concentration per acre. The concentration for Velpar is three gallons per acre, for Arsenal four pints per acre, for Garlon 3A seven quarts per acre, and for Tordon one and a half gallons per acre (Bullington, 1987). When the 20 foot (0.00379 miles) width spray zone is considered, the cost per mile for each chemical can be determined. Table 5.11 demonstrates a sample calculation for the Velpar chemical cost calculation, and Table 5.12 summarizes the chemical cost per mile for the various chemicals.

Since the chemical costs per mile noted are grouped into two broad cost categories of high and low, chemical costs of $250 per mile and $425 per mile will be used. Converting to a 1991 dollar base, they become $260 per mile and $442 per mile respectively. The Tordon cost of $182 per mile will not be used for projecting costs. Use of higher values results in a conservative estimate with some margin of error included.

For each cost category considered, equipment, labor, and safety costs, the costs can be converted to a per mile basis. The productivity of the vegetation control method must be considered for the per mile conversion. Productivities of 33 miles per day and 67 miles per day will be used with one shift per day, as discussed previously. A sample calculation of the per mile equipment cost, using the 33 mile per day productivity, is included in Table 5.13. Table 5.14 summarizes the per mile costs for the other cost categories.

Mobilization and demobilization costs, on the amount of time and distance required to get the herbicide application vehicle to and from the application site, are determined by taking five percent of the equipment, labor, and materials costs. When the chemical cost of $260 per mile is considered the total cost per mile ranges from $285 to $288 (Table 5.15), depending on the productivity rate. For the chemical cost of $442 per mile, the total cost per mile ranges from $476 to $487 (Table 5.16).

The overhead and indirect costs for herbicide application are determined by using ten percent of the total costs, including mobilization and demobilization. Table 5.17 demonstrates a sample calculation of the overhead and indirect costs associated with the total cost of $271 per mile and a mobilization and demobilization cost of $13.60 per mile.

The profit cost can be calculated in a similar manner by taking 15 percent of the total costs plus mobilization and demobilization costs (Table 5.18). Table 5.19 summarizes the overhead and indirect cost and the profit for each item on a per mile basis. The total U.S. average city cost (1991 dollar base) for herbicide application ranges from $356 to $609 per mile. The final herbicide application costs were converted to Anchorage, Alaska data base, using the Construction Cost Index as demonstrated in Chapter 4, and are included in Table 5.19.

Brushcutting - The brushcutting operation consists of using a brushcutter to remove vegetation, mainly woody species, along the track, on the shoulders and in the ballast area outside the tie ends. Most brushcutters have the capability of reaching into the wider right-of-way to cut vegetation, but this analysis concentrates on vegetation control in the roadbed. An assumption is made (Sheahan, 1988) that this equipment is in operation for 100 shifts per year, exclusively in the summer months.

The initial purchase price, maintenance costs, and fuel costs are included in the equipment costs. The 1986 purchase price for a brushcutter is $180,000 (Sheahan, 1988). A life span of ten years with no salvage value after that time is assumed. This cost translated to the 1991 dollar base, using CPI-US, is $213,000, which amortizes into a yearly cost of $34,700. A maintenance cost of 20 percent of the purchase price (Cataldi and Elkaim, 1980), $42,700, is assumed for this operation. Sheahan (1984) lists yearly maintenance costs for a brushcutter as $34,000. This is this is $42,300 in a 1991 dollar base, which corresponds closely with Cataldi and Elkaim's maintenance costs. The yearly fuel cost is $6,000 (Sheahan, 1988) for the 1991 dollar base, or $7,460. Table 5.20 summarizes the equipment costs.

Labor costs include two workers, the typical crew size for a brushcutting operation is (Sheahan, 1988). The daily labor rate as shown in Table 5.3 is $255 for a grade 4 operator and $153 for a laborer. If the brushcutter operates 100 shifts a year at one shift per day, the yearly labor cost is $40,700. A sample calculation of this procedure is shown in Table 5.9.

Five percent of equipment and labor costs was assumed for mobilization and demobilization. Labor and equipment costs total $126,000 yearly, giving a $6,280 expenditure for mobilization and demobilization and an annual sum of $132,000.

The annual overhead and indirect costs for this type of operation are assumed to be ten percent of the total equipment, labor, mobilization, and demobilization costs with $13,200 yearly for overhead and indirect costs.

Profit for this operation is assumed to be 15 percent of the total expenses or $132,000 (sum of equipment, labor, mobilization and demobilization costs). This results in an annual profit of $19,800 (Table 5.21).

Methods of vegetation control can be more easily compared when the data are in a cost per mile form. Equipment productivity must be considered to change the yearly costs into a cost per mile value. Sheahan (1988) reports a daily brushcutting productivity of 0.89 miles of right-of-way, with a swath that is 24 foot wide. Another source (Anonymous, 1970) states that 1.12 miles of right-of-way was cut in a day with a 28 foot width. Considering one day as a shift and the given productivities, results in costs per mile (average U.S. city data, 1991 dollar base) of $1850 (Table 5.22) and $1,470, respectively. The brushcutting cost per mile (1991) when converted to Anchorage, Alaska data base, is $2,430 for 0.89 miles per day productivity and $1,930 for 1.12 miles per day productivity.

Each cost item for brushcutting has been converted to a cost per mile for the specific cost components and is reported in Table 5.23.

Ballast Regulator - The ballast regulator is used to scrape away vegetation along the shoulders of the ballast and to brush vegetation between the rails. An average equipment usage of 200 shifts/year is assumed per Cataldi and Elkaim (1980).

The purchase cost, maintenance costs, and fuel costs must be considered in determining the cost of the equipment. The original purchase cost (1986) of a ballast regulator is about $90,000 (Burns, 1987a). This translates, using CPI-US, into a 1991 cost of $107,000. If the machine has a 14 year life, is rebuilt for $32,000 (1991 dollar base) after an eight year period (Burns, 1987a), and has a zero salvage value, the yearly cost is $16,500. An interest rate of ten percent is assumed (Table 5.24).

A yearly maintenance cost of 20 percent of the purchase price, following Cataldi and Elkaim's (1980) guidelines, is assumed. This results in an annual maintenance cost of $21,300. The fuel cost to operate this equipment is $33 per shift (Burns, 1987b), which translates, using the CPI-US conversion, to a cost of $39 per shift in a 1991 dollar base. When 200 shifts per year with one shift per day are considered, the annual fuel cost is $7,800. The total equipment costs are $45,700 annually (Table 5.25).

It is assumed that a ballast regulator requires a two person crew for operation, one laborer at $153/day and one equipment operator (Grade 4) at $255/day (Table 5.3) with 200 shifts per year, the total yearly labor cost is $81,500.

An assumption of five percent of the total labor and equipment is used to determine the cost to mobilize and demobilize a ballast regulator. The cost for labor and equipment is $127,000. The resulting mobilization and demobilization cost is $6,360. The total cost thus far is the sum of equipment, labor, mobilization, and demobilization, which is $127,000 plus $6,360 for $133,400 annually.

The overhead and indirect costs are calculated using the assumption of ten percent of the total annual costs calculated, or $133,400 yearly. The yearly overhead and indirect cost is $13,300.

Profit for this operation is calculated using the assumption of 15 percent of the total equipment, mobilization and demobilization costs. With yearly costs of $133,400, this results in $20,000 annually for profit.

The total annual costs (average U.S. city data, 1991 dollar base) for vegetation control with a ballast regulator are $167,000, and the yearly per item costs for both average U.S. city data and Anchorage, Alaska data are summarized in Table 5.26.

The equipment productivity is used to determine the per mile cost of vegetation control by a ballast regulator. For this calculation the productivity is assumed to be 1,000 feet per hour, suggested by the Alaska Railroad (Preston, 1991), with the equipment operating five hours per shift. As with herbicide application and brushcutting, the laborers worked eight hours daily. The increased maintenance and operational difficulties, plus the amount of time it takes to clear the track for other traffic, restricts the equipment productivity to five hours per shift. The ballast regulator is used for one shift daily. Following Cataldi and Elkaim's (1980) equipment usage guidelines of 200 shifts yearly, the cost per mile (average U.S. city data, 1991 dollar base) is $880 for ballast regulator vegetation control (Table 5.27). The cost for loss of ballast during this operation has not been included.

Reballasting - A reballasting operation requires a ballast regulator and the associated personnel as listed in Table 5.27, along with raw materials and additional equipment. To control vegetation with this technique, ballast is added to the track structure to reduce vegetation by burying any vegetation. For this analysis, it is assumed that a three inch cover of ballast material, the typical amount of ballast distributed during reballasting operations on the Alaska Railroad, is sufficient to control plant growth for one treatment life in the ballast area and along the shoulders. The analysis does not include the costs for a tamper to realign the track.

A ballast regulator, in general, has a reach of ten feet on each side of the track centerline. This reach limits the area of ballast application. In standard track maintenance operations, as described by the Alaska Railroad, a total width of ten feet of ballast is applied to the roadbed, generally five feet left and right of centerline. In this analysis, a width of ten feet will be used so that reballasting for track maintenance purposes and vegetation control are comparable.

Equipment costs for reballasting include all the costs associated with ballast regulator operations as specified in the previous section. The cost of additional laborers, support, and transport for the ballast material that is needed for reballasting is included in the cost of the materials. Table 5.25 is a summary of the annual equipment costs for a ballast regulator, which are $45,700 (average U.S. city data, 1991 dollar base).

The labor requirements for reballasting are similar to those used for ballast regulator operations. It is assumed that additional labor is not required for reballasting. The labor cost for a two person crew of a laborer and a grade 4 equipment operator is $81,500 annually (average U.S. city data, 1991 dollar base).

Burns (1987b) has developed cost estimates on the price of railroad ballast. His assumptions were that the ballast was obtained in a rural environment and that the on-line movement of the ballast to the application site was less than 250 miles. The price for ballast varies with the type of material that is used and is a function of the quality of the material and its weight. Ballast prices range from $3.10 (1991) per ton for ferrous metal slag (when 300,000 or more tons are purchased) to $7.70 (1991) per ton for harder granites (Burns, 1987b).

Ferrous metal slag weighs approximately one ton per cubic yard and granite weighs about 1.45 tons per cubic yard (Burns, 1987b). A three inch lift of material over the old ballast ten feet wide, results in 489 cubic yards of material per mile of track. This gives a materials cost of $1,520 per mile of track reballasted with ferrous metal slag, and $5,450 per mile of track reballasting with granite ballast (Table 5.28).

In addition to the actual cost of the ballast, the cost to transport the material must be considered. The material transport cost varies with the material type, the transport distance to the application site, and whether the material is hauled on the rail or by road. Burns lists a transport cost for ballast based on a United States average for single car movement, assuming there is no switching, along a company owned railroad line. He lists on-line costs (translated to 1991 dollar base using CPI-US) for slag that range from $0.01 to $0.021 per cubic yard of material and mile of transport, and costs (translated to 1991 dollar base using CPI-US) for granite from $0.017 to $0.05 per cubic yard of material and mile of transport. According to Burns (1987a), transport distances of ballast can vary from a low of ten miles to a high of 1,000 miles. He suggests that a 250 mile transport distance is the average for major railroads in the United States. It is assumed that the cost for ballast cars to carry the material and a support crew for its placement is included in the transport cost of the ballast.

A haul distance of 250 miles and a placement volume of 489 cubic yards per mile is assumed. The transportation cost is added to the materials cost to determine the total cost per mile of the ballast. A sample calculation is demonstrated in Table 5.29 for metal slag with a materials cost of $1,520 per mile. Table 5.30 summarizes the ballast costs per mile.

The ballast cost per mile can be converted to a yearly cost using a productivity of 1,000 feet per hour for this operation, which is similar to ballast regulator operations discussed previously. Table 5.31 demonstrates a sample calculation for metal slag, totaling per mile costs of $2,740. The equipment usage following Cataldi and Elkaim's guidelines is 200 shifts per year, with one shift per day and an equipment workday of five hours. Table 5.32 is a summary of the yearly ballast costs.

The mobilization and demobilization costs for reballasting are calculated using an assumption of five percent of the equipment, labor, and materials costs. Table 5.32 shows that the material cost varies, depending on the transportation rate and the material type, from $2,740 to $9,130 per mile, which is $519,000 to $1.73 million annually (average U.S. city values, 1991 dollar base).

Since mobilization and demobilization costs do not vary with the widely varying material costs, annual mobilization and demobilization costs are calculated using an average value of the materials cost, $5,860 per mile, which is $1.12 million per year. This is added to the equipment and labor costs and used to calculate the mobilization and demobilization cost.

The total equipment and labor costs are $127,000 annually. When added to the average yearly ballast cost of $1.12 million this results in a subtotal of $1.24 million. Mobilization and demobilization is five percent of that cost, or $62,200 per year, which is $382 per mile based on the average ballast costs (average U.S. city data, 1991 dollar base).

The overhead and indirect costs were calculated using ten percent of the total equipment, labor, and materials cost (Table 5.33). The profit for reballasting will be computed as 15 percent of the project cost (Table 5.34). Table 5.35 summarizes the yearly cost for reballasting.

To convert the annual cost data to a per mile basis, an equipment productivity for the reballasting operation is assumed of 1,000 feet per hour based on a five hour equipment workday and an equipment usage of 200 shifts per year. The cost per mile (average U.S. city data, 1991 dollar base), for reballasting with metal slag ballast ranges from $4,730 to $6,390, and for granite from $10,930 to $12,800 (Table 5.36). The cost of the reballasting operation is reported for a range of values because it is influenced by the transportation rate used in the calculation. The per mile reballasting costs for Anchorage, Alaska data base (1991 dollar base), using the Construction Cost Index conversion as shown in Chapter 4, range from $6,210 to $8,380 for metal slag and $14,300 to $16,800 for granite ballast. It is emphasized that these costs do not provide for tamping and surfacing/resurfacing the track or dressing.

Undercutting - The undercutting operation is complex, as it requires several pieces of equipment and good coordination of labor forces to accomplish. Undercutting generally consists of removing a specified amount of fouled ballast from within and under the ties, screening the material (in an undercutting/cleaning operation), and adding sufficient new material to fill the voids left by the discarded ballast. For these calculations an undercutting/cleaning operation is selected such that a minimum amount of new ballast will have to be applied. The minimum cut an undercutter can make below the ties is six inches. A six inch cut and a 200 shift per year machine usage, as suggested by Cataldi and Elkaim's guidelines (1980), will be assumed for the cost calculations. According to product literature by Kershaw Manufacturing Company (Kershaw, undated), the minimum support for an undercutting operation is one undercutter, one production tamper, and a ballast regulator. A minimum crew consists of three foremen, two assistant foremen, three machine operators, and ten laborers. These equipment and labor guidelines are used for the following cost analyses.

It was assumed that the track is in sufficiently good condition so that replacement of a large number of ties and spikes is not required. If the track is in poor condition, these replacements may greatly increase the cost of undercutting.

The undercutting operation requires a ballast regulator, a tamper, and an undercutter. The equipment costs associated with the ballast regulator are outlined in Table 5.24.

The 1980 purchase price of a production tamper is $140,000 and yearly maintenance comprises 30 percent of the initial cost of the equipment (Cataldi and Elkaim, 1980). Translated into 1991 dollar base, using the CPI-US conversion, the purchase price is approximately $213,000. The average expected life of a tamper is seven years (Burns, 1987b). When the purchase price is amortized over that time with a ten percent interest rate, the yearly cost is $43,800. Table 5.2 shows a sample calculation of the conversion to an annual cost. The annual maintenance cost is 30 percent of the $213,000 purchase price or about $63,900 per year. The fuel cost is $37 (1980) for an eight hour shift (Cataldi and Elkaim, 1980), and when translated to the 1991 dollar base is $56 per shift. With the standard use of 200 shifts per year (Burns, 1987b), the annual fuel cost is $11,200. The total equipment cost for the tamper is $119,000 yearly. Table 5.37 summarizes annual equipment costs for the tamper.

The undercutter purchase price ranges from $500,000 (Anonymous, 1975a) to $850,000 (Cataldi and Elkaim, 1980). When converted to the 1991 dollar base using CPI-US, the purchase costs are $1.18 million and $1.29 million, respectively. When these costs are amortized using a ten percent interest rate over an assumed eight year equipment life, the resulting yearly costs are $221,000 and $242,000. Cataldi and Elkaim list undercutter maintenance costs as $3,025 per mile (1980 dollar base), which translates to $4,590 per mile in a 1991 dollar base. Using 104 miles/year as recommended by Cataldi and Elkaim, the annual maintenance cost is $478,000. The fuel cost of $104 per shift (Cataldi and Elkaim, 1980) converted to a 1991 dollar base is $158 per shift. When a 200 shift per year equipment usage is assumed, the yearly fuel cost is $31,600. A summary of equipment cost for an undercutter is listed as Table 5.38.

The annual equipment cost for the undercutting operation when the cost of a ballast regulator, a tamper, and an undercutter are added together ranges from $896,000 to $917,000 depending on the equipment purchase price (Table 5.39).

As noted previously, the labor requirements for this operation are three foremen, two assistant (track) foremen, three machine operators, and ten laborers. Daily wage rates from Table 5.3 will be used in conjunction with a 200 shift per year equipment usage. Table 5.40 summarizes the labor costs.

For the undercutting/cleaning operation, the amount of ballast recovered influences the cost of the replacement materials. For this analysis, three different recovery rates were considered: no recovery, 25 percent recovery, and 50 percent recovery. According to Alaska railroad personnel (Preston, 1991), the actual recovery rate is probably 25 percent or less. In areas where track ballast conditions are very good, higher recovery rates may be found. The quantity of ballast that is required with no material recovery is calculated assuming that there is eight inches of ballast to the bottom of the ties, and a minimum cut of six inches is made below the tie for a width of ten feet. With these values, the total number of cubic yards of ballast required is 2,280 per mile (Table 5.41).

Two different ballast materials are considered for this operation, metal slag and granite. The price per ton for the ballast and the number of tons per cubic yard are reported in the section on reballasting. The price per mile for each kind of ballast can be computed in a similar manner to the calculation in Table 5.28. For metal slag the cost per mile is $7,070 and for granite the cost per mile is $25,500.

Transportation costs must be considered with the raw material price of the ballast. As mentioned in the Reballasting Section, the transportation cost of metal slag ballast ranges from $0.01 to $0.021 per cubic yard, and from $0.017 to $0.05 per cubic yard of granite. An assumed transport distance of 250 miles is used (Table 5.42). The two values of each cost item in Table 5.42 represent the range of costs associated with different material transport rates.

The materials cost for undercutting can also be calculated for 25 percent and 50 percent recovery of the ballast. For 25 percent recovery, 75 percent of the ballast would need to be replaced. Similarly, for 50 percent recovery, 50 percent of the material is needed. The price per mile for the different recoveries is shown in Table 5.43 with a range of costs for each item based on different material transport rates.

These per mile costs can also be converted into annual costs using the productivity rate of the undercutting operation. Kershaw Manufacturing Company (Kershaw, undated) states that this operation has a productivity of 2,000 feet per day for an eight hour day when a six inch cut is made. For this illustration, a five hour machine operating time will be used as a conservative estimate to compensate for down time from mechanical problems or time to clear the track for other vehicles. A sample calculation is shown in Table 5.44 for conversion to an annual cost of metal slag.

Table 5.45 lists annual values for the per mile material costs with varying recovery rates. Two values are shown for each recovery rate because of the variance in material transport costs.

The mobilization and demobilization costs were determined by a five percent assumption of the equipment and labor costs. The total annual equipment costs range from $896,000 to $917,000. Labor is $700,000 yearly, giving total annual costs that range from $1.60 million to $1.62 million, respectively. Calculating the mobilization and demobilization costs for the undercutting operation poses similar problems as the reballasting operation because the total project price is dependent on the materials cost. For this case, an approach is used similar to that which was used for the reballasting cost estimate. The mobilization and demobilization costs are determined by averaging the ballast costs and adding them to the equipment and labor costs. The average value for the ballast, including the transportation costs, (average U.S. city data, 1991 dollar base) is $22,700 per mile or $981,000 annually. Adding the ballast cost to the equipment and labor costs gives a range of $2.58 million and $2.60 million annually. Five percent of these costs results in a range of $129,000 to $130,000 annually for mobilization and demobilization.

The overhead and indirect costs are calculated by taking ten percent of the total cost of the vegetation control operation, while profit is calculated by taking 15 percent of the total project cost. The total costs are summarized in Table 5.46 along with the overhead, indirect and profit costs. For each recovery rate in Table 5.46 there are two values that reflect varying material transport costs.

With an equipment productivity rate of 2,000 feet per shift, one shift per day, five hours per shift daily equipment utilization, and Cataldi and Elkaim's 200 shift per year assumption, the costs can be converted into a per mile value. Tables 5.47 and 5.48 are summaries of the total per mile costs for the undercutting operation for the average U.S. city data base (1991 dollar base) and Anchorage, Alaska data base respectively. Both tables show two values for each recovery rate reflecting different material transport rates.

Hand Clearing - This method of vegetation control employs a group of laborers that pull or cut vegetation, by hand, in the ballast area. It is a labor intensive chore requiring little or no equipment. Since the laborers are in the immediate track area, safety precautions must be taken in order to prevent accidents.

For hand clearing, it is assumed that the only equipment required is for transportation of the workers to and from the desired site. This cost will be included in the mobilization and demobilization estimate. The costs for small hand tools or gloves are included in the overhead and indirect costs.

As this process is labor intensive, a relatively large crew will be needed. For this estimate a crew of 20 laborers will be used. This crew size was chosen because when combined with the individual worker productivity, the crew can clear one mile of track in a day. One supervisor is needed for every ten workers so two supervisors will be used, for a total of 22 workers. Adding the twenty laborers' costs (Table 5.3) of $3,050 to the two supervisors' costs of $352 gives a total of $3,410 daily for labor.

For hand clearing (weeding and cutting vegetation with non-power tools), an assumption is made that, in one hour, one person can pull and clip 30 to 100 feet of vegetation along the track for a width of 24 feet. This productivity is dependent greatly on the density and type of vegetation present, and the value was based upon field estimates of small amounts of hand clearing done in 1989 along the Alaska Railroad. With this productivity and assuming an eight hour work day, the cost per mile is $3,410. In order to allow for the cost due to travel, Table 5.49 shows a sample calculation assuming the worst case (most dense vegetation) of 30 feet per hour.

For hand clearing, the mobilization and demobilization costs are five percent of the labor and equipment costs. Five percent of $3,410 per mile is $170 per mile for mobilization and demobilization.

The overhead and indirect costs are calculated as ten percent of the total of the equipment, labor, mobilization, and demobilization costs ($3,580) or $358 per mile.

Profit is 15 percent of the sum of equipment, labor, mobilization, and demobilization or 15 percent of $3,580 for $536 per mile. Adding these costs together gives a total cost for hand clearing, based on a 30 feet per worker per hour productivity for a 20 foot width, of $4,470 per mile (Table 5.50). This analysis does not include any equipment costs for transporting workers to the site.

ALASKA RAILROAD

Methods

Economic analyses considered here are for those vegetation control alternatives appropriate for the trackbed of the Alaska Railroad. Six main alternatives for vegetation control within the trackbed are presented. The cost per track mile as well as a normalized cost are given for each alternative. The normalized cost estimates an actual cost to the Alaska Railroad Corporation (ARRC) for each treatment. This normalized cost addresses specific treatment considerations to obtain an annual treatment cost. The approach is sometimes referred to as an incremental analysis. All costs are reported in an Anchorage, Alaska 1991 dollar base. The alternatives and costs are detailed in the following sections.

The alternatives include herbicide spraying, reballasting, ballast regulating, undercutting, brushcutting and hand clearing. Each alternative is analyzed from an "in-house" perspective, in which treatment is effected by the Alaska Railroad. When appropriate, alternatives that might be contracted outside of ARRC are also examined. Because of the geographic location of the state and the relatively minimal industry, many physical alternatives that require railroad maintenance equipment are only feasible when conducted by ARRC. For example, no Alaskan contractors operate a ballast undercutter. The Alaska Railroad is the only railroad in the state, so the only source of work would be through ARRC. Although cost, insurance and training required for an in-state contractor for such limited application would be prohibitive, contractors from the contiguous 48 states are available.

These costs are based on data obtained from the Alaska Railroad and other sources. Where no information is available, assumptions must be made. Engineering economic principles are applied to adjust costs to a 1991 dollar base and to express costs on an annual basis.

Within the analyses, attempts have been made to use real data. Because the focus is on vegetation control for the Alaska Railroad Corporation, preference has generally been given to Alaskan data. This is especially appropriate with data concerning productivity and effective treatment life because these factors vary geographically. When necessary, data have also been taken from the literature or from other sources. These data are referenced within the text. Where no applicable data can be obtained, assumptions are made and they are supported or referenced when used.

Costs are initially reported in the dollar base given from the information source. These costs are then adjusted to an Anchorage, Alaska 1991 dollar base. This is done by using the construction cost indices reported by Means (1989). Means records the city cost indices for the United States average from 1945 to 1989, as well as the Anchorage 1989 value. The city average indices for 1990 and 1991 are estimated by averaging the yearly changes for the years 1984-1988.

An Anchorage, Alaska cost index is obtained by comparing the 1989 Anchorage index to the U.S. average index for the same year. The 1989 average city index is 100. The Anchorage index is 131.2. Therefore, it is assumed that Anchorage costs are 31.2 percent higher than the U.S. city average for every year. All Anchorage indices, except 1989, are assumed from this ratio (Table 5.51). The city average indices for 1990 and 1991 are also estimated as previously explained.

Once costs have been translated to an Anchorage 1991 dollar base, some costs may need to be annualized. Equipment costs are treated in this manner. To be able to express the cost per mile for a piece of machinery, the 1991 capital cost, an average service life and a salvage value must be known. From these data, an equivalent annual cost is calculated. Generally, costs and service lives are assumed from literature references. All salvage values are assumed to be zero, which in actuality may not be the case. Some large railroads sell equipment to smaller branch lines or other buyers after the service life is complete. However, this is not applicable to the Alaska Railroad. Shipping from Alaska is such a large expense that equipment is not sold or salvaged to another company, precisely because there are no buyers in close proximity. The discount rate used to achieve an annual cost is ten percent for all analyses within this text. Ten percent is a customary assumption of the discount rate for many engineering estimates at the present time (Bennett, 1990). The annual coefficient for a ten percent discount rate for the various service lives is taken from the interest tables in Grant et al. (1982).

For each option of an alternative, a cost per track mile treated is first calculated. For the flat rate, all alternatives are assumed to have the same efficacy and to treat the entire track. Six hundred miles is used as an approximate length for ARRC. In this way, each alternative can be compared directly in terms of a cost per mile treated. Costs reported in these sections are not rounded because it may affect comparison of alternatives of similar costs. Gross rounding is only done on normalized costs.

However, not all treatments actually have the same effectiveness and treatment length. Therefore, a normalized or incremental analysis is also done which takes other factors into account. These may include treatment life, mileage treated, other uses of the equipment, and partial costs borne by track maintenance. These considerations are particularly pertinent to herbicide, reballasting and ballast regulating operations. With the exception of herbicide treatments, all alternatives are directly comparable within the normalized cost sections. These sections show the estimated cost to the ARRC to treat the entire 600 miles of track with any one alternative. For this analysis it is assumed that herbicide spraying would be allowable on 56 percent of the track due to stipulations in previous permits. But, the most recent estimate by ARRC is that spraying would be permitted on 65 percent of the track (Leggett, 1989a & 1991). Therefore, the normalized herbicide costs are not directly comparable to other alternatives because a substantial portion of the track would not be treated with chemicals.

<u>Results</u>

The chemical alternatives examined are herbicide application by ARRC as well as by contractor.

Herbicide Application by ARRC - The Alaska Railroad does not own a spray rig for herbicide application at this time. ARRC has considered spraying by contract in recent years. Since there are no major herbicide contractors in Alaska and any herbicide contractor chosen would most likely be based in the continental United States, this introduces large costs in mobilization, travel time and lost revenue while traveling. The most cost effective means of spraying the Alaska Railroad would probably be for ARRC to spray, as shown in the following cost analysis.

The cost to spray the entire 600 miles of line, in 1991 dollars, is $692 per track mile. The cost components are detailed in the following sections.

Many types of spray rigs are available, from small tanks on hi-rails to sophisticated spray trains. The Alaska Railroad does not have enough line to justify purchase of a costly, high-speed spray train. However, a 5,000 gallon truck equipped with two independent tanks is feasible for railroad use.

The 1990 cost for such a rig is approximately $150,000 (Limming, 1990). Using the cost indices tabulated in Table 5.51, this cost translates to a 1991 cost of $200,735, as shown in the following calculation.

$$(\$150,000)(136.5/102) = \$200,735 \qquad \text{Eq. 5-1}$$

The annual equipment cost is calculated using the interest tables in Grant et al., 1982. Assuming a ten percent discount rate and a service life of ten years as conservative, the annualized cost conversion is 0.16275. This allows computation of the annualized equipment cost, as shown in Equation 5-2.

$$(\$200,735)(0.16275/yr) = \$32,670/year \qquad \text{Eq. 5-2}$$

This allows calculation of an equipment cost per mile, as shown below in Equation 5-3.

($32,670/yr)(1 yr/600 mi) = $54/mile Eq. 5-3

No data are available on maintenance and operation costs. Maintenance and operation for herbicide application are probably less than for heavy equipment used in track maintenance. In the absence of real data, the minimum maintenance ratio of twenty percent of the capital cost, proposed by Cataldi and Elkaim (1980) for other railroad equipment, is assumed appropriate to cover both maintenance and operation. This provides an estimate of the cost shown in the following equation.

(0.20/yr)($200,735)(1 yr/600 mi) = $67/mile Eq. 5-4

For safety purposes, ARRC does not use less than two people for any operation. One person operates the spray rig and the other assists in supervising, monitoring train movement, and with the radio.

The 1989 average ARRC hourly wage for supervision and labor during surfacing operations was $19.43, including wages, benefits and insurance. This adjusts to a 1991 cost of $20.21 per hour.

It is also necessary to project a productivity for the spray rig. This operating speed may be lower than the actual travel speed for the spray rig because attempts must be made to control drift of the chemicals away from the target area. A prominent herbicide contractor in the continental United States averages productivities of 50-100 miles per day with a rig similar to the one used for this analysis (Limming, 1990). However, this productivity may be high for ARRC conditions because of the increased degree of regulation imposed by the Alaska Department of Environmental Conservation. Productivity is also affected by the lower average track possession time on the Alaska Railroad (five hours per day). Productivity with a small hi-rail used in research in 1989 averaged 2.4 miles per hour. For this analysis, five miles per hour is assumed as a conservative average productivity. An hourly labor cost per mile can now be calculated.

(2 persons)($20.21/person-hr)(1 hr/5 mi) = $8/mile Eq. 5-5

The ARRC per diem cost is fifty dollars per person, for food and lodging. This yields the second component of the labor cost shown in equation 5-6.

(2 persons)($50/person-day)(1 day/5 hr)(1 hr/5 mi) = $4/mile Eq. 5-6

The total labor cost is the summation of the hourly labor and per diem charges, as shown below.

($8/mi + $4/mi) = $12/mile Eq. 5-7

Application costs are generally reported on a per acre basis. These charges vary from $30-$120 per acre for the continental United States, with most of the cost attributed to the cost of chemicals (Limming, 1990). The cost varies with the chemicals chosen. To be conservative, the high of $120 per acre, in 1990 dollars, is assumed. This translates to a 1991 cost of $161 per acre in Anchorage, Alaska. For a 24 foot right-of-way, which is the desired width of treatment for the Alaska Railroad, there are 2.91 acres per track mile. A chemical charge per mile can now be calculated, as shown in Equation 5-8.

($161/acre)(2.91 acres/mi) = $469/mile Eq. 5-8

The indirect and overhead costs are estimated at fifteen percent of the subtotaled costs. This percentage is standard for engineering estimates and includes such cost factors as engineering services, project management, permitting fees, field supplies, cleanup and worker transportation (Bennett, 1990; Clough, 1986). The subtotal is $602 per mile. The indirect and overhead charges are shown in the following equation.

$$(0.15)(\$602/mi) = \$90/mile \qquad \text{Eq. 5-9}$$

The cost to treat the entire line by ARRC herbicide spraying is $692 per track mile, as summarized in Table 5.52. For emphasis, it is noted that these costs do not include monitoring, intangibles, externalities or liability.

This cost per mile neglects some components that ultimately must be considered. Non-productive time may increase costs. These delays may result from rain, high winds, travel time and passing trains. Some consideration must be given to the potential for spills, contamination of water supplies, cleanup costs, ensuing court costs and compensatory damages. Adverse public relations may also be a cost factor.

It is likely that some sort of monitoring program will be required. This may increase the actual cost considerably. For example, assuming ARRC applies two herbicides and is required to monitor each herbicide at two depth intervals per mile, then four samples must be analyzed every mile. For the entire 600 miles of track, assuming a laboratory analysis cost of $200 per sample, the monitoring cost is $480,000. Distributed over the 600 miles of track treated, this cost is $800 per mile. This more than doubles the cost to apply herbicides, excluded labor and shipping costs. If only one sample per mile was required, the cost would be $400 per mile for monitoring, bringing the total cost of herbicide application to $1092 per mile ($400 + $692). However, it is possible, but not probable, that monitoring would not be required and these herbicides could be very economically competitive.

The flat cost per track mile assumes that the entire 600 mile line may be sprayed. This is done to facilitate comparison with other alternatives. However, the Alaska Department of Environmental Conservation and the Alaska Department of Fish and Game have previously proposed that the Alaska Railroad be restricted from spraying within 100 feet of water. This leaves approximately 213 mainline miles and 120 miles of yards and spurs for which spraying is allowable (Leggett, 1989a). Therefore, the total possible mileage that can be treated by chemicals is 333 miles, or about 56 percent of the track.

Using the estimated 1991 cost per track mile for ARRC spraying of $692, the total cost to spray the 333 miles of eligible track is approximately $230,000 per year. However, this total cost may be compared directly to only other herbicide analyses because of the 56 percent of the line being treated. To compare the normalized herbicide costs to those of other alternatives, treatment of the remaining 44 percent of the line by some alternative method must be considered as well.

Herbicide Application by Contract - In 1988, the Alaska Railroad advertised a request for proposals to apply herbicides to the trackbed. From the respondents, one bid was chosen. Although ARRC was subsequently denied a permit to apply the chemicals, the bid chosen nonetheless may be used as a contract cost estimate. The costs reported are from the bid document (Alaska Railroad Corporation, 1988) in 1988 dollars for Alaska and are adjusted to a 1991 dollar base for the purpose of this analysis.

The chosen bid outlines the cost in components of mobilization/ demobilization, daily charge, standby charge, and application charge.

The mobilization and demobilization is a one-time cost independent of the duration of treatment. As the contractor chosen was from the continental United States, this cost component is the amount required to transport the equipment and personnel to and from Alaska.

The mobilization/demobilization cost in 1988 dollars is $7,750. Based on the ratio of cost indices in Table 5.51, this translates to a 1991 dollar base cost of $8,119, or $13 per mile for the 600 miles of track.

The daily cost is the charge to ARRC for each working day. The 1988 charge was $2,500 per day for the bid chosen with the stipulation that the daily charge was to be waived for the first five days. This adjusts to a 1991 Alaska dollar charge of $2,619 per day.

To calculate the total daily cost, some assumption of the productivity is next required. Five miles per hour is assumed in accordance with the previous analysis. For a track possession time of five hours per day, 25 miles may be treated per day. To treat the entire 600 miles of track at a productivity of 25 miles per day would require 24 working days. With the first five days' daily charge waived, this means nineteen days daily charge would be applied. The daily charge to treat the Alaska Railroad, in 1991 dollars, is shown below.

($2,619/day)(19 days) = $49,761 Eq. 5-10

This daily charge can be distributed over the 600 miles of track treated to express the cost to treat one mile of track as $83 per mile.

The standby rate is the charge imposed by the contractor to be paid for non-productive days. Such delays would be due primarily to weather restrictions. Restrictions on allowable wind speed and precipitation during herbicide application are likely to be imposed by the Alaska Department of Environmental Conservation. As weather is not predictable, an estimate of five standby days is assumed as conservative for this analysis. The 1988 standby rate was $500 per day. This adjusts to a 1991 dollar rate of $524 per day. The standby cost is calculated below.

($524/day)(5 days) = $2,620 Eq. 5-11

This standby rate equates to a treated cost per mile of $4 per track mile for the entire line.

The application rate incorporates the equipment, labor, chemical and miscellaneous costs. The 1988 application charge was $245 per acre treated, or $257 per acre in 1991 dollars. Assuming a right-of-way treatment width of 24 feet, there are 2.91 acres treated per track mile. This enables calculation of the application cost to treat the entire track, as shown in Equation 5-12.

($257/acre)(2.91 acres/mi)(600 miles) = $448,722 Eq. 5-12

This application rate may be distributed over the entire 600 miles treated to express the application cost per track mile as $748 per mile.

In addition to the charges for the contractor time, ARRC will also have some indirect costs related to its administration of the contract. These are assumed, as in the previous example, to be fifteen percent of the subtotal costs. For this analysis, the costs incorporated in this figure may include engineering services, project management, legal expenses, publication costs, permitting fees, and transportation. This indirect and overhead cost is shown in the following equation.

(0.15)($849/mi) = $127/mile Eq. 5-13

The summation of the above costs provide an estimate in 1991 dollars of the cost to treat the Alaska Railroad by contract. The cost, as outlined by the accepted bid document chosen by ARRC in 1988 and adjusted to a 1991 dollar base, is $976 per track mile. The cost components are detailed in Table 5.53.

There are many intrinsic cost components that are difficult to calculate. Most of these have been noted within the previous herbicide analyses. It is stressed that the monitoring cost, as illustrated in the previous example, can double the cost to apply herbicide.

As with the previous herbicide analysis, the actual mileage for which chemical application is possible is 333 miles of track. The estimated contract spray cost, in 1991 dollars, is $976 per track mile. Therefore, the cost per year to spray the allowable 333 miles is approximately $325,000.

Physical Alternatives - Physical alternatives examined include reballasting, ballast regulating, undercutting, brushcutting and hand clearing. The first three are track maintenance procedures that may be applied for vegetation management. These are considered only as in-house, conducted by ARRC. However, brushcutting and hand clearing can be conducted in-house or by contract, and are considered accordingly.

Costs have been broken down into equipment, maintenance, operation, labor, per diem, indirect and overhead costs. Equipment, maintenance and operation costs generally follow the work of Cataldi and Elkaim (1980). Labor and per diem costs are from actual ARRC data. Labor costs per hour were arrived at by averaging the labor costs paid by ARRC when surfacing. These costs included supervision and crew labor. Overhead and indirect costs are assumed, following the construction engineering standard, as fifteen percent of the subtotal cost of the operation (Bennett, 1990; Clough, 1986).

Reballasting - The main cost components include ballast, equipment, maintenance and operation, labor, ballast transport, and indirect and overhead.

The cost to reballast track, in 1991 dollars, is $12,901 per track mile, as detailed in the following discussion.

Estimation of ballast cost requires assumptions to calculate the quantity of ballast required and to obtain a projected ballast cost.

The minimum practical depth of new ballast cover during reballasting is assumed to be three inches. This depth is suggested as the standard in surfacing operations (Burns, 1987a).

The width of treatment is generally constrained to the ballast area. Ten feet is standard width for reballast operations (Leggett, 1990a).

The ballast cost for ARRC in 1990 was $6.41 per cubic yard (Rulien, 1990), or $6.54 per cubic yard in 1991 dollars. The same source pit has been relied upon exclusively from 1986 - 1990 (Leggett, 1990b) with prices and quality relatively consistent. The most recent contract price is $7.55 per cubic yard from the Spencer pit for 1991.

These assumptions allow calculation of the quantity of ballast required, as shown below.

$$(3\ \text{in})(1\ \text{ft}/12\ \text{in})(10\ \text{ft})(5{,}280\ \text{ft/mi})(\text{yd}^3/27\ \text{ft}^3) = 500\ \text{yd}^3/\text{mile} \qquad \text{Eq. 5-14}$$

This is the average quantity of ballast utilized in ARRC reballast operations (Leggett, 1990b). Ballast cost per track mile can now be calculated, as shown in the following equation.

$$(\$6.54/\text{yd}^3)(500\ \text{yd}^3/\text{mi}) = \$3{,}270/\text{mile} \qquad \text{Eq. 5-15}$$

Estimation of equipment cost requires assumptions for the work season, productivity and cost projections as detailed below. The operation requires two ballast regulators and two tampers. The equipment cost for each piece of machinery is calculated below.

One of ARRC's newest ballast regulators was purchased in 1986 for $151,161. Using the cost indices ratio, this cost projects to a

1991 cost of $168,850. The service life is assumed to be 14 years, requiring rebuilding after the eighth year (Burns, 1987a). The purchase price and service life allow estimation of the annual capital cost. At a discount rate of ten percent, the annual cost conversion is 0.13575 per year. Following the same procedure detailed in the herbicide equipment cost, Equations 5-1 and 5-2, the annualized equipment cost is calculated as $22,921.

Cataldi and Elkaim (1980) report an average annual maintenance productivity of 200 shifts per year. This is unrealistic for most equipment in Alaska because of the relatively short summer. The operable work season for maintenance on the Alaska Railroad is 17 weeks per year (Leggett, 1990a). Assuming crews work five shifts per week, the annual productivity is 85 shifts per year. The average track possession time on the Alaska Railroad is five hours per shift (Leggett, 1990a).

The average ballast regulator productivity is 1,000 feet per hour (Burns, 1987a; Leggett, 1990a). This average is associated with surfacing operations.

These assumptions allow calculation of the ballast regulator equipment cost per track mile shown in Equation 5-16.

($22,921/yr)(1 yr/85 shifts)(1 shift/5 hrs)(1 hr/1,000 ft)*
(5,280 ft/mi) = $285/mile Eq. 5-16

The ARRC lists its most recent tamper purchase as $215,235 in 1985, an equivalent in 1991 of $245,239. Assuming a seven year service life (Burns, 1987a) at a ten percent discount rate yields an annual capital recovery cost of $50,375. The tamper equipment cost per track mile is shown in Equation 5-17.

($50,375/yr)(1 yr/85 shifts)(1 shift/5 hrs)(1 hr/1,000 ft)*
(5,280 ft/mi) = $626/mile Eq. 5-17

The total equipment cost per track mile can now be calculated. The cost includes two ballast regulators and two tampers, as shown below.

(2)($285/mi) + (2)($626/mi) = $1,822/mile Eq. 5-18

The maintenance and operation costs for reballasting include annual maintenance and fuel costs for the tampers and ballast regulators and the annualized cost of rebuilding the ballast regulators after eight years of service.

After the work of Cataldi and Elkaim (1980), the annual maintenance for a ballast regulator averaging 200 shifts per year is twenty percent of the capital cost. Since ballast regulators are used by ARRC in the winter for snow plowing, the 200 shifts per year total usage is probably appropriate. However, the vegetation control program should only have to pay maintenance on 85 shifts, or 43 percent of the total annual maintenance.

An annual ballast regulator maintenance cost per track mile can now be calculated, as follows.

(.43)(.20/yr)($168,850)(1 yr/85 shifts)(1 shift/5 hr)*
(1 hr/1,000 ft)(5,280 ft/mi) = $180/mile Eq. 5-19

According to Burns (1987a), the ballast regulator has a service life of fourteen years, including a rebuild for $27,000 after the eighth year, in 1987 dollars. This is in addition to annual maintenance. This cost, adjusted to 1991 Alaska dollars, is $38,034. However, this is a future cost, payable in eight years, in constant 1991 dollars. The actual 1991 cost is found by using the interest factor from Grant et al. (1982) for calculating a present cost given future cost. For the twelve year equipment life and ten percent discount rate, this factor is 0.4665, yielding a 1991 rebuild cost of $17,743. This cost is then annualized over the fourteen year life of the ballast regulator, using the Grant et al. (1982) interest factor of 0.1357 to obtain an annual cost of $2,408. The annual rebuild cost per mile is then estimated as shown in Equation 5-20.

($2,408/yr)(1 yr/85 shifts)(1 shift/5 hr)*
(1 hr/1,000 ft)(5,280 ft/mi) = $30/mile Eq. 5-20

Cataldi and Elkaim (1980) suggest an average fuel cost per year based on the engine horsepower to estimate operation cost. They suggest a 175-hp engine and an energy ratio of 0.5 as suitable for a ballast regulator. This is assumed appropriate to the ARRC machine. Additionally, a $1.00 per gallon fuel cost is assumed.

The fuel cost per track mile is the last component of maintenance and operation. This is calculated below.

(0.4 lb fuel/hp-hr)(175 hp)(0.5)(1 gal/7.2 lb)($1.00/gal)*
(1 hr/1,000 ft)(5,280 ft/mi) = $26/mile Eq. 5-21

The sum of the annual maintenance, annualized rebuilding, and annual fuel costs yields the total maintenance and operation cost for a ballast regulator, as follows.

($180/mile + $30/mile + $26/mile) = $236/mile Eq. 5-22

Tamper maintenance costs average thirty percent of the capital recovery cost for 227 miles tamped per year (Cataldi and Elkaim, 1980). At the assumed rates for productivity and track possession time, the annual vegetation control use is 90 miles per year, or forty percent of the annual tamper use. The cost per track mile is shown in the following equation.

(0.40)(0.30/yr)($245,239)(1 yr/85 shifts)(1 shift/5 hrs)*
(1 hr/1,000 ft)(5,280 ft/mi) = $366/mile Eq. 5-23

The annual operation cost, from Cataldi and Elkaim (1980), assumes a 150 horsepower engine and 0.75 fuel ratio. The fuel cost is calculated below.

(0.4 lb/hp-hr)(150 hp)(0.75)(1 gal/7.2 lb)($1.00/gal)*
(1 hr/1,000 ft)(5,280 ft/mi) = $33/mile Eq. 5-24

The maintenance and operation cost for one tamper is calculated by summing these two equations, as follows.

($366/mi) + ($33/mi) = $399/mile Eq. 5-25

A total maintenance and operation cost for the two tampers and two ballast regulators is calculated in Equation 5-26.

(2)($236/mi) + (2)($399/mi) = $1,270/mile Eq. 5-26

For computing labor costs, the average wage is $20.21 per hour as in the previous ARRC herbicide example.

The crew size for ARRC surfacing operations ranges from 7-11 people (Leggett, 1989b). Eight people are assumed for this analysis.

The salary cost per track mile for reballasting may now be calculated. This is shown in Equation 5-27.

(8 persons)($20.21/person-hr)(1 hr/1,000 ft)(5,280 ft/mi)
= $854/mile Eq. 5-27

The per diem component of the labor cost is now calculated. Per diem is assumed to be $50 per day for food and lodging.

($50/person-day)(8 persons)(1 day/5 hr)(1 hr/1,000 ft)*
(5,280 ft/mi) = $422/mile Eq. 5-28

The sum of the wage and per diem costs per track mile comprises the total labor costs per track mile, as shown in the following equation.

$$\$854/\text{mile} + \$422/\text{mile} = \$1{,}276/\text{mile} \qquad \text{Eq. 5-29}$$

The ARRC does not keep record of transport costs. Burns (1987a) addresses transport costs associated with surfacing and suggests an average of 2.54 cents per cubic yard of ballast per mile of movement. This is adjusted, by use of the cost indices in Table 5.51, to an Alaskan 1991 cost of 3.58 cents per cubic yard per mile.

ARRC has operated two gravel pits with ballast crushed by contractors in recent years. However, since 1986, one pit has been relied upon exclusively. It is located at mile 388 so the maximum transport distance for ballast is 388 miles. The average transport distance is assumed to be half of this distance, or approximately 200 miles. (If the Spencer pit is used the maximum transport distance would be approximately 440 miles.)

These assumptions lead to a ballast transport cost as calculated in the following equation.

$$(\$0.0358/\text{yd}^3\text{-mi})(200\ \text{mi})(500\ \text{yd}^3/\text{mi}) = \$3{,}580/\text{mile} \qquad \text{Eq. 5-30}$$

The indirect and overhead costs are assumed to be fifteen percent of the subtotal costs, $11,218 per mile.

$$(0.15)(\$11{,}218) = \$1{,}683/\text{mile} \qquad \text{Eq. 5-31}$$

The total cost to the Alaska Railroad to reballast the trackbed for vegetation control, in 1991 dollars is calculated as $12,901 per track mile. The cost components are shown as Table 5.54.

Not included in this estimate for reballasting is the equipment shipping cost. This component may be considered in the indirect cost but could increase the cost per mile.

With cost per track mile calculated, the true cost to reballast for vegetation control can be evaluated. Some reballasting is done every year as part of track maintenance surfacing cycles and will continue to be done regardless of the vegetation management program implemented. When considering reballasting for vegetation control, the portion of track reballasted by the surfacing program becomes an economic benefit to the vegetation control program. For the purpose of developing an annual treatment cost estimate, it is assumed that the sections of track surfaced, for which the reballasting is paid by the track maintenance program, are treated at no cost to the vegetation control program. Therefore, the vegetation control program must pay only to treat the additional sections of track.

On the Alaska Railroad, some sections of track require surfacing annually while other sections, especially side spurs and yards, are surfaced infrequently. For the purpose of this analysis, an average surfacing cycle must be used. The surfacing cycle for the entire 600 miles of track averages treatment once every five years (Leggett, 1990a). Therefore, for this analysis, twenty percent of the track is considered to be surfaced every year by track maintenance.

The incremental cost born by the vegetation control program for reballasting treatment depends on the frequency of reballasting necessary for vegetation management. Since there is no information available on treatment life in the literature, reballasting is conservatively assumed to offer control for one or two years (Leggett, 1990a; Sheahan, 1990).

If reballasting were to be relied upon for all the vegetation control needs of the Alaska Railroad Corporation, and assuming an annual treatment, the reballasting cost per mile from Table 5.54 can be used. If the track maintenance program treats twenty percent of the track yearly, then the vegetation control program must treat the remaining eighty percent of the track every year, or 480 miles of track. Therefore, the annual cost born by the vegetation control program to reballast solely for vegetation control, at $12,901 per mile in 1991 dollars, is approximately $6,192,000 per year.

If reballasting can offer effective treatment for two years. Track maintenance would treat forty percent of the track in two years. Therefore, vegetation control bears the cost for treating the other sixty percent of the line every two years. At thirty percent treatment per year, vegetation control must reballast 180 miles of track annually. This gives an incremental cost born by the vegetation control program of approximately $2,322,000 per year.

Ballast Regulating - For the purpose of vegetation control, ballast regulating is assumed to entail the dressing of the track by plowing and redistributing the existing ballast layer with the regulator arms.

The cost to use the ballast regulator is the same as for the reballast operation minus the tampers, one ballast regulator, ballast and transport costs and with a reduction in the indirect and overhead costs. The previous section on reballasting documents many of the assumptions and costs common to the two alternatives. Costs which are not directly comparable are calculated in the following section.

The cost, in 1991 dollars, for ballast regulating is $966 per track mile, as shown in the following calculations.

The equipment cost is calculated in Equation 5-16 as $285 per track mile.

The annual maintenance and operation costs, including an annualized rebuilding charge after eight years of service, are shown in Equation 5-22 as $236 per track mile.

The labor costs per track mile are for a minimum crew of two or

$$(2 \text{ persons})(\$20.21/\text{person-hr})(1 \text{ hr}/1{,}000 \text{ ft})(5{,}280 \text{ ft/mi}) = \$213/\text{mile} \qquad \text{Eq. 5-32}$$

Following the previous procedures for calculating per diem, total labor, and indirect and overhead costs gives the total cost to the ARRC for reballasting the trackbed, in 1991 dollars of $966 per track mile (Table 5.55).

Since ballast regulating is performed on twenty percent of the ARRC annually by the track maintenance program during surfacing operations (Leggett, 1990a). the cost to treat this increment of track is carried outside of the vegetation control program.

Assuming ballast regulating offers control for one year, the vegetation control program must pay for eighty percent of the treated line or 450 miles per year, with twenty percent of the cost born by the track maintenance program.

The cost to ballast regulate, in 1991 Alaska dollars, is $966 per track mile. For 480 miles treated annually, the cost born by vegetation control to ballast regulate is approximately $464,000 per year.

Undercutting - Undercutting by use of a ballast undercutter-cleaner is analyzed. For brevity, reference to undercutters in the following text may be understood to include ballast undercutter-cleaners. The first example addressed assumes no ballast recovery, while those that follow detail the costs incurred with ballast recoveries of twenty, fifty and seventy percent.

The cost to undercut track with no ballast recovery, in 1991 Alaska dollars, is $97,785 per track mile, as detailed in the following paragraphs.

Estimation of equipment cost requires assumptions for the work season, productivity and cost projections.

Cataldi and Elkaim (1980) suggest a 1980 capital cost for a ballast undercutter-cleaner of $850,000, which is equivalent to a 1991 Alaska cost of $1,669,424. Since no data are available on the service life of an undercutter, eight years is assumed. This gives of an annual capital recovery cost of $312,917 per year at a ten percent discount rate.

Work days, shifts, and productive time assumptions are the same as for ballast regulating.

Productivity estimates reported in the literature vary over a range of 400-1,000 feet per hour. For these analyses, 500 feet per hour is assumed.

These assumptions enable calculation of the equipment cost per track mile as shown in the following equation.

($312,917/yr)(1 yr/85 shifts)(1 shift/5 hrs)(1 hr/500 ft)*
(5,280 ft/mi) = $7,775/mile Eq. 5-33

The maintenance and operation costs for ballast undercutting include annual maintenance and annual fuel charges.

According to Cataldi and Elkaim, the ballast undercutters are the only conventional track maintenance machinery for which the cost to maintain the equipment bears no relationship to the purchase price. Rather, the annual maintenance is purely a function of the usage, or miles of track undercut each year. They suggest a standard maintenance cost, in 1980 dollars, of $3,025 per mile. This adjusts to a 1991 cost of $4,261 per mile. However, this cost is based on a productivity of 104 miles cut per year (Cataldi and Elkaim, 1980). Since the annual productivity for this analysis is 40.25 miles per year, this deflates the maintenance cost to $1,649 per mile.

A fuel utilization ratio of eighty percent for a standard engine horsepower of 352 hp is assumed (Cataldi and Elkaim, 1980). As in previous examples, a $1.00 per gallon fuel cost is assumed.

The annual operation cost is obtained as shown in the following equation.

$$(0.4\ \text{lb/hp-hr})(352\ \text{hp})(0.8)(1\ \text{gal}/7.2\ \text{lb})(\$1/\text{gal})*$$
$$(1\ \text{hr}/500\ \text{ft})(5{,}280\ \text{ft/mi}) = \$165/\text{mile} \qquad \text{Eq. 5-34}$$

The total maintenance and operation cost for the ballast undercutter is

$$(\$1{,}649/\text{mile} + \$165/\text{mile}) = \$1{,}814/\text{mile} \qquad \text{Eq. 5-35}$$

In addition to the ballast undercutter, undercutting operations generally utilize a minimum of two tampers and two ballast regulators (Anonymous, 1975a; Anonymous, 1976). One tamper is run in front of the undercutter to tamp and break up the consolidated ballast. The other tamper is needed to tamp and align the track once it has been undercut and new ballast has been placed.

The annualized cost for a tamper is assumed to be \$50,375, in 1991 dollars. However, the cost per track mile is not the same because the productivity is different. The cost per track mile is calculated below.

(\$50,375/yr)(1 yr/85 shifts)(1 shift/5 hrs)(1 hr/500 ft)*
(5,280 ft/mi) = \$1,252/mile Eq. 5-36

Tamper maintenance costs average thirty percent of the capital recovery cost for 227 miles tamped each year (Cataldi and Elkaim, 1980). For the productivity assumed in this analysis, 45 miles of track can be treated per year. This means vegetation control must pay for twenty percent of the published maintenance cost noted above. The cost per track mile is shown in Equation 5-37.

(0.20)(0.30)(\$245,239/yr)(1 yr/85 shifts)(1 shift/5 hrs)*
(1 hr/500 ft)(5,280 ft/mi) = \$366/mile Eq.5-37

The annual operation cost, from Cataldi and Elkaim (1980), assumes a 150 horsepower engine and 0.75 fuel ratio. The fuel cost is

(0.4 lb/hp-hr)(150 hp)(0.75)(1 gal/7.2 lb)(\$1.00/gal)*
(1 hr/500 ft)(5,280 ft/mi) = \$66/mile Eq. 5-38

Summation of the equipment, maintenance and operation charges give a total cost per tamper, minus labor and overhead, as follows.

(\$1,252/mi + \$366/mi + \$66/mi) = \$1,684/mile Eq. 5-39

Undercutting operations also require two ballast regulators for distributing ballast and dressing the track (Anonymous, 1975a; Anonymous, 1976). The cost per track mile is different than for reballast and ballast regulating operations because the productivity of the work train is greatly reduced.

As in the reballasting section, the 1991 capital recovery cost of a ballast regulator is assumed as $22,921 per year. This enables calculation of the equipment cost of a regulator as part of the undercutting operation.

($22,921/yr)(1 yr/85 shifts)(1 shift/5 hrs)(1 hr/500 ft)*
(5,280 ft/mi) = $570/mile Eq. 5-40

The annual maintenance cost is assumed to be twenty percent of the total capital recovery cost each year (Cataldi and Elkaim, 1980), for 200 shifts per year. Vegetation control should pay maintenance on 85 of these shifts, or 43 percent of the usage. The capital cost is $168,850. The annual maintenance cost is.

(0.43)(0.20/yr)($168,850)(1 yr/85 shifts)(1 shift/5 hrs)*
(1 hr/500 ft)(5,280 ft/mi) = $357/mile Eq. 5-41

The annual operation cost consists of the fuel expenses. Cataldi and Elkaim (1980) suggest a 175 hp engine and 0.5 fuel ratio as appropriate. This enables calculation of the operation cost as shown in Equation 5-42.

(0.4 lb/hp-hr)(175 hp)(0.5)(1 gal/7.2 lb)($1.00/gal)*
(1 hr/500 ft)(5,280 ft/mi) = $51/mile Eq. 5-42

These calculations allow a total cost for ballast regulating, minus labor and overhead, as the sum of the equipment, maintenance and operation costs. For one ballast regulator, the cost is shown below.

($570/mi + $357/mi + $51/mi) = $978/mile Eq. 5-43

Undercutting is a complex operation and quite labor-intensive. A crew is needed for each piece of equipment as well as personnel to replace old ties. For the undercutting equipment and support, a crew of six has been suggested as appropriate (Murphy, 1989). Adding this to the two member crews required for each tamper and ballast regulator, a total crew of fourteen is assumed for this operation.

The hourly labor wage, in 1991 dollars, for ARRC crew is $20.21. This allows a wage, benefit and insurance cost per track mile as follows.

(14 men)($20.21/man-hr)(1 hr/500 ft)(5,280 ft/mi)
= $2,988/mile Eq. 5-44

The per diem rate for ARRC is fifty dollars per person per day. Since the track possession time is five hours per day, this is the relevant productivity for converting to costs per track mile.

(14 men)($50/shift)(1 shift/5 hrs)(1 hr/500 ft)*
(5,280 ft/mi) = $1,478/mile Eq. 5-45

These figures give a total labor cost for undercutting consisting of the labor and per diem charges.

($2,988/mi + $1,478/mi) = $4,466/mile Eq. 5-46

Although the equipment cost for undercutting operations is sometimes viewed within the railroad industry as being prohibitive, it is actually the materials cost that is the major cost component. Even with a high ballast recovery percentage, the ballast and transport cost is significant.

This first undercutting analysis considers a track with such degraded ballast that no recovery is possible. This worst case scenario is unlikely but provides an upper limit for undercutting costs.

For these analyses, it is assumed that the undercutter chain is set to remove ballast to a depth of twelve inches below the ties, or twenty inches total cut. Undercutter chains have the capability of cutting 6-18 inches below the ties. The vegetation control benefit achieved by undercutting stems primarily from providing a thicker substrata of sterile ballast with corresponding good drainage. However, productivity will decrease with increasing depth of cut. In an attempt to achieve the most vegetation control with the least expense, a cut of twelve inches below the ties, twenty inch total cut, is assumed for this work.

The ballast cost, in 1991 dollars, is \$6.54 per cubic yard and the width of cut is ten feet. These data enable calculation of the materials cost.

$$(20\ in)(1\ ft/12\ in)(10\ ft)(5{,}280\ ft/mi)(1\ yd^3/27\ ft^3)*(\$6.54/yd^3) = \$21{,}315/mile \qquad \text{Eq. 5-47}$$

As in the reballasting analysis, the transport cost is related to the amount of material and distance of transport (Burns, 1987c). The average transport distance is assumed to be 200 miles. The transport cost is shown below.

$$(\$.0358/yd^3\text{-}mi)(200\ mi)(20\ in)(1\ ft/12\ in)(10\ ft)*(5{,}280\ ft/mi)(1\ yd^3/27\ ft^3) = \$23{,}336/mile \qquad \text{Eq. 5-48}$$

The total ballast cost per mile is the sum of the materials and transport costs, as shown in the following equation.

$$(\$21{,}315/mi + \$23{,}336/mi) = \$44{,}651/mile \qquad \text{Eq. 5-49}$$

The undercutting operation may destroy ties when the rail is lifted. The percentage of ties lost depends on the condition of the ties. When ARRC undercut sections of damaged track in 1987 with a leased undercutter, the average tie replacement was 700 ties per track mile (Leggett, 1990a).

For this calculation, it is assumed that 700 ties per mile will need replacement. The 1989 cost per tie for ARRC was $29, or a 1991 cost of approximately $30 per tie.

(700 ties/mi)($30/tie) = $21,000/mile   Eq. 5-50

The indirect and overhead costs incurred are assumed to be fifteen percent of the subtotaled charges or $85,030. The indirect and overhead cost is calculated in Equation 5-51.

(0.15)($85,030/mi) = $12,755/mile   Eq. 5-51

The total cost to the Alaska Railroad to undercut the trackbed, in 1991 dollars, is calculated as $97,785 per track mile for no ballast recovery. The cost components are shown as Table 5.56.

Although the likelihood of track being in such poor condition that no ballast is recoverable is small, the recent changes in ballast specifications for the ARRC may increase this occurrence. This analysis assumes a lower bound of twenty percent recovery. For the same productivity of 500 feet per hour, the costs which would change are ballast, which includes materials and transport, and indirect and overhead.

The recovery of twenty percent of the existing ballast reduces the materials cost per mile calculated in Equation 5-47 to $17,502 and the transport cost per mile in Equation 5-48 to $18,669. This yields a total ballast cost of $36,171 per track mile.

The decrease in ballast costs affects the subtotal and lowers the indirect and overhead costs accordingly. The subtotal for twenty percent recovery is $76,550 per mile. This reduces the indirect and overhead costs, as shown in Equation 5-51, to $11,483 per mile.

The total cost to ARRC, in 1991 dollars, to undercut track with a ballast recovery of twenty percent is $88,033 per track mile. The cost components are shown in Table 5.57.

Assuming a fifty percent ballast recovery, the cost to undercut track is lowered again. The reduced costs incurred are from ballast, indirect and overhead costs.

The materials cost for a ballast recovery of fifty percent is half the cost for no recovery. This reduces the materials cost in Equation 5-47, to $10,657 per mile and the transport cost, Equation 5-48, to $11,668 per mile. The total ballast cost is therefore $22,325 per mile.

The subtotaled costs are now $62,704 per mile. This reduces the indirect and overhead charges in Equation 5-51 to $9,406 per mile.

The total cost for ARRC to undercut track with a ballast recovery of fifty percent would be $72,110 per track mile.

One literature reference (Anonymous, 1974) reported ballast recoveries of seventy percent as feasible. This represents an upper bound on recovery and lower bound on the costs.

The materials cost with seventy percent recovery reduces Equation 5-47 to $6,395 per mile and the transport cost, Equation 5-48, reduces to $7,001 per mile. These result in a net ballast cost of $13,396 per mile.

The subtotaled costs are now $53,775 per mile which reduces the indirect and overhead charges, Equation 5-51, to $8,066 per mile.

The total cost to ARRC, in 1991 dollars, is therefore $61,841 per track mile for a seventy percent ballast recovery.

No incremental cost is borne by track maintenance for undercutting operations. There are only a few railroads in the United States that operate undercutters and the Alaska Railroad is not one of these. Because undercutting is quite expensive per track mile, it is doubtful that a railroad would undercut as part of a vegetation control program. However, when the effective treatment life is considered, undercutting becomes less extreme in price.

Although no information is available on the treatment life of undercutting for vegetation management, it is probably comparable to that of new line construction. The time between construction and vegetation encroachment would vary geographically, and there is no source of such information for Alaska. For the purpose of this analysis, treatment lives of five, eight and ten years are examined. Data utilized assumes the costs incurred when fifty percent of the ballast is recoverable as appropriate. This results in a 1991 cost per track mile of $72,110.

The Alaska Railroad Corporation undercut some sections of track in 1986 with a leased undercutter. Near the end of the 1990 growing season, there was virtually no vegetation in these sections as observed in the field. Therefore, undercutting may be assumed to provide effective treatment for more than four years. If the effective treatment life is five years, then twenty percent of the track, or 120 miles, would require undercutting every year by the vegetation control program. The cost to undercut 120 miles per year, in 1991 dollars, is approximately $8,653,000.

If the efficacy of treatment is assumed to be eight years, only 75 miles of track must be treated yearly. In 1991 dollars, this results in a cost of approximately $5,408,000 annually.

If undercutting is assumed to provide effective treatment for ten years, then the vegetation control program must treat only 60 miles per year. At a 1991 cost of $72,110 per track mile, the cost to undercut for vegetation control is approximately $4,327,000 annually.

Brushcutting - Brushcutting is utilized on most railroads for vegetation control. Generally, mechanical brushcutting is used on the wider right-of-way. However, railroads with severe brush encroachment or neglected vegetation control programs may require other hand or mechanical brushcutting in the trackbed. For this reason, brushcutting is included in this context. Brushcutting is one of the few alternatives for which it is feasible to consider contracted work as well as in-house. Brushcutting by ARRC is first considered.

A mechanical brushcutter can only cut vegetation beyond the ends of the ties. The cost for ARRC to use a mechanical brushcutter for vegetation control, in 1991 dollars, is $1,226 per track mile, as shown in the following calculations.

Calculation of equipment cost per mile for brushcutting requires assumptions on capital cost and productivity.

ARRC operates one brushcutter which was purchased for $84,231 in 1976 (Murphy, 1989). Using the cost indices in Table 5.51, this purchase price is equivalent to a 1991 cost of $169,081. Although the ARRC brushcutter is still in use, it is in very poor condition and represents an uncharacteristically long service life. A service life of ten years (Sheahan, 1988) is assumed to give an annual capital recovery cost of $27,518 at a discount rate of ten percent.

Daily productivity varies widely in the ARRC brushcutting records. Much of this may be attributed to an inordinate amount of mechanical down-time. Therefore, productivity estimates are taken from the literature and assumed as 0.25 miles per hour (Sheahan, 1988).

The work season assumed is 85 shifts per year with five hours track possession time per day.

($27,518/yr)(1 yr/85 shifts)(1 shift/5 hrs)(1 hr/0.25 mi)
= $259/mile Eq. 5-52

Sheahan (1988) reported annual maintenance and operation costs for railroad brushcutting. In 1986 dollars, annual maintenance averaged $34,000 for a 100 day season. This adjusts to a 1991 Alaska dollar base of $49,850. For Alaska's 85 day season, this annual cost would actually cover 1.18 years. Therefore, the annual maintenance for ARRC brushcutting is calculated as shown below.

($49,850/1.18 yrs)(1 yr/85 shifts)(1 shift/5 hrs)*
(1 hr/0.25 mi) = $398/mile Eq. 5-53

Annual operation costs are reported by Sheahan (1988) as averaging $6,000 for a 100 day season, in 1986 dollars. This figure adjusts to a 1991 Anchorage dollar base of $8,800 per 100 day season. Again, because of the 85 day season assumption, the annual cost actually spans 1.18 years. This allows computation of the operating cost as shown in Equation 5-54.

($8,800/1.18 yrs)(1 yr/85 shifts)(1 shift/5 hrs)*
(1 hr/0.25 mi) = $70/mile Eq. 5-54

The total maintenance and operation cost is therefore the sum of Equations 5-53 and 5-54, as shown below.

($398/mi + $70/mi) = $468/mile Eq. 5-55

An hourly wage of $20.21 with a two person crew for brushcutting gives a cost per track mile as shown below.

(2 men)($20.21/man-hr)(8 hr/shift)(1 shift/5 hr)*
(1 hr/0.25 mi) = $259/mile Eq. 5-56

The per diem paid to each crew member is $50. This yields a cost per track mile as follows.

(2 men)($50/shift)(1 shift/5 hr)(1 hr/0.25 mi)= $80/mile Eq. 5-57

The summation of the crew cost and per diem yields the labor cost component.

($259/mi + $80/mi) = $339/mile Eq. 5-58

The indirect and overhead costs are estimated as fifteen percent of the subtotaled costs. The subtotal is $1,067 per track mile.

(0.15)($1,066/mi) = $160/mile Eq. 5-59

The total cost per mile for ARRC brushcutting is $1,226 (Table 5.60).

This cost per mile neglects such intrinsic cost components as potential worker injury and damage to adjacent lands and properties. This alternative may be too hazardous to operate near highway crossings. Additionally, costs may increase as a result of adverse weather, equipment failure, travel time and track possession delays.

The annual cost to clear vegetation with a mechanical brushcutter depends on the treatment life. Treatment lives of one and two years are considered. The cost to brush one mile of track in-house, in 1991 dollars, is $1,226.

Some areas of ARRC track are brushed every year while most of the line is brushed every five to six years (Leggett, 1990b). To treat the complete 600 miles of track each year, the cost in 1991 dollars is approximately $736,000 annually.

If brushing is effective for two years, the cost borne by the vegetation control program is halved. Treating 300 miles of track each year, the cost is approximately $368,000 annually.

The Alaska Railroad retained one contractor for the 1990 season to operate a HydroAx, an off-track brushcutter, along the right-of-way. This one was used primarily to maintain brush in the wider right-of-way. During 1990 the HydroAx cleaved 22 track miles (Leggett, 1991). Other costs, primarily for moose control, were incurred (ARRC, $15,000) and ADF&G ($25,000)

It would be difficult to delineate such costs as equipment, maintenance and operation for contractors. The work done for ARRC is but a small part of the contractor's work load and it would not be valid to attribute all of the equipment or maintenance costs to the ARRC work. Therefore, the contractor's flat rate is used to obtain a preliminary value.

The contractor charges $90 per hour for brushcutting with a HydroAx, in 1990 dollars. This translates to a 1991 dollar figure of $92 per hour. Assuming an average productivity of 0.25 miles per hour, this yields a contract cost per track mile, as in Equation 5-60.

$$(\$92/hr)(1\ hr/0.25\ mi) = \$368/mile \qquad \text{Eq. 5-60}$$

The ARRC supplied one person to work with the contractor and also equipment to move the HydroAx. There is also a cost to ARRC for administration and assistance. This can be covered by the indirect and overhead charges. Assuming the fifteen percent of previous examples, the indirect and overhead charges are shown below.

$$(0.15)(\$368/mi) = \$55/mile \qquad \text{Eq. 5-61}$$

The summation of these two components yields a total cost to brushcut by contract, in 1991 dollars, of $423 per track mile.

The same intrinsic costs noted for the previous brushcutting analysis apply to contract brushcutting. Additionally, the contractor probably must carry liability insurance. Contractor mobilization and demobilization costs will be higher than for operations conducted by the ARRC.

The cost to contract brushcut with a HydroAx, in 1991 dollars, is $423 per track mile. As with the previous brushcutting analysis, treatment lives of one and two years are examined.

For an effective treatment life of one year, the entire line must be treated annually. Therefore, the cost to contract brushcutting for the Alaska Railroad, in 1991 dollars, is approximately $254,000 annually.

If effective treatment can be attained for a two year period, only half the track must be cut each year, halving the contract cost.

To treat 300 miles each year, in 1991 dollars, the contract cost is approximately $127,000 annually.

Hand Weeding - Because no railroads use hand weeding on a large scale, there are little real data available. Many options are possible in terms of labor, which is the main expense. The railroads in the continental United States which incorporate hand weeding in their vegetation control programs commonly use prison labor. This is generally applied to the wider right-of-way, however, and not to the ballasted area. In such situations, hand clearing refers to manual brushcutting.

Two hand weeding options are analyzed for the Alaska Railroad. The first option examined is in-house work by an ARRC crew. The second possibility is modeled after a student work program utilized in Fairbanks.

The cost for ARRC hand clearing, in 1991 dollars, is $3,522 per track mile, as shown in the following calculations.

No data are available on worker productivity for hand clearing. This is unfortunate because productivity greatly affects the labor cost, which is the main component of hand clearing. Productivity will vary depending on the condition of the trackbed and the motivation of the crew. As part of this project, hand weeding was initiated for a few short sections of track in 1989. The treatment width was approximately 24 feet. Generally, one hundred feet of track was cleared in one hour. However, productivity would be reduced for full-time labor. This reduction is necessary to account for worker productivity variations, vegetation type and density, meal and rest breaks, transportation time and non-productive time allowed for passing trains. Therefore, a productivity of fifty feet per man-hour is assumed for this analysis.

The worker wage, benefit and insurance charge is calculated in the following equation.

($20.21/person-hr)(1 person-hr/50 ft)(5,280 ft/mi)
= $2,134/mile   Eq. 5-62

Per diem charges are fifty dollars per person-day, as shown in Equation 5-63.

($50/person-day)(1 day/8 hr)(1 person-hr/50 ft)(5,280 ft/mi)
= $660/mile   Eq. 5-63

Total labor cost is obtained by summing the hourly cost and the per diem cost per track mile.

($2,134/mi + $660/mi) = $2,794/mile   Eq. 5-64

Indirect and overhead costs are assumed as fifteen percent of the subtotaled cost of $2,794 per mile. This results in an indirect and overhead amount as shown below.

(0.15)($2,794/mi) = $419/mile   Eq. 5-65

The total cost to hand clear the trackbed with Alaska Railroad personnel is $3,213 per mile. The cost components are shown below in Table 5.61.

The principal cost component in this alternative is labor. The labor cost calculated for this example is conservative in using skilled labor for hand weeding. Although this was done to maintain consistency with other ARRC operations, actual labor costs may be lower.

The cost for contract hand clearing is $2,429 per track mile, as detailed below.

Almost all ARRC maintenance is done in-house. One of the reasons for this is the expense of the equipment necessary for track work. In addition to the capital expenses, however, labor is expensive and it is generally less costly for ARRC to do work in-house than to pay a contractor with a profit. To provide a competitive alternative for hand clearing, it is necessary to reduce labor costs. This is done by modeling this analysis after a program called the Alaskans for Litter Prevention and Recycling (ALPR).

ALPR is a non-profit youth program funded by a grant through the Fairbanks Chamber of Commerce. The ALPR program pays workers $4.30 per hour (Meyer, 1990). This figure is in 1990 dollars and adjusts to a 1991 dollar base of $4.39 per hour. Since the ARRC worker productivity was fifty feet per hour, thirty feet per hour is assumed for the youth program as a feasible productivity. This allows a labor cost calculation as follows.

($4.39/man-hr)(1 man-hr/30 ft)(5,280 ft/mi) = $773/mile   Eq. 5-66

The existing ALPR program uses a ratio of one supervisor for every three youths. However, with a radio contact to alert for oncoming trains, there may be less potential hazard when working on the trackbed compared to a road system (Meyer, 1990). Therefore, a supervisor ratio of one for every six youths is assumed as appropriate for this analysis, twice the required ratio now in use. The ALPR program supervisors currently are paid $8.00 per hour, in 1990 dollars (Meyer, 1990). This translates to a 1991 cost of $8.16. These assumptions yield a supervisor cost per mile, as shown in the following equation.

($8.16/6 person-hrs)(1 person-hr/30 ft)(5,280 ft/mi)
= $239/mile   Eq. 5-67

The per diem is assumed as fifty dollars per person per day, giving an estimate for this labor cost component as below.

($50/person-day)(1 person-day/8 person-hrs)*
*(1 person-hr/30 ft)(5,280 ft/mi)
= $1,100/mile Eq. 5-68

Total labor costs are obtained by summation of the labor and per diem costs, as shown below.

($773/mi + $239/mi + $1,100/mi) = $2,112/mile Eq. 5-69

The indirect and overhead costs are assumed to be fifteen percent of the subtotaled costs. The only costs are for labor so the subtotal is shown in Equation 5-69. The indirect and overhead charges are calculated in the following equation.

(0.15)($2,112) = $317/mile Eq. 5-70

The 1991 contract cost to hand clear, as modeled after the Fairbanks ALPR program, is $2,429 per track mile. The cost components are detailed below in Table 5.62.

Costs not included in this analysis include potential worker injury and liability insurance, worker compensation insurance, laborer relocation costs, and costs for supervision (ARRC and ALPR).

Depending on the condition of the ballasted area and the degree and type of vegetation encroachment, hand weeding may be an effective method of treatment. Productivity is the primary factor affecting the cost per mile to hand clear and after one thorough treatment, productivity should increase because the subsequent growth will not be as well established. Treatment is assumed effective for at least one year for these analyses.

The vegetation management program must treat the entire 600 miles every year. If this work is completed by ARRC labor, the cost of treatment is approximately $2,113,000 annually, in 1991 dollars.

For work contracted through a program similar to the ALPR grant, the cost to the vegetation control program is reduced. In 1991 dollars, the cost to treat the entire 600 miles of track is approximately $1,457,000 annually.

Costs Per Mile - The treatment costs per mile are summarized in Table 5.63 and shown in Figure 5.2. Treatment lifew heavily influences cost (See 5-63 __) For example, increasing herbicide treatment life to three years might halve its cost. However, for this analysis, a uniform treatment life of one year is used for all but undercutting. The undercutting alternative is omitted in Figure 5.3 to allow a clearer comparison of the other alternatives. From Figures 5.2 and 5.3, it can be seen that the least cost alternative is contract brushcutting, followed by ARRC herbicide application. Undercutting and reballasting were found to be the most costly alternatives.

DISCUSSION

Survey Dollar Base Conversion

The cost per mile of the various treatment methods as gathered from the survey data were converted to a 1991 dollar base using the CPI-US index. Herbicides averaged $188 per mile, brushcutting $720 per mile, and ballast regulating $357 per mile for average U.S. city data.

The hand clearing cost (without the use of power tools), when converted to 1991 dollar base (average U.S. city data) was $4,470 per mile. The cost of burning vegetation as reported by the survey, converted to a 1991 dollar base was $1,150 per mile.

Numerous factors influence the cost of a vegetation control method. When cost data are gathered from outside sources, determining which factors have been considered in an estimate is difficult. For example, when a railroad hires a contractor to do track maintenance or vegetation control operations, the cost includes a profit or markup normally of 10 to 15 percent. The same project when completed by internal labor forces includes no profit. Another item that is overlooked in economic evaluations is the cost of overhead and indirect for a project which can increase the total project cost 10 to 20 percent.

Productivity greatly influences the cost of a vegetation control operation and may vary because of a number of factors. As the amount of rail traffic along a particular line increases, the productivity of a vegetation control operation decreases because equipment must clear the track for other traffic to pass. Some operations, such as undercutting, require complete closure of the track for a specified period of time which may impede other rail traffic. For most construction projects, the efficiency is lowest at the beginning of the operation. Efficiency and productivity increases, once the crew becomes familiar with the equipment and the process.

Mechanical failures are unpredictable and costly because much time may be spent in repair. Good maintenance can alleviate some of these problems, but unexpected situations arise. With so many variables influencing the operation efficiency, establishing an accurate efficiency for an operation is difficult, and operation efficiencies are site specific. Several different productivities in the independent cost analyses were considered for most operations in order to establish some of the cost deviations associated with productivity.

The cost of equipment varies depending on the brand and the model of the product. Equipment cost is a substantial portion of the total treatment cost for brush cutting, using the ballast regulator, and undercutting. Maintenance and fuel costs are less obvious costs and likely to be neglected in a cost estimate. Usually these costs do not contribute a large percentage toward the total treatment cost, but for brush cutting, using the ballast regulator and undercutting they should not be ignored as the final treatment cost will be noticeably influenced.

The materials cost is a large portion of the treatment cost for undercutting, reballasting, and herbicide application. The materials cost is influenced by a number of factors including the quality of materials purchased, the distance of materials transport, and the type of materials used. These factors also contribute to the cost of herbicide application chemicals.

Figures 5.4, 5.5 and 5.6 graphically delineate the portion of the total treatment cost that each component comprises. These figures are based on 1991 dollar base, U.S. average city data from the independent cost estimate.

The primary cost component for herbicide application is the materials cost. The independent estimate was based on a materials price for a small quantity of herbicide. The price would be substantially less, if the product was purchased in bulk directly from the manufacturer.

The cost of brush cutting, as shown in Figure 5.4, is composed of nearly equal portions of maintenance and fuel; labor; purchase price; and overhead, indirect and profit costs.

Labor is a large portion of the cost of using a ballast regulator to control vegetation. Labor costs can fluctuate from region to region, making this operation more expensive in some areas than others.

The cost of reballasting is greatly influenced by the materials costs as this composes the majority of the treatment cost for the operation. If less expensive materials of acceptable quality are available, the cost for this alternative will be decreased substantially.

Undercutting is divided almost equally between labor, maintenance and fuel, materials, and overhead plus indirect and profit costs.

Hand clearing is a labor intensive process (Figure 5.6). If a minimum wage work force was used, the cost for this method could be substantially reduced and thus it would be a more attractive alternative. Labor through a volunteer or convict work program would also greatly reduce the cost of this project. Additional insurance may be needed for this type of work force, but it would make this alternative one of the least expensive vegetation control options.

Adjustment for Treatment Life

Direct comparisons between the cost of treatment options are not valid unless the treatment life is considered. Each of the alternatives can be adjusted to reflect application frequency of the vegetation control method. The costs are adjusted to reflect the treatment life by dividing the treatment life by the cost per treatment. A discussion of each of the vegetation control methods and the estimated treatment life follows.

In the contiguous states, it is customary to apply chemicals for herbicide application every year to the right-of-way. Chemicals must be applied twice yearly in some areas because of the long growing season. Although Alaskan conditions may permit a longer application cycle, such as two years, a standard one year treatment life is assumed for the analysis. From the data reported by the survey respondents, the average cost (average U.S. city data, 1991) was $188 per mile to apply herbicides for approximately a 16 to 24 foot application width. The cost computed in the independent estimate was $485 per mile for a 20 foot application width. The difference in the independent estimate costs and survey costs may caused by numerous factors such as varying chemical costs, the exclusion of profit, overhead and indirect costs in the survey costs, and varying application rates and productivities.

The cost reported in the literature (Brauer, 1983) is $25 to $125 per acre or $79 to $392 per mile when converted to an average U.S. city data base in 1991 for a 20 foot width. Sheahan (1988) reports an herbicide application cost of $296 per mile (average U.S. city data, 1991 dollar base) for a 24 foot width. The range of values per mile for a 20 foot width is $79 to $392.

The frequency of brush cutting for railroads is dependent on the type and growth rates of vegetation present locally. Literature and the survey responses show that shrubs are commonly removed along the right-of-way every two or three years (Sheahan, 1988). The cost of this operation is strictly for vegetation control and has no other track maintenance benefits. The average cost (average U.S. city data, 1991 dollar base) per mile reported for brush cutting from the survey was $720, and for the independent estimate $1,850 per mile (for a 24 foot cut) and $1,470 per mile (for a 28 foot cut). The two brush cutting cost values from the independent estimate are based on different productivities. Sheahan (1988) reported a brush cutting cost (converted to average U.S. city data, 1991 dollar base) of $1,090 per mile for a 24 foot width.

For two and three year treatment lives the survey cost was $360 and $240 per mile, respectively. For a two year treatment life the independent estimate ranged from $735 to $925 per mile with an average of $830 per mile. When a three year treatment life was considered the brush cutting cost ranged from $490 to $617 per mile with an average of $554 per mile.

Since the ballast regulator is commonly used for railroad track maintenance operations along the rail, part of the cost for this vegetation control operation can be borne by the track maintenance program. Using the ballast regulator to control vegetation may "waste" ballast by pushing good material outside of the roadbed area. This is not critical in the limited areas where there is excess ballast, but in other locations the wasted ballast must be replaced and increases maintenance costs. The ARRC has virtually no excess ballat in the roadbed. Careful use of the ballast regulator, by a skilled operator, so that the equipment scrapes away the vegetation without permanently removing ballast is possible. However, vegetation control using this method is not as effective since some roots will regrow.

Assuming that the ballast regulator is used on the entire track every four years, 25 percent of the track is treated annually (Preston, 1991). Therefore the vegetation control program would only have to expend 75 percent of the costs per year. For the purpose of this study a treatment life of one to two years is estimated for this method of vegetation control. Since this method is not one normally employed for vegetation control, specific data on the time period for vegetation regrowth is unavailable.

The cost (average U.S. city data, 1991 dollar base) per mile reported from the survey respondents was $357, and from the independent estimate was $880 per mile. When the cost shared by the track maintenance program is considered the costs are $268 from the survey data and $660 from the independent analyses. Considering a two year treatment life and 25 percent of the cost borne by the maintenance program, the survey cost and the independent estimate is $134 and $330 per mile, respectively.

Reballasting or resurfacing is another track maintenance operation that can be modified for vegetation control so some of the cost can be borne by the track maintenance program. Reballasting frequency varies greatly, from up to three times per year to less than once every five years. If it is assumed the entire track is reballasted in five year cycles, as estimated on the Alaska Railroad (Preston, 1991) and in the literature (Cataldi, 1981), then it can be considered that 20 percent of the total track is reballasted for maintenance procedures annually. This would result in the vegetation control program only bearing 80 percent of the cost of reballasting per year. There are track maintenance benefits associated with reballasting for vegetation control such as increased track structure strength.

Treatment lives of three, five and seven years are assumed for this estimate. Similar to ballast regulator vegetation control, the process of reballasting for vegetation control is not common; thus specific data on vegetative regrowth is unavailable. A range of treatment life values was chosen to account for this uncertainty.

No cost data from the survey respondents were reported for reballasting. From the independent estimate the average cost per mile for reballasting (average U.S. city data, 1991 dollar base) was $8,710. For reballasting on three, five, and seven year cycles the cost per mile was $2,320, $1,390, and $992, respectively. Table 5.64 demonstrates a sample calculation.

Since undercutting is used in track maintenance, part of the cost for this operation can be shared by the track maintenance program. The track is undercut for track maintenance on a less frequent basis than reballasting, approximately every five to seven years. A five year value was chosen for this estimate. When the track is undercut every five years 20 percent of the track is undercut annually. Similar to reballasting, 80 percent of the cost of the undercutting operation is borne by the vegetation control program. Treatment lives of five and seven years are assumed with this operation. Longer treatment life values are assumed since undercutting removes most vegetation and also adds a deeper layer of ballast than reballasting.

No data for undercutting costs were given by the survey respondents. The calculated cost per mile from the independent estimate for metal slag ballast with a 20 percent recovery rate was $86,800. The cost per mile for granite with a 20 percent recovery rate was $114,000. Considering five and seven year treatment lives, the cost per mile ranged from $13,900 to $9,920 for metal slag and $18,200 to $13,000 for granite ballast.

Hand clearing is used strictly for vegetation control and has no track maintenance applications. The reported cost per mile (average U.S. city, 1991 dollar base) from the survey data was $2,490 and from the independent estimate the cost per mile was $4,470.

Treatment lives of one, two and three years were considered, and the amount of vegetation control gained by the hand clearing operation depends on the vegetative species present. When the two and three year treatment lives were considered, the costs from the survey were $2,490 and $1,245 per mile, respectively. The cost per mile for the independent estimate considering two and three year treatment lives was $2,240 and $1,490, respectively.

Table 5.65 contains a summary of the treatment lives considered and the cost per mile of the treatment methods for average U.S. data base and Anchorage, Alaska data base (for the independent analysis).

The treatment methods were arranged in order of increasing cost on a per mile basis (Figure 5.7). The treatment life chosen influenced the position of the alternative in the ranking scheme. For both the survey data and the independent cost estimate calculations, vegetation removal using the ballast regulator with a two year treatment life was the least expensive option.

The three lowest cost alternatives in both estimates were herbicide application, using the ballast regulator, and brush cutting. Reballasting ranked next in the independent estimate followed by hand clearing. If volunteer or convict labor was used for hand clearing then the cost would be reduced substantially since labor is the major cost component. Figure 5.8 illustrates the ranking of the five least expensive alternatives when a conservative approach is taken and the shortest treatment life is considered for each treatment method. Herbicide is the least expensive vegetation control alternative under these conditions. Table 5.66 is a key to Figures 5.7 and 5.8.

Part of the theory of integrated vegetation management is that all alternatives should be considered. This includes investigating several alternatives simultaneously. One alternative may be limited by either a physical or a regulatory restraint and thus lend itself to combination with another alternative for vegetation control. For example, some states have regulations that require a certain setback distance from water when herbicides are applied. Therefore, another form of vegetation control would be needed to complete the vegetation control program to eliminate vegetation in those areas. Public concern and resistance may also be an important influencing factor.

The practice of developing a combination of vegetation control techniques to eliminate unwanted vegetation is very site specific. Each railroad has to examine its specific needs to determine which method or combination of methods is most cost effective for the desired level of control. This lends itself to establishing a system-wide vegetation control program that considers the level of treatment desired, the cost of each alternative, and the effectiveness of each control method on the undesired vegetation species present.

SUMMARY

A summary of the vegetation control costs per mile for herbicide application, brushcutting, ballast regulator, reballasting, undercutting, and hand clearing are included in Table 5.63. For emphasis it is repeated that the cost for herbicide application does not include monitoring, intangibles, externalities or liability. The assumptions used in the analysis for each vegetation control method must be evaluated to reflect the conditions at a specific site. To compare the cost of the vegetation control methods to each other requires that the frequency for a particular method be considered. For example, if one method must be used yearly to control vegetation adequately and another method is effective for a five year period, then the costs for these methods cannot be directly compared without further manipulation. (Table 5.65). Since this was only a two year study, overall treatment life could not be determined. It may well be that herbicides, as well as other treatments, may have longer treatment lives than assumed in this analysis.

A method to compare vegetation control techniques with different treatment lives is discussed along with a discussion of the vegetation control benefits of maintenance procedures and how they can be assigned a portion of the vegetation control costs.

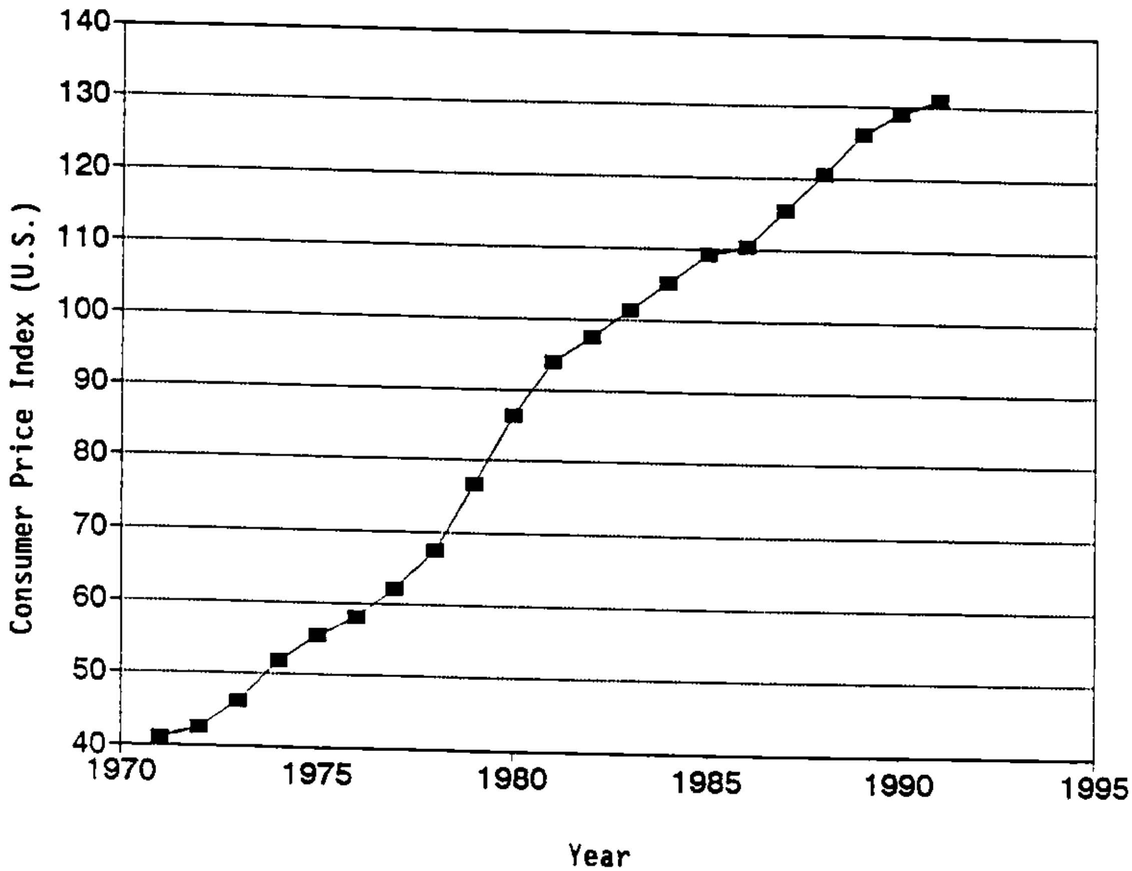


Figure 5.1. Year Versus U.S. Consumer Price Index, U.S. Average City Data. (Adapted from U.S. Department of Labor, 1990.)

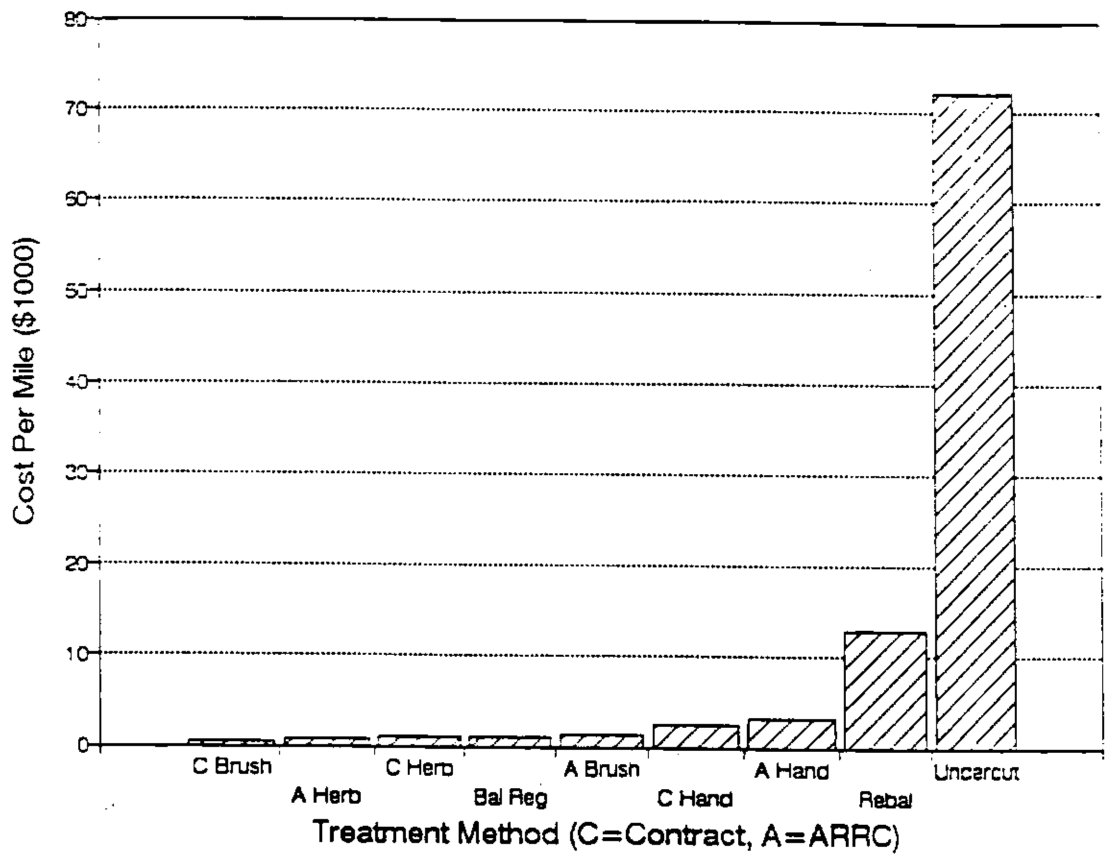


Figure 5.2. 1991 Treatment Comparison: Alaska Cost Per Mile.

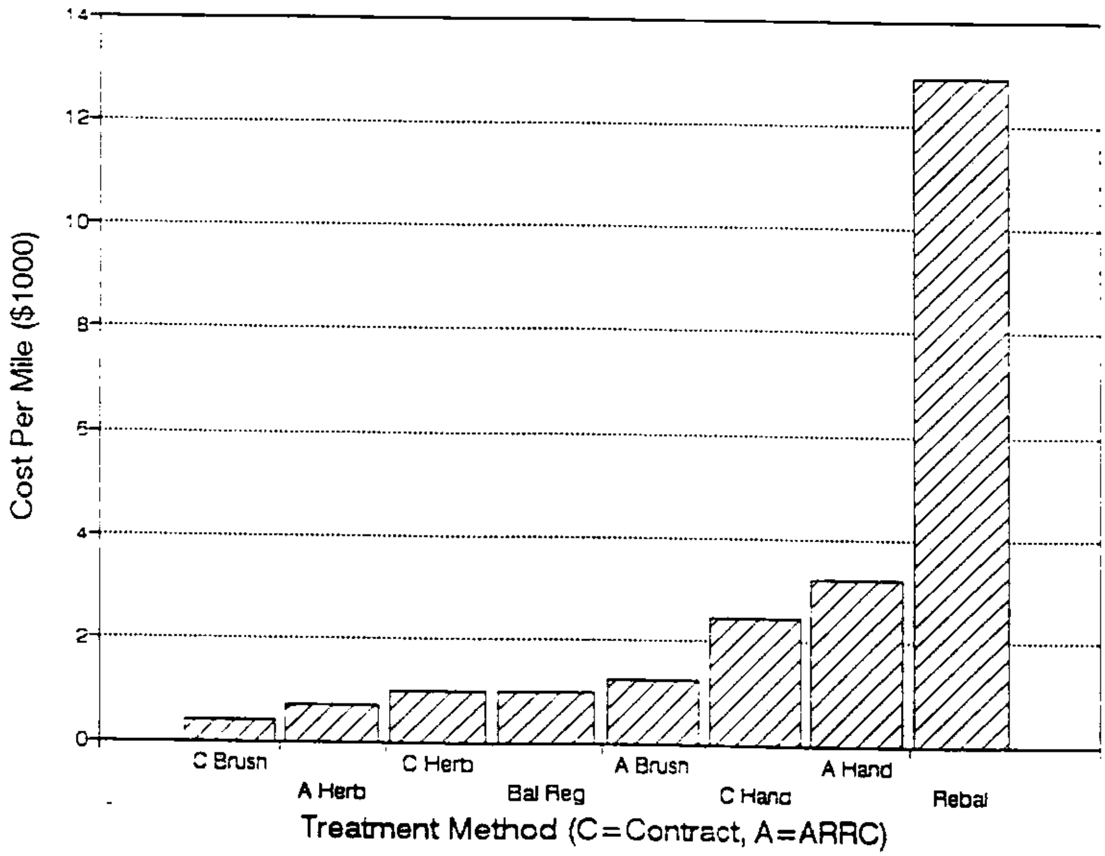


Figure 5.3. 1991 Treatment Comparison: Alaska Cost Per Mile. Undercutting Alternative is omitted.

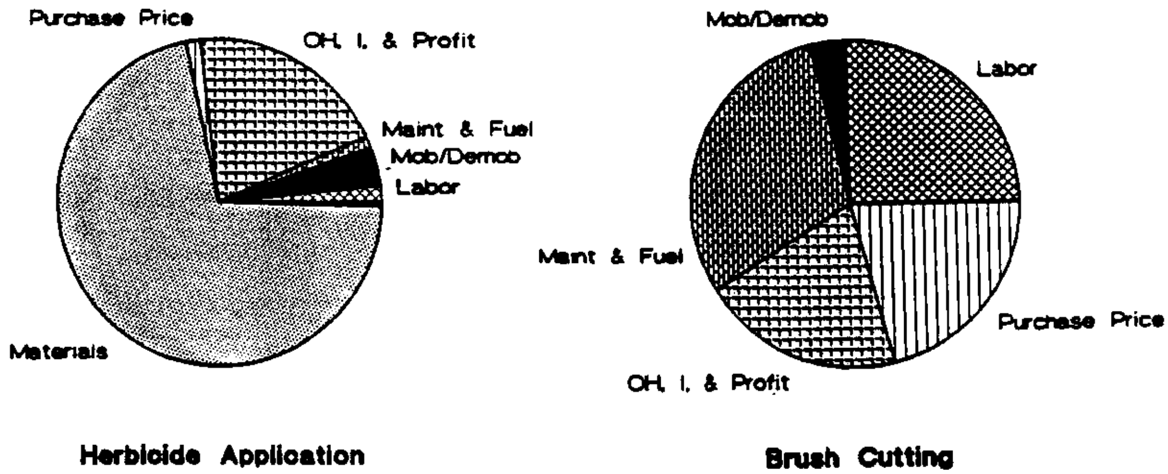


Figure 5.4. Cost Components For Herbicide Application and Brush Cutting. Average U.S. city data, 1991 dollar base.

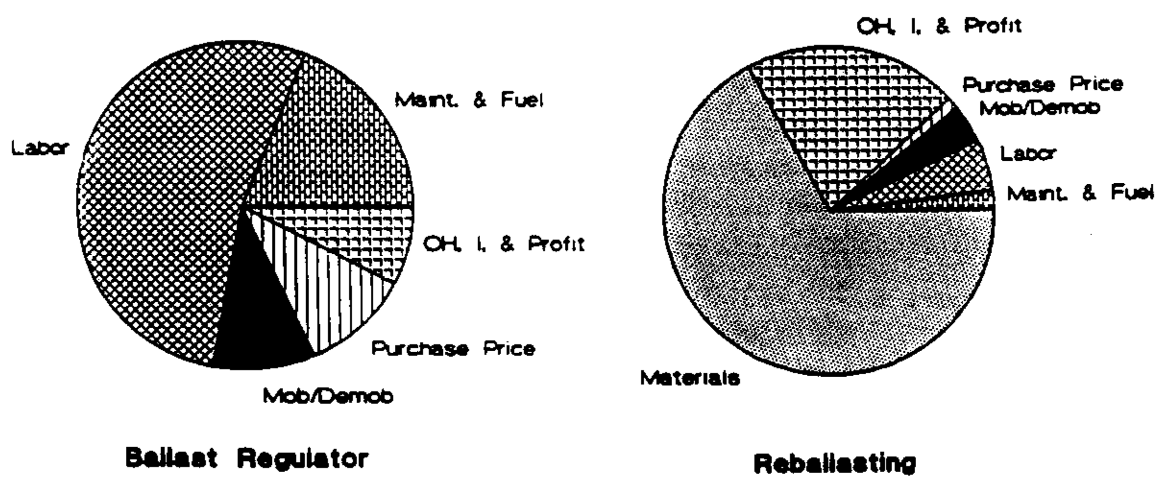


Figure 5.5. Cost Components for Using the Ballast Regulator and Reballasting. Average U.S. city data, 1991 dollar base.

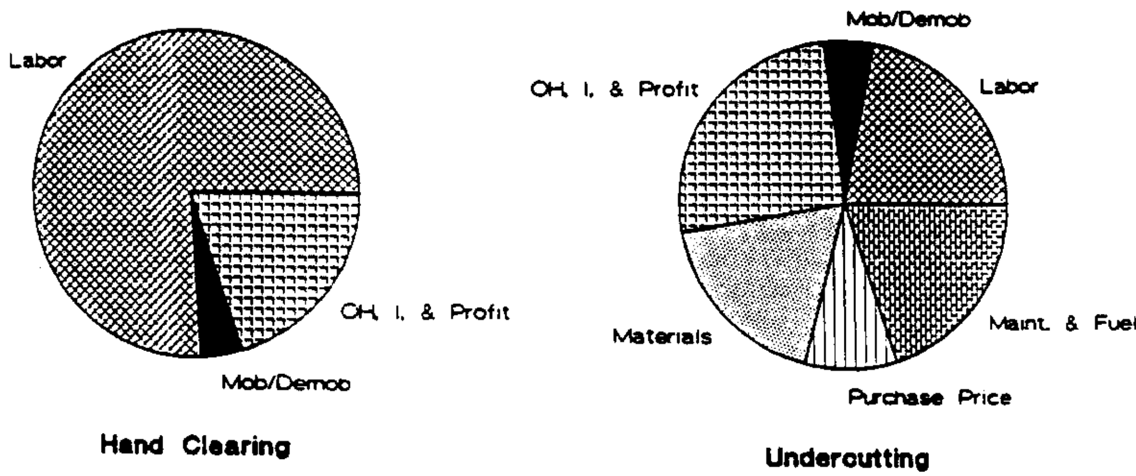


Figure 5.6. Cost Components for Undercutting and Hand Clearing. Average U.S. city data, 1991 dollar base.

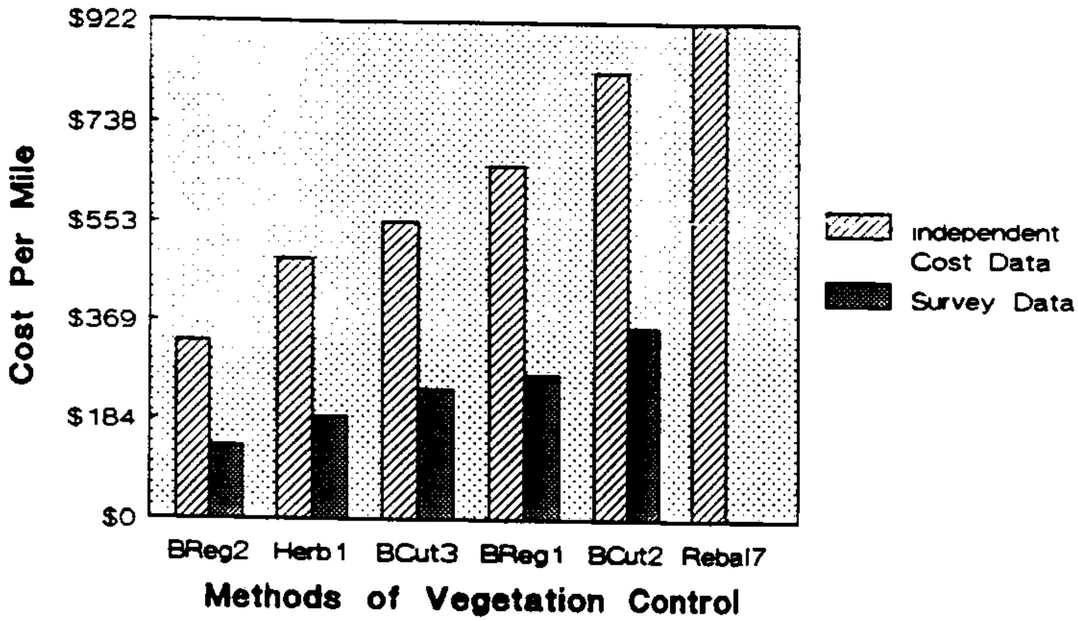


Figure 5.7. Ranking of Alternatives for Six Lowest Cost Vegetation Control Methods. (Assumes the longest treatment life for each alternative. See text section "Adjustment for Treatment Life" for details and Table 5.66 for abbreviation key.) Average U.S. city data, 1991 dollar base.

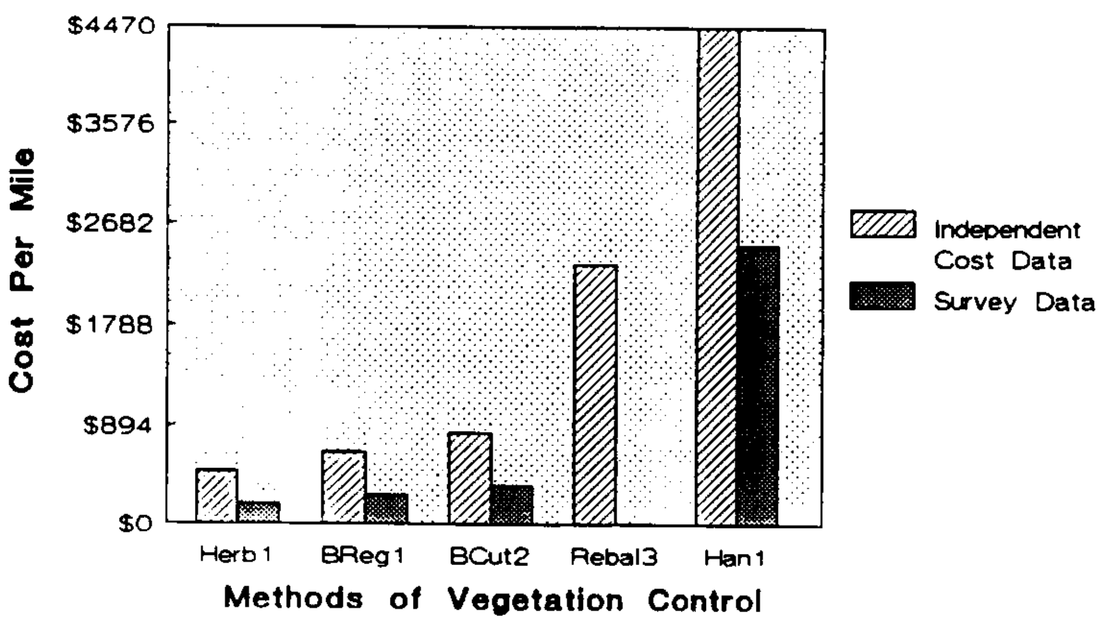


Figure 5.8. Ranking of Vegetation Control Alternatives Using Conservative Treatment Lives. (Assumes the shortest treatment life for each alternative. See text section "Adjustment for Treatment Life" for details and Table 5.66 for abbreviation key.) Average U.S. city data, 1991 dollar base.

Table 5.1. Sample Calculation of CPI-US Conversion

<u>Given</u>: Purchase price in 1977 = $50,000
<u>Find</u>: Price of item in 1991

<u>Calculation</u>: CPI-US for 1977 is 62.1
CPI-US for 1991 is estimated at 131

Price in 1991 = (CPI-US for 1991/CPI-US for 1977) * Price in 1977
= (131/62.1) * $50,000
= $105,000

Table 5.2. Sample Calculation of Yearly Cost

<u>Given</u>: Purchase price = $50,000
Product life = 10 years
Interest Rate = 10%
<u>Find</u>: Yearly cost of that product over its life

<u>Calculation</u>: A/P, 10% for 10 years = 0.16275
Yearly Cost = (A/P, 10%, 10) * Purchase price
= (0.16275) * ($50,000)
= $8,140

Table 5.3. Daily* Wage Rates by Job Classification. Reported in 1991 Dollar Base.

Title	Base Pay	Plus 41% Benefits	Expenses	Total U.S. Avg. Labor	Anchorage AK Labor
General Foreman	$161	$226	$61	$287	$475
Track Foreman	$112	$158	$18	$176	$291
Operator Grade 4	$138	$194	$61	$255	$422
Operator Grade 3	$112	$158	$18	$176	$291
Operator Grade 2	$109	$154	$18	$172	$286
Operator Grade 1	$100	$141	$18	$159	$264
Laborer	$95	$134	$18	$153	$254

Adapted from Cataldi and Elkaim, 1980.
* Based on an 8-hour day.

Table 5.4. Summary of General Assumptions

Item	Value
Interest Rate	10%
Maintenance	10-30% first cost
Operation	150-300 shifts/year
Labor	8 hour workday
Benefits	41% of base pay
Overhead & Indirect	10%
Profit	15%
Mobilization & Demob.	5% of equipment & labor

Table 5.5. Sample Calculation for Herbicide Maintenance Costs. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Purchase Price = $150,000
Maintenance Cost is 20% of Purchase Price

<u>Find</u>: Maintenance Cost per Year

<u>Calculation</u>: ($150,000/year) * (20%) = $30,000/year

Table 5.6. Sample Calculation for Herbicide Annual Fuel Costs. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Fuel Cost per Shift = $46
Equipment Operates 200 Shifts per Year

<u>Find</u>: Yearly Fuel Costs

<u>Calculation</u>: ($46/shift) * (200 shifts/year) = $9,110/year

Table 5.7. Summary of Annual Herbicide Application Equipment Costs. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$24,400
Maintenance Costs	$30,000
Fuel Costs	$9,110
TOTAL YEARLY EQUIPMENT COSTS	$63,500

Table 5.8. Safety and Spill Cleanup Equipment. Average U.S. city data, 1991 dollar base.

Eye Wash Station, 16 gallon			$382
Safety Goggles	5	@ $6.50 ea	$33
Respirators	5	@ $16.47 ea	$82
Respirator Cartridges	20	@ $4.93 ea	$99
Tyvex Coveralls w/Boot	Box	of 25	$149
Unlined Nitrile Gloves	20	@ $2.10/pair	$42
Shovel	2	@ $18.70 ea	$37
Spill Absorbent Blanket	8	@ $141/roll	$1,128
Spill Absorbent	18	@ $28.20/can	$508
TOTAL FOR SPILL KIT		$2,460	

Table 5.9. Sample Calculation of Yearly Labor Cost. Average U.S. average city data, 1991 dollar base.

Given: Labor Costs of $153 and $255 per Shift
Personnel Work 200 Shifts per Year
Find: Yearly Labor Cost

Calculation:
$153/shift + $255/shift = $408/shift
($408/shift) * (200 shifts/year) = $81,600/year

Table 5.10. Summary of Herbicide Chemical Costs. Average U.S. city data, 1991 dollar base.

Chemical Name	Quantity	Average U.S.City Cost
Velpar L	30 gallons	$1,750.00
Arsenal	1 quart	$87.25
Garlon 3A	2.5 gallons	$149.00
Tordon	2.5 gallons	$49.95

Table 5.11. Sample Calculation for Velpar Chemical Cost. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Velpar Chemical Cost = $1,750 for 30 Gallons
Application Concentration = 3 gallons per acre
<u>Find</u>: Chemical Cost for Velpar per Mile

<u>Calculation</u>:
($1,750/30 gallons) * (3 gallons/acre) * (0.00379 miles) * (640 acres/square miles) = $425/mile

Table 5.12. Summary of Chemical Costs per Mile. Average U.S. city data, 1991 dollar base.

Chemical	Application Concentration	Total
Velpar	3 gallons/acre	$425/mi
Arsenal	4 pints/acre	$423/mi
Garlon 3A	7 quarts/acre	$253/mi
Tordon	1.5 gallons/acre	$182/mi

Table 5.13. Sample Calculation for Equipment Cost per Mile. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Yearly Equipment Cost = $63,500
Equipment Utilization = 200 Shifts per Year
Productivity = 33 Miles per Day
<u>Find</u>: Equipment Cost per Mile

<u>Calculation</u>:
($63,500/year) * (shift/33 miles) * (year/200 shifts) = $9.62/mile

Table 5.14. Summary of Costs for Herbicide Application per Mile. Average U.S. city data, 1991 dollar base.

Productivity:	67 miles/day	33 miles/day
Equipment	$4.74/mi	$9.62/mi
Safety Equipment	$0.18/mi	$0.37/mi
Labor	$6.09/mi	$12.40/mi
Subtotal Costs	$11.00/mi	$22.40/mi

Table 5.15. Summary of Mobilization and Demobilization Costs For a Chemical Cost of $260 per Mile. Average U.S. city data, 1991 dollar base.

	67 miles/day Productivity	33 miles/day Productivity
Equipment, Safety & Labor	$11/mi	$22/mi
Chemical Cost	$260/mi	$260/mi
Subtotal Costs	$271/mi	$283/mi
Mobilization & Demobilization	$13.6/mi	$14.2/mi
TOTAL COST	$285/mi	$297/mi

Table 5.16. Summary of Mobilization and Demobilization Costs For a Chemical Cost of $442 per Mile. Average U.S. city data, 1991 dollar base.

Equipment,Safety & Labor	$11/mi	$22/mi
Chemical Cost	$442/mi	$442/mi
Subtotal Costs	$453/mi	$464/mi
Mobilization & Demobilization	$22.7/mi	$23.2/mi
TOTAL COST	$476/mi	$487/mi

Table 5.17. Sample Calculation of Overhead and Indirect Cost. Average U.S. city data, 1991 dollar base.

Given: Total Cost = $271/Mile
Mobilization and Demobilization = $13.6/Mile
Overhead and Indirect = 10%
Find: Overhead and Indirect Costs per Mile

Calculation:
($271/mile) + ($13.60/mile) = $285/mile
($285/mile) * (10%) = $28.50/mile

Table 5.18. Sample Calculation for Herbicide Application Profit. Average U.S. city data, 1991 dollar base.

Given: Total Cost = $271 per Mile
Mobilization and Demobilization = 15%
Find: Profit per Mile

Calculation:
($285/mile) * (15%) = $42.80/mile

Table 5.19: Summary of Overhead, Indirect, Profit and Total Costs for Herbicide Applications. 1991 dollar base

Total Costs	Overhead & Indirect	Profit	Total Avg. U.S. City Costs	Total Anchorage AK Costs
Productivity of 67 miles/day:				
$285/mi	$28.50/mi	$42.80/mi	$365/mi	$479/mi
$476/mi	$47.60/mi	$71.40/mi	$595/mi	$781/mi
Productivity of 33 miles/day:				
$297/mi	$29.70/mi	$44.60/mi	$371/mi	$487/mi
$487/mi	$48.70/mi	$73.10/mi	$609/mi	$799/mi

Table 5.20. Summary of Annual Brushcutter Equipment Costs. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$34,700
Maintenance Costs	$42,700
Fuel Costs	$7,460
TOTAL ANNUAL EQUIPMENT COSTS	$84,900

Table 5.21. Summary of Annual Brushcutting Costs. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$34,700
Maintenance Costs	$42,700
Fuel Costs	$7,460
Labor Costs	$40,700
Mobilization and Demobilization	$6,280
Overhead and Indirect Costs	$13,200
Profit	$19,800
TOTAL YEARLY COST	$165,000

Table 5.22. Sample Calculation for per Mile Conversion for Brushcutting. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Yearly Cost = $165,000
Productivity = 0.89 Miles per Day
Operate 100 Shifts per Year

<u>Find</u>: Cost per Mile for Brushcutting

<u>Calculation</u>:
($164,869/year) * (1 year/100 shifts) * (1 shift/0.89 mile) = $1,850/mile

Table 5.23. Summary of Brushcutting Costs per Mile. Average U.S. city data, 1991 dollar base.

Productivity Rates	0.89 mi/day	1.12 mi/day
Purchase Price	$390/mi	$310/mi
Maintenance Costs	$480/mi	$381/mi
Fuel Costs	$84/mi	$67/mi
Labor Costs	$458/mi	$364/mi
Mobilization & Demob.	$71/mi	$56/mi
Overhead and Indirect	$148/mi	$118/mi
Profit	$222/mi	$177/mi
TOTAL COST FOR BRUSHCUTTING	$1,850/mi	$1,470/mi

Table 5.24. Sample Calculation of Amortized Ballast Regulator Cost. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Ballast Regulator Purchase Price = $107,000
Ballast Rebuild Cost = $32,000
Equipment Life = 14 years
Must Rebuild Equipment After 8 Years
Interest Rate = 10%

<u>Find</u>: Yearly Cost for Ballast Regulator

<u>Calculation</u>:

Equipment Price =
Purchase Price + (P/F, 10%, 8) * Rebuild Price

P/F, 10% for 8 years = 0.4665
Equipment Price = $107,000 + $32,000 * (0.4665)
= $121,900

Yearly Cost = (A/P, 10%, 14) * Equipment Price

A/P, 10% for 14 years = 0.13575
Yearly Cost = $121,900 * (0.13575)
= $16,500

Table 5.25. Summary of Annual Ballast Regulator Equipment Costs. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$16,500
Maintenance Costs	$21,300
Fuel Costs	$7,800
TOTAL YEARLY EQUIPMENT COSTS	$45,700

Table 5.26. Summary of Annual Ballast Regulator Costs. 1991 dollar base.

	Average U.S. City Costs	Anchorage AK Costs
Amortized Purchase Price	$16,500	$21,600
Maintenance Costs	$21,300	$27,900
Fuel Costs	$7,800	$10,200
Labor Costs	$81,500	$107,000
Mobilization & Demobilization	$6,360	$8,340
Overhead and Indirect Costs	$13,300	$17,400
Profit	$20,000	$26,200
TOTAL ANNUAL COST	$167,000	$219,000

Table 5.27. Summary of Ballast Regulator Costs per Mile. 1991 dollar base.

	Average U.S. City Costs	Anchorage AK Costs
Amortized Purchase Price	$87/mi	$114/mi
Maintenance Costs	$112/mi	$150/mi
Fuel Costs	$41/mi	$54/mi
Labor Costs	$430/mi	$564/mi
Mobilization and Demobilization	$34/mi	$45/mi
Overhead and Indirect Costs	$70/mi	$92/mi
Profit	$106/mi	$139/mi
TOTAL PER MILE COST	$880/mi	$1,160/mi

Table 5.28. Sample Calculation of Material Cost per Mile. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Ballast Spread on a 10 foot Width
Metal Slag Weighs 1 Ton per Cubic Yard
Granite Weighs 1.45 Tons per Cubic Yards
Materials Cost: Metal Slag = $3.10 per Ton
Granite = $7.70 per Ton

<u>Find</u>: Cost per Mile for Ballast

<u>Calculation</u>:

Volume of Material: (10 ft) * (1 feet/12 inches) * (1 cubic yard/27 cubic feet) * (5280 feet/mile)

Volume of Material = 489 cubic yards

Material Cost:

Metal Slag -
(1 ton/cubic yard) * (489 cubic yards/mile) * ($3.10/ton) = $1,520/mile

Granite -
(1.45 ton/cubic yard) * (489 cubic yards/mile) * ($7.70/ton) = $5,450/mile

Table 5.29. Sample Calculation for Ballast Material Costs per Mile. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Transportation Cost = $0.01/cubic yard-mile
Quantity = 489 per Mile
Distance = 250 Miles

<u>Find</u>: Total Ballast Cost for Metal Slag

<u>Calculation</u>:

Transportation Costs = ($0.01/cubic yard-mile) * (489 cubic yard/mile) * (250 miles) = $1,220/mi

Materials Costs = $1,520/mi

Total Ballast Cost = Transport Costs + Materials Costs
= $1,520/mile + 1,220/mile
= $2,740/mile

Table 5.30. Summary of Ballast Costs per Mile. Average U.S. city data, 1991 dollar base.

Transport Rate	Transport Cost	Material Cost	Total Cost
METAL SLAG			
$0.01/cubic yard-mile	$1,220/mi	$1,515/mi	$2,740/mi
$0.021/cubic yard-mile	$2,530/mi	$1,515/mi	$4,050/mi
GRANITE			
$0.017/cubic yard-mile	$2,080/mi	$5,450/mi	$7,530/mi
$0.05/cubic yard-mile	$3,680/mi	$5,450/mi	$9,130/mi

Table 5.31. Sample Calculation of Conversion to Annual Ballast Cost. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Cost per Mile = $2,740
Productivity = 1,000 Feet per Hour
5 Hours per Shift, 1 Shift per day
Operate for 200 Shifts per Year
<u>Find</u>: Yearly Ballast Cost for Metal Slag

<u>Calculation</u>:
Ballast Cost/year = ($2,740/mile) * (1 mile/5,280 feet) *
(1,000 feet/hour) * (5 hours/shift) * (200 shifts/year)
Ballast Cost = $519,000/year

Table 5.32. Summary of Annual Ballast Material Cost. Average U.S. city data, 1991 dollar base.

Transport Rate	Per Mile Cost	Yearly Cost
METAL SLAG		
$0.01/cubic yard-mile	$2,740/mi	$519,000
$0.021 cubic yard-mile	$4,050/mi	$767,000
GRANITE		
$0.017 cubic yard-mile	$7,530/mi	$1.45 Million
$0.05 cubic yard-mile	$9,130/mi	$1.73 Million

Table 5.33. Summary of Annual Overhead and Indirect Costs for Reballasting. Average U.S. city data, 1991 dollar base.

Ballast Cost	Equipment & Labor	Mob. & Demob.	Subtotal Costs	Overhead & Indirect	Total
METAL SLAG					
$519,000	$127,000	$62,200	$708,000	$70,800	$779,000
$767,000	$127,000	$62,200	$956,000	$95,600	$1.05 mil*
GRANITE					
$1.45 mil	$127,000	$62,200	$1.64 mil	$164,000	$1.80 mil
$1.73 mil	$127,000	$62,200	$1.92 mil	$192,000	$2.11 mil

* mil = million

Table 5.34. Summary of Annual Profit Costs for Reballasting. Average U.S. city data, 1991 dollar base.

Cost Subtotal	Profit	New Total
METAL SLAG		
$779,000	$117,000	$896,000
$1.05 million	$158,000	$1.21 million
GRANITE		
$1.80 million	$270,000	$2.07 million
$2.11 million	$317,000	$2.23 million

Table 5.35. Annual Cost Summary for Reballasting. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$16,500
Maintenance Costs	$21,300
Fuel Costs	$7,800
Labor	$81,500
Mobilization and Demobilization	$62,200

METAL SLAG

	Transportation Rate (dollars per cubic yard-mi)	
	$0.01	$0.021
Materials Cost	$519,000	$767,000
Overhead and Indirect	$70,800	$95,600
Profit	$117,00	$158,000
TOTAL	$896,000	$1.21 million

GRANITE

	Transportation Rate (dollars per cubic yard-mi)	
	$0.017	$0.05
Materials Cost	$1.45 million	$1.73 million
Overhead and Indirect	$164,000	$192,000
Profit	$270,000	$317,000
TOTAL	$2.07 million	$2.43 million

Table 5.36. Per Mile Cost Summary for Reballasting. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price		$87.1/mi
Maintenance Costs		$112/mi
Fuel Costs		$41.2/mi
Labor		$430/mi
Mobilization and Demobilization		$328/mi
METAL SLAG		
Materials Cost	$2,740/mi	$4,050/mi
Overhead and Indirect	$374/mi	$505/mi
Profit	$618/mi	$834/mi
TOTAL	$4,730/mi	$6,390/mi
GRANITE		
Materials Cost	$7,660/mi	$9,130/mi
Overhead and Indirect	$866/mi	$1,010/mi
Profit	$1,430/mi	$1,670/mi
TOTAL	$10,930/mi	$12,800/mi

Table 5.37. Summary of Annual Tamper Equipment Costs. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$43,800
Maintenance Costs	$63,900
Fuel Costs	$11,200
TOTAL YEARLY TAMPER COST	$119,000

Table 5.38. Summary of Undercutter Equipment Costs. Average U.S. city data, 1991 dollar base.

Amortized Purchase Price	$221,000	to	$242,000
Maintenance Costs	$478,000		$478,000
Fuel Costs	$31,600		$31,600
TOTAL ANNUAL EQUIPMENT COSTS	$731,000	to	$752,000

Table 5.39. Summary of Annual Undercutting Operation Equipment Costs. Average U.S. city data, 1991 dollar base.

Ballast Regulator	$45,700		$45,700
Tamper	$119,000		$119,000
Undercutter	$731,000	to	$752,000
TOTAL ANNUAL EQUIPMENT COST	$896,000	to	$917,000

Table 5.40. Summary of Annual Labor Costs for the Undercutting Operation. Average U.S. city data, 1991 dollar base.

Position	Wage	Number Workers	Daily Total	Yearly Total
Foremen	$287	3	$861	$172,000
Track Foremen	$176	2	$352	$70,300
Machine Operators	$255	3	$764	$153,000
Laborers	$153	10	$1,530	$305,000
TOTAL			$3,500	$700,000

Table 5.41. Sample Calculation of Ballast Quantity Required for Undercutting.

<u>Given</u>: Depth of Ballast to Bottom of Tie = 8 Inches
Depth of Undercutting = 6 Inches
Width of Undercutting = 10 Feet

<u>Find</u>: Quantity of Ballast Required for Undercutting

<u>Calculation</u>:
8 inches + 6 inches = 14 inches of ballast

Ballast Quantity = (14 inches) * (12 inches/foot) * (10 feet) * (5,280 feet/mile) * (1 cubic yard/27 cubic feet)

Ballast Quantity = 2,280 cubic yards/mile

Table 5.42. Summary of Ballast Costs per Mile With No Recovery. Average U.S. city data, 1991 dollar base.

Material Cost	Transport Cost	Total Cost
METAL SLAG		
$7,070/mi	$5,700/mi	$12,800/mi
$7,070/mi	$11,970/mi	$19,000/mi
GRANITE		
$25,500/mi	$9,690/mi	$35,200/mi
$25,500/mi	$28,500/mi	$54,000/mi

Table 5.43. Summary of Ballast Costs per Mile For Various Recovery Rates. Average U.S. city data, 1991 dollar base.

No Recovery	25% Recovery	50% Recovery
METAL SLAG		
$12,800/mi	$9,600/mi	$6,400/mi
$19,000/mi	$14,300/mi	$9,500/mi
GRANITE		
$35,200/mi	$26,400/mi	$17,600/mi
$54,000/mi	$40,500/mi	$27,000/mi

Table 5.44. Sample Calculation of per Mile to Annual Cost Conversion. Average U.S. city data, 1991 dollar base.

Given: No Ballast Recovery
Ballast (Metal Slag) Cost per Mile = $12,800
Productivity = 2,000 Feet per Shift
Work for 5 Hours per Shift, 1 Shift per Day
Equipment Operates for 200 Shifts per Year

Find: Yearly Ballast Cost for Metal Slag

Calculation:

Ballast Cost = ($12,800/mile) * (1 miles/5,280 feet) * (2,000 feet/8 hour) * (5 hour/shift) * (200 shifts/year)

Ballast Cost = $606,000/year

Table 5.45. Summary of Annual Ballast Costs for Various Recovery Rates. Average U.S. city data, 1991 dollar base.

	No Recovery	25% Recovery	50% Recovery
METAL SLAG			
	$606,000	$455,000	$303,000
	$900,000	$677,000	$450,000
GRANITE			
	$1.67 million	$1.25 million	$833,000
	$2.26 million	$1.92 million	$1.28 million

Table 5.46. Summary of Annual Undercutting Costs For Various Recovery Rates. Average U.S. city data, 1991 dollar base.

METAL SLAG

	No Recovery	25% Recovery	50% Recovery
Subtotal Costs			
	$3.32 million	$3.17 million	$3.01 million
	$3.63 million	$3.41 million	$3.18 million
Overhead and Indirect Costs			
	$332,000	$317,000	$301,000
	$363,000	$341,000	$318,000
Profit			
	$498,000	$476,000	$452,000
	$545,000	$512,000	$477,000
Total Annual Undercutting Costs for Metal Slag Ballast			
	$4.15 million	$3.96 million	$3.76 million
	$4.54 million	$4.26 million	$3.98 million

GRANITE

	No Recovery	25% Recovery	50% Recovery
Subtotal Costs			
	$4.14 million	$3.96 million	$3.54 million
	$4.99 million	$4.65 million	$4.01 million
Overhead and Indirect Costs			
	$414,000	$396,000	$354,000
	$499,000	$465,000	$401,000
Profit			
	$621,000	$594,000	$531,000
	$749,000	$698,000	$602,000
Total Annual Undercutting Costs for Granite Ballast			
	$5.18 million	$4.95 million	$4.43 million
	$6.34 million	$5.81 million	$5.01 million

Table 5.47. Summary of per Mile Undercutting Costs for Various Recovery Rates. Average U.S. city data, 1991 dollar base.

METAL SLAG

Total Undercutting Cost per Mile

No Recovery	25% Recovery	50% Recovery
$87,700/mi	$83,600/mi	$79,400/mi
$95,900/mi	$90,000/mi	$84,100/mi

GRANITE

Total Undercutting Cost per Mile

No Recovery	25% Recovery	50% Recovery
$109,000/mi	$105,000/mi	$93,600/mi
$134,000/mi	$123,000/mi	$106,000/mi

Table 5.48. Summary of per Mile Undercutting Costs for Various Recovery Rates. Anchorage, Alaska data, 1991 dollar base.

METAL SLAG

Total Undercutting Cost per Mile

No Recovery	25% Recovery	50% Recovery
$115,000/mi	$110,000/mi	$104,000/mi
$126,000/mi	$118,000/mi	$110,000/mi

GRANITE

Total Undercutting Cost per Mile

No Recovery	25% Recovery	50% Recovery
$143,000/mi	$138,000/mi	$123,600/mi
$176,000/mi	$161,000/mi	$139,000/mi

Table 5.49. Sample Calculation of Labor Rate per Mile for Hand Clearing. Average U.S. city data, 1991 dollar base.

Given: Productivity = 30 Feet per Worker per Hour
22 Workers are on a Crew
Wage rate for Workers is $3,406 per Day
Personnel Work 8 Hours per Day

Find: Labor Rate per Mile of Track

Calculation:

Daily Wage = (20 laborers) * ($153/day) + (2 supervisors) * ($176/day) = $3,410/day

Crew Productivity = (30 feet/man-hour) * (22 workers) * (8 hours/day) * (5,280 feet/mile) = 1 mile/day

Labor Rate = ($3,410/day) * (1 day/1 mile)
= $3,410/mile

Table 5.50. Summary of Cost per Mile for Hand Clearing. 1991 dollar base.

	Average U.S. City Cost	Anchorage AK Cost
Equipment	$0/mi	$0/mi
Labor	$3,410/mi	$4,470/mi
Mobilization and Demobilization	$170/mi	$223/mi
Overhead and Indirect	$358/mi	$470/mi
Profit	$536/mi	$703/mi
TOTAL COST FOR HAND CLEARING	$4,470/mi	$5,870/mi

Table 5.51. Cost Indices for the years 1980-1991.

Year	U.S. Average City	Anchorage, Alaska
1980	69.5	91.2
1981	77.4	101.6
1982	84.2	110.5
1983	88.6	116.2
1984	90.6	118.9
1985	91.3	119.8
1986	93.1	122.2
1987	96.9	127.1
1988	99.3	130.3
1989	100.0	131.2
1990	102*	133.8*
1991	104*	136.5*

(* denotes an assumed value)

Table 5.52. 1991 ARRC Herbicide Cost Per Track Mile.

Equipment Cost	$54/mile
Maintenance and Operation Cost	$67/mile
Labor Cost	$12/mile
Chemical Cost	$469/mile
Indirect and Overhead Cost	$90/mile
Total ARRC Herbicide Cost	$692/mile

Table 5.53. 1991 Contract Herbicide Cost Per Track Mile.

Mobilization/Demobilization Cost	$14/mile
Daily Cost	$83/mile
Standby Cost	$4/mile
Application Cost	$748/mile
Indirect and Overhead Costs	$127/mile
Total Contract Herbicide Cost	$976/mile

Table 5.54. 1991 Reballasting Cost Per Track Mile.

Ballast Cost	$3,270/mile
Equipment Cost	$1,822/mile
Maintenance and Operation Cost	$1,270/mile
Labor Cost	$1,276/mile
Transport Cost	$3,580/mile
Indirect and Overhead Cost	$1,683/mile
Total Cost to Reballast	$12,901/mile

Table 5.55. 1991 Ballast Regulating Cost Per Track Mile.

Equipment Cost	$285/mile
Maintenance and Operation Cost	$236/mile
Labor Cost	$319/mile
Indirect and Overhead Cost	$126/mile
Total Cost to Ballast Regulate	$966/mile

Table 5.56. Undercutting Cost Per Track Mile: No Ballast Recovery.

Undercutter Equipment Cost	$7,775/mile
Undercutter Maintenance and Operation Cost	$1,814/mile
Tampers (2)	$3,368/mile
Ballast Regulators (2)	$1,956/mile
Labor Cost	$4,466/mile
Ballast Cost	$44,651/mile
Tie Replacement Cost	$21,000/mile
Indirect and Overhead Costs	$12,755/mile
Total Cost to Undercut	$97,785/mile

*denotes that cost includes equipment, maintenance and operation

Table 5.57. Undercutting Cost Per Track Mile: 20% Ballast Recovery.

Undercutter Equipment Cost	$7,775/mile
Undercutter Maintenance and Operation Cost	$1,814/mile
Tampers (2)*	$3,368/mile
Ballast Regulators (2)*	$1,956/mile
Labor Cost	$4,466/mile
Ballast Cost	$36,171/mile
Tie Replacement Cost	$21,000/mile
Indirect and Overhead Costs	$11,483/mile
Total Cost: 20% Ballast Recovery	$88,033/mile

*denotes that cost includes equipment, maintenance and operation

Table 5.58. Undercutting Cost Per Track Mile: 50% Ballast Recovery.

Undercutter Equipment Cost	$7,775/mile
Undercutter Maintenance and Operation Cost	$1,814/mile
Tampers (2)*	$3,368/mile
Ballast Regulators (2)*	$1,956/mile
Labor Cost	$4,466/mile
Ballast Cost	$22,325/mile
Tie Replacement Cost	$21,000/mile
Indirect and Overhead Costs	$9,406/mile
Total Cost: 50% Ballast Recovery	$72,110/mile

*denotes cost includes equipment, maintenance and operation)

Table 5.59. Undercutting Cost Per Track Mile: 70% Ballast Recovery.

Undercutter Equipment Cost	$7,775/mile
Undercutter Maintenance and Operation Cost	$1,814/mile
Tampers (2)	$3,368/mile
Ballast Regulators (2)	$1,956/mile
Labor Cost	$4,466/mile
Ballast Cost	$13,396/mile
Tie Replacement Cost	$21,000/mile
Indirect and Overhead Costs	$8,066/mile
Total Cost: 70% Ballast Recovery	$61,841/mile

*denotes cost includes equipment, maintenance and operation

Table 5.60. 1991 ARRC Brushcutting Cost Per Track Mile.

Equipment Cost	$259/mile
Maintenance and Operation Cost	$468/mile
Labor Cost	$339/mile
Indirect and Overhead Cost	$160/mile
Total Cost for ARRC Brushcutting	$1,226/mile

Table 5.61. 1991 ARRC Hand Clearing Cost Per Track Mile.

Labor Cost	$2,794/mile
Indirect and Overhead Cost	$419/mile
Total ARRC Hand Clearing Cost	$3,213/mile

Table 5.62. 1991 Contract Hand Clearing Cost Per Track Mile.

Labor Cost	$2,112/mile
Indirect and Overhead Cost	$317/mile
Total Cost to Hand Clear	$2,429/mile

Table 5.63. Treatment Comparison: 1991 Cost Per Mile.

Treatment		Cost Per Mile
Herbicide:	ARRC	$692
	Contract	$976
Reballasting		$12,901
Ballast Regulating with Brooming		$971
Undercutting:	No Ballast Recovery	$97,785
	20% Ballast Recovery	$88,033
	50% Ballast Recovery	$72,110
	70% Ballast Recovery	$61,841
Brushcutting:	ARRC	$1,226
	Contract (outside tie ends)	$423
Hand Clearing:	ARRC	$3,213
	Contract	$2,429

Table 5.64. Sample Calculation of Reballasting Treatment Life Adjustment. Average U.S. city data, 1991 dollar base.

<u>Given</u>: Yearly Reballasting Cost = $9,460/mile
Treatment Life = 3 Years
80% of Cost is Borne by Vegetation Control
<u>Find</u>: Reballasting Cost for 3 Year Treatment Life

<u>Calculation</u>:
($8,710/mile) * (80%) * (1 treatment/3 years) = $2,320/mile

Table 5.65. Cost Summary of Vegetation Control Methods. 1991 dollar base.

Vegetation Control Method	Treatment Life (years)	Cost/Mile Survey Avg. U.S.	Independent Avg. U.S.	Independent Anch., AK
Herbicide	1	$188/mi	$485/mi	$636/mi
Brush Cutting	2	$360/mi	$830/mi	$1,090/mi
	3	$240/mi	$554/mi	$727/mi
Ballast Reg.	1	$268/mi	$660/mi	$866/mi
	2	$134/mi	$330/mi	$433/mi
Reballasting	3	*	$2,320/mi	$3,040/mi
	5	*	$1,390/mi	$1,390/mi
	7	*	$922/mi	$1,820/mi
Undercutting				
Metal Slag (20% recovery)	5	*	$13,900/mi	$18,200/mi
	7	*	$9,920/mi	$13,000/mi
Granite (20% recovery)	5	*	$18,200/mi	$23,900/mi
	7	*	$13,000/mi	$17,100/mi
Hand Clearing	1	$2,490/mi	$4,470/mi	$5,860/mi
	2	$1,250/mi	$2,240/mi	$2,940/mi
	3	$830/mi	$1,490/mi	$1,960/mi

* No data reported from the survey respondents for this method

Table 5.66. Key of Abbreviations Used in Figures 5.7 and 5.8.

Abbreviation	Vegetation Control Method	Treatment Life
Herb1	Herbicide Application	1 Year
BReg1	Ballast Regulator	1 Year
BReg2	Ballast Regulator	2 Years
BCut2	Brush Cutter	2 Years
BCut3	Brush Cutter	3 Years
Rebal3	Reballasting	3 Years
Rebal5	Reballasting	5 Years
Rebal7	Reballasting	7 Years
Han1	Hand Clearing	1 Year
Han2	Hand Clearing	2 Years
Han3	Hand Clearing	3 Years
Undr5	Undercutter	5 Years
Undr7	Undercutter	7 Years

Table 5.67. Summary of Cost per Mile for Vegetation Control Methods Shown for Various Productivities. 1991 dollar base.

A. Herbicides Productivity	Chemical Cost	Average U.S. City Cost	Anchorage AK Cost
67 miles/day	$260/mile	$365/mi	$479/mi
33 miles/day	$260/mile	$371/mi	$487/mi
67 miles/day	$442/mile	$595/mi	$781/mi
33 miles/day	$442/mile	$609/mi	$799/mi
B. Brushcutting:	0.89 miles/day	$1,850/mi	$2,430/mi
	1.12 miles/day	$1,470/mi	$1,930/mi
C. Ballast Regulator		$881/mi	$1,160/mi
D. Reballasting	Transport Rate		
Metal Slag:	$0.01/cu yard-mi	$5,700/mi	$6,210/mi
	$0.021/cu yard-mi	$7,230/mi	$8,380/mi
Granite:	$0.017/cu yard-mi	$11,600/mi	$14,300/mi
	$0.05/cu yard-mi	$13,300/mi	$16,800/mi
E. Hand Clearing		$4,470/mi	$5,870/mi

F. Undercutting

	No Recovery	25% Recovery	50% Recovery
METAL SLAG:			
Average U.S. City Costs			
	$87,700/mi	$83,600/mi	$79,400/mi
	$95,900/mi	$90,000/mi	$84,100/mi
Anchorage, Alaska Costs			
	$115,000/mi	$110,000/mi	$104,000/mi
	$126,000/mi	$118,000/mi	$110,000/mi
GRANITE:			
Average U.S. City Costs			
	$109,000/mi	$105,000/mi	$93,600/mi
	$134,000/mi	$123,000/mi	$106,000/mi
Anchorage, Alaska Costs			
	$143,000/mi	$138,000/mi	$123,600/mi
	$176,000/mi	$161,000/mi	$139,000/mi

EFFECTIVENESS OF CONTROL METHODS

INTRODUCTION

The primary objective of this program was to evaluate the effectiveness of methods for eliminating and preventing reestablishment of all vegetation within the Alaska Railroad roadbed. Seven different treatments (herbicide mixture, hand weeding, hand cutting, multiple hand cutting, ballast regulation, reballasting, and a combination of ballast regulation and reballasting) were evaluated at four sites (Fort Wainwright, Clear, Birchwood, and Seward) during the 1989 and 1990 growing seasons. A control plot that received no treatment was also evaluated at each of the four sites.

Treatment effectiveness was measured by plant abundance as indicated by 1) percent cover and 2) stem counts of woody species. Additional field studies included evaluation of plant abundances at two sites where the track structure had been rebuilt during the last decade, ballast particle size analysis at the six sites, and excavation of plant root systems at each of the four intensive study sites. Table 6.1 shows the dates and timing of the various components of these studies.

SITE DESCRIPTIONS

Four sites were chosen for intensive sampling and alternative methods testing. Two of these were interior in nature (Fort Wainwright, Clear) and two were coastal (Birchwood, Seward), reflecting the various climatic zones through which the Alaska Railroad passes. Two other sites (Samlom River, Bible Camp Road) were sampled once to assess recently rebuilt track. Finally, two other sites were used solely for herbicide studies (Fire Creek and Chulitna).

Fort Wainwright

The Fort Wainwright site was located between Fairbanks and Eielson Air Force Base on the Eielson Branch of the Alaska Railroad, near ARR Milepost

G-8. The track runs northwest-southeast, and the rail surface was about 0-2m above the ballast surface. The subgrade material was a gravel mix, with noticeable amounts of sandy material. The ballast was from the Clear pit.

Vegetation in and adjacent to the right-of-way was typical of interior Alaska lowlands. Near the edge of the railbed was an open shrubland with a mixed herbaceous and shrubby understory. Species present include balsam poplar saplings, willow, quaking aspen, raspberry, bearberry, bluejoint grass, and fireweed. Farther from the tracks was a closed mixed forest with a mixed understory. Species noted there include balsam poplar, paper birch, quaking aspen, tamarack, prickly rose, soapberry, and fireweed.

At this site, we sampled vegetation along eight portions of the railbed, seven manipulative treatments plus a control. From "railroad north" to "south" these treatments were: herbicide, hand cut, hand weed, ballast regulator, combination (ballast regulator first and than reballast), reballast, control, and multiple hand cut (Figure 6.1). See the Methods section for a description of each of these treatments. In ARRC jargon, "railroad north" is the along-track direction towards Fairbanks and its extensions from Seward; conversely, south is towards Seward. There is no site-specific relationship to compass direction.

Clear

The Clear site was located adjacent to the Clear gravel pit between Clear and Healy on the main line of the Alaska Railroad, near ARR Milepost 388. The track runs generally north-south, and the rail surface was about 2-3m above the parent surface. The subgrade material was a sandy gravel mix; ballast was from the adjacent Clear pit.

Vegetation in the right-of-way reflects the dry, well-drained, interior location of the site. The managed areas, outside the roadbed but within the wider right-of-way, were mostly vegetated with shrubby alder and balsam poplar saplings. Quaking aspen forest covered adjacent areas with a shrubby understory, including prickly rose, soapberry, and bunchberry.

At this site, we sampled vegetation along six portions of the railbed, five manipulative treatments plus a control. From railroad south to north these treatments were: herbicide, hand weed, hand cut, control, ballast regulation, and reballasting (Figure 6.2).

Chulitna

The Chulitna site was located on the northern arm of the Chulitna wye, near ARR Milepost 274. No intensive vegetation assessment was done at this site, although casual observations were made and photographically documented.

Birchwood

The Birchwood site was located between Anchorage and Wasilla on Track #2 of the Birchwood Yard, near ARR Milepost 136. The track runs northeast-southwest, and the rail surface was about 0-2m above the parent surface. The subgrade was a gravel mix containing both sand and boulders; experimental ballast was from the Clear pit.

Vegetation adjacent to the study site was all within the Birchwood Yard, and therefore managed. The area was a shrubby mix of alder and raspberry, with patches of grasses and clover. Beyond the yard was a mixed conifer-deciduous forest. This reflects the moist near-coastal location of the site.

At this site, we sampled vegetation along six portions, five manipulative treatments plus a control. From railroad south to north these treatments were: herbicide, control, hand cut, hand weed, ballast regulation, and reballasting (Figure 6.3).

Bible Camp Road

The track at this site (ARR Milepost 133) was realigned in 1982, and the ballast area rebuilt, with a total lift of 6-9 inches. The track runs northeast-southwest here, and was about .5-1m above the parent surface. We used temporary plots to sample vegetation along the rebuilt railbed.

Fire Creek

The Fire Creek site was located on a spur to the old explosives storage bunkers near ARR Milepost 131. No intensive vegetation assessment was done at this site, although casual observations were made and photographically documented.

Salmon River

The Salmon River site was located just north of the bridge over the West Branch of the Salmon River, near ARR Milepost 5. The track runs approximately north-south, and the rail surface is about 3-5m above the parent surface. This section of track was washed out in a flood in 1986. The subgrade and ballast were rebuilt using riverbed materials; the ballast was undercut to nine inches below the ties the next year and replaced with more appropriate ballast material. We used temporary plots and sampled vegetation along the rebuilt railbed.

Seward

The Seward site was located partially on the Jessie Lee track and partially in the adjacent Seward Yard of the Alaska Railroad, near ARR Milepost 3 (Figure 6.4). The tracks run roughly north-south. The Jessie Lee rail surface was about 2m above the parent surface. The yard tracks have no apparent subgrade. The Jessie Lee subgrade material was beach gravel and sand.

Vegetation in the areas reflect the wet, cool coastal nature of this site. Shrub alder and willows were common. The Jessie Lee right-of-way has vigorous herbaceous growth as well, particularly horsetail and cow parsnip.

At this site, we sampled vegetation along seven portions, six manipulative treatments plus a control. From railroad south to north these treatments were: hand weed, hand cut, herbicide (yard tracks, Figure 6.5), reballasted, combination (ballast regulation and reballasting), ballast regulation, and control (Jessie Lee track, Figure 6.6).

METHODS

Sampling Design

Each site consisted of a portion of the railroad; that is, track plus the railbed under it to a width of 24 ft, 12 ft each side from the center line of the track. At each site, various treatments were applied to between 50 and 105 linear feet of railbed, with at least 20 feet between treatments (Figure 6.7). There were no chemical and mechanical treatment replicates due to equipment constraints. Each site had at least six treatments: herbicide mixture, control, reballast, ballast regulation, hand weed, hand cut. In addition, two sites (Fort Wainwright and Seward) had a seventh treatment (combination, ballast regulation followed by reballasting) and Fort Wainwright had an eighth treatment (multiple hand cut).

The placement of chemical and mechanical treatments within each site was determined by railbed conditions and form. We rolled a die to determine placement of the control and hand treatments.

Each treatment had a series of plots laid out in it. There were 18 to 22 multiple plots of three types: tie, ballast, and edge. Tie plots (0.25 by 1.0 m) were in the spaces between the ties within the rails and sampled those areas; ballast plots (0.5 by 1.0 m) were spaced 0.1 m off the end of the ties parallel with the rails, and sampled true ballast outside the high disturbance of the rail area; edge plots (1.0 by 1.0 m) were spaced 1.5 m off the ends of the ties and sampled the subgrade at the edge of the heavily managed railbed, at or near the transition to the less managed railroad right-of-way.

Each plot was assigned at random within the treatments. A series of die rolls determined the spacing between successive tie plots and whether the tie plots were abutted against the tie ahead or behind the space being sampled. Ballast and edge plots were indexed off to the sides of the locations of the tie plots. Ties and rails were painted in order to mark the necessary reference points, and two opposite corners of each ballast and edge plot were staked to allow repeatable sampling.

Vegetation Assessments

Vegetation was evaluated at three times during the two-year life of the project. The first was shortly prior to treatment in order to establish baseline data; the second time was near or at the end of the first growing season; and the third evaluation took place near the peak biomass of the second growing season, when cover was greatest. To record cover, a frame was placed around the plot and vegetative cover was recorded. Categories used were 0 (none), 1 (up to 1%), 10 (>1% to 10%), 20 (>10% to 20%), 30 (>20% to 30%) . . . 100 (>90% to 100%) to describe the areal extent of total vascular cover and lichen and moss cover, as well as cover by individual vascular species groups (grasses, forbs, and trees). (Species listed by site are given in Appendix H.) Cover was determined by ocular estimation, using marks on the sampling frames for guidance. Whenever possible, the same individual estimated the cover all three times for each plot. The number of stems of woody species were counted at heights of 10 cm and 50 cm above substrate. A stem was defined as each unit visible at the substrate surface, hence a shrub with many branches emanating from a common visible shoot was counted as one stem.

Treatments

Chemical treatment areas were about 100 feet long while control, mechanical and hand treatments were approximately 50 feet long. Each treatment was about 24 feet wide, centered on the tracks.

Herbicide treatments were carried out by ARRC and University of Alaska Fairbanks personnel. A combination of Velpar and Garlon 3A was applied in an effort to control a wide variety of plants. The reader is referred to the Herbicide Persistence and Migration sections for details of herbicide mix and application.

Hand weeding was done at each of the four sites. All plants above the substrate were pulled out by hand for about 50 feet of railbed to a width of 25 to 30 feet centered on the rails.

Hand cutting was done at each of the four sites. All plants were cut at the substrate surface with a hedge shears or pruning shears as appropriate. Treated dimensions were the same as for hand weeding. Multiple cutting was done only at the Fort Wainwright site. It involved hand cutting the treated area twice during the 1989 growing season, once just after baseline assessment and a second time at the point of maximum growth in early August.

Ballast regulation was done at each of the four sites, using the ARRC ballast regulators to cut down the railbed shoulder, pushing substrate plant propagules away from the rail and ballast areas. Following reshaping of the shoulder, a mechanical roller broom was used on the tie area. At Fort Wainwright and Clear, the broom was set even with the top of the ties, while at Birchwood and Seward it was set to scour out an inch or two of the material in the crib in an effort to disturb any vegetation that might be there.

Reballasting was done at all four sites. In this treatment, new ballast was dumped between the rails then partially plowed out, a tamper was used to adjust track alignment and elevation, and the ballast was broomed to fill and level the crib. A final pass with the broom was made with the broom low and scouring in an effort to remove vegetation between the ties. At Fort Wainwright a heavy dump of ballast was used, and the lift was about six inches. Additional ballast was also dumped from the side doors. At the other sites, a medium dump was used, from the center doors only.

A combination treatment was done at the Fort Wainwright and Seward sites. This was a double treatment, combining first ballast regulation and then reballasting.

Rebuilt Track Sections

The Bible Camp Road and Salmon River sites were sampled once, using temporary plots, at the end of the 1990 growing season. Plot layout and measurements were the same as for plots at the four permanent sites.

Ballast Particle Size

Grab samples of ballast were shoveled from near the ends of the ties at all sites. An effort was made to ensure that the sample obtained was representative of the ballast down to a depth of the shovel blade (approximately 6-9 inches). All samples were analyzed for particle size distribution by Alaska Department of Transportation and Public Facilities personnel at University of Alaska Fairbanks and the ADOT&PF Materials Lab in Fairbanks.

Root Excavations

Root systems of various dominant species were excavated at each of the sites to gather information on root depth, rhizome penetration and distribution, and interactions of below ground structure with differing ballast materials. Excavations were done by hand, and data were recorded using notes, drawings, and photographs.

Data Analyses

Data were recorded in the field onto field notebooks and specially prepared data forms. All pertinent information was transferred from these sources to a series of computer data files for manipulation and analyses. The files were checked for transcription errors, any errors found were corrected, and a uniform system of numbering and record headers was established. Summary statistics, frequency tables and histograms have been developed for each site/variable combination to detect outliers and obvious keypunching errors.

The data from this project may be characterized as interval data (Conover, 1980) made up of values for continuous measurement variables (Sokal and Rohlf, 1981), generated by random sampling in the sense that each of the possible samples was equally likely to occur (Conover, 1980). For hypothesis testing, one should arrange the analyses such that what may be thought of as "conventional wisdom" or the "status quo" will be accepted unless proven otherwise. Conventional wisdom in this instance was: there is no treatment effect, and if there was a treatment effect, all treatments had the same effect. Therefore, most of our hypotheses took the form of H_0: There was no effect due to any treatment, versus H_a: There was an effect due to at least one treatment; or H_0: All treatments have the same effect, versus H_a: At least one treatment was more effective than the others.

Because of perceived differences in physical and climatic conditions that likely affect plant establishment and growth, we kept each type of plot (tie, ballast, or edge) separate from the others for the analyses. The initial analyses for each data set involved the variables of greatest interest to the ARRC, namely total vascular cover (TVC) and the total number of stems at the assessment heights of 10 cm and 50 cm. Analyses of growth form followed where appropriate.

Total Vascular Cover - Plots where the baseline cover was greater than zero were used to evaluate treatment effectiveness. We examined the effectiveness after one growing season, (relative differences between baseline and end of first growing season, B-1), effectiveness after two growing seasons (baseline and end of second growing season, B-2), and durability of initial effectiveness (end of 1st and end of 2nd growing seasons, 1-2). In each case, the appropriate difference was divided by the baseline value to generate relative differences so that plots with divergent initial covers could be used in the same analysis. Because these relative differences were not normally distributed, we used a Kruskal-Wallis analysis, with multiple comparisons where appropriate (Conover, 1980). Significance levels were 0.05.

Plots where the baseline cover was zero allowed us to examine the establishment or invasion rates for each treatment and site. Since all such plots had the same initial value, we could use the absolute differences between the same periods as for the previous plots. Again, the differences were examined using a Kruskal-Wallis analysis.

Woody Stems - The analyses for total stems at 10 cm and at 50 cm paralleled those for TVC. All stems counted at the respective height in a given plot were summed over all species, and the sums expanded to a per square meter basis. These values were then evaluated using the same criteria and comparisons as those used for TVC.

Growth Forms - The cover values for the species within various growth forms were added to create a composite cover value. For example, all cover values from low shrub species, tall shrub species, and tree species were added to give a value for woody cover. While these composite cover values are not directly comparable to TVC because of the possibility for layering and resulting composite covers greater than 100%, this method is valuable since such a layered plot certainly presents a greater management problem to the ARRC than one with only one layer of vegetation present. Growth form cover values were analyzed identically to those for TVC.

Ballast Fines - Analysis of the ballast particle size distributions was limited to the percent by weight of material that passed a #200 sieve screen ("fines"). We followed the traditional approach to such continuous percentage data and performed an arcsine transform (using the arcsine of the root of the proportion represented by the percentage). The analysis that followed was the classical equivalent of those used for TVC and stems: a one-way analysis of variance to test whether the percent fines means were the same for all sites, followed by a Tukey-Kramer test to examine which pairs of values differed (Sokal and Rohlf, 1981).

RESULTS

Total Vascular Cover

Total vascular cover (TVC) is the percent of ground covered by the downward projection of all foliage and stems, excluding mosses and lichens. This single value, between 0 and 100%, gives an excellent estimate of the severity of vegetation problems for the Alaska Railroad. Table 6.2 gives the mean, standard deviation, and maximum values of TVC for each of the four test sites prior to treatment and for each type of plot (tie, ballast, and edge).

Table 6.2 clearly identifies several trends.

1. At three sites, TVC increases from the ties through ballast, to edge plots. The only exception (Seward) has a mean TVC for the ballast (2.13%) that is lower than the ties (4.18%).

2. At all sites, the mean TVC values for both tie and ballast plots is less than 5%.

3. The two interior sites (Ft. Wainwright and Clear) have consistently lower TVC values in every category than do the coastal sites (Birchwood and Seward).

4. Clear has the lowest values for ties and ballast of the four sites.

5. Only the edge plots have a mean TVC that exceeds 10% at any of the sites.

Since the key parameter is the change in TVC before and after treatment, the individual TVCs for each time and treatment are not discussed in the text. The mean and standard deviations are presented in Appendix I for each time period (baseline, end of first season, end of second season) and treatment. Instead, the results of the Kruskal-Wallis analyses are presented in Tables 6.3-6.6. As previously explained, this test compares, by treatment, the differences between the TVC at baseline (before treatment) and after treatment. For example, if a plot starts with a 20% TVC cover and finishes with 10% TVC, the relative change is (20-10)/20 or .5. This is comparable to a plot with an initial 40% TVC dropping to 20% TVC, or (40-20)/40 = .5.

The entry "lost due to reballasting" in Table 6.3 is necessary because of the accidental destruction by reballasting the tie plots on five of the eight treatments at Ft. Wainwright at the beginning of the 1990 growing season. The results reported for this site are solely for the ballast and edge plots.

The tables of Kruskal-Wallis results show the treatments in increasing order of effectiveness, with the highest average rank indicating the most effective treatment. For example in Table 6.3, interval B-1, cutting, herbicide, and the combination treatments all have an average rank of 31.5. However, a line above the rank indicates that the treatment's effectiveness is not statistically different (at the .05 level of significance) from the other treatments indicated by the line. Hence, although the multiple cut treatment has a lower (22.0) average rank, it is not significantly different in effectiveness from the previously mentioned three treatments. The rightmost group of treatments, linked by a line, are the most effective.

Table 6.3 indicates that initially, for time interval B-1, herbicide, hand weed, and multiple cut are the most effective treatments on the edge; reballast, combination, and herbicide are most effective on the ballast; while combination, herbicide, cut, and multiple cut are most effective on the tie plots. By the end of the second growing season, B-2, herbicide is the single most effective treatment for edge, and reballast is most effective on the ballast. As mentioned, there are no significant results for ties.

Regrowth rates between treatment application and the end of the second growing season are indicated by interval 1-2. In Table 6.3 these results show low regrowth for the ballast and edge plots treated by herbicide, combination, or reballast. This is indicated by the fact that their TVCs are not different at the .05 level from the untreated (control) treatment. The hand weed treated ballast plots also show low regrowth.

If there is no analysis of the "invasion" scenario, those plots with zero percent initial cover, in this or any of the Kruskal-Wallis results tables, it is because there were either too few plots or the results were not significant at the 0.05 level.

The results of the TVC changes for Clear are shown in Table 6.4. There were no statistically significant differences in the tie treatments, but some ballast and edge treatments showed significant differences in effectiveness. At the end of the first and the second growing seasons, the herbicide and reballast treatments were most effective for the ballast plots, while the herbicide treatment was the most effective for the edge plots.

Regrowth rates are indicated by TVC results of the 1-2 interval.For that interval the herbicide, ballast regulator and cut treatments showed the slowest regrowth.

Results from TVC values for Birchwood are shown in Table 6.5. At interval B-1, the herbicide and reballast were most effective for the tie plots, while herbicide alone was most effective for the ballast and edge plots. For the two-year intervals, herbicide alone was most effective again for the ballast and edge plots, while the herbicide, reballast, hand weed, and untreated (control) were equally effective for the tie plots.

Regrowth rates were lowest for the herbicide, ballast regulate, and hand weed treated edge plots, for the herbicide and hand weed ballast plots, and were not significantly different at the .05 level for the tie plots.

Finally, for TVC at the Seward site (Table 6.6) the most effective treatments after one season were the reballast and herbicide for tie plots, herbicide and combination for ballast plots, and combination alone for the edge plots. After two growing seasons, reballast and herbicide were still most effective for tie plots, herbicide alone for ballast plots, and combination and herbicide for the edge plots.

The 1-2 interval analyses showed that herbicide, reballast, and cut treatments for the ties had the slowest regrowth rates, while control and herbicides had the lowest regrowth for the ballast, and hand weed had the lowest regrowth for the edge plots.

Woody Stems

Woody stems greater than 10 cm and 50 cm above the surface were analyzed using methods similar to TVC. Stems above a certain height are of particular concern because they more readily obscure the trackbed surface. They may also be a hazard for personnel trying to dismount from vehicles or a train. The two heights, 10 cm and 50 cm, were selected to give an estimate of frequency at both a maximum acceptable height (10 cm) and at a height that obviously is a problem both for visibility and trafficability (50 cm).

Table 6.7 gives the summary stem values for the control (untreated) treatments at both 10 cm and 50 cm heights for Ft. Wainwright, Clear, and Birchwood. For Seward, since the yard area was hand cut earlier by ARRC crews, stem values are for the ballast regulate treatment (on the Jesse Lee track) at baseline. As might be expected, the values for stem counts are lower than those for TVC. Values for every site and time interval are shown in Appendix I.

The following general comments can be made.

1. No stems were recorded for tie plots at any site.

2. At each of the four sites, mean stem values increased from the tie, through the ballast, and were greatest in the edge plots. Maximum stems showed a similar trend.

Tables 6.8-6.11 present the Kruskal-Wallis analyses for the treatment effectiveness upon stem counts at each of the four sites. At the Ft. Wainwright site once again, there are no data available for the tie plots, but the multiple cut, herbicide, and hand weed treatments were the most effective treatments in eliminating 10 cm stems in the edge plots after both one and two growing seasons.

There were no significant differences at the .05 level for treatments on the ballast plots after either one or two growing seasons or for regrowth rates either using the 1-2 interval.

At Ft. Wainwright, the only results for 50 cm stems that showed significant differences at the .05 level were for the edge plots. After the first growing season, multiple cut, hand weed, herbicide, and cut were the most effective treatments. Following the second growing season, the multiple cut, herbicide, and hand weed treatments continued to be the most effective. This is consistent with the 1-2 interval data, which shows that the control, combination, reballast, multiple cut, herbicide, and hand weed treatments have the lowest regrowth rates.

At the Clear site (Table 6.9) a similar picture emerged. There are no stems in the ties and too few stems in the ballast plots to be statistically significant at the .05 level. But after one year, ballast regulate, herbicide, and hand weed treatments were most effective in removing 10 cm stems from edge plots. Ballast regulate and herbicide continued after two years to be the most effective treatments for removing 10 cm stems in edge plots. This was consistent with the 1-2 interval data showing herbicide, ballast regulate, and control treatments to have the lowest regrowth rates in edge plots.

For 50 cm stems at Clear, only the edge plots showed statistically significant results with all treatments except reballasting being equally effective after one year, and all treatments, statistically at the 0.05 level, being equally effective after two growing seasons.

At Birchwood, there were no stems in the tie plots and too few stems for statistically significant results in the ballast plots. For stems greater than 10 cm in the edge plots, the most effective treatments at the .05 level after the first year were hand weed, herbicide, and hand cut, and after two years--herbicide and hand weed. For stems greater than 50 cm, the cut and herbicide treatments were most effective after both the first and second growing season. There was no statistically significant differences in regrowth at the .05 level for either stems greater than 10 cm or stems greater than 50 cm.

Finally, at Seward, the only significant differences in effectiveness were for stems greater than 10 cm in the ballast plots. After two years, the hand weed and herbicide treatments were most effective, and hand weed, combination, ballast regulate, and herbicide were the most effective treatments in the interval between the two growing seasons.

Growth Forms

In order to determine if treatment effectiveness varied with the growth form of the vegetation, the total cover of both herbaceous and woody plants was again analyzed using the Kruskal-Wallis test. Table 6.12 shows the summary results for total cover of herbaceous and woody vegetation at baseline on the control treatments, except for the Seward site where the baseline values for the ballast regulate treatment are given. At all but the Seward site, woody plants contributed more cover overall than did herbaceous vegetation. But, for tie plots for all but Ft. Wainwright, herbaceous vegetation had greater cover.

The Kruskal-Wallis analyses for each of the four sites are shown in Tables 6.13-6.16.

At Ft. Wainwright the ballast regulate, herbicide, and combination treatments were the most effective edge plot treatments for herbaceous growth after one year, while herbicide was most effective after two years. For woody vegetation, hand cut, combination, herbicide and multiple cut were highly effective on tie plots; reballast, combination, and herbicide on ballast plots; and hand weed and herbicide on edge plots (Table 6.13). Regrowth of herbaceous vegetation was lowest on edge plots treated with herbicide, untreated (control), multiple cut, cut, or reballast. Woody vegetation regrowth on edge plots was lowest in the reballast, combination, and control treatments.

At Clear, herbaceous vegetation after both one and two years was most effectively controlled by reballast, herbicide, or ballast regulator treatments on ballast plots, and by herbicide treatment on edge plots (Table 6.14). Woody vegetation was most effectively reduced by the herbicide or ballast regulator treatments after one or two years for edge plots, and by the reballast, herbicide, or ballast regulator treatments on ballast plots after two years. Regrowth was lowest on ballast regulator, control, herbicide, and reballast treatments.

At Birchwood (Table 6.15), woody vegetation on edge plots was most effectively controlled both years by herbicide, hand weed, or cut treatments. Herbaceous vegetation control was also most effectively controlled by herbicide, although ballast regulating and reballast were also effective. Regrowth of herbaceous vegetation was lowest on the herbicide or hand weed treated ballast plots and with ballast regulate, herbicide, or reballast treatments on edge plots.

Finally, data from Seward (Table 6.16) also show varying treatment effectiveness upon herbaceous vegetation. The herbicide treatment was one of the most effective after both one and two growing seasons, but depending upon year and plot location, reballast, combination, or ballast regulator were not statistically different at the .05 level from the herbicide treatment in their effectiveness. Results for woody vegetation indicate that herbicide, combination, or reballast were among the most effective treatments. Regrowth was lowest with all treatments for herbaceous vegetation except weed and combination on tie plots, cut and reballast for ballast, and ballast regulate and combination for edge plots. Woody vegetation was consistently controlled by herbicide and combination treatments, with reballast and ballast regulate treatments also showing effectiveness.

Rebuilt Track Sections

The results of Kruskal-Wallas analyses for Salmon Creek compared to the Seward control and for Bible Camp Road compared to the Birchwood control are presented in Tables 6.17 and 6.18. Since vegetation values were only taken once, in 1990, for the rebuilt section, only a single comparison was performed for each parameter (TVC, stems at 10 cm, stems at 50 cm, herbaceous TVC, and woody TVC). The 1990 values for the control treatments at Seward were used for comparison.

At Salmon River, as compared to Birchwood (Table 6.17), TVC was significantly reduced at the .05 level in the tie, ballast and edge plots. Similarly, Salmon Creek had lower values that were significant at the .05 level, for stems at 10 cm in the tie plots, for herbaceous TVC at all locations, and for woody TVC in tie and ballast plots.

Comparing Bible Camp Road to the 1990 Birchwood control gave consistent results for all instances where differences were significant at the .05 level. Values were lower for the rebuilt section. These include TVC for the tie plots, stems at 10 cm for edge plots, herbaceous TVC for tie plots, and woody TVC for both ballast and edge plots (Table 6.18).

Ballast Fines

Table 6.19 presents the data for the percent fines (passing a #200 sieve screen) in the ballast at the four main sites plus the two rebuilt track sections at Bible Camp Road and Salmon River.

Only the new ballast from Clear used to reballast the Clear test site met the ARRC specifications for less than 1% fines. A Tukey-Kramer test of the fines (Table 6.20) shows that the Birchwood ballast has more fines and that both the Salmon River and Clear (new) have less fines at the .05 level. Although the correlation coefficient using percent TVC for the ballast plots at the above six sites and percent fines is $r^2 = 0.34$, the Bible Camp Road site appears to be an anomaly, since the rebuild only slightly elevated the track (6-9 inches). Most of the edges remained undisturbed and this produced much of the vegetation cover. When the Bible Camp Road site is eliminated, the $r^2 = 0.83$. Such a high value indicates a high correlation between ballast fines and TVC.

<u>Root Excavations</u>

Lateral spread and maximum rooting depths for specimens of dominant woody species at the four main sites are presented in Table 6.21. At least three individual plants were excavated for each species. The above ground height was not correlated with maximum rooting depth. The majority of roots of all species were in the upper 5 cm of ballast, but individual roots, generally of rapidly decreasing diameter, did penetrate deeper. The deepest root of greater than 2 mm diameter was at 40 cm. Root characteristics varied according to species, with balsam poplar having the greatest lateral spread, due to its suckering characteristic.

Several horsetail (*Equisetum arvense*) at Clear were also excavated to determine maximum rooting depths. Although most roots were within the upper 20 cm of ballast, roots up to 1 mm diameter were found at 46 cm.

<u>Observations</u>

Although no additional systematic vegetation studies were performed at the field sites, several other observations should be reported. First, at the Chulitna herbicide site, the vegetation response was markedly different from the four monitored sites. When the Chulitna site was observed in August, 1990, a year after herbicide treatment, the majority of vegetation was still alive and appeared healthy. A few species, such as fireweed (*Epilobium angustifolium*), were either killed or markedly reduced. Others, particularly yarrow (*Achillea borealis*), had their flowering markedly reduced, but most species within the herbicide spray zone looked healthy. It should be noted that Chulitna was sprayed late in the growing season and that it was the most heavily vegetated of any of the test sites. One possibility is that application of herbicides for controlling vegetation in Alaska may only be effective if applied early enough in the growing season.

A second observation relates to damage to mature trees outside the herbicide treatments at Ft. Wainwright and Clear. At both sites, balsam poplar trees up to approximately 50 feet in height and 8 inches in diameter had foliage turning brown and shriveling in August, 1989. The affected trees were up to approximately 70 feet beyond the outer edge of the herbicide spray zone. At Clear, a total of 16 trees were affected, 13 balsam poplars and 3 aspen. When these sites were observed again in August, 1990, many of these same trees and some additional trees exhibited similar symptoms, with some leaves totally brown and shriveled and other leaves with patches of brown.

At all sites, there was some regrowth in all treatments. For the herbicide treatments, some balsam poplar saplings seemed to be particularly resistant at Ft. Wainwright and at Clear. Horsetail persisted to some extent at Birchwood and Seward, while some alders persisted at the edge of the spray zone at Seward. Finally, butter-and-eggs (*Linaria vulgaris*) survived, to a limited degree, at Birchwood.

Although no quantitative vegetation studies were performed on the Birchwood herbicide treatments where Velpar and Garlon were applied singly, the vegetation response was observed over time. The degree of vegetation mortality for Velpar alone was very similar to the mortality for the combination herbicide treatment. Garlon alone had much less effect, killing a few species such as raspberry (*Rubus ideaus*) and clover (*Trifolium pratense*), and merely damaging others.

DISCUSSION

The results of the field testing do not indicate that any single method is most effective at all sites, nor at all locations on the railbed (tie, ballast, and edge). There are a number of possible explanations for this result. For one thing, the response of different vegetation growth forms may differ according to the type of treatment. The comparisons of herbaceous TVC and woody TVC did show some differences, although they were not pronounced. Another possible explanation is that the initial or baseline values for vegetative cover and number of stems were too low to give many statistically significant differences. This was particularly true of the ties (Tables 6.2 to 6.4) and to a lesser extent for the ballast. The greater the initial or baseline value, the higher the probability that an effective treatment will remove enough of the vegetation to be statistically different from less effective treatments. Although results were not consistent, the herbicide treatment did have the highest number of instances where it was among the most effective group of treatments (Table 6.22).

Finally, it may be that no single method will be most effective under all conditions. For example, the very limited effectiveness, for unknown reasons, of the herbicide treatment at Chulitna indicates that such factors as a thick organic layer, late season application, or unusual precipitation patterns may dramatically alter the effectiveness of a single treatment. This indicates a need to develop an integrated vegetation management (IVM) program that uses multiple methods of vegetation control. Multiple methods make it very difficult for any species to be flexible enough to persist through all the disturbances. Since multiple methods will undoubtedly be necessitated by such factors as logistics and environmental restrictions, such as no herbicides adjacent to water bodies, it is important to integrate these multiple approaches.

The results from the rebuilt track sections and the ballast fines analyses indicate that ballast quality may be a direct or indirect factor in deterring vegetation problems for a number of years and possibly for much longer time spans. As stated previously, the ARRC recently revised and upgraded their ballast specifications. The results presented here suggest that as the ARRC upgrades its trackbed it may significantly reduce vegetation problems.

The ballast specifications and their significance for vegetation are excellent examples of how good engineering can reduce an environmental problem. Generally, what improves the engineering characteristics of the roadbed will also alleviate vegetation problems. Further, as mentioned in the vegetation management methods evaluation, routine track maintenance such as reballasting and resurfacing will also help reduce vegetation in the trackbed.

There is a great deal of uncertainty regarding the relationship between vegetation and trackbed performance. Although vegetation may promote ballast degradation, it is more correct to say that ballast degradation itself initiates vegetation establishment and promotes growth by providing water and nutrients. Further, this study has been unable to find any reports that quantify track and tie damage caused by vegetation in the trackbed.

Although vegetation in the trackbed may impede drainage, no quantitative studies of this relationship were available for this study. (Ironically, the U.S. Army Corps of Engineers removes vegetation from earthen dams and levees because roots are thought to accelerate drainage (Johnson et al., 1981)). The root excavations in this study verified that most roots are very shallow (less than 10 cm). This raises the question of whether or not they can significantly affect drainage.

Another point that needs to be stressed is that most railroads, including the Alaska Railroad, have two general classes of vegetation problems. First, there are heavily vegetated areas of trackbed that need to be treated to remove vegetation for trafficability and safety reasons. Second, there are areas with limited vegetation that creates minimal problems, but which must be treated before the vegetation becomes so dense and/or large and deeply rooted that it becomes difficult to treat. For example, deeply rooted species such as horsetail or interconnected individuals such as balsam poplar are very difficult to eradicate once they become well established. Even herbicides may not be able to kill deep roots or distant buds away from the point of application (Dekker and Chandler, 1985).

This leads to the idea of a vegetation management plan that utilizes IVM. In order to quantify the extent of vegetation problems, a railroad must first initiate a vegetation survey of the right-of-way. Such a survey would provide information on the types of vegetation, as well as the density and frequency of vegetation. These data can then be used to develop an IVM program to remove dense vegetation and to treat other lightly vegetated areas in a timely manner to prevent future problems. Different treatments may be used on the densely vegetated sections than on the lightly vegetated sections.

This portion of the study evaluated the effectiveness of the herbicides treatment, using Velpar and Garlon 3A, as well as other vegetation control treatments. It did not evaluate the potential effectiveness of other herbicides. Therefore, no conclusions can be made regarding the relative effectiveness under Alaskan conditions of other herbicides, such as Arsenal or Oust.

Finally, in a short-term study such as this, many findings are tentative. The longer term (greater than two years) effectiveness of treatments is unknown. Also, the severity of the off-site impacts of the herbicide treatment can not be fully determined yet. At the Ft. Wainwright and Clear sites, mature balsam poplar trees and, to a lesser extent, aspen trees were severely affected by the herbicides. Since there was no evidence of drift, it is postulated that the herbicide was translocated via suckering roots from saplings (balsam poplar) or via feeder roots (aspen) growing within the roadbed back to the parent trees. At the end of the 1990 season, the affected trees still had minimal live foliage and it would be premature to make a final determination of their fate.

CONCLUSIONS

1. No one treatment was always among the most effective treatments in reducing total vascular cover (TVC) or number of (woody) stems at 10 cm and 50 cm. However, the herbicide treatment had the highest frequency of any single treatment for being among the group of most effective after one year (37%) and after two years (47%).

2. The herbicide treatment at one site, Chulitna, was relatively ineffective in controlling vegetation. Although the reasons for the

limited effectiveness are not clear, it indicates the need for using multiple methods.

3. High quality ballast, as required by the new ARRC specifications, may significantly reduce vegetation problems for an unknown period of time.

4. An integrated vegetation management (IVM) plan could both reduce vegetation problems and optimize labor and equipment usage.

5. The herbicide treatment had off-site effects upon mature trees at two of the four sites.

RECOMMENDATIONS

1. Conduct a vegetation survey of the ARRC trackbed to determine species, density, and frequency of vegetation.

2. Continue to monitor herbicide movement and degradation, off-site vegetation impact, and vegetation recovery on treatments, but at a much reduced level, for at least two more years.

3. Develop a vegetation management plant, with public involvement, which utilizes IVM and the results of the vegetation survey.

4. Continue to examine new alternatives for vegetation management, including new herbicides and new techniques, such as the C.P. Rail steam train.

5. Encourage engineering studies of vegetation impact. This includes mechanisms of ballast degradation, vegetation influence upon drainage, and quantification of track damage associated with types and amount of vegetation.

6. Improve railroad record-keeping to more accurately determine vegetation recovery rates and frequency of treatment required.

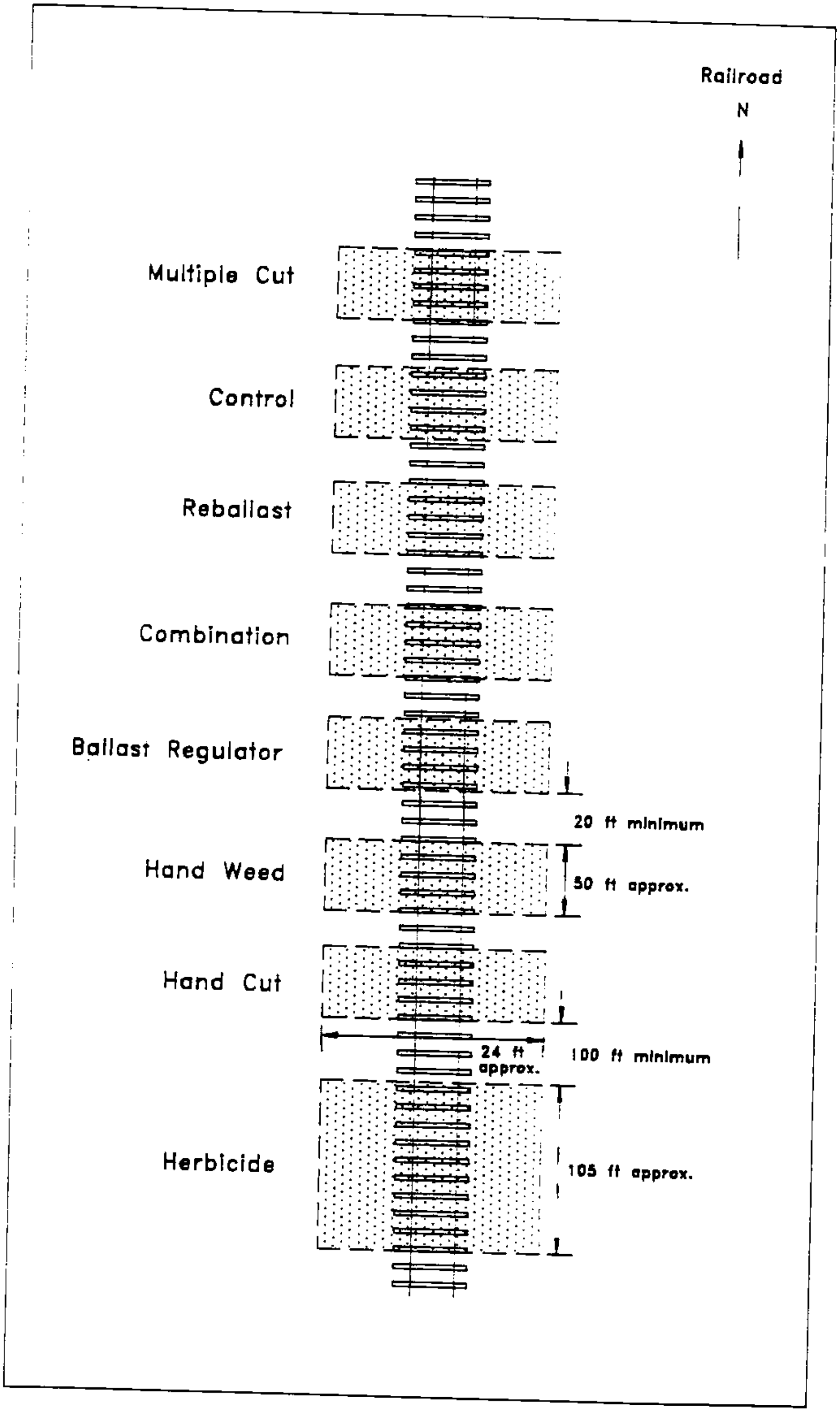


Figure 6.1 Ft. Wainwright site treatments

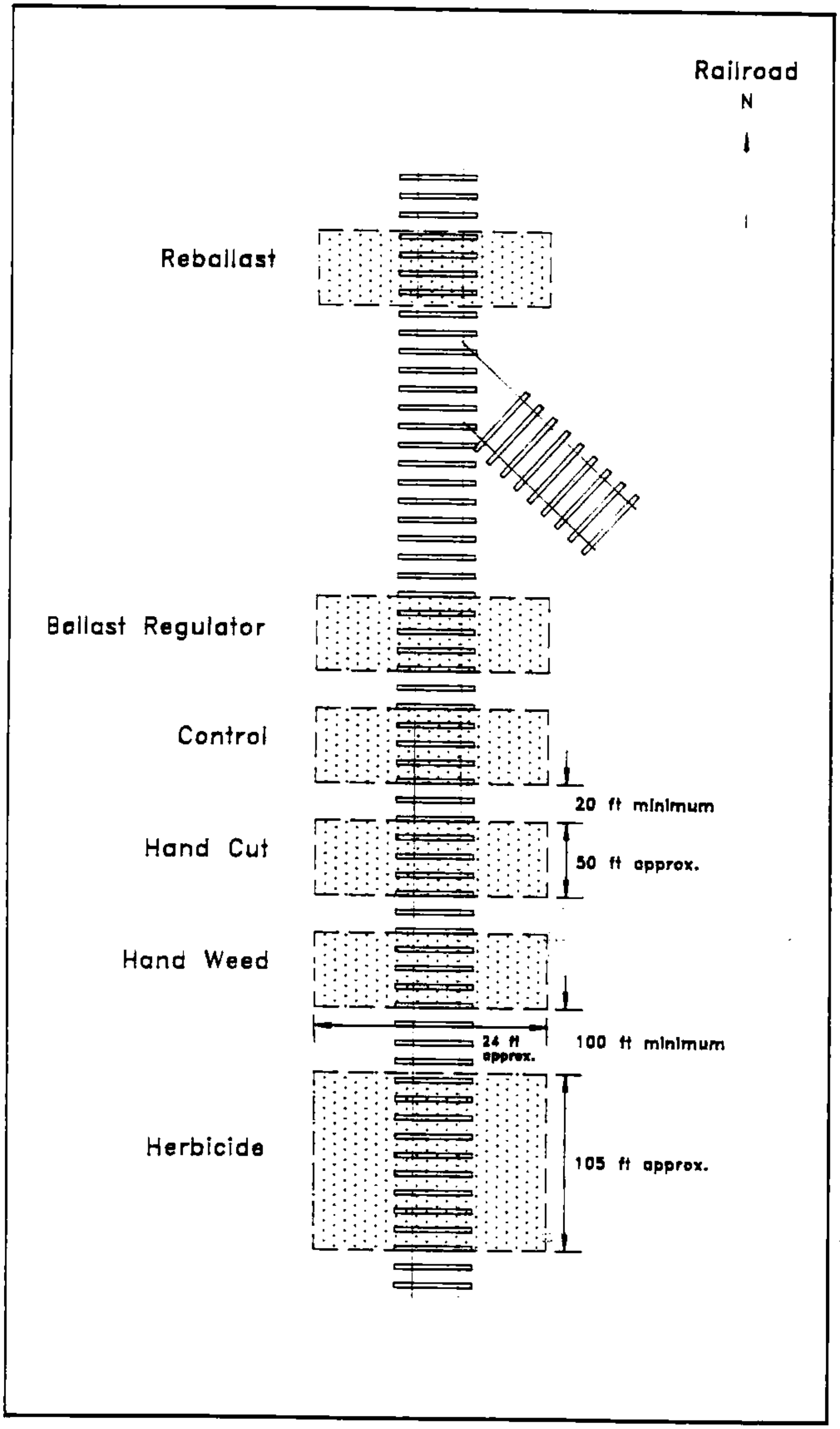


Figure 6.2 Clear site treatments

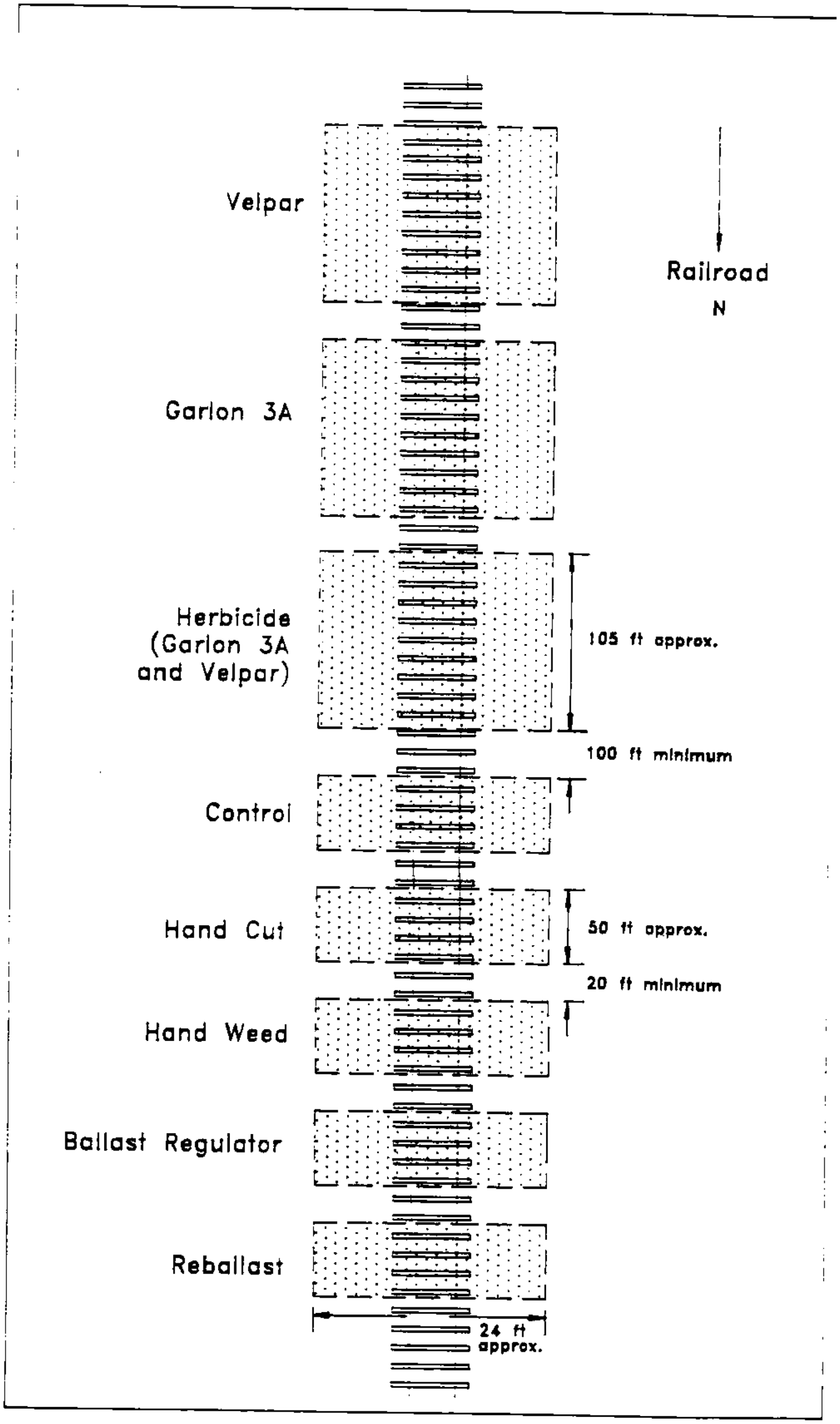


Figure 6.3 Birchwood site treatments

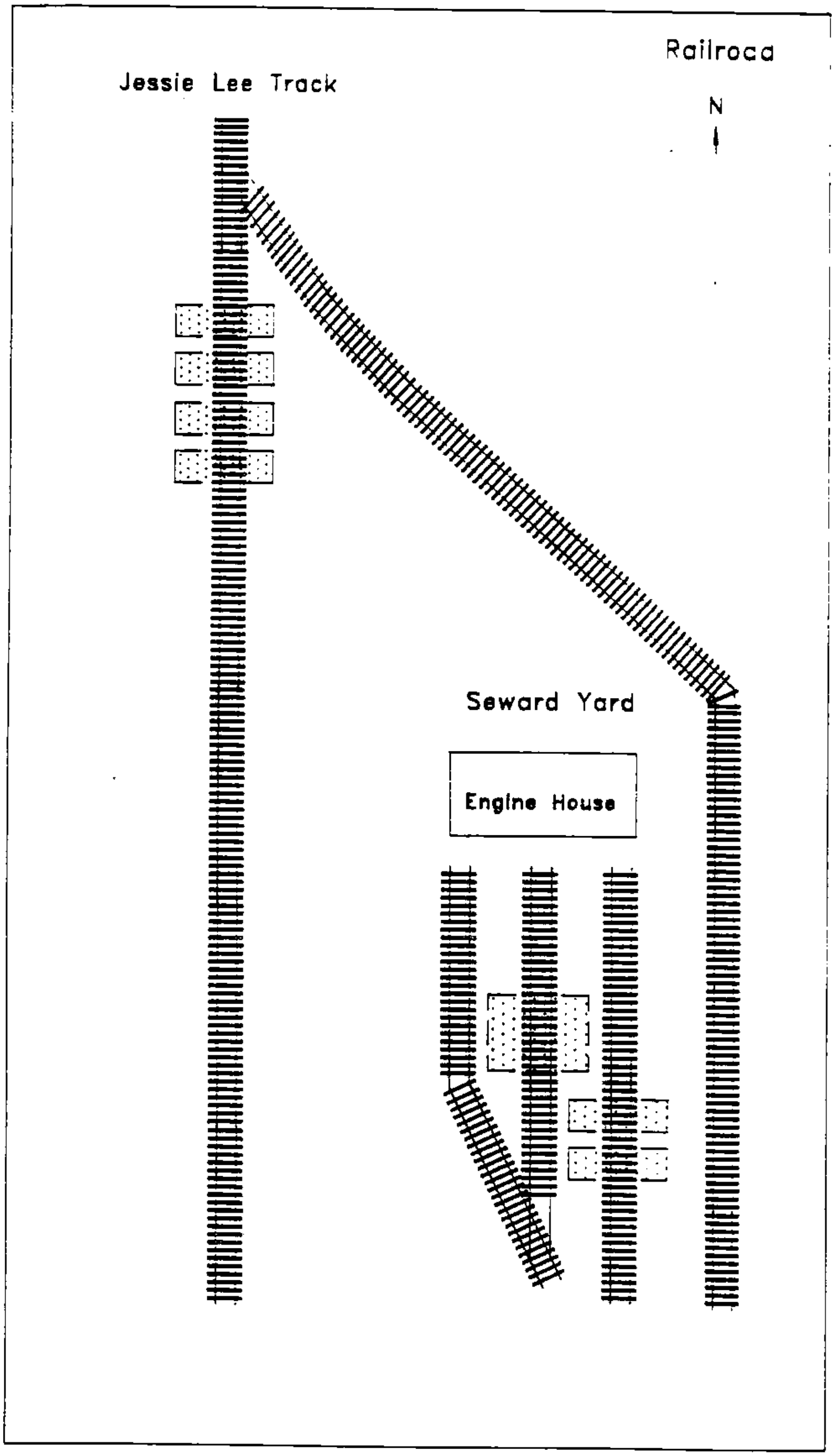


Figure 6.4 Seward site general plan

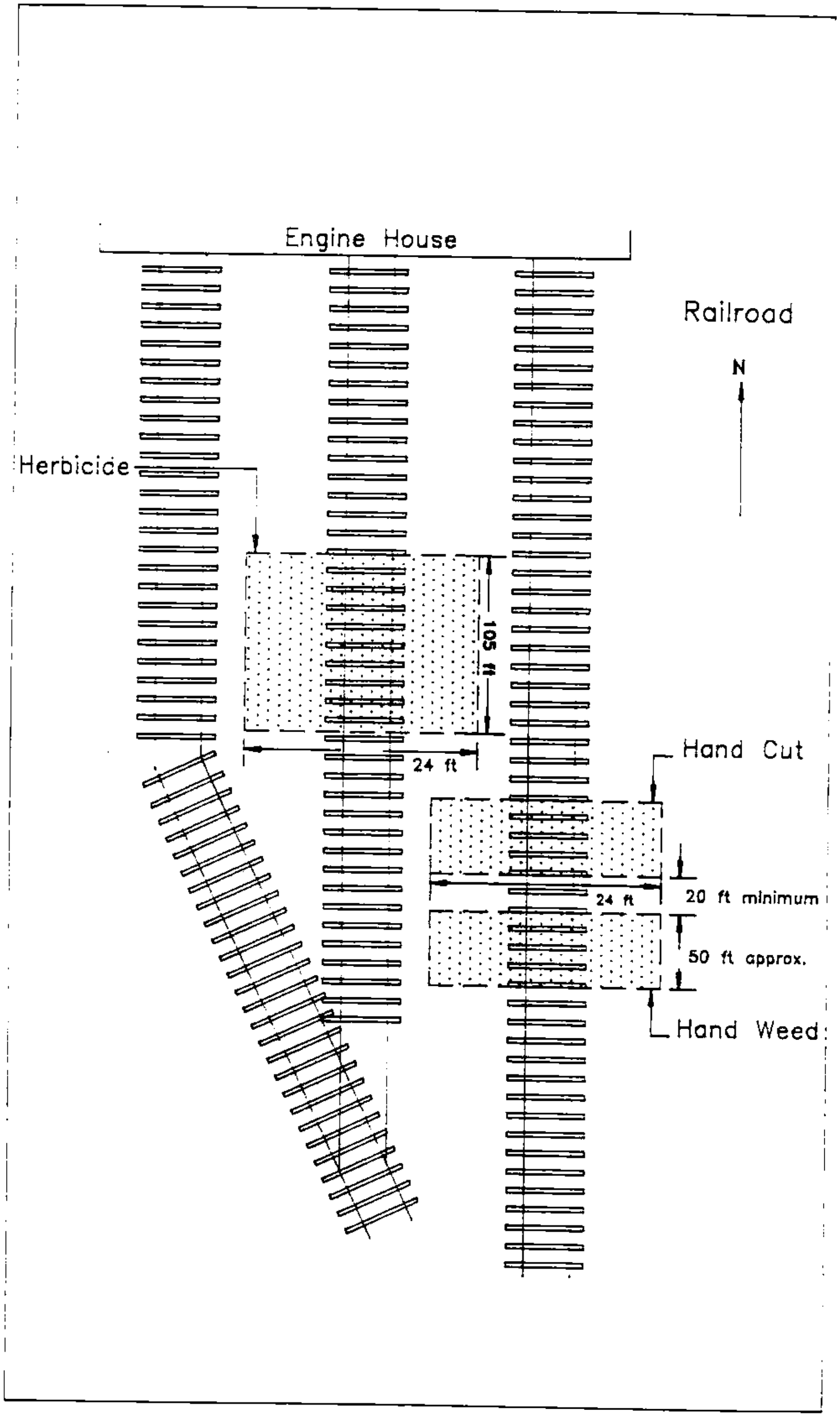


Figure 6.5 Seward Yard treatments

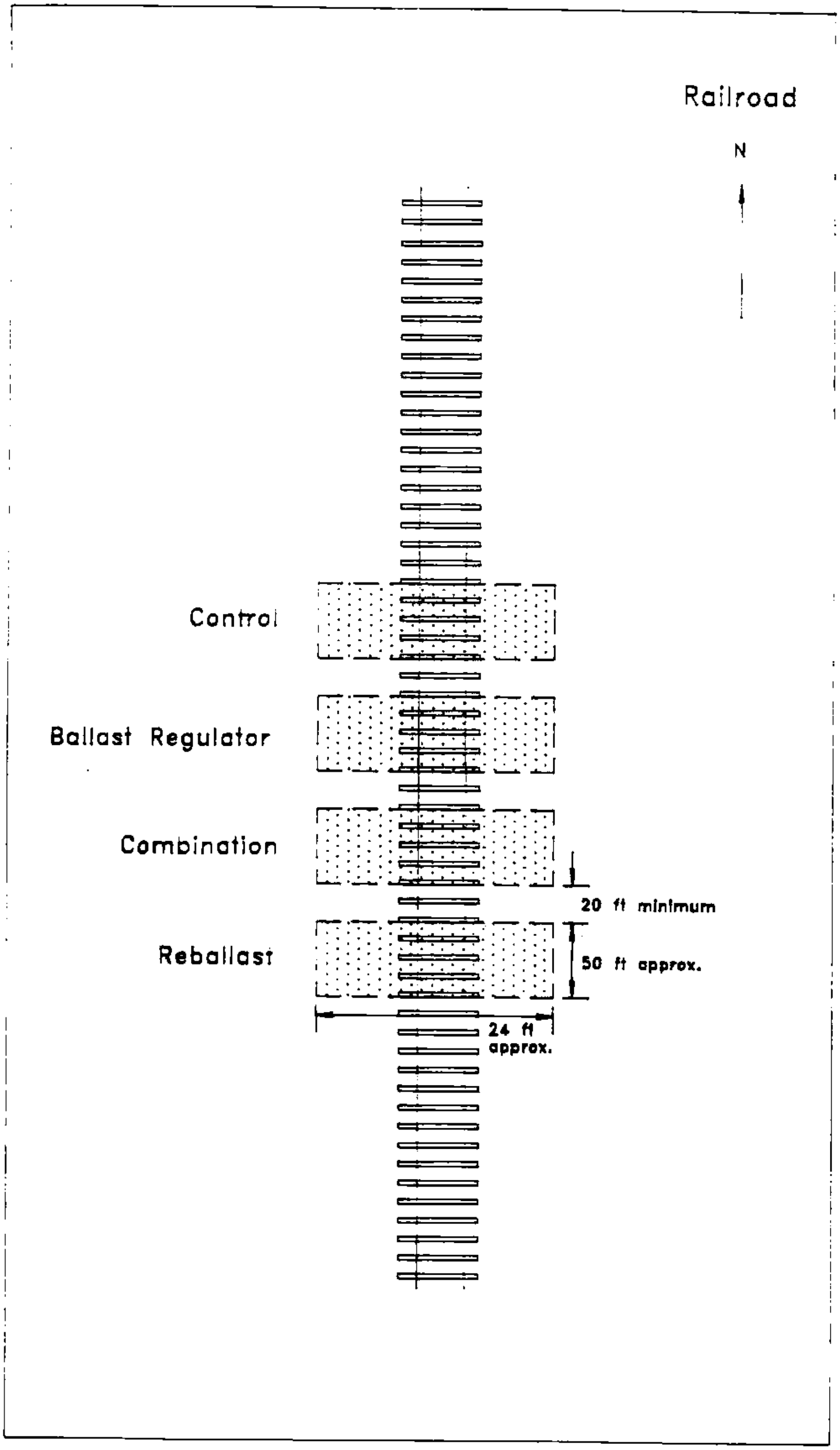


Figure 6.6 Jessie Lee treatments

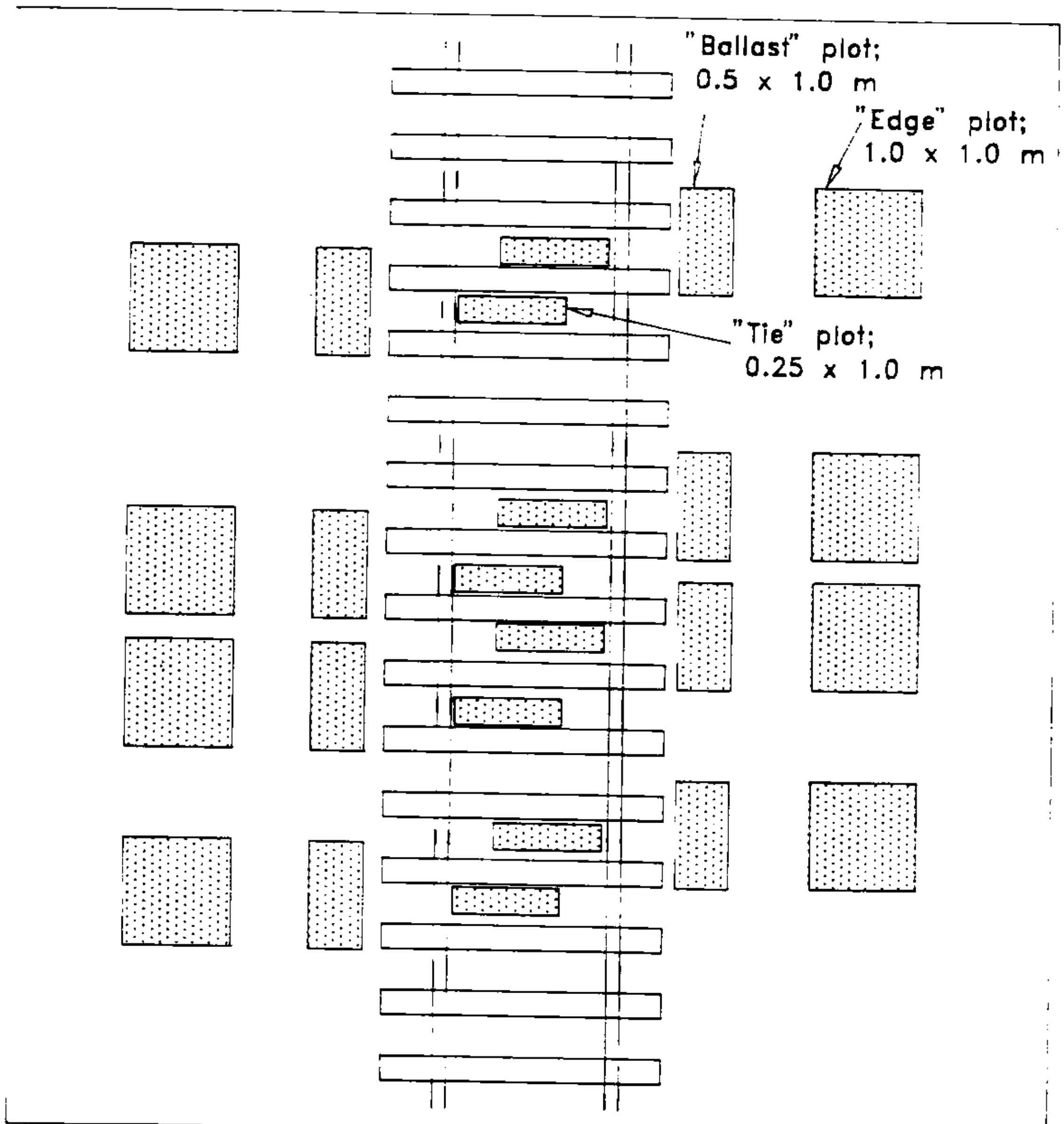


Figure 6.7 Plot schematic for effectiveness of control methods.

Table 6.1. Dates and timing of events of the ARRC Integrated Vegetation Management Research Project. Sites: FT = Fort Wainwright (ARRC MP G-8), CL = Clear (MP 388), CH = Chulitna (MP 274), BI = Birchwood (MP 136), FI = Fire Creek (MP 131), SE = Seward (MP 3).

Site	Event	Timing		
		T	Date[1]	Julian
FT	Baseline Veg'n	-6	5/30/89(1)	150
	" "	-4	6/01/89(2,3,5,7)	152
	" "	-3	6/02/89(8)	153
	" "	0	6/05/89(4)	156
	" "	1	6/06/89(6)	157
	Spray	0	6/05/89	156
	T = 49	49	7/24/89	205
	1st Season Veg'n	73	8/17/89(1-6)	229
	" "	74	8/18/89(8)	230
	" "	94	9/07/89(7)	250
	Ballast Samples	380	6/20/90	171
	Root Excavations	381	6/21/90	172
	2nd Season Veg'n	403	7/13/90(3-8)	194
	" "	408	7/18/90(1-3)	199
CL	Baseline Veg'n	-12	6/14/89(1-3)	165
	" "	-11	6/15/89(4-6)	166
	Spray	0	6/26/89	177
	T = 49	49	8/14/89	226
	1st Season Veg'n	57	8/22/89	234
	Ballast Samples	361	6/22/90	173
	Root Excavations	361	6/22/90	173
	2nd Season Veg'n	386	7/17/90	198
CH	Spray	0	7/17/89	198
	T = 49	49	9/04/89	247
BI	Baseline Veg'n	-20	7/11/89(1-4)	192
	" "	-19	7/12/89(5-6)	193
	Spray	0	7/31/89	212
	1st Season Veg'n	42	9/11/89(1,3-6)	254
	" "	49	9/18/89(2)	261
	T = 49	49	9/18/89	261
	Ballast Samples	331	6/27/90	178
	Root Excavations	331	6/27/90	178
	2nd Season Veg'n	359	7/25/90	206
	Bible Road Veg'n	387	8/22/90	234
FI	Spray	0	8/14/89	226
	T = 49	49	10/02/89	275

Table 6.1 (continued):

Site	Event	Timing		
		T	Date[1]	Julian
SE	Baseline Veg'n	-9	6/27/89(1-4)	178
	" "	-8	6/28/89(5-7)	179
	Spray	0	7/06/89	187
	T = 49	49	8/24/89	236
	1st Season Veg'n	54	8/29/89(1-4)	241
	" "	55	8/30/89(5-7)	242
	Ballast Samples	355	6/26/90	177
	Root Excavations	355	6/26/90	177
	2nd Season Veg'n	382	7/23/90(5-7)	204
	" "	383	7/24/90(1-4)	205
	Salmon Rvr Veg'n	411	8/21/90	233

[1] Numbers in parentheses are treatments, shown when not all treatments were sampled on same date.

Table 6.2. Total vascular cover (TVC) before treatment (in percentages).

	Ft. Wainwright	Clear	Birchwood	Seward
All:				
Mean	5.43	5.53	14.17	11.30
Std Dev	11.04	11.60	22.15	19.88
Maximum	65.0	65.0	95.0	95.0
Ties:				
Mean	0.51	0.18	1.31	4.18
Std Dev	1.97	0.09	3.44	5.38
Maximum	15.0	0.5	15.0	45.0
Ballast:				
Mean	1.27	0.72	4.82	2.13
Std Dev	2.06	1.68	10.67	4.15
Maximum	5.5	5.5	85.0	25.0
Edge:				
Mean	14.5	15.85	36.37	27.71
Std Dev	15.3	15.55	24.56	27.27
Maximum	65.0	65.0	95.0	95.0

Table 6.3. Kruskal-Wallis analyses of total vascular cover (TVC) for Ft. Wainwright.

Time Interval: Baseline - First Season (B-1)

```
                               ................
                     ..........              ..........................
            ND      4.0    12.8    17.9    22.0    31.5    31.5    31.5
Tie     -----|-------|-------|-------|-------|-------|-------|-------|--
           RB      BR      Weed    Ctrl    MCut    Cut     Herb    Comb

                                                      .................
                                     ........................
             ........................................
           31.1    35.0    36.6    39.7    48.0    48.6    55.7    64.2
Ballast -----|-------|-------|-------|-------|-------|-------|-------|--
           Weed    BR      MCut    Cut     Ctrl    Herb    Comb    RB

                                     .........................
             .........       ..................      ...................
           28.4    30.9    64.0    76.6    83.6    94.2    96.6    107.2
Edge    -----|-------|-------|-------|-------|-------|-------|-------|--
           Ctrl    RB      Comb    Cut     BR      MCut    Weed    Herb
```

Time Interval: Baseline - Second Season (B-2)

```
Tie      Lost due to reballasting

                                     .........................
                     ........................
             .........................
           26.1    34.5    36.1    37.9    49.5    53.9    61.1    65.3
Ballast -----|-------|-------|-------|-------|-------|-------|-------|--
           Cut     BR      MCut    Weed    Ctrl    Comb    Herb    RB

             .........        ................................
           36.3    37.8    68.3    78.5    79.3    80.1    85.4    114.5
Edge    -----|-------|-------|-------|-------|-------|-------|-------|--
           Ctrl    RB      Cut     Comb    BR      Weed    MCut    Herb
```

Table 6.3 (continued):

Time Interval: First Season - Second Season (1-2)

Tie lost due to reballasting

```
                          ......................................
                 .........             ...............................
                 25.4     40.5     43.3     47.8     50.7     55.5     57.5     63.7
Ballast     -----|--------|--------|--------|--------|--------|--------|--------|--
                 Cut      MCut     BR       Ctrl     Comb     RB       Weed     Herb

                          ......................................
                 ..........................           ......................
                 54.1     61.3     64.6     67.0     79.0     79.8     81.7     91.6
Edge        -----|--------|--------|--------|--------|--------|--------|--------|--
                 Weed     Cut      MCut     BR       RB       Ctrl     Herb     Comb
```

Notes for this and all other Kruskal-Wallis tables:

ND = no data
RB = reballast
BR = ballast regulate
Weed = hand weeding
Ctrl = control plot
Cut = hand cut with shears
MCut = multiple cuttings
Herb = herbicide application
Comb = ballast regulate then reballast
.... = tie line indicating treatments that are not significantly different from each other at the 0.05 level
Numbers are "average rank," the summary statistic of the Kruskal-Wallis analysis.
The treatment below (- - -) is not included in the relationship.

Table 6.4. Kruskal-Wallis analyses of total vascular cover (TVC) for Clear.

Time Interval: Baseline - First Season (B-1)

Tie   p = 0.224, therefore not significant at the 0.05 level

```
              .....( - )............
              ...............             ........
             8.0   10.1   13.4   18.5   26.5   29.0
Ballast  -----|------|------|------|------|------|-----
             Cut   Ctrl     BR   Weed   Herb     RB
```

```
                     ........
              ........             ........
            22.6   34.0   42.5   66.4   69.6   91.7
Edge     -----|------|------|------|------|------|-----
             RB    Ctrl    Cut   Weed     BR    Herb
```

Time Interval: Baseline - Second Season (B-2)

Tie   p = 0.224, therefore not significant at the 0.05 level

```
                                   ........
              ......................      ........
             9.9   10.5   15.4   17.9   24.2   31.0
Ballast  -----|------|------|------|------|------|-----
           Ctrl     Cut   Weed    BR     RB    Herb
```

```
                            ........
                     ........      ........
            22.8   41.1   47.5   61.1   68.9   87.2
Edge     -----|------|------|------|------|------|-----
             RB    Ctrl    Cut   Weed     BR    Herb
```

Time Interval: First Season - Second Season (1-2)

Tie   p = 1.000, therefore not significant at the 0.05 level

```
                     .....( - - - - )............
              .............................
            14.3   16.3   16.9   19.2   25.5   28.2
Ballast  -----|------|------|------|------|------|-----
           Weed     Cut   Ctrl    RB     BR    Herb
```

Edge   p = 0.673, therefore not significant at the 0.05 level

Note: See Table 6.3 for explanations.

Table 6.5. Kruskal-Wallis analyses of total vascular cover (TVC) for Birchwood.

Time Interval: Baseline - First Season (B-1)

```
                 ......................      ........
                5.0    5.0    9.3   10.3   19.4   21.0
Tie         -----|------|------|------|------|------|-----
                Ctrl   Weed   BR     Cut    RB     Herb

                               ...............
                 ...............
               20.9   23.2   25.4   36.7   36.8   56.1
Ballast     -----|------|------|------|------|------|-----
                Ctrl   Cut   Weed    RB     BR     Herb

                 .............................
               44.1   45.4   47.4   57.1   58.4   79.7
Edge        -----|------|------|------|------|------|-----
                RB     Ctrl  Weed    BR     Cut    Herb
```

Time Interval: Baseline - Second Season (B-2)

```
                        ..........( - -).............
                 .................( - -)......
                 ......................
                4.0   10.5   10.5   10.9   18.4   21.5
Tie         -----|------|------|------|------|------|-----
                Cut    Ctrl  Weed    BR     RB     Herb

                 .............................
               23.0   26.4   30.4   30.6   32.3   60.4
Ballast     -----|------|------|------|------|------|-----
                Ctrl   Cut    RB    Weed    BR     Herb

                        ......................
                 ......................
               38.3   44.4   49.4   50.0   61.8   86.9
Edge        -----|------|------|------|------|------|-----
                RB     Cut    Ctrl   Weed   BR     Herb
```

Table 6.5 (continued):

Time Interval: First Season - Second Season (1-2)

Tie   not significant at the 0.05 level

```
                                          ........
              .............................
            28.9   29.0   33.7   34.5   39.5   50.3
Ballast  -----|------|------|------|------|------|-----
            Ctrl   RB     Cut    BR     Weed   Herb

                            ...............
              ...............      ...............
            34.0   41.4   52.6   61.5   66.0   77.0
Edge     -----|------|------|------|------|------|-----
            Cut    RB     Ctrl   Weed   BR     Herb
```

Note: See Table 6.3 for explanations.

Table 6.6. Kruskal-Wallis analyses of total vascular cover (TVC) for Seward.

Time Interval: Baseline - First Season (B-1)

```
                                          ........
              ...............      ........      ........
            29.3   34.9   37.8   57.1   64.0   78.1   82.8
Tie      -----|------|------|------|------|------|------|-----
            Cut    Weed   Ctrl   Comb   BR     Herb   RB

                     ...............      ........
              ........      ...............      ........
            21.0   24.2   34.7   37.9   41.7   56.6   61.9
Ballast  -----|------|------|------|----- |------|------|-----
            Cut    Ctrl   BR     Weed   RB     Comb   Herb

                     ........      ........
              ........      ........
            20.3   33.3   41.3   52.4   58.9   77.5   95.4
Edge     -----|------|------|------|------|------|------|-----
            Cut    Weed   RB     Ctrl   Herb   BR     Comb
```

Table 6.6 (continued):

Time Interval: Baseline - Second Season (B-2)

```
                        ......................
                 ...............                    ........
               30.5   37.4   41.2   49.2   50.8   87.3   87.9
Tie         -----|------|------|------|------|------|------|-----
               Ctrl   Weed   Cut    Comb   BR     Herb   RB

                        .............................
                 ........
               21.0   32.2   35.8   38.2   44.5   46.3   65.3
Ballast     -----|------|------|------|------|------|------|-----
               Cut    RB     BR     Weed   Ctrl   Comb   Herb

                                      ...............
                        ......................      ........
               15.8   47.7   50.7   57.1   60.9   70.7   82.3
Edge        -----|------|------|------|------|------|------|-----
               Cut    RB     Weed   BR     Ctrl   Herb   Comb
```

Time Interval: First Season - Second Season (1-2)

```
                                      ...............
                        ......................
                 ......................      ...............
               40.9   46.9   49.8   54.3   67.3   69.2   73.7
Tie         -----|------|------|------|------|------|------|-----
               BR     Ctrl   Comb   Weed   Cut    RB     Herb

                                      ...............
                 .............................      ........
               29.5   29.9   34.4   39.1   39.1   50.0   61.9
Ballast     -----|------|------|------|------|------|------|-----
               RB     Comb   Cut    BR     Weed   Herb   Ctrl

                 ........      ......................
               30.9   31.5   63.8   64.0   64.7   67.3   89.3
Edge        -----|------|------|------|------|------|------|-----
               Comb   BR     Ctrl   Cut    RB     Herb   Weed
```

Note: See Table 6.3 for explanations.

Table 6.7. Summary values for stems at 10 cm and 50 cm.

	Ft. Wainwright Control	Clear Control	Birchwood Control	Seward Ballast Regulate
All:				
10 cm				
Mean	1.30	.61	.87	.19
Std Dev	2.63	1.85	1.93	.55
Maximum # Stems	11.0	9.0	10.0	2.0
50 cm				
Mean	.74	.33	.19	.07
Std Dev	2.04	1.21	.55	.33
Maximum # Stems	10.0	7.0	2.0	2.0
Ties:				
10 cm				
Mean	0	0	0	0
Std Dev	0	0	0	0
Maximum # Stems	0	0	0	0
50 cm				
Mean	0	0	0	0
Std Dev	0	0	0	0
Maximum # Stems	0	0	0	0
Ballast:				
10 cm				
Mean	.56	0.11	.33	.22
Std Dev	1.92	.47	1.03	.65
Maximum # Stems	8.0	2.0	4.0	2.0
50 cm				
Mean	0	0	0	.11
Std Dev	0	0	0	.47
Maximum # Stems	0	0	0	2.0
Edge:				
10cm				
Mean	3.33	1.72	2.28	.33
Std Dev	3.34	2.91	2.72	.69
Maximum # Stems	11.0	9.0	10.0	2.0
50 cm				
Mean	2.22	1.00	.56	.11
Std Dev	3.08	1.97	.86	.32
Maximum # Stems	10.0	7.0	2.0	10.0

Table 6.8. Kruskal-Wallis analyses of stems for Ft. Wainwright.

A. Total stems, 10 cm.

Time Interval: Baseline - First Season (B-1)

Tie no data

Ballast p = 0.231, therefore not significant at the 0.05 level

```
                             ...............
                      ...............      ........
               ...............                    ...............
             23.8   24.3   32.6   37.8   45.7   61.5   67.9   74.0
Edge      -----|------|------|------|------|------|------|------|-----
             Ctrl   RB     Cut    BR     Comb   Weed   Herb   MCut
```

Time Interval: Baseline - Second Season (B-2)

Tie no data

Ballast p = 0.175, therefore not significant at the 0.05 level

```
                                    ......................
                             ...............
               ...............                    ...............
             21.9   24.6   36.5   43.8   51.7   59.4   60.3   67.9
Edge      -----|------|------|------|------|------|------|------|-----
             RB     Ctrl   Cut    BR     Comb   Weed   MCut   Herb
```

Time Interval: First Season - Second Season (1-2)

Tie no data

Ballast p = 0.061, therefore not significant at the 0.05 level

Edge p = 0.623, therefore not significant at the 0.05 level

Table 6.8 (continued):

B. Total stems, 50 cm.

Time Interval: Baseline - First Season (B-1)

Tie   no data

Ballast no data

```
                                  ........
              ......................     ......................
            18.3   18.6   25.2   29.8   39.9   46.7   48.5   48.5
Ballast  -----|------|------|------|------|------|------|------|-----
            Ctrl   RB    Comb    BR     Cut   Herb   Weed   MCut
```

Time Interval: Baseline - Second Season (B-2)

Tie   no data

Ballast no data

```
                            .....................
                     .....................
              ......................            ...............
            18.9   22.8   25.5   26.4   33.8   40.6   48.3   48.9
Edge     -----|------|------|------|------|------|------|------|-----
            Ctrl   RB     Cut    BR    Comb   Weed   Herb   MCut
```

Time Interval: First Season - Second Season (1-2)

Tie   no data

Ballast no data

```
                            ...................................
                     .....................
              ...............
            17.2   22.3   26.2   34.2   35.4   39.0   41.1   41.8
Edge     -----|------|------|------|------|------|------|------|-----
             Cut   BR    Weed   Herb   MCut    RB    Comb   Ctrl
```

Note: See Table 6.3 for explanations.

Table 6.9. Kruskal-Wallis analyses of stems for Clear.

A. Total stems, 10 cm.

Time Interval: Baseline - First Season (B-1)

Tie   no data

Ballast p = 0.224, therefore not significant at the 0.05 level

```
                            ...............
                     ........
              ........             ...............
             8.2   20.3   28.8   33.2   34.2   39.0
Edge     -----|------|------|------|------|------|-----
            Ctrl    RB     Cut    Weed   Herb   BR
```

Time Interval: Baseline - Second Season (B-2)

Tie   no data

Ballast p = 0.224, therefore not significant at the 0.05 level

```
              ......................      ........
            17.5   19.9   22.0   25.9   40.9   43.8
Edge     -----|------|------|------|------|------|-----
             Cut    Ctrl   RB     Weed   Herb   BR
```

Time Interval: First Season - Second Season (1-2)

Tie   no data

Ballast p = 1.000, therefore not significant at the 0.05 level

```
                     ...............
              ...............      ...............
            14.8   21.9   24.9   32.6   38.1   38.8
Edge     -----|------|------|------|------|------|-----
             Cut    RB     Weed   Ctrl   BR    Herb
```

Table 6.9 (continued):

B. Total stems, 50 cm.

Time Interval: Baseline - First Season (B-1)

Tie   no data

Ballast   no data

```
             ........      ......................
            3.5    7.0   18.3   20.0   20.0   20.0
Edge    -----|------|------|------|------|------|-----
           Ctrl    RB    Herb    BR    Weed    Cut
```

Time Interval: Baseline - Second Season (B-2)

Tie   no data

Ballast   no data

```
                    .............................
             ........
            5.3   10.0   17.3   19.2   19.3   21.5
Edge    -----|------|------|------|------|------|-----
           Ctrl    RB    Weed    Cut   Herb    BR
```

Time Interval: First Season - Second Season (1-2)

Tie   no data

Ballast   no data

Edge   not significant at the 0.05 level

Note: See Table 6.3 for explanations.

Table 6.10. Kruskal-Wallis analyses of stems for Birchwood.

A. Total stems, 10 cm.

Time Interval: Baseline - First Season (B-1)

Tie no data

Ballast p = 0.224, therefore not significant at the 0.05 level

```
                          ..................
            ..................    ..................
            18.0   18.1   28.6   33.9   42.5   45.5
Edge     -----|------|------|------|------|------|-----
            Ctrl    RB     BR    Cut    Herb   Weed
```

Time Interval: Baseline - Second Season (B-2)

Tie no data

Ballast p = 0.224, therefore not significant at the 0.05 level

```
                          ..................
            .........................   ...........
            18.2   24.0   26.3   28.4   43.3   45.6
Edge     -----|------|------|------|------|------|-----
             RB    Ctrl    BR    Cut    Weed   Herb
```

Time Interval: First Season - Second Season (1-2)

Tie no data

Ballast p = 0.473, therefore not significant at the 0.05 level

Edge p = 0.868, therefore not significant at the 0.05 level

B. Total stems, 50 cm.

Time Interval: Baseline - First Season (B-1)

Tie no data

Ballast no data

```
                           ..........    ..........
                    ..........    ..........
             ND     7.6    8.6   13.3   17.5   22.0
Edge     -----|--//--|------|------|------|------|-----
            Weed    RB    Ctrl    BR    Herb   Cut
```

Table 6.10 (continued):

Time Interval: Baseline - Second Season (B-2)

Tie   no data

Ballast no data

```
                                   ........
                     ...............      ........
             ND     7.4    8.2   12.7   18.9   22.0
Edge     -----|--//--|------|------|------|------|-----
            Weed    RB     BR    Ctrl    Cut    Herb
```

Time Interval: First Season - Second Season (1-2)

Tie   no data

Ballast no data

Edge   p = 0.429, therefore not significant at the 0.05 level

Note: See Table 6.3 for explanations.

Table 6.11. Kruskal-Wallis analyses of stems for Seward.

A. Total stems, 10 cm.

Time Interval: Baseline - First Season (B-1)

Tie   p = 1.000, therefore not significant at the 0.05 level

Ballast p = 0.058, therefore not significant at the 0.05 level

Edge   p = 0.364, therefore not significant at the 0.05 level

Time Interval: Baseline - Second Season (B-2)

Tie   p = 0.686, therefore not significant at the 0.05 level

```
                                                 ........
                            ........      ........
             ND     ND     2.0    3.0    7.8   10.5   10.5
Ballast  -----|------|--//--|------|------|------|------|-----
            Ctrl    RB     Cut    BR    Comb   Herb   Weed
```

Edge   p = 0.557, therefore not significant at the 0.05 level

Table 6.11 (continued):

Time Interval: First Season - Second Season (1-2)

Tie p = 0.686, therefore not significant at the 0.05 level

```
                                    .......................
               ND      ND      1.5     9.0     9.0     9.0     9.0
Ballast   -----|-------|--//--|-------|-------|-------|-------|-----
              Ctrl     RB      Cut    Herb     BR     Comb    Weed
```

Edge p = 0.896, therefore not significant at the 0.05 level

B. Total stems, 50 cm.

Time Interval: Baseline - First Season (B-1)

Tie too few cases

Ballast too few cases

Edge p = 0.318, therefore not significant at the 0.05 level

Time Interval: Baseline - Second Season (B-2)

Tie too few cases

Ballast too few cases

Edge p = 1.000, therefore not significant at the 0.05 level

Time Interval: First Season - Second Season (1-2)

Tie too few cases

Ballast too few cases

Edge p = 1.000, therefore not significant at the 0.05 level

Note: See Table 6.3 for explanations.

Table 6.12. Summary values for total herbaceous and woody cover.

	Ft. Wainwright Control	Clear Control	Birchwood Control	Seward Ballast Regulate
All:				
Herbaceous				
Mean	.23	4.10	4.94	30.11
Std Dev	.85	7.80	7.96	44.20
Woody				
Mean	6.87	4.73	9.48	1.42
Std Dev	13.35	12.86	16.80	2.86
Ties:				
Herbaceous				
Mean	.08	.03	.31	2.94
Std Dev	.19	.12	1.30	2.66
Woody				
Mean	1.47	0	0	1.78
Std Dev	2.05	0	0	2.46
Ballast:				
Herbaceous				
Mean	.06	.39	.47	2.78
Std Dev	.16	1.29	1.53	4.40
Woody				
Mean	1.33	.39	1.75	1.22
Std Dev	2.18	1.29	3.11	3.71
Edge:				
Herbaceous				
Mean	.56	11.89	14.06	84.61
Std Dev	1.42	9.56	7.85	36.69
Woody				
Mean	17.81	13.81	26.69	1.25
Std Dev	18.90	19.57	19.94	2.34

Table 6.13. Kruskal-Wallis analyses of growth forms for Ft. Wainwright.

A. Herbaceous Forms

Time Interval: Baseline - First Season (B-1)

Tie p = 0.081, therefore not significant at the 0.05 level

Ballast p = 0.494, therefore not significant at the 0.05 level

```
                             ...............      ...............
               ......................      ...............
             24.5   35.3   40.5   42.6   58.8   66.7   77.2   81.4
Edge      -----|------|------|------|------|------|------|------|-----
             Ctrl    RB     Cut   Weed   MCut   Comb   Herb   BR
```

Time Interval: Baseline - Second Season (B-2)

Tie too few cases

Ballast p = 0.161, therefore not significant at the 0.05 level

```
                             .....(- -)...................
               ....................................
             35.6   39.0   44.0   47.3   50.9   60.3   69.4   90.1
Edge      -----|------|------|------|------|------|------|------|-----
             Weed    Cut   Ctrl    RB    Comb   MCut   BR    Herb
```

Time Interval: First Season - Second Season (1-2)

Tie too few cases

Ballast p = 0.365, therefore not significant at the 0.05 level

```
                                    .............................
                      ....................................
               ....................................
             42.6   44.9   48.7   56.3   60.1   60.7   71.9   75.4
Edge      -----|------|------|------|------|------|------|------|-----
             Comb    BR    Weed    RB     Cut   MCut   Ctrl  Herb
```

Table 6.13 (continued):

B. Woody Forms

Time Interval: Baseline - First Season (B-1)

```
                                          ......................
                                   ...............
                     ......................
             ND     1.0   15.6   15.7   19.0   29.0   29.0   29.0
Tie      -----|--//--|------|------|------|------|------|------|-----
             RB     BR    Ctrl   Weed   MCut   Herb   Comb    Cut

                                                 ...............
              .....(- - - - - - - - -)...................
              ....................................
            28.2   31.8   33.5   34.1   41.0   44.0   51.1   56.9
Ballast  -----|------|------|------|------|------|------|------|-----
            Weed   MCut    Cut    BR    Ctrl   Herb   Comb    RB

              ........      ......................      ........
            29.3   34.0   60.0   74.6   75.6   75.8  100.8  113.6
Edge     -----|------|------|------|------|------|------|------|-----
            Ctrl    RB    Comb    BR     Cut   MCut   Herb   Weed
```

Time Interval: Baseline - Second Season (B-2)

Tie p = 0.284, therefore not significant at the 0.05 level

```
                                   ....(- - )...................
                                   ..................(- - ).....
                     .........................(- - - - - -).....
              ......................
            22.0   33.4   34.0   35.2   43.2   50.8   58.4   60.5
Ballast  -----|------|------|------|------|------|------|------|-----
             Cut   MCut    BR    Weed   Ctrl   Comb    RB    Herb

                            ......................
                     ...............                    ........
              ...............                    ........
            34.4   46.4   56.9   68.5   73.6   79.3   98.1  103.6
Edge     -----|------|------|------|------|------|------|------|-----
            Ctrl    RB     Cut   Comb    BR    MCut   Herb   Weed
```

Table 6.13 (continued):

Time Interval: First Season - Second Season (1-2)

Tie   p = 0.350, therefore not significant at the 0.05 level

```
                                 ..................................
                          ..................................
                  22.0    38.7    40.8    42.4    47.8    50.6    52.5    67.8
Ballast      -----|-------|-------|-------|-------|-------|-------|-------|-----
                  Cut     BR      MCut    Ctrl    Comb    RB      Weed    Herb

                                 ...........................
                          ...........................
                 .....(- - - - - - - - - - - - - - - - - - - - - - - - )....
                 .....(- -)..................
                 ....................                           ..............
                  47.2    53.0    60.5    67.8    72.1    77.1    83.2    98.8
Edge         -----|-------|-------|-------|-------|-------|-------|-------|-----
                  Cut     Weed    Herb    BR      MCut    Ctrl    Comb    RB
```

Note: See Table 6.3 for explanations.

Table 6.14. Kruskal-Wallis analyses of growth forms for Clear

A. Herbaceous Forms

Time Interval: Baseline - First Season (B-1)

Tie   p = 0.224, therefore not significant at the 0.05 level

```
                                 .....................
                          ..............
                  ND      6.0     11.3    12.3    13.9    17.0
Ballast      -----|--//--|-------|-------|-------|-------|-----
                  Cut     Ctrl    BR      Weed    Herb    RB

                 ..............          ........
                  29.8    33.9    39.2    55.8    64.1    85.8
Edge         -----|-------|-------|-------|-------|-------|-----
                  RB      Ctrl    Cut     Weed    BR      Herb
```

Table 6.14 (continued):

Time Interval: Baseline - Second Season (B-2)

Tie p = 0.224, therefore not significant at the 0.05 level

```
                                 ..................
                   ........................
             ND     6.8    7.9   14.0   14.1   18.5
Ballast  -----|--//--|------|------|------|------|-----
             Cut   Weed   Ctrl    BR     RB    Herb
```

```
                   ........
            ........    ...............
            25.6   39.5   43.4   56.3   56.9   88.2
Edge     -----|------|------|------|------|------|-----
             RB    Weed   Ctrl   Cut     BR    Herb
```

Time Interval: First Season - Second Season (1-2)

Tie p = 1.000, therefore not significant at the 0.05 level

```
                          ................
                   ................   ........
             ND     5.7   11.0   12.4   16.5   19.1
Ballast  -----|--//--|------|------|------|------|-----
             Cut   Weed   Ctrl    RB     BR    Herb
```

```
                   .......................
            ...............     ...............
            32.9   43.9   44.2   58.2   61.7   68.3
Edge     -----|------|------|------|------|------|-----
            Weed    BR     RB    Ctrl   Herb    Cut
```

B. Woody Forms

Time Interval: Baseline - First Season (B-1)

Tie no data

Ballast p = 0.074, therefore not significant at the 0.05 level

```
                                        ........
            ...............     ........
            21.6   24.4   31.5   51.9   57.2   65.9
Edge     -----|------|------|------|------|------|-----
            Ctrl    RB    Cut    Weed    BR    Herb
```

Table 6.14 (continued):

Time Interval: Baseline - Second Season (B-2)

Tie   no data

```
                          ................
                   ................   ................
                 5.0     5.0     8.2    11.5    15.5    15.5
Ballast     -----|-------|-------|-------|-------|-------|-----
                Ctrl    Cut    Weed     BR     Herb     RB

                          ........
                   ........       ........       ........
                18.2    28.4    34.6    44.8    63.7    64.2
Edge        -----|-------|-------|-------|-------|-------|-----
                 RB     Cut    Ctrl    Weed     BR     Herb
```

Time Interval: First Season - Second Season (1-2)

Tie   no data

Ballast p = 0.279, therefore not significant at the 0.05 level

```
                                  .......................
                          .......................
                   ................
                31.1    35.7    35.9    47.9    51.8    53.7
Edge        -----|-------|-------|-------|-------|-------|-----
                Cut     Weed     RB     Herb    Ctrl     BR
```

Note: See Table 6.3 for explanations.

Table 6.15. Kruskal-Wallis analyses of growth forms for Birchwood.

A. Herbaceous Forms (without Raspberry)

Time Interval: Baseline - First Season (B-1)

```
                                   .....(- -).....
              ......(- )............
              ...............             ........
             4.5    4.5    8.1    9.0   16.3   18.0
Tie      -----|------|------|------|------|------|-----
            Ctrl   Weed    BR     Cut    RB    Herb

                            ...............
              ......................
            12.5   14.6   23.5   24.0   33.0   46.9
Ballast  -----|------|------|------|------|------|-----
            Weed    Cut    RB    Ctrl    BR    Herb

              ......................
            39.4   40.8   42.9   45.2   65.9   95.2
Edge     -----|------|------|------|------|------|-----
            Weed    Cut    RB    Ctrl    BR    Herb
```

Time Interval: Baseline - Second Season (B-2)

```
                     ...................(- -).....
                     .............(- )............
              ......................
             3.8    8.5    8.5    9.9   15.7   18.5
Tie      -----|------|------|------|------|------|-----
             Cut   Ctrl   Weed    BR     RB    Herb

              .............................
            16.9   17.5   19.2   24.0   26.6   49.7
Ballast  -----|------|------|------|------|------|-----
             Cut   Ctrl   Weed    RB     BR    Herb

                     ...............      ........
            25.3   41.3   45.1   50.2   80.1   88.5
Edge     -----|------|------|------|------|------|-----
             Cut   Weed   Ctrl    RB     BR    Herb
```

Table 6.15 (continued):

Time Interval: First Season - Second Season

Tie p = 0.544, therefore not significant at the 0.05 level

```
                                 ........
     ............................
   14.0   23.5   25.5   26.8   36.5   42.2
Ballast  -----|------|------|------|------|------|-----
   Ctrl   Cut    RB     BR    Weed   Herb
```

```
                          ...............
            .....................
   29.3   49.3   51.8   61.2   67.6   74.8
Edge     -----|------|------|------|------|------|-----
   Cut    Weed   Ctrl   RB    Herb    BR
```

B. Woody Forms (with Raspberry)

Tie p = 0.230, therefore not significant at the 0.05 level

Ballast p = 0.068, therefore not significant at the 0.05 level

```
                   ........
     ...............      ...............
   29.6   31.9   43.9   58.8   63.2   66.0
Edge     -----|------|------|------|------|------|-----
   Ctrl    RB     BR    Weed   Herb   Cut
```

Time Interval: Baseline - Second Season (B-2)

Tie p = 0.123, therefore not significant at the 0.05 level

Ballast p = 0.097, therefore not significant at the 0.05 level

```
            ...............
     ...............      ...............
   29.3   40.3   43.2   52.2   60.9   65.5
Edge     -----|------|------|------|------|------|-----
    RB    Ctrl    BR    Weed   Cut    Herb
```

Time Interval: First Season - Second Season (1-2)

Tie p = 0.413, therefore not significant at the 0.05 level

Ballast p = 0.620, therefore not significant at the 0.05 level

Edge p = 0.061, therefore not significant at the 0.05 level

Note: See Table 6.3 for explanations.

Table 6.16. Kruskal-Wallis analyses of growth forms for Seward.

A. Herbaceous Forms

Time Interval: Baseline - First Season (B-1)

```
                                                 ........
              ...............      ...............
            30.6   32.7   34.2   54.4   57.1   68.5   80.3
Tie      -----|------|------|------|------|------|------|-----
             Cut   Weed   Ctrl    BR    Comb   Herb   RB

              .....(- - - - - ).....      ...............
              ...............      ........
            12.5   13.4   14.5   23.3   32.6   35.5   40.0
Ballast  -----|------|------|------|------|------|------|-----
            Ctrl   Weed   Cut     BR     RB    Herb   Comb

                     ...............
              ........     ........
             9.8   24.4   33.3   39.3   46.4   67.1   84.8
Edge     -----|------|------|------|------|------|------|-----
            Weed    Cut    RB    Ctrl   Herb    BR    Comb
```

Time Interval: Baseline - Second Season (B-2)

```
                     ......................
              ......................             ........
            30.9   37.9   38.3   40.2   50.7   79.0   79.2
Tie      -----|------|------|------|------|------|------|-----
            Ctrl   Weed   Comb    Cut    BR     RB    Herb

                                          ...............
                            ...............
              ...............      ............(- -).....
            14.6   15.2   17.4   26.9   32.0   38.0   40.0
Ballast  -----|------|------|------|------|------|------|-----
            Weed    Cut    RB     BR    Ctrl   Herb   Comb

                     ......................
              ......................      ...............
            23.2   35.3   39.0   40.5   54.2   64.6   67.0
Edge     -----|------|------|------|------|------|------|-----
            Weed    Cut    RB    Ctrl    BR    Herb   Comb
```

Table 6.16 (continued):

Time Interval: First Season - Second Season (1-2)

```
                                 .............................
                          .............................
                   ...................(- -).....
                 33.6   43.2   50.5   56.5   57.0   60.8   66.7
Tie           -----|------|------|------|------|------|------|-----
                 Comb   Weed   Ctrl   RB     BR     Cut    Herb

                                 .............................
                          ...............
                   ...............
                 11.8   17.3   25.5   27.4   28.1   28.4   43.3
Ballast       -----|------|------|------|------|------|------|-----
                  RB    Cut    Comb   Herb   BR     Weed   Ctrl

                                 .............................
                          ...................(- -).....
                   ............(- -).....
                 32.2   37.8   51.3   54.7   58.6   64.5   67.0
Edge          -----|------|------|------|------|------|------|-----
                 Comb   BR     Ctrl   Weed   RB     Cut    Herb
```

B. Woody Forms

Time Interval: Baseline - First Season (B-1)

```
                   ...............             ...............
                 20.9   23.4   26.9   43.5   57.0   58.5   59.2
Tie           -----|------|------|------|------|------|------|-----
                 Cut    Ctrl   Weed   BR     RB     Comb   Herb

                                        ...............
                   ......................             ........
                 13.8   15.0   15.8   23.6   30.3   31.9   41.5
Ballast       -----|------|------|------|------|------|------|-----
                 Cut    Ctrl   RB     BR     Weed   Comb   Herb

                   ......(- )............      ...............
                   ...............      ........
                  6.5    7.3   12.0   22.5   31.1   36.5   38.8
Edge          -----|------|------|------|------|------|------|-----
                 Ctrl   RB     Cut    Weed   Herb   Comb   BR
```

Table 6.16 (continued):

Time Interval: Baseline - Second Season (B-2)

```
                                   ........
              ......................      ...............
            24.5   27.4   28.9   38.8   47.5   59.4   60.8
Tie      -----|------|------|------|------|------|------|-----
            Ctrl    BR     Cut   Weed   Comb   Herb    RB

                     .............................
              ...............
            13.0   17.2   19.0   26.9   28.7   30.7   42.1
Ballast  -----|------|------|------|------|------|------|-----
             Cut    RB    Ctrl    BR    Weed   Comb   Herb

              ......(- - - - -)............
              ......(- )............      ...............
              ...............      ...............
             6.5    7.3   11.8   25.4   30.6   32.9   40.2
Edge     -----|------|------|------|------|------|------|-----
            Ctrl    Cut    RB    Weed   Herb   Comb    BR
```

Time Interval: First Season - Second Season (1-2)

```
                            .............................
                     .............................
              ...............
            24.5   33.8   41.4   46.5   46.5   50.0   56.3
Tie      -----|------|------|------|------|------|------|-----
             BR    Comb   Ctrl   Herb    Cut    RB    Weed
```

Ballast p = 0.116, therefore not significant at the 0.05 level

Edge p = 0.348, therefore not significant at the 0.05 level

Note: See Table 6.3 for explanations.

Table 6.17. Kruskal-Wallis analyses for Salmon River (MP 4.8) as compared to Seward "Control" (no applied treatment).

	Location	p	Site with More Growth
TVC			
	Tie	0.000, significant	Seward
	Ballast	0.000, significant	Seward
	Edge	0.000, significant	Seward
Total Stems, 10 cm			
	Tie	0.037, significant	Seward
	Ballast	0.152, results not significant	
	Edge	0.039, significant	Salmon River
Total Stems, 50 cm			
	Tie	1.000, results not significant	
	Ballast	1.000, results not significant	
	Edge	0.031, significant	Salmon River
Herbaceous			
	Tie	0.000, significant	Seward
	Ballast	0.000, significant	Seward
	Edge	0.000, significant	Seward
Woody			
	Tie	0.000, significant	Seward
	Ballast	0.000, significant	Seward
	Edge	0.000, significant	Salmon River

Note: 1) 36 analyses were performed on tie, on ballast, and on edge plots at each site for the comparisons.
2) $p \le 0.05$ are accepted as significant.

Table 6.18. Kruskal-Wallis analyses for Bible Camp Road as compared to Birchwood "Control" (no applied treatment).

Location	p	Site with More Growth
TVC		
Tie	0.037, significant	Birchwood
Ballast	0.066, results not significant	
Edge	0.962, results not significant	
Total Stems, 10 cm		
Tie	0.152, results not significant	
Ballast	0.075, results not significant	
Edge	0.003, significant	Birchwood
Total Stems, 50 cm		
Tie	0.318, results not significant	
Ballast	0.318, results not significant	
Edge	0.067, results not significant	
Herbaceous (with raspberries)		
Tie	0.037, significant	Birchwood
Ballast	0.330, results not significant	
Edge	0.669, results not significant	
Woody (without raspberries)		
Tie	0.152, results not significant	
Ballast	0.000, significant	Birchwood
Edge	0.007, significant	Birchwood

Note: 1) 36 analyses were performed on tie, on ballast, and on edge plots at each site for the comparisons.
2) $p <= 0.05$ are accepted as significant.

Table 6.19. Mean percent fines in ballast, mean percent TVC.

Site	Mean % Fines	Mean % TVC on Ballast Plots
Ft. Wainwright	2.4	1.78
Clear (new)	0.1	
Clear (old)	2.3	1.86
Birchwood	6.2	6.17
Bible Camp Road	2.5	6.20
Salmon River	1.5	0.01
Seward Jesse Lee	4.5	2.08
Seward Yard	3.6	

Table 6.20 Tukey-Kramer of Ballast Fines.

				% Fines --->				
mean	0.1	1.5	2.3	2.4	2.5	3.6	4.5	6.2
	Clear New	Salmon River	Clear Old	Ft. Wain- wright	Bible Road	Seward Yard	Seward Jessie Track	Birch wood
			....	....	....	....		
							....	....

Table 6.21. Rooting depths for selected species.

Site	Species	Avg Height	Max Depth	Avg Lateral Spread to <2mm Diameter
Ft. Wainwright	Balsam Poplar	59 cm	26 cm	140 cm
Clear	Balsam Poplar	89 cm	40 cm	90 cm
	Aspen	39.7 cm	30 cm	30 cm
Birchwood	Alder	103.3 cm	22 cm	55.3 cm
Seward	Alder	87 cm	23 cm	27.3 cm

Table 6.22. Summary of Treatment Effectiveness by Site - number of instances where treatment is among the most effective as determined by Kruskal-Wallis analyses

Interval	Site	Treatment Type					
		Herb	RB	Weed	BR	Cut	Comb
B-1 (Baseline to end of First Season)	Ft. Wainwright	5	1	3	0	1	2
	Clear	3	1	1	1	0	0
	Birchwood	2	1	1	0	2	0
	Seward	3	1	1	0	0	2
B-2 (Baseline to end of Second Season)	Ft. Wainwright	4	1	2	0	1	1
	Clear	3	1	0	1	0	0
	Birchwood	4	1	1	0	1	0
	Seward	4	1	1	1	0	2
TOTAL		28	8	10	3	5	7

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