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Innovation, Winter Maintenance, and Roadside Management

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Contents

Foreword

Papers in this Record fit into five categories: (a) innovation, (b) mathematical modeling and data analysis for maintenance planning, (c) enhancing maintenance practices, (d) winter maintenance, and (e) finding solutions to requirements that environmental areas touched by transportation-related construction either not be harmed or, if harmed, be replaced in kind.

William Hyman suggests the need for an openness to new and innovative ideas and, more specifically, calls for managers to encourage development of widely accepted performance tests and specifications so that there is a foundation for awarding highway product procurement and construction contracts on the basis of long-term performance and life-cycle costs. Guaranteed bid systems have been tested and found to be useful, but problems involving such considerations as performance bonds extending over the life of highway products have inhibited expansion of the concept on a large scale.

Although current maintenance organizations and practice are not particularly conducive to applying the knowledge being gained, mathematical models are being developed that can conceivably be applied to improve the quality of maintenance management. For instance, normal practice is to assign work forces and equipment on the basis of expected work load; Wright et al. offer a more sophisticated approach in the form of a mathematical model that will assign personnel on the basis of minimizing total travel distance for the work force as a whole, minimizing the number of state-owned vehicles and at the same time the maximum distance any individual would be required to travel to work.

In the category of enhancing maintenance practices, a study by Zeigler reveals that risk management of roadside trees is more complex than merely removing all trees within a specified distance from the travel way, even if other environmental issues could be overcome. No single feature of the road environment accounts for all the accidents that occur and cannot be used to determine the level of risk. Dickens identifies four compounds that show good activity (more than 50 percent) in controlling seedheads in tall fescue with herbicides.

Three papers deal with winter maintenance. Setting quality levels and determining a proper balance between allocations for system preservation and provision of services are always troublesome. Hill et al. have confirmed an intuitive feeling that some categories of users will tolerate a lower level of winter maintenance on county roads and trunk highways and that substantial dollar savings are possible if that tolerance is recognized and acted on. Eck et al. provide another in a series of reports on the use of natural brines. These investigators find that natural brines can be used as an additive to stockpiles to prevent freezing. They report that optimum brine-abrasive combinations require an analysis of the aggregate type because the type of abrasive affects results. They also conclude that the best procedure is to spray an optimum amount as the stockpile is formed, followed by supplemental applications as needed. Interest in alternatives to sodium chloride for road deicing has led to studies of calcium magnesium acetate (CMA), acetate salt in solution, and other compounds as possibly less corrosive materials. Palmer suggests the use of formates as an alternative deicer to CMA. He projects that it may be possible to produce sodium or calcium dolomitic lime formates at one-half the cost of CMA.

Environmental studies include another report on a continuing program of study of vegetation management along the Blue Ridge Parkway. Previous reports, dating back more than 25 years, may be found in other Highway Research Board (now Transportation Research Board) publications. Smardon et al. continue to document a landscape classification of scenic overlooks. Classification permits selection of suitable images for simulation of alternative vegetation management practices that can be tested by visual preference surveys of users. Kober and Kehler find that mitigative design features incorporated into culverts and relocated stream channels during highway construction are effective in accelerating recovery of biological communities. Both postconstruction habitat and aquatic populations were similar to or better than preconstruction conditions, and the overall cost of the project with mitigation was slightly less than that of the project without mitigation. Lesley reports on the third year of evaluation of smooth cordgrass establishment in tidal wetlands by various methods, which is a function of mitigation requirements in wetlands. Fwa describes innovative forms of parking lot pavement construction that allow planting trees and growing grass within and around car parks.

Fostering Innovation in the Strategic Highway Research Program

WILLIAM A. HYMAN

The theme of the Strategic Highway Research Program (SHRP) is innovation and SHRP's Final Research Plans provide a thoughtful guide to the development of new highway technology, materials, and processes. To enhance the environment for innovation in SHRP and more generally in the national highway program, there must be an openness to unusual and novel ideas and the means and incentives to bring about change in the highway product procurement and construction contracting process. Presented here is some of the background material developed to create a climate conducive to the serious consideration of creative ideas and unsolicited proposals, the support of innovation, and the extensive involvement of private industry in SHRP and public-sector highway research. In particular SHRP should encourage the development of widely accepted performance tests and specifications so that there is a foundation for awarding highway product procurement and construction contracts on the basis of long-term performance and life-cycle costs. These would provide the incentive for widespread innovation and the development of premium products and materials not only within the duration of SHRP but also thereafter.

Planning under the preimplementation phase for the $150 million, 5-year Strategic Highway Research Program (SHRP) was completed in May 1986. This research program seeks to generate technological breakthroughs for highway materials, equipment, and processes in six technical areas: asphalt, long-term pavement performance, maintenance cost-effectiveness, protection of bridge components, cement and concrete, and snow and ice control. The main theme of this research program, "The Search for Innovation: Highways," was outlined in TRB Special Report 202 *(1)* by the Strategic Transportation Research Study (STRS), which called upon the nation to undertake this historic research program.

During the SHRP preimplementation phase three strategies were pursued to create an environment for innovation. The first was to review the nation's current highway technology and identify research activities that have a high probability of extending the frontier of knowledge in the six technical areas that form SHRP. The process resulted in a detailed and integrated research agenda *(2)*. This is a guide to a visionary set of new products, materials, and processes likely to produce a large payoff to the nation in terms of more durable highway facilities and more cost-effective construction and maintenance practices.

The second strategy was to explore the feasibility of earmarking some portion of SHRP funds expressly for innovation. Grants in various sizes could be offered to various sectors of the highway research community to propose novel ideas and to develop prototypes and test their technical and economic feasibility.

The third strategy was aimed primarily at finding ways to increase the innovative resources of the private sector devoted to highway research, particularly in coordination and cooperation with SHRP.

Discussed here are some general principles for fostering innovation, a proposal to earmark a portion of SHRP funding to stimulate innovation, and additional ideas that stemmed from a workshop in which private industry representatives participated. The purpose of the workshop was to find new ways to involve private firms in SHRP and public-sector highway research.

GENERAL PRINCIPLES FOR FOSTERING INNOVATION AND CREATIVITY

Early in SHRP's preimplementation phase, the staff identified principles known to be conducive to innovation and creativity. Many of these principles come from the literature on creative problem solving *(3–6)*. Others are derived from sound practices for managing applied research programs *(7–9)*. These principles were intended to stimulate the thinking of AASHTO's Task Force, SHRP's policy-making body, regarding how to create an environment for innovation.

Incremental Problem Solving or Conceptual Leaps

Novel ideas do not occur within a vacuum. To a large extent radically different and effective ideas are based on previous work and occur within some context. Highly creative and structured problem solving, even the incremental sort, can take researchers a long way from the starting point. Eventually ideas may emerge that appear altogether new, even though they were reached step by step.

The alternative is to jump out of the customary conceptual framework. A term for this that is creeping into the popular lexicon is "jootsing" (jumping out of the system) *(10)*.

SHRP can foster true innovation in two ways: (a) by encouraging very effective, highly structured incremental problem solving aimed at producing novel solutions to specific problems and (b) by trying to stimulate conceptual leaps.

Courting the Illogical

In normal logic A *and* B cannot be true at the same time. However, too often the transportation research community

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remains under the spell of normal logic and sees a problem as a distasteful or insoluble dilemma, A *or* B, black or white. For instance, on the one hand a research engineer may balk at trying to develop a superdurable pavement because of a conviction that it will be uneconomical: initial construction costs will be too high. On the other hand, short-lived pavements mean high subsequent maintenance and traffic management costs.

Under the logic of creativity both A and "not A" can be true. One may have low initial construction costs and low maintenance expenses. Innovative thought searches for ways to sidestep or transcend dilemmas and to render trade-offs inconsequential.

Encouraging Counterintuitive and Contradictory Ideas

To encourage innovation SHRP needs to cultivate ideas that are counterintuitive or even contradict the conventional wisdom. Invention often comes from a tinkerer, a lonely genius, or some free-wheeling team or task force that had a brainstorm. But a great idea is not enough. Innovators need the strength to champion their ideas or they need a beneficent patron to provide the encouragement, support, means, and will for implementation. SHRP has to seek out and support individuals with unusual ideas and shelter such free thinkers until their ideas are demonstrably infeasible.

SHRP needs also to try to stimulate spontaneity and unusual thought patterns. A serious type of playfulness and casual thinking is in order—for example, metaphorical thought. Metaphors point to useful analogies. To say "transportation is weather forecasting" suggests that it is important to be able to predict moisture, humidity, and snow and ice conditions. These conditions clearly have a bearing on all six SHRP topics but most obviously on the mechanisms of setting and strength development in concrete, bridge protection, and snow and ice control. Weather forecasting involves advanced techniques of remote sensing, communications, and early warning of problems. By thinking of highways metaphorically as weather forecasting, new perspectives and ideas begin to emerge that may have practical value.

SHRP also needs to create crucibles—intense problem-solving situations—in which those with very different or opposing perspectives wrestle with research dilemmas and seek innovative solutions.

Internalizing Externalities

Every perspective is bounded. Creative solutions usually require stepping outside those bounds. Conversely, bringing the outside perspective inside, or internalizing externalities, may be required, which is a well established and desirable principle in economics and psychology, as well as the kind of change that leads to innovation. An individual's perspective may be enlarged to encompass unfamiliar views by serving on a multidisciplinary team. Still another way to internalize externalities is to complement one perspective with its opposite:

Maintain/improve: A highway research team composed of construction engineers should be complemented with maintenance engineers, and vice versa.

Young/old: A group of senior, seasoned professionals should be complemented by young professionals fresh from the universities and conversant with the state of the art as well as speculative and unproven ideas.

Public/private: A group of public officials should be complemented by some from private enterprise.

Expert/lay person: A group of experts should be complemented with articulate lay people.

Micro/macro: A group with a tendency to look at everything as a unique problem should be complemented by those who can see each unique problem as a part of a larger interrelated set of problems and who are sensitive to gestalt properties—phenomena evident in the whole but invisible in the parts.

Hard/soft: "Hard" engineers should interact with "soft" engineers and vice versa. Ultimately the products of hard engineering will be used for decision making and will depend on the soft side of engineering—top-quality software, database management, planning, and decision-making tools. Particularly difficult will be the melding of the now incompatible perspectives of (a) emphasizing the extension of the physical life of pavements and (b) making decisions based upon economic life, which derives from such concepts as life-cycle cost analysis.

Producer/user: Engineers and planners build and sell transportation products and services. Their views should be complemented by the user—the customer. The idea to research what level of pavement smoothness the highway user desires, at different costs, is good. It forces engineers to look at the problem not from their customary viewpoint but from that of the user. *A Passion for Excellence (9)*, the sequel to *In Search of Excellence (8)*, emphasizes two points that make successful companies: innovation and staying close and listening to the customer.

Highway/vehicle: SHRP tends to focus on the roadway, but an inverted perspective, one that approaches the problem from the standpoint of vehicles, is useful. From this perspective come such ideas as reducing pavement deterioration by regulating tire pressure of heavy trucks or the concept of designing trucks to fit the highway instead of the reverse.

Constructing Counterfactuals

A powerful and commonly used technique for producing innovation is to visualize a future that has solved a problem intractable in the present. By working backward from the future visualization, one is often led to a solution to the current problem. SHRP should give free play to counterfactual thinking and guided fantasies, and try to create a climate for bridging novel conceptions of the future and current practices.

Innovations occurring in fields outside transportation can serve as guides to the future. Rapid progress in material science, remote sensing, nondestructive testing, robotics, computer hardware and software, artificial intelligence, and financial management, when combined, can suggest a future in some ways very different from today. Visualizing how this constellation of new technology might be applied to highways and what highway practice might consist of 5 years from now can lead to thinking about what steps to take in order to build a more productive future that represents a conceptual leap from current thinking.

Nurturing Competition

Private firms and others are increasingly finding that competition sparks innovation. Indeed, competition is no stranger to architecture, engineering design, and the research community. Design contracts are frequently awarded on the basis of design competition, and consulting firms and research organizations regularly compete on the basis of qualifications or innovative proposals for research contracts. The competitive process normally results in a better product. Innovation within SHRP is more likely to occur if SHRP nurtures competition aimed at producing novel ideas.

Leveraging Research Dollars

Research programs like SHRP should use their limited resources to stimulate innovation and find ways to engage as many people as possible in productive, focused, creative, and unconventional thinking.

These are not incompatible terms. Corporations, whose survival depends upon constant innovation, create a climate in which research is structured but unfettered. Breaking habitual thought patterns must be consistent with the research agenda and business at hand and put in the service of creating new products or procedures that yield profits in the private sector.

Analogously, SHRP must yield net benefits in the public sector, and is more likely to do so if it can induce large numbers of thoughtful people to work on a carefully worded research agenda.

Loose-Tight Goals and Objectives

Research objectives must be carefully worded to stimulate innovation. The problem statements must be clear, but not so focused to be prejudiced against novel ideas.

In the area of snow and ice control, if the overall objective were a new way to overcome the bonding between ice and pavement, it would be too narrow. In contrast an overall objective of solving the problem of keeping vehicles from facing icy or snowbound roads invites broader, more creative thinking. Indeed, SHRP research may lead to the invention of a new type of snow fence, better bad-weather warning systems, new types of pavement to which ice does not adhere, new deicing chemicals, and electronic signs that recommend less hazardous routes to motorists.

EARMARKING FUNDS FOR INNOVATION

During the preimplementation phase, SHRP's Advisory Committee for Overview and Integration recommended to the AASHTO/SHRP Task Force that SHRP seek unsolicited proposals to bring about technical innovation and create an open program for innovative research.

The Advisory Committee for Overview and Integration grappled with the question of what incentives should be provided to researchers. Any level of funding devoted expressly to stimulating innovation should be large enough to create a critical mass and result in meaningful new ideas, but should not be so large as to detract from SHRP's general tenor and focus on the six technical areas prescribed in the Strategic Transportation Research Study [Special Report 202 *(1)*]. Nor should the level of funding devoted to innovation be so large that suggestions for innovation would result in questioning the basic thrust of SHRP, for which a consensus had already been built.

In short, the majority of SHRP's resources should be devoted to carrying out research tasks recommended by the contractors for the six technical areas as described in the SHRP Research Plans *(2)*, but some modest portion of SHRP's funding might be applied to stimulating innovation. Perhaps 2 percent of the $150 million, 5-year program, or $3 million, could be devoted to sparking innovation. The $3 million would not have to be divided equally over the 5-year period nor equally among the six research areas, although initially $500,000 could be reserved for each. Rather the money could be spent where it would do the most good, on promising opportunities as they arose. There should be several checkpoints when innovative suggestions would be evaluated, developed further, dropped, or held in reserve for a more suitable time.

The $3 million could be dispensed in the following manner.

First, SHRP could define primary and secondary research objectives in each of the six technical areas: asphalt, long-term pavement performance, maintenance, bridge protection, cement and concrete, and snow and ice control.

Second, through a variety of means, including issuance of Requests for Proposals (RFPs), conducting student and faculty research competitions, and holding brainstorming sessions, SHRP could gain ideas for innovative technology in each of the six technical areas. SHRP could offer the prospect of large cash awards, grants, or other incentives such as profitable contractual arrangements to colleges and universities, research-oriented consulting firms, research institutes and laboratories, private industrial firms, industry associations, and state, local, and federal government.

Third, for each technical area, panels of experts could select the most innovative and promising ideas. SHRP advisory committees, subcommittees, or contractors might serve in this role. Professional resources for the review process could come from AASHTO, TRB, ASCE, ITE, National Science Foundation consultants, colleges, universities, and federal, state, or local government. These panels could award small grants to further develop innovative proposals most likely to yield a large payoff and be implemented by the end of the 5-year research program. Grants could be offered to the proposers if they were qualified to more fully develop the proposal and if not, to others (e.g., universities or consultants).

Fourth, the panels could evaluate the more fully developed proposals and make a judgment about investing more in each idea. The amount of additional investment would be tailored to the size of the expected payoff and the feasibility of delivering a practical, economical, and implementable product by the end of SHRP. Funding could be dispensed in increments as progress on innovation unfolded. Usually up to $500,000 could be awarded in any single technical area to fully develop innovative ideas. More, however, might be available in a single area if an innovation there were exceptionally promising while ideas in other areas were less so.

INDUSTRY PARTICIPATION

During the SHRP preimplementation phase several obstacles to industry participation in highway research, especially the kind leading to innovation, were identified:

1. Too much of the materials market is controlled on the basis of lowest cost;

2. The climate for change is not present nor given sufficient priority;
3. The market is fragmented, frequently parochial, and characterized by an indomitable spirit of independence, both in technical and management activities;
4. There are no generally accepted criteria for evaluating materials and structural performance, and a variability of views is not uncommon even within the same highway agency; and
5. There is a barrier to the acceptance of research and hence an inability to maximize its payoff *(11)*.

To address these obstacles SHRP held a workshop in which 11 individuals knowledgeable about the highway research and development process conducted a brainstorming session regarding how to involve private industry in generating new technology, materials, or processes directly for or in coordination with SHRP. Half the participants were from private industry: General Motors, 3M Corporation, Dow Chemical Company, Owings-Corning Fiberglas, and the National Asphalt Pavement Association. The remainder were Chief Executive Officers of state departments of transportation, SHRP staff, TRB staff, and representatives from the academic community.

The group originally generated more than 100 ideas, which fell into three broad categories:

1. Need for procurement based on performance criteria instead of lowest initial cost,
2. Ways to develop a strong public–private-sector research partnership, and
3. Need for a research champion.

SHRP staff distilled, refined, and added to these ideas to produce a variety of proposals to stimulate the involvement of private industry in SHRP and more generally in highway research and development (R&D) for the public sector. The following discussion concerns the first two categories.

Procurement Based on Performance Specifications

Public highway agencies have a legal requirement to procure new materials, processes, and technology from the lowest bidder. Highway agencies also award highway construction contracts in a similar manner. The lowest bid is typically defined as the lowest initial cost and fails to take into account long-term performance, life-cycle costs, or a long-run benefit-cost ratio that captures user benefits. Product and construction specifications are usually based on material and engineering characteristics and normally do not stipulate future performance.

In contrast many private firms try, through accelerated testing, to simulate long-term performance. Some also use economic, risk, and market analyses to decide whether to fully develop a product from a prototype and to manufacture, market, and distribute it. Products are improved or dropped in response to market feedback. New products and features are introduced so fast in some markets (obsolescence is as short as 3 years in the electronics industry) that observation of product performance over long periods like 10 or 20 years is irrelevant. Yet private industry finds that it must take life-cycle costs into account and build durability and quality into products from the start. The public highway sector could emulate the private sector more than it has in the past.

Information is currently available to draw conclusions concerning some aspects of long-term performance of highway facilities and products, and it is lacking regarding other aspects. For example, engineers understand fairly well how pavement serviceability (a measure of ride quality) deteriorates over time for rigid and flexible pavements under many environmental conditions. There is a much poorer understanding of pavement distress over the long run.

Similarly across the spectrum of private firms and public highway agencies, performance tests—or the basis for conducting them—exist for some features of highway facilities and products. For other features, both tests and a basis for conducting them are nonexistent. Clearly there exist performance tests for highway lighting. Manufacturers of light bulbs have developed performance tests pertaining to illumination and service life. But performance tests related to the extent of air void entrainment in concrete are lacking.

A major advantage of performance specifications is that they encourage research and development. If the performance specifications are geared to the long run, R&D is likely to lower life-cycle costs. Left free to meet a long-term performance specification in any manner chosen, a manufacturer or highway contractor will have a strong incentive to increase productivity through innovation, provided that the rigors of competition are also involved.

In summary, the information on long-term performance of highway facilities and products is spotty, and many types of performance tests have yet to be developed. Yet enough information is available to begin to change the current specification process to reflect life-cycle costs for products that will be affected by SHRP.

Develop Model Performance Specification on Which Contract Would Be Awarded

There are two possible types of long-run performance specification. The first pertains to behavior of the highway facility or product in real time. Performance is not evaluated until some substantial block of time has elapsed. This sort of specification might stipulate that after 15 years, a performance measure shall not fall below some value *X*.

The second type of performance specification is based upon an accelerated test. Suppose the Accelerated Loading Facility (ALF) being built for SHRP were operational and mobile. Then it might be possible to develop a performance specification based on an ALF test. The specification might require that a newly built pavement be able to withstand the equivalent of 100,000 loadings simulated by ALF over several months without having a measure of performance (present serviceability index, rutting, cracking) fall below *Y*.

Sweden has recently been experimenting with performance specifications as an alternative to their traditional process. The Swedish concept calls for "terminal functional requirements" (performance specifications) for a "room," a length and cross section of road. The highway agency specifies geometric characteristics and performance that must be met at the end of some lengthy period. The functional requirements are expressed in quantitative mechanical or electronic measures.

The client furnishes boring logs for subsurface conditions to bidders, who assume responsibility for the full roadway section, not just the surface. The contractor guarantees the work for 5 to 10 years and is responsible for structural repairs during the period. The contractor provides insurance (a bond) against failure to meet the specifications. It must also insure itself against going out of business during the guarantee period. The Swedish experiment also addresses the bonding capacity of the contractors. The contractors guarantee their work for the first 2 years and rely on insurance for the balance of the performance period.

The proposal here is to develop a model performance specification and award a contract based on it as a demonstration project. This project can pertain to highway projects, products, materials, or processes. The demonstration project should be one that, if successful, would have broad ramifications and could be applied widely in regard to either a specific highway feature or equipment (flexible pavements, bridge decks, drainage, instruments for condition assessment) or bring about substantial change in the current contract letting or procurement process.

Industry-Proposed Long-Term Performance Tests

Developing a model performance specification and awarding a contract based on it can be considered a first step toward changing the current specification process. Widespread change may depend, however, on the development of many additional performance tests, both feasible and infeasible to implement today.

Given the huge market opportunities, there is incentive for private industry to propose performance tests that the public sector could use to formulate long-term performance specifications. These tests must correlate well with long-term performance. It is likely that industry is already in a position to propose a variety of performance tests for at least some highway products on the basis of their past R&D and product-testing efforts.

The process of arriving at tests that can support performance specifications is a delicate one. A test proposed by a firm is a two-edged sword. It can be a way to open up a new market for a new product that meets the test and an associated performance specification. At the same time it can be a way to restrict competition. Firms that participate in setting standards and specifications in the computer industry face this problem all the time. The problem is compounded in the highway sector where understandably public highway agencies insist that they have a role in protecting the public's interest.

Precisely how should these tests be proposed and evaluated so that they can become fully accepted by the public sector and form the basis for performance specifications? There are at least three ways to accomplish this.

First, the highway industry could rely upon existing institutions. Industry currently provides input into the process for formulating specifications of the American Association of State Highway and Transportation Officials (AASHTO), the American Society for Testing and Materials (ASTM), and the National Electrical Manufacturers Association (NEMA). AASHTO's materials subcommittee writes specifications with industry input. ASTM is largely an industry group whose specifications are usually similar to those of AASHTO. NEMA is an industry association that sets specifications for electronic equipment, including traffic signals. All these institutions work with testing laboratories to develop uniform and reliable tests. "Round robin" testing by different laboratories is necessary to determine the variability of a test procedure and develop reliable tests within acceptable tolerances. With encouragement from SHRP and industry leaders, AASHTO, ASTM, and NEMA might agree to evaluate more performance tests proposed by industry.

A second option is to include in the current procurement process for new highway products a requirement that firms propose a long-term performance test along with their competitive bid for supplying the product. Firms might submit bids to supply a product in two stages. First, they would propose a long-term performance test. The government would then request AASHTO, ASTM, NEMA, or other organizations to evaluate the tests and pick the best one. The traditional competitive bidding process would follow. The performance test could serve as part of the basis for selecting the best bid, monitoring the performance of the product over time, or setting performance specifications. SHRP with industry support could encourage FHWA and AASHTO to try this procurement process as a demonstration.

The third option is to rely upon a nontraditional institution whose mission includes developing acceptable performance tests to serve as the basis for performance specifications. An independent testing laboratory, discussed later, is one possibility.

Feasibility Study of Independent Testing and Certification Organization and Warranty System

An independent testing laboratory could conduct tests fundamentally different from the traditional ones performed by the existing materials testing community. Instead government could contract with an independent testing organization to develop and conduct performance tests for highway facilities and innovations that emerge from SHRP.

As a result it would be easier to devise performance specifications that reflect life-cycle costs. Also, it would provide some of the brick and mortar to pursue novel procedures for letting highway construction contracts, such as that developed in Sweden.

Part of this proposal also calls for investigating warranty systems or insurance arrangements to enable contractors to guarantee performance. This was a key part of the contractual arrangement in the Swedish experiment.

In short, it is suggested that an RFP be issued to independent testing laboratories and insurance underwriters to conduct a feasibility study of (a) an independent testing and certification organization for highway facilities, products, and technology and (b) a warranty system with insurance to guarantee performance the costs of which would be paid by contractors or private industry, as the case may be.

Funding for the feasibility study might not be required. A good feasibility study might provide strong leverage for its implementation. Many testing firms and insurance companies might be interested in this concept and be willing to investigate it as a part of their normal effort to find new business. If funding were required for a study, perhaps either SHRP or a consortium of private industry firms could put up $25,000 to $50,000.

Topics addressed by the feasibility study are as follows; they fall into two categories, one pertaining to testing and the other pertaining to a warranty system with insurance:

1. Testing

- Mission of organization;
- Feasibility of developing and conducting performance tests and devising performance specifications;
- Short- and long-run costs predicated first on testing a few highway products or facilities and then later on testing a broad array;
- Alternative methods of covering costs, including requiring contractors or private industry, or both, to cover all costs;
- Test reliability;
- Ability to certify performance;
- Safeguards against low testing standards that everyone can meet; and
- Test liability exposure.

2. Warranty system and insurance

- Identify alternative warranty and insurance procedures for guaranteeing performance of highways and highway products:
  a. Examples from Europe and other countries,
  b. Other options that the insurance industry may propose;
- Costs of different warranty systems and insurance;
- Options for covering costs
- Product and tort liability (limits on second- and third-party liability); and
- Effect of FHWA's advance notice of proposed rulemaking to eliminate the prohibition against guaranteeing performance for some highway products.

Specify in Generic Form Use of New Products

At the brainstorming session it was suggested that if a major corporation were initially allowed to capture 80 percent of the market for a new product in a state, within 4 years there would be six major companies bidding against it. As long as bids were based upon performance and included maintenance contracts, many firms would be attracted to the market.

Although this suggestion has merit, no state is likely to guarantee a market for a proprietary product. A state or the federal government could, as an alternative, specify that a particular type of product be used, even if only one company produces it.

There is already an important precedent for doing this. FHWA desired a way to protect reinforcing bars from corrosion. FHWA developed and publicized criteria for determining how to evaluate a product's ability to retard or eliminate corrosion. Next they invited private industry to develop a corrosion-resistant reinforcing bar that would be evaluated using the criteria and stipulated that the best product would be required in new bridge decks on the federal-aid highway system. FHWA specified a type of product that would be required, not a proprietary product. Once the firm that developed the best product, an epoxy-coated rebar, began selling it, other firms sought to enter and compete in the market. The result over time has been lower cost and better corrosion-resistant rebars.

It is proposed to follow the example of the epoxy-coated rebars, and to encourage FHWA or some states to require the use in highway projects of some new products recently developed by private industry or developed during SHRP. One possibility might be to specify that calcium magnesium acetate (CMA), a less corrosive and more environmentally benign deicing agent than road salt, be used on 10 percent of the federal-aid system—on roads through environmentally sensitive areas and on long structures. Feasibility studies have indicated that CMA would be 10 times as expensive to produce on a large scale as road salt. But a requirement to use CMA on a substantial portion of the U.S. highway network is likely to induce many private firms to produce CMA, compete with one another, and eventually find innovative ways to bring the cost down.

Contract with Industry to Perform SHRP Research and Retain Patents and Licensing Rights

This concept call for "no-risk research" for private industry. Simultaneously it provides industry with ample incentive to market its products. In return for SHRP funding, industry would share some of its profits with the government.

The following example reveals this concept more fully. SHRP will be seeking to develop many new types of equipment for nondestructive testing of concrete in bridge pavement. In the concrete technical research area alone, SHRP will be seeking new equipment to determine the water–cement ratio, free moisture in aggregates, permeability, air void entrainment, consolidation, adequacy of curing, and the residual service life.

Participation by private industry will be key to successfully developing this kind of equipment and instrumentation. Manufacturers like Hewlett-Packard and General Electric are widely known for their capability to develop new technology. To engage such firms in SHRP research, SHRP would issue RFPs to industrial firms for each type of equipment. The RFP would state that SHRP would provide a certain amount of funding to conduct the research and the contractor that wins the award would retain all proprietary rights, patents, and licenses. The RFP would seek competitive proposals and state that they would be judged on the basis of (a) the qualifications of the firm and its ability to deliver and (b) the firm's best offer for sharing the proceeds of its research with government.

Demonstration Project on Three Different Levels of Long-Term Performance

This proposal represents a way to award contracts for highway construction or new products on the basis of long-run performance. To use highway construction as an example, suppose that contractors were invited to submit separate bids for a highway facility with 10-, 20-, or 30-year service life. A contractor may wish to submit a bid on one or all three levels of service life. The highway agency would then convert the bids to a common measure, such as the number of years of service per dollar, and award the contract on the basis of the lowest bid.

The highway agency could even devise a procedure for calculating the discounted cost savings of one bid over another and use that as the criterion to award contracts.

Model Contracts for Highway Construction and Highway Product Procurement Process

A large number of the proposals presented so far involve defining novel procedures for letting highway construction contracts or engaging private industry in R&D for the public highway sector. The various types of contractual procedures discussed so far are as follows:

- Develop a model performance specification and award a contract based on it;
- Include in the current procurement process for new highway products a requirement that firms propose a long-term performance test along with their competitive bid for supplying the product;
- Develop a contractual procedure similar to Sweden's calling for terminal functional requirements and a warranty and insurance system to guarantee performance;
- Specify in generic form that several new and cost-effective highway products be used in a substantial number of highway projects;
- Contract with industry to perform SHRP research and allow them to retain patents and licensing rights; industry would compete for contracts through competitive bids and would return a fee to government; and
- Invite separate bids on three different levels of long-term performance of a highway facility, product, material, or process.

In addition, many states have been experimenting with the contract-letting process in order to encourage contractors to be innovative and lower costs. Some of these procedures include design-build and detail-build projects and value engineering.

In a design-build project contractors bid both on the design and the construction of a project. They are given substantial freedom in the design stage to develop a prescribed project concept. The freedom allows for innovation and the contractor can trade off the advantages of certain design features against construction costs.

The design-build concept could be expanded to "design-build-and-maintain." This emphasizes life-cycle performance by putting competitive pressure on firms to minimize not only initial costs but maintenance costs as well. An ideal bid selection criterion would be to award a contract to the firm that proposes to deliver the product for the smallest discounted life-cycle costs or discounted net benefits (i.e., this would include user benefits and initial and maintenance costs, while avoiding externalities such as wetland damage or haphazard toxic waste disposal).

The design-build concept has proved practical in relatively few cases in the United States, though it is fairly widespread in Europe. State highway agencies find design-build impractical where there are (a) significant environmental effects to address, (b) right-of-way acquisition, and (c) utility relocation. The complexity of these activities and the need to protect the public interest interfere with the freedom to innovate that the design-build concept offers.

To provide some flexibility in the design stage, at least one state highway agency has used a detail-build concept, in which the key design features are specified and the contractor is left to add minor details and construct the facility. This offers some room for innovation in the design stage.

A more widely applied approach is to attach a value-engineering rider to the contract, which says that if the contractor can identify a more cost-effective design solution and successfully implement it, he can share the savings with the state, say 50 percent of the cost reduction.

Both the detail-build and the value-engineering concepts could also be expanded to included maintenance over the project life as part of the contract.

Because the contractor would have responsibility for the facility over its service life, the problem arises of the ability of the firm to guarantee performance. The average lifespan of highway construction contractors is probably shorter than durable pavements lasting 20 or 30 years. How do firms that remain in business an average of 10 or 15 years guarantee that they will maintain the facilities they constructed and guarantee that performance meets specifications? Similarly how does a private firm with a short life expectancy guarantee the long-run performance of its new products? Another problem is how highway contractors and private industry firms protect themselves against tort liability.

It is proposed here that a small task force of legal experts in private industry and the public highway sector direct a study that would produce a set of model contracts for highway construction and the highway product procurement process. The study would look to both American and European experience for guidance. The model contracts would offer a wide variety of ways to

1. Reward long-run cost performance,
2. Provide incentive for innovation,
3. Guarantee against failure to perform or meet long-term performance specifications, and
4. Protect against tort liability.

The intent of the study would be to produce some contracts that might be used by SHRP with private industry to develop new products, materials, or processes called for in SHRP's six technical research areas.

A valuable by-product would be model contracts that state and local highway agencies could use to select contractors that will improve the long-term cost performance of new and rehabilitated highways.

Study Application of SHRP Research Results to Public-Sector Decision-Making Process

Public- and private-sector decision-making processes differ sharply, impeding the cooperation and input of industry in the innovation process. Suggestions offered at the brainstorming session to increase conformity included "understand the different public-sector and private-sector motivations," "show industry how to make a profit (in the public sector)," and "standardization of terminology could be a big help."

The study suggested here would anticipate how the public sector is likely to convert to a decision-making process more like that of the private sector once SHRP has produced substantive results. The study would recognize existing obstacles to behaving more like the private sector, such as the reliance on low bid on front-end costs and fragmentation of the industry—in short, market failure. It would anticipate a construction contract and product procurement process that changes from material to performance specifications and rewards superior life-cycle cost performance. Results of SHRP are also likely to permit the public sector to think in terms of

1. Depreciation of extremely durable capital assets;
2. Creation of capital recovery accounts;
3. More extensive use of present-value analysis and internal rate of return to make short- and long-term investment and maintenance decisions (in other words, much greater reliance on life-cycle cost analysis);
4. Possibly more frequent entry into the capital markets for financing (despite more stabilized gas tax financing), thus forcing the consideration of short-versus long-run financial trade offs;
5. Sounder decisions regarding whether to build more durable (higher quality) projects or to perform more miles of work (greater quantity); and
6. Risk analysis of R&D expenditures for new highway technology.

Ultimately there could even be legislation that requires a shift from categorical funding to block grants. Such legislation would recognize that it is more cost-effective to give state highway agencies more freedom in substituting maintenance dollars for rehabilitation and new construction dollars. Data from SHRP's long-term pavement performance study and other technical areas are likely to provide justification for this type of legislative change.

Public-Private Partnership

Results of the brainstorming session suggested that private industry had much to contribute directly to the SHRP innovation process. Private industry could loan staff, offer laboratories and proving grounds for testing, and provide industry teams that include business managers. Several forms of SHRP–industry partnerships were proposed: a common data base for researchers in university, business, and government; contractual relationships for sharing risks and benefits; joint efforts to establish research objectives; and, perhaps most important, help to devise means for establishing performance specifications.

Industry will not offer its resources with little to gain in return. SHRP must establish clear objectives, targets, or guidelines for industry participation that do not hamper industry's R&D process and impede their access to markets or significantly restrict remuneration.

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Efficient Personnel Management for Winter Highway Maintenance

JEFF R. WRIGHT, STEVEN C. EGLY, AND DENNIS BERG

The focus of this research was the development of a model for addressing the problem of reassignment of snow removal personnel for the LaPorte District Office of the Indiana Department of Highways. This consists of assigning transfer personnel to winter snow removal routes so as to minimize the total distance that the workforce as a whole must travel to work during snow emergencies while keeping to a minimum the number of state-owned vehicles that must be issued for this purpose. During the course of this work, a third objective was identified, which addressed the issue of equity in assignment strategy. A methodology was developed for determining a feasible assignment strategy that minimized the maximum distance that any individual would be required to travel to work. The result of this work is a microcomputer-based model that can greatly improve personnel management strategies for winter highway maintenance operations. The model structure, solution procedure, and interpretation of model results are discussed.

The maintenance of the nation's highway system requires personnel trained in the use of a wide range of equipment. The efficiency of operations such as road surface repair, painting and labeling, mowing and weed control, and signal maintenance depends in part on the manner in which these personnel are assigned to job sites. This is particularly important in developing a strategy for winter snow and ice control, where the public safety depends on a rapid mobilization of the workforce.

Winter snow and ice control is extremely labor intensive. Because of an insufficient number of permanent maintenance personnel to staff all routes, snow and ice control operations for most of the northern states require a seasonal reassignment of personnel from summer activities such as construction inspection and materials testing to winter snowplow operation. This avoids the problem of seasonal hirings and firings but may disrupt normal work patterns, because workers may be assigned to work out of different site locations for the winter season. Most important, the way in which these job reassignments are made may have a dramatic effect on the overall cost and efficiency of snow and ice control.

When up to 150 persons must be reassigned to up to 20 different job sites, each with an expected demand for workers, the problem of determining an efficient assignment strategy becomes severe. First, the number of possible different assignment strategies is extremely large. Second, there may be multiple and conflicting objectives in developing criteria for judging a particular assignment strategy. Finally, the use of sophisticated operations research techniques for aiding the design of assignment strategies may not be justfied on the basis of the computational requirements of such models; until recently, optimization procedures capable of solving such management problems required expensive computer hardware and software as well as specialized expertise in modeling.

The design and development of a model for aiding maintenance engineers in making decisions about personnel reassignment are described. The model was developed for the Indiana Department of Highways for use in staffing distributed site locations with sufficient personnel to conduct winter roadway maintenance. The model is small enough to be solved by using modern microcomputer technology and can be used by managers with little or no previous experience in systems modeling. In addition to generating efficient solutions to the personnel reassignment problem, the model also provides valuable and explicit information about the quality of any particular solution.

After a brief overview of related research, the specific problem addressed by this work will be presented. The general structure of the model developed to solve this problem and a discussion of interpreting the model results will be presented. Readers interested in a more detailed discussion of model design and solution procedure are referred to work by Wright et al. *(1)*, and those wishing more information about the microcomputer implementation of the model may wish to see work by Wright and Egly *(2)*.

MODELING SNOW AND ICE CONTROL MANAGEMENT

The removal of snow and ice from the nation's highways is an expensive undertaking. For example, clearing of state-maintained roads cost an estimated $334 million in 1976 *(3)*. Considering the expenditures involved, small improvements in operational procedures and the selection of appropriate alternatives can produce substantial savings. As stated by Minsk *(4)*, "Decision makers need better information and methodology to make economic determinations of snow-removal system operation and effectiveness."

Snow and ice removal operations have occasionally been studied from the broad systems perspective. Minsk *(4)* identified many of the parameters pertinent to establishing a framework for the systematic management of snow removal activities. Climatic elements, traffic quantities, equipment capabilities, and the road network were all included in the system description. Personnel management practices, however,

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were left outside the system boundary. In another study *(5)*, a statewide snow and ice control program was dissected into small functional parts. These portions were examined for potential cost savings, and one area, the analysis of various staffing and shift arrangements, was given a high probability of success; improved personnel management could produce an estimated 5 percent reduction in staff expenditures. Responsibility for personnel scheduling was delegated to district-level administrations. The topic was targeted for further research but no concrete suggestions for improvements in the area were offered.

Much of the research related to snow and ice removal operations has focused on the design of optimal snowplowing and chemical-spreading routes. Simulation *(6,7)*, mathematical programming *(8)*, and graph theory *(9)* techniques have all been applied to this portion of the problem. Although this is an interesting topic, routing solutions are not particularly relevant to the reallocation of the work force unless these solutions alter route structures to the extent that the demand for snow and ice removal personnel shifts from one site to another.

Cifelli et al. *(10)* developed parameters and equations to estimate the manpower and equipment requirements of road-clearing operations. These formulas were designed to provide for equitable allocation of existing equipment from the service-level perspective. The number of employees needed to maintain a highway network and the cost of such operations could be estimated through the application of these equations, which considered not only the base manpower requirements of the equipment involved, but also employee benefit time and personnel attrition rates. Provisions for allocating these personnel were not part of that research; the reassignment or transfer of employees was not considered.

Manpower scheduling and allocation separate from the issue of snow and ice removal has been studied within the private sector on a much larger scale. United Airlines *(11)*, for example, developed the Station Manpower Planning System (SMPS) in 1983. This system combined integer and linear programming with network optimization techniques to develop work schedules for 4,000 employees, approximately 8 percent of United Airlines' work force. Although the model addressed the reallocation of excess manpower, this issue was but a small part of a much larger scheduling problem. With the support of several subordinate elements, the SMPS scheduling module solved a matrix of around 5,000 columns, 1,000 rows, and 20,000 elements on an IBM 9081 computer. Thus, the solution techniques employed were not suited to the microcomputer environment.

On a smaller scale, Baker et al. *(12)* considered manpower allocation in terms of cyclic shift scheduling. The problem was to find the minimum number of employees needed to staff a job where the demand for personnel changed in a cyclic pattern. Shifts ran for 8 hr and manpower requirements changed every 4 hr. An algorithm was developed that allowed the generation of solutions "by hand" for small problems. Cyclic shifting cannot, however, be extrapolated to account for personnel requirements that change seasonally.

Satpute *(13)* developed the model Personnel Allocation using Linear Programming (PALP) in the late 1970s. This formulation could be used to assign individuals, grouped into "employee categories" on the basis of their qualifications, to tasks requiring specific skill levels. Associated with the tasks were estimates of the time to job completion and the number of personnel required. Costs (matrix elements) were developed for the assignment of individuals from various skill categories (rows) to specific jobs (columns) and the formulation was driven by a "minimize cost" objective. The model was developed in general terms and could be applied to a broad range of assignment problems. Models such as PALP may become very popular in the microcomputer era.

Even before microcomputer technologies advanced to their present level, researchers began to investigate the issues associated with moving large programs to small machines. Rooney et al. *(14)* examined the problem on the basis of storage, translation, and economic issues. This was, however, an extreme example. A large program was transferred to an intentionally undersized microcomputer system. Storage problems were a major focus of the work, but translation difficulties relating the essential differences between the FORTRAN and BASIC programming languages were also highlighted. A conclusion was that "squeezing large codes onto small machines is now [1982] governed by economics, not necessity."

Some of the concerns involved in moving linear programming software to microcomputers were enumerated by McKay *(15)*. Although this work did not deal with a specific example, it did provide a reminder that different algorithms, while all falling under the general heading of "linear programming," can have very different storage requirements. If the revised simplex is selected over the full-tableau method, for example, storing the inverse matrix in the form of eta vectors and using decomposition techniques to limit the size of these vectors may reduce storage requirements to about 10 to 20 percent of that required to store the explicit inverse. McKay *(15)* estimated that "it would be reasonable to expect a capacity of up to about 150 rows on a machine with an address limit of 64kb and a hardware floating point unit." Finally, in a direct reference to microcomputer technology, McKay states: "Prices of hardware are now sufficiently low that it is usually cheaper to buy a machine of suitable size rather than to spend a great deal of effort in fitting a program into a smaller machine."

Since their emergence some 15 years ago, microprocessor-based computers have drastically changed the potential for integrating analytical models into the public decision-making process. Indeed, advances in computer technology have not ceased to accelerate during this period. Today modern microcomputers far exceed the capabilities of the multimillion-dollar mainframe computers of the early 1970s. Furthermore, research in the areas of hardware architecture *(15)*, networking *(16)*, and artificial intelligence and knowledge-based systems *(7)* suggests that the past influence of computers may be small compared with what might be expected in the future.

These developments will bring new capabilities to a wide range of the public sector at a time when new levels of efficiency are essential. However, hardware is only one side of the issue; the full impact of this technological surge will not be felt until the applications software is available. As Minsk *(4)* pointed out: "System optimization by computer modeling needs further work and refinement and translation into a practical format for wide use by large and small winter maintenance organizations."

OPTIMIZING WINTER PERSONNEL ASSIGNMENTS

The responsibility for the removal of snow and ice from the Indiana Interstate highway system during the winter lies with the Indiana Department of Highways (IDoH). Maintenance operations are conducted out of six separate district offices, each having up to three subdistrict offices *(17)*. Available winter maintenance personnel are assigned to one of up to 20 site locations where vehicles and other equipment are housed. Plowing and abrasive-spreading routes emanate from these facilities.

The assignment of workers to site locations is guided by two related objectives. First, it is desirable that workers be assigned to sites so that the total distance traveled by all workers to all job sites is as small as possible. If the distance that a worker must drive is great, it is possible that he or she might be unable to report to work in extreme emergency conditions. The second major objective in snow and ice control is one of equity; it is desirable to provide a uniform level of service throughout the service area and to distribute the workload as evenly as possible among the work force. This objective is achieved if the distance traveled by each worker to his or her job assignment is close to that of other workers or if the distance traveled by the worker traveling farthest is as small as possible (minimizing the deviation in travel distances may result in assignments to distances greater than necessary or, in some cases, assignments where workers are passing each other on the way to the job site).

In addition to these two major objectives, the design of efficient reassignment strategies must observe resource limitations. A major resource limitation to winter maintenance for IDoH is the availability of state-owned vehicles that can be issued to workers. The policy of IDoH is that if a person is assigned to a site that is not the closest site to his or her home station, and if that is more than 15 mi away, that person must be given use of a state-owned vehicle (see Figure 1). It is important that any reassignment strategy adhere to this policy and still observe a limit on available vehicles.

The personnel reassignment problem may be stated as follows: Find that strategy for the reassignment of summer personnel to snow removal units during the winter such that the total distance traveled by all workers to their respective job sites is as small as possible while keeping the maximum distance traveled by any one worker as small as possible and that requires the issuance of no more vehicles than are currently available. The problem may be complicated by other factors such as worker seniority or other concerns that restrict the range of sites to which an individual worker may be assigned. An effective management tool must be able to accommodate such contingencies.

A technique has been developed for solving the personnel reassignment problem. The methodology employs multiobjective optimization to generate a tradeoff relationship between the objectives of minimizing total travel distance and minimizing maximum travel distance. Demand for workers at each job site and limitations on vehicles are treated as system constraints. The model is solved using a variation of the constraint method of multiobjective optimization discussed by Cohon *(18)* and has thus been titled Systematic Analysis of Noninferior Transfer Assignments (SANTA).

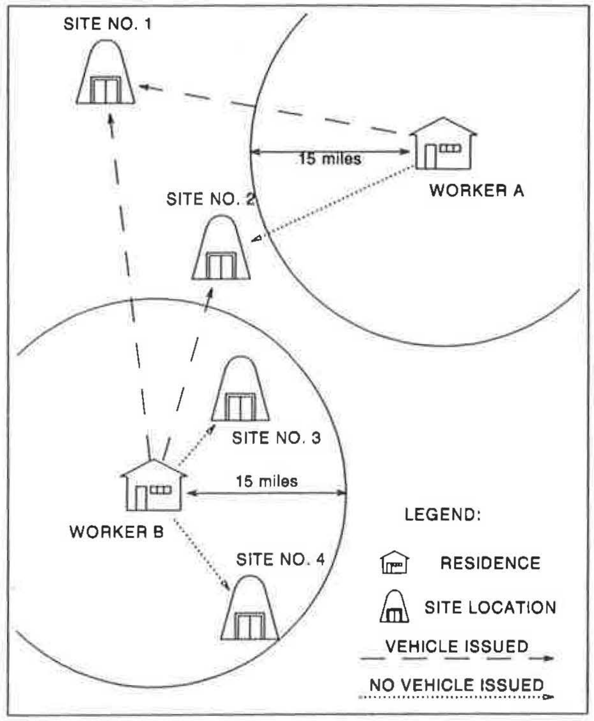

FIGURE 1 Schematic representation of IDoH vehicle assignment policy.

The formulation for the personnel reassignment problem that minimizes maximum travel distance is presented in Table 1. Let *DMAX* be a decision variable representing the maximum travel distance at optimality. The objective function (Equation 1) seeks the assignment strategy that makes this as small as possible. *DMAX* is actually defined by Equation 2, which ensures that *DMAX* is at least as great as each assigned travel

TABLE 1 MODEL FORMULATION FOR MINIMIZING MAXIMUM DISTANCE

$$\text{Minimize } Z = DMAX \tag{1}$$

$$\text{s.t.} \quad DMAX - \sum_{j \in N_i} d_{ij} x_{ij} \geq 0 \quad \forall i \tag{2}$$

$$\sum_{j \in N_i} x_{ij} \leq 1 \quad \forall i \tag{3}$$

$$\sum_{i} x_{ij} \geq T_j \quad \forall j \tag{4}$$

$$\sum_{i} \sum_{j \in N_i} A_{ij} x_{ij} \leq C \tag{5}$$

$$x_{ij} = \{0,1\} \quad \forall i, j \in N_i \tag{6}$$

where:

$A_{ij} = \begin{cases} 1, \text{ if the assignment of worker i to unit j requires a vehicle} \\ 0, \text{ otherwise} \end{cases}$

C = Number of vehicles available fo assignment

D = Maximum allowable travel distance

DMAX = The maximum assigned travel distance

d_{ij} = The distance worker i would travel if assigned to unit location j (miles)

i = The index on workers

j = The index on jobsites

$N_i = \{j \mid d_{ij} \leq D\}$

T_j = Demand for workers at unit location j

$x_{ij} = \begin{cases} 1, \text{ if worker i is assigned to unit j} \\ 0, \text{ otherwise} \end{cases}$

distance $d_{ij}x_{ij}$ when $x_{ij} = 1$ and therefore equal to the largest. Note that the only eligible assignments are those that would require travel of distances shorter than some absolute maximum regardless of whether a state vehicle is assigned. Equation 3 restricts an assignment from being made more than once, whereas Equation 4 ensures that demand for workers at each job site is met. Equation 5 is included to prevent the use of more state-owned vehicles than are available. Equation 6 imposes integrality restrictions on the solution space.

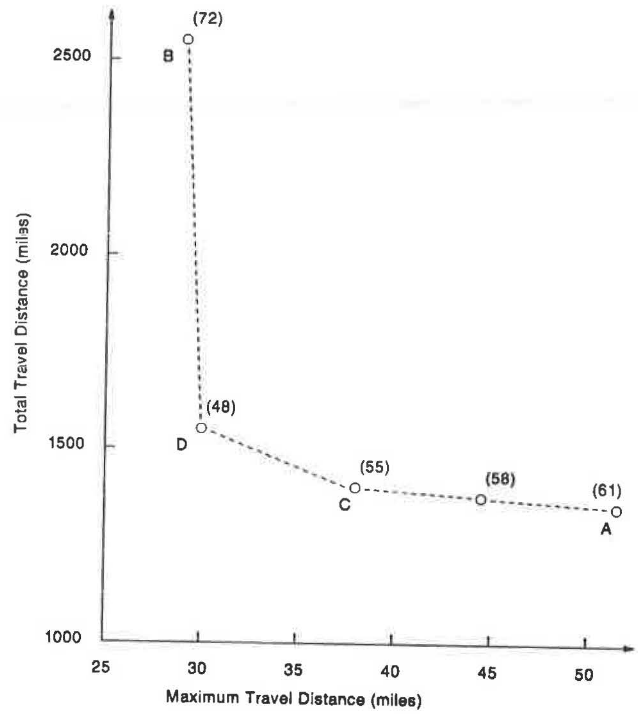

FIGURE 2 Tradeoff curve for distance objectives.

A similar model formulation may be used to address the problem of minimizing maximum travel distance [see report by Wright et al. *(2)*] and together a tradeoff relationship between these two objectives may be generated. An example of this relationship is presented in Figure 2. Each point on the curve in Figure 2 represents a unique personnel assignment profile. Endpoints of the curve represent solutions that result in the shortest overall travel distance (Point A) and shortest maximum travel distance (Point B), whereas the interior points are compromise solutions. The numbers adjacent to each solution indicate the number of vehicles required for that solution. By knowing that the points presented in such a figure represent all efficient solutions, the maintenance engineer responsible for snow control may select the solution that best represents his objectives in personnel management (Figure 2).

INTERPRETATION OF MODEL RESULTS

The SANTA model as implemented in a microcomputer environment *(2)* can be used to generate efficient personnel reassignment strategies like those presented in Figure 2. Each point on the graph of "noninferior" solutions represents a specific personel assignment profile with a unique cost and pattern of resource use. For each solution, a complete multipage assignment report is provided. Figures 3–5 and Table 2 present an example of these assignment reports, the report from the solution corresponding to Point C on Figure 2.

```
        DISTANCE SUMMARY                          VEHICLE SUMMARY
        -------- -------                          ------- -------

   MAXIMUM ALLOWED =     38.0             STATE VEHICLES:
                                            NUMBER AVAILABLE:       55
     TOTAL DISTANCE =  1853.1               TOT. ALLOCATED =        55
                                            TOTAL DISTANCE =    1405.0
   AVERAGE DISTANCE =    14.8               AVERAGE DISTANCE =    25.5

   MAXIMUM DISTANCE =    38.0             PRIVATELY OWNED:
                                            TOTAL DISTANCE =     448.1
       DEV DISTANCE =    38.0               AVERAGE DISTANCE =     6.4

                          ONE-WAY DISTANCE PROFILE

        INTERVAL 0    5    10   15   20   25   30   35   40   45   50
TOTAL    (miles) +--------------------------------------------------+
                 |                                                  |
(36)     0 -  5  |PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP              |
(17)     5 - 10  |PPPPPPPPPPPPPPPPP                                 |
(17)    10 - 15  |PPPPPPPPPPPPPPPP*                                 |
(18)    15 - 20  |P*****************                                |
(13)    20 - 25  |*************                                     |
( 6)    25 - 30  |******                                            |
( 9)    30 - 35  |*********                                         |
( 9)    35 - 40  |*********                                         |
                 +--------------------------------------------------+
                 0    5    10   15   20   25   30   35   40   45   50

                      NUMBER OF EMPLOYEES IN EACH INTERVAL

                          P - PERSONAL VEHICLE
                          * - STATE VEHICLE
```

FIGURE 3 Assignment summary statistics format.

POSSIBLE ALTERNATE ASSIGNMENTS

Baillieul R	to UNIT 4301	Lietzan W	to UNIT 4501
Bell B	to UNIT 4301	Ludwig J	to UNIT 4502
Carey R	to UNIT 4101	Rynearson K	to UNIT 4103
Ewing R	to UNIT 4102	Standifer L	to UNIT 4702
Gastineau D	to UNIT 4402	Stigen L	to UNIT 4102
Kinsey M	to UNIT 4202	Strom J	to UNIT 4701
Leinbach E	to UNIT 4501	Weatherwax K	to UNIT 4201

FIGURE 4 Alternative assignments report format.

The first page of each report (Figure 3) presents a summary for the current solution for the districtwide solution. The Distance Summary presents statistics that may be of interest to the personnel manager, including the maximum travel distance allowed by the model, the total (one-way) travel distance by all workers, the average travel distance, the maximum travel distance assigned by the model, and the maximum deviation in distances (the difference in travel distance between the worker who travels the farthest and the one who travels the shortest distance to work). The Vehicle Summary provides summary information about the requirements for state-owned vehicles dictated by the current solution in comparison with privately owned vehicles. At the bottom of the first page of output, a histogram showing the overall assignment profile is provided indicating the distance frequency for the current assignment. The assignment summary provides the decision maker with an efficient means of comparing different assignment strategies.

The second page of the assignment report (Figure 4) provides a list of possible alternative assignments that were "discovered" by the solution process *(1)*. For example, with the current solution, it would be possible to make an assignment for worker Carey (to Unit 4101) that is equally as good as his current assignment (Unit 4302 from Table 2). Finding this new assignment profile would require rerunning the SANTA model and "fixing" worker Carey to Unit 4101, a capability that is available with this model. The list of possible alternative assignments is provided so that the personnel manager may exercise some degree of subjective judgment in making assignments without drastically changing the quality of the overall solution.

The actual personnel site assignments are listed beginning on the third page of the assignment report form (Table 2). This is simply an alphabetical listing of workers, their site assignments, and mileage to work and an indication as to whether a vehicle must be assigned. The same information is provided organized by subdistrict and unit location (Figure 5).

The overall assignment report is provided for each feasible solution determined by the model. The model is designed to be executed on an IBM PC/XT or AT running the DOS 3.0 operating system and supported by a math coprocessor

TABLE 2 JOBSITE ASSIGNMENT REPORT FORMAT

ASSIGNMENT REPORT

	EMPLOYEE	UNIT	MILES		EMPLOYEE	UNIT	MILES
*	Allen K	4102	19.0	*	Howard H	4502	21.0
	Alverez A	4701	9.0	*	Hudson M	4102	34.0
	Arens B	4103	4.0	*	Insco F	4501	28.0
*	Armstrong D	4702	24.0		Jacks R	4103	1.0
	Atkinson T	4202	2.0		Jackson J	4701	9.0
	Baillieul R	4602	1.0		James L	4601	15.0
	Baker D	4302	7.0	*	Johnson B	4702	32.0
	Barta M	4701	11.0		Johnson R	4701	11.0
*	Bell B	4302	29.0		Jones J	4701	9.0
*	Berg K	4702	37.0		Jones T	4701	9.0
*	Bohm D	4102	34.0	*	Kemp J	4702	16.0
	Bradfield R	4702	16.0	*	Kinsey M	4201	22.0
	Brown K	4101	12.0		Kroening R	4103	1.0
*	Cain E	4402	21.0	*	Kruzick C	4102	34.0
*	Carey R	4302	29.0	*	Lamb M	4301	36.0
	Chrzan R	4302	3.0		Lane K	4302	12.0
*	Collins M	4702	24.0		Larson C	4701	1.0
	Crane S	4101	1.0		Leinbach E	4102	10.0
*	Dalka C	4501	32.0	*	Lemay R	4502	21.0
	Donovan P	4302	2.0		Lemons E	4701	10.0
	Edging S	4301	4.0		Lestinsky S	4101	5.0
*	Egolf B	4702	27.0	*	Lietzan W	4502	16.0
*	Ekovich A	4502	15.0		Link H	4101	1.0
*	England W	4502	21.0	*	Lorenz R	4501	37.0
	Epley B	4502	5.0		Lotter R	4101	1.0
	.	.	.		.	.	.
	.	.	.		.	.	.
	.	.	.		.	.	.

* State Vehicle Issued

```
                    SUMMARY FOR SUBDISTRICT 4500

UNIT:  4501      DEMAND:   7           SUBDISTRICT LISTING
---------------------------           -------------------
 1. * Dalka C              32.0        1. Dalka C          4501
 2. * Henrichs G           28.0        2. Ekovich A        4502
 3. * Insco F              28.0        3. England W        4502
 4. * Lorenz R             37.0        4. Epley B          4502
 5. * Marshall W           37.0        5. Hammons J        4502
 6. * Mougin M             36.0        6. Henrichs G       4501
 7. * Ropp W               30.0        7. Henry L          4502
                                       8. Howard H         4502
                                       9. Insco F          4501
                                      10. Lemay R          4502
UNIT:  4502      DEMAND:  12          11. Lietzan W        4502
---------------------------           12. Lorenz R         4501
 1. * Ekovich A            15.0       13. Marshall W       4501
 2. * England W            21.0       14. Mougin M         4501
 3.   Epley B               5.0       15. Pope J           4502
 4. * Hammons J            21.0       16. Ropp W           4501
 5. * Henry L              21.0       17. Rundzaitis A     4502
 6. * Howard H             21.0       18. Rynearson K      4502
 7. * Lemay R              21.0       19. White D          4502
 8. * Lietzan W            16.0
 9.   Pope J                4.0
10.   Rundzaitis A          5.0
11. * Rynearson K          21.0
12.   White D               3.0
```

FIGURE 5 Unit-specific assignment report format.

TABLE 3 EVALUATION OF MODEL RESULTS

Item	Season 1983–1984[a]	1984–1985[b]
Personnel	85	118
Vehicles	75	48
Total distance (mi)	2,017	1,540
Maximum distance (mi)	56	30
Average Distance (mi)	24	13

[a]Solution used for the 1983–1984 winter season developed without the SANTA model.
[b]Solution used for the 1984–1985 winter season developed using the SANTA model.

[optional but very important for reasonable performance *(19)*]. Each solution requires approximately 15 min of running time *(2)*. Experience has shown that the entire noninferior solution for a given assignment problem may be generated by using SANTA in a matter of a few hours, even by an inexperienced user.

A dramatic indication of the value of the information provided by SANTA is provided in Table 3. Several assignment parameters are presented for each of two actual personnel assignments; the first, the 1983–1984 assignment for an IDoH district office and the second, the 1984–1985 assignment for the same district office. The 1983–1984 assignment strategy was generated manually, without the aid of a model of any kind, whereas the 1984–1985 solution was incorporated directly as generated by SANTA. (This solution corresponds to that indicated by Point D on Figure 2.) Though the requirements for personnel were different (85 in 1983–1984 compared with 118 in 1984–1985), the overall improvement in assignment effectiveness is clear. It has been estimated that the overall cost savings to the state were approximately $100,000 during the winter season for this single district alone *(1)*. Since that time, the model has been used by other district offices with similar results. Work is currently under way to link the model to a personnel database with the intent to help manage operations on a weekly or biweekly schedule.

CONCLUSIONS

The SANTA model has proven successful in its ability to aid personnel managers in making important decisions about the reassignment of summer highway construction workers to winter maintenance operations in the state of Indiana. The model is easy to use and able to be supported by relatively inexpensive computer hardware. Most important, SANTA provides the decision maker with an explicit indication for the range of choice available to develop useful personnel reassignment strategies.

Beyond the identification of efficient assignment strategies, SANTA may also be used to justify those strategies by its ability to give an explicit indication of the inferiority of other solutions. For example, the user may wish to demonstrate how the current solution is better than some other solution by running SANTA in a mode that allows specific assignments to be made. Still other possible uses for the model would be in personnel hiring decisions or to aid in making decisions about modifications to existing route designs and related demand for personnel.

Modern computer technology has advanced to the point where sophisticated modeling algorithms can be made available to decision makers at remote locations in a cost-effective manner. The SANTA model is an example of the successful incorporation of such technology into the arena of highway maintenance operations.

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Natural Brine as an Additive to Abrasive Materials and Deicing Salts

RONALD W. ECK, WILLIAM A. SACK, AND RONALD TICKLE

Large quantities of natural oil and gas field brines are available at little or no cost at many locations in the Appalachian Region. Because these brines contain significant quantities of both sodium and calcium chloride salts, they appear to be an attractive substitute for conventional chemicals as an additive to abrasive materials and as a prewetting agent for deicing salts. Such additives are used for freezeproofing abrasive stockpiles and improving salt's performance as a deicing chemical. To evaluate the technical and economic feasibility of using brine in these applications, five abrasives (bottom ash, cinders, sand, sawdust, and limestone) were studied. It was found that the first four could be freezeproofed effectively over a wide range of initial moisture contents and at temperatures as low as 10°F when natural brine with total dissolved solids (TDS) of 265 670 mg/L was used. Overall, few trends or generalizations can be drawn between the various abrasives; each brine-abrasive combination must be considered as an individual case when freezeproofing application rates are developed. For limestone, application of brine for freezeproofing is limited by the physical properties of the aggregate. Only limestone containing less than or equal to 3 percent initial moisture could be freezeproofed. Spraying brine on the abrasive materials as a stockpile is being formed, followed by supplemental applications dictated by the frequency and intensity of precipitation, appears to be the optimum procedure for freezeproofing stockpiles. The highway agency should have brine storage tanks at its maintenance stations to assure a reliable brine supply when needed during storm periods. Laboratory tests were conducted to evaluate the use of brine as a prewetting agent for rock salt. Results of melting, penetration, and bounce-off tests for the natural brine used indicated performance almost identical to that of a 32 percent solution of calcium chloride. It was concluded that prewetted salt initiated slightly more rapid melting compared with dry salt, but there did not appear to be a significant difference. Wetted salt stayed closer to the point of contact than dry salts. As the liquid application rate increased, there was a small but not significant reduction in bounce-off.

Increased public demand for bare pavements throughout the winter months has led highway agencies to greater reliance on sodium and calcium chloride deicing agents. Advantages of sodium and calcium chlorides include ease of application, solubility in water, and effectiveness as a melting agent. In recent years, however, the costs of sodium and calcium chlorides have increased to the point where providing a bare pavement places a serious financial strain on highway agencies. Tight operating budgets and the adverse environmental impacts associated with increased salt usage have led these agencies to seek less use of traditional deicing chemicals.

For a number of years, highway agencies have used abrasive materials in conjunction with salts to provide traction and deicing. Abrasives are especially helpful in very cold weather when deicing salts are not effective and to provide a traction aid when clear plowing is not possible. Statistics compiled by the Salt Institute *(1)* indicate that use of abrasives has risen in many regions of the country as the cost of chemical deicing agents has increased.

Limited amounts of sodium or calcium chloride, or both, are usually added to abrasive materials. The salt prevents the abrasives from freezing both in the stockpiles and in the mechanical spreaders. In addition to decreasing pavement slipperiness, such a mixture also has the capability of melting snow during periods when air temperature rises.

Usually conventional dry chemicals are mixed with abrasive materials. In recent years, however, there has been increased interest in using liquid calcium chloride as a substitute for conventional dry chemicals. This liquid can be sprayed over rock salt just before application (a concept referred to as "prewetting") or it can be mixed with abrasive materials alone to provide stockpile freezeproofing and some melting capability. Although several agencies *(2–5)* have reported success with liquid calcium chloride, a primary drawback to its use is the relatively high cost of the material.

Large quantities of natural oil and gas field brines are available at little or no cost at many locations in the Appalachian Region of the eastern United States. These brines, whose major ionic species include chloride, sodium, calcium, magnesium, and potassium, are usually much more concentrated than seawater. For example, seawater contains about 20 000 mg/L of chloride, whereas the content in oil and gas field brines from the eastern United States may range from 15 000 to 350 000 mg/L of chloride. Recently completed research at West Virginia University *(6)* assessed the deicing potential of a number of West Virginia brines.

Because these brines contain significant quantities of both sodium and calcium chloride salts, they would appear to be an attractive substitute for conventional chemicals as an additive to deicing salts and abrasive materials. However, a review of the literature indicates that there is virtually no documented information on this application of natural brine. Thus, it seemed appropriate to investigate the technical and economic feasibility of using natural brine as an additive to deicing salts and abrasive mixtures. The work was a logical extension of the previously mentioned research *(6)*, which focused primarily on the deicing potential of direct application of brine to snow- and ice-covered pavements.

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STUDY OBJECTIVES

The overall objective of the research project described here was to assess the feasibility of using West Virginia oil and gas field brines as an additive to deicing salts and abrasive mixtures. Several specific objectives were established to complete this assessment:

- To mix brine with bottom ash, cinders, limestone chips, sand, and sawdust to determine application rates required to prevent freezing of stockpiles under typical winter conditions in West Virginia.
- To identify efficient procedures for mixing brine with the identified abrasive materials and, on this basis, determine the costs associated with using brine in abrasive mixtures.
- To assess the technical and economic feasibility of using natural brine to prewet rock salt and to establish appropriate application rates.

Two aspects of brine were studied primarily: as an additive to abrasives and as a prewetting agent for salt. The acquisition and characterization of the materials used in the study are discussed in the following section. This is followed by sections on use of brine to freezeproof abrasives and on brine as a prewetting agent. Included in these latter two sections are descriptions of the test procedures used along with summaries of results in both narrative and graphical form.

MATERIALS ACQUISITION AND TESTING

Brine

The brine used was obtained from one of two brine storage tanks located at the Sabraton Maintenance Station of the West Virginia Department of Highways (WVDOH). These tanks were used to provide brine for a separate but related project involved with assessing the field performance of brine as a deicing agent. This brine was a combination of four brines obtained from the following West Virginia counties and geologic formations: Raleigh (Maxon), Boone (Weir and Big Lime), Lewis (Fifth), and Wood (Oriskany).

The brine was subjected to a series of tests to determine its physical and chemical characteristics. Of prime importance to this study was the relative strength of the brine as measured by the amount of total dissolved solids (TDS), sodium and calcium chlorides (NaCl, CaCl), and the existence of any potential water-polluting heavy metals such as lead (Pb) and barium (Ba). A partial physical and chemical evaluation of the brine is as follows:

Component	*Amount (mg/L)*
TDS	265 670
Chlorides	153 630
Sodium	78 600
Calcium	19 610
Lead	4.5
Barium	3.02

Abrasive Materials

The abrasive materials studied in this project were bottom ash, cinders, limestone, sand, and sawdust. They were obtained from the original suppliers rather than from stockpiles at the Sabraton Maintenance Station for two reasons: (a) a relatively large volume was required and (b) much of the material at the Sabraton site had been freezeproofed with sodium chloride the same day that it was delivered. Thus, to ensure a large uncontaminated sample for testing, the original suppliers were selected.

The nature of some of the abrasives is important. The limestone was a high-calcium variety obtained from a local quarry. The sand used was of natural origin. The sawdust was produced from walnut, poplar, and cherry cuttings.

After being screened of all materials not passing a 1/2-in. sieve, the abrasives were screened by using the following sieve sizes: 3/8 in., No. 4, No. 8, No. 16, No. 50, and No. 100. Gradation curves were plotted and compared with WVDOH standards. Gradation data for the five abrasives are given in Table 1. In addition to the gradation analysis, dry bulk densities were determined for each abrasive as follows:

	Dry Bulk Density	
Abrasive	*Kg/m^3*	*Lb/yd^3*
Bottom ash	1390	2,340
Cinders	750	1,260
Limestone	1400	2,360
Sand	1400	2,360
Sawdust	205	345

USE OF BRINE TO FREEZEPROOF ABRASIVES

Freezeproofing Tests

The use of dry salts to freezeproof abrasive stockpiles is widespread. For example, West Virginia policy *(7)* calls for the

TABLE 1 GRADATION DATA FOR FIVE ABRASIVES CONSIDERED

	Percentage of Fines by Sieve Size						
Abrasive	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 100
Bottom ash	100	95.5	75.2	51.0	29.1	6.4	3.5
Cinders	100	79.9	38.9	18.9	9.4	1.9	1.8
Limestone	99.2	96.6	51.9	19.0	10.2	3.4	1.9
Sand	100	100	100	99.7	99.2	26.6	7.6
Sawdust	99.3	98.9	96.7	90.7	38.0	1.4	0.1

addition of 100 lb of dry salt per cubic yard of abrasives. Liquid salts, both commercially prepared calcium chloride and natural brine, are also in use for freezeproofing. One oil and gas producer reported the use of natural brine on limestone piles in Pennsylvania at an application rate of approximately 6 gal/ton. It was observed that brine application quickly melted any frozen crust that may have formed and produced a workable stockpile.

During the literature review, no formal studies of abrasive stockpile freezeproofing requirements (for either dry or liquid chemicals) were found. Apparently the available published guidelines and rules of thumb were developed empirically on the basis of experience over time for a particular location. Thus, no standard test procedure was available to evaluate freezeproofing. The freezeproofing experiments developed in this study were designed to determine the feasibility of utilizing natural brine as a freezeproofing agent to ensure free-flowing abrasive supplies under winter conditions.

One of the first tasks was to determine the saturation value of the five abrasives under free-draining conditions. Addition of brine will obviously raise the moisture content of a stockpile. In order to avoid oversaturation and runoff, saturation values must be known. Saturation moisture contents obtained are as follows: bottom ash, 35 percent; cinders, 50 percent; limestone, 7 percent; sand, 24 percent; and sawdust, 250 percent. Tests on subsequent batches of the abrasives showed some variation from batch to batch.

Each of the abrasive materials was mixed with a known quantity of water to achieve a desired moisture content. Moisture contents evaluated ranged from 0 percent (no water added) to nearly saturated values. A known quantity of freezeproofing agent was then mixed with the abrasive. Application rates of 25, 50, 75, and 100 lb (dry basis) /yd^3 were used in most cases. Both brine and dry salt were evaluated as freezeproofing agents for purposes of comparison. With a cold room, the mixes were subjected to three different freezing temperatures (10, 18, and 26°F) to determine the mix proportions required to prevent stockpiles of each of the materials from freezing.

At the completion of the 24-hr freezing period, the abrasive mixtures were analyzed in the cold room to determine their workability and ability to be free-flowing. Because no literature had been found containing information on freezeproofing criteria, the investigators developed their own. The criteria involved two properties of the abrasive mixtures: (a) the percentage by weight of the abrasive retained on a 1/2-in. sieve (after moderate agitation) and (b) the hardness of the material retained. Hardness was evaluated by the resistance to the penetration into the undisturbed stockpile of a steel probe, and by the resistance to a squeezing pressure, applied by hand, of the material retained on the sieve. Although the results of these procedures may appear to be highly subjective, repetitive tests using identical mixtures and analyzed separately by each of two investigators performing these laboratory tests showed that the test results could be reproduced. The specific details of the criteria employed to determine the freezeproofing class of the abrasive mixtures are presented in the project final report *(8)*.

The results of the sieve analysis and the hardness-factor determination of the test pile allowed categorization of each of the mixtures tested into one of five freezeproof classes: A, B, C, D, or E. Mixtures in Classes A and B were defined as "freezeproofed" and considered to be free-flowing and workable. Class C represents an intermediate zone, in which the stockpile consisted of either a large chunk retained on the sieve or of hard material that had smaller amounts retained on a 1/2-in. sieve. Classes D and E were determined to be nonworkable, or "not freezeproofed."

Test Results

Space limitations preclude discussion of individual test results for each of the five abrasives tested. To illustrate the testing performed for each abrasive, the results for cinders will be presented as an example, along with a summary of results for the remaining abrasives. Figure 1 shows the linear relationship that exists between the initial moisture content of the cinders and the amount of brine that can be added without runoff. It is

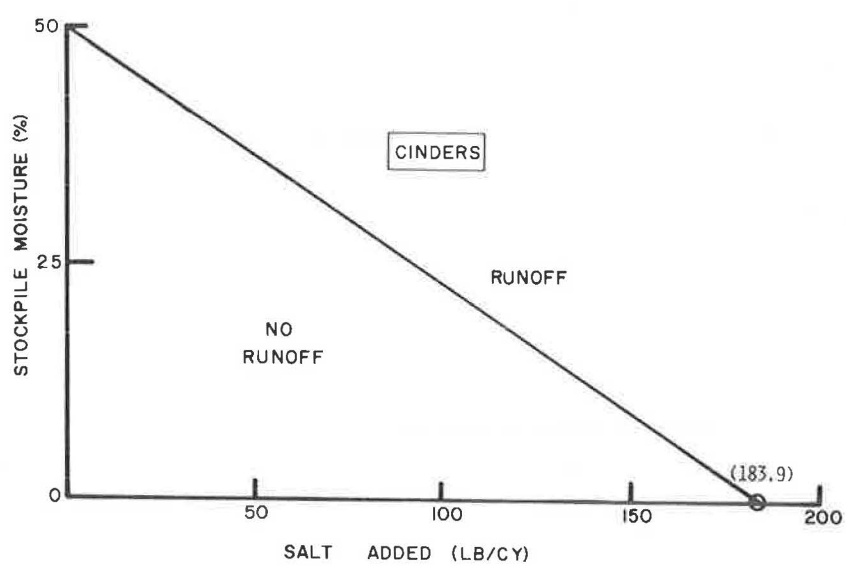


FIGURE 1 Initial stockpile moisture versus brine application rate for cinders (brine TDS = 265 670 mg/L).

TABLE 2 RESULTS OF FREEZEPROOF TESTS FOR CINDERS

Initial MC of Stockpile (%)	Brine Tests[a] 25 lb/yd³ Final MC (%)	25 lb/yd³ Temperature (°F) at Freezeproofing 10	18	26	50 lb/yd³ Final MC (%)	50 lb/yd³ Temperature (°F) at Freezeproofing 10	18	26	75 lb/yd³ Final MC (%)	75 lb/yd³ Temperature (°F) at Freezeproofing 10	18	26	100 lb/yd³ Final MC (%)	100 lb/yd³ Temperature (°F) at Freezeproofing 10	18	26	NaCl Tests: Application Rate and Temperature (°F) at Freezeproofing 50 lb/yd³ 10	18	26	100 lb/yd³, 10
0	6.8	F	F	F	13.6	F	F	F	20.5	F	F	F	27.3	F	F	F	F	F	F	F
10	16.8	F	F	F	23.6	F	F	F	30.5	F	F	F	37.3	F	F	F	F	F	F	F
20	26.8	F	F	F	33.6	F	F	F	40.5	F	F	F	47.3	F	F	F	F	F	F	F
30	36.8	–[b]	–	F	43.6	–	–	F	50.5	F	F	F	–[c]	–	–	–	F	F	F	F
40	46.8	–	–	F	53.6	–	–	F	–[c]	–	–	–	–[c]	–	–	–	F	F	F	F
45	51.8	–	–	F	–[c]	–	–	–	–[c]	–	–	–	–[c]	–	–	–	–	F	F	F
50	–[c]	–	–	–	–[c]	–	–	–	–[c]	–	–	–	–[c]	–	–	–	–	–	F	F

NOTE: MC = moisture content = weight of water/weight of solids. F = freezeproofed.

[a]Brine at 265 670 mg/L.
[b]No freezeproofing.
[c]Cinders are saturated at 50 percent moisture; therefore no brine can be added without undesirable runoff.

indicated that the maximum amount of brine TDS that can be added to dry cinders is approximately 184 lb/yd^3; this amount decreases as the initial moisture content of the cinders increases.

The results of the freezeproof testing of cinders are shown in Table 2. Both the brine and rock salt additions and their freezeproofing abilities at the three experimental temperatures are given. From Table 2, it can be seen that when the test brine is applied at a rate of 25 lb/yd^3, an additional 6.8 percent water is added. This means that no brine can be applied to an almost saturated stockpile at 50 percent initial moisture. Cinders containing more than 30 percent initial moisture can be freezeproofed with the addition of brine at the rates of 25 and 50 lb/yd^3, but only at the highest test temperature of 26°F. With the addition of 75 lb/yd^3 of brine salts, however, cinders containing 30 percent initial moisture can be effectively freezeproofed at all experimental temperatures. This appears to be the optimum brine application rate capable of freezeproofing cinders of 30 percent initial moisture and less while minimizing the amount of salt exposed to the environment.

As shown in Table 2, the 50-lb/yd^3 application rate of dry rock salt performs better than an equivalent application rate of brine. This is attributable to the lower moisture content of the stockpile in the salt tests compared with that in the brine treatment. Even at 45 percent moisture, the dry NaCl freezeproofed at all but 10°F. Applying 100 lb of rock salt per cubic yard freezeproofed all moisture contents at 10°F.

Summary curves relating the initial moisture content of the cinder stockpile and the resulting TDS at the final moisture content were prepared. Separate curves were prepared for each temperature; however, only the results at 18°F are shown in Figure 2 for sake of brevity.

A summary of the results of freezeproof testing for all five abrasives is given in Table 3 for 10°F. Included are observed stockpile in situ moisture contents for limestone, sand, and sawdust. The cinders had essentially zero moisture when collected directly from the hopper at the heating plant. Table 3 shows that four of the abrasives (bottom ash, cinders, sand, and sawdust) can be freezeproofed effectively by utilizing natural brine at temperatures down to 10°F. Application of brine for freezeproofing is limited in limestone because of its low saturation capacity of only 7 percent. As noted in Table 3, the maximum initial moisture content of limestone that could be freezeproofed by brine without runoff was only 3 percent. This value is below the in situ moisture contents actually obtained during limited stockpile sampling.

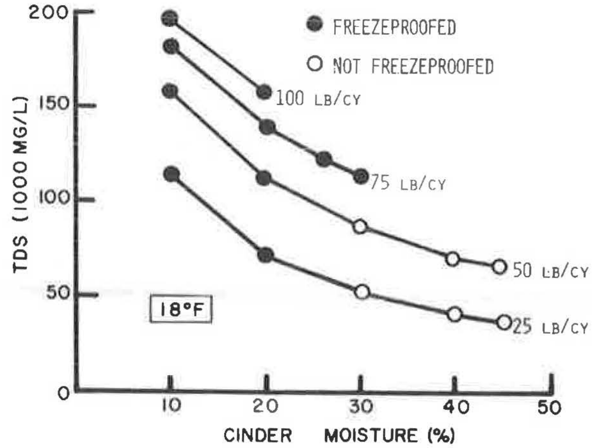


FIGURE 2 Initial moisture content of cinder stockpile versus total dissolved solids of final moisture content at 18°F.

Also shown in Table 3 are the brine application rates required (in pounds per cubic yard) and the weight of salt required per ton of abrasives (dry basis). Application rates required varied from 25 to 100 lb/yd^3, which is within expected ranges. For example, Landsness *(9)* reported the use of up to 75 lb/yd^3 of dry salt for freezeproofing sand in Wisconsin. Table 3 shows that the weight of salt per ton of abrasive varied from 22 lb/ton (limestone) to 119 lb/ton (cinders) except for sawdust, which required 290 lb/ton. The higher value for sawdust is to be expected because of its markedly different physical properties. Keyser *(10)* recommended the use of 50 to 100 lb of salt per ton of abrasive and hence the foregoing data (except for sawdust) are close to this range.

Brine Application and Economic Evaluation

Several different approaches for application and mixing of brine with the abrasives were considered. The freezeproofing procedure recommended here is one that has been used by the Pennsylvania Department of Transportation (PennDOT) in Clearfield County. Brine is sprayed on the stockpile, preferably as it is being formed. This is done by the oil or gas producer with a pump on the brine delivery truck. Small applications at several intervals are made so as to ensure that no runoff occurs. Supplemental applications may be required later as dictated by the frequency and intensity of precipitation. This method

TABLE 3 RESULTS OF FREEZEPROOF TESTING WITH BRINE AT 10°F

Abrasive	Saturation Moisture Content (%)	Stockpile in Situ Moisture (%)	Maximum Initial Moisture That Can Be Freezeproofed (%)	Brine Application Rate To Freezeproof at Maximum Moisture (lb/yd^3)	Final Moisture Content (%)	Weight of Salt Divided by Weight of Abrasive (Dry) (lb/ton)
Cinders	50	N.A.	30	75	50	119
Bottom ash	35	17–20	15	100	29.7	85
Limestone	7	3–7	3	25	7	22
Sand	24	8–20	10	50	17.3	43
Sawdust	250	72–102	100	50	150	290

requires no stockpile mixing, thus saving man hours and machine time, as compared with conventional methods of mixing dry salt with abrasives by using an endloader.

A cost estimate for freezeproofing a 900-ton pile of bottom ash at 100 lb/yd^3 was made by using both brine and dry salt. The estimate included costs for manpower and equipment following guidelines suggested by WVDOH maintenance personnel. The estimate assumes that a brine storage tank (steel) will be built at the maintenance station so as to have brine available at all times. It is assumed that the brine supplier will deliver the brine free of charge to the storage tank. If the highway agency pays for the storage tank, use of brine becomes the lower-cost alternative when dry salt costs reach $35.60/ton. During the winter of 1985–1986, WVDOH paid an average of $33/ton. On the other hand, discussions with oil and gas companies suggest that the companies would be willing to continue to furnish steel tanks at no cost to the highway agency, as was done during this pilot study. If this were the case, cost savings on the order of $1,500 per year per stockpile could be realized.

BRINE AS A PREWETTING AGENT FOR SALT

Prewetting Effectiveness Tests

One of the research tasks was to develop test procedures to assess the feasibility of using natural brine as a prewetting agent. This assessment included effectiveness tests for both melting and bounce-off.

Common highway rock salt was utilized to compare the melting performance of dry rock salt (NaCl) to rock salt prewet with natural brine and with liquid calcium chloride. Performance was characterized by two criteria: (a) the volume of ice melted and (b) the average depth to which the salt penetrated into an ice block.

The rock salt used was obtained from stockpiles of the Sabraton Maintenance Station of the WVDOH. The natural brine used in the prewetting effectiveness tests was the same as that which had been used in the abrasive testing. For comparison purposes, a 32 percent calcium chloride solution (commonly used in practice) was prepared by dissolving solid calcium chloride in distilled water. The rock salt was prewet at the rate of 10 gal/ton of rock salt with either the brine or the calcium chloride just before application to the ice.

A layer of ice was frozen in 4.5-in. diameter metal test cans in the cold room (relative humidity of approximately 40 percent). Ten grams of rock salt were applied per ice sample and permitted to react with the ice for specified periods of time. Note that this application rate far exceeds traditional roadway application rates; the high application rate was chosen because preliminary testing indicated that traditional application rates produced insignificant quantities of meltwater. After each specified time period, the meltwater was decanted and collected in a graduated cylinder. Particles of salt were manually dislodged from the ice. A tire-tread depth gauge was used to measure the extent to which the rock salt had penetrated into the ice. Five separate depths were measured at random for each sample and averaged to yield depth of penetration. All tests were run in duplicate or triplicate at 18 and 8°F. Because time constraints did not permit running the experiment at all three temperatures, the two lower temperatures were chosen to provide a more severe test.

Another purported benefit of prewetted salt is that it reduces salt loss due to bounce-off. One task of the research effort was to develop a procedure for measuring the amount of bounce-off that could be used to compare dry rock salt with prewetted salt. The literature provided little guidance in the way of experimental procedures; only one published study *(11)* could be found dealing with the bounce and scatter characteristics of dry versus wet salt. The test reported was made during the summer using actual spreading equipment on an unopened section of Interstate highway. Project resource and time constraints precluded a similar approach in this case. A number of different field and laboratory procedures were tried. The procedure selected, because it demonstrated the best reproducibility, involved dropping salt from a specified height onto a bull's-eye marked on a concrete surface and measuring the fraction of salt in each ring.

Three forms of salt were used in the experiment: dry rock salt, rock salt mixed with a 32 percent calcium chloride solution, and rock salt mixed with brine solution. For the wetted salt, application rates of 8, 10, and 12 gal/ton were used. For all tests, a 10-g sample of rock salt was used. With a plastic spatula, the samples were pushed off a level surface from a height of approximately 36 in. onto a relatively smooth concrete floor. Five concentric circles drawn on the floor divided the drop zone into five ring-shaped areas, as shown in Figure 3.

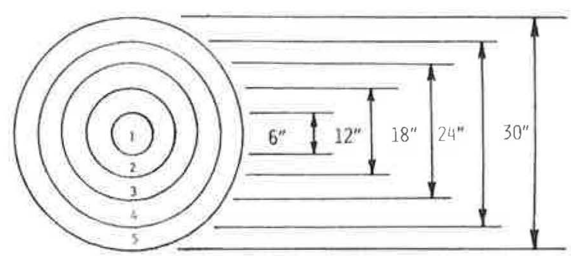


FIGURE 3 Arrangement of concentric circles used in salt bounce-off experiment.

The quality of salt accumulated in each of the five areas was collected and weighed. The fraction of the total sample in each area was determined. Five replications of the drop test were performed; the values presented in the following section represent the averages of the five tests.

Test Results

Results of the prewetting melting effectiveness tests are plotted in Figure 4. Data for the liquid calcium chloride are not plotted because they are similar to the natural brine results. The conclusions reached for the natural brine apply equally well to the liquid calcium chloride. At 18°F, in comparing dry rock salt with the two prewetted salts, the largest variation occurred at the 5-min duration. The difference between dry and wetted salt, in terms of volume of melt, decreased with time. As noted in Figure 4, the difference between the volume of melt produced by the dry rock salt and that produced by prewetted salt was less than 10 percent for durations of 10 min or more.

Although, as expected, melt volumes were lower at 8°F, the relationship between dry and prewetted salt was generally the

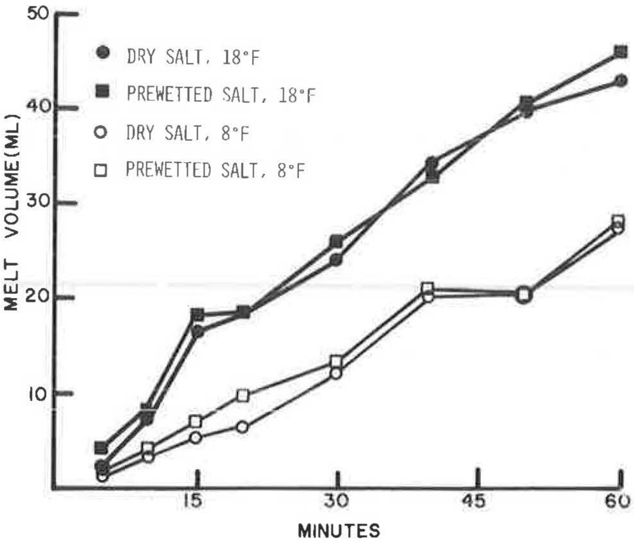


FIGURE 4 Volume of melt by brine-prewet and untreated rock salt as a function of time and temperature.

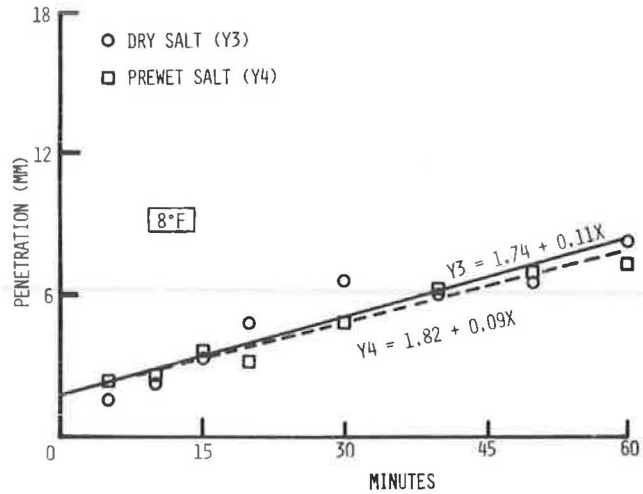


FIGURE 6 Penetration of prewet and untreated rock salt as a function of time at 8°F.

same as that at 18°F. The quantity of melt produced by the prewetted salt after 5 min was greater than that produced by dry rock salt. However, after 30 min, the amount of melt produced by the dry rock salt and the prewetted salt differed by less than 5 percent.

These results agree with what would be expected intuitively. The reason for prewetting is to initiate a melt rather than to melt more ice. Test results show that more prewetted salt went into solution than dry salt. After 5 min, however, more dry salt was available to go into solution. Theoretically, the same amount of melt should be produced by both the prewetted and dry salt. In practice, the results shown will vary with humidity and available free water on the ice or snowpack.

Plots of depth of penetration as a function of melting time are shown in Figures 5 and 6 for 18 and 8°F, respectively. At 18°F, the prewetted salt had a higher initial penetration and appeared to maintain a slightly higher rate of penetration as time went on. At 8°F, there was very little difference in rate of penetration between the dry salt and the prewetted salt.

To provide a more thorough evaluation of the relationships among the four conditions examined, a least-squares regression line was fitted to each set of points. Regression lines for the dry salt and the prewetted salt at 18°F are shown in Figure 5. The general linear test for the equality of two regression lines was used (at the 95 percent level of confidence) to determine whether the regression lines for depth of penetration for dry salt and prewetted salt were the same.

Results of the general linear test for the 18°F data indicated that the linear regression functions for the two penetration lines were the same. No formal analysis was performed for the 8°F data because it could be seen that there was less difference between the dry salt and prewetted salt lines than there had been at 18°F. Thus it was concluded that there was no statistically significant difference for either the initial penetration or the rate of penetration between dry rock salt and prewetted rock salt.

Bounce-off test results are shown in Figure 7. It is apparent that the dry rock salt spread out more than the wetted salts. The percentage of dry salt in each area was more uniform than that for the wetted salts, which were concentrated near the drop point in Areas 1 and 2. Thus, it can be concluded that the wetted salts stayed closer to the point of contact than the dry salts. As the application rate for brine increased, bounce-off was reduced; results for calcium chloride were not conclusive. There was virtually no difference in bounce-off characteristics between salts mixed with brine and those mixed with calcium chloride at the 12 gal/ton application rate; there was some difference at the other application rates.

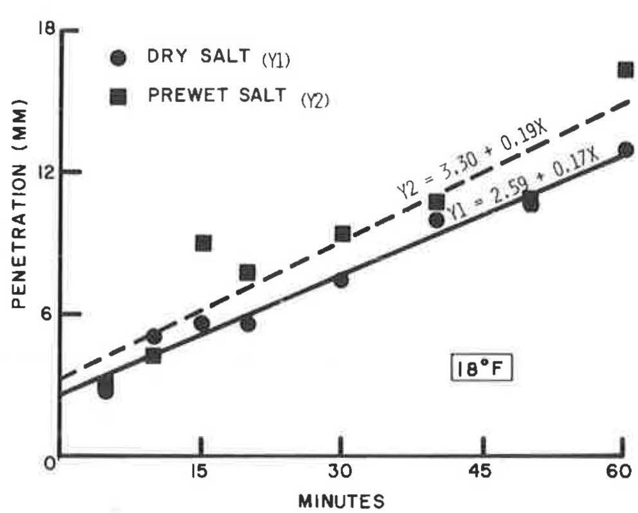
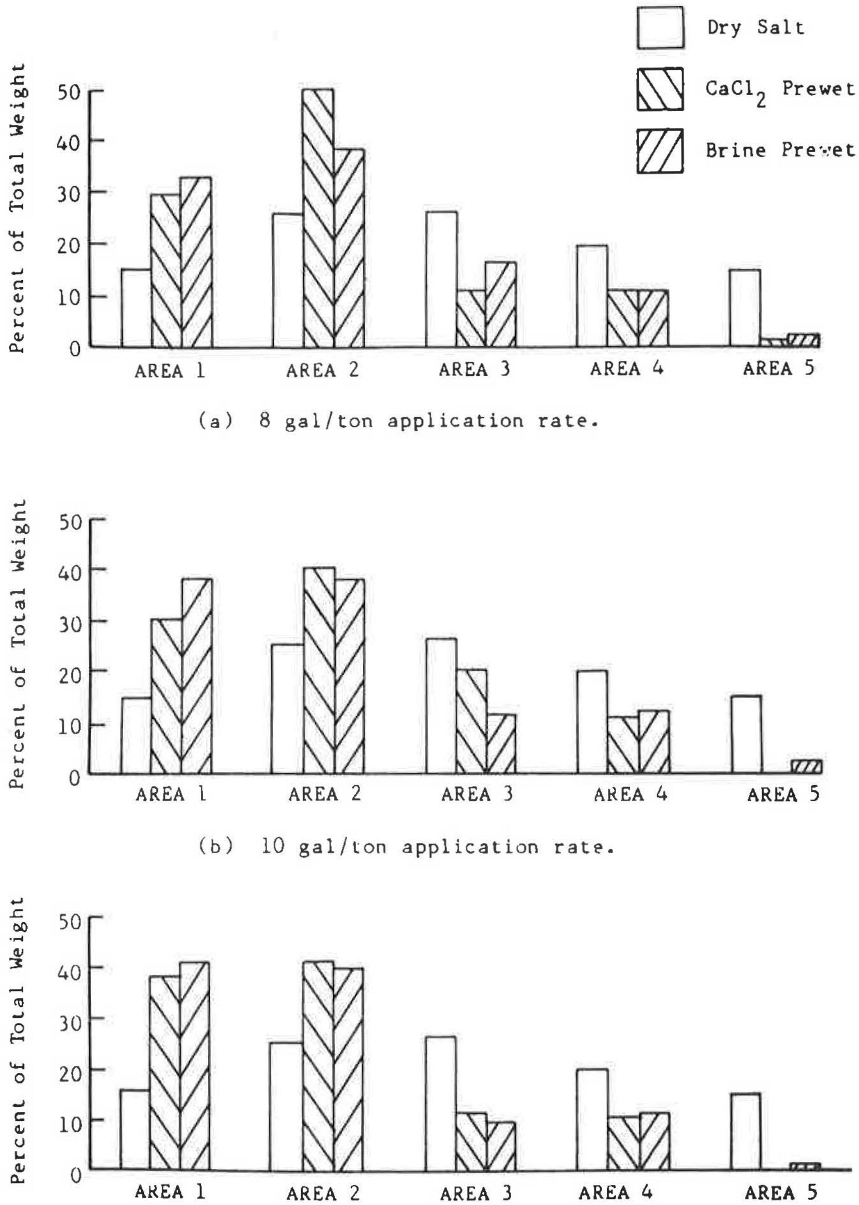


FIGURE 5 Penetration of prewet and untreated rock salt as a function of time at 18°F.

Application Procedures

The laboratory tests described earlier indicated that brines of the strength used in this procedure are feasible substitutes for



(a) 8 gal/ton application rate.

(b) 10 gal/ton application rate.

(c) 12 gal/ton application rate.

FIGURE 7 Results of salt bounce-off experiment.

liquid calcium chloride in prewetting applications. Given that an appropriate application rate can be established, it is necessary to determine procedures for prewetting the salt and applying it to the roadway. One research task examined the prewetting procedures available, assessed the technical and economic factors associated with each procedure, and recommended one that was believed to be the most appropriate for WVDOH use.

There are essentially three procedures for applying liquid chemicals to rock salt:

1. Applying the liquid to salt stockpiles, either during or after their formation;
2. Spraying the liquid on top of rock salt in the spreader truck before spreading; and
3. Using spreader-mounted equipment to spray the liquid on rock salt as it leaves the truck during the spreading operation.

Techniques are available for applying liquid before and during stockpile formation. The salt and the liquid can be mixed in a pugmill to obtain a uniformly wetted product. This material can then be formed directly into stockpiles. Alternatively, a spray bar can be mounted on a conveyor so that the liquid is sprayed onto the salt as the conveyor is loading it onto the stockpile. A system as simple as spraying brine on the untreated pile with an ordinary garden hose can also be used. However, to assure thorough distribution of the liquid, use of a special nozzle is recommended. The nozzle, consisting of about 5 ft of perforated piping, is inserted into the salt pile at 5-ft intervals as the brine is flowing to ensure that the salt pile is saturated. It is essential that wetted stockpiles be covered and stored on impervious asphalt or concrete floors.

With truckload wetting, the liquid is stored in a bulk tank. Rock salt is loaded into the spreader truck, which is then driven beneath a spray bar arrangement. Once the truck is properly located, the liquid is sprayed on the rock salt in the desired amount (either by an operator or automatically).

Spraying during the spreading operation also involves storing the liquid in a bulk tank. However, the spreader truck is equipped with a 50- to 60-gal liquid feed tank and an applicator system, which may include a pump and a spreader bar. As the rock salt is applied to the road surface, the liquid is metered to wet the salt simultaneously.

A cost estimate was prepared to determine the initial cost associated with installing a stockpile wetting system. It was estimated that an initial investment of just under $10,000 would be required to install a salt stockpile wetting system. The estimate includes a 6,000-gal fiberglass storage tank, a bituminous concrete pad, a centrifugal pump, and a length of rubber hose.

Systems for spraying brine on truckloads of salt can either be built by the highway agency or be purchased commercially. To provide a conservative estimate, costs were calculated for a commercially available automatic salt wetting system. Initial costs to install such a system, including concrete slab and utility pole, were estimated at slightly more than $17,000. Although the initial costs of this approach are substantially higher than those for stockpile prewetting, it must be remembered that, because the spray system is essentially automatic, there are no ongoing personnel costs (other than periodic routine maintenance).

Many of the early applications of wetted salt involved spraying the salt with calcium chloride as it moved through the spreader mechanism. Although truck-mounted spraying is best in terms of fully wetting the salt, the approach has a number of equipment-related limitations, for example, serious maintenance problems caused by the corrosive liquid. Because truck-mounted prewetting systems are no longer made commercially, all such systems would have to be homemade. It was estimated that installation of a truck-mounted spray would cost approximately $500 per truck (which includes supply tank, pump, valves, nozzles, and spray bar).

Although the truck-mounted system had the lowest initial cost (depending on the size of the fleet) of the three systems under consideration, it was not recommended for implementation because of the large number of maintenance and operational problems associated with it. Similarly, the stockpile-wetting approach, although having the second lowest cost, suffers from serious drawbacks, mainly the reliance on the human element to obtain a properly wetted product. If too much brine is applied, salt loss and environmental degradation can occur. The recommended system, because it is automated and provides thorough wetting, was the truck-spraying system.

CONCLUSIONS AND RECOMMENDATIONS

Salts are mixed with abrasive materials for either of two primary reasons, or for both: to freezeproof abrasive stockpiles to ensure a free-flowing supply and to enhance the performance of abrasives when applied to slippery road surfaces. The first goal is usually accomplished with significantly less salt than the second. By far the most frequent practice in achieving these goals is to mix dry sodium and calcium chloride with abrasive materials.

Use of liquid calcium chloride for both freezeproofing and highway applications has increased in recent years. Information on use of liquids for freezeproofing applications is limited at best. Though uses have been reported, almost no literature was available on application rates, storage practices, effectiveness, or potential problems associated with liquid use. It is known through personal communication and site visits with highway agencies that natural brine is being used for freezeproofing and highway applications. However, documented information relative to brine use is even more limited than that for liquid calcium chloride. Application rates, storage and handling practices, and other procedures appear to be empirically based, relying more on subjective judgment and trial and error than on an objective, rational approach.

Results of laboratory testing conducted to answer some of these questions indicated that natural brine could be used to freezeproof four of the abrasives studied (bottom ash, cinders, sand, and sawdust) effectively over a wide range of initial moisture contents and at temperatures as low as 10°F. Overall, few trends or generalizations could be drawn between the various abrasives. Each brine-abrasive combination must be considered as an individual case when freezeproofing application rates are developed.

For limestone, application of brine for freezeproofing is limited by the physical properties of the aggregate. Only limestone containing less than or equal to 3 percent initial moisture could be freezeproofed. Thus, freezeproofing of limestone stockpiles should be accomplished with conventional solid-form chemicals.

It was concluded that spraying brine on the abrasive materials as a stockpile is being formed, followed by supplemental applications dictated by the frequency and intensity of precipitation, would be the optimum procedure for freezeproofing stockpiles. The procedure has the advantage that there is no mixing of the stockpile, with resultant savings in manpower and equipment costs, in addition to reductions in the amount of dry sodium chloride needed.

A number of approaches are available for storing and applying brine for freezeproofing. The most economical method would be to have the oil or gas producer periodically spray the stockpile by using a pump on the brine delivery truck. Although this approach involves no costs to the highway agency, it can present problems if the supplier cannot provide brine on demand, as might be the case during the winter months. The investigators concluded that the highway agency should have brine storage tanks at its maintenance stations to assure a brine supply when local producers may not be able to provide the liquid. It is quite likely that the brine supplier would be willing to supply both the storage tanks and the brine at no cost to the highway agency.

Laboratory tests were conducted to evaluate the use of brine as a prewetting agent for rock salt. Examination of the melting effectiveness of prewetted versus dry salt indicated that prewetted salt initiated slightly more rapid melting compared with dry salt. However, the differences were not statistically significant. There appeared to be no advantage to using liquid calcium chloride over natural brine. Salts wetted with each agent performed almost identically in the melting and penetration tests.

On the basis of a laboratory bounce-off test, it was concluded that wetted salts stay closer to the point of contact than dry salts. As the liquid application rate increases, there is a small but not significant reduction in bounce-off. An automated system involving spraying the loaded truck appears to be the most appropriate procedure for prewetting the salt.

Before large-scale implementation of a brine freezeproofing program is undertaken a trial program is recommended for one winter at several different maintenance locations. Data could be collected on relevant conditions such as stockpile size, moisture content, temperature variation, and daily precipitation. Natural brine could be applied at the rates recommended in this paper. The timing and quantity of brine application would be monitored and compared with stockpile performance (in terms of being in a workable or frozen state) to provide field verification of the laboratory findings. Detailed records should be kept of all costs involved to provide a true accounting of the benefits of freezeproofing with brine. Assuming that the findings would be verified, it would be a relatively straightforward matter to proceed to large-scale use of brine for freezeproofing.

A laboratory study indicated that wetted salt reduced bounce-off. However, actual field trials are needed to verify the savings due to prewetting. One maintenance headquarters could be selected as a test site and a truck spraying system installed. Thus, in addition to providing an opportunity to determine the reduction in bounce-off, the study would permit a field evaluation to be made of the technical and economic benefits and costs associated with truck spray systems in particular and prewetted salt in general.

ACKNOWLEDGMENTS

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DISCUSSION

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After reading the paper by Eck et al., I wish to call attention to several important considerations overlooked when adding brine to deicing salts.

The distinction between natural brine and oil and gas well brine needs to be made because these two types of brine are referred to interchangeably in this paper. Oil and gas well brines, which are produced inadvertently during the production of oil and gas and are the type of brine incorporated in this paper, usually contain aromatic hydrocarbons. It is because of these hydrocarbons that the state of Michigan regulates usage of this material in deicing and dust control applications.

Michigan's consent order dated January 2, 1987, requires users to submit monthly reporting records of approved oil and gas brines and to analyze for 25 inorganic chemicals as well as five organic constituents. Testing of these compounds is to be at the well separator (when physically possible), storage tank, and spreader bar on the vehicle.

Natural brines are not associated with oil and gas wells but can be found at shallow depth under the state of Michigan. The distinction between these two brines needs to be addressed in this paper.

Eck et al. also state that one method of using oil and gas well brines is to apply them to salt stockpiles either during or after their formation. However, no suggested application rate for this approach was provided, although 8, 10, and 12 gal/ton were used in the bounce-off and scatter tests and 10 gal/ton of salt was used in the melting test.

Present application rates for both salt stockpiles and salt prewetting have been established either by research or by 20 years of field use in truck salt prewetting. The normal truck salt-prewetting rate is 10 to 12 gal of 32 percent $CaCl_2$ per ton of salt and the stockpile-wetting rate is 8 gal of 42 percent $CaCl_2$ per ton of salt.

Stockpile wetting requires a high percentage of brine concentration, such as 42 percent $CaCl_2$, to prevent liquid migration through the salt pile. At brine concentrations less than 42 percent, liquid did migrate through the salt when researched under normal expected winter use. Based on our research data, we would therefore expect the brine concentration of 26.57 percent used by Eck et al. to migrate in a substantial quantity out of the salt pile.

In conclusion, if oil and gas well brines are used, they must be used only with strict care to protect the environment from hydrocarbons normally associated with this material. The environment also needs to be protected against stockpile runoff, which likely would be expected from such dilute oil- and gas-based brines.

AUTHORS' CLOSURE

We greatly appreciate the thoughtful and constructive remarks offered by Kirchner on our paper. We agree with his comments relative to the distinction between natural brine and oil and gas well brine. Certainly both brines are "natural" as opposed to being manufactured, but as Kirchner notes, oil and gas well brines usually contain aromatic hydrocarbons, which are not found in natural brines of the type he describes. We are aware of the environmental problems associated with the hydrocarbons. To date, an admittedly limited amount of testing on West Virginia gas brines shows hydrocarbon levels well below those reported from Michigan oil wells.

Kirchner is correct in noting that we did not suggest any application rates for salt stockpile prewetting. This was because, for a number of reasons, we recommended a system whereby truckloads of salt would be sprayed lightly with brine before the vehicle proceeded onto the roadway. We recognize that oil and gas well brine is more dilute than liquid calcium chloride and believe that a properly managed truck spraying system would avoid the problem of stockpile runoff. Our concern over the runoff problem is the dominant theme in the first part of the paper, which deals with brine application rates for freezeproofing abrasive stockpiles. Unfortunately, we have not conducted a laboratory experimentation program for salt stockpile prewetting analogous to the abrasive stockpile freezeproof testing. Therefore, we cannot say how much brine can safely be applied without runoff. Such a laboratory testing program would be an appropriate follow-on study to the work under discussion here.

The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the state or of FHWA. These materials do not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Winter Maintenance.

Grygla Snow and Ice Service Level for Low-Volume Highways

Arthur Hill, Roland Sinn, Robert Nibbe, and Glen Korfhage

The level of winter maintenance on a low-volume trunk highway in northern Minnesota was reduced during the winter of 1984–1985. Sand or salt was used only at hazardous locations and plowing coverage was limited to 8 hr a day. The roadway conditions were assessed periodically on this section of highway as well as on two control sections, one a county road and the other a trunk highway where the normal level of winter maintenance was provided. Questionnaires were used to obtain public reaction. Primary findings from the study were that farmers are more tolerant of a lower level of service than nonfarmers, two-thirds of the respondents were satisfied with the lower level of service, road users expect a higher level of service on trunk highways than on county roads, and an annual cost savings of $140 per roadway mile (approximately 40 percent) was realized by the reduced service.

In recent years, the Minnesota Department of Transportation (Mn/DOT) has conducted several research studies to determine the level of winter maintenance desired and required by the road users. These studies have been limited almost exclusively to higher-volume roads; the service level for low-volume roads has not been adequately addressed.

Three factors indicate that the level of winter maintenance on low-volume trunk highways could be reduced. These are

1. A general acceptance by road users in some parts of the state of a much lower level of service on county roads that often have higher traffic volumes than on low-volume trunk highways in the area,
2. Occasional complaints of excessive sand or salt use on low-volume trunk highways, and
3. Growing public awareness of the need to fully evaluate cost-effective maintenance operations in order to keep public funding needs in perspective.

SCOPE

In order to examine the effects of reduced service, the winter maintenance level was reduced on sections of low-volume (secondary) trunk highway in northwestern Minnesota. The level of service on these roadway sections was measured subjectively by a panel and compared with similar information from a nearby, parallel county road. In addition, an adjoining section of secondary low-volume trunk highway was maintained at the normal level and evaluated for condition and cost. The study can also be considered another effort to reduce the amount of salt use, as directed by the state legislature some years ago.

Minnesota Department of Transportation, John Ireland Boulevard, St. Paul, Minn. 55155.

LOCATION

The roadway sections involved in the reduced level of service included T.H.-89 from Grygla to the south junction of Roseau County Road 2 and T.H.-219 from T.H.-1 to T.H.-89. The county roads used as comparison sections were Pennington County Road 28, Marshall County Road 54, and Roseau County Road 9. The trunk highways maintained at the normal level and used as comparison sections were T.H.-89 from Grygla south to the Red Lake River and T.H.-1 from the west Beltrami County line east to the junction of T.H.-89 (Figure 1). The average annual snowfall in this area is 37.5 in.

USER BACKGROUND

The local roadway user population in the area of the study was split into two categories: those employed in farming and those not employed in farming. The population was divided in this manner to differentiate between those who do not have to travel to get to work and those who do. From 1980 census data provided by the Northwest Regional Development Commission, the farm-employed group made up 30.4 percent of the working population, and the non-farm-employed group made up the remaining 69.6 percent.

METHOD OF EVALUATION

The evaluation stage consisted of two phases: (a) the comparison of the level of service (actual roadway surface condition) on the trunk highway sections with the level of service on the county road sections and (b) the determination of whether the level of service on the trunk highway sections met the needs and desires of the road users.

The evaluation of Phase 1 was based on the subjective opinion of a rater who observed the surface condition and reported it on evaluation forms provided by the Project Coordinator. Type and rate of precipitation, temperature, and wind velocity were also noted. Raters tried to evaluate the test sections and the control sections after each significant snowfall event on the roadways. Phase 2 data were obtained through use of a questionnaire, which was distributed to all post office box holders along the affected routes. The questionnaire addressed such items as occupation, road usage, and maintenance rating.

LEVEL OF SERVICE PROVIDED

The local counties were contacted to determine their procedures and standards. These criteria were then used to target levels of service for the trunk highway sections. The reduced

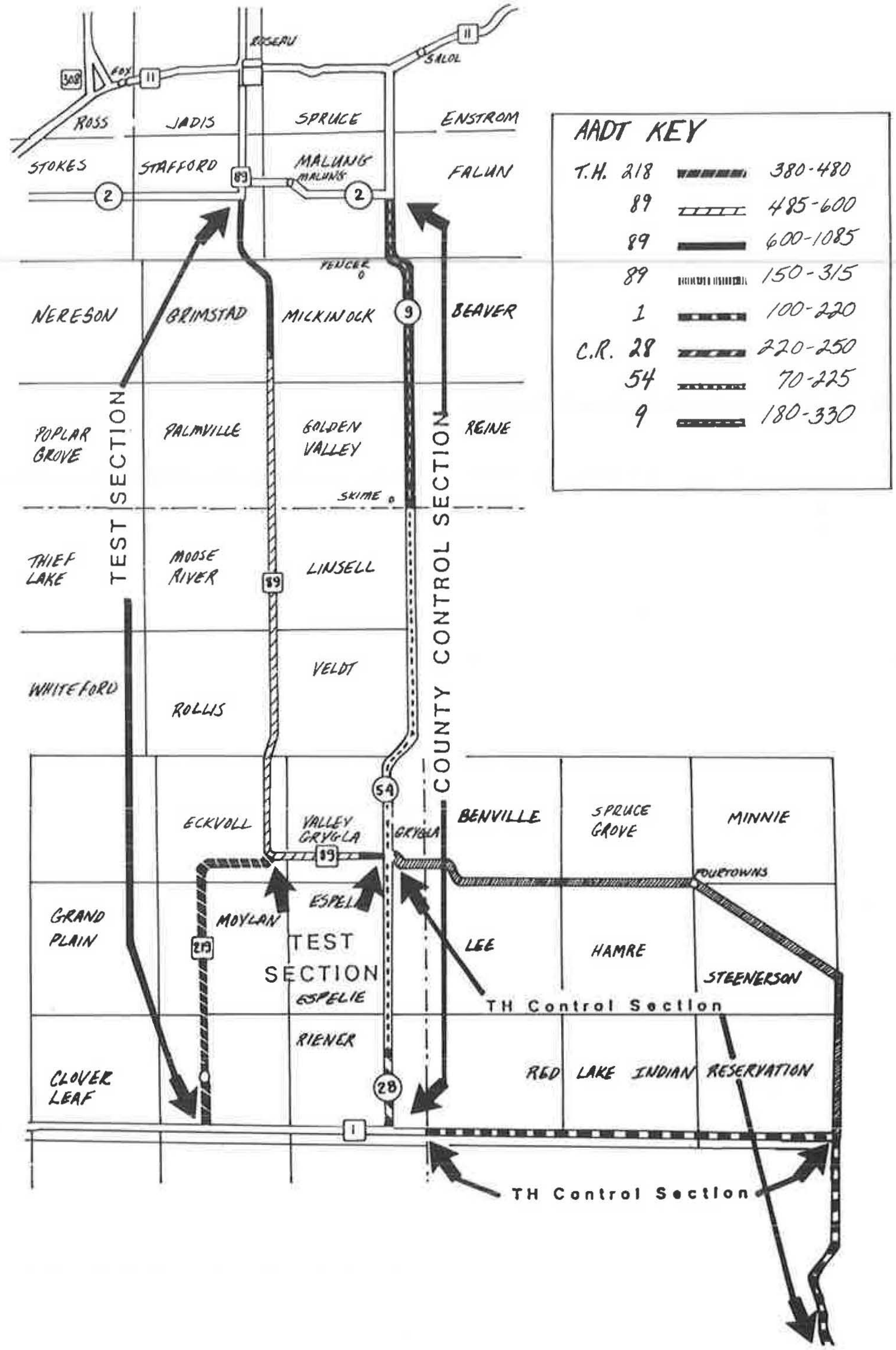

FIGURE 1 Location of test sections and control sections.

level of maintenance used in this test was to limit straight plowing with sanding (10 percent salt) to curves and unsafe locations. No overtime was accumulated and because the truck route was quite long, only one cycle (round trip) per day was run. Trouble spots were provided for in the 8-hr work day; however, no weekend or holiday coverage was provided. It should be noted that during the study period, requests from law enforcement officials were acknowledged and acted on as necessary. Table 1 compares the different levels of service. The established criteria were deviated from temporarily in late December to remove thick ice and compacted snow caused by an unusual rain and snowfall event.

RESULTS OF SNOW AND ICE EVENTS: ROAD CONDITIONS

Table 2 is a summary of the data collected from condition ratings of the driving surfaces after approximately 6 months of

TABLE 1 COMPARISON OF SERVICE LEVELS

	Mn/DOT Standards for Secondary Routes	County Policy	Proposed Study Standards
Lane miles/unit	95	200–250	120+
Coverage time (hr)	12	Varies, <12	8
Cycle time (hr)	5	Varies, 12–24	1/day
Chemical or sand application	Intermittent bare wheel path	Min. (8%) salt/sand mixture applied to extremely hazardous areas only	10 percent salt/sand to hazardous areas only

TABLE 2 SNOW AND ICE EVENTS AND CORRESPONDING CONDITIONS

		Section Condition, Duration After Event, and Remarks			
		Trunk Highway			
Event No. and Date	Weather	Test Section	Control Section	County Control Section	Duration and Remarks
First Mailing: November 15, 1984, to December 19, 1984					
1, 11/01	Freezing rain				No data collected
2, 11/15	Light snow	95% bare	100% bare	75% bare	
3, 11/27	Freezing rain	60% ice glaze	100% bare	60% ice glaze	All sections bare within 7 days
4, 12/16	Heavy freezing rain with 4-in. snow temperature drop to <0°F	100% compacted snow and ice	100% compacted snow and ice	100% compacted snow and ice	Continuous
Second Mailing: December 20, 1984, to January 1, 1985					
5, 12/21	Light snow	100% compacted snow and ice	100% snow covered	100% compacted snow and ice	Relatively continuous
6					
12/28	Light rain with light snow	5% bare	10% bare	25% bare	Maintenance changed to apply sand and salt on test section
12/31	–30°F	60% bare	40% bare	30% bare	Too cold to do anything with ice
1/02	Trace of snow, no rain, –20°F, wind 5–10 mph, no plows out				Heavy application of salt
1/03					Heavy application of salt
Third Mailing: January 2, 1985, to February 13, 1985					
7, 1/04	No snow, 30°F, wind 10–25 mph, plows out sanding	100% bare	100% bare	40% bare, 20% ice-glaze, 40% compacted snow and ice	
8, 1/07	Trace of snow, no rain, 16°F, wind 0–5 mph, no plows out				
9, 1/14	Trace of snow, no rain, –6°F, wind 10–15 mph, plows out				
10, 1/18	Trace of snow, no rain, –22°F, wind 5–10 mph, plows out				
11, 1/21	10–20°F, wind 10–25 mph, plows out	100% bare	90% bare, 10% compacted snow and ice	100% bare	Small drifts on road, wind from NW
12, 1/22	Trace of snow, no rain, 8°F, wind 5–10 mph, plows out spot sanding				
13, 1/25	1 in. snow, no rain, –5°F, wind 5–10 mph, plows out				
14					
1/28	0.5 in. snow, –9°F, wind 0–5 mph, plows out	100% bare	98% bare, 2% compacted snow and ice	100% bare	Sanded in Grygla
1/29	Trace of snow, no rain, 13°F, wind 0–5 mph, no plows out				
15					
2/05	No snow, no rain, –10°F, wind 0–5 mph, plows out sanding				
2/06	1 in. snow, no rain, –1°F, wind 5–20 mph, plows out				
2/07	No snow, –10°F	100% bare	99% bare, 1% compacted snow and ice	100% bare	Sanded in Grygla

TABLE 2 *continued*

		Section Condition, Duration After Event, and Remarks			
		Trunk Highway			
Event No. and Date	Weather	Test Section	Control Section	County Control Section	Duration and Remarks
16					
2/09	6–8 in. snow, no rain, 12°F, wind 5–10 mph, plows out sanding				
2/11	5 in. snow, dry, 0°F, wind 10 mph	98% bare, 2% ice-glaze	95% bare, 5% ice-glaze	95% bare, 5% ice-glaze	T.H.-89 and 219 snow-packed and sanded; county roads and trunk highways bare with very little snow packed in sheltered areas; towns and intersections sanded; research area in excellent winter driving condition
17, 2/13	1 in. snow, no rain, 12°F, wind 0–5 mph, plows out				
Fourth Mailing: February 14, 1985, to March 14, 1985					
18					
2/25	No snow, 1 in. rain, 36°F, wind 0–5 mph, no plows out				
2/26	Light snow, dry, 6°F, wind 5–10 mph, plows out	90% bare, 10% compacted snow and ice	80% bare, 20% compacted snow and ice	80% bare, 20% compacted snow and ice	Compacted snow in sheltered areas; bare and dry in Grygla; some compacted snow in Wannaska and Goodridge
19, 3/01	No data	100% bare	100% bare	100% bare	
20					
3/04	2–3 in. snow, no rain, 16°F, wind 15–20 mph, plows out				
3/05	Heavy snow, 10°F, wind 5–10 mph, plows out	85% bare, 15% compacted snow and ice	71% bare, 11% compacted snow and ice, 18% uncompacted snow > 2 in.	50% bare, 50% compacted snow and ice	Approx. 20 mi of northern Co. Rd. 9 was not plowed; snow was 2 ft deep in some areas, with one trail to follow
21, 3/07	Blowing snow, 11°F, wind 25+ mph, plows out	95% bare, 5% compacted snow and ice	45% bare, 65% compacted snow and ice	15% bare, 85% compacted snow and ice	On T.H. 89 and 219 majority of compacted snow was melted or melting; by 11:00 roads were getting wet; T.H.s were very wet but clean; county roads were bad because the day before was windy and probably caused blowing snow to stick to roadway
22, 3/13	1 in. snow, 28°F, wind 0–5 mph, plows out	70% bare, 30% compacted snow and ice	100% bare	100% bare	Less than 1 in. compacted snow and ice; melting
23, 3/22	No snow, some rain, 42°F, wind 5–10 mph, no plows out				
24, 3/25	No snow, some rain, 36°F, wind 0–5 mph, no plows out				
25, 3/27	No snow, some rain, 34°F, wind 5–10 mph, no plows out				
26, 3/29	5–6 in. snow, some rain, 22°F, wind 5–10 mph, plows out sanding				

monitoring. Ratings were conducted on the dates indicated in the table; the weather events similarly correspond to the given dates.

USER QUESTIONNAIRE

The user questionnaires were distributed by general delivery to all box holders along the affected routes and were handed out at information meetings. In addition, a supply was made available at the Roseau post office, the general store in Wannaska, and the Grygla elevator. A total of 1,962 forms were distributed through four separate mailings (mailings 2–4 were to previous respondents), of which 774 were returned (some of these were from fourth-time participants). A brief summary of the data collected is shown in Table 3, in which the four time frames given represent the four mailings from the date they went out until just before the next mailing.

TABLE 3 USER QUESTIONNAIRE DATA SUMMARY

			Median Ratings			
	No. of Responses		T.H. Test Section		County Control Section	
Date	Farmers	Nonfarmers	Farmers	Nonfarmers	Farmers	Nonfarmers
11/15/84 to 12/19/84	167	235	3.55	3.34	3.55	3.34
12/20/84 to 1/01/85	19	53	1.68	1.60	1.94	1.90
1/02/85 to 2/13/85	49	116	3.22	3.09	2.66	2.79
2/14/85 to 3/14/85	48	83	3.72	3.66	3.61	3.57

NOTE: Median response rating values were as follows: 1 = poor; 2 = fair; 3 = satisfactory; 4 = good; 5 = excellent. "Farmers" = farming as sole occupation; nonfarmers = all others.

The summary was divided into two groups of data to show the attitude of a group who depend on the highways to get to work daily versus one whose occupation is not geared to daily highway use. The median rating represents a split in response values at the point where about half the responses are less than and the other half greater than the median value.

SUMMARY AND DISCUSSION

A total of 26 weather-related events were recorded during the 1984–1985 winter. Total snowfall for the winter recorded by the state climatologist's office was 35.8 in. as opposed to an average annual snowfall of 37.4 in. The snowplows were out plowing or sanding for all of these events, and in only one case during the winter was there an extremely negative reaction from the public. During this event a temporary suspension of the study was required and a sand and chemical mixture was applied to clear the roads. This ice storm, which occurred on December 16, was, according to the subarea foreman, one of the two worst ice storms he could recall in his 20 years of experience. A description of that event follows.

Before the December 16 ice storm, 28 percent of the questionnaire responses requested an increase in maintenance level on the trunk highway test section. This proportion increased to 86 percent of the responses after the December 16 storm. The 2-week period following that particular ice storm produced numerous calls and letters, including ones from the Roseau law enforcement agency and the Roseau school superintendent. All were very critical of the condition of the trunk highway test section, which became very slippery (as the compacted snow eroded away, it left a surface of polished ice). Travel on the northerly 10 to 15 mi had been reported as limited to 20 to 25 mph. Most of the more vocal criticism appeared to be centered around school transportation. Buses were running up to 1 hr late, and mothers expressed deep concern for the safety of their children. Of course, much of the bus time is on county roads, but people seem to expect county roads to be slippery.

In reality, the conditions between December 16, 1984, and January 4, 1985, were anything but normal. When the storm hit, temperatures were above freezing, but they quickly dropped, which caused freezing rain (4 in. was reported at Roseau). The rain eventually changed to snow, which stuck to the wet highway and became compacted by the traffic. This all occurred late in the afternoon, and by morning the temperature was below the effective working range of chemicals (above 15°F) and it stayed that way until December 20, which produced poor conditions on all the trunk highways in this area. On December 20 and 21, temperatures moderated enough to allow some chemical use; however, a number of area routes still remained with significant amounts of compacted snow and ice because of additional snowfall coupled with blowing snow. Following this, another cold wave (0 to –20°F) persisted until December 28, when a warming trend brought another snow and ice storm followed immediately by subzero temperatures. In other words, from December 16 until January 3, 1985, conditions were next to impossible for maintaining highways. On December 31, 1984, a news release was sent out stating that the study would be temporarily postponed to remove the thick, compacted ice and snow, after which the reduced service level set up for the study would return. As stated, heavy application of chemical on January 2 and 3, 1985, produced bare, wet pavement by January 4, 1985.

Responses to the third mailing indicated that 58 percent of the public was again satisfied with the level of service, and the fourth mailing indicated that 90 percent of the public was satisfied with the level of service on the test section. At the same time, the regularly maintained county control section roads were rated, respectively, at a 48 and 88 percent satisfactory or better level of service.

COST COMPARISONS

The total cost of snow removal for the trunk highway test section, including equipment, labor, and materials, was $187.70 per roadway mile, and the trunk highway control section snow removal cost $327.70 per roadway mile. This comes to a $140.00/mi cost savings on the test section (Figure 2). However, it should be noted that the trunk highway control section includes more miles of sheltered (wooded) areas, which could have contributed to the higher maintenance cost. The maintenance cost for Marshall County Road 54 was $96.47/mi, as provided by the Marshall County Engineer.

The trunk highway test section would have experienced a further cost reduction of at least $14/mi if emergency salt and sand had not been needed during the severe ice event in December. Even with the reduced level of service on the trunk highway section, the cost per mile is still nearly twice that of the county control section.

Man and Truck Hours

1984–1985

There is an obvious reduction in man and truck hours between the trunk highway test and control sections, with the test

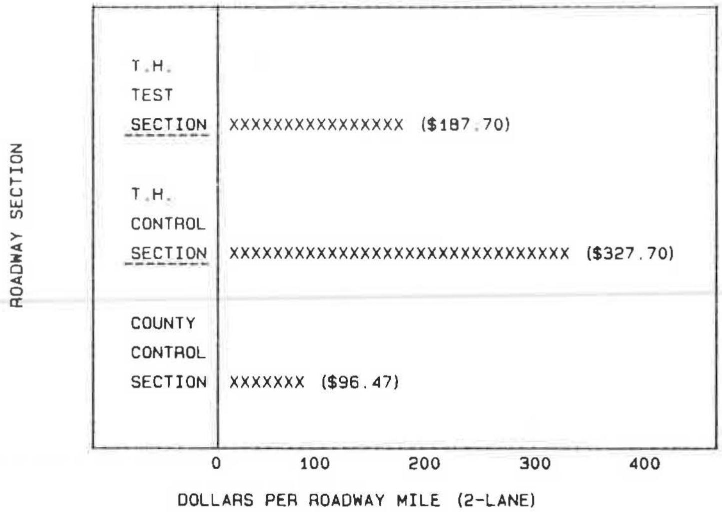

FIGURE 2 Summary of total cost per mile.

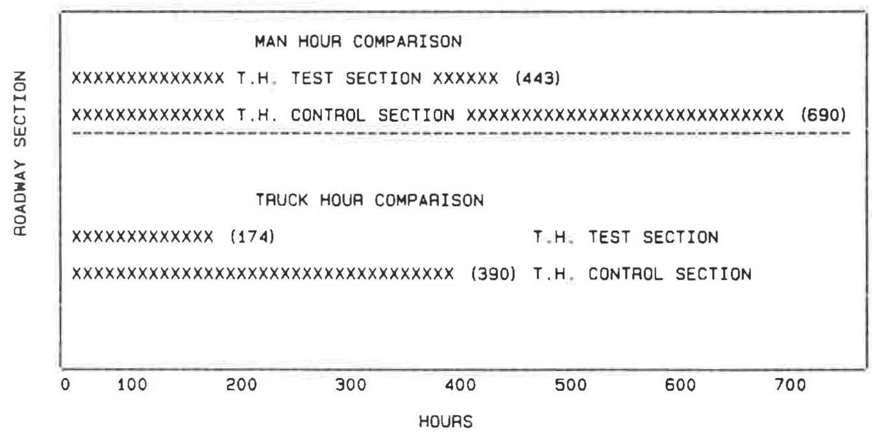

FIGURE 3 Summary of 1984–1985 man and truck hours.

section realizing about half the hours of the control section. This resulted in a savings of $6,239.80 on the trunk highway test section, or $115.21/mi (Figure 3). Again, a further cost reduction would have been experienced on the trunk highway test section if emergency man and truck hours had not been needed during the December ice storm.

1983–1984

The following information is provided as a yardstick for comparing section differences and winter severity. Compared with man and truck hours for the winter of 1983–1984 (Figure 4), the 1984–1985 study period realized nearly the same hourly levels, with the exception of the trunk highway test section. This would be attributable to the lower level of service on the test section. This comparison indicates that service levels on the trunk highway control section were at near-normal winter maintenance levels and that the study period experienced near-normal winter weather conditions (excluding the December ice storm). It should be remembered that the winter of 1983–1984 was not in the study season.

Salt and Sand Application

Application of salt and sand on the trunk highway test section was about half that used on the trunk highway control section. This reduction amounted to a cost savings of $1,841.87, or $34/mi. During the December ice storm, a sand-salt mixture of 1.5:1 was needed on the test section to remove the thick ice. This additional application added $14 more to the test section's total cost per mile. Subtracting the emergency salt and sand cost results in a $48/mi cost savings for the test section over the control section. Figure 5 compares total salt and sand quantities used during the study period.

FINDINGS AND CONCLUSIONS

The following findings and conclusions resulted from this study:

1. It became obvious through the course of this study that any future studies or any new policy should provide for the emergency treatment of severe ice conditions such as those that occurred during December 1984.

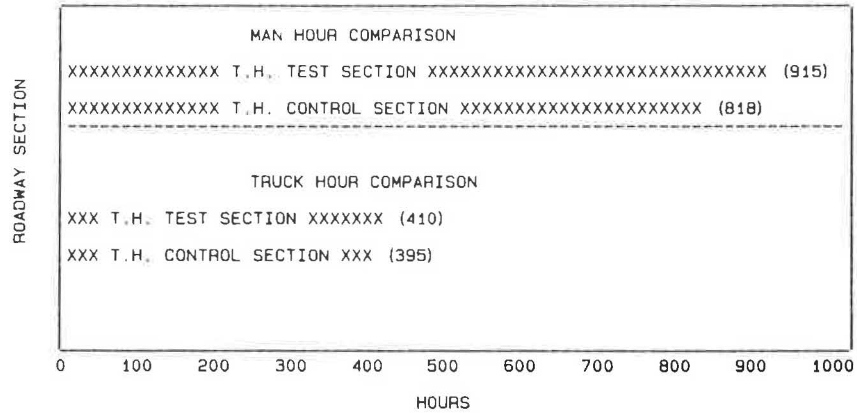

FIGURE 4 Summary of 1983–1984 man and truck hours.

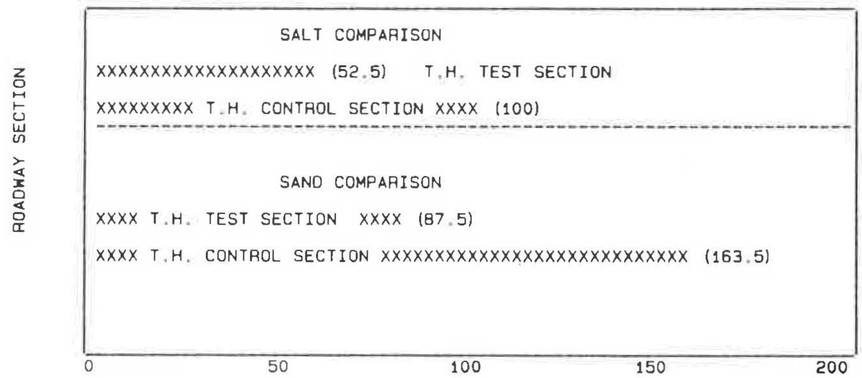

FIGURE 5 Summary of sand and salt comparison.

2. It appears that a distinct difference in user attitudes regarding the level of service is based on occupation. The farm-employed user group in this study was much more tolerant of a lower level of service than the non-farm-employed users. This could be due in part to the farmer's less frequent use of the roads during the winter months as opposed to the nonfarmer, who commutes on a daily basis and therefore desires a higher level of service.

3. Overall, two-thirds of all the respondents were satisfied with the lower level of service. This indicates that, except in times of extreme conditions, service levels on low-volume trunk highways with these characteristics may be reduced and still provide acceptable transportation for the majority of the users. However, the key question may very well be what group's service level should be targeted.

4. On the basis of user interviews, a large portion were tolerant of the county roads' lower level of service. It appears that this lower level of service is tolerated because the users believe that they can use the trunk highways, which they expect to be maintained at a higher level. However, suggestions have been made that approximately 40 percent of Minnesota's trunk highway system—primarily those having traffic volumes less than 1,000 average daily traffic—be turned over to the counties. If this were to happen, the level of service on these roads would most likely be reduced to that of the current county system.

5. Economically, a cost savings of $140 per roadway mile on the trunk highway test section was realized as a result of the reduced service level compared with that on the control trunk highway section.

RECOMMENDATIONS

1. The study should be repeated at one or two other locations in the state to determine whether results are similar to those obtained in the Grygla study. These studies should be coordinated with the local media and regional leaders so that the objectives of the study are fully understood.

2. All Mn/DOT districts should consider using the level of service developed in this study on some of its low-volume roads.

3. In selecting roads for a reduced level of service, factors such as expected amount of drifting, direction and intensity of wind, and amount of shelter need to be considered.

4. Future studies with reduced level of service need to provide for treating unusually severe conditions, such as ice storms.

ACKNOWLEDGMENTS

The authors wish to acknowledge and thank the following individuals for their contributions in conducting this study: District Two materials and maintenance personnel for their cooperation and assistance with the data collection; Mark Anderson, District Communications Officer, for helping in the design and distribution of the questionnaire; and Marvin Bates, former Maintenance Services Engineer, for his guidance in developing the work plan.

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Formates as Alternative Deicers

DAVID A. PALMER

The cost of deicing the nation's road system is roughly 20 times greater than the cost of the salt that is spread. This is due to chloride corrosion, which hits the vehicle fleet hardest. Next hardest hit are the nation's bridges, whose life has been reduced from about 20 to 5 years. Because corrosion inhibitors have proven ineffective, attention has turned to alternative chemical deicers. Though most current government support is dedicated to evaluation of calcium magnesium acetate (CMA), this chemical compound has many technical and economic drawbacks. In fact, CMA might continue to be too expensive to generate much use. At less than half the cost, it may be possible to produce sodium, calcium, or dolomitic lime formates. They can probably be made directly from carbon monoxide, rather than using formic acid. Sodium formate is much less toxic than initially thought. Further, it can probably be spread as a very concentrated solution or even as a slurry. The freezing-point curve of sodium formate is similar to that of sodium chloride down to about −14°C. It has now been demonstrated experimentally that sodium formate does not spall cured concrete.

Maintenance of a workable and safe transportation system is essential to this country's economy. Plowing to remove snow and sanding in icy conditions were the primary tools of winter highway maintenance until the 1950s. Gradually it was discovered that addition of sodium and calcium chloride salts would remove both snow and ice. From 1960 to 1980, salt use in the United States jumped from 2,000,000 to 12,000,000 tons per year *(1)*.

Unfortunately, chloride salts are very corrosive. The corrosion products of iron occupy 2.2 times as much volume *(1)*. The internal pressure of 4,000 psi caused by rebar oxidation is sufficient to crack the concrete. Today, sodium chloride is regarded as the primary cause of bridge failure. Though motorists gain an advantage in the winter, bridge repair is a leading cause of motorist delay and highway maintenance expense at other times of the year. Sodium chloride has reduced average bridge life from 20 to 5 years. The areas where bridges are most corroded are in the Northeast. According to the Environmental Protection Agency, about 100,000 bridges are affected *(2)*. That represents almost one-sixth of the nation's bridge inventory. The replacement cost for those bridges would be about $900,000,000 in current dollars.

Automotive corrosion is also very severe. In fact, it has been loosely correlated to the amount of salt being used on the roadways *(1)*. The rapid deterioration of our vehicle fleet is the single largest cost of highway desalting. A joint study by the National Bureau of Standards and the Batelle Laboratories concluded that 1975 automobile corrosion costs were about $12 billion per year *(3)*. Presumably, at least half of that cost is attributable to salt acceleration. There is no question that today, with car prices much higher, vehicle corrosion is still a major concern.

Amoco Chemicals Company, P.O. Box 400, Naperville, Ill. 60566.

PREVIOUS RESEARCH ON ALTERNATIVE DEICERS OR CORROSION INHIBITORS

Corrosion inhibitors have been subjected to several large tests. The Illinois Institute of Technology Research Institute (IITRI) found that corrosion inhibitors did retard chloride corrosion. However, the results were marginal, and none of the combinations of salt plus inhibitor gave corrosion rates as low as those with organic salts and no inhibitor. The inhibitors studied included amines, imidazolines, pyrophosphates, polyphosphates, sodium metasilicates, calcium hydroxide, borax, and trisodium phosphate *(4)*. Another study, in 1951, showed that automobile body corrosion was as high in Rochester and Akron, where inhibitors were being used with salt, as in cities where salt alone was used *(5)*.

The ideal deicer would be free or would cost no more than sodium chloride. It would be noncorrosive. It would not spall concrete of any type. It would be nontoxic. It would be nonflammable. It would not harm the environment. It would be nonvolatile. It would have an attractive freezing-point curve. Chemicals such as methanol, which are toxic, volatile, flammable, and harmful to the environment, should be ruled out. From the previous discussion it is clear that chloride chemicals must also be excluded because of corrosiveness.

Freezing-point lowering is a function of the concentration of ions or other species. For that reason, it is advantageous to use molecules that either dissociate into many ions or have low molecular weight, or both. Calcium magnesium acetate (CMA) was recommended in a study carried out by the Bjorksten Research Laboratories. FHWA liked their idea and has placed a great deal of money into CMA research.

Two large CMA research projects were funded with Stanford Research Institute (SRI). Their first effort, biological production of acetic acid from corn grain, was a failure *(6)*. Their idea was to carry out the fermentation in the presence of dolomitic lime to get continuous neutralization of the acetic acid. They eventually concluded that they had been using the wrong organism. Even in their most optimistic economic studies, the cost of their acetic acid was 19 to 27 cents/lb, depending on volume. That represents no improvement over current commercial technology, carbonylation of methanol. (Produced from synthesis gas in the Near East with Monsanto technology and delivered to the United States, acetic acid could cost as little as 15 cents/lb.) Of more significance was the actual production of CMA for research.

SRI manufactured CMA from dolomitic lime and acetic acid, both purchased. The 200-ton sample, which cost about 80 cents/lb, is being used for field tests, primarily in the state of Washington and in other locations. A realistic price of 25 cents/lb plus freight has been quoted by Chevron Chemical Company, which has now begun commercial manufacture.

Washington State consumed half of the SRI sample. They used their regular distribution equipment without modification *(7)*. Three sites were chosen: downtown Spokane on the freeway and two stretches of freeway at the Snoqualmie Pass. They concluded that CMA has a significant advantage when spread just before a snowstorm: it kept the road quite free of snow, even when just a light application was used. It exhibited a number of negative features, however, including the following:

1. CMA is slower to react with snow and ice than are sodium chloride salts.
2. CMA is most useful above 25°F.
3. CMA is very dusty, creating potential safety problems during spreading. Also, personnel moving the CMA had to wear dust masks.
4. CMA has a low density and tends to blow off the delivery truck.
5. CMA tends to cake on the dump-truck bodies and in the chute and spinner assemblies, and the material has to be chipped off.
6. CMA draws frost in areas of previous application. Areas that would normally dry out during daylight hours stay wet and ice up in late afternoon or early morning.

CMA is normally supplied with a bulk density of only 35 lb/ft^3. Therefore, it tends to blow off the road, if still a solid, after passage of a few cars. Therefore, W. Rippie of the Iowa Department of Transportation developed a method of coating dark river sand. It is done at the time that the dolomitic lime and acetic acid are reacted to form CMA. The product is heavy and bulky enough (78 lb/ft^3) to stay in place on the highway. The dark color also helps promote melting of the ice because of absorption of radiation *(8)*. Nevertheless, the researchers from the state of Washington recommended development of a "hydrated compound of CMA" to solve the stated problems.

The state of Maine produced its own CMA in aqueous solution. This FHWA-supported project planned on using waste acetic acid and dolomitic lime to manufacture the compound. They also observed the dustiness of the dried CMA; however, they only made one application of it. It initially took longer to react than sodium chloride, but persisted for a longer period of time *(9)*.

THE CASE FOR FORMATE DEICERS

It may be premature to focus all development on the acetates as alternative deicers. Formates have been essentially overlooked and merit at least a modest amount of study. Calcium formate was first mentioned in a study by IITRI *(4)*, but that research was possibly missed in the literature survey by the Bjorksten Research Laboratories.

From a strictly theoretical point of view, the formates should be more effective than the acetates. Fewer pounds are needed per equivalent mole of dissolved species. Though formic acid is just as expensive as acetic acid, formic acid does not need to be used directly. Rather, carbon monoxide can probably be used instead. Its cost would be just a fraction of the cost of acetic acid.

A preliminary freezing-point curve was measured for sodium formate (Figure 1). It is almost identical to the freezing-point curve for sodium chloride, down to about −14°C (+7°F). At that temperature it appears to form a eutectic with water. These preliminary data should be confirmed with more precise measurements. Over the temperature range of interest, this chemical could function almost as well as ordinary road salt. However, that would have to be tested in field trials.

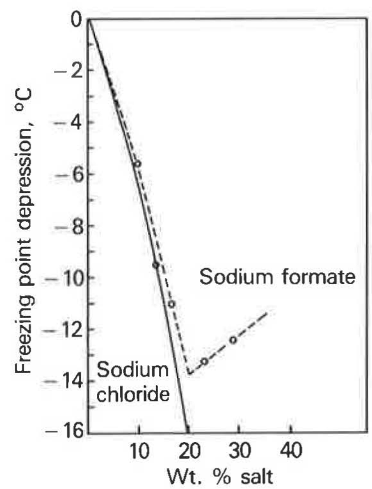

FIGURE 1 Preliminary freezing-point curves for sodium chloride and sodium formate.

One of the very attractive features of sodium formate is its high water solubility. If it is applied at 60°C, its solubility would be approximately 117 lb sodium formate per 100 lb water. This is derived from the somewhat inconsistent data in the literature:

t (°C)	*Solubility (lb/100 lb water)*
0	44
20	97.2
100	160.

If sodium formate is applied as a solution, there would be no concern over dusting. Also, it is possible that a slurry could be applied, perhaps approaching 250 lb of deicer per 100 lb of water. That would be equivalent to about 133 lb of undissolved deicer per 217 lb of solution.

Another advantage of a sodium formate solution is that it could be used as a deicer at airports. In Chicago, a mixture of urea in ethylene glycol is now used because it can be sprayed onto airplanes as well as runways. Chloride chemicals are not used for deicing at airports because they corrode the aircraft.

United Airlines has indicated by letter that the following technical problems would be of particular interest to them:

1. Composition, particularly of tracts of sulfates, sulfides, and chlorides;

2. Cadmium plate removal;
3. Total immersion corrosion;
4. Polycarbonate craze;
5. Pavement scaling resistance;
6. Slipperiness on concrete and asphalt; and
7. Hydrogen embrittlement of metals.

The Celanese Chemical Company is running tests on these problem areas. The most difficult problem that United Airlines suggested was to have a jet engine manufacturer test the effect on one of their engines of ingesting sodium formate.

Toxicity and environmental effects must be considered. A literature search revealed that acute toxic effects of sodium formate are low; the LD 50 for rats is 11.2 g/kg (nontoxic). Intravenous injection toxicity is also low. The acute toxic effects for calcium formate are moderate; the LD 50 for rats is between 1.9 and 2.6 g/kg. This compound is actually used as a silage preservative and as a food preservative for human consumption. This suggests that regardless of the choice of base, toxicology may not pose a serious problem.

A literature report that calcium formate causes spalling of concrete has been verified at the Celanese Chemical Company. This essentially eliminates calcium formate as an alternative deicer. In a California study, sodium formate was likewise found to cause spalling *(10)*. However, in the Bjorksten study, a similar problem was encountered with CMA. It was traced to application on uncured concrete. Thus, it was thought possible that sodium formate would not spall cured portland cement concrete. Subsequent experiments at Celanese have proven that sodium formate does not spall concrete. It has also been shown that sodium formate does not injure asphalt. It can already be purchased at a price lower than that of CMA from the Celanese Chemical Company.

Celanese has collaborated in two field trials of sodium formate. In Minnesota it was mixed with sand and performed as well as sodium chloride. However, there was some caking due to small particle size. In Ottawa, Ontario, there was another test, but the particles were found to be too small. Celanese will be providing larger-sized particles for subsequent tests.

Overall, sodium formate currently appears to have a bright future as an alternative deicer. It has low toxicity and a very good freezing-point curve. Its good solubility characteristics suggest that it has potential for spreading as a solution or a slurry, as well as dry spreading.

CONCLUSIONS

1. Sodium formate is essentially nontoxic and does not spall concrete.
2. Sodium formate can probably be spread as a saturated solution or slurry. Its high density may make conventional spreading feasible also. However, particle sizes will have to be large.
3. Sodium formate has an attractive freezing-point curve.
4. Sodium formate has no volatility or flammability.
5. Concerns that must be addressed are (a) rapidity with which it reacts with snow and ice, (b) useful temperature range, (c) any caking during dry spreading, and (d) frost absorption.
6. The cost of manufactured formate should be in the range of 7 to 10 cents per pound, based on raw material costs and possible process flowsheets.
7. Some of the technical difficulties with CMA can apparently be overcome with sodium formate.

RECOMMENDATIONS

1. A freezing-point curve should be accurately measured as a function of composition and temperature.
2. A water-solubility curve should be determined for sodium formate as a function of temperature and salt concentration.
3. Other physical properties, such as heat capacity of different solution concentrations, should be studied.
4. The practical questions of sodium formate use should be assessed.

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Risk of Vehicle-Tree Accidents and Management of Roadside Trees

ANDREW J. ZEIGLER

Research conducted by the Michigan Department of Transportation has resulted in recommendations regarding both safety and environmental issues for management of roadside trees. Intended for local and state road authorities, recommendations resulted from research that included analysis of nearly 500 sites of vehicle-tree accidents across Michigan. Statistical analysis of vehicle-tree accidents in Michigan reveals, among other characteristics, that the typical driver may be intoxicated or unfamiliar with the road or both. Vehicle-tree accidents typically occur along winding rural roads and involve a vehicle that leaves the pavement on the outside of a curve. No single feature of the road environment accounts for all the accidents that occur and so can be used to determine the level of risk. The distance of the tree from the road is not sufficient by itself to determine the probability of a vehicle-tree accident. Treatment of locations should address both safety and environmental issues. High-risk locations should be identified for treatment first on the basis of both accident history and potential accident frequency. Accident profiles have been developed to identify high-risk locations while eliminating random accident sites from consideration. Tree removal is only one of many alternatives that should be considered depending on site-specific environmental and safety issues. Contact with adjacent property owners and judgment of professional engineers are essential in the treatment process rather than strict adherence to set clear-cut distances. Because it is expected that safety issues will continue to conflict with environmental issues associated with roadside trees, the management process offered will be useful in addressing the vehicle-tree accident problem.

The Michigan Department of Transportation (MDOT) has recently completed a *Guide to Management of Roadside Trees (1)*, which presents a step-by-step approach to identify and treat rural roadways that have a high risk of vehicle-tree accidents. It is intended for use by state highway personnel and local road authorities responsible for maintaining roads. Both safety and environmental issues are addressed, along with alternative treatments to reduce the risk of vehicle-tree accidents.

Prepared under an FHWA grant for national distribution, this guide is a result of more than 10 years of comprehensive research *(2–5)*. Defining the exact nature and extent of the vehicle-tree accident problem on a statewide and site-specific basis required supportive statistical analysis of accident data and field surveys of vehicle-tree accident sites.

Environmental and highway safety research consultants were employed to identify and evaluate the problem *(4,6)*. Following study of the state-of-the-art research, evaluation of five consecutive years of vehicle-tree accident data in Michigan, field surveys, and analysis of nearly 500 vehicle-tree accident sites across Michigan, a statistical basis for research findings and recommendations was developed. Subsequent evaluation and revisions by the MDOT were based on field testing by the Ingham County Road Commission (Michigan) and review by other Michigan county road agencies and transportation departments in other states *(2)*.

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DEFINING THE PROBLEM

Trees are valued as a resource along the roadways. However, they have come under scrutiny in recent years as posing a risk. In Michigan, for example, review of accidents for the 5-year period from 1981 through 1985 reveals that although tree-related accidents constitute only about 2.8 percent of all accidents, they represent 11.1 percent of all fatal crashes *(7)*. A review of fatal accident involvement from 1978 through 1985 reveals that although crashes involving trees vary significantly by year, the absolute number appears to stay relatively constant *(7)* (Figure 1).

Vehicle-tree accidents are not distributed evenly throughout a geographic area. In Michigan, for example, the vehicle-tree accident problem occurs with much greater frequency in the lower half of the lower peninsula. According to recent data on the cumulative number of vehicle-tree accidents for both local and U.S. or state roads (fatal, injury, and property damage) from 1979 to 1983, these accidents occurred with greater frequency in 13 counties *(7)*, which appear to include those associated with both higher population concentrations or density and greater vehicle miles traveled as well as areas having roadside trees.

Research devoted to identifying, ranking, and tabulating the risk potential of many characteristics of vehicle-tree accidents was completed as part of this study. These characteristics fall into three categories:

1. Driver characteristics;
2. The road design, or geometrics; and
3. Trees and the roadside environment.

Driver Characteristics

The discussion in this section is based on two studies *(3,6)*. Traffic-related research has drawn a profile of the driver most typically involved in run-off-road accidents. He is typically a young man between 20 and 25 years old. He is a weekend driver, out during the early morning hours between 2:00 and 4:00 a.m. He is driving faster than the posted speed limit and may also be intoxicated or unfamiliar with the road, or both.

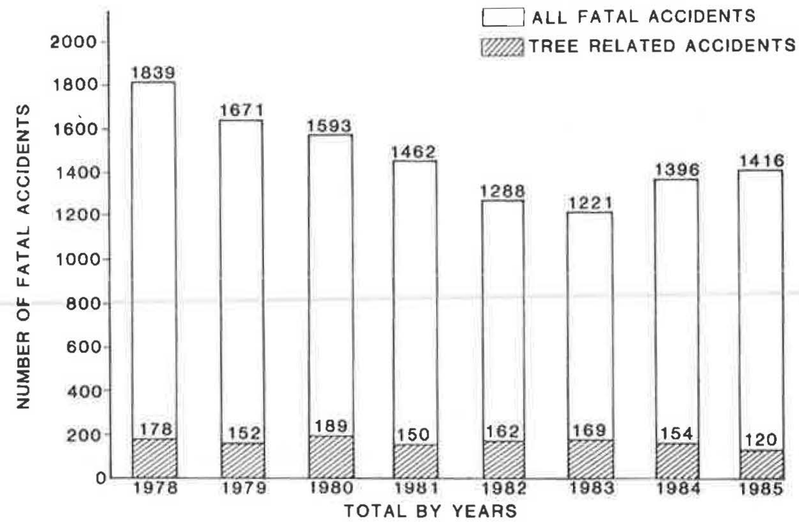

FIGURE 1 Fatal vehicle accidents in Michigan, total and tree related, from 1978 through 1985.

Drinking is a common ingredient in vehicle-tree accidents. More than 60 percent of the drivers killed in vehicle-tree crashes had been drinking; less than 30 percent of the drivers involved in property-damage-only accidents were reported to have been drinking.

More than two-thirds of vehicle-tree collisions occur on weekends. Most of these accidents occur on Friday and Saturday nights between 2:00 and 4:00 a.m. on the following day. Crashes are most frequent during the winter months, suggesting some correlation with longer periods of darkness and, perhaps, snow-covered or icy roads.

Many of the factors that correlate with speeding, such as nighttime hours and young drivers, are also typical of run-off-road accidents.

Design

Vehicle-tree accidents typically occur along winding rural roads on which a vehicle leaves the pavement on the outside of a curve *(6)*. The road type and various physical features (lane and shoulder width, traffic volume and direction, presence of curves, etc.), as well as the driver characteristics described earlier, determine the probability of running off the road.

Accidents involving trees are mainly a rural phenomenon, occurring most frequently on rural local roads *(3)*. Of the fatal accidents occurring during 1985, for example, 81.7 percent occurred on rural roads; 72.9 percent of the injury-producing and 70.7 percent of the property-damage-only vehicle-tree accidents occurred in unincorporated areas *(7)*.

Seventy-seven percent of tree-related accidents on curves occur on the outside of the curve, that is, to the right of a left curve or the left of a right curve *(6)*. Inside curves account for 23 percent of the crash frequency. Most vehicle-tree crashes on curves involve right departures on left curves.

This study addresses two road classifications, rural U.S. or state and rural local. Rural U.S.-state roads are identified as rural arterials and major collectors. These roads include all U.S. and state-designated routes. Rural local roads include the remaining ones, generally maintained by local road authorities (county, township, etc.). Because of lower traffic volumes, these roads also include gravel surfaces and are maintained to lower standards than higher volume arterials and some collectors.

Trees and the Roadside Environment

The typical vehicle-tree accident involves a larger tree within 30 ft (9.15 m) of the road edge. The tree is typically located in a drainage ditch or at the bottom of a downward grade. The target tree and its immediate surroundings (size, density, distance from the road, the presence of other obstructions, etc.) determine the probability that the vehicle will strike the tree.

Although trees involved in accidents have been as far from the pavement edge as 90 ft (27.45 m), 85 percent of the trees involved in vehicle-tree crashes were within 30 ft (9.15 m) of the road edge *(6)* (Figure 2).

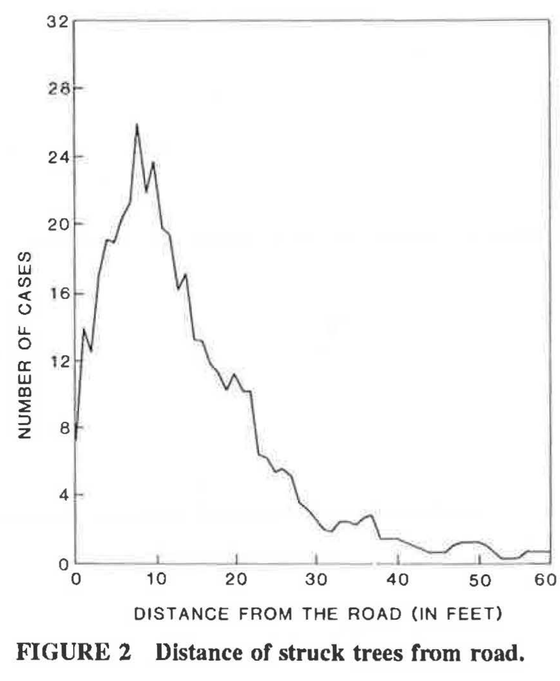

FIGURE 2 Distance of struck trees from road.

A number of other factors may reduce or increase the probability of striking a tree as well as affect the severity of the crash. For instance, the presence of guardrails may change the character of the accident; roadside edge slope design may reduce the speed of a vehicle before it strikes a solid object; a drainage ditch may guide the vehicle directly into a tree.

Accident Profiles

In the explanation of run-off-road accidents, no single feature of the road environment accounts for all the accidents that occur and thus the level of risk. For example, the distance of the tree from the road is not sufficient by itself to determine the probability of a vehicle-tree accident. Accidents involving trees have occurred in a wide range of distances from the pavement's edge. Employing such one-dimensional models limits the ability to understand and consequently to prevent vehicle-tree accidents.

Identifying and ranking nonhuman factors that contribute to the risk of vehicle-tree accidents is an essential task in developing guidelines. Two areas of the roadside environment must be considered: the actual roadway and the off-roadway environment.

Studies indicate that the various roadway and off-roadway characteristics of vehicle-tree accidents cluster in particular patterns associated with road type and alignment *(5,6)*. These accident profiles identify potential high-risk sites so they can be treated.

The accident profiles relate to the road types identified earlier. They include both rural U.S.-state roads and rural local roads, along with the horizontal alignment (curved or straight sections) of these roads. Curved rural local roads typically involve the higher risk, followed by curved rural U.S.-state roads, and then straight rural local roads and rural U.S.-state roads *(1)*.

A comparison of the number of fatal vehicle-tree accidents was made in this study for U.S.-state and local road classifications in Michigan *(7)* (Figure 3). Measured by the number of fatal vehicle-tree accidents per 100 million mi traveled, curved local road sections are by far the highest-risk areas. In 1985, for example, curved local roads, with 564.4 vehicle-tree accidents per 100 million mi traveled, had nearly 10 times the number of accidents as the next highest category, curved U.S.-state roads, with 57.9 accidents per 100 million mi. This is followed by straight local roads with some 21 vehicle-tree accidents and, finally, straight U.S.-state roads with 3.9 vehicle-tree accidents per 100 million mi traveled.

A program for the management of roadside trees should be focused on these road types. City streets have been excluded from the MDOT guide because of the difficulty of defining what they are and a lack of data on vehicle-tree accidents occurring along this road type *(1)*. Exceptions include rural U.S.-state and rural local roads that pass through city limits, but more closely resemble rural conditions (i.e., no curbs).

Curved Rural Local Roads

Curved rural local roads constitute a substantially higher-risk driving environment than do straight rural local roads. Most curved rural local road accident sites are found on left-hand turns with downhill grades following a series of curves. The likelihood of an accident increases with tree density near the outside of the curve *(6)*. The impacted tree is often 20 ft (6.1 m) or more from the road edge.

Curved Rural U.S.-State Roads

In every case studied, accidents along curved rural U.S.-state roads occurred on left-hand curves *(5)*. Most often, the fatal tree was in a grove of trees and was rarely the first tree struck. Typically, the vehicle ran down an embankment into a grove of trees. Almost half of the accidents studied occurred at the location of at least one previous serious vehicle-tree accident.

Treatment of curved rural U.S.-state roads is more difficult than treatment of curved rural local roads. The trees tend to be even farther from the road edge.

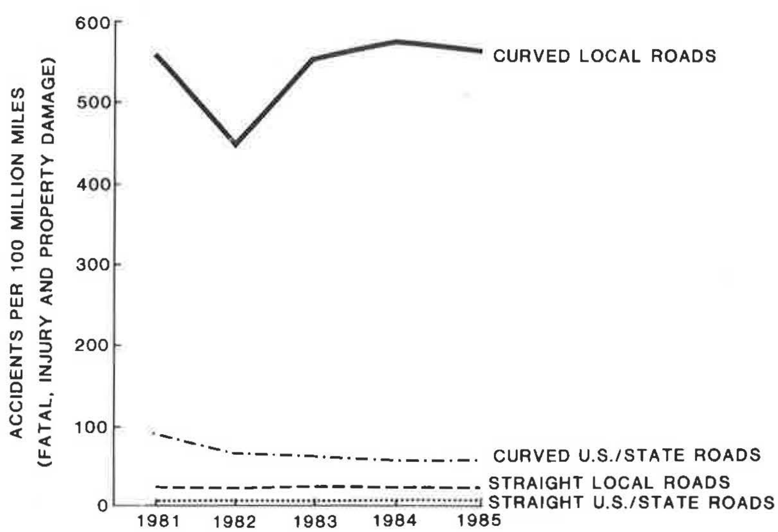

FIGURE 3 Vehicle-tree accidents per miles traveled by road type (curved or straight sections) in Michigan, 1981 to 1985.

As is the case with accidents on curved rural local roads, vehicles often miss a left turn and continue down a side slope into a tree. Slope of the road is a less critical factor on rural U.S.-state roads than on rural local roads.

Straight Sections of Rural Local Roads

Straight sections of rural local roads have accident profiles that are considerably different from those of curved sections. The distance of trees from the road edge tends to be appreciably less along straight rural local roads. Typically the vehicle enters a ditch from a narrow and often unstable (i.e., soft) shoulder and is then channelled into several trees.

Straight Sections of Rural U.S.-State Roads

The impacted trees along straight rural U.S.-state road sections are farther from the road edge than trees along rural local roads. The ditches are usually wider and less likely to direct the vehicle into a tree. Another tree is usually struck first; the vehicle then careens into the fatal one.

SOLVING THE PROBLEM

How does one solve the vehicle-tree accident problem? A method for examining roadside vehicle-tree accident risk is necessary in areas where roads are lined with trees.

Although a county or state may appear to have an existing vehicle-tree accident problem along specific road sections, many of these locations may simply reflect random accident occurrence. A policy to treat only sites that demonstrate accident risk (because of perceived legal or liability issues or because of limited funding, or both) is therefore likely to miss the majority of high-risk locations. Many sites where there have been no accidents will have a much higher potential risk, although it has not been demonstrated within the last 5 years.

Sufficient resources do not exist to remove all roadside trees, nor would this be desirable. Resources do not exist to upgrade all roads or easily modify driver behavior. Therefore, those road sections with a high risk for a serious accident involving a tree must be identified for treatment.

Accident profiles just discussed allow one to identify potential high-risk locations for treatment based on road type and alignment. Ranking by risk has been taken further to identify locations having vehicle-tree accidents that should not be considered random occurrences. To address this, average daily traffic (ADT) and the incidence of vehicle-tree accidents are taken into account. This allows one to more appropriately rank locations that are more frequently traveled first.

A more responsive approach, therefore, is to consider both expected accident occurrence and locations of significant accident frequency to determine priorities for field verification and treatment. This would both address long-term prevention (10 to 20 years) and be responsive to locations that have a significant accident history.

To do this, accident history over the last 3 to 5 years should be used to identify locations where particularly high vehicle-tree accident frequency has occurred. For example, when the actual vehicle-tree accident frequency along a road section is significantly higher than what is expected (based on both probability and local accident data), these should not be considered random accident locations. Instead, the number of accidents may indicate a real and statistically significant deviation from this expectation. The threshold, or the number of vehicle-tree accidents that represents a statistically significant deviation from the expected, can be calculated for each location. For those locations meeting or exceeding this threshold, the actual number of vehicle-tree accidents (equated per year) may be used to determine the priority for treatment. This will identify both straight road sections as well as curved road sections that have an unusually high vehicle-tree accident frequency (risk).

A method for examining roadside vehicle-tree accident risk was developed in this study and involves five tasks *(1,2)* (Figure 4). It enables the road engineer to identify road sections by risk for priority treatment. The method can be used to consider both potential risk and accident frequency for any location.

Developed for practical application, the methodology is presented as a step-by-step procedure. It can be completed manually or programmed for use with the aid of a computer as part of an already existing accident data system for analysis.

Along with both safety and environmental concerns, the procedure is based on driver characteristics, factors concerning the road environment, and characteristics of roadsides with trees (Figure 4).

Task 1: Prepare a Base Map and Plot Roadway Information

The first task is broken into six steps that create a base map or computer file for interactive use. Identified are rural roads by type (rural local or rural U.S.-state), ADT, curved road sections, locations of past vehicle-tree accidents, and locations of natural and cultural significance that may be affected along the roadside. These may include champion trees, locations of endangered plant species, and historic sites. The base map or computer file would exhibit or list this type of information.

Areas of natural and cultural significance in Michigan, for example, are available through an existing Natural Features Inventory from the Michigan Department of Natural Resources (MDNR). Similar inventory or heritage programs are available in other states.

Any particular county road system may include 400 or more locations with high vehicle-tree accident risk. However, less than half of these, and probably not more than the top 10 to 20 percent, would reasonably be considered part of a 3- to 5-year program of priority safety improvement. A computer-based file could, of course, accommodate a much more comprehensive inventory system.

Task 2: Assign Priorities for Field Verification

Divided into four steps, the second task determines the order in which to field check the high-risk road sections. The step-by-step approach allows one to consider both potential risk and actual accident frequency. A master county (or state) map (or computer listing) is developed that pinpoints locations of high risk. This is then used to identify sections rank ordered by risk for field review and treatment.

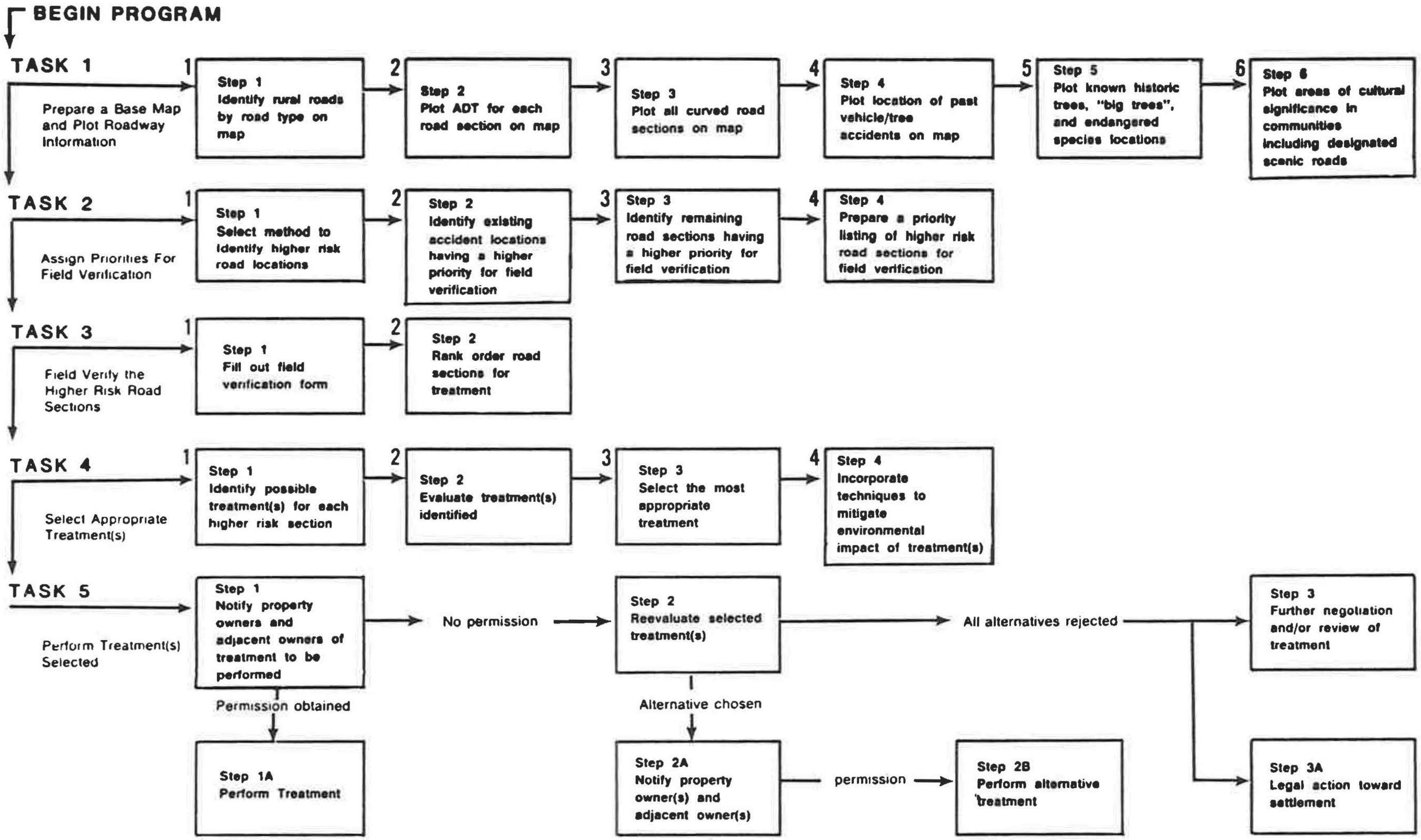

FIGURE 4 Method for evaluating higher-risk roadside environments.

Task 3: Field Verify High-Risk Road Sections

Using the priority listing established in Task 2, high-risk road sections should be field reviewed first. This provides a more cost-effective approach to confirm or eliminate potential road sections for treatment. It avoids a random approach of both field review and treatment.

A field verification form is filled out for each road section location identifying the location and recording all the pertinent safety, environmental, and other considerations that may have a bearing on the treatment to be selected. This may include discussion with the adjacent property owners concerning the location.

Task 4: Select Appropriate Treatments

Alternative treatments for each of the higher-risk road sections are next selected. This involves a review of the field verification forms and listing of higher-risk road sections to determine or confirm appropriate treatments. The treatments selected should be based on a simplified benefit/cost analysis of the alternatives considered for the sites.

Roadway and roadside treatments that may be considered to reduce the risk of vehicle-tree accidents include

- Pavement marking
- Installing delineators and advance warning signs
- Installing advisory speed signs
- Designating special-purpose roads
- Superelevating or modifying road cross-slope
- Widening and paving shoulders
- Removing trees
- Installing guardrails
- Regrading ditch sections
- Making slope alterations
- Using protective plantings
- Relocating or realigning road

The feasibility and effectiveness of any treatment, including tree removal, will depend on specific applications and whether treatments are used in combination or individually.

Alternatives that improve the design characteristics of the road should be investigated first. Such treatments as pavement marking, superelevation correction, and shoulder paving make it easier for motorists to stay on the road.

Improvements that should be considered next are those that involve the roadside. From a safety standpoint, the most effective treatment may be tree removal. This is generally the least costly and the simplest to accomplish. However, as will be discussed shortly, tree removal is sometimes not an appropriate treatment because of a number of environmental constraints.

Other treatments such as guardrails, ditch regrading, and slope alterations also provide a more forgiving roadside for motorists who inadvertently leave the road. These need to be considered as well and may provide suitable alternatives to tree removal. Combinations of alternatives that both improve the design characteristics of the road and create a more forgiving roadside would provide the most complete improvement.

When the appropriate treatment to alleviate the risk of run-off-road accidents is selected, it is important to keep in mind that the interaction of the driver, the vehicle, and the roadway is a complex relationship. Therefore, combinations of treatments, rather than one treatment used exclusively, are more likely to alleviate the risk of vehicle-tree accidents.

Environmental factors also need to be considered in the selection of treatment to reduce risk *(1,8,9)*. Following the consideration or application of various alternatives, it may then be appropriate to consider tree removal, grading and slope changes, and so on. If tree removal is an appropriate alternative to reduce the risk, certain environmental factors need to be considered before a final decision is made or action is taken. These considerations should include issues associated with ownership, endangered or threatened species and unique habitats, tree species size, historic vegetation, erosion and sedimentation, safety, and mitigation of environmental impacts. These factors are not to be taken lightly and may represent the most significant hurdle before any safety or maintenance program can be carried out.

Task 5: Perform Treatment or Treatments Selected

The last task involves contacting property owners and adjacent owners, securing property owners' permission to perform the selected treatment, and performing the treatment. This is particularly important in locations adjacent to residences, nature areas, plant preserves, parks or landscaped areas, and designated scenic roads.

This should be done not only to promote good public relations, but also to facilitate implementation of maintenance programs by helping to identify or avoid environmentally sensitive or controversial locations.

MAINTENANCE

Continued maintenance of cleared or treated higher-risk roadsides cannot be overemphasized. Maintenance of these higher-risk roadsides as clear zones is necessary to avoid future safety problems and an increase in vehicle-tree accident risk as vegetation naturally reestablishes itself along the roadside. Without a maintenance program, a much more costly tree-removal or treatment program, or both, would again have to be implemented. Brush and tree maintenance programs developed from this guide should be integrated into the responsible department's overall maintenance program.

CONCLUSIONS

It is expected that there will continue to be issues of safety versus environment and liability associated with roadside trees. These are serious issues and cannot easily be solved.

The vehicle-tree accident problem exists predominantly along curved rural local road sections. With limited resources available to improve roadside safety, it becomes important to focus these resources on a priority-risk basis. Treatment must take into account both safety and environmental issues for effective management of roadside trees.

ACKNOWLEDGMENTS

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Publication of this paper sponsored by Committee on Roadside Maintenance.

Controlling Seedheads in Tall Fescue with Herbicides

RAY DICKENS

Experimentals were conducted over 2 years at four locations in Alabama to evaluate several herbicides for seedhead suppression in tall fescue turfs. Herbicides showing good activity (more than 50 percent seedhead reduction) included Sulfometuron, Metsulfuron, Chlorsulfuron at 1/8 to 3/4 oz a.i. (active ingredient) per acre, and Glyphosate at 4 to 8 oz a.i. per acre. Rates of Sulfometuron, Metsulfuron, and Chlorsulfuron as low as 1/8 oz a.i. per acre were effective in reducing seed heads. There was no difference between results for March 15 applications and those made on March 30 at the same location. Combinations of Glyphosate and Sulfometuron were not more efficacious than Sulfometuron applied alone at the same rate. The amount of seedhead suppression was highly correlated to the amount of injury to the tall fescue stands as reflected in appearance ratings. Injury to tall fescue stands from repeated annual use could be unacceptable in some instances.

Tall fescue is the predominant turf species on many acres of roadside in the northern half of Alabama. It has many characteristics that make it a useful species, including excellent cold and drought tolerance. The primary disadvantages of tall fescue are its rapid growth rate and numerous persistent seedheads, which grow to unattractive and unsafe heights. Tests were conducted at four sites in Alabama during 1984 and 1985 to evaluate several herbicides for their effect on seedhead production in tall fescue.

MATERIALS AND METHODS

Tests in 1984 were located on I-65 in Chilton County near Clanton and on I-85 in Lee County near Auburn. In 1985 the tests were conducted on I-65 in Butler County near Greenville and on I-85 in Macon County near Tuskegee. In each case the experimental design was a randomized complete block with three replications. Plots were 10 × 25 ft in size. The herbicides (Table 1) were applied with a tractor-mounted sprayer in 26 gal of water per acre through flat fan nozzles spaced 20 in. apart on a boom.

The test sites were mowed front slopes having good to excellent stands of tall fescue. Two dates of application were included in the tests each year. The first application was made March 15 ± 2 days, and the second application was made April 1 ± 3 days. Appearance was evaluated by visual (color) ratings 1 month after the first application. Counts of seedheads were made about May 1. A second series of counts and general appearance ratings were made during the last week of May.

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RESULTS AND DISCUSSION

Most all treatments reduced seedheads at the Chilton County location in 1984 (Table 1). There was generally no response to rates of Chlorsulfuron or Metsulfuron at this location on either April 26 or May 22. Seedhead control from Chlorsulfuron was not influenced by the addition of surfactant. However, on May 22 Metsulfuron applied at 1/8 oz per acre produced more inhibition when surfactant was added at the March 15 application date, but the March 30 results were not affected by surfactant additions. Appearance effects paralleled those of seedhead inhibition for the most part. That is, applications of either Metsulfuron or Chlorsulfuron caused appearance to be reduced on April 10, regardless of rate or the presence of surfactant, or both. Little or no injury was detectable at the later evaluation date.

Sulfometuron effects on seedhead production were influenced by rate and added surfactant. Plots receiving less than 1/2 oz per acre had more seed heads than those receiving 1/2 oz or more at both dates of application and both locations. The response to added surfactant was significant when 1/8 oz of Sulfometuron was applied, but not when the rate was increased to 1/2 oz. Appearance was reduced by all rates in early April, but only by the higher rates in late May.

Combinations of Glyphosate and Sulfometuron gave better seedhead control in most instances than Glyphosate alone when evaluated in late May. There was no apparent advantage of the combination treatments over Sulfometuron alone.

The 1984 test on I-85 in Lee County was mowed by highway personnel before the second counts and appearance ratings could be obtained. Appearance ratings made on April 10, 1984, showed that all herbicide treatments were more injurious to tall fescue when applied March 15 than when application was made 2 weeks later (Table 2). Injury was not increased by the addition of surfactant to any of the herbicides tested at this location.

Seedhead control was enhanced when surfactant was added to 1/8-oz rates of Sulfometuron or Metsulfuron, but not when added to Chlorsulfuron. Effective seedhead suppression was obtained at this location with rates of Sulfometuron above 1/4 oz per acre. Control from Chlorsulfuron or Metsulfuron was poor in this test. Combinations of Sulfometuron and Glyphosate were much more effective than comparable rates of Glyphosate applied alone. The results were similar to those obtained from the test near Clanton. However, effects of treatments on late season seedhead control were not obtained at this location.

TABLE 1 EFFECTS OF HERBICIDE TREATMENTS ON TALL FESCUE IN CHILTON COUNTY, ALABAMA, 1984

Application Rate (oz/acre)	Apr. 10 Appearance Rating[a] by Application Date		Apr. 26 Seedhead Counts (no./yd^2) by Application Date		May 22 Appearance Rating by Application Date		May 22 Seedhead Counts (no./yd^2) by Application Date	
	March 15	March 30	March 15	March 30	March 15	March 30	March 15	March 30
Chlorsulfuron								
1/8	60 b[b]	70 b	4 bc	10 ab	93 a	88 a	21 b	24 b
1/4	70 b	73 b	9 abc	9 abc	92 a	93 a	23 b	21 b
1/2	55 bc	63 b	8 abc	9 abc	87 a	87 a	17 b	25 b
3/4	53 bc	70 b	6 bc	5 bc	97 a	90 a	18 b	20 b
1/8[c]	35 c	72 b	3 bc	7 bc	92 a	85 a	19 b	20 b
1/2[c]	55 bc	73 b	4 bc	2 c	93 a	92 a	19 b	12 b
Check	90 a	90 a	14 a	14 a	94 a	94 a	35 a	35 a
Metsulfuron								
1/8	58 bcde[b]	68 bcd	7 bc	2 c	95 a	88	17 bc	15 bc
1/4[c]	47 ef	55 cd	4 bc	1 c	93 a	73 a	18 bc	10 bc
1/2[c]	50 def	72 bcd	3 bc	1 c	92 a	78 a	12 bc	10 bc
3/4[c]	32 f	63 bcd	1 c	0 c	92 a	75 a	17 bc	8 c
1/8	63 bcde	67 bcd	10 ab	6 bc	87 a	85 a	36 a	23 bc
1/2	50 def	77 b	5 bc	5 bc	97 a	85 a	12 c	26 b
Check	90 a	90 a	14 a	14 a	94 a	94 a	35 a	35 a
Sulfometuron								
1/8	45 cdef[b]	72 b	1 b	12 a	93 ab	88 ab	12 b	11 b
1/4	57 bcd	67 bc	2 b	12 a	93 ab	88 ab	7 c	11 b
1/2	53 bcde	65 bc	4 b	4 b	83 abc	82 abc	12 b	17 b
3/4	52 bcde	62 bc	1 b	2 b	70 bcd	78 bc	11 b	4 c
1.0	28 f	65 bc	0 b	1 b	23 de	22 e	0 c	2 c
1/8[c]	33 ef	68 b	0 b	2 b	87 ab	92 ab	3 c	9 c
1/2[c]	37 def	63 bc	0 b	0 b	55 cd	45 d	0 c	3 c
Check	90 a	90 a	14 a	14 a	94 a	94 a	35 a	35 a
Glyphosate and Sulfometuron[d]								
4	65 bcde[c]	70 b	6 b	4 b	87 abcd	90 abcd	21 b	10 bcdef
6	60 bcde	68 bc	3 b	3 b	93 ab	88 abcd	20 bc	17 bcde
8	47 cdefg	57 bcde	1 b	3 b	92 abc	85 abcde	12 bcde	9 bcdef
(4+1/4)[e]	43 efg	67 bcd	0 b	1 b	65 cde	85 abcde	1 f	6 bcdef
(4+1.0)	33 fg	63 bcde	0 b	0 b	17 f	20 f	1 f	1 f
(8+1/4)	28 g	45 defg	0 b	0 b	82 abcde	78 bcde	7 bcdef	6 bcdef
(8+1/2)	43 efg	62 bcde	0 b	0 b	63 de	63 e	3 def	3 de
(8+1.0)	27 g	65 bcde	0 b	0 b	15 f	28 f	0 f	1 f
Check	90 a	90 a	14 a	14 a	94 a	94 a	35 a	35 a

[a]Ratings based on 0 to 100 scale with 0 = bare ground and 100 = ideal turf.
[b]Means within columns not followed by the same letter are different (P = 0.05) by Duncan's multiple-range test.
[c]Surfactant (X-77) added at the rate of 0.75 percent by volume to spray admixture.
[d]Surfactant (X-77) added at the rate of 0.5 percent by volume to spray admixture.
[e]First value = Glyphosate; second value = Sulfometuron.

TABLE 2 EFFECTS OF HERBICIDE TREATMENTS ON TALL FESCUE IN LEE COUNTY, ALABAMA, 1984

Application Rate (oz/acre)	Apr. 10 Appearance Rating[a] by Application Date		Apr. 27 Seedhead Counts (no./yd²) by Application Date	
	March 15	March 30	March 15	March 30
Chlorsulfuron				
1/8	58 bcdef[b]	67 bcd	32 abc	36 a
1/4	55 cdef	67 bcd	46 a	47 a
1/2	52 def	65 bcde	19 bcde	26 bcd
3/4	43 f	73 b	35 ab	13 cde
1/8[c]	48 ef	68 bc	12 cde	32 abc
1/2[c]	47 f	67 bcd	5 e	9 de
Check	83 a	83 a	34 ab	34 ab
Metsulfuron				
1/8	45 def[b]	63 bc	10 cde	14 bcde
1/4	42 ef	60 bcd	23 bcd	5 de
1/2	47 def	72 b	13 cde	10 de
3/4	35 f	60 bcd	9 cde	1 e
1/8[c]	52 cde	67 bc	20 bcde	52 a
1/2[c]	47 def	68 bc	29 bc	18 bcde
Check	83 a	83 a	34 ab	34 ab
Sulfometuron				
1/8	60 cde[b]	77 ab	24 a	22 ab
1/4	50 def	70 bc	16 bcd	20 bc
1/2	37 g	75 abc	2 d	8 bcd
3/4	40 fg	65 bcd	6 bcd	3 cd
1.0	38 g	65 bcd	1 d	0 d
1/8[c]	47 efg	70 bc	1 d	5 cd
1/2[c]	45 efg	70 bc	3 cd	1 d
Check	83 a	83 a	34 a	34 a
Glyphosate and Sulfometuron[d]				
4	48 bcde[b]	60 b	15 abcd	38 ab
6	37 defg	60 b	5 cd	10 bcd
8	35 efg	55 bc	9 bcd	4 cd
(4+1/4)[e]	38 cdefg	55 bc	4 cd	0 d
(4+1.0)	32 efg	57 b	1 d	3 d
(8+1/4)	30 fg	45 bcdef	2 d	1 d
(8+1/2)	23 gh	53 bcd	1 d	0 d
(8+1.0)	17 h	53 bcd	2 d	0 d
Check	83 a	83 a	34 a	34 a

[a]Ratings based on 0 to 100 scale with 0 = bare ground and 100 = ideal turf.
[b]Means within columns not followed by the same letter are different ($P = 0.05$) by Duncan's multiple-range test.
[c]Surfactant (X-77) added at the rate of 0.75 percent by volume to spray admixture.
[d]Surfactant (X-77) added at the rate of 0.5 percent by volume to spray admixture.
[e]First value = Glyphosate; second value = Sulfometuron.

TABLE 3 EFFECTS OF HERBICIDE TREATMENTS ON TALL FESCUE IN BUTLER COUNTY, ALABAMA, 1985

Application	Apr. 17 Appearance Rating[a] by Application Date		May 2 Seedhead Counts (no./yd^2) by Application Date		May 29 Appearance Rating by Application Date		May 29 Seedhead Counts (no./yd^2) by Application Date	
Rate (oz/acre)	March 15	March 30	March 15	March 30	March 15	March 30	March 15	March 30
Chlorsulfuron								
1/8	68 bcd[b]	87 bcd	20 bc	8 c	58 a	55 a	24 bcd	14 d
1/4	77 bcd	90 bc	21 bc	20 bc	78 a	73 a	23 bcd	34 abc
1/2	75 cd	87 bcd	24 b	16 bc	68 a	70 a	33 abc	17 d
3/4	60 e	91 b	11 bc	15 bc	72 a	65 a	17 d	22 cd
1/8[c]	70 de	82 bcd	17 bc	12 bc	58 a	70 a	23 bcd	22 cd
1/2[c]	70 de	75 cd	17 bc	7 c	72 a	75 a	16 d	18 d
Check	99 a	99 a	47 a	47 a	73 a	73 a	38 a	38 a
Metsulfuron								
1/8	73 bcd[b]	83 bcd	9 bc	6 cde	70 ab	72 ab	14 b	14 b
1/4[c]	77 bcd	80 bcd	9 bc	7 bcde	78 a	80 a	12 b	4 b
1/2[c]	80 bcd	85 b	21 b	6 cde	67 ab	72 ab	10 b	3 b
3/4[c]	45 e	63 de	4 de	1 e	58 ab	62 ab	7 b	1 b
1/8	65 cde	85 b	7 bcde	7 bcde	50 b	62 ab	12 b	18 b
1/2	73 bcd	82 bcd	12 bcde	6 cde	70 ab	63 ab	13 b	11 b
Check	99 a	99 a	47 a	47 a	73 a	73 ab	38 a	38 a
Sulfometuron								
1/8	78 b[b]	85 b	7 b	7 b	72 a	72 a	10 b	11 b
1/4	67 b	85 b	5 b	3 b	68 ab	60 abc	6 b	4 b
1/2	58 cd	75 bc	1 b	2 b	62 ab	50 abc	3 b	3 b
3/4	58 cd	78 b	0 b	2 b	43 bcd	33 cd	1 b	1 b
1.0	47 d	82 b	0 b	1 b	23 d	23 d	0 b	1 b
1/8[c]	70 bcd	78 b	2 b	0 b	72 a	57 abc	7 b	1 b
1/2[c]	58 cd	77 b	0 b	2 b	60 abc	52 abc	1 b	4 b
Check	99 a	99 a	47 a	47 a	73 a	73 a	38 a	38 a
Glyphosate and Sulfometuron[d]								
4	80 b[b]	82 b	15 b	2 c	75 a	65 ab	21 b	6 cd
6	73 bc	63 bcdefg	12 bc	2 c	63 abc	63 abc	17 bc	2 cd
8	65 bcdef	52 cdefgh	6 bc	1 c	77 a	68 ab	12 bcd	1 d
(4+1/4)[e]	43 fgh	50 defgh	2 c	0 c	58 abc	58 abc	4 cd	2 cd
(4+1.0)	48 efgh	50 defgh	1 c	1 c	43 bcde	32 defg	2 cd	1 d
(8+1/4)	50 efgh	40 gh	0 c	0 c	53 abc	22 efg	1 d	0 d
(8+1/2)	33 h	35 h	0 c	0 c	38 cdef	20 efg	0 d	0 d
(8+1.0)	35 h	32 h	0 c	0 c	13 g	18 fg	0 d	0 d
Check	99 a	99 a	47 a	47 a	73 a	73 a	38 a	38 a

[a]Ratings based on 0 to 100 scale with 0 = bare ground and 100 = ideal turf.
[b]Means within columns not followed by the same letter are different ($P = 0.05$) by Duncan's multiple-range test.
[c]Surfactant (X-77) added at the rate of 0.75 percent by volume to spray admixture.
[d]Surfactant (X-77) added at the rate of 0.5 percent by volume to spray admixture.
[e]First value = Glyphosate; second value = Sulfometuron.

TABLE 4 EFFECTS OF HERBICIDE TREATMENTS ON TALL FESCUE IN MACON COUNTY, ALABAMA, 1985

Application Rate (oz/acre)	Apr. 17 Appearance Rating[a] by Application Date		May 2 Seedhead Counts (no./yd^2) by Application Date		May 30 Appearance Rating by Application Date		May 30 Seedhead Counts (no./yd^2) by Application Date	
	March 15	March 30	March 15	March 30	March 15	March 30	March 15	March 30
Chlorsulfuron								
1/8	68 b[b]	75 b	7 c	7 c	57 ab	60 a	9 de	11 cde
1/4	82 b	78 b	20 b	11 bc	68 a	62 a	25 b	17 bcde
1/2	67 b	82 b	12 bc	14 bc	50 b	67 a	7 e	20 bcd
3/4	72 b	83 b	12 bc	7 c	57 ab	58 a	20 bc	14 bcde
1/8[c]	82 b	85 b	16 bc	11 bc	72 a	68 a	20 bcd	8 de
1/2[c]	72 b	85 b	7 c	12 bc	72 a	67 a	12 cde	20 bc
Check	99 a	99 a	32 a	32 a	70 a	70 a	40 a	40 a
Metsulfuron								
1/8[c]	70 bc[b]	82 b	10 bc	4 c	57 ab	68 a	14 b	6 b
1/4[c]	67 bc	82 b	14 b	11 bc	67 a	67 a	15 b	15 b
1/2[c]	63 bc	70 bc	5 c	1 c	48 b	55 ab	5 b	8 b
3/4	53 c	75 b	6 bc	5 c	40 b	62 a	5 b	12 b
1/8	73 b	83 b	17 b	16 b	73 a	60 a	16 b	16 b
1/2	70 bc	77 b	7 bc	6 bc	57 ab	62 a	7 b	8 b
Check	99 a	99 a	32 a	32 a	70 a	70 a	40 a	40 a
Sulfometuron								
1/8	78 bcd[b]	85 b	10 b	3 b	63 ab	53 bcd	16 b	4 c
1/4	72 bcd	82 bc	3 b	0 b	65 a	52 abcde	3 c	2 b
1/2	75 bcd	82 bc	2 b	0 b	43 abcdef	38 abcdef	8 bc	1 c
3/4	62 cd	72 bcd	0 b	1 b	70 bcd	78 bc	11 b	4 c
1.0	58 d	73 bcd	1 b	0 b	25 cdef	17 f	1 c	0 c
1/8[c]	62 cd	80 bcd	0 b	0 b	20 ef	40 abcdef	0 c	0 c
1/2[c]	63 cd	80 bcd	0 b	0 b	40 abcdef	22 ef	4 c	0 c
Check	99 a	99 a	32 a	32 a	70 a	70 a	40 a	40 a
Glyphosate and Sulfometuron[d]								
4	70 bc[b]	67 bc	7 b	0 b	68 a	43 bcde	9 bc	2 c
6	73 b	58 bcd	6 b	0 b	67 a	70 ab	7 bc	5 bc
8	42 de	48 cdee	10 b	0 b	68 a	57 abc	17 b	1 c
(4+1/4)[e]	47 cde	48 cde	0 b	0 b	27 cde	37 bcd	1 c	0 c
(4+1.0)	40 de	53 bcde	0 b	0 b	20 de	32 bcde	0 c	0 c
(8+1/4)	47 cde	40 de	0 b	0 b	40 bcde	20 de	0 c	0 c
(8+1/2)	27 e	38 de	0 b	0 b	18 de	17 de	0 c	0 c
(8+1.0)	30 e	35 de	0 b	0 b	12 e	12 e	0 c	0 c
Check	99 a	99 a	32 a	32 a	70 a	70 a	40 a	40 a

[a]Ratings based on 0 to 100 scale with 0 = bare ground and 100 = ideal turf.
[b]Means within columns not followed by the same letter are different (*P* = 0.05) by Duncan's multiple-range test.
[c]Surfactant (X-77) added at the rate of 0.75 percent by volume to spray admixture.
[d]Surfactant (X-77) added at the rate of 0.5 percent by volume to spray admixture.
[e]First value = Glyphosate; second value = Sulfometuron.

Results at both locations in 1985 were generally comparable with those from the 1984 experiments (Tables 3 and 4). Again no great response to rate, date, or surfactant from either Metsulfuron or Chlorsulfuron at either location was found in terms of seedhead supression or turf appearance. All treatments reduced seedheads and decreased the appearance of the turf early in the season. Again, as in 1984, Sulfometuron responses were influenced by rate and, in some cases, by timing of applications. The rates above $^1/_2$ oz per acre tended to cause more injury and seedhead reductions than the lower rates. There were no increases in seedhead control due to combinations of Glyphosate and Sulfometuron over the results from either herbicide applied alone.

Several herbicides, including Chlorsulfuron, Sulfometuron, Metsulfuron, and Glyphosate, offer control of seedheads in tall fescue. The timing of applications of these materials does not appear to be as critical as that of the currently used plant growth regulators. This factor would make it easier to work seedhead control applications into the vegetation management program.

It appears that Sulfometuron offers the most promise among the herbicides tested for control of tall fescue seedheads. The addition of Glyphosate to Sulfometuron increased injury to the tall fescue but did not increase control of seedheads. Chlorsulfuron and Metsulfuron were generally less effective than Sulfometuron.

One serious problem is the injury, which causes the turf to be unsightly for several weeks. This injury can lead to serious stand reductions, especially if the treatment is repeated annually. Of the materials tested, Sulfometuron and Glyphosate appear to offer the most promise for adequate seedhead control with acceptable injury to the turf.

The contents of this paper reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Alabama Highway Department or FHWA. This paper does not constitute a standard, specification, or regulation.

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An Analysis of Design Features in Mitigating Highway Construction Impacts on Streams

WAYNE W. KOBER AND STUART E. KEHLER

In March 1986 the Pennsylvania Department of Transportation and FHWA completed Research Project 84-31, *An Analysis of Design Features in Mitigating Highway Construction Impacts on Streams.* During this research project and a previous research project, the biological conditions were evaluated in two streams before, during, and after the construction of two large arch culverts and the relocation of about 1 mi of stream. In addition, the cost and effectiveness of the mitigative design features incorporated into the culverts and relocated stream channels to promote recovery of the biological communities were analyzed. The results of the research clearly showed that the mitigation was effective in accelerating stream recovery. Postconstruction habitat and aquatic populations were similar to or better than under preconstruction conditions. The overall cost of the project with mitigation was slightly less than that of the project without mitigation. The results of Research Project 84-31 are documented in the Final Report completed in March 1986. The highlights of the research presented in that report are given. This research complements Research Project 79-10, *The Impact of Stream Relocation on Fish Populations and Bottom Fauna.*

In March 1986 the Pennsylvania Department of Transportation (PennDOT) and FHWA completed Research Project 84-31, *An Analysis of Design Features in Mitigating Highway Construction Impacts on Streams (1).* During this research project and a previous research project the biological conditions were evaluated in two streams before, during, and after the construction of two large arch culverts and the relocation of about 1 mi of stream. In addition, the cost and effectiveness of the mitigative design features incorporated into the culverts and relocated stream channels to promote recovery of the biological communities were analyzed.

Construction of the missing link of the Allegheny Valley Expressway between Kittanning and Pittsburgh, Pennsylvania, which was completed in 1985, was the subject of this research. The expressway construction near Tarentum, Pennsylvania, required relocation of 5,150 ft of Bull Creek and 1,815 ft of Little Bull Creek and construction of two concrete arch culverts, 885 and 449 ft long, respectively, on Bull Creek and Little Bull Creek. A unique aspect of the Bull Creek relocation and culvert design was that as a flood channel it had to safely carry a 50-year frequency flood as well as provide a recreational fishery. Figure 1 shows the relocated Bull Creek channel.

Environmental Quality Section, Pennsylvania Department of Transportation, 1113 Transportation and Safety Building, Harrisburg, Pa. 17120.

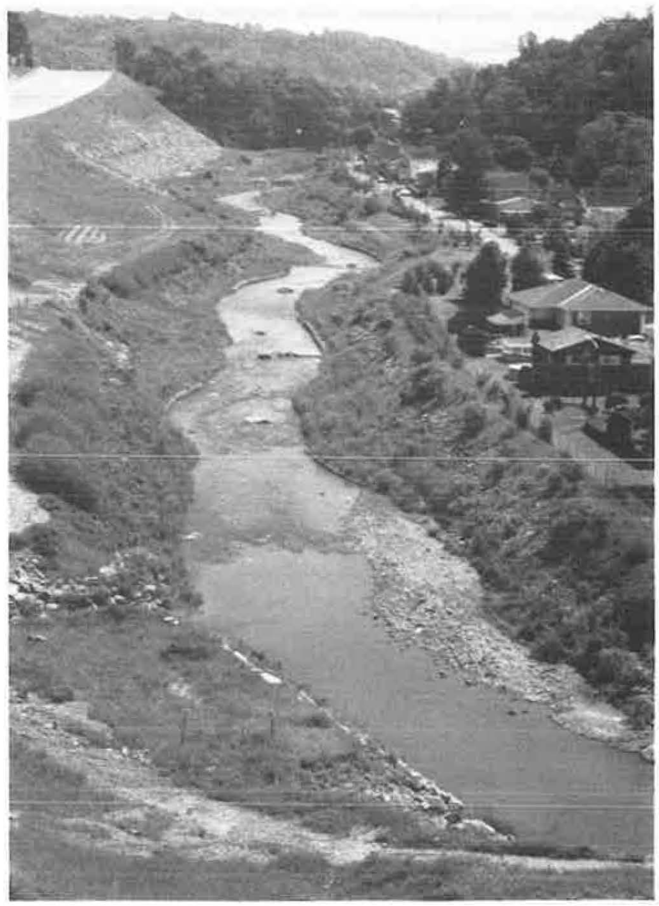


FIGURE 1 Downstream view of relocated Bull Creek channel along Bull Creek Road.

PROJECT DEVELOPMENT

Four construction sections (5D–5G) made up the final portion of the Allegheny Valley Expressway construction project. Figure 2 shows Bull Creek and Little Bull Creek with respect to these final sections. Although most of the expressway was designed before the passage of the National Environmental Policy Act of 1969 (NEPA) and completed in the 1970s, these sections were designed but not constructed because of the lack of funding. In 1976 federal funding became available and PennDOT and FHWA prepared and circulated an Environmental Impact Statement (EIS).

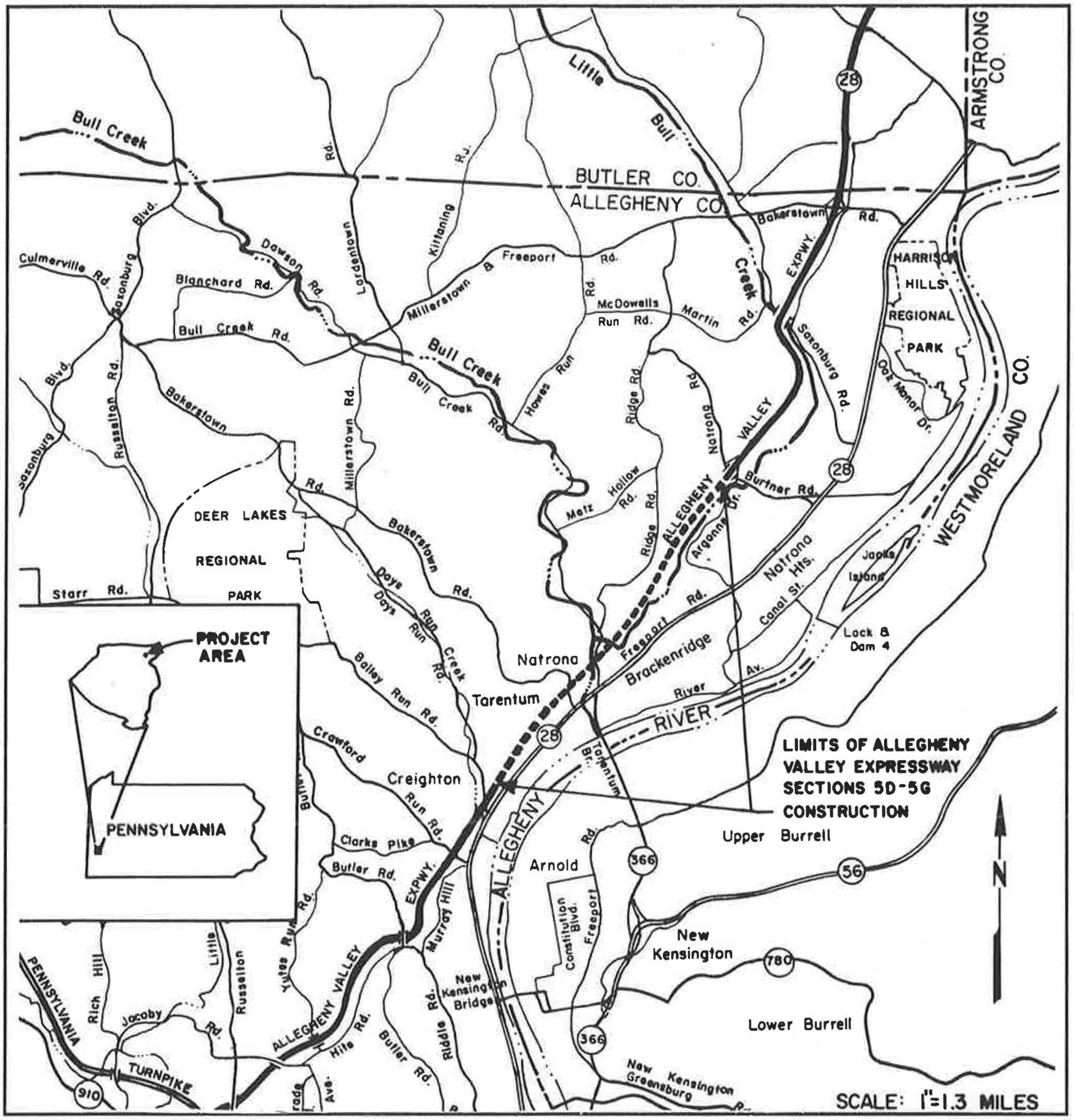


FIGURE 2 Project location map.

The original design for each of the sections included some mitigative design features for the stream relocations but no mitigative features for the construction of the large arch culverts. The primary goal of the original design appeared to be the safe passage of flood waters.

During the agency and public review of the draft EIS for the final sections of the expressway, the state and federal resource agencies strongly objected to the adverse impacts of the proposed design on the biological communities in Bull Creek and Little Bull Creek. In addressing the agency concerns, PennDOT and FHWA worked closely with the resource agencies to revise the project design and to incorporate measures to mitigate the adverse impacts on these streams. However, during this effort, all those involved realized that little information existed on which to base the revised stream relocation, mitigation, and culvert designs.

As a cooperative effort to fill this information gap, PennDOT and FHWA implemented Research Project 79-10, which was completed in 1983 *(2)*. In this project the biological conditions in the two streams were documented before, during, and after the majority of the stream relocations and the culvert construction, which made up Sections 5D and 5E of the four last stages of construction of the expressway. Following completion of the remaining two sections (5F and 5G) in 1985, PennDOT and FHWA initiated Research Project 84-31 to comprehensively document the construction effects of all the last construction sections on the stream biological communities, with special emphasis on the cost-effectiveness of the mitigative design features.

RESEARCH OBJECTIVES

The objectives of the research project were to

1. Identify and describe any biological impacts of the construction project within the Bull Creek and Little Bull Creek watersheds.
2. Determine the effectiveness of the mitigative design features that were incorporated into the culverts and relocated stream channels to prevent or minimize adverse biological impacts.
3. Compare costs of the project as built with its costs if mitigative design features were not incorporated.
4. Produce a report and slide presentation that would encourage highway designers and environmental professionals to incorporate mitigative design features into similar projects.

MITIGATION DEVELOPMENT AND DESIGN

The overall mitigation plan for Bull Creek and Little Bull Creek and the design of mitigation features evolved through a coordination process involving the department and the resource agencies. It is apparent that this coordination was undoubtedly a product of the EIS process. In retrospect, if the EIS had not been required, the original project design, which did not include these mitigation measures, would probably have been used for construction. The resource agencies involved in the mitigation design and waterway permit process included the Pennsylvania Department of Environmental Resources, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, the USDA Soil Conservation Service, the Pennsylvania Fish Commission, the Pennsylvania Game Commission, and the U.S. Fish and Wildlife Service.

It is important to note that the EIS also resulted in the consideration of highway location and structure alternatives to completely avoid the impacts of the stream relocations and culvert construction. During the development of the final EIS and efforts to resolve the agency concerns, PennDOT and FHWA demonstrated through additional engineering and environmental studies that it was in the best public interest to relocate the streams and construct the culverts. However, the designs for this construction were to include adequate mitigative measures to minimize adverse impacts on the streams.

The coordination that ensued during the circulation of the draft EIS and preparation of the final EIS continued throughout the final design and construction of the project. Four mitigation goals were agreed upon early in the coordination process and served throughout the development of the project:

1. The highway and interchange were to be built so as to ensure the maintenance of the present and future potential of the Bull Creek watercourse to support aquatic life, which is beneficial and necessary to the creek's use as a fishery resource.

FIGURE 3 Bull Creek Road Interchange of the Allegheny Valley Expressway.

Therefore, modifications to the existing watercourse were not to inhibit the migration and habitation of fish and aquatic flora and fauna. Figure 3 shows the Bull Creek Road Interchange, under which Bull Creek and Little Bull Creek pass in arch culverts.

2. The department was to take whatever action was necessary to promote development of a recreational fishery within the relocated stream channels.
3. Habitats for game and non-game species were to be provided along the relocated streambank.
4. The relocated stream channel for Bull Creek and arch culverts for Bull and Little Bull creeks were to provide for adequate passage of the 50-year frequency flood, as required by U.S. Army Corps of Engineers.

In order to achieve the four mitigation goals for Bull Creek and Little Bull Creek, mitigative design features were incorporated into the channel relocations and culvert construction as follows.

Bull Creek

Relocated Channel

1. The gradient and length of the original stream channel were maintained as much as possible.
2. The new stream channel was constructed in the dry and stabilized with bottom and bank stabilization measures. The channel bottom was excavated into bedrock. The banks within the normal flow channel were lined with dumped rock, seeded, and mulched. The banks above the normal flow channel were either planted with shrubs and mulched with wood chips from the clearing and grubbing operations or planted with a legume-grass mixture and mulched with straw. Figure 4 shows typical sections of the relocated channel.
3. An uneven natural bottom was excavated.
4. Streambanks were lined with dumped rock in the normal flow channel. Above the normal flow channel, they were lined with rock, covered with soil, and planted.
5. A meandering subchannel was incorporated into the main channel with the use of deflectors constructed of gabions and logs and an elevated floodplain of dumped rock. Figure 5 shows a plan view of these and other mitigation features.
6. Large boulders were randomly placed in the subchannel.

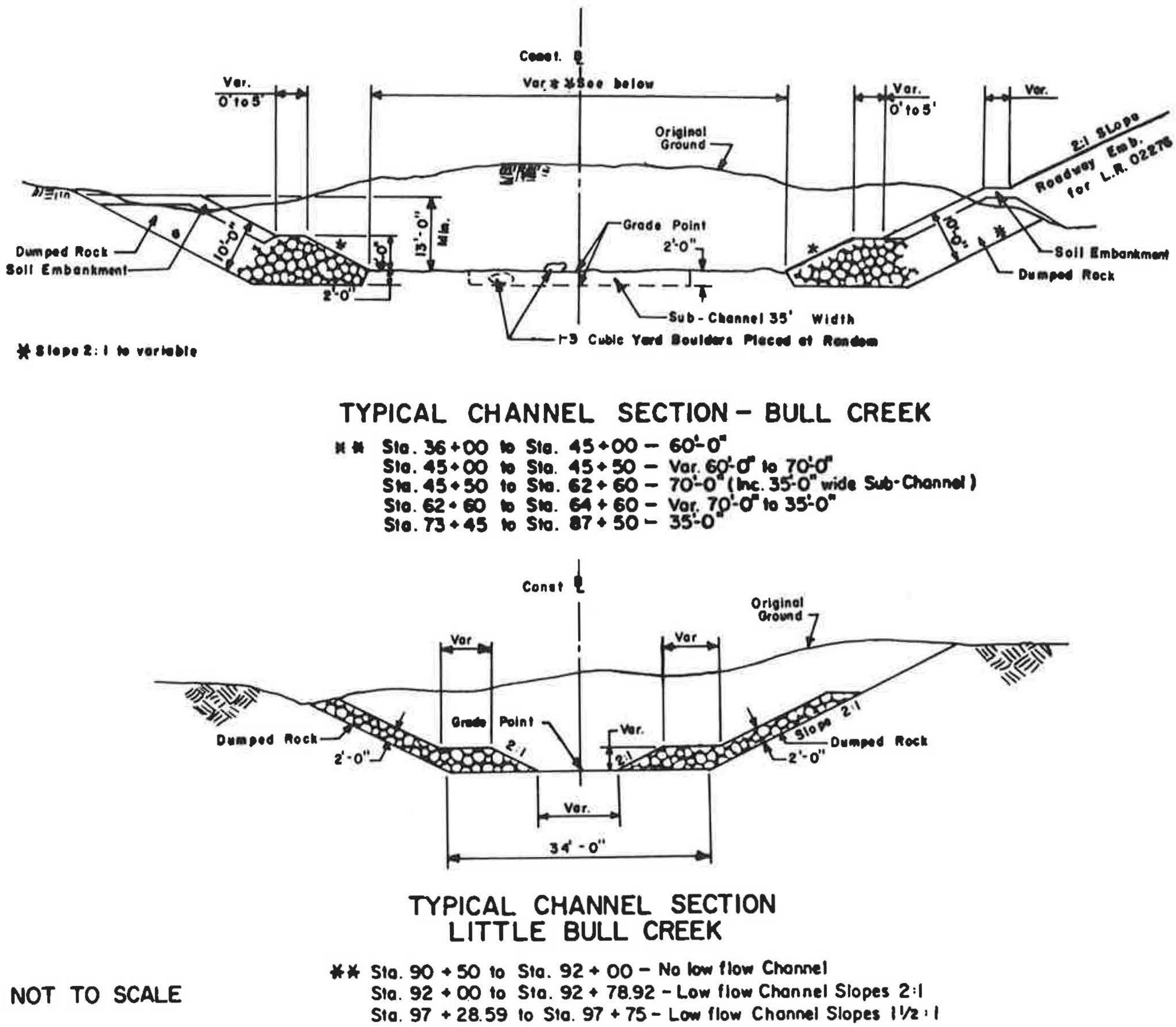


FIGURE 4 Typical channel sections of relocated Bull and Little Bull creeks.

7. Special grass and legume mixtures, shrub clusters, and trees were planted above the flood channel to provide wildlife habitat.

Arch Culvert

1. A bottom gradient of 2 ft per 1,000 was constructed to produce stream-flow velocities that would permit fish movement upstream under most flow conditions. Figures 6 and 7 show a cross section of the culvert.
2. A low-flow fish channel was constructed in the concrete bottom to permit fish passage during periods of low flow.
3. Dams and half dams were constructed every 50 ft to provide resting places in low-velocity pockets. Between the dams, rock fill was placed to provide bottom substrate.

Little Bull Creek

Relocated Channel

The channel was constructed similar to the Bull Creek channel except that the streambanks and stream bottom were lined with either gabion mattresses or riprap to provide erosion protection.

Arch Culvert

1. A bottom gradient of 12.9 ft per 1,000 was constructed to produce stream-flow velocities that would permit fish movement upstream under most flow conditions. Figure 8 shows a plan view of the mitigation features in the culvert.
2. A natural earth bottom was excavated and backfilled with rock to prevent scouring and provide bottom substrate.

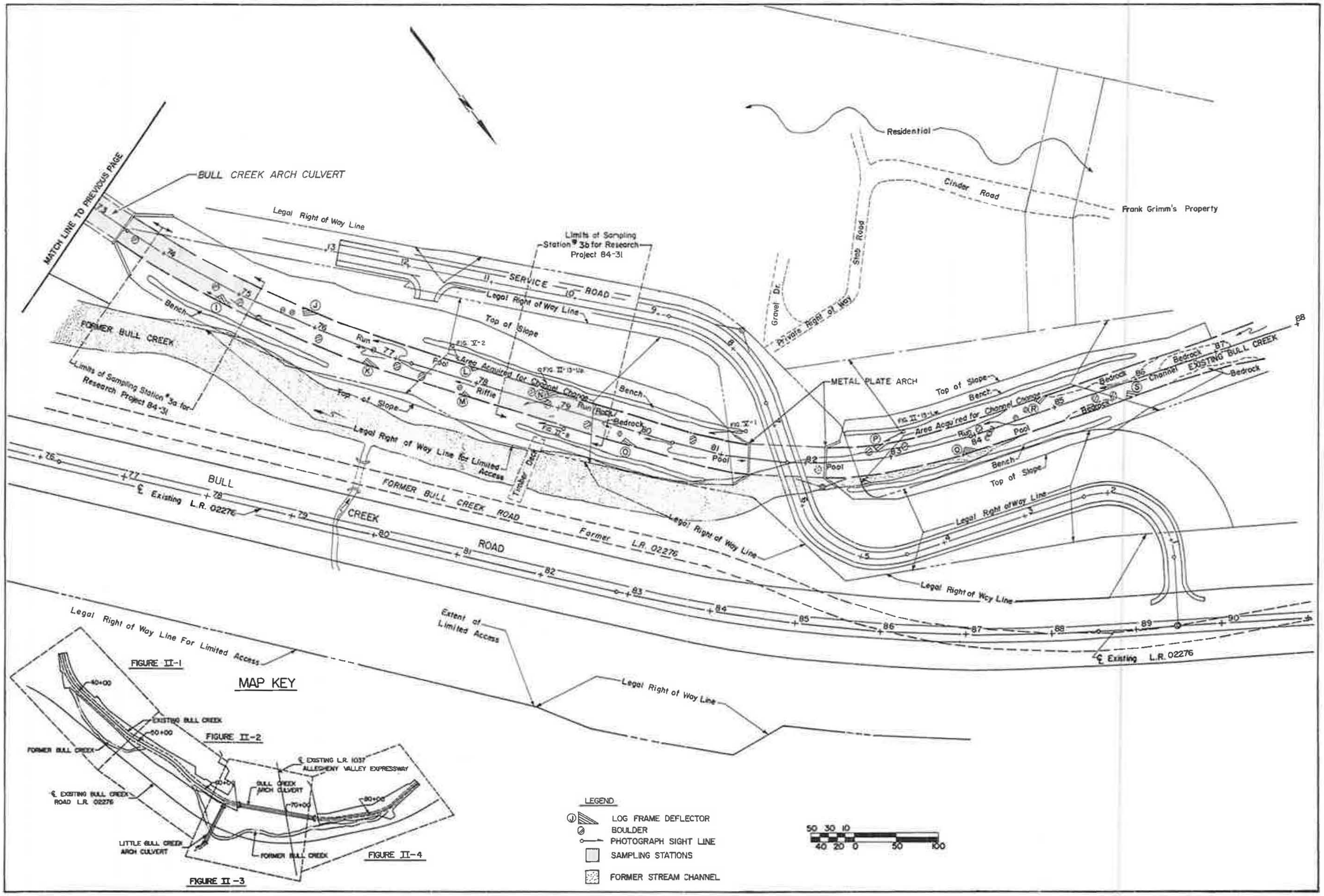


FIGURE 5 Mitigation features for channel relocation of Bull Creek.

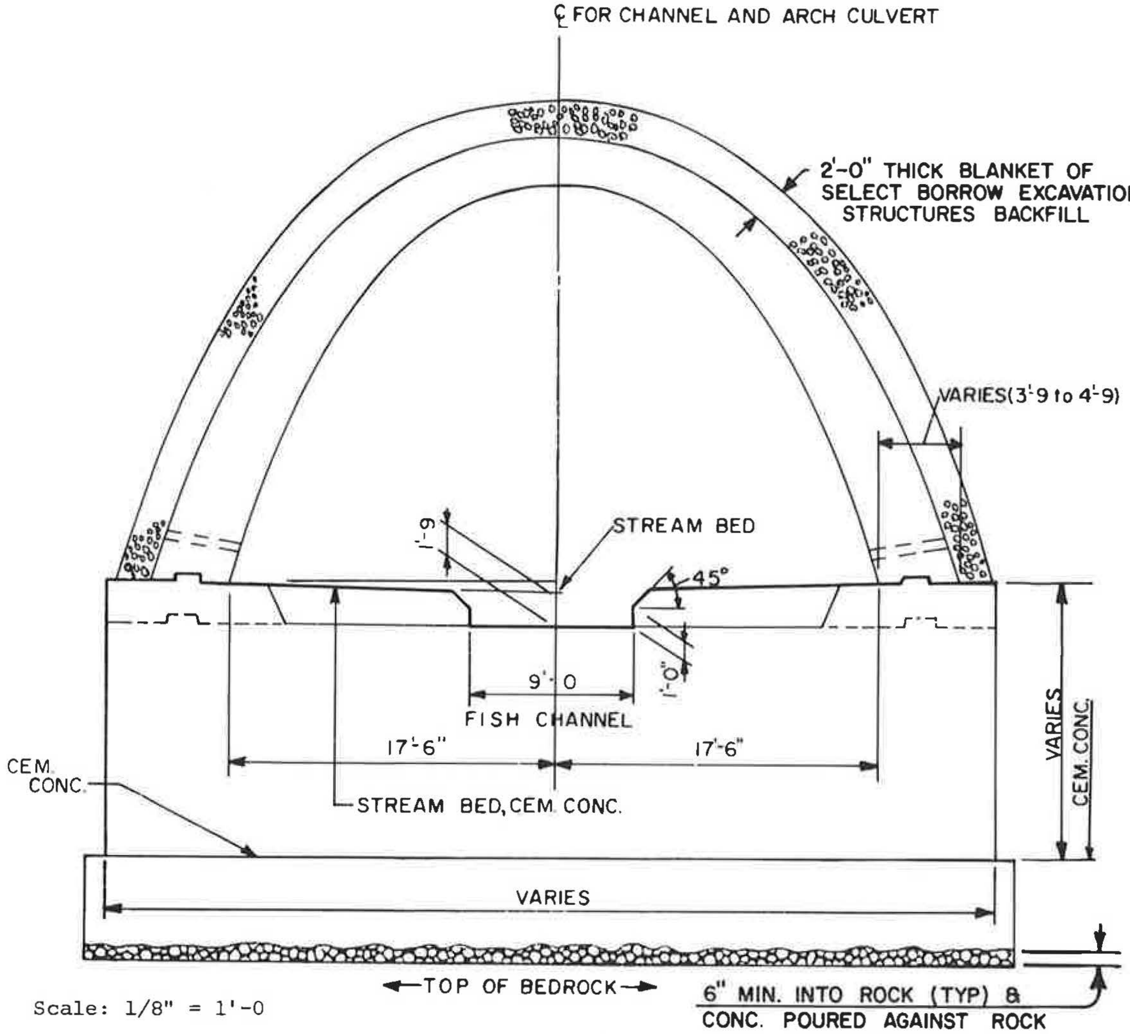


FIGURE 6 Cross section of Bull Creek arch culvert.

3. Five reinforced-concrete dams spaced at 75-ft intervals were constructed to provide resting places in low-velocity pockets. Low-flow notches were constructed in the dams to constrict flow and allow fish passage during a 7-day duration, 10-year frequency low flow.

4. Immediately downstream of each dam, pockets were left in rock riprap to provide resting places. Figure 9 shows the downstream end of the culvert.

In addition to the mitigative design features incorporated into the stream channels and culverts, special erosion and sedimentation control measures were implemented during construction. Examples of these measures include

- Constructing stream relocations and culverts in the dry,
- Maintaining natural vegetative buffers and straw bale barriers adjacent to streams,
- Constructing temporary pipe causeways and prohibiting stream fordings,
- Seeding and mulching soil stockpiles and graded areas that will lie dormant for extended periods,
- Directing flow from foundation dewatering operations and other disturbed areas into a series of sedimentation ponds, and
- Chipping all cleared vegetation and using chips for mulching banks with shrub cluster plantings.

MITIGATION COSTS

The total cost for the construction of the final link of the expressway was $44.9 million. The construction cost for the mitigation for Bull Creek and Little Bull Creek was about 4 percent of the total cost, or $1,849,650. Table 1 summarizes the costs for all the mitigation measures for Bull Creek and Little Bull Creek.

The original design for this final link of the expressway included a concrete-paved trapezoidal channel to carry the relocated Bull Creek, at an estimated cost of $1,750,000. In comparison, the mitigated channel for Bull Creek was constructed for $1,714,000.

As discussed earlier, the resource agencies requested that a bridge structure over Bull Creek be investigated as an alternative. As part of this investigation PennDOT performed a cost analysis comparing the construction costs of the structure alternative with the design utilizing arch culverts and fill embankment. The construction cost of the structure alternative was 15 percent higher than that of the arch culvert design. Also, the

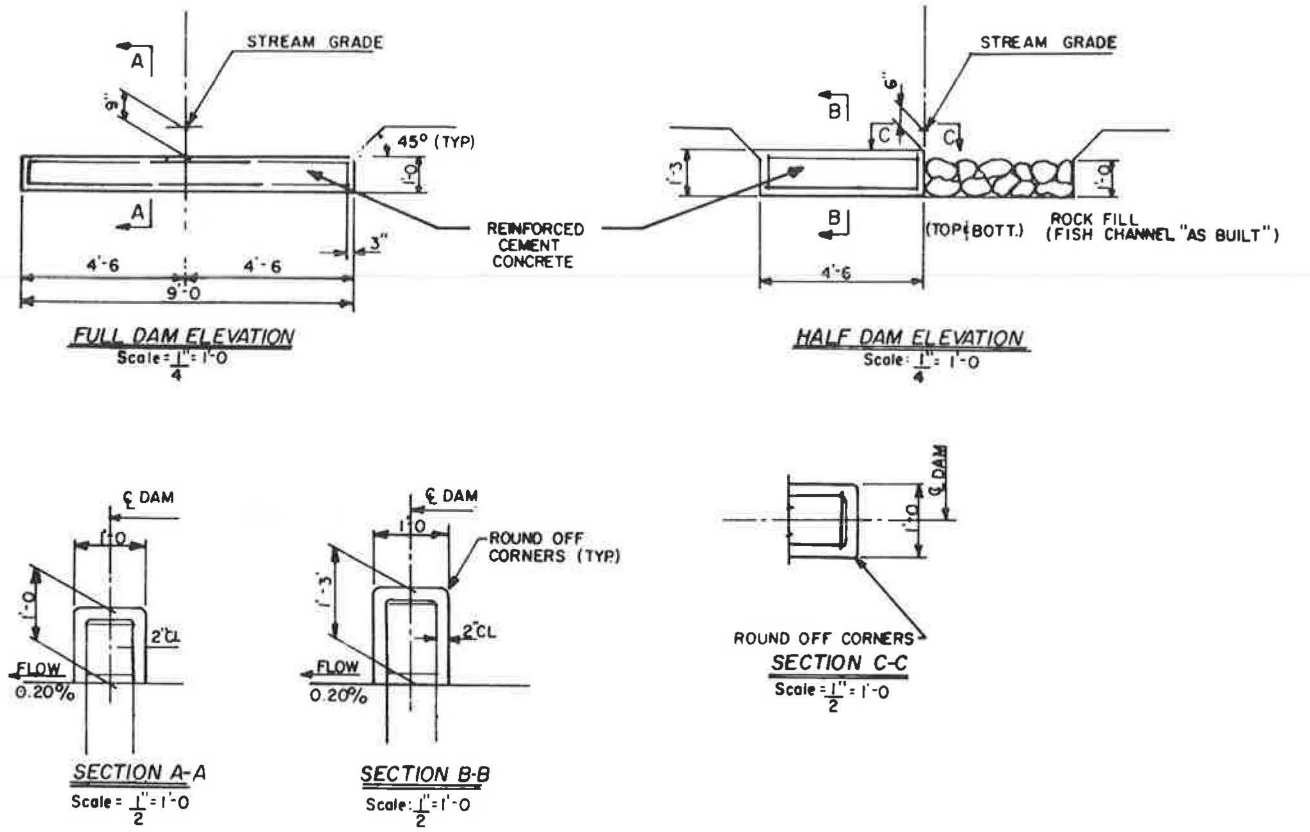


FIGURE 7 Fish channel dams in Bull Creek arch culvert.

redesign effort required to convert to a bridge structure alternative would have caused substantial project delays and would not have significantly reduced the amount of relocation required for Bull Creek. After reviewing the results of the alternatives analysis, the resource agencies agreed to the arch culverts if adequate mitigative features were incorporated.

MITIGATION EFFECTIVENESS

An important part of determining the effectiveness of the mitigation measures was an evaluation of the fish and macroinvertebrate communities and their habitat, the relocated channels and culverts.

Research Project 79-10 *(2)* described the biological conditions and water quality in Bull Creek and Little Bull Creek immediately before, during, and after construction of Sections 5D and 5E of the expressway. Most of the channel relocation and culvert construction on Bull Creek and the lower reaches of Little Bull Creek was completed as part of Sections 5D and 5E.

Research Project 84-31 *(1)* reassessed the biological and physical conditions and water quality in Bull Creek and Little Bull Creek after construction of Sections 5F and 5G, which completed the expressway. Two channel relocations in the middle and upper reaches of Little Bull Creek in the project area were the only direct stream involvements with these sections. Equivalent sampling and analysis methods were used for both research projects.

The major components of the Research Project 84-31 biological study were

1. Description of physical habitat,
2. Measurement of water quality,
3. Characterization of resident fish and macroinvertebrate communities,
4. Assessment of success with streambank planting,
5. Incidental wildlife observations, and
6. Comparison with Research Project 79-10 data.

Eight sampling stations were utilized for both research projects. Control stations upstream and downstream of the expressway construction area were sampled. Some stations were moved to adjacent areas when necessary because of construction.

The physical condition and function of the mitigation features were evaluated in June, July, and August 1985, approximately 4 years after most of them had been installed. The observations were made in what was considered to be the normal to low stream flow conditions during which the mitigation features would be expected to function throughout most of the year. In addition, the physical effects of a major storm event in July 1985 were evaluated.

By analyzing and comparing the results of the biological and physical studies of both research projects, the effectiveness of the mitigation was assessed in view of the mitigation goals established early in the design process.

In summary, the assessment of the mitigation effectiveness showed that overall, all of the mitigation goals were met as follows:

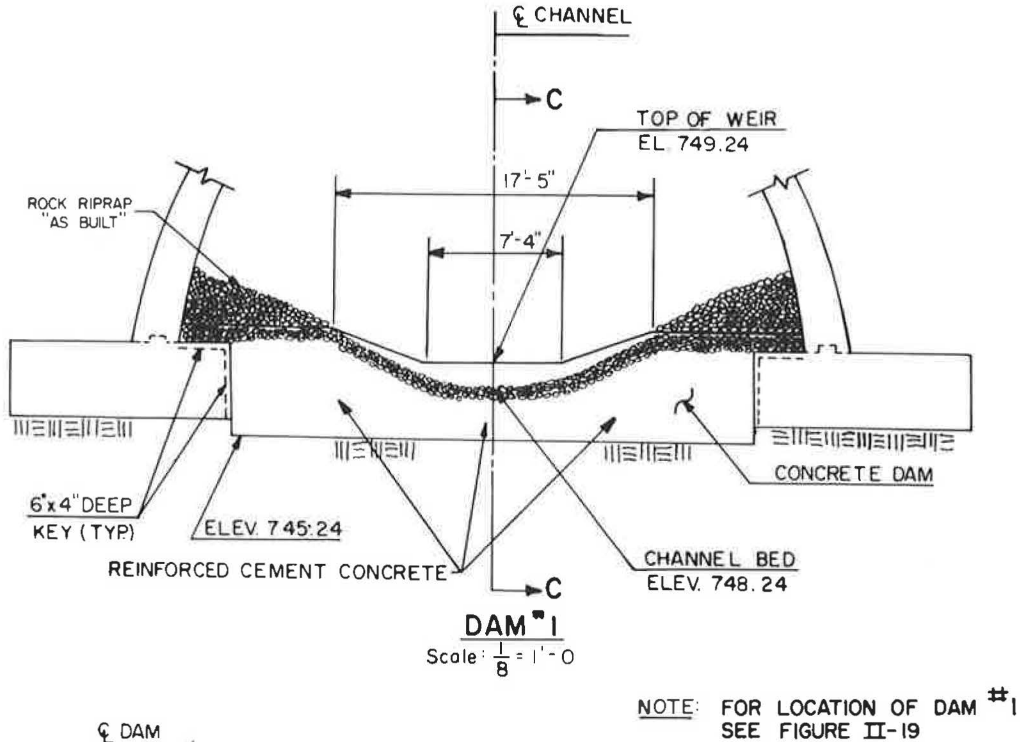
• The affected portions of Bull Creek include varied stream width, water depth, flow velocity, and meandering subchannel, which do not inhibit the migration and habitation of fish and associated aquatic flora and fauna.

• A diversity of aquatic habitat types are present in both streams, including riffles, runs, pools, and scour holes, which are in similar or better than preconstruction conditions.

• Postconstruction populations of fish species throughout Bull Creek are as high as or higher than before construction.

• Numbers, identity, and importance of macroinvertebrates in relocated reaches were generally as good as or better than before construction. Benthos in the Little Bull Creek culvert were generally similar to those in the relocated stream reaches, whereas those in the Bull Creek culvert were degraded compared with those in downstream reaches.

• Both the presence of sport fishes such as largemouth bass, smallmouth bass, and brown trout and frequent observations of anglers fishing in the relocated portions of Bull Creek and



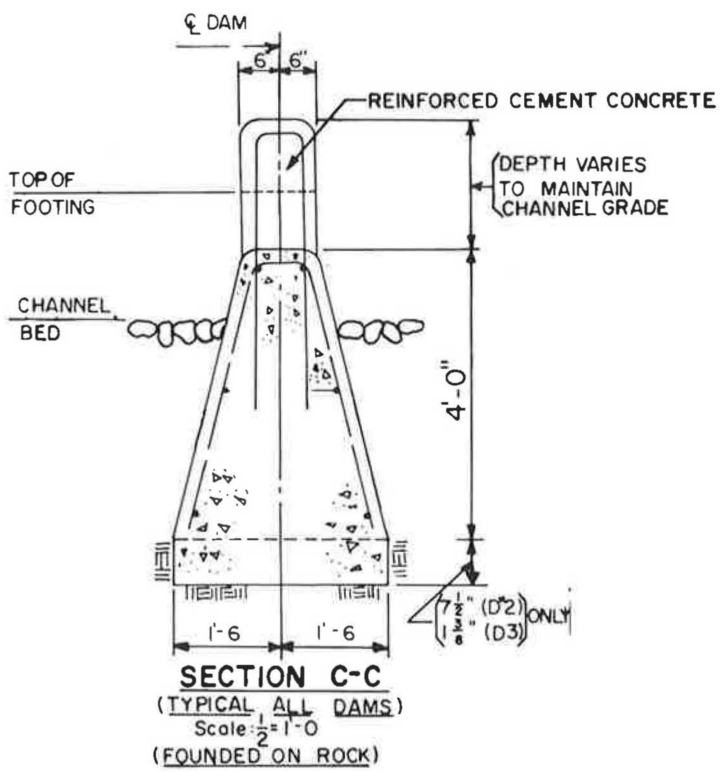


FIGURE 8 Mitigation features in Little Bull Creek arch culvert.

TABLE 1 MITIGATION COSTS FOR BULL CREEK AND LITTLE BULL CREEK

MITIGATION MEASURE	DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST[a]
BULL CREEK				
Log-Frame Deflectors	Type A	6	$ 3,200 ea.	$19,200
	Type B	11	$ 2,800 ea.	30,800
	Type C	2	$ 2,400 ea.	4,800
				$54,800
Gabion Deflectors	Avg. 106' long 3'-3" wide 3'-3" high	9 (1,039 cy.[b])	$13,850 ea. ($120/cy.)	$124,680
Channel Treatment Boulders	1-3 cy. ea.	50 Boulders	$120 ea.	$6,000
Select Rock Borrow Excavation - Bull Creek Channel Lining	12" minimum dimension	84,120 cy.	$17/cy.	$1,430,040
Rock Fill - Fish Channel	4" minimum dimension	289 cy.	$85/cy.	$24,565
Select Rock Borrow Excavation - Little Bull Creek Channel lining near arch culvert	12" minimum dimension	1,766 cy.	$19/cy.	$33,554
Bull Creek Arch Culvert	fish channel dams	17	$235 ea.	$4,000
Little Bull Creek Arch Culvert	fish dams	5	$3,375 ea.	$16,875
Supplemental Streambank Plantings	native shrubs	9,280 one year bare rooted cuttings $2 ea. 3,521 sy[b] direct seeding of two herbaceous seed mixtures $.30-$.35/sy		$19,694
			TOTAL COST	$1,714,208
LITTLE BULL CREEK				
Gabion Mattress Stream Channel Paving	12'x6'x9"	1,290 cy.	$105/cy.	$135,450[c]
Channel Treatment Boulders	1-3 cy. ea.	25 Boulders	-0-[d]	-0-

[a]Costs were adjusted to 1981 dollars.
[b]cy. = cubic yard and sy. = square yard.
[c]These costs are presented in 1984 dollars.
[d]Contractor placed boulders at no charge.

the culvert indicate that a recreational fishery has developed. This is also demonstrated by the recent addition of a 1.8-mi portion of Bull Creek, including the relocated section, to the 1986 trout-stocking list of the Pennsylvania Fish Commission. Although a creel survey has not been conducted, observations made during the opening day of the 1986 trout season showed several fisherman with trout they had caught in this area.

- Good to excellent survival rates of streambank plantings and aggressive colonization by native plant species provide a wildlife habitat for several species observed during the field work. Figure 10 shows the streambank vegetation.
- As shown by the safe passage of flood flows from a July 1985 storm event that approached or exceeded the 50-year frequency, the relocated streams and culverts are hydraulically adequate.

RECOMMENDATIONS

On the basis of the experience and knowledge gained during these research projects and the expressway's construction, several recommendations were made by the research team for planning, designing, constructing, and maintaining mitigative features for stream relocations.

Planning Stage

1. Thoroughly investigate the physical, hydrological, chemical, and biological characteristics of the stream to be affected.
2. Coordinate with the environmental regulatory and review agencies as early as possible in the planning process. Ideally,

FIGURE 9 Downstream end of Little Bull Creek arch culvert.

the resource agencies should be involved in development of alternatives. Also, conduct field views throughout the development of the project to show the agencies how the mitigation measures are constructed and how they are working.

3. Determine whether relocation can reasonably be avoided or, if not, whether mitigation will be applicable on the basis of water or fishery resource values.

4. Define specific goals and objectives for mitigation in terms of both physical and biological parameters and time frames. Specify how and when mitigation success will be measured.

5. Plan for enhancement or improvement of the resource where possible.

Design Stage

1. Design mitigation devices such as log frame and gabion deflectors to withstand the anticipated variations in streamflow velocities under flood conditions.

2. Where flood flow passage within the channel is a primary objective, specify in-stream mitigation devices such as gabion deflectors, which do not greatly inhibit flow passage.

3. Where a relatively wide channel is required to pass flood flows, provide a subchannel defined by deflectors for low-flow fish habitat diversity.

4. Use boulders in the stream channel large enough to resist movement (1 to 3 yd^3 depending on stream characteristics) to provide cost-effective stream habitat diversity.

5. Use log frame deflectors, properly anchored, to create channel narrowing and deepening at specific locations.

6. Use gabion deflectors to create subchannel meanders and depositional floodplain areas within the main channel.

7. Plan changes in stream channel gradient carefully to avoid unwanted zones of siltation and sedimentation.

8. In "flashy" flow streams, design deflectors and other in-stream devices to accommodate large variability in discharge rates, but design them to function at normal or median flows.

9. Avoid gabion mattress channel bottom and streambank paving where fish and wildlife mitigation is a primary consideration.

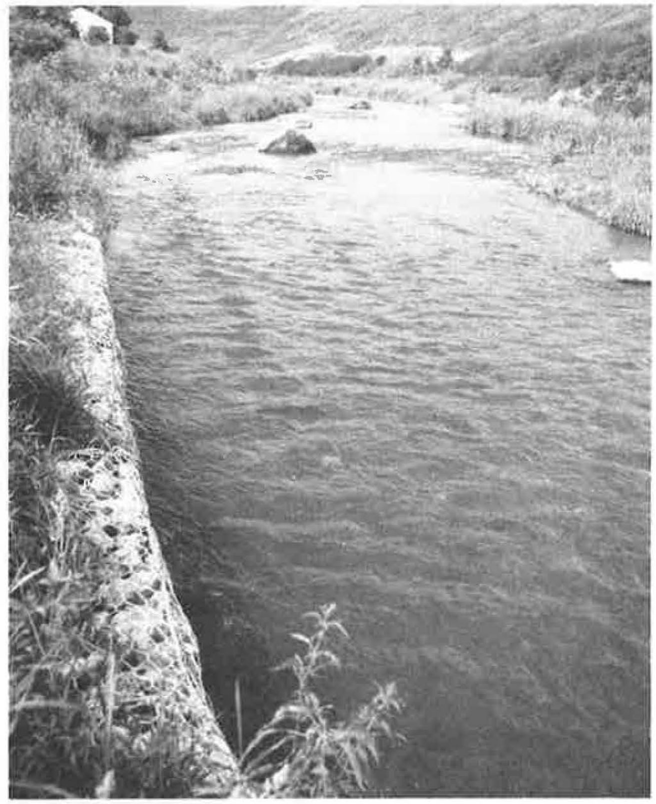


FIGURE 10 Streambank vegetation.

10. Include in planting plans native shrubs and trees located as close to the stream as flood passage considerations will permit.

11. Specify bare-rooted cuttings of native shrubs to maximize survival.

12. Where long culverts are to be utilized, consider the following design recommendations:

a. Address design and implementation of fish passage through culverts on a case-by-case basis.

b. Consider the following physical attributes of the stream in culvert design: stream gradient, substrate, sediment load, and flood and low-flow characteristics.

c. In planning for fish movement or migration through culverts, consider the streamflow regimes at the time of year when migration normally occurs. Where general fish movement is the prime consideration, consider various streamflow regimes.

d. Design through-culvert flow velocities and fish movement aids to suit particular target fish species. Design for a flow velocity in the culvert that will allow upstream fish movement based on empirical studies.

e. Design the culvert so that large variations in stream discharge produce only small changes in flow velocity through the culvert.

f. If a low-flow fish channel is to be used inside the culvert, provide for low-velocity resting areas by including dams and half-dams. Line the bottom of the fish channel with rock to approximate natural stream bottom conditions, but do not fill it.

g. If heavy siltation is a persistent problem in the impacted stream, do not provide a low-flow channel; let it develop naturally within the culvert.

h. Depress the culvert invert grade line below normal stream-bed level to encourage pool formation in the culvert where possible.

13. Use design experts knowledgeable and experienced in fish and wildlife mitigation techniques.

14. To the extent practicable, utilize other streambank protective measures (e.g., live stakes) in lieu of riprap.

Construction Stage

1. Consider placing mitigation devices in relocated channels after establishment of streamflow to assist in setting proper elevations.

2. Selectively place large rocks along the leading edge of log frame deflectors to break up current velocity and protect the devices from undercutting.

3. Use riprap rock to protect the upstream ends of gabion deflectors from washout or creation of channel behind the gabion. Also key the upstream end of gabion deflectors into streambanks where washout protection is necessary.

4. Generally avoid placement of deflectors in the stream channel where bedrock is exposed. The rock will generally provide adequate channel bottom roughness and habitat diversity.

5. Ensure that plantings are carried out within specified dates to maximize survival.

6. Follow specified planting sequence to minimize construction damage and have the construction inspector consult with the professionals knowledgeable in habitat planting design.

7. Remove stakes and guy wires from planted material after plants are well established (longer than 2 years).

Postconstruction Maintenance

1. Provide inspection of stream mitigation measures on a periodic basis and after all major precipitation events.

2. Perform maintenance such as debris removal, gabion repair, or major erosion repair as necessary to ensure stream-bank and channel protection.

3. Avoid in-stream maintenance where possible after reestablishment of the stream ecosystem.

ACKNOWLEDGMENT

Special thanks to the panel members who guided these research efforts and the research team who professionally performed the research. The principal researchers were John Wakelee and Derek Piper of Skelly and Loy, Engineers-Consultants; and Robert Blye, William Ettinger, and Douglass Nieman of RMC Environmental Services.

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Smooth Cordgrass Establishment in Tidal Wetlands

S. JOSEPH LESLEY

This project, developed by the Delaware Department of Transportation, involves the establishment of smooth cordgrass by various methods in tidal wetlands; it is an ongoing study in the third year of evaluation. This concept represents one phase of an important link to marshland highway-bridge construction activity as a function of mitigation requirements in wetlands.

Beginning in 1983, the Delaware Department of Transportation realigned a 1.5-mi portion of US-113 located 7.5 mi south of the city of Dover in Kent County. The realignment included the upgrading of the roadway from two to four lanes, the removal of the existing bascule bridge, and the construction of a new concrete bridge crossing the St. Jones River and surrounding tidal wetland.

In addition, the construction contract called for the excavation of the existing causeway and restoration of the site to wetlands with suitable native vegetation. These mitigation requirements, as spelled out in the department's subaqueous and wetland permits, served as the basis for planting. For this purpose, a perennial rhizomatous plant known as smooth cordgrass (*Spartina alterniflora* Loisel) was selected. This species is typically encountered in the tidal floodplain throughout the region and recognized as an important link in the Atlantic coastal salt marsh plant community (*1*, Chap. 2).

MATERIALS AND METHODS

The purpose of this study was to evaluate the possible establishment of smooth cordgrass by direct seeding, transplanting, and planting. The smooth cordgrass establishment was let as a separate contract to be performed concurrently with the excavation.

In this regard, a contract was advertised to provide for the items of work shown in Table 1.

Before planting, a number of ground preparation requirements had to be met. The excavation of the causeway and the adjacent area, herein referred to as a haul road, under the bridge construction contract was carried out in two steps. The causeway portion was begun in 1984 and the haul road was added in 1985. This occurred because of a broader interpretation of the mitigation requirements rendered by the Delaware Department of Natural Resources and Environmental Control, resulting in the addition of the haul road after the excavation work had been initiated on the causeway. Excavation began at the river crossing and proceeded north; a large backhoe, drag line, and the haul road were used to remove excavated material. The totalexcavation area covered 22,771 yd^2. Both sites were cross-

TABLE 1 WORK DETAILS FOR CORDGRASS ESTABLISHMENT

Proposed Work	Planting Season	Bid Price	Unit of Measurement
Smooth cordgrass			
Planting	1984	$2.72	Per square yard
Planting	1985	$2.72	Per square yard
Transplanting	1985	$2.72	Per square yard
Seeding	1985	$0.56	Per square yard
Aerial herbicide application	1984	$3,388.00	Lump sum

sectioned to determine the actual volume for removal and surveyed to ensure compliance with the required elevation. A total of 4,812 yd^3 of material was removed from the project.

The required planting elevation of 2.75 ft above mean sea level [National Geodetic Survey 1929 vertical datum base for mean sea level (MSL)] represented an elevation 3 to 6 in. lower than that of the surrounding marsh. Reducing the elevation below that of the surrounding marsh throughout the excavated haul road and causeway allowed the tide to ebb and flow freely throughout the planting area, a requirement critical to the establishment of smooth cordgrass (*1*; *2*, Vol. 1, p. 511).

Establishment of the required elevation is a critical factor, because the ponding or impounding of water over the planting site reduces the survival of smooth cordgrass (*1*).

The smooth cordgrass planting completed in the summer of 1984 involved the area located at the original bascule bridge crossing site along the St. Jones River. Planting criteria were based on the assumption that the most critical site would be that portion of the excavation subject to the highest erosion potential through tidal action and wave exposure.

The specifications required the use of well-rooted seedlings that had been growing for a minimum of 5 months in peat pots. Seedlings were to be planted between May 15 and October 1 and fertilized with 1 oz of a 3- to 4-month slow-release 19–6–12 analysis fertilizer, or an approved equivalent, placed in the excavated plant pit. The specifications required the contractor to obtain 1985 transplants by thinning the area planted in 1984. However, because identical bids were received for planting and transplanting and the available nursery seedlings were of superior quality, it was decided that the total area specified for 1985 would be planted with nursery stock.

Attempts to provide the proper elevation (2.75 ft MSL) within critical limits utilizing heavy grading equipment

Delaware Department of Transportation, P.O. Box 778, Dover, Del. 19903.

were made extremely difficult by the poor load-bearing capacity of the site. As a result, certain areas of ponding did occur.

An existing ditch line was then extended to the northernmost limit of the project and connected to an active tidal branch along the western boundary. Several interconnecting rivulets to relieve localized ponding were hand excavated during the actual planting. However, the disturbance of the site in this manner made it difficult for the contractor to maintain a uniform grid as bid. As a result, the requirement for all plants to be placed on a 2.0-ft grid was deleted, because it was believed that over the course of several years, all sites other than ditch lines would fill with volunteer smooth cordgrass plants through seed dissemination *(1)*.

Because of the delays mentioned in the completion of the required grading work, the smooth cordgrass seeding specified was not attempted until 1986. Field observation in the spring of 1986, before actual seeding in May, revealed volunteer seedlings randomly covering 15 percent of the proposed site. It was determined that any attempt to prepare the seedbed and avoid the existing seedlings in the process would be impractical. Following seedbed preparation with a harrow, seed was mechanically broadcast during low tide at the rate of 100 seeds per square yard. Soluble fertilizer at the rate of 90 lb of actual nitrogen and 50 lb of actual phosphorus per acre was then broadcast over the seedbed at low tide in late June and again in July. This resulted in a very uniform stand of seedlings when evaluated in late September.

Another method employed to enhance establishment of smooth cordgrass involved the ground application of the herbicide Glyphosate to control a common reed (*Phragmites communis* Thin.) infestation along the western boundary of the planting site. Common reed is classified as a noxious weed in the state of Delaware because it is extremely invasive, spreads rapidly by rhizomes, and offers little in food value to the marsh ecosystem *(3)*. Initially, it was believed that the aerial application of herbicide could be utilized to control the problem. However, it was subsequently determined that the application timing requirements of herbicide (August through September) could jeopardize the initial planting of smooth cordgrass if the herbicide were to accidentally drift over the planted area. To prevent this possibility from occurring, the contractor opted to utilize ground application equipment.

With regard to the attempted eradication of common reed with herbicide, subsequent evaluation in May 1985 revealed a 95 percent level of control, which significantly reduced the species as an encroachment threat on the excavated roadbed.

SUMMARY AND CONCLUSION

To summarize the plant establishment, 3,800 yd^2 of marshland were planted in 1984, 11,600 yd^2 in 1985, and 7,291 yd^2 in the spring of 1986. Utilizing the unit bid prices shown in Table 1, a total cost of $50,119 was generated for planting and seeding, to include an additional payment of $3,093 for unanticipated site preparation by the planting and seeding contractor. The earthwork, which included the excavation of the haul road and causeway, trucking, grading, and ditching, totaled $101,216. Because definitive cost standards for vegetative marshland restoration do not exist, to this investigator's knowledge, no attempt was made to evaluate the cost-effectiveness of the project. Rather, the establishment of a uniform stand of the desired vegetation in compliance with mitigation requirements remained the chief objective.

As an interim observation, it can be stated that smooth cordgrass may be established satisfactorily by direct seeding or through the planting of nursery-grown seedlings.

Further, it is believed that continued monitoring of the site will be necessary to determine whether changes in elevation through the natural movement and deposition of sediments will so alter the site that a uniform stand as planted cannot be maintained.

Given the proper elevation and drainage conditions, continued research into the rate of volunteer smooth cordgrass seedling establishment will be necessary to determine whether a satisfactory stand can be achieved, given the presence of less desirable but highly invasive forms of vegetation.

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Concrete Slabs and Blocks for Car Park Paving

T. F. FWA

Car park pavement design and construction did not receive much attention in Singapore until the early 1970s, when special landscape and public policy regulations requiring planting trees and growing grass within and around car parks were enforced. This rendered the conventional method of flexible or rigid pavement construction unsuitable for certain areas of a car park, parking lots in particular. The evolution is described of several innovative forms of parking lot pavement construction implemented by local pavement engineers in their decade-long search for a workable engineering solution to the problem. The features and performance of three satisfactory forms of construction are discussed and compared.

Singapore is a city state with a population of 2.5 million. More than 80 percent of Singapore's population are housed in multistory residential flats. Public housing estates consisting of hundreds of blocks of multistory buildings have become a landmark of Singapore. Above-ground car parks form an important element of these housing estates, which are situated mainly in suburban locations. Within the city area, parking facilities are always in great demand. More above-ground car parks are being constructed as urban renewal development projects continue in the older sections of the city.

The shortage of car parks is most acute in the public-housing sector. In terms of dwelling units, more than 500,000 flats had been constructed by the end of 1984 *(1)*. The number is expected to reach 600,000 in the 1990s. In 1984 the number of passenger cars and pickups owned by residential flat dwellers was estimated to be 160,000 *(2)*, amounting to approximately one car per three dwelling units. On the basis of the past year's record, the number of cars owned by flat dwellers is expected to rise by more than 8 percent per year. Many existing car parks have had to be expanded in order to cope with the constantly increasing demand.

Construction and maintenance of public car parks represents an important expenditure item in the annual budget of Singapore road agencies. In public housing estates alone, on the basis of the expected 600,000 flats in the 1990s and assuming 150 parking spaces for an average car park, more than 1,300 car parks in total would be required. Like any large engineering project, the search for the most cost-effective construction materials, construction method, and maintenance procedure for car parks under local conditions presents a challenge to the road engineers in Singapore.

It is interesting that in Singapore car park construction is not a straightforward engineering problem. The impacts of car parks on the landscape of housing estates has been a major concern since large-scale construction of multistory residential flats began in the early 1970s. In line with the then-existing public policy of keeping the city green, it was introduced as a standard practice in Singapore to plant trees and grass in all public car parks. In a typical public car park, as shown schematically in Figure 1, two neighboring rows of parking spaces are usually separated by a median on which grass and trees are planted. Efforts have also been made to plant grass on part or all of the parking areas.

Certain engineering problems were encountered during the early phase of implementing the policy of planting of trees and grass within car parks. A number of car park pavement designs and constructions have been introduced and tried by engineers of various local highway agencies with varying degrees of success. In this paper the local experience involved and problems faced in providing car park pavements that are both structurally sound and aesthetically compatible with the adjacent landscape are discussed. A review on the development of various designs and types of construction in Singapore since the early 1970s is also presented.

EARLY FORMS OF CAR PARK PAVEMENTS

Traditionally, public roads in Singapore have been constructed of bituminous materials. One of the reasons that concrete roads are uncommon in Singapore is the lower capital costs of constructing bituminous pavement. The early phase of Singapore road network development in the 1950s and 1960s was involved mainly with construction and improvements of urban streets and rural roads. The need for frequent maintenance and upgrading of utility services beneath roadway pavements in urban areas was another factor contributing to the continuing use of asphalt pavements for urban streets. However, the concept of asphalt pavement stage construction, which allowed for strengthening as the need arose, was adopted as the practice for developing rural roads.

As a logical extension of roadway construction, car parks as well as bus terminals constructed during this period were also the flexible-pavement type. The combined effects of fuel spillage, oil leakage, and heat in the tropics that cause softening of asphalt binder make bituminous materials particularly vulnerable as bus terminal and car parking lot pavements in Singapore's climate. By the mid-1970s, although most bus terminal pavements had been converted into concrete slabs, concrete construction for car parks was still not regarded as an attractive alternative because the distresses found on parking lot pavements were less severe and less objectionable under the lighter traffic of automobiles.

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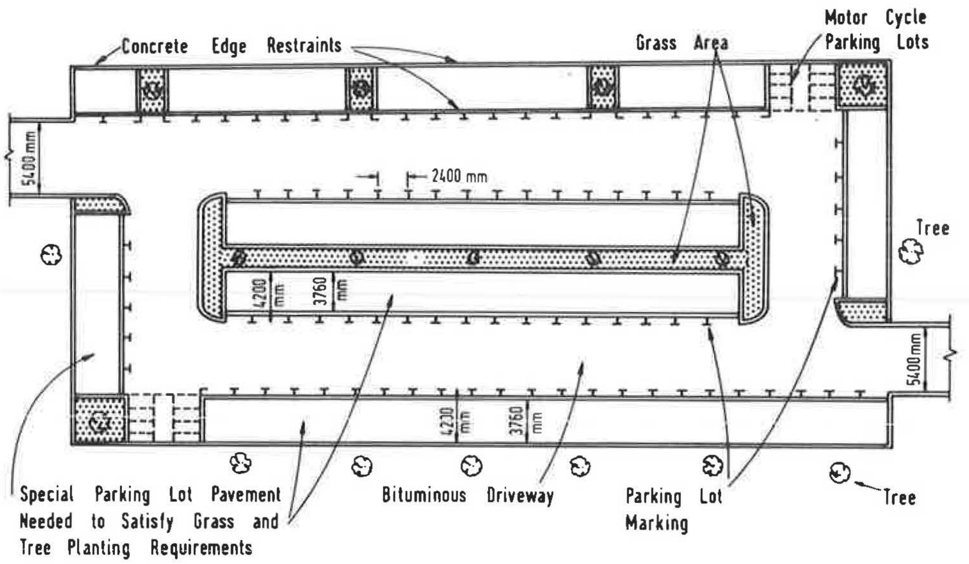


FIGURE 1 Typical layout of a public car park.

The continued use of bituminous pavements for parking areas was questioned when problems began to surface as the tree-planting policy was implemented. The adverse impacts of planting trees within a bituminous car park area were highly noticeable in the form of heaving and cracking of the bituminous pavement (Figure 2), which is caused by upward growth of tree roots. This is a direct consequence of the presence of the impervious bituminous pavement, which cuts off the surface water supply to the tree roots.

FIGURE 2 Asphalt pavement damaged by tree-root heaving.

The use of concrete construction for a part of each parking area became unavoidable subsequently when it was further required that a patch of grass wider than the ordinary grass median be provided so as to produce a more pleasant landscape. In other words, the shaded areas in Figure 1 are required to be sufficiently strong all-weather load-bearing surfaces with the appearance of natural grass. Neither the ordinary bituminous pavement nor the conventional concrete slab construction could satisfy this requirement. A new form of pavement construction was needed.

STUDDED-SLAB PAVEMENT

The versatility of concrete that allows it to be cast into different shapes and its durability under exposed environmental conditions make it a logical choice of material for the problem at hand. A studded-concrete-slab paving method (Figure 3) was a popular form of construction during the 1970s.

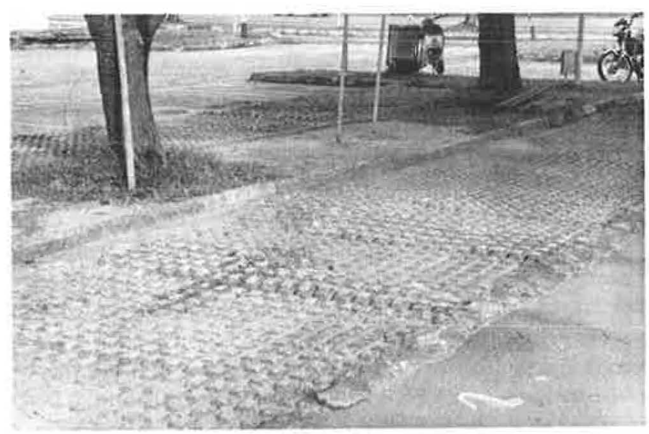


FIGURE 3 Studded-concrete-slab pavement construction for parking areas.

Two structural components of a studded slab can be differentiated, although in actual construction the two components are always cast together monolithically. The main component is the base slab from which the rigidity of the pavement is derived. The base slab acts to distribute vehicular loads to underlying base and subbase layers in the same way that a conventional concrete pavement does. It is the component that provides structural resistance to applied loads and temperature stresses. As such, the structural design of the base slab of a studded concrete pavement and the underlying base and subbase layers is the same as that of conventional concrete pavement.

Vertical concrete studs protruding from the base slab are the second component of a studded slab. The main functions of these studs are to provide a stable contact surface for vehicular wheels and to transmit the wheel loads to the base slab below. The spacing of the studs has to be sufficiently close so that vehicles can maneuver smoothly in and out of a parking area, but it must be wide enough to provide space for grass to grow.

The studded-slab construction in Figure 3 separates the surface grass-growing soil from the load-bearing base and subbase materials by means of a base slab. This is desirable from an engineering point of view because fines and organic soils could be harmful to the structural properties of load-bearing layers. Field applications in the 1970s showed that grass could grow well on studded concrete parking areas, and structural failures of the base slab due to vehicular loads were rare. Unfortunately, just as a bituminous pavement seals off surface water, studded slabs also prevent surface runoff from entering the subsoil. Tree-root heaving remains a problem to be solved. Figure 4 shows a studded concrete pavement that was damaged by tree-root heaving.

FIGURE 4 Studded-slab pavement damage by tree-root heaving.

A modified construction process utilizing precast studded-slab units was subsequently tried. Each precast slab unit shown in Figure 5 is 585 mm (23 in.) long and 370 mm (14.5 in.) wide, with a base thickness of 100 mm (4 in.). The main purpose of using the precast-slab paving construction was to maintain joints between slab units through which surface water could enter the subsoil. The construction method also had the advantage of easy repair or replacement of individual damaged slab units and easy installation and maintenance of underground utilities. This modified construction process, unfortunately, did not produce the expected improvement in pavement performance problems with tree-root heaving. Heaving of slab units continued to occur even when a joint as wide as 50 mm (2 in.) was used.

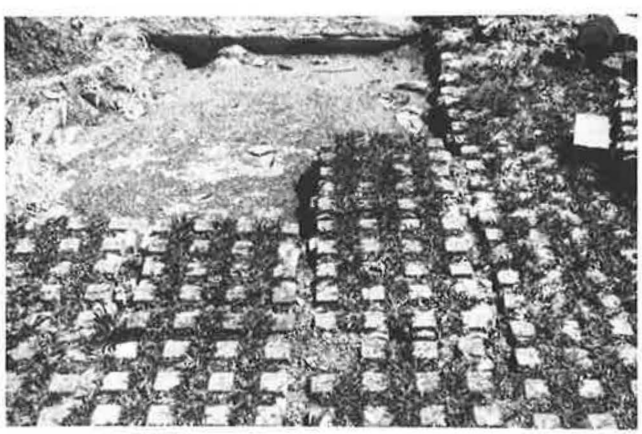


FIGURE 5 Precast studded-slab construction.

The experience with studded-slab pavements in Singapore also showed that they did not offer a comfortable surface for car owners and pedestrians to walk on. These pavements were found to be particularly inconvenient, if not hazardous, to female motorists wearing high-heeled shoes. Because of their unsatisfactory performance with tree-root heaving and the inconvenience caused to users, studded slabs are now rarely used for paving car parks in Singapore.

THE CONCEPT OF THE PERFORATED SLAB

The failure of precast studded slabs with joints to eliminate tree-root heaving led to several more in-depth research studies by pavement engineers of local road agencies. An early conclusion common to these studies was that a sufficiently large open space was necessary around a tree to alleviate the phenomenon of tree-root heaving.

The area of open space required around a tree varies with the type of tree planted. For those commonly planted in public car parks in Singapore, studies have found that an open area with a radius of 3.0 m (9 ft 10 in.) or more is desirable under the local climatic conditions *(3)*. With the standard car park layout shown in Figure 1, this means a loss of at least four parking spaces for every tree planted in a traditional bituminous pavement car park if tree-root heaving problems are to be avoided. This is not a desirable solution in either public housing estates or city areas where parking spaces are in great demand.

To provide as many parking spaces as possible in a car park without tree-root heaving problems, the parking spaces around a tree have to satisfy the following two conditions: (a) sufficient surface water must be able to enter the underlying soil and reach tree roots; and (b) the pavement surface must have sufficient strength and durability to support vehicular loads. In addition, a pavement surface with an appearance of high aesthetic value, such as a natural grass surface, is highly desirable.

The search for a suitable paving surface eventually led to the use of concrete perforated slabs. A perforated slab has openings to facilitate water passage into the underlying soil. A number of different designs have been tried in Singapore. The key issue, as far as tree-root heaving is concerned, is to determine the perforation area required that would allow sufficient surface water into subgrade soil.

There exist two variables in the design of slab perforations: (a) average perforation area per unit slab surface area and (b) size and distribution of perforations. On the basis of the performance of various perforated-slab designs, it appears that the average perforation per unit slab area is the controlling factor for preventing tree-root heaving problems. Distribution of perforations does not appear to affect the performance of the pavement much as long as it is fairly uniform over the pavement area concerned.

Perforation sizes are related to the perforation area required per unit slab area. In general, an opening should not be so small as to become clogged up easily. Openings smaller than 25 mm in diameter are undesirable. However, an opening wider than the imprint of a normal vehicle tire would not offer a stable contact surface to support vehicular loadings. Similarly, grass would not grow well in too small an opening. When the opening sizes are too big, grass tends to get damaged by repetitive moving wheel loads. From the car owner's or passenger's point of view, perforated slabs with small openings are preferable because they provide a smoother drive and a more comfortable walking surface.

Figure 6 shows the major types of precast perforated-slab units that are available in Singapore. Types A and B are the most commonly used for public housing estate car parks. On the basis of field performance, it has been found that Types D and E, with 20.4 and 16.6 percent openings, respectively, in surface area, were still adversely affected by upward growth of tree roots. In general, assuming that openings are uniformly distributed over the entire slab area, it may be said that slabs providing openings in excess of 30 percent in total surface area have been successful in eliminating tree-root-related heaving problems. Job specifications for car park perforated slabs in Singapore usually require a perforation area of 35 percent or more of the entire covered surface.

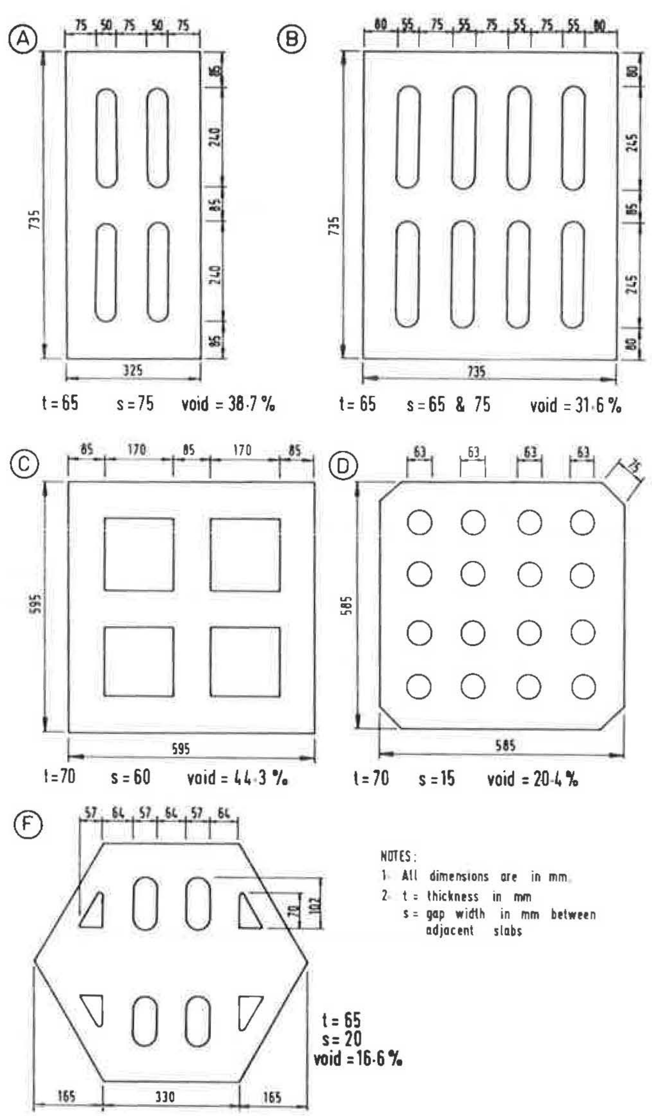


FIGURE 6 Types of precast perforated slabs.

PERFORMANCE OF PRECAST PERFORATED SLABS

The overall performance of a pavement constructed of precast perforated slab units may be evaluated by considering the following aspects: functional serviceability, structural stability, and aesthetic requirements. Functional serviceability refers to the perforation design of a perforated slab. As discussed earlier, small-width openings would provide a smoother ride and a relatively more comfortable walking surface.

The results of a survey to compare the functional serviceability of Types A and C slabs are as follows. The survey was conducted at a Type C perforated-slab car park by direct interview with the drivers who used the car park during lunch hour on a working weekday. A Type C perforated-slab car park was selected because it was believed that most motorists in Singapore were familiar with Type A slabs, whereas relatively few were familiar with Type C slabs.

	Response (N=132)					
	Yes		*No*		*No Difference*	
Question	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Does Type A provide smoother drive?	91	68.9	5	3.8	36	27.3
Is Type A more comfortable to walk on?	74	56.1	23	17.4	35	26.5
Is Type A aesthetically more pleasing?	49	37.1	37	28.0	46	34.9

On the basis of the foregoing survey, it appears that Type A slabs have better functional serviceability than Type C slabs. The functional serviceability of a perforated-slab pavement is a function of (a) percentage of perforation area, (b) distribution pattern of slab perforation, and (c) size of individual openings. In general, better functional serviceability can be achieved with a lower percentage of perforation area, more uniform distribution of slab openings, and smaller or narrower openings. No quantitative relationship, however, has been developed between functional serviceability and the three variables.

Landscape aesthetic value was the consideration that led to tree planting within car parks and the use of perforated slabs for parking areas. Two components of slab aesthetics are of interest to a landscape planner. These are the perforation pattern of the slab and whether grass could grow in these openings to give the pleasing appearance of a natural grass surface. Grass growing within perforated slab pavements has been a constant problem confronting car park maintenance agencies. Parking movements of automobiles are especially destructive to the growing grass.

In lightly used car parks, grass could grow well with most designs of perforated-slab pavement. In a heavily used car park such as the one in which the foregoing survey took place, the design of slab openings becomes important. For example, Type

A slabs with narrow oblong openings provide more protection against vehicular movement than Type C slabs with big square openings. Experience, however, has shown that even Type A slabs would not be able to produce a desired grass surface appearance when the frequency of parking movements is high. In comparison, studded-slab pavements are more satisfactory for growing grass in car parks with frequent vehicular movements.

Structural stability is perhaps the most important factor in the engineering design of perforated slab pavements. Beside the tree-root-heaving problems described earlier, two other common types of instability can be identified. One is structural cracking of slabs due to the action of wheel loads; another is movement of slabs, also caused by vehicular loadings. There are two general forms of slab movements, namely, tilting and rocking. Tilting occurs mostly on slabs that are subjected to edge loadings, whereas rocking is usually restricted to slabs centrally located on a wheelpath.

Table 1 summarizes the findings of a recent survey of several public car parks in Singapore that were affected by various forms of structural instability. This survey covered only Type A slabs because the number of car parks constructed with Type A slabs far exceeds the combined number of car parks using other slab types. Tilting and rocking together accounted for more than 90 percent of instability occurrences. Structural cracking was the next most frequent form of instability. It was common to find tilted or rocking slabs and cracked slabs both within one parking space. The results confirmed that the use of perforated slabs was effective in arresting tree-root heaving problems.

Figure 7 shows some cracked slabs. Typically cracks are found across longitudinal ribs adjacent to slab openings. In a number of cases, slab cracking was found to be related to upside-down placement of slabs. The reinforcement layout of Type A slabs is such that an upside-down slab could have its bending capacity reduced by more than 60 percent. It is therefore of importance to mark the top face when the slabs are cast in a fabrication yard to avoid placement mistakes in the field. Another frequent cause of slab cracking is nonuniform supporting conditions due to uneven compaction of underlying layers.

Most of the slab tilting and rocking problems were believed to be caused by unsound base materials and lack of interlocking between slab units. A standard layout of perforated slabs for a parking area is shown in Figure 8. The essential elements of perforated slab construction consist of a 200-mm (8-in.) crusher run granite base course and a 50-mm (2-in.) thick sand bedding. Subsequent to placement of slab units, all joints and slab openings are filled with organic soil and then close-turfed with grass. Although insufficient or uneven compaction may lead to slab tilting and rocking, it is unlikely that the foregoing construction procedure might be partially responsible for the instability problem. First, the use of compressible soils in the joints would not provide effective interlocking between slab units. Second, the top organic soils and impurities may work their way into the underlying bedding sand, thereby impairing the latter's load-bearing capacity.

FIGURE 7 Cracked precast perforated slabs.

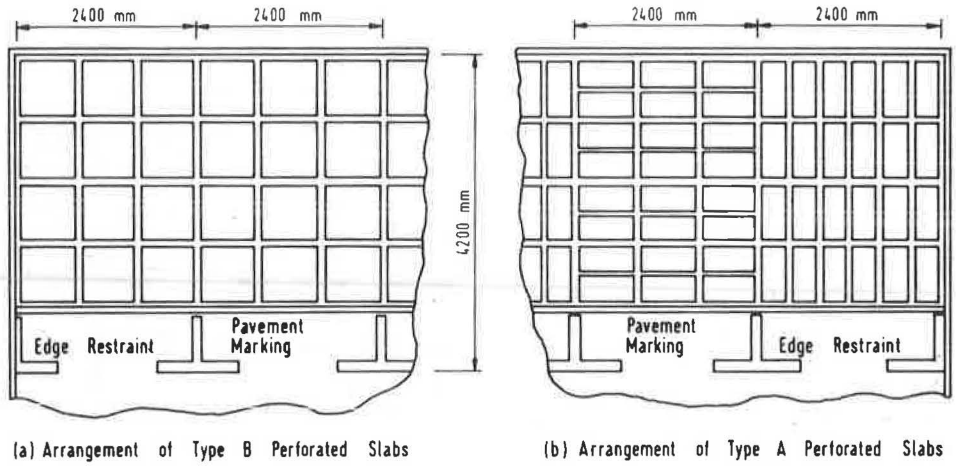
A study is now under way to seek a compromise solution so that both load-bearing and grass-planting requirements can be met. In this study sand is used for both slab bedding and joints, and grass planting is restricted to interior slab openings only. In addition, a filter blanket is also suggested to prevent contamination of bedding sand from the overlying organic soils. The aim of the study is to determine whether these measures would significantly reduce the occurrences of slab tilting and rocking.

In another recent effort to arrest the problem of slab tilting and rocking, all new public housing estate parking spaces are now laid with Type B instead of Type A slabs. These two types of slabs are similar in most design features, but the Type B slab is much wider and has a surface area more than twice that of the Type A slab. In terms of load bearing, there is a clear advantage in using a larger slab unit. For a given magnitude of wheel load applied at the center of each of the two slab types, the bearing pressure beneath a Type B slab will be only about 45 percent of the pressure under a Type A slab. Reductions of the same order are also obtained in cases of edge loadings. Given the same construction materials and procedure and the same vehicular loading conditions, it is therefore logical to expect that slab tilting and rocking would be less likely to occur with a Type B perforated-slab pavement.

TABLE 1 TYPE A PERFORATED-SLAB INSTABILITY

Car Park Location	No. of Defective Car Park Spaces	No. of Spaces by Instability			
		Cracking	Tilting	Rocking	Tree-Root Heaving
Geyland East	65	14	65	31	0
Toa Payoh Centre	47	31	44	19	0
Telok Blangah Ht	41	3	36	15	1
Ang Mo Kio West	36	8	35	7	0
Clementi Central	33	6	33	9	0

NOTE: A defective parking space may contain one or more than one type of slab instability.



Notes: 1. Perforation pattern of individual slabs are not shown
2. All perforations and joints are filled with mixture of quality top soil and sludge for turfing
3. See Figure 1 for overall layout of a typical car park

FIGURE 8 Layout of Types A and B perforated-slab pavements.

Another merit of using Type B slabs is that they would help to reduce the occurrences of edge loading along longitudinal joints. As with Type A slabs, the structural performance of Type B slabs depends very much on the soundness of the foundation construction. Furthermore, the problems of interlocking between slabs and possible contamination of bedding sands that affect Type A slabs are also present with Type B slabs. Figures 9 and 10 reveal that instabilities similar to those experienced with Type A slabs are also found in Type B slab pavements. The long-term field performance of Type B slabs is being monitored, and relevant data are being collected to determine whether occurrences of slab tilting and rocking will decrease.

FIGURE 10 Rocking and cracked Type B perforated slabs.

PERFORATED INTERLOCKING PAVING BLOCKS

Interlocking concrete block paving is not commonly used for road pavements in Singapore. Its use has been limited to car parks and driveways of private properties and hotels where aesthetic appeal of colored block units is an important architectural consideration. Although interlocking blocks are ideal for car park driveways, they are not suitable for paving parking areas, where openings must be allowed to prevent tree-root heaving. The joint spaces in a standard interlocking-block pavement do not allow for sufficient surface water to drain downward into the subsoil. Very often these joints are covered with dirt and become quite impervious after the pavement is opened to traffic.

FIGURE 9 Tilted Type B perforated slabs.

A patented design, known as Turf-Pave *(4)*, was used in Singapore in 1984 in a private housing estate to pave parking areas. It combines the concept of the perforated concrete slab with interlocking-block paving construction. Each Turf-Pave block is 470 by 470 mm (18.5 by 18.5 in.) and 120 mm (4 in.) thick. They are much bigger and heavier than ordinary interlocking paving blocks. They weigh 30 kg (66 lb) each, whereas an ordinary paving block weighs about 5 kg (11 lb). As shown in Figure 11, each Turf-Pave block has a 35 percent perforation area to cater to tree planting. The blocks are constructed of 35-MPa grade concrete and no steel reinforcements are used.

FIGURE 11 Interlocking-perforated-block pavement.

The construction of a perforated interlocking block pavement is similar to that for normal interlocking blocks. As with installation of other forms of perforated slabs, the subgrade must be compacted, leveled, and adequately drained and protected from inundation. The subbase usually consists of two or three layers of crusher run with a total thickness of 200 mm (8 in.) or more. A sand bedding layer is then laid and compacted to a thickness of about 30 mm (1.18 in.). The bedding sand used is well-graded sand passing a 4.75-mm sieve. The next step involves laying perforated interlocking blocks in the pattern shown in Figures 11 and 12. These blocks are vibrated to a uniform level with two or three passes of a powered vibrating plate. After this final compaction, dry angular sands are brushed over the surface of the blocks to fill the joints between paving blocks. All the interior perforations are then filled with loamy soil and turfed.

It is important that edge restraints be provided along the entire perimeter of an interlocking-block pavement to ensure effective interlocking. Such edge restraints are usually effected by constructing concrete edge strips or side curbs. It is hoped that the interlocking effect will help eliminate or reduce the slab rocking and tilting problems encountered in ordinary perforated-slab pavements. The perforated interlocking block parking lot pavement constructed was relatively small in area and subjected to very low frequency of vehicular movement by

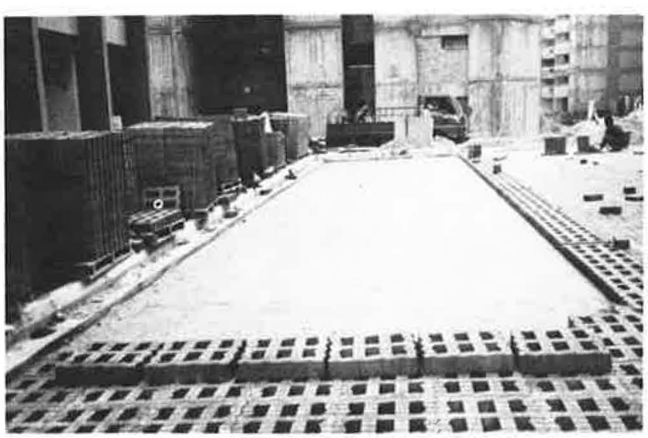


FIGURE 12 Construction of interlocking-perforated-block pavement.

lightweight automobiles. More field applications will be required before sufficient data can be collected for a detailed evaluation of the performance of perforated interlocking-block pavements.

The main deterrent to widespread use of perforated interlocking blocks for parking areas is cost. The unit cost for each square meter of paving (not including gravel subbase and sand bedding) is about 35 Singapore dollars, which is nearly twice the cost of the Type A or B perforated-slab pavement described in the preceding section. This construction, with higher initial cost, may be more economical in the long run because of the expected lower maintenance cost due to the reduced number of rocking and tilted slabs. Unfortunately, there are insufficient maintenance and cost data at the present time to enable such a cost analysis to be conducted.

CAST-IN-SITU JOINTED PERFORATED CONCRETE SLAB

Another patented form of perforated-concrete-slab construction recently introduced in Singapore is known as Grasscrete *(5)*. The construction is similar to that for conventional jointed-concrete-slab construction except that special polystyrene formers are used to make the required perforation pattern (Figure 13). Steel mesh reinforcements are laid in position on preformed spaces provided within each former. Concrete is then poured around the formers and screed level with the top of the formers. After gaining its initial set, the concrete is brushed to leave the tops of the formers exposed. The exposed former tops are burned away after 48 hr. The voids that remain are then filled with good-quality friable topsoil and turfed.

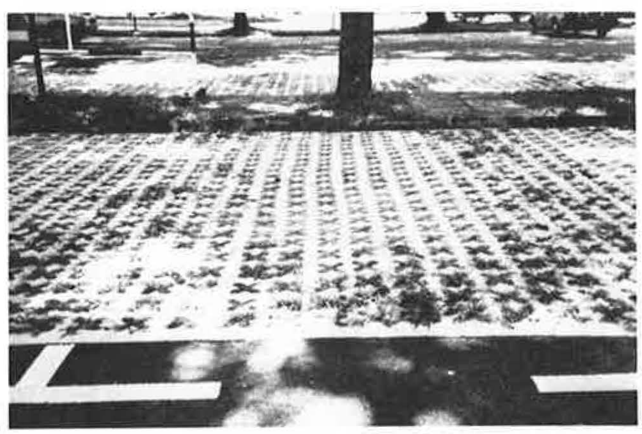


FIGURE 13 Cast-in-situ perforated concrete slab.

Expansion joints are usually provided at 9800-mm (12-ft) intervals so that each span will cover exactly the width of four parking spaces. The construction gives a 37 percent perforation area, which should be sufficient to avoid tree-root heaving problems. The cast-in-situ construction does not produce a surface as smooth as those of either precast slabs or blocks. The perforation edges tend to be rather sharp. As a result, the ride is relatively rough, even for vehicular parking movements. The discomfort can also be easily felt by pedestrians walking on the surface.

TABLE 2 COMPARISON OF VARIOUS FORMS OF PARKING LOT PAVEMENT CONSTRUCTION

Item	Precast Perforated Slab	Interlocking Perforated Block	Cast-in-Situ Jointed Perforated Slab
Installation	Easy	Moderately easy	Labor intensive and time consuming
Construction cost	Low	High	High
Need for maintenance	Relatively high	Moderate	Low
Repair of defects	Easy	Moderately easy	Tends to be more elaborate
Structural stability	Satisfactory	Good	Good
Ride quality	Satisfactory	Comparatively most satisfactory	Comparatively least satisfactory
Pedestrian comfort	Satisfactory	Comparatively most satisfactory	Comparatively least satisfactory
Aesthetics	Satisfactory	Good	Satisfactory
Grass growing	Satisfactory	Satisfactory	Satisfactory
Underground utilities	Easy to accommodate	Moderately easy to accommodate	Not suitable

It is believed that concrete-slab construction provides the benefits of rigid pavement such as low maintenance and long service life. It is also expected that the pavement will be less prone to rocking and tilting as compared with individual smaller precast units of Type A or B perforated slabs (Figure 8). The cast-in-situ construction, however, tends to be more labor intensive and time consuming. In terms of construction cost, the jointed-perforated-slab pavement is nearly 40 percent more expensive than the precast-perforated-slab system. Table 2 presents a comparison of this construction with the other two forms of perforated pavement construction described in this paper.

CONCLUSION

Special landscaping and public policy requirements for car parks in Singapore have made it necessary for pavement engineers to search for innovative designs for parking area pavements. In addition to its primary function of providing a stable and durable surface for vehicular movement, the parking area pavement must also allow sufficient open spaces for turfing and tree planting.

After several years of trial and error and field experimentation, a pavement system consisting of discrete precast perforated-concrete-slab units was found to offer a reasonably satisfactory solution. It gained approval from leading car park construction authorities in Singapore in the mid-1970s and was the only form of parking lot pavement construction for many years in Singapore.

The experience of more than 10 years of field application has revealed that the discrete precast perforated-slab pavement is not a problem-free system. The belief that some other form of construction exists that might be more cost-effective in the long run has led to the introduction in the last 2 years of two new forms of parking area construction, namely, the interlocking-perforated-concrete-block pavement and the cast-in-situ jointed-perforated-concrete-slab pavement. Although both innovations have led to higher construction costs, their superior structural stability and lower maintenance requirements may justify their use on the basis of life-cycle cost considerations.

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The Blue Ridge Parkway Study: Landscape Management—History, Classification, Simulation, and Evaluation

RICHARD C. SMARDON, JAMES F. PALMER, AND TIMOTHY R. DAY

The historical practices of vegetation management along the Blue Ridge Parkway in North Carolina and Virginia are reviewed. These management practices include girdling, slash burning, grazing, and natural succession. A landscape classification is documented that includes more than 250 scenes from scenic overlooks along 469 mi of parkway. Classification is needed to select suitable images for simulation of alternative vegetation management practices along the parkway and at scenic overlooks. Techniques for actual photographic simulation of vegetation management alternatives are described and evaluated. Finally, a visual preference survey that was administered to users of the Blue Ridge Parkway to solicit preferences for vegetation management alternatives is statistically analyzed and discussed. Management recommendations are made that synthesize survey results, historical management practices, and physical, vegetative, and soil factors.

In 1984 the School of Landscape Architecture of the State University of New York (SUNY), in cooperation with the University of Tennessee, undertook a research project to study viewer reactions to certain vegetation management techniques used by the National Park Service on the Blue Ridge Parkway, North Carolina. The aims of SUNY were twofold. The first was to generate a series of photographic simulations of the visual effect produced by the control of vegetation immediately surrounding the parkway's scenic overlooks. Ultimately, the simulations were incorporated into a visitor questionnaire *(1, 2)*. The second aim and the purpose of this article involved the investigation and documentation of alternative methods of vegetation management to those currently used by the Park Service.

PURPOSE

In 1936 governance of the Blue Ridge Parkway became part of the National Park Service [see the Land Tenure chronology in Table 1 *(3–12)*]. The initial idea of a Blue Ridge Parkway was conceived before World War I, but the concept of a scenic road connecting the Shenandoah to the north and the Great Smokey Mountains National Park to the south developed mostly during the Depression years.

One of the prime goals then and today was to provide the users with a living museum of natural and man-made form. The problem in pursuing this goal lies in the difficulty of maintaining the open quality of the Blue Ridge that the visiting public prefers. Rapid vegetation growth produced from highly conducive environmental conditions can eventually block the visitors' view from the road.

Most vegetation management techniques used by the Park Service in the Blue Ridge are very expensive and time-consuming and, perhaps more important, inconsistent with the living-museum goal. The approach here was to investigate alternative methods that might be more consistent with this goal by presenting the following:

- A clear picture of the most historically significant cultures of the Blue Ridge settlement;
- The kinds of land management techniques utilized by native Americans and settlers; and
- The relationship between these techniques, where applicable, and the kinds of management practice problems faced by the National Park Service today.

BLUE RIDGE CULTURE AND MANAGEMENT PRACTICES

The first known party to have explored the Blue Ridge Mountains was DeSoto in 1560, followed by the Bickell Party in the 1730s *(4)*. In addition to finding Indians inhabiting the area, they found a pristine virgin landscape described as "beautiful valleys covered with woods, pastures and savannahs." The trail system developed by the Indians was extensive, particularly on the slopes and summits where they set up summer camps. Some evidence indicates that these campsites, referred to as "balds," are still identifiable because of the intense use by the Indians and later settlers *(13)* (see Figure 1).

By 1950 the Blue Ridge was sparsely settled by isolated family farming units (Figure 1). The land, like most of the South at this time, was managed as garden rather than field. Once suitable farm and pasture land was found by analyzing vegetation cover, hillsides were cleared by burning and girdling *(11)*.

Among the early mountaineers, the Scot-Irish rapidly adopted the Indian ways of cultivation (see the Land Tenure chronology, Table 1). They used the simple technique of slash and burn but with no replenishment of the soil *(14)*. Following the Germans, they settled first in the bottom lands where soil and game were best. But as they moved into the smaller coves where the soil was shallower, widespread erosion led the U.S.

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TABLE 1 HISTORICAL BACKGROUND *(3)*

Period	Location	Land Tenure Practice	Culture	Source
Late 1600s	Virginia and Carolinas	Plantation settlement, extensive agricultural practice, free-range of livestock, crude structures, cash cropping	English with Scot-Irish servants	Stilgoe *(11)*
Pre-1716	Shenandoah Valley	Timber burned to increase game habitats	Native American	Kercheval *(6)*
Early 1700s	Appalachia	Tree girding, rough ploughing between dead stands	Scot-Irish	Kercheval *(6)*
1718	Pennsylvania, Great Valley, North Carolina Piedmont, and Blue Ridge	Small patch farming; trees girdled, left standing, or burned; corn and tobacco crops	Scot-Irish	Stilgoe *(11)*, Graeff *(5)*, Opie *(8)*, Kercheval *(6)*
1775	North Carolina	German movement continues from Pennsylvania into western countries and highlands of North Carolina	German	Bittenger *(4)*
1776	Blue Ridge, North Carolina	Blue Ridge and Alleghenys opened up for settlement by Continental Congress		
1700s	Pennsylvania	Permanent meadows ploughed; pasturing May 1–Nov. 1; vegetable gardening on warm side of house; neatly fenced; efficient farm practices; tilled intensively, rotated crops, manured; farmstead kept orderly and clean; frequently cattle and sheep turned out into newly cut-over land to subdue it for cultivation; prevailing practice was to pasture livestock on worn-out field reverting to succession; fewer farmers laid down land in grass after taking two to four grain crops; upland meadows pastured several years before reverting to crop rotation; apple orchards common; fences symbolize good farming	German	Long *(12)*
1700s	Pennsylvania	German farm distinguished from Scot-Irish by superior size of barns, plain compact form of houses, height of enclosures, extent of orchards, fertility of fields, luxuriousness of meadows, appearance of plenty and order	German	Long *(12)*
1700–1800	Blue Ridge	Bottom lands settled first, most fertile soil and game; future settlers moved into hills and coves	Scot-Irish	Kercheval *(6)*, Weller *(10)*
1700–1800	Appalachia	Houses built on bottom lands near streams; slopes farmed (perpendicular farming)	Scot-Irish	Weller *(10)*
1700–1800	Appalachia	Unfamiliar with manuring or soil conditioning; hillside patches cleared as lower fields depleted	Scot-Irish	Kollmorgen *(7)*
1700–1800	Appalachia	Principal crops corn and tobacco	Scot-Irish	Weller *(10)*, Stilgoe *(11)*
Mid–late 1800	Blue Ridge, North Carolina	Exploitation by lumber and mining companies results in large tracts of cut-out, burned-out, washed-out lands; feldspar and mica; primarily small operations	Scot-Irish	Sheppard *(9)*
1936–present	Blue Ridge, North Carolina	Governance by National Park Service	National Park Service	Smathers *(4)*

Department of Agriculture to proclaim that 100,000 farms were unfit for agriculture *(15)*.

Unlike the Scot-Irish, the goal of the Germans was to own the land and manage it more efficiently. They chose land heavily timbered with hardwoods in valleys composed of limestone soils similar to those in their homeland *(12)*. They planted small gardens on the warm side of their homes in which several types of exotic and domestic vegetables were grown. In addition, they usually planted orchards of fruit trees in the first cleared field.

The Germans consolidated some of the abandoned patches left by the Scot-Irish and, following their European traditions, allowed cattle and sheep to graze and subdue the land for several years before cultivation. After a period of intense tilling, crops were planted and rotated followed by more manuring to increase fertility. Cattle were routinely allowed to free-range (unmanaged grazing) after the fields became permanent.

MANAGEMENT TECHNIQUES UTILIZED

The land management mind set carried into the Blue Ridge by these cultures largely determined how the Blue Ridge looks today. Research indicates four major categories of use and management. They were sometimes used singly but most often in combination with other techniques.

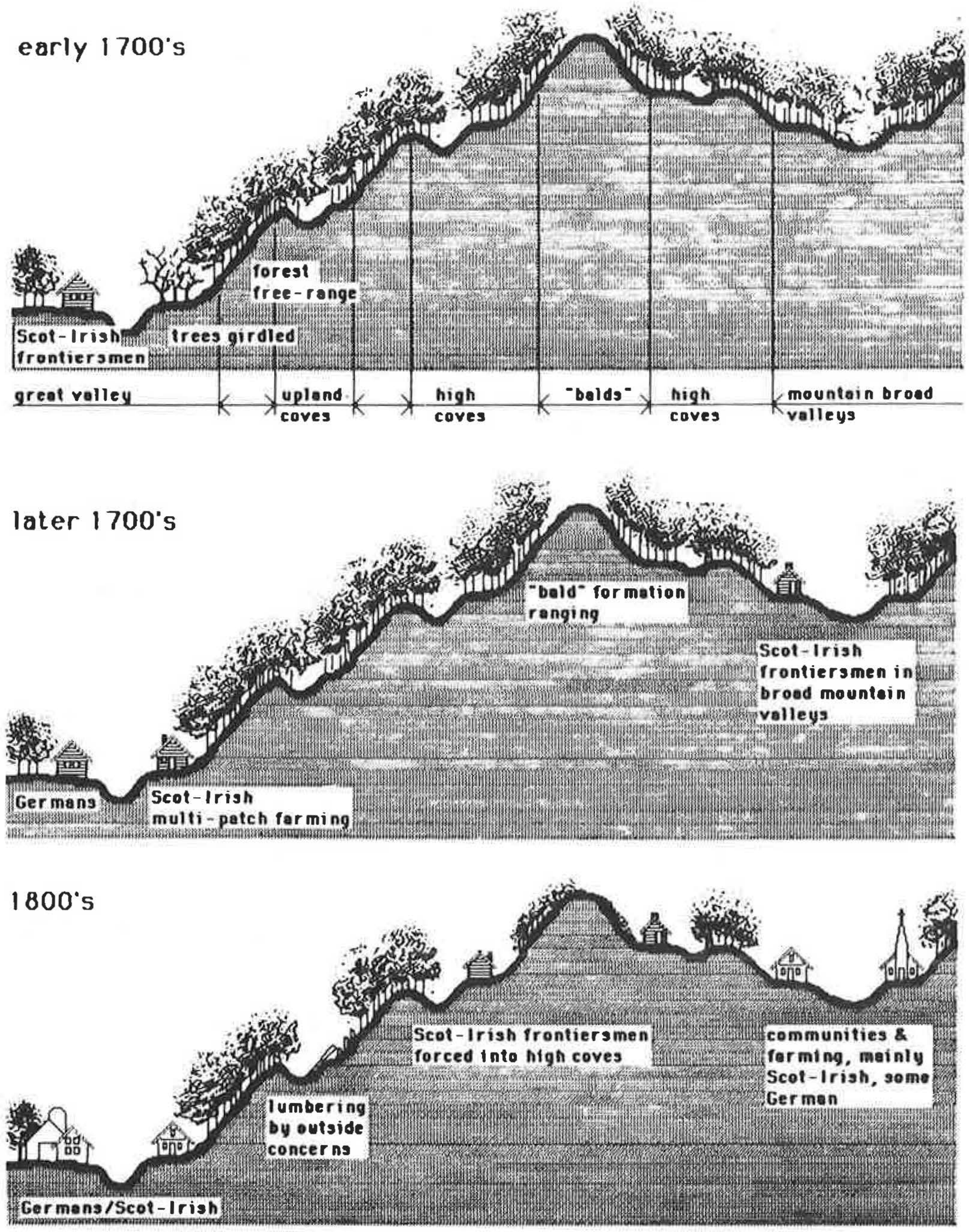

FIGURE 1 Management practices of the different cultures settling in the Blue Ridge Mountains *(3)*.

Girdling

During the mid-1800s to early 1900s, a form of vegetation management called girdling was used, primarily by the Scot-Irish. The technique involves simply removing a band or belt of a tree's bark and cambium layer, thus inhibiting the flow of moisture and nutrients to the upper stems. Eliminating the tree canopy encourages understory growth for forage or cultivation.

Slash Burning

The slash-burning technique, most closely associated with the German culture, had as its goal the superenrichment of the soil. Tree limbs and slabs were piled evenly across the ground and fired, singeing the soil. Then rye was planted and harvested, after which more limbs were spread and fired, followed by a planting of grains. The process was repeated every 5 or 6 years.

A by-product of this technique was the resumption of successional growth. Large areas called "colicks" were formed after the fields became derelict and are composed even today of a dominant cover of compact heath shrubs.

Grazing

The settlers raised a variety of domestic animals, including sheep, cattle, and mules. Due to the thinness of the upland soils,

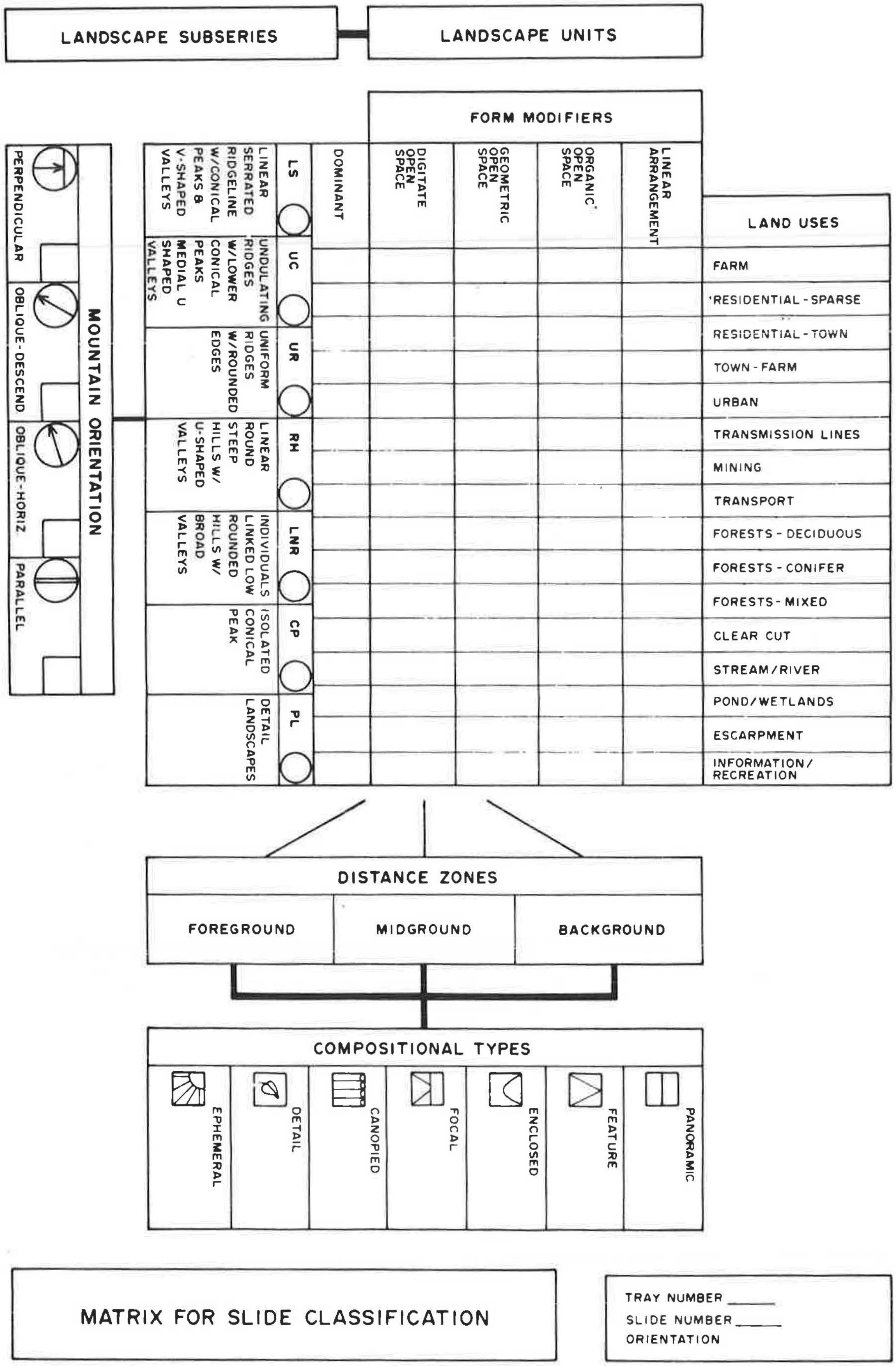

FIGURE 2 Matrix for slide classification.

evidence indicates that many of the so-called grassy balds referred to earlier were maintained and extended by the constant trampling. The succeeding grasses, mostly mountain oat grass (*Danthonia ompressa* and *Rumex acetosella*), were too competitive and choked most tree and shrub volunteers *(4)*.

Natural Succession

The natural succession process is exhibited by the ongoing emergence of plant species and is seen most dramatically following catastrophic phenomena like cutting and burning by man or by natural processes like high winds or soil erosion. The result is usually associated with deep erosion to less fertile subsoil in the margins of old fields and includes heath or broom sedge and asters, which can compete with other grasses and usually replace them quickly.

Growing in sparse stands, broom sedge (*Andropogon* spp.), for example, survives as a monoculture until enough ground litter is produced to support other forms of grass and woody vegetation *(16)*. At the time of writing, the authors had not found enough reference material to indicate the length of time before other pioneering plants outcompete broom sedge on abandoned farmland. However, it appears that the plant has potential applications in a vegetation management policy for the parkway. Broom sedge is particularly suitable because it does not pose the same entangling and overgrown characteristics as kudzu or the woody pioneering plants that it outcompetes. It presents to the viewer a fine-textured, uniform mass of vegetation for an apparently extended period of time, and its maintenance needs are minimal.

LANDSCAPE CLASSIFICATION

Along the 469 mi of the Blue Ridge Parkway, more than 250 scenic overlooks have been established. Because of logistical and financial constraints, as well as the tolerance levels of questionnaire respondents *(17)*, simulation of vegetation management techniques at every overlook was beyond the scope of this project. Therefore, it became necessary to select several overlook scenes representative of the range of visual experiences encountered along the entire parkway.

In order to initiate this selection process, a library of Ektachrome slides was obtained from the University of Tennessee. The photographic library of 298 slides contained a view from each of the established parkway overlooks plus a number of duplicate photographs made to compensate for poor lighting conditions or technical problems.

The slide selection process involved four sequential steps:

1. Formulation of a landscape classification system,
2. Classification of each of the slides in the photographic library,
3. Grouping of overlook scenes on the basis of similar landscape components, and
4. Selection of one or two representative slides from each of the established groups of overlook scenes on the basis of degree of photographic quality and suitability for simulation purposes.

The classification system used to denote the representativeness of all the images and assist in selection of images for management prescription and simulation included land use, landform pattern, and landform spatial configuration; distance zones seen; and landscape compositional types (see Figure 2). Further details may be found elsewhere *(18)*.

Selection of Views for Vegetation Management Simulations

Determining what views (slides) were suitable for simulation purposes was based largely on foreground vegetation. In order to simulate the results of possible management techniques for vegetation, it was important to choose views that contained as much foreground plant material as possible. Views that show vegetation from the ground to the crowns of the plants produce a more accurate simulation than the views that show just the tops of plants. For example, if one option for management of vegetation was controlled burning of shrubs and the original view contained just the crowns of the plant material, the simulation of burning would not portray the total effect of the burning. The effect on surrounding grass and plants and the appearance of the ground could not be simulated.

Foreground Vegetation Suitability

The first phase in determining foreground vegetation suitability for simulation was an area measurement of all slides. The foreground vegetation in each slide was measured as a percentage of the entire scene. The slides were projected onto a grid. The number of grid sectors with foreground vegetation on them was then counted. If less than one-third of the sectors were filled with foreground vegetation, the view was eliminated from further consideration for simulation. The one-third rule was used for several reasons. First, if less than one-third of the slide showed foreground vegetation, the view could be overpowered by the emergent background scenery during a simulation of vegetation removal. The view might then be judged on the quality of the background and not on the management technique that was simulated. Second, the one-third rule proved to be an effective means of eliminating some of the 298 slides so that a manageable number remained. The slides that contained more than one-third foreground vegetation were then classified according to the foreground vegetation suitability index (Figure 3).

The foreground vegetation suitability index accomplished several things. It was a means to identify the amount of primary and secondary vegetation that could be seen from base to crown alone. A grid system was used to determine the dominant vegetation. Then the vegetation was classified in order of dominance for easy reference and comparison of vegetation among slides; without this classification, grass was usually viewed as the dominant foreground vegetative feature, shrubs or shrub grown as secondary foreground vegetation, and mature deciduous trees as the third most dominant (Figure 3).

As stated before, views that showed the vegetation from base to crown were determined to be most applicable for simulation. The final phase for foreground vegetation suitability was the grouping of views in two final categories: those that showed

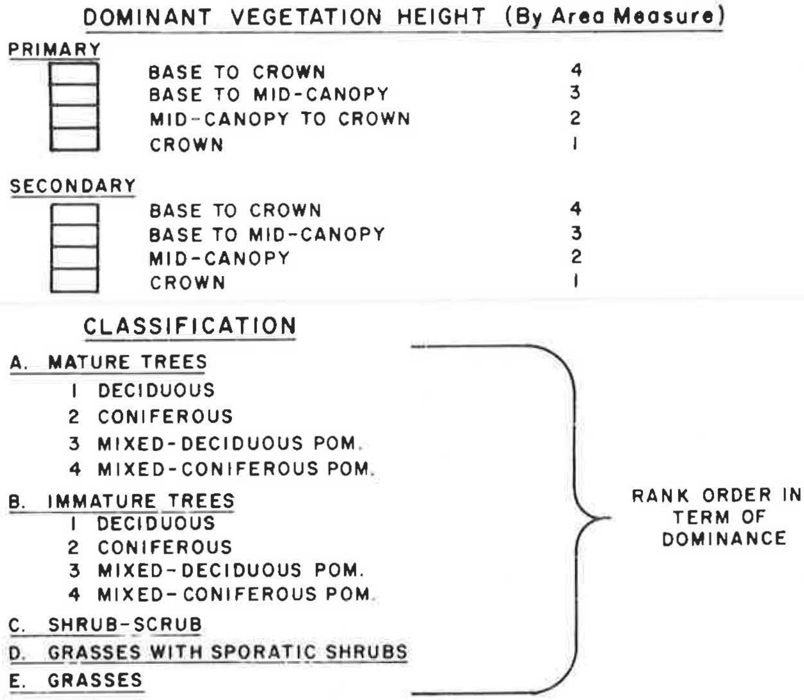

FIGURE 3 Foreground vegetation suitability index.

both the primary and secondary foreground vegetation from base to crown (most suitable for simulation) and those that showed either the primary or the secondary foreground vegetation from base to crown and either the primary or the secondary foreground vegetation, or both, from base to mid-canopy. This category was marginal for simulation. In the final analysis, 10 views were determined suitable for simulation according to foreground vegetation, and 21 views were marginal.

The next step was to determine what images would be required to produce the simulations. In this project, two factors were of prime concern: (a) the visual impact of roadside vegetation on the visitor to the parkway and (b) the impact of management techniques utilized by the Park Service along the parkway.

Data Treatment

Once the most suitable views had been selected, the next step was to apply appropriate management techniques to each scene. To accomplish this task, advice from Park Service managers was needed. Each of the 10 representative views was printed, inserted into an acetate envelope, and sent, together with an acetate marker, to the Blue Ridge Parkway Management Supervisor in Asheville, North Carolina. Comments and graphic delineation from the Park Service managers were drawn directly on the acetate overlay, and the views were returned. The managers identified three major management techniques common to the 10 representative views: (a) mowing either by bush hog on accessible sites or by hand cutting, (b) selective cutting of brush or trees to allow for significant views, and (c) controlled burning in places inaccessible to machines.

Three types of information were needed for the simulation: U.S. Geological Survey (USGS) quadrangle maps for background topological data, photographs taken behind the vegetation to be removed or modified, and photographs taken in front of the scene for contextual information. Photographs behind vegetation were crucial because the three management techniques supplied by the Park Service involved eliminating vegetation in one form or another, which would reveal new vegetation, topography, or man-made forms.

Another concern to be addressed was seasonal variation. Some management techniques might have a significant impact on views in summer, but the impact on views in winter might be quite different. Possible procedures were to consider proposed changes with different seasonal impacts or to choose the season with the highest visitation frequency, such as summer with vegetation in full leaf. In this case, the latter procedure was used. It is important that simulations be made for the same season in which subjects will be responding to a photograph questionnaire.

Specific Visual Simulation Techniques

Prototypical Scene Development

As stated before, the purpose of the project was to solicit visitor responses to certain Park Service vegetation management techniques. After the representative scenes were chosen and comments were received from the National Park Service, each scene was analyzed to determine the appropriate montage technique. This was accomplished by overlaying the original 8- by 10-in. print with acetate and with the USGS quads to determine hidden topographic features. Ideas were tested using markers.

It was decided that two pages with eight views per page would be prepared. Each page would contain the before-and-after views of four scenes, and each photograph would be 2 by

3 in. to allow for a rating scale beneath the images. Consequently, each montage was created at the 8- by 10-in. size and then photographically reduced.

Montage Techniques

In the development of the simulations themselves, several ideas and media were tried. The first and most commonly used montage technique was "cut and paste." Depending on the amount of change required, two approaches can be utilized. First, in relatively small areas—for example, a bank of large shrubs that has to be eliminated and replaced with smaller shrubs or grass while providing appropriate background material—a technique called "windowing" can be performed (Figure 4).

When relatively large areas of the image, such as a tree mass, mountains, or sky, have to be altered, a technique called "layering," which is similar to the "windowing" technique, can be used (Figure 5). Again, the material to be changed is trimmed away, the backing is stripped from the edge to be retained, and new material is cemented in place. Experimentation proved to be equally successful in both front and back applications.

The next most common technique used is called "coloring." In this instance, a variety of materials was used, ranging from color dyes to air brush techniques. In this project, coloring was confined to touch-ups. Color dyes, matched to Cibachrome print material, appeared to work best for touch-ups in most instances *(19, 20)*.

The last type of montage involves the techniques of "dodging" and "burning-in" commonly utilized in a darkroom *(21)*. These procedures have been documented in a number of professional darkroom manuals. Basically, in slide printing, "dodging" means masking an area so that after development, the area appears black or dark, whereas "burning-in" produces the opposite effect. Experimentation with this approach was not as satisfactory as that with the cut-and-paste technique. The various techniques are summarized in Table 2.

VISUAL SURVEY APPROACH TO EVALUATE VEGETATION MANAGEMENT ALTERNATIVES

Introduction

These simulations were used by the University of Tennessee team in the preparation of a questionnaire to assess vegetation

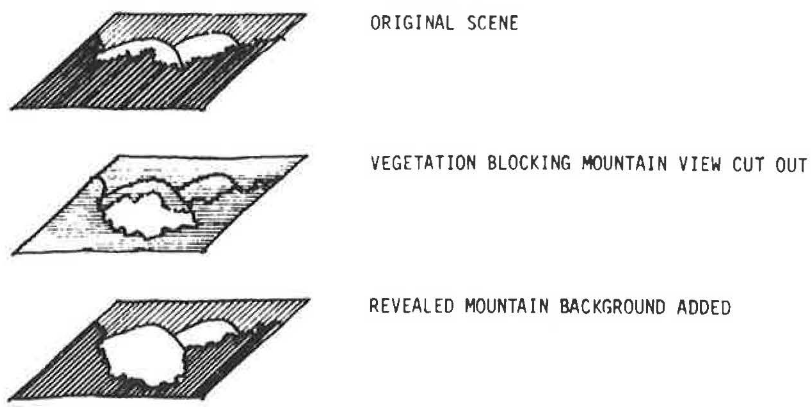

FIGURE 4 Windowing.

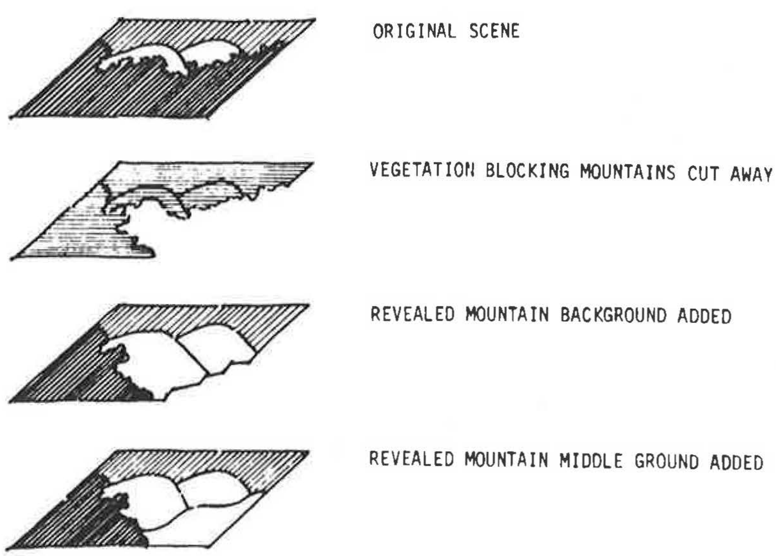

FIGURE 5 Layering.

TABLE 2 SUMMARY MATRIX OF MONTAGE TECHNIQUES

Technique	Simulation Condition	Materials Needed	Skills Needed
Windowing	Small areas, minor modifications	New materials to substitute and blend with removed areas	Cut and paste; no special skills
Layering	Major modifications	Same as above	Same as above
Feathering	To blend vegetation	New material	Same as above
Coloring	Touch-up to hide cut edges	Color dyes, felt markers	Artistic skills
Dodging and burning-in	Blending homogeneous zones—sky, etc.	Darkroom equipment	Trial and error

management alternatives for the Blue Ridge Parkway. Each questionnaire was divided into five response sections: visual preference evaluations of pairs of photographic simulations; ratings of vegetation management alternatives; reported participation in outdoor activities; rating of leisure attitude statements; and respondent characteristics. In addition, half the questionnaires included a leaflet that indicated that ecological and economic benefits could be derived from reduced roadside mowing. Approximately 500 questionnaires were distributed between Tuesday, August 9, and Sunday, August 21, 1983. Questionnaire booklets were handed out and retrieved at pullouts along the full length of the parkway.

In this section the visual preferences and attitudes toward vegetation management alternatives are investigated. Also considered is the potential of an information leaflet to influence these responses. The primary methods used in this investigation are the analysis of variance (ANOVA) and t-test. The following description of the three relevant portions of the questionnaire will establish the context needed to interpret the results of the analyses.

Information Leaflet

The information leaflet at the beginning of the visual preference section in half of the questionnaires consisted of three photographs, arranged diagonally on the page from left to right. Two of these photographs were also used to represent two sites in the questionnaire (Sites 3 and 8). The third photograph was only used on this page. In the upper right-hand corner was the following "ecological" message:

> There are idle spots on every farm—and every highway is bordered by an idle strip as long as it is. Keep cow, plow, and mower out of these idle spots, and the full native flora, plus dozens of interesting stowaways could be part of the normal environment of every citizen (Alda Leopold, pioneer ecologist, from *A Sand County Almanac*).

In the lower left corner was the following "economic" message: "Just a 50% reduction in mowing on the Blue Ridge Parkway will save taxpayers $71,000 per year."

Visual Preference Evaluations

The general instructions in the questionnaire were as follows:

> Vegetation management along the Blue Ridge Parkway can be conducted at various levels of intensity. For example, the roadside grass can be mowed weekly, monthly, bimonthly, etc. We would like your opinion of some possible levels of grass mowing and tree-clearing that might be practiced on the Parkway. By rating the vegetation management examples in our photo, we can determine what Parkway visitors prefer.
>
> There is a collection of photographs presented as three (3) pairs per page. Each picture has a short description under it. Please pay particular attention to the described feature as you rate each photograph. First, look through them quickly to get a general feeling for the photographs. Then, go back and carefully read the description. Rate EACH photo (compared to its pair) for HOW MUCH YOU LIKE IT. Simply circle the number of your choice below each photograph.
>
> 1 = not at all
> 2 = a little
> 3 = somewhat
> 4 = quite a bit
> 5 = very much

The questionnaire presented 18 photograph pairs, each representing an alternative intensity of management. In most cases, both photographs appeared to be of the same site. However, two pairs of photographs were obviously of different sites; in several other pairs, the montage process caused slightly noticeable differences between pairs that might have been interpreted as site differences.

These photograph pairs represented two general types of management activity: 8 simulated roadside mowing and 10 vista maintenance. The mowing comparisons ranged from a single mower's width from the roadside to complete mowing to the treeline (Sites 2, 6, and 7). Other mowing-width comparisons were also presented (Sites 1, 3, and 9). One pair addressed the frequency of mowing (Site 8) and the eighth pair mowing around a road sign (Site 4). Among these photo pairs, two were the same but with different captions (Sites 3 and 8) and two other pairs had one photograph in common (2a and 7b) and used the same captions.

Three management alternatives were represented among the 10 vista management comparisons. Two sites (5 and 15) represented the effects of controlled burning as a vista management tool. Intensive cutting of woody vegetation was represented at four sites (10, 12, 13, and 16), whereas four more represented moderate or selective cutting (11, 14, 17, and 18). Of particular interest among these photographs were the reuse of one photograph (10a and 17a) to create a three-sequence comparison (10a, 10b and 17a, 17b) and the removal of a single foreground tree to reduce vista enframement (Sites 14 and 18). The management treatment was generally tree removal at these sites; however, at one, it was specifically removal of hardwoods to emphasize conifers (Site 18). At two other sites (13 and 17), the treatment resulted in a mown foreground crest rather than residual wood vegetation.

Vegetation Management Alternatives

Respondents were also asked to state their support or nonsupport for the various levels at which the grass and shrubs along the Blue Ridge Parkway could be maintained. Responses were recorded on a seven-point bipolar scale: (1) strongly support, (2) support, (3) probably support, (4) don't know, (5) probably don't know, (6) don't support, (7) definitely don't support. Twelve management alternatives were described in all: four of these alternatives concerned the frequency of mowing, four described the width of the mown area, one posed safety as the sole criterion for mowing, and three addressed intensity of cutting or trimming of woody vegetation to maintain vistas at roadside pulloffs.

MANAGEMENT FINDINGS

Vegetation Management Alternatives

The overall statistical analysis for each alternative management statement showed, in general, that less intensive management practices received greater support (see Table 3). An average or typical evaluation supported mowing every 3 or 4 weeks when the grass becomes about 8 in. tall. Mowing should extend to some natural break close (within a couple of mower's widths) to the road's edge. Moderate tree thinning was preferred, but the pulloff vistas should be maintained in any case. Overall, respondents were more supportive of vista maintenance than of mowing activities.

The mean ratings for both those respondents who did and those who did not receive the leaflet about the ecological and economic benefits of reduced mowing are also compared in Table 3. In general, those provided with this information tended to be more supportive of reduced mowing and less supportive of intensive mowing. This is the direction of influence that one would expect; however, the differences are statistically significant only for the most intensive mowing practices and the restriction of mowing to reasons of safety. The mowing leaflet did not appear to influence ratings of vista maintenance alternatives in any significant way.

The relationship between the intensity of management and the influence of the leaflet was further investigated by using two-way ANOVA models. The management alternatives are grouped for these analyses according to mowing frequency (Statements 1 through 4), mowing width (Statements 5 through 8), and vista maintenance (Statements 10 through 12). The results in Table 4 indicate that the variation in ratings attributable to management intensity is significant in all three models.

TABLE 4 EFFECT OF MANAGEMENT INTENSITY AND INFORMATION ON RATINGS OF VEGETATION MANAGEMENT ALTERNATIVES

Management Action	Effect	*df*	*F*-value
Mowing frequency	Intensity	3	130.0[a]
	Information	1	9.7[b]
	Interaction	3	3.4[c]
Mowing width	Intensity	3	38.9[a]
	Information	1	6.0[c]
	Interaction	3	4.4[b]
Cutting woody vegetation	Intensity	2	3.5[c]
	Information	1	0.9n.s.
	Interaction	2	0.6n.s.

NOTE: n.s. = $p \geq .05$
[a] $p < .001$.
[b] $p < .01$.
[c] $p < .05$.

TABLE 3 MEAN RATINGS OF VEGETATION MANAGEMENT ALTERNATIVES AND EFFECT OF INFORMATION LEAFLET

Vegetation Management Alternative	Information Leaflet: With (N = 241)	Information Leaflet: Without (N = 222)	t
The roadside grass should be mowed			
1. Weekly, like a lawn	6.15	5.64	3.47[a]
2. Every 2 weeks, when 3 to 6 in. tall	4.50	3.88	3.21[a]
3. Once per month, when at least 10 in. tall	3.79	3.86	−0.41n.s.
4. Once in fall after wildflowers are through blooming	3.65	3.57	0.42n.s.
5. Only one mower's width (7 ft) from the edge of the road surface	3.22	3.41	−1.04n.s
6. Two mower's widths (14 ft) from the road's edge	4.43	4.23	1.20n.s.
7. From the road's edge to the ditch or swale	3.92	3.73	1.14n.s.
8. From the road's edge to the treeline	4.90	4.18	3.67[a]
9. As little as possible, only when necessary to maintain driver safety and help prevent grass fires	3.76	4.21	−2.11[b]
Shrubs and trees at pull-off vistas should be cut or trimmed			
10. Annually to maintain a completely clear view	3.70	3.46	1.19n.s.
11. Every 5 to 7 years, before the shrubs in foreground block much of distant view	3.32	3.21	0.63n.s.
12. Just often enough so that no more than 1/3 of view is blocked	3.53	3.57	−0.22n.s.

NOTE: On a seven-point bipolar scale: (1) strongly support, . . . , (4) don't know, . . . , (7) definitely don't support.
n.s. = $p \geq .05$.
[a] $p \leq .001$.
[b] $p \leq .05$.

These differences were further investigated through multiple-comparison mean separation tests. Tukey's honestly significant differences (HSD) procedure with a significance level of .05 was used. These results indicated that there was no significantly different support for monthly or fall mowings. However, both practices were preferred to biweekly mowings, which were preferred to weekly mowings. A similar situation existed for alternative mowing widths. A single mower's width was preferred above mowing to the swale; both were preferable to double-width mowing or mowing to the treeline. No difference was evident between these latter, more intensive alternatives. In the case of vista maintenance, waiting 5 to 7 years, before much of the distant view is blocked, was preferred. The other two alternatives, annual maintenance and maintaining at least 66 percent openness, were equally preferred. It is important to remember that, overall, there was greater support for vista management than for intensive mowing.

The information leaflet also had a significant effect on the ratings associated with grass management. However, it did not cause any difference in vista management preferences between the two groups. The influence of the leaflet was not even among all the statements. Rather, it had a significantly greater effect on opinions about more intensive mowing activities, as previously indicated by the t-tests in Table 3. In addition, those who did not receive the leaflet supported mowing to the treeline over double-width mowing, whereas those who received the information leaflet preferred double-width mowing.

Visual Preference Evaluations

The ratings of how much respondents liked the simulated effects of management alternatives are summarized in Table 5. The sites have been grouped according to the general management practice they represent, as previously described. The mean values (x) represent the difference between the ratings for the less managed or control condition and the more managed or treatment condition. Therefore, a negative value represents visual improvement and a value of zero indicates no change in visual quality. A t-test was used to identify those cases in which the mean change was significantly different from zero. The mean differences and t-tests are reported for both those who received the information leaflet and those who did not. A paired-comparison t-test was used to identify significant differences between the mean change in ratings for these two groups.

ANOVA models reported in Table 6 were used to investigate the effects of these factors. Among the effects incorporated into these models was "activity" or the significance of the change in rating from the control condition (Photograph A) to a treatment condition (Photograph B). The "information" effect refers to the difference between those who did and those who did not receive the information leaflet. In a sense, each of the simulated sites was a repetition or repeated measure of a particular management activity. Collectively, they represented the visual variation of using these practices in the landscape. This variation was represented by a "site" effect. For the analysis of vista clearing, a second model grouped the sites into clearing activities of major and moderate intensity. All possible two-way interactions were also included in these models.

The pattern of visual preference for mowing alternatives was very similar between the two groups. Overall, respondents preferred the control or less mown condition. The major exception was a preference for mowing vegetation around a low road sign (Site 8). The treatment in Site 7 also received a very

TABLE 5 MEAN CHANGE IN VISUAL PREFERENCE RATINGS FOR SIMULATED MANAGEMENT SITUATIONS

		With Leaflet		Without Leaflet		Paired
Condition	Site	x	t	x	t	t
Mowing width	1	1.57	10.4^a	1.72	11.7^a	−0.7n.s.
	2	1.32	9.0^a	0.95	5.9^a	1.7n.s.
	3	0.21	1.2n.s.	−0.29	−1.7n.s.	2.1^c
	6	1.03	6.4^a	0.47	2.7^b	2.4^c
	7	−1.50	−10.1^a	−1.19	−7.3^a	−1.4n.s.
	9	1.00	5.8^a	0.64	3.4^a	1.4n.s.
Mowing frequency	8	0.13	0.8n.s.	−0.45	−3.0^a	2.6^b
Sign mowing	4	−1.71	−10.7^a	−2.36	−18.1^a	3.1^b
Major clearing	10	−1.89	−14.5^a	−2.13	−17.7^a	1.4n.s.
	12	−0.30	−1.8n.s.	−0.16	−1.0n.s.	−0.6n.s.
	13	−0.06	−0.4n.s.	−0.23	−1.3n.s.	0.7n.s.
	16	−2.57	−23.4^b	−2.55	−24.7^a	−0.1n.s
Moderate clearing	11	−0.32	2.1^c	−0.31	−1.9n.s.	−0.1n.s.
	14	1.53	11.2^a	1.36	9.8^a	0.9n.s.
	17	1.35	9.6^a	1.18	7.9^a	0.8n.s.
	18	0.35	2.5^c	0.25	1.7n.s.	0.5n.s.
Controlled burning	5	1.35	9.1^a	1.19	7.7^a	0.8n.s.
	15	−0.19	−1.1n.s.	−0.17	−1.0n.s.	−0.1n.s.

NOTE: The mean difference is a less managed or control condition rating minus a more managed or treatment condition. Negative values indicate visual improvement. n.s. = $p \geq .05$.

$^a p < .001$.

$^b p < .01$.

$^c p < .05$.

TABLE 6 EFFECT OF MANAGEMENT ACTIVITY, INFORMATION, AND SITE ON RATINGS OF VISUAL PREFERENCE

Management Action	Effect	*df*	*F*-value
Mowing width	Activity	1	595.4[a]
	Information	1	6.2[b]
	Site	5	10.1[a]
	Information × activity	1	23.5[a]
	Information × site	5	0.4n.s.
	Activity × site	5	40.5[a]
Controlled burning	Activity	1	69.6[a]
	Information	1	0.2n.s.
	Site	1	2.4n.s.
	Information × activity	1	0.5n.s.
	Information × site	1	0.1n.s.
	Activity × site	1	140.8[a]
Vista clearing	Activity	1	92.8[a]
	Information	1	0.1n.s.
	Site	7	13.2[c]
	Information × activity	1	1.2n.s.
	Information × site	7	0.2n.s.
	Activity × site	7	295.5[a]

NOTE: Among the effects incorporated into these analysis-of-variance models, "Activity" refers to control (Photograph A) and treatment (Photograph B) conditions. "Information" refers to those who did or did not receive the information leaflet. "Site" refers to those sites simulating the activity; in a sense these are simulation repetitions or repeated measures of the management activity. "Intensity" regroups the vista-clearing sites into major and moderate clearings. The two-way interactions are indicated by "×." n.s. = $p \geq 0.5$.

[a] $p < .001$.
[b] $p < .01$.
[c] $p < .05$.

positive rating. However, this may have been because the two photographs were of distinctly different sites.

There were significant differences between the mean changes for these two groups at half the sites, which is similar to the influence among the mowing management statements. This result is are supported by a significant effect in the ANOVA model for mowing width, as well as the *t*-tests for mowing frequency (Site 8) and mowing around road signs (Site 4). In all these analyses, the information leaflet was associated with preference for reduced mowing activity. This effect was accentuated among those who received the leaflet, accounting for the significant interactive term.

The most significant effect in the ANOVA model for mowing width concerned the change at each site from a more intensive management practice. As has already been described, respondents generally supported less intensive mowing. The actual variation among the sites was also very highly significant, possibly indicating the relative difference in treatment intensity between photographs at a particular site, as well as the visual sensitivity of different sites to management practices. The significant interaction between activity and site is attributable to the essential lack of difference between the photographs at Site 3.

The overall preference for the visual effects of vista management practices was clearer, though different, than it was for mowing practices. Cutting activity that removes large amounts of woody vegetation from an overgrown vista to establish an open view was preferred. However, respondents did not appear to support cutting when the vista was only slightly blocked or when a significant residual was left that still blocked the view. This result was more accentuated but appeared to support responses to the management statements in which cutting was preferred every 5 to 7 years (seemingly a long time) over annual clearing or clearing before one-third of the view was blocked. Controlled burning also received poor ratings, particularly for the case in which there was little change in the vista's extent. Finally, there were no significant differences between the two groups, indicating that the information leaflet had no effect. This may have been because the leaflet focused on mowing and the effect failed to carry over to tree clearing. Alternatively, it may have been because respondents already had a clear position on vista management that was based on a cultural reticence to cut down trees but a strong visual preference for vistas.

These results are supported by the ANOVA results. The actual change in evaluation from before to after the activity is highly significant. There is also a very highly significant effect, which becomes strengthened, when the results are divided into major and moderate intensity groups. There is also a very highly significant interaction effect between the activity and site or intensity factors. Essentially, this represents the strong preference for major clearing and the perceived undesirability of only modest clearing. The controlled burning analysis exhibits a similar pattern for activity and the interactive term.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Biophysical and Historical Management Recommendations

Any vegetation management technique utilized should be preceded by a thorough analysis of the goals and objectives to be accomplished. Because the primary object of this research has been the human cultural aspect of viewing from the Blue Ridge Parkway, a number of physical parameters should be considered. Basically, viewing from the Blue Ridge Parkway involves two major components: the position of the viewer and the scene to be viewed. The viewer position generally means either viewing at a scenic overlook while standing or sitting or viewing along the road while in a moving car. The speed of the car and the road configuration are also important because an impressive view is more likely to be seen while on a straight road at a low speed than on a curve (except by a passenger). The amount of vegetation to be removed should be determined not only by what is viewed but by whether the viewer is moving or standing still.

The major management constraint on the scene to be viewed is not only vegetation but also the underlying topography. Most of the Blue Ridge Parkway is located on relatively steep slopes or on a ridge top, which means that major long views contain foreground sloping away from the viewer. The management techniques utilized, controlled burning and cutting or mowing, are effective especially in preventing severe erosion on steep slopes and in soils that are largely thin, well-drained, and sterile. However, because of a climate highly conducive to plant growth, sites of prime viewing require constant care.

Plant material to be considered should in general be self-maintaining and physically and microclimatically appropriate to the area and the surrounding vegetal context of the view and the slope on which it is placed.

Environmentally, perennial vegetation to be introduced should have the following characteristics. First, because most soils on steep slopes and ridge lines are thin and depleted of nutrients, plants should be shallow rooted, fibrous, and able to absorb and hold nutrients for extended periods of time. Second, because the climate is humid and temperate and rainfall is abundant, plants should be able to withstand the potential erosive effects of heavy rainfall, snow, and sedimentation.

Physically, plants should be complementary in terms of form, size, and texture to the surrounding site context, but even more important, the height of the plant should be self-maintaining and predictable because placement on a given slope with respect to the viewer position is crucial in maintaining the desired view. Grasses such as broom sedge could be used in near foreground areas, but if the slope falls away sharply, shrubs should be used. Again, consideration should be given to the two major components—the viewer position and the scene to be viewed.

Perceptually Based Management Recommendations

Perceptually based results support roadside mowing every 3 or 4 weeks when the grass becomes about 8 in. tall. Mowing should extend to some natural break close (within a couple of mower's widths) to the road's edge. Annual maintenance and maintaining 66 percent openness of vistas are equally preferred, so it would make sense to wait 5 to 7 years before trimming or cutting shrubs that would block distant views. Cutting that removes large amounts of woody vegetation from an overgrown vista is supported but not when the vista is only partially blocked or when significant residual woody material is left that partially blocks the view. In other words, cutting should not be done unless there is potential for creating substantially increased visual access or open views. Controlled burning also should not be performed unless there is substantial improvement in vista quality and extent.

Synthesis

The foregoing summarized perceptual results regarding roadside mowing and vista maintenance speak for themselves. In addition, this analysis shows greater support for vista maintenance than roadside mowing. The major synthesis would be the combination at suitable locations of periodic mowing of roadsides and brush clearing of vistas with introduction of plant species that either maintain low height and uniform texture or are historically representative of past vegetative management practices. Plant species of the latter type would be especially appropriate near interpretive areas and facilities.

The determination of the total mix of vegetation management over the length of the parkway is more difficult. Because the investigators dealt primarily with static images and simulations, it is proposed that questions involving spatial sequences of visual experience need sequential or dynamic simulation. A future agenda item for research would be video simulation of moving sequences of vegetation management changes along the Blue Ridge Parkway using different simulation media [scale models, computer-assisted graphics, or electronic photomontage (computer and video)] to illustrate different management alternatives in real-time sequence.

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