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Contents

Authors of Papers in This Record

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Safety Rest Areas: Planning, Location, and Design

DENNIS ADAMS AND JAMES REIERSON

The value of rest areas along Interstate highway routes is recognized by many people. Rest areas provide a safe place for motorists to pull off the highway. Rest and relaxation return a motorist to the highway a safer and better-informed driver. Although the Interstate system is approaching 100 percent completion, the rest-area program is only about 50 percent complete. The design of current rest areas often lacks consistency because a common body of knowledge about the state of the design art is not available. An effort was made to improve the procedures and features provided in Interstate rest areas by interviewing states with successful rest-area programs. This paper, which is a synopsis of a recently published manual, identifies rest-area development procedures in three steps: planning, location, and design. This paper is a state-of-the-art review of rest-area development.

The development of Interstate safety rest-area programs in various states is marked by many stages of completion. Recent surveys show that, although the Interstate highway program is approaching completion, rest-area programs are only about 50 percent complete. Some states have completed their programs, others are approaching completion, while some have hardly begun developing a rest-area system.

For states that have successful programs, public acceptance and response have been very favorable. They recognize the impact that good rest-area programs have on the image of their transportation agencies and states. Transportation agencies should favor programs that promote a positive public image. An example of a quality rest area is shown in Figure 1.

The Federal Highway Administration (FHWA) has recognized the importance of safety rest areas. Rest areas promote safer drivers by providing a place for rest and relaxation. They also are a valuable tool in promoting tourism. In order to identify this importance, the Minnesota Department of Transportation (MnDOT) was asked to prepare an up-to-date review of rest-area design principles and typical facilities. The manual that we prepared encourages a minimum level of rest-area design. This project was recently completed and a training course is currently offered to interested states. It is entitled Safety Rest Areas: Planning, Location, and Design (1).

This paper represents a synopsis of material from the manual. It points out the significant procedures required to develop a safety rest-area system and indicates special features normally provided in rest areas that contribute to their success. On Interstate routes, the system is not complete until a rest-area development program has been completed.

While preparing the manual, we interviewed designers in nine states, discussed their procedures, and visited representative rest areas. Their procedures were combined with specific experiences from MnDOT to form the basis for the manual.

The development of a safety rest-area system involves three main phases. Initially, the program must be planned and the general system framework stated in a printed document. Then, sites must be located along each route. Finally, each site must be designed to include a minimum level of services and features that should be considered in all rest areas.

PLANNING THE SAFETY REST-AREA SYSTEM

The process of planning a rest-area system along an Interstate highway should begin with a thorough development program. Seven major areas should be discussed, including scope, funding, budget, timetables, staffing, rest-area locations, and systems analysis. When a development program is prepared, administrators and others can clearly understand the ramifications that will result from developing a rest-area system. This is important, especially when administrators carefully analyze the necessity of each new program.

Program Scope

In order to efficiently plan a rest-area system, it is essential that everyone involved have a clear understanding of what services will be provided and how the system will operate. In order to identify the operation of a rest-area system, it is suggested that a series of operational guidelines be evaluated, including the following.

1. Traffic type--What type of traffic will each route handle and what will be the proportion of commercial, recreational, or through traffic? The facilities and services will vary depending on the type of traffic.
2. Spacing and volume--What rest-area spacing will be best to serve the traffic volume along each Interstate route? Spacing might vary from route to route in a state. Desirable spacing intervals are 80 km (50 miles) for average rest-area locations.
3. Tourism--Will tourism opportunities be an integral part of a rest-area system? If it is significant, buildings will require room for display space, and site development might require space for outside displays.
4. Quality of service--Each state must determine what services it will provide and what impression it wants its rest areas to make on travelers. This point is related to the attitude of the state toward tourism.
5. Maintenance--The operation and maintenance of a rest-area system must be considered as a rest-area program is developed. This is important when considering funding, since maintenance is an ongoing operation without federal funding sources.
6. Wastewater disposal--A decision on how extensive a wastewater-treatment system should be will affect all phases of planning. Some states select sites only if a certain kind of disposal system can be used.
7. Facility scheduling--The scope of a proposed rest-area program must include a general discussion about how rest areas will be built. Will they be constructed concurrently with other projects or combined with other state-operated facilities? If upgrading existing areas is required, how will that work be handled?

Analysis of these guidelines provides a sound basis for understanding the scope of the proposed rest-area program.

Program Funding

As administrators review a proposed development program, a major concern will be funding sources for the system. Therefore, a successful rest-area development program must include a discussion of funding sources. For Interstate rest areas, funding will generally be 90 percent federal dollars matched

Figure 1. Vanderbilt rest area on Interstate 75 in Michigan.

by 10 percent from the state. This will be the case both for new construction and for upgrading of existing projects.

A good program will help administrators determine the acceptability of specific funding sources for a proposed system. In some cases, especially for travel information facilities, funds other than Highway Trust Fund monies might be provided by other state or local agencies.

Development Budget

A good rest-area program should include a complete description of the development budget. The budget figures should be based on averages either from past experience or construction costs from other states. Since a program will be developed over several years, budget figures should include an inflation factor.

Budget figures might also include maintenance costs for operation of the rest areas. Since these costs are the responsibility of state transportation agencies, they are especially important when considering a rest-area system.

Development Timetable

In order to be effective, the development program should include a definite timetable for system completion. The timetable should include all projects and indicate a steady progression toward program completion.

Development Staffing

Staffing requirements necessary to complete a rest-area system should be identified. Staff requirements will be useful to administrators as they consider the value of proceeding with rest-area system development, especially if new professional specialties are required.

General Location

Once the initial facets of the program have been discussed, maps for each Interstate route should be used to show the probable locations for rest-area sites. These locations should be based on traffic flows and the rest-area needs as indicated by a system analysis process, which is a process that involves eatablishing rest-area needs based on the percentage of highway traffic likely to stop at regularly spaced intervals along a route.

Systems Analysis Process

A system analysis process was developed to eliminate the hit-and-miss method of identifying rest-area needs and locations. Many times rest areas were located based on someone's judgment that traffic on the highway at a given point would require a rest area. A more specific rationale was often not available.

In addition to anticipating rest-area needs as expressed by the number of parking spaces provided, systems analysis calculations also can be used to determine other design factors. Site features such as tables, waste receptacles, water and wastewater system sizing, and number of restroom facilities can be quantified. Any site feature that can be related to traffic volume can be calculated by the systems analysis process.

Several parameters govern the development of systems analysis results: existing and projected traffic volumes, annual usage survey data, recommended spacing interval, thorough inventory of existing rest areas, and determination of the maximum number of parking spaces to be provided at any single rest-area location.

1. Traffic volumes. Existing and projected traffic volumes used in systems analysis calculations can be obtained from state traffic forecasting offices. These are average daily traffic (ADT) volumes commonly projected for all highway-related planning. The existing and projected traffic volumes provide the basis from which future rest-area needs and site facilities are calculated.

2. Annual Usage Surveys. Usage surveys taken annually at selected rest-area locations can provide current design data and information required in the detail design of future rest areas. Annual surveys identify the current percentage of vehicles stopping at rest areas, persons per vehicle, vehicle distribution, traffic classification, and other important information.

Some form of usage survey has been conducted in several of the states interviewed. When surveys are taken, it is valuable to have rest-area designers involved. This is an excellent way for them to see how rest areas function. The on-site experience permits them to remain current in their design thinking.

3. Recommended spacing interval. In analyzing an Interstate highway for safety rest-area needs and location requirements, an 80-km (50-mile) spacing interval is recommended. This interval is approximately one hour's travel time at the national speed limit of 88 km/h (55 miles/h).

Spacing between rest-area locations should be adjusted to allow for unusually high or low traffic volumes. Spacing should also be adjusted for sites with unique features or scenic quality that would make quality rest areas. As a rule, however, an 80-km spacing interval will most often result in parking needs and rest-area developments that are manageable and will not exceed the capacity of the available site. Most states interviewed have adopted such a spacing interval.

4. Existing rest-area inventory. If the highway route being studied has been partly developed or is being reevaluated for upgrading, a thorough inventory of existing rest areas and related facilities must be made based on existing rest-area facilities versus construction of new facilities.

5. Maximum parking spaces. The final parameter is determining the maximum number of parking spaces desired at any single rest-area location. A decision on maximum parking spaces will dictate the minimum-sized site that can be acquired to prevent overuse. Designers should avoid large shopping-center-style parking lots in rest areas, because they concentrate activity and they are visually disturbing. To minimize traveler and environmental impacts on sites, a parking-to-site-size ratio should be developed that limits the total number of parking

spaces for a certain size site.

The systems analysis process involves developing a series of factors and reducing those factors to a formula that provides the number of vehicle parking spaces for each rest area. Some factors are constants, which normally will not vary from state to state. Other factors must be derived based on traffic and user conditions in each state. The process should be systematically applied to all highway routes in a state.

Along a route to be analyzed, the first requirement is to identify study segments that correspond to logical breaks in the route. These segments are called design section lengths (DSLs). The DSL is divided into a series of base section lengths (BSLs). The BSL is the desirable spacing interval for rest areas (i.e., 80 km).

For each DSL, both current and projected ADT and design hourly volume (DHV) figures must be developed. Normally, the projected ADT and DHV will be for a 20-year design period. When a DSL has several ADT and DHV figures along the route, they should be averaged to arrive at a single representative figure.

A ratio is then established between ADT and DHV. The resultant figure is the design hour (DH) factor (i.e., DHV/ADT = DH). Minnesota's factor, based on its experience, is 0.15.

The percentage of traffic expected to stop at a proposed rest area must be developed for each DSL. This percentage will vary from state to state and can also vary along a route. It is best if each state conducts rest-area usage surveys to determine this percentage for their routes. Minnesota uses a 12 percent stopping figure on its rural Interstate routes except for information centers. Once the percentage is identified, it must be adjusted by the ratio of DSL to BSL. This adjusted vehicles stopping percentage (P) is derived by the calculation:

P = percentage of mainline stopping X (DSL/BSL).

The percentage of traffic using the rest area must be broken down by vehicle type. This vehicle distribution is spread between car parking (Dc), truck parking (Dt), and an optional category, recreational parking (Dr). Truck and recreational vehicles can also be combined in one parking lot. This distribution varies from state to state and should be substantiated by usage surveys. Minnesota uses a distribution of 0.75 for cars and 0.25 for trucks and recreational vehicles combined in one lot.

Usage surveys also provide information on the average length of stay by travelers. This factor should be developed on a per-hour basis. It is expressed as vehicles per hour per parking space (VHS). Minnesota experiences 3 VHS for an average vehicle stay of 20 min.

In Minnesota it has been noted that rest-area use is much higher in the summer months. August is the busiest month, with almost one-quarter of all rest-area use recorded in that month. To compensate for this variable, a peak factor (PF) should be developed. The PF is derived by developing a ratio between the average number of people per day for the five summer months when traffic increases (May through September in Minnesota) to the average daily use for the year [i.e., PF = average daily use (5 summer months)/average daily use for year]. This PF becomes a constant used in the systems analysis calculations. In Minnesota, the factor is 1.8. Other states may have different peak months or none at all. The final decision must be based on the traffic in each state.

Systems Analysis Calculations

The calculation for parking spaces required at a rest-area site applies the variables and constant factors discussed in the previous paragraphs. The formulas for car (Nc) and truck (Nt) parking spaces are as follows:

$$Nc = (ADT \times P \times DH \times Dc \times PF)/VHS \quad (1)$$

$$Nt = (ADT \times P \times DH \times Dt \times PF)/VHS \quad (2)$$

If independent parking space calculations are required for recreational vehicles (Nr) in the DSL, the following formula would apply:

$$Nr = (ADT \times P \times DH \times Dr \times PF)/VHS \quad (3)$$

By using the factors that apply to Minnesota's situation, the formulas can be reduced to the following equations that use the variables DH = 0.15, VHS = 3, Dc = 0.75, Dt = 0.25, and PF = 1.8:

$$Nc = [(ADT \times P \times 0.15 \times 0.75 \times 1.8)/3] = ADT \times P \times 0.067 \quad (4)$$

$$Nt = [(ADT \times P \times 0.15 \times 0.25 \times 1.8)/3] = ADT \times P \times 0.023 \quad (5)$$

The systems analysis process can be used to analyze a specific portion of a route or the entire length of a highway.

The systems analysis is the final ingredient in the rest-area planning process. It provides the justification for rest-area recommendations made in the development program.

SAFETY REST-AREA LOCATION

The discussion on the planning phase indicated that designer judgment was important in creating a successful safety rest-area program. The location phase requires these same judgments. There are no hard and fast rules that dictate how a designer locates rest-area sites.

In interviewing states for the training manual, we found that each one developed a location procedure that fit its system. The degree of refinement in the procedure was partly dependent on the amount of public involvement required to locate sites. The location process offers the state a good opportunity to develop a positive public response toward its transportation agency. However, we did find certain procedures that were commonly used and are recommended for states that are starting a rest-area system. This common location procedure begins with development of site-selection criteria. These criteria must be developed to fit each state's operation and development requirements.

Site-Selection Criteria

Site-selection criteria cover six major areas. The first and most important criterion should be an emphasis on selecting the best-quality site available. Quality sites provide the designer with a clear advantage when developing a rest area, especially if budgets are limited.

The definition of a quality site varies around the country. It might be wooded or have rolling topography or even have a water feature or interesting view. Some sites might include historical or cultural features. For some states, a quality site might be a clearing in a dense mass of trees. In any case, by selecting the best available site, a better quality rest area will result because the qualities of the site will enhance all parts of the design.

The second criterion, emphasized by many states, is the importance of having certain utilities available. The ability to obtain potable water and dispose of wastewater will determine if a rest area can be developed at a site. In sparsely settled states, the availability of electricity and phone service is also a factor.

The third criterion, spacing between potential rest-area sites, is also important. The systems analysis process used a BSL of 80 km (50 miles). However, in reality, spacings of 56 km (35 miles) to 96 km (65 miles) can be used in order to take advantage of all available sites. Consideration of a range of spacing distances should be exercised in conjunction with selecting the highest-quality site available. Since the best sites are never evenly spaced, the designer must exercise judgment so that the advantages of sites are compared against potential problems with spacing that is not 80 km.

A fourth criterion emphasizes that the designer should identify all significant rest-area sites for study, regardless of potential geometric design problems. Often a potential site will be rejected very early in the process because a conventional geometric alignment solution will not fit the site. However, because geometric alignments that involve sharper curves or more complex traffic movement can be applied so that special sites can be used (such as the rest area shown in Figure 2), these sites should continue to be analyzed until all alternatives have been exhausted. A potential site must also be compatible with the adjacent highway alignment. Such factors as sight distance, horizontal and vertical curves, and distances between interchange and rest-area ramps must be considered. The rest-area alignment must relate smoothly to the mainline geometrics to avoid dangerous vehicle transitions.

The impact of rest-area development on the natural surroundings of a potential site must also be carefully considered. Identifying an acceptable impact is the fifth selection criterion. The designer must anticipate the effect of construction on each potential site and determine if it is manageable of if adverse environmental impacts can be mitigated during construction.

The final selection criterion suggests that states consider the availability of land-locked or vacant parcels of right-of-way when locating potential sites. Normally this type of parcel is easier to acquire. In some states, however, rest areas cannot be acquired through eminent domain proceedings, so sites must be purchased from willing landowners. The positive public reaction that can develop when dealing with landowners willing to sell property should not be overlooked.

These criteria serve only as a catalyst in selecting rest-area sites. The process should also include locating and using the best possible base maps available. Topographic maps or high resolution aerial photographs should be used to study the highway routes along which rest areas are to be located.

All potential rest-area sites should be plotted on the base mapping prior to making field reviews. It is essential that the designer visit each site to evaluate its potential, preferably several times. In order to establish consistency, a site-reconnaisance form should be used to reduce the potential sites to those selected for development. This process involves many compromises and trade-offs, especially when many sites are available. Eventually, final sites are selected when the designer identifies one determinant that takes precedence in the evaluation process.

Figure 2. Unusual geometric solution for Funks Grove rest area on Interstate 55 in Illinois.

Preliminary Design Process

Once sites are selected, the manual suggests that these selections be substantiated by a preliminary design process. This process involves a series of studies that result in a design concept in the form of a concept plan for each site that fits that site and is geometrically workable.

Environmental documentation required for rest-area construction will vary significantly from state to state. A well-rendered concept plan is the best means available of conveying the design development to the public, both at meetings and in environmental impact statements and project design reports. The four steps in the preliminary design process are briefly noted here.

Site Analysis

The site analysis is a graphic evaluation of the site's "feel" and its potential for development. Site features that should be incorporated as part of the rest area or that affect the design are identified. Drainage patterns, slopes, vegetation cover, views, and scenic qualities should be graphically identified on the drawing.

Relationship Diagram

The relationship diagram builds on the information identified in the site analysis. It represents the functional relations of design components that make up a rest area, shown in diagrammatic form. These components include

1. Parking lots for cars, trucks, and recreational vehicles;
2. Buildings, including restroom buildings, picnic shelters, and maintenance-related structures such as storage or wastewater treatment buildings;
3. A major use area, including most picnic tables and shelters, childrens' play area, and walkways; and
4. Secondary use areas that extend some distance from parking lots and often include special points of interest such as overlooks, interpretive areas, and other features.

Alignment Study

Once the functional relations have been resolved to

Figure 3. Two common rest area relationship diagrams.

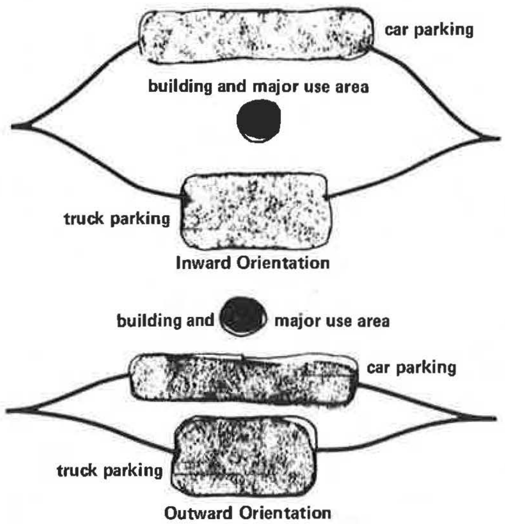

Figure 4. Goose Creek rest area on Interstate 35 in Minnesota.

the satisfaction of the designer, a workable geometric alignment must be developed. Accurate horizontal and vertical alignments, based on earlier quick studies, should be prepared. Figure 3 shows the relationship diagrams of two of the most common geometric designs for rest areas.

By using the inward-oriented plan, the building and major use areas are located among the car, truck, and recreational vehicle parking lots. This concept permits easy access to all features within the major use areas from the parking lots. For this plan to be effective, the area within the parking lots must be large enough to avoid concentrated activity that destroys grass and vegetation and leads to overuse of the site. Overuse results in long-term maintenance problems.

By using the outward-oriented plan, the building and major use areas are located beyond the parking lots that are adjacent to one another. This plan avoids concentrated activity and permits larger, more unrestricted use areas. The design permits development flexibility and is particularly suited to sites with variable topography.

Design Concept Plan

A graphic representation of the rest-area design (the design concept plan) should be prepared to show the workability of the concept. This plan, drawn to scale, shows the actual locations for proposed facilities and identifies the specific features that should be provided at the rest area. The concept plan should be used as the basic tool to explain the purpose for and the effect of the rest area on its surroundings.

SAFETY REST-AREA DESIGN

The design development of rest areas involves many different steps. Each state visited had different steps for assembling construction plan packages and constructing rest areas. The manual thoroughly identifies detail design procedures that should be used by states that develop rest-area systems.

The major emphasis in this section is that good design procedures must take advantage of the features on the site. The ability of the designer to resolve many design questions and blend diverse site elements together will determine how well a rest area serves the traveling public. The designer should be permitted to carefully consider all appropriate detail design elements for a site and should have considerable latitude in construction techniques, materials, and budgets.

States with successful programs allow the rest-area designer to participate in all phases of rest-area development, from site selection to construction advice. Active participation leads to better understanding of rest-area operations, which leads to better design solutions.

Designers have a difficult time remaining familiar with new rest-area service facilities being provided around the country. A goal for the design chapter was to provide a review of current rest-area facility state of the art. Necessary facilities that should be provided in Interstate rest areas are discussed. Examples from several states illustrate these facilities.

Rest areas must provide a complete range of facilities to operate successfully. Careful design placement of these facilities, incorporating them into a quality site, is the major thrust of a successful program.

The first important rest-area design step should be to preserve or enhance what is already there. The final roadway alignment should approach the building location in a way that will clearly show the organization of the area and create a positive visual impression. The grading of the entire site should further enhance those views and build on the existing topography. Large cuts and fills, severe slopes, and other intrusions should be avoided. Drainage in parking areas and around buildings should be controlled by curbs and drainage structures. This design approach avoids carving up sites with drainage channels that destroy natural topography and restrict pedestrian movements. All detail design efforts should be geared to improve the appearance and function of the rest area and blend it into the existing site.

Rest-area buildings should be designed to be compatible with other features of the site design and should be properly sized to meet traffic needs (see Figure 4). Rest areas are playing an increasingly significant role in tourism. There should be provision for tourism-related displays in the building and around the site. The building design and choice of materials should include materials that are durable and easily maintained so that they present a positive image to travelers and reflect concern against vandalism. The building and materials selection should be compatible with natural site features and should include energy-conserving design features, such as earth sheltering or solar systems. They must also meet federal accessibility requirements for the handicapped.

Where appropriate, the building and site should be enhanced with special design features. These might include wood decks, terraces, and historical and geologic displays. Special features add interest and can serve as an extension of the building. Overlooks or interpretive areas take advantage of natural features of a site and can enhance the tourism potential of the area.

Site furniture is an important design element in rest areas. Picnic tables should be durable, comfortable, and well designed. Benches and waste receptacles should be attractively designed yet function efficiently. For example, barrels are not appropriate as waste receptacles because they are unsightly and function poorly. Benches that are built into other elements such as retaining walls or decks are encouraged. Drinking fountains and aesthetically pleasing information signs should also be provided. Wood signs with messages regarding use of the site are a good signing system.

Childrens' play areas that incorporate a simple play structure with a sand cushion beneath it are an important safety feature in a rest area. Walkways that encourage travelers to explore a site and stay away from their cars several moments longer will result in more-rested travelers. It is important that both adults and children be relaxed and refreshed before returning to the highway. States with these types of facilities report nothing but positive comments from travelers when rest-area usage surveys are taken.

Lighting plans should be carefully designed to provide varying illumination levels. Entry ramps and parking lots should have higher poles to broadly light these areas for safety. Areas along the entry walks and car parking lots can have lower mounting heights to provide a feeling of security. There should be enough light in the rest area so that it looks open and safe. Designers should select light poles and luminaires from one manufacturer for visual continuity. Careful selection of materials, furniture, and site elements enhances the architectural quality and consistency of the rest-area design.

Where tourist-related displays are developed, they should be integrated into the rest-area design. If covered displays are developed, materials and roof design should match those of other structures. These displays should be located so they fit the flow of pedestrians within the site.

FHWA has recognized the significant effect that properly designed wastewater disposal and water supply systems have on safety rest area success. These topics were of such importance to the development of rest-area programs that separate training manuals were prepared for each one [e.g., Wastewater Treatment Systems for Safety Rest Areas (2) and Manual for Safety Rest Area Water Supply Systems (3)].

The design process should also include preparation of site management plans that identify how the rest area should be managed once it opens. This attention to rest-area management and operation keeps the designer in touch with the rest-area system. Management tasks include building management, mowing and turf management, irrigation, fertilization, and vegetation maintenance. These plans should be formulated for a one-to-five-year period. They serve as the designer's final link between the initial concepts that motivated the original design and the operation and management of the rest area.

The overriding focus of the training manual and course we prepared is that rest areas are an essential part of the highway system. They promote safe travel and can be used to enhance state tourism programs. In order to be effective, safety rest areas must be designed with care and sensitivity to many factors. Quality rest-area sites and careful, thorough design procedures will result in successful safety rest-area systems that meet the needs of the traveling public.

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We wish to acknowledge the efforts of many individuals who helped in the preparation of our design manual. The manual was prepared for the Office of Research and Development, FHWA. Robert D. Thomas of that office was coordinator for preparation of the manual and his work, as well as that of his steering committee, was appreciated.

The rest-area design staffs of nine states were interviewed for information on development and design of their rest-area systems. This information was very valuable in preparing the manual. The states interviewed included Virginia, North Carolina, Texas, Illinois, Nebraska, California, Arizona, Washington, and Michigan. Much of the material in the manual was developed through the experiences of MnDOT since 1967. MnDOT procedures were found to parallel the procedures of other states with successful programs.

REFERENCES

1. Safety Rest Areas: Planning, Location, and Design. Training Manual, FHWA, U.S. Department of Transportation, 1980.
2. Wastewater Treatment Systems for Safety Rest Areas. FHWA, U.S. Department of Transportation, Rept. FHWA-RD-77-107, 1977.
3. Manual for Safety Rest Area Water Supply Systems. FHWA, U.S. Department of Transportation, Rept. FHWA-RD-77-113, 1977.

On-Site Land Treatment Systems for Freeway Rest Areas

A.E. ERICKSON, M.L. DAVIS, R.T. SPRAGUE, D.P. BRATT, AND W.A. RUECKERT

This study evaluates the effectiveness of existing on-site sewage treatment systems used at freeway rest areas in Michigan. It also evaluates the effectiveness of land-treatment systems designed to polish and dispose of the partially treated effluents from septic tanks and lagoons. The selection of the proper system or combination of systems to match the physical constraints of a particular site can ensure quality effluents and dispose of them so that they will not harm the environment. Tile drain field, seepage pits, seepage beds, sand filters, overland flow evapotranspiration systems, and a modified barriered landscape water renovation system were studied. The parameters measured included total coliforms, fecal coliforms, total streptococci, fecal streptococci, biological oxygen demand, total organic carbon, total phosphorus, inorganic phosphate phosphorus, total Kjeldahl nitrogen, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, and suspended solids.

The easiest solution to sewage treatment at freeway rest areas is to use nearby sanitary sewers, if available. However, because of the remoteness of most rest areas, this is not always an option, and a method of treating sewage and disposing of the wastewater must be developed on-site. In Michigan, the most common methods of primary sewage treatment at rest areas have been with septic tanks or lagoons. Disposal of wastewater has usually been to surface waters or to groundwaters through tile drain fields.

Environmental concerns and the Clean Water Act of 1972 (and its more restrictive effluent discharge standards) prompted this research between the Michigan Department of Transportation and Michigan State University. The purpose was to evaluate the effectiveness of existing on-site systems and to design and evaluate land-treatment systems that would polish and dispose of effluents.

Septic tank systems have been used when a continuous discharge can be tolerated, i.e., to a drain field. Lagoon systems have been used when a continuous discharge is not possible and where there are enough space and suitable soil conditions for lagoon construction. Land-treatment systems for polishing and disposing of these effluents have been designed to fit the site, taking into account conditions of soil, landscape, depth to water table, and land availability.

The various systems that have been developed and tested are discussed. Each system has been evaluated by sampling the wastewater before, during, and after treatment; sampling the soil at various depths; and sampling the water tables on, adjacent to, and at a distance from the treatment facility. Water samples were analyzed for total coliforms, fecal coliforms, total streptococci, fecal streptococci, biological oxygen demand (BOD), total organic carbon (TOC), total phosphorus (TP), inorganic phosphate phosphorus, (i-PO_4), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), and suspended solids (SS) according to methods in U.S. Environmental Protection Agency manuals (1,2).

SEPTIC TANK-TILE FIELDS

The best septic tank-tile field design provides for a three-compartment septic tank that leads to a distribution box that in turn can feed into any of four separate tile fields. Each field is capable of supporting the entire sanitary requirements of the rest area. This design allows good flexibility in managing the system because it permits the complete rest of three fields while one is being used. Furthermore, the operator can open two fields should very high use be expected in special situations, such as a holiday weekend.

The multiple-field design has been used for the last 10 years in Michigan freeway rest areas and to date no system has failed hydraulically. One of these systems was evaluated for nutrient leakage for a period of two years. The soils on this site are loam texture with a water table at 25-30 ft. Wells for water sampling were placed adjacent to and on all sides of the drain field and at distances from the field.

It was found that i-PO_4, TKN, NH_4-N, and fecal coliforms do not appear in the water table; however, NO_3-N is found in the water table adjacent to the drain field in an average concentration of 25 parts per million (ppm). The concentration of NO_3-N varies in the well samples with the lowest well averaging 3.1 ppm and the highest averaging 66 ppm. This system, which could be considered conventional, failed with regard to NO_3-N removal, although the NO_3-N was rapidly diluted as it moved through the aquifer.

Septic Tank-Leaching Pits

The septic tank-leaching pits system consisted of a septic tank that had several leaching pits located at a site with variable soils, made up of granular pockets in fine-textured soils in association with rugged terrain, and a deep water table. Except for the failures of three leaching pits, located incorrectly in the adjacent clay soils rather than in the granular pockets, the system worked satisfactorily. The long, tortuous path to a water table at a depth of 80 ft appeared to polish the effluent as no nutrient leakage was found in the sampling wells.

Septic Tank-Sand Filter-Overland Flow Evapotranspiration

The septic tank-sand filter-overland flow evapotranspiration system was in a rest area that was located on a poorly drained clay loam soil with a high water table that would not allow the use of a conventional drain field. Treatment was with a septic tank because of space limitations. The effluent was pumped into an elevated sand filter that had tile drains at the base. A schematic cross section of this sand filter is shown in Figure 1. Intensive use of this facility during the summer season caused the overloading of the system with a breakthrough of nitrogen (N), phosphorus (P), and coliforms.

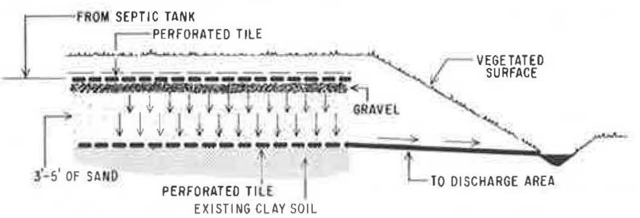
An overland flow evapotranspiration (OF-ET) system was designed as an alternate system for summer use. The OF-ET was placed in the median between the traffic lanes because the rest-area property could not be expanded. It was 20 ft wide and 1600 ft long with a uniform slope of 0.3 percent. Reed canary grass, *Phalaris arundinacea*, was planted on the OF-ET. The septic tank effluent, which had a very short retention time during the summer, was collected in a 1000-gal tank that was continuously ozonated to oxidize the volatile organics and to control odors. Thousand-gallon batches of ozonated effluent were pumped to the control structure at the top of the OF-ET. The adjustable notched weir on the control structure distributed the wastewater across the OF-ET. The grass grew well and produced a tortuous path for the shallow flow of effluent. The ozonation and aerated flow on the OF-ET controlled any potential odor problem.

The system was operated and studied for two months at an average loading of 5000-6000 gal/day, which was equivalent to 0.25 in over the whole OF-ET area. There were peak days in the operation when 12 000-15 000 gal/day were applied with no problems.

Measurements of the changes in quality of the wastewater as it moved down the OF-ET showed that all of the parameters except NO_3-N were greatly reduced when the effluent had flowed 400 ft. The NO_3-N concentration peaked at 30 ppm at this distance but declined beyond this point as the grass and denitrification at the soil surface removed NO_3-N from the system. The table below shows the efficiency of both the sand filter and OF-ET in reducing pollutants from septic tank effluent:

		OF-ET (%)	
Pollutant	Sand Filter (%)	200 ft	800 ft
BOD	87	62	91
TP	70	75	89
Total nitrogen (TN)	28	55	98
SS	83		62
Fecal coliforms	99		99

Figure 1. Sand filter section above a clay soil.



The sand filter reduced TN by only 28 percent and TP by 70 percent, while the OF-ET did better than this at 200 ft. At 800 ft on the OF-ET, BOD was reduced by 91 percent, TP by 89 percent, and TN by 98 percent.

Most of the time the wastewater infiltrated the soil or was evapotranspirated so that it never reached the outfall at 1600 ft. During three heavy rains there was some outfall from the system, but only on one occasion was there enough to measure at the weir. This outfall amounted to 1700 gal, or one-third of one day's application, and had at least a 95 percent reduction in all parameters.

These two polishing treatment systems complement each other. During the winter season, when the sewage loading was low, the septic tank effluent was of better quality and the sand filter satisfactorily polished the effluent. During the summer season, when the bulk of the sewage was produced, the OF-ET did an excellent polishing of the poorly treated effluent with little discharge except during heavy rainfall.

LAGOON SYSTEMS

Lagoons have an advantage over septic tanks in that they also provide for storage during the winter season when land-treatment systems do not operate well. Recently constructed lagoons in Michigan are three-cell systems that have less than the recommended maximum of 20 lb/BOD per acre per year. They have the full flexibility of moving the wastewater to any cell and can be operated either in parallel or in series. Lagoon effluent is usually polished by an on-site land-treatment system with eventual discharge to the water table.

Lagoon-Seepage Beds

The lagoon-seepage bed system that was studied consisted of a three-celled lagoon system that discharged into seepage beds on a level, slowly permeable clay loam soil that had a high water table. The water table fluctuates from the surface in the spring to 5 or 6 ft deep in a dry summer. This area had adequate space so that the seepage beds could be constructed at the rest area. The seepage beds were designed so that the release of effluent from one of the lagoons would add between 1 and 1.5 ft of wastewater to the beds. This provided good aeration during the seepage process that proceeded at a rate of 0.5-0.6 in/day.

Sampling wells that reached the shallow water table were placed around the seepage beds and at a distance from them for control samples. Water from these wells was sampled throughout a two-year period with more frequent sampling during discharge. There were seasonal changes in NO_3-N in all of the wells, but the wells adjacent to the seepage lagoons were never different than the control wells.

These lightly loaded seepage beds filtered the organic matter and microbes, absorbed the phosphate, and converted the TN to NO_3-N. The NO_3-N was denitrified in the anaerobic zone just below the flooded soil surface of the seepage bed. Because the beds were used only once or twice a year, there was ample time for rejuvenation of the soil and vegetation before recharge. As long as these beds were used during the warm part of the year, when the natural water table was several feet below the surface, this system performed well.

Lagoon-Overload Flow Evapotranspiration

The lagoon OF-ET system was on one of the busiest information centers in the state. It was situated in the median with ample land but with an uneven landscape and variable soils, some of which have high water tables. The sewage was given primary treatment in two lagoons. An OF-ET was constructed on a 4-acre field that had soil with 1-3 ft of sand over clay and a slope of 4 percent. Figure 2 is a sketch of this OF-ET. The OF-ET had a 23 000-gal chlorination tank at the top. The chlorinated lagoon effluent was distributed across the top of the OF-ET by using perforated flexible plastic drain tile. Six level ditches were plowed across the existing slope to reduce channeling and to keep the water evenly distributed as it moved down the slope. Reed canary grass was planted over the original wild grasses.

Operation of the system during the eight-month open season involved operating the lagoons in series, pumping 23 000 gal of effluent from the second lagoon up to the chlorination tank for overnight chlorination, and allowing the chlorinated wastewater to discharge by gravity over the OF-ET system for a 6-h period. The system was usually operated five days per week but could be operated more intensively. Depending on the amount of rainfall, 10-20 percent of the added wastewater ran off the OF-ET and accumulated in the south catchments for recirculation.

Water from the ditches, catchments, shallow wells that reached into the perched water table on the OF-ET, and perimeter wells that reached the water table were sampled intensively for three months during one summer and analyzed twice a week. The data are summarized in the table below:

Pollutant	Concentration (ppm)	Reduction (%)
BOD	2.5	96
TOC	32.7	48
i-PO_4	0.09	97
TKN	1.9	97
NH_4-N	0.12	99
NO_3-N	0.45	0
TN	2.35	94
Water		87

The concentrations of all pollutants leaving the OF-ET were very low and the percentage reductions in BOD, i-PO_4, and TN were 96, 97, and 94 percent, respectively. Only TOC stayed at one-half its original concentration, but probably was this high because of the contribution of organic carbon from the dense grass cover. Nitrate-N remained at a constant of about 0.5 ppm, which was probably the limit that the grass could extract under these conditions. Microbiological studies showed that the lagoon and chlorination had effectively killed those microbes associated with human feces. Any fecal coliform populations in the OF-ET effluent were attributed to wildlife.

For this system to ensure complete evapotranspiration of the effluent, it should be 50 percent larger. However, the quality of the outfall exceeded any reasonable standards.

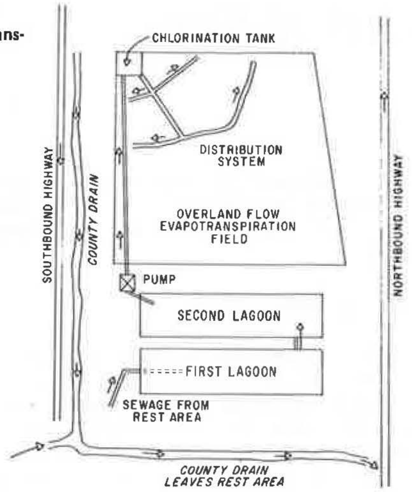


Figure 2. Plan view of overland flow evaportranspiration system.

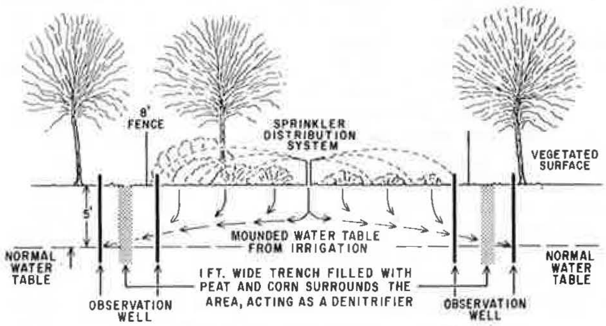


Figure 3. Modified BLWRS that uses a shallow water table as the barrier.

Lagoon-Modified Barriered Landscape Water Renovation System

The next information center has a two-lagoon system on a sandy loam soil with a water table 3-6 ft below the surface, depending on the season. In order to eliminate the discharge of the lagoons into a ditch that led to a river, a modified barriered landscape water renovation system (BLWRS) (3,4) was constructed in the highway median that used the natural water table as the barrier for the system.

The BLWRS is an efficient land-treatment system that uses all the properties of an aerated soil to decompose organics, nitrify N to NO_3, and absorb P. In addition, there is a barrier 4-6 ft below the surface to intercept the water, create an anaerobic environment, and direct the anaerobic water through a trench into which organic matter is placed. In this environment, the denitrifying bacteria will denitrify the NO_3 to nitrogen gas (N_2) and in this way remove N from the wastewater. The modified BLWRS is shown in Figure 3. The natural water table acts as the barrier to direct the anaerobic water through the peat-filled trench as it moves away.

In the operation of the system, lagoon effluent is taken from the second lagoon. The effluent is ozonated continuously in a 12 000-gal holding tank to reduce the odors. The ozonated effluent is spread on the two-third acre BLWRS with low-angle sprinklers operated at low pressure so as not to produce any aerosols. The spraying required 6-8 h.

Wells on and off the BLWRS were used to obtain water samples from the top of the aquifer for analysis. Soil samples from the BLWRS were also analyzed to monitor the movement of pollutants through the system. After 10 weeks of spraying during the summer of 1979, there was no change in the carbon (C), N, P, and microbiological parameters measured in well waters from wells adjacent to or at a distance from the BLWRS. All indications were that the system was operating as designed.

CONCLUSIONS

The wide range of conditions at the various freeway rest areas in Michigan required a variety of on-site treatment systems. Various land-treatment systems have proved useful in treating, polishing, and disposing of wastewaters in some cases. The selection of the proper system or combination of systems to match the physical constraints of a particular site can ensure quality effluents and dispose of them so that they will not harm the environment.

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REFERENCES

1. Methods for Chemical Analysis of Water and Waste. Office of Technology Transfer, U.S. Environmental Protection Agency, EPA-625/6-74-003, 1974.
2. Microbial Methods for Monitoring the Environment. Office of Research and Development, U.S. Environmental Protection Agency, EPA-600/8-78-017, 1978.
3. A.E. Erickson, J.M. Tiedje, B.G. Ellis, and C.M. Hansen. A Barriered Landscape Water Renovation System for Removing Phosphate and Nitrogen from Liquid Feedlot Waste. Proc., International Livestock Waste Conference, Columbus, Ohio, American Society of Agricultural Engineers, St. Joseph, MI, 1971, pp. 232-234.
4. A.E. Erickson, B.G. Ellis, J.M. Tiedje, A.R. Wolcott, C.M. Hansen, F.R. Peabody, E.C. Miller, and J.W. Thomas. Soil Modification for Denitrification and Phosphate Reduction of Feedlot Waste. U.S. Environmental Protection Agency, EPA-660/2-74-057, 1974.

Use of Prairie Vegetation on Disturbed Sites

DARREL G. MORRISON

Interest and activity in the use of native prairie vegetation on disturbed sites have increased in the past decade. The primary objective in this paper is to summarize and document the observations and experiences of researchers who have studied prairies, prairie vegetation, and prairie-restoration techniques. Particular emphasis is placed on design and implementation techniques that might be applied in the design and establishment of prairie vegetation on relatively large land areas, such as those associated with transportation rights-of-way. Quantitative and qualitative analyses of natural prairie stands as models for prairie plantings on disturbed sites are presented (e.g., species density, plant distribution patterns, and resulting aesthetic effects). Design implications for prairie restorations are drawn from these observations. An example of a sizable prairie-restoration project on a construction site is presented. Its success after six growing seasons is evaluated relative to the original design objectives of developing a prairielike vegetational cover on a corporation headquarters site with a low maintenance requirement. It is assessed in terms of prairie species presence and distribution, presence of exotic species, and visual similarity to natural prairie stands.

This paper explores the use of native prairie vegetation on land disturbed by construction activity, with implications for applying information gained from past work to other situations. Such work is identified as "prairie restoration" in this paper. Technically, prairie restoration is the reestablishment of the prairie ecosystem to sites that once supported such a system, but from which all or nearly all of the original vegetation has been removed through a series of disturbances or manipulative actions over time, such as those associated with agriculturization and urbanization. It is unrealistic, however, to expect that a complex ecosystem can be totally reinstated on sites that have been dramatically altered. Hence, in practice and in this paper, prairie restoration refers to the establishment of native prairie plant species to disturbed sites that can reasonably be expected to support them, whether or not the sites were covered originally by prairie vegetation. Such plantings will almost always be simplifications in that there will initially be fewer species than in a natural prairie; however, the goal is usually to achieve the outward appearance of true prairie within 5-10 years.

The concept of using native prairie species in the designed landscape is increasingly mentioned as an alternative to mowed lawns for a variety of ecological, educational, and aesthetic reasons (1). In the recent past, potential or real shortages of fuel, fertilizer, and water have provided additional impetus for considering vegetation that is functionally and aesthetically acceptable without requiring mowing and without inputs of supplemental fertilizer and water. These considerations become particularly important to corporations or public agencies with large land areas to maintain (2).

In this paper, I first relate the current attention being given to prairie plantings in its historical context, with a brief summary of the use of native prairie vegetation in designed landscapes and the development of a body of knowledge to help prairie restorationists. Next, some of the research findings that relate to the design and establishment of prairie plantings, as well as observations made in actual prairie-restoration projects (with emphasis on findings that seem most applicable to moderately large acreages, such as those associated with transportation corridors), are summarized and synthesized. Finally, an example of a prairie-restoration project on a construction site is described. The design and implementation of an 80-acre planting on the General Electric Medical Systems site near Waukesha, Wisconsin, are assessed as to its success in terms of species composition, distribution patterns, and visual character after six growing seasons.

HISTORICAL PERSPECTIVE

Although the conscious planting of prairielike combinations of native species in the designed landscape is considered to be a new direction, there are precedents for this approach in the history of American landscape architecture. Probably the most notable proponent of the use of native plant species in the designed landscape was Jens Jensen, a Danish-born landscape architect who worked in the Chicago Park System and throughout much of the Midwest from the mid-1880s to the 1940s (3). In 1888 he designed and planted the American Garden in a corner of Chicago's Washington Park, which was a collection of native wildflowers that he had dug up and brought in from the country. The garden gained immediate popularity with park visitors who recognized the plants as species that were being lost as the city expanded.

Although Jensen's first avowed native garden in Washington Park was small in size, it was followed by many works later in his career that were much larger in size and impact, which demonstrated the design potential of a group of plant species that had previously been rejected by most landscape architects and horticulturists as being too coarse for landscape use. Among these projects were Jensen's prairie rivers in Humboldt Park and Columbus Park in Chicago. Both of these rivers were curving lagoons bordered by plantings of wetland and prairie species with large open-mowed meadows adjacent to them. The borders were planted with native Illinois prairie grasses and flowers, along with cattails, reeds, and other wetland plants. They were symbolic representations of the prairie, which suggested the power and movement of the native tallgrass prairie, but the land area devoted to them was quite limited.

Wilhelm Miller (4) of the University of Illinois promoted the prairie style of landscape gardening in a publication with that title in 1915, which suggested that Jensen and a small corps of other Chicago-area landscape architects were developing a regional style of landscape design, parallel with the Prairie School of architects, epitomized by Louis Sullivan and Frank Lloyd Wright. Miller's treatise went on to propose preservation of at least one 1000-acre prairie park in each of the prairie states and restoration of 2- to 5-acre prairies in the city parks of Illinois. He provided lists of woody and herbaceous plants appropriate for different types of states, but did not suggest relative proportions or techniques for implementing the proposed restorations.

In 1929, a book entitled American Plants for American Gardens (5), written by Edith A. Roberts, a plant ecologist, and Elsa Rehmann, a landscape architect, promoted the use of native plants in groupings based on natural plant communities. This collaborative work provided underlying ecological concepts as well as recommended lists of predominantly native plant species for use in landscape design. The geographic area covered in the book is the northeastern United States, and it includes discussion of the open field association. The list of plant species for use in the open field includes a number of naturalized Eurasian species as well as true native vegetation of open, sunlit areas. The authors do not purport to provide propagation or establishment information in their book.

There is little evidence that the ideas espoused by Jensen, Miller, or Roberts and Rehmann were widely accepted or adopted by other landscape architects during the 1930s and 1940s. However, valuable work in studying prairies and techniques for prairie restoration was being done by plant ecologists during this period. Foremost among these researchers in Wisconsin were John T. Curtis and Henry C. Greene of the University of Wisconsin Botany Department. They began their first attempts at reestablishment of the prairie in 1935. By 1950, the two reported that it had become abundantly clear that such restoration could be successful (6). They began their work, logically enough, with studies of as many remnant prairies as they could find, listing species most commonly found on wet, mesic, and dry prairies in the region, along with their average numbers per acre (7). The two prairie restorations that they established in the University Arboretum, each about 40 acres in size, now bear their names. Their original notes and publications, as well as subsequent studies of the two restoration sites, continue to provide valuable information to landscape restorationists and managers.

Somewhat farther west, but still in the tallgrass prairie region, John E. Weaver, a plant ecology professor at the University of Nebraska, studied prairies, prairie vegetation, and their dynamics for half a century beginning in 1916. His own work and that of his students are well documented (8,9) and provide substantial insight into the natural models on which restorationists can draw.

After 1960 a number of other ecologists and naturalists began to use the knowledge generated by Weaver, Curtis, and Greene to reestablish small plots of prairie vegetation and experiment with new techniques. One example of such a project is the prairie planting at the Morton Arboretum at Lisle, Illinois, executed under the direction of Ray Schulenberg. For much of the original prairie restoration at this site, seed was hand collected from local remnants, germinated in flats in the greenhouse, transplanted to the field site, and hand weeded for the first several growing seasons.

However, not until the last decade has the landscape architecture profession again considered the reestablishment of prairielike plantings as a viable alternative to standard lawns and woody ornamental plantings seen throughout most of the country's cities and suburbs. Evidence of a degree of acceptance of this alternative occurred with the publication in October 1975 of a special issue of Landscape Architecture, the official journal of the American Society of Landscape Architects, entitled The Search for a Native Landscape, which included two articles with strong prairie orientation (10,11).

Meanwhile, a series of biennial prairie conferences has been held in the states of the tallgrass prairies, which began in 1968 with the First Midwest Prairie Conference at Knox College, Galesburg, Illinois. Broadening into the North American Prairie Conferences, these meetings bring together a mix of scientists, landscape architects, and interested lay people to hear wide-ranging papers, such as detailed studies of prairie ecosystems, which include various strategies and techniques for preservation, management, rehabilitation, and restoration of prairie vegetation in a variety of settings. The proceedings from the various conferences provide a wealth of specific research results and personal observations of value to present restorationists (12-16).

In summary, there has been a thread of interest in native prairie restoration in the designed landscape during much of the past century, although early proponents' concepts were not widely accepted or adopted. A body of knowledge based on restoration experience has been developing since the 1930s, primarily through the efforts of botanists such as Curtis and Greene. In the last decade, landscape architects have begun to merge this knowledge with their own aesthetic judgments by using prairie vegetation in designed landscapes ranging from residential (17) to industrial sites (2).

DESIGN AND ESTABLISHMENT OF PRAIRIE VEGETATION

Although prairie-restoration efforts have increased markedly during the last decade, there is not, and indeed there cannot be, a single recipe for the design and implementation of a successful prairie planting. First, goals and objectives vary with different projects. Some may be educationally oriented, with a primary goal of introducing people to a large number of native species. Some may be functionally oriented, with a primary goal of controlling erosion and runoff. Some may be aesthetically oriented, with a primary goal of recreating the visual essence of a prairie with tall grasses waving in the wind, interspersed with contrasting colors and textures of prairie forbs. Whatever the goal, however, the likelihood of attaining it is enhanced by a basic understanding of natural prairies, their structure, and their composition.

Another factor that precludes development of a formula for prairie restoration is the fact that widely varying individual site characteristics and growing conditions make it difficult or hazardous to generalize. Nevertheless, each new project that is carried out can provide new information that may be of use in subsequent work as long as the local conditions and multiple variables are considered.

Following, then, is a compilation of research findings of ecologists, as well as observations by myself and others, who have studied prairies or worked with the restoration of prairie vegetation. Taken together, this research provides some basic guidelines in (a) natural prairie composition and (b) restoration techniques appropriate to different settings.

Emphasis will be on design considerations and implementation techniques for relatively large plantings, i.e., 5-100 acres, with the goal of achieving the visual character of natural prairie within five years, more or less. This assumes a less-than-complete ecosystem restoration, with all the species diversity and complex interactions implied by that, but it does suggest a vegetational cover that includes a variety of dominant species that occur in naturally evolved prairies with macrodistribution patterns similar to those of natural prairies.

In designing a prairie planting, there are two major considerations. First, there are species selection and determination of relative proportions of species. Second, there is the placement or distribution of species relative to each other and to the varied microenvironments that may occur on the site. The logical place to begin to determine appropriate species composition and distribution for restoration is from the natural stands that have been studied.

Species Selection

One of the initial questions to explore relates to the number of species typically growing in natural prairie stands. Curtis (18) studied species density in stands of different prairie types based on soil moisture and determined species density (average number of species per stand) as shown in the table below:

Prairie Type	Species Density	No. of Stands
Dry	47	17
Dry-mesic	55	66
Mesic	55	45
Wet-mesic	62	31
Wet	44	22

A species density range of 40-70 species/acre in relic prairies in Illinois further suggests that the typical number of species in small areas is not excessive (19).

Studies in Wisconsin dry lime prairies, reported by Curtis, indicate that 10 species constitute the great majority of the flora. From this, we can interpret that a prairie planting within a relatively homogenous environment (i.e., in terms of soil moisture, soil depth, and slope orientation) might look much like a true prairie with as few as 10 of the most prevalent species on natural prairies with similar physical properties. If these can be supplemented with an additional 10-15 species in smaller numbers, so much the better.

In regard to grass species composition, Weaver's studies (9) in Nebraska, Kansas, and Iowa revealed that 95 percent of the grass population in 135 different stands consisted of 10 species. He separated the prairie environment into two segments: lowlands, identified as sites with relatively high soil-water content, and uplands, sites with low soil-water content.

The five most prevalent grasses in his summary of lowland sites are Andropogon gerardi, big bluestem; Spartina pectinata, cordgrass; Sorghastrum natans, Indian grass; Panicum virgatum, switch grass; and Elymus canadensis, Canada wild rye. The five most prevalent species on upland sites were Andropogon scoparius, little bluestem; Sporobolus heterolepis, prairie dropseed; Stipa spartea, needlegrass; Bouteloua curtipendula, sideoats grama grass; and Koeleria cristata, Junegrass.

Note that in the prairie stands studied by Weaver, the two bluestems (Andropogon gerardi and A. scoparius) constituted 70 percent or more of the vegetation. He found that big bluestem provided 80-90 percent of the cover on well-watered but well-aerated soils. Little bluestem exceeded all other upland species combined, as it comprised 50-75 percent of the vegetation on drier sites as a whole and up to 90 percent on steep loess hills (9). These data reinforce the idea that in these geographic areas, a natural prairielike effect can probably be achieved without having extremely large species numbers.

Within the general category of species selection, an important consideration in ultimately achieving the appearance of a prairie is the proportion of grasses to forbs. In the prairie stands studied by Weaver, he found that grasses constituted 95 percent of the vegetational cover. The importance of grasses is not only in quantitative terms but also in terms of the visual character of prairies. The linear form of the grass blades, repeated throughout a prairie composition, unify it visually. Further, this screen of narrow, predominantly vertical lines filters the sometimes blatant flower colors and modifies the effect of coarse-textured leaves. Extending a bit further into the subjective evaluation of the effects of grasses on prairie aesthetics, there is the important element of movement displayed by them. This quality, perhaps more than any other, is critical in imparting a prairie spirit to a landscape (20).

If grasses constitute the unifying element within a prairie landscape, the forbs, or broad-leaved flowers, provide the diversity within it. There is less species homogeneity between regions among the forbs than among the grasses (18). Therefore, it is difficult to generalize about the most abundant forb species for consideration in restoration plantings. Specific forb composition of local remnant prairies on sites similar to the restoration site would, of course, be very helpful to a restorationist in a specific region. With such background information, forb species could be selected for planting on the basis of (a) numerical importance and/or (b) visual significance in local prairies.

Species Distribution

Closely related to species selection for a prairie planting is a determination of the placement or distribution patterns within a stand. Once again, a starting point for determining this characteristic is to look at patterns in natural models.

In a naturally evolved prairie, as well as restoration plantings, the first requirement is for propagules (e.g., seeds, roots, and tubers) to be introduced to the site. Beyond this, two major categories of factors influence the distribution patterns: (a) environmental factors, such as soil moisture, soil depth, and biotic competition, which includes allelopathic relations; and (b) the individual species' manner of reproduction and spreading.

A visual analysis of natural prairies from a distance often reveals a degree of zoning of species, seen as bands or drifts of different colors or textures, which blend or grade one into the next. Typically, these zones are not sharply defined, but in some cases, they may be quite apparent. Weaver (9) found changes along a topographic gradient for the two bluestems (Andropogon gerardi and A. scoparius). He found hillcrests and dry slopes to be dominated by A. scoparius. On moist midslopes, A. scoparius and A. gerardi shared dominance. On lower slopes and ravines, A. gerardi was dominant. Similar phenomena are displayed by other species combinations, gradually changing positions of dominance along an environmental gradient. Note that it is usually a gradual change, with an intermediate zone that includes individuals of both species.

On the other hand, with abrupt environmental changes, there may be almost a clear line where one species or set of species ends and another begins. Sometimes these environmental differences, such as differences in soil depth, may not be apparent at the surface. Anderson (21) studied this phenomenon in Wisconsin dry lime prairies and classified the species in three groups: (a) those found only in quadrats of very thin soil, (b) those found only in quadrats with deep soil, and (c) those that occurred in either type of quadrat.

Competition from other species can contribute to the appearance of different zones of different colors and textures. For example, both cordgrass (Spartina pectinata) and big bluestem (Andropogon gerardi) may nearly eliminate shorter species, primarily because of shading (9). Further, a number of prairie plants are considered to be allelopathic, which produces an antibiotic effect that inhibits other species. Examples in Wisconsin prairies include Helianthus laetiflorus, Coreopsis palmata, and Antennaria neglecta (all composites). They may appear as almost solid clonal stands of contrasting color and texture within a prairie because of their ability to exclude competition.

In addition to environmental factors that affect distribution, reproduction methods may have a noticeable effect. Those species that depend primarily on vegetative reproduction means, such as underground rhizomes, tend to exhibit tightly aggregated colonies (22). Curtis (18) also noted that aggregated species were typically rhizomatous. On the other hand, randomly distributed species were typically annuals, biennials, or nonspreading taprooted perennials.

All of the above studies on distribution patterns reinforce the idea that a prairie is not a homogenous blend of species that are randomly or equally spaced. Instead, it has a highly complex organization with certain areas dominated by closely spaced individuals of one or a few species and with resulting contrasts in color and texture.

In planning a prairie restoration, one philosophical approach would be to plant a homogenous, uniform seed mix over an entire site, with the expectation that, over time, a natural sorting out will occur, with each species doing well in its own microhabitat so that a natural-looking pattern will result. A contrasting approach, and one I subscribe to, is to analyze the physical characteristics of the site sufficiently to determine differences in microhabitat and then match different species mixes to different parts of the site.

IMPLEMENTATION OF PRAIRIE RESTORATION PLANTINGS

To be practicable on large sites, it must be possible to implement prairie restorations primarily through the use of mechanical equipment, without the luxury of intensive hand labor by highly trained workers under close surveillance. To be practical, planting will be predominantly by seeding, with seed mixtures designated for different areas of the site.

Seed for such plantings should be from a local seed source, if at all possible. Not only is the likelihood of successful germination and survival increased but this practice eliminates the possibility of interbreeding of foreign varieties of native species with local varieties, which could possibly lead to a long-term loss of the local genetic type. [The Soil Conservation Society of America provides a list of native seed and plant suppliers, listed by state, in Sources of Native Seeds and Plants (23). It may be obtained from the society at 7615 Northeast Ankeny Road, Ankeny, IA 50021, for $2.00.]

Native grass seed is available in quantity from commercial sources in areas where those species are planted on rangeland. Such suppliers typically sell the grass seed on the basis of pure live seed (PLS), which takes into account the germination rate and percentage of purity.

Forb seed, even from some commercial suppliers, is often hand collected from prairie remnants. It is highly variable in both germination and purity, which makes it extremely difficult to predict reliably the number of plants that might germinate from a given amount of seed. Seed costs from commercial sources range from $6 to $10/lb of PLS for grasses to $50-$80 or more/lb for forb seed.

Soil Preparation

In addition to providing a good medium for seed germination and growth, a major objective in preparing soil for prairie plantings is to reduce the potential competition from cool-season grasses and agronomic weeds. If one has the luxury of a year's lead time, two different soil treatments are possible. One is fallowing the soil, i.e., first deep plowing it and then disking it throughout the growing season, whenever a new crop of weeds germinates.

If fallowing the soil is unacceptable because of potential erosion or other reasons, a preparatory cover crop can be planted. Annuals such as oats, soybeans, or buckwheat are possibilities. These crops may be harvested and the stubble permitted to remain.

The following year, if cool-season weed species appear before the prairie planting date, the site may be disked lightly to remove them, and the seeding can follow. If the fallowing process or the cover crop is used, deep plowing should not be repeated during the spring of the prairie seed planting, since this potentially would only bring a new crop of weed seed to the surface. In cases where weeds are not apparent prior to planting, and if a drill is used, the seeding may take place directly in the stubble of the cover crop.

If the year's lead time is not feasible, an alternative soil preparation procedure is to deep plow (10-12 in) as soon as the soil is workable in the spring and follow this by one or more diskings to remove germinated weeds, with the last disking just before seeding. The seedbed does not have to be prepared to as fine a texture as a lawn seedbed, however, since it will not be mowed to a short height. Fertilizing is not usually recommended for prairie plantings, since it is inclined to favor the undesirable agronomic weeds more than it does the native species.

Curtis and Greene (6) reported success with a technique that might be adopted on sites where there is already some vegetational cover that cannot be removed practically because of erosion potential. The technique was to scarify an open sod of Canada bluegrass and redtop in the fall, which exposed the soil without necessarily breaking the sod, and then seeding into it with a mix of native species. They reported prairie cover in five years, with the bluegrass and redtop suppressed.

Planting Techniques

For seeding, two basic techniques, with variations, are available. The first is broadcasting into a prepared seedbed, followed by raking to cover the seed with soil and compacting it with a "cultipacker" or other roller to ensure contact between soil and seed. It is possible to broadcast by hand for small areas of a couple of acres or less. Some advantages to hand broadcasting are the small investment in equipment and the natural distribution of seed where it falls, which is enhanced even more by a slight wind. Some disadvantages include the near impossibility of getting a uniform distribution, coupled with the difficulty of a uniform covering.

Recommended depth of seeding varies. Briggs (24) of the Soil Conservation Service recommends a depth between 0.25-0.50 in. A compromise at 0.48 in is appropriate for many species.

The second basic technique is to drill the seeds, preferably by using a drill designed for prairie planting. A popular brand in the past has been the Nesbit drill, which is no longer manufactured. More recently, Jim Traux, who has done extensive prairie plantings in Minnesota, has developed the Truax model grass drill for this purpose.

This tractor-drawn drill has 12 pairs of discs, 8 in apart, which cut furrows into which seed is dropped from a seedbox, followed by a rubber-tired wheel that closes the furrow and compacts the soil. The advantages of drilling include its labor efficiency and the predictability of seeding rates and depth. The major disadvantage is the fact that seed is planted in rows, which may be apparent for some time.

For planting of steep slopes that are not negotiable with a drill, hydroseeding and/or hydromulching techniques may be considered. By using this procedure, seed is sprayed onto a slope in a liquid slurry. Wood-fiber mulch can be applied in the same slurry, but there is evidence that better results may be obtained by applying the mulch in a separate, second operation because the seed should be in contact with mineral soil in order to germinate and grow (25).

Planting Time

For southern Wisconsin, planting is recommended in the last half of May, or about the same time that corn is planted in the area. Warm-season grasses, as well as many forbs, do not germinate until the soil is 60°F or above. Planting at this date permits the removal of the first wave of cool-season weeds before planting the prairie species. If weeds are well under control, an earlier seeding in the spring, or even during the preceding October or November, permits a more natural stratification of the seed in the soil before germination.

Seeding later than June 1 presents a greater probability that rainfall needed for germination and early growth will diminish or be nonexistent. However, if water can be supplied at a rate equivalent to 1 in of rainfall per week, prairie planting may be continued through July, with a reasonable expectation of some success during the first year. Further, a straw mulch applied at a rate of 1.5 ton/acre will help retain some of the moisture.

For added species diversity, seedlings can be introduced into a prairie planting as roots or tubers early in the spring (e.g., up to mid-May), before lush new growth begins. Fall transplanting of seedlings has also proved quite successful in some experiments. For example, Christiansen and Landers (26) report 87 and 92 percent winter survival for two groups of fall transplants in an Iowa experiment.

Seeding Rates

Various individuals' opinions on the amount of seed to use is highly variable. Site characteristics and weather conditions during any specific growing season are factors that affect the seeding rate. Great fluctuations in the degree of purity of seed (i.e., freedom from other plant parts) and germination rates further complicate the already cloudy picture.

For the establishment of a prairielike planting in a reasonably short time period, a range of 15-20 lb of PLS per acre has been successful. For hand-broadcast plantings, the upper end of this range is appropriate. For drilled seedings, the lower end of the range is suitable because of the greater efficiency of this method.

What to Expect the First Year

With sufficient rainfall, some of the prairie species planted as seed will appear the first year, but they are not likely to make a very dramatic showing. Except under truly optimum conditions of soil and moisture, grasses will not flower or seed with any abundance the first year. With a shortage of moisture or poor soil, the tops of many species will be no more than 2-3 in tall by the end of the first growing season. They may be imperceptible before frost. After a frost, which kills annual weeds and stimulates the natural fall coloring of native perennials, they may be more visible. Although the visible parts of the plants are inclined to be undramatic, activity beneath the surface may be much more exciting, with root growth two to three times the length of above-ground shoots.

Meanwhile, annual weeds will have germinated and may visually dominate the prairie planting. A common invader during the first year is foxtail (Setaria spp.), but it is not likely to persist. Broad-leaved species, such as lambsquarter (Chenopodium album), pigweed (Amaranthus retroflexus), ragweed (Ambrosia artemisiifolia), dandelion (Taraxacum officinale), and curled dock (Rumex crispus), are all frequent invaders in the open habitat of a new prairie planting.

Conveniently, the fact that the prairie perennials are putting their major first-year effort into root development, rather than into tops, means that the planting can be mowed two or three times the first year to suppress the weeds without damaging the prairie plants. Actual cutting times and heights vary with the growing season and should be determined in the field. As a general suggestion, a mowing approximately a month after planting and a second mowing about one month later can be beneficial. Besides making the planting more visually acceptable to the public, mowing serves the useful function of keeping the annual weeds from flowering and seeding. It also permits sunlight to reach the small prairie seedlings. The height of mowing, which stays above the tops of the taller prairie seedlings (i.e., heights that range from 4 to 8 in), may increase as the growing season progresses.

What to Expect the Second Year

Prairie plants that have remained very conservative during their first year may become much more assertive the second. With an average amount of moisture, most of the grass species will flower and produce seed although they may not attain their typical mature height.

Several early-successional forb species will bloom the second year, assuming their roots have become established the first growing season (e.g., Monarda fistulosa, Ratibida pinnata, and particularly the biennial Rudbeckia hirta).

There may be new germination of prairie species during the second year if they did not have optimum conditions the first year. This delayed germination may continue for five years or more, as conditions become right for more species to germinate and grow.

Foxtail will have diminished by the second year in most prairie plantings. Daisy fleabane (Erigeron strigosus) may appear abundantly, but is no cause for alarm because it will be succeeded by long-lived prairie perennials. On the other hand, quackgrass (Agropyron repens) may appear and does represent a problem. In small patches, actual removal of the plants, including rhizomes, may be a possibility. For larger areas, a long-term suppression program for quackgrass should be instituted. Its ability to start growth early in the season makes it possible to suppress by strategically timed burning in the spring. Burning should occur after the quackgrass has started photosynthesizing but before the native species have done so (usually mid-April in the Madison, Wisconsin, area).

Subsequent Management

By the third season, prairie plantings usually benefit from a spring burn and, with sufficient rainfall, can take on the characteristics of real prairies. If the planting has been successful, it may be hard to introduce new species.

CASE STUDY: PRAIRIE RESTORATION IN WAUKESHA COUNTY, WISCONSIN

An 80-acre prairie-restoration planting that was implemented in 1974 in Waukesha County, Wisconsin, at the General Electric Medical Systems site provides an illustration of the application of restoration techniques to a large area with minimal on-site supervision and monitoring. After six complete growing seasons, it is possible to begin to assess the degree of success achieved by these techniques.

Design Objectives

The primary objective in the design of this planting was to provide an erosion-controlling vegetational cover with the visual character of a natural prairie on the extensive land area that surrounded a central building and parking complex. It was expected that after the first year maintenance input would be very low and that there would not be major opportunities for enrichment through the addition of plant species after the initial planting in 1974.

The site is in an urban area, with suburban development occurring around it. Interstate 94 and its access road provide the southern boundary and county highway "T" constitutes its eastern boundary.

Site Characteristics

The topographic character of the prairie planting site is generally rolling with up to 6 percent slopes with a variety of solar orientations. There were natural swales throughout the site and constructed swales adjacent to the driveway that separate the prairie planting from the building and parking complex.

At the time of planting, the soil had been greatly disturbed adjacent to the building and road construction sites. The compacted rocky clay soil was covered by a 4- to 6-in layer of topsoil in late summer 1973 in those areas disturbed by construction. Outlying portions of the site were predominantly farm fields in the early stages of old-field succession, which had not been cultivated in 1973. Soil there could be characterized as a clay loam with poorly drained areas at low points.

Vegetation that existed on the site included predominantly exotic weed species in the former farm fields, with an abundance of curly dock (Rumex crispus), velvet leaf (Abutilon theophrasti), mullein (Verbascum thapsus), thistle (Cirsium spp.), fleabane (Erigeron spp.), and foxtail (Setaria spp.). Fencerow vegetation at borders of the prairie planting included predominantly oaks (Quercus spp.), black cherry (Prunus serotina), and boxelder (Acer negundo). Cattails (Typha latifolia) and sedges (Carex spp.) dominated some of the poorly drained low areas not disturbed by construction activity.

After placement of the 4- to 6-in topsoil layer during August 1973, a seeding of annual ryegrass was specified for the areas disturbed by construction. This seeding was effective in controlling erosion during the fall and winter 1973. It reappeared, vigorously, in early spring 1974. Instead of annual ryegrass, perennial ryegrass (Lolium perenne) had apparently been seeded.

Planting Plan

As the prairie-restoration consultant on this project, I prepared a two-layer planting plan for the site. The plan consisted of (a) a grass seeding plan with five different combinations of grasses matched up with apparent environmental conditions, with potential aesthetic effect and seed availability also entering into the determinations, and (b) a forb plan with nine different forb seed combinations superimposed over the grass planting by using similar criteria for selection.

Table 1 lists the grass seed mixes used at the General Electric site. The mixes should not be construed as recommended mixes for all sites, but were derived for this site on the basis of (a) microenvironmental factors (soil, slope, and moisture), aesthetic considerations (degree of refinement, size, and color), and (c) seed availability (species not commercially available were used in smaller proportions). The grasses were drilled with a Nesbit seed drill during the period May 15 to June 6, 1974, at the rate of 24 lb PLS/acre.

The following list of forb species was broadcast in drifts (i.e., superimposed over the drilled grass planting) with forbs concentrated in relatively conspicuous portions of the site.

1. D-1, dry prairie mix 1: Coreopsis palmata, Liatris cylindracea, Lespedeza capitata, Petalostemum purpureum, Solidago nemoralis, and Solidago speciosa;
2. D-2, dry prairie mix 2: Amorpha canescens, Lespedeza capitata, Ratibida pinnata, Rudbeckia hirta, and Solidago rigida;
3. M-1, mesic prairie mix 1: Amorpha canescens, Baptisia leucantha, Echinacea pallida/purpurea, Liatris aspera, Rudbeckia hirta, Solidago rigida, and Solidago speciosa;
4. M-2, mesic prairie mix 2: Amorpha canescens, Lespedeza capitata, Monarda fistulosa, Ratibida pinnata, and Solidago rigida;
5. M-3, mesic (semi-shade tolerant) mix 3: Anemone cylindrica, Helianthus strumosus, Monarda fistulosa, Rudbeckia hirta, Rudbeckia subtomentosa, and Veronicastrum virginicum;
6. M-4, mesic mix 4: Ascelpias tuberosa, Ceonothus americana, Echinacea pallida/purpurea, Liatris aspera, Solidago speciosa, and Veronicastrum virginicum;
7. W-1, wet prairie mix 1: Liatris pycnostrachya, Pycnanthemum virginianum, Ratibida pinnata, Rudbeckia subtomentosa, and Veronicastrum virginicum;
8. W-2, wet prairie mix 2: Aster novae-angliae, Rudbeckia subtomentosa, and Solidago graminifolia; and
9. W-3, wet (tall) prairie mix 3: Asclepias incarnata, Eupatorium maculatum, and Rudbeckia subtomentosa.

Aesthetic considerations led to the exclusion of the tallest prairie grass species immediately adjacent to the interior driveway, even though the physical characteristics of the site would have been suitable for them. It was felt that the tallest species would block the more distant prairie views and would contrast too extremely with the mowed lawn on the other side of the driveway. Aggregations of forbs were placed, in part, where they would create the greatest visual impact.

All forb seed was hand collected during the fall and winter 1973, with more than 150 lb of 27 forb species collected by students who were paid by General Electric. Prairie dropseed (Sporobolus heterolepis) and cordgrass (Spartina pectinata) were also hand collected and provided to the landscape contractor for planting in the spring. All remaining grass seed was obtained from a commercial source in eastern Nebraska.

Site Preparation

Originally, on the suppostion that annual ryegrass had been seeded in August 1973, the plan was to mow the erosion-controlling ground cover in the spring 1974, drill the grasses into the stubble, and then broadcast forb seed into it. In practice, the

Table 1. Grass seed mixes, General Electric prairie restoration.

Mix	Species	Percentage by Weight
Short grass 1	Andropogon scoparius	75
	Bouteloua curtipendula	10
	Stipa spartea	15
Short grass 2	Andropogon scoparius	70
	Sporobolus heterolepis	10
	Bouteloua curtipendula	10
	Stipa spartea	10
Dry hillside	Andropogon scoparius	40
	Andropogon gerardi	10
	Sporobolus heterolepis	10
	Bouteloua curtipendula	20
	Stipa spartea	10
	Sorghastrum nutans	10
General	Andropogon gerardi	40
	Sorghastrum nutans	30
	Panicum virgatum	15
	Andropogon scoparius	15
Swales and low area	Andropogon gerardi	50
	Spartina pectinata	10
	Panicum virgatum	40

annual ryegrass came back vigorously in the spring 1974 and, as a way of suppressing the lush new growth, much of it was sprayed with paraquat in early May 1974. This is not a recommended treatment today, and roundup would now be considered for this situation.

The portions of the site in the early stages of old-field succession were plowed deeply (12 in) as soon as the soil could be worked in 1974, and disked just before planting time with the objective of killing any already germinated weedy species.

Seeding and Planting

A rented Nesbit seed drill was used by a local landscape contractor for seeding the grasses into the site during the May 15-June 6 period. The drill was run in one direction, and then a second pass was made over the same area, this time perpendicular to the first pass. Different seed mix zones were laid out in the field by using stakes and colored flagging tape based on the previously prepared grass planting plan.

Forb islands were hand broadcast and hand raked within a few days of the grass seed drilling. These areas were also marked on the ground by small stakes with colored flagging tape color-coded to the seed mix. In addition to the seeding, year-old transplants of nine forb species were planted in relatively conspicuous locations in an effort to accelerate flowering on the site.

Early Maintenance

The entire prairie planting was mowed to about 4 in on or about July 20, 1974. Grasses had appeared and were, in many cases, 1-4 in tall at this time. Dense areas of forbs had also appeared but were very short (i.e., less than 2 in tall for the most part), so the mowing was not detrimental to them. A slightly higher August and September mowing occurred for the purpose of cutting fast-growing annual weeds that otherwise would have provided unnecessary competition for light and nutrients.

Almost no maintenance or management of the planting was performed during the subsequent five years, i.e., through the 1979 growing season. Because of this, the General Electric restoration provides some insight into what can happen with a plant-and-neglect approach.

A record or near-record drought occurred during 1976. Its occurrence in the third growing season, after the reintroduced native species had established their deep and fibrous roots, gave them a competitive edge over many non-native species such as quackgrass (Agropyron repens) with its shallow network of rhizomes.

On April 19, 1980, a controlled burn of almost the entire prairie planting was conducted. It was overdue in the sense that a great quantity of dead material from the six previous years' growth had accumulated and was suppressing new growth.

Assessment of General Electric Prairie Planting

In late 1978 and 1979, visual analyses of the prairie planting suggested that it was providing the erosion-controlling cover that was part of the original intent. At a broad level of visual analysis, it also had the character of prairie, with the different combinations of grasses blending into each other and with somewhat more pronounced aggregations of forbs in the originally planted drifts.

In the fall 1979, a more detailed analysis was initiated, when a permanent sampling grid was established with 110 sampling points located and marked at 100-ft intervals throughout a central portion of the planting. In addition, three north-south transects, 150 ft in length, were laid out to determine presence of species at 1-ft segments of the line. The transects crossed an area in which the dry hillside grass mix was drilled in 1974 and in which forb mixes M-1, M-2, and M-3 were broadcast.

Of the six grass species planted, four occurred in more than 5 percent of the 1-ft segments. These were Andropogon scoparius (64.4 percent), Panicum virgatum (25.6 percent), Bouteloua curtipendula (14.0 percent), and Sorghastrum nutans (5.8 percent). Andropogon gerardi occurred in less than 4 percent of the segments. Sporobolus heterolepis did not appear along the transect.

Of the 15 forb species planted in zones crossed by the transects, 8 appeared along the transect and others were noted as occurring but not crossing the transect. By far the most abundant forb, on the basis of its observed frequency, was yellow coneflower (Ratibida pinnata), followed by bergamot (Monarda fistulosa), black-eyed susan (Rudbeckia hirta), and showy goldenrod (Solidago speciosa).

Eight exotic weed species occurred in more than 2 percent of the 1-ft segments of the transects. These included, in descending order, Kentucky bluegrass (Poa pratensis), sweet clover (Melilotus alba), dandelion (Taraxacum officinale), thistle (Cirsium spp.), alfalfa (Medicago sativa), timothy (Phleum pratense), quackgrass (Agropyron repens), and meadow goatsbeard (Tragopogon major).

Observations continued during the summer 1980 to determine both the overall visual aspect and more detailed presence and absence data. Initial analyses indicate that the planting has benefitted from the April 1980 burn. The distant views are increasingly prairielike. Close-up views are highly variable. Some of the most prairielike segments of the property are wet areas where cordgrass (Spartina pectinata), swamp milkweed (Asclepias incarnata), joe pyeweed (Eupatorium maculatum), and sweet black-eyed susan (Rudbeckia subtomentosa) occur with no visible exotic species.

The plantings of forbs in dense aggregations have not changed in form to any degree. As a result, they appear almost too pronounced, especially when the yellow coneflowers are in bloom. Meanwhile, the areas with only grasses planted would benefit visually from some contrasting color and texture, if only in small quantities.

Overall, the planting is achieving the original objectives. Refinements and modifications are suggested for future plantings of this nature--e.g., the inclusion of more species that bloom earlier in the summer and a thin seeding of forbs included with the grass seeding. However, the visual effect, especially as seen late in the season, is becoming more like a true prairie. With a continuing program of management by carefully timed burns, the prognosis for this planting is bright.

SUMMARY

There is now sufficient experience and documentation of prairie-restoration work to suggest that this alternative is a viable one to pursue, particularly on large land areas. Continuing study of already planted projects, such as the General Electric restoration, will yield additional helpful information.

Some areas of future research are also worth noting. We need more information on actual seeding densities and reliable information on expected purity and germination rates. We need a more reliable way to measure success of a planting, at one, two, and three years after planting, especially for plantings that are done under contract. Sources of local seed in quantities sufficient for large sites are needed in many areas.

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REFERENCES

1. R.W. Dyas. Landscape Design with Prairie Plants. In Prairie: A Multiple View, Univ. of North Dakota Press, Grand Forks, 1975.
2. W. Brakeman. Industry Uses of Prairie Grasses for Erosion Control and Landscaping. In Prairie: A Multiple View, Univ. of North Dakota Press, Grand Forks, 1975, pp. 417-418.
3. L.K. Eaton. Landscape Artist in America. Univ. of Chicago Press, Chicago, 1964.
4. W. Miller. The Prairie Style of Landscape Gardening. Univ. of Illinois at Champaign-Urbana, 1915.
5. E.A. Roberts and E. Rehmann. American Plants for American Gardens. MacMillan, New York, 1929.
6. J.T. Curtis and H.C. Greene. The Re-establishment of Prairie in the University of Wisconsin Arboretum. Wildflower, Vol. 29, 1953, pp. 77-88.
7. J.T. Curtis and H.C. Greene. A Study of Relic Wisconsin Prairies by the Species-Presence Method. Ecology, Vol. 30, 1949, pp. 83-92.
8. J.E. Weaver. North American Prairie. Johnson Publishing Co., Lincoln, NE, 1954.
9. J.E. Weaver. Prairie Plants and Their Environment. Univ. of Nebraska Press, Lincoln, 1968.
10. D.G. Morrison. Restoring the Native Midwestern Landscape. Landscape Architecture, Vol. 65, No. 4, 1975, pp. 398-403.
11. D. Kropp. The Prairie Annual. Landscape Architecture, Vol. 65, No. 4, 1975, pp. 410-419.
12. P. Schramm, ed. Proceedings of a Symposium on Prairie and Prairie Restoration. Knox College, Galesburg, IL, 1970.
13. J.H. Zimmerman, ed. Proceedings of the Second Midwest Prairie Conference. Univ. of Wisconsin, Madison, 1972.
14. L.C. Hulbert, ed. Third Midwest Prairie Conference Proceedings. Kansas State Univ., Manhattan, 1973.
15. M. Wali, ed. Prairie: A Multiple View. Univ. of North Dakota Press, Grand Forks, 1975.
16. R.Q. Landers, ed. Proceedings of the Fifth Midwest Prairie Conference. Iowa State Univ., Ames, 1978.
17. D.G. Morrison. The Prairie Invades the Backyard. Landscape Architecture, Vol. 69, No. 2, 1979, pp. 141-145.
18. J.T. Curtis. The Vegetation of Wisconsin. Univ. of Wisconsin Press, Madison, 1959.
19. R.F. Betz and H.F. Lamp. The Species Composition of Old Settler Cemetery Prairies in Northern Illinois and Northwestern Indiana. Third Midwest Prairie Conference, Proceedings. Kansas State University, Manhattan, 1973.
20. D.G. Morrison. Sea of Grass: The Phenomenon Called "Prairie". Wisconsin Trails, Vol. 21, No. 3, 1980, pp. 36-38.
21. O. Anderson. The Phytosociology of Dry Lime Prairies of Wisconsin. Univ. of Wisconsin, Madison, Ph.D. thesis, 1954.
22. T.L. Steiger. Structure of Prairie Vegetation. Ecology, Vol. 11, pp. 170-217, 1930.
23. Sources of Native Seeds and Plants. Soil Conservation Society of America, Ankeny, IA, 1979, 20 pp.
24. W. Briggs. Native Grasses for Roadsides. Soil Conservation Society, Madison, WI, 1971.
25. S.K. Dickinson, Jr., and D.G. Youngman. Taconite Tailing Basin Reclamation. Erie Mining Company, Hoyt Lakes, MN, mimeographed paper, 1971.
26. P.A. Christiansen and R.Q. Landers. Notes on Prairie Species in Iowa: Establishment by Sod and Seedling Transplants. Iowa Academy of Science, Vol. 76, 1969, pp. 94-104.

Cost Analysis for Several Mulching Systems Used in Surface-Mine Reclamation in Eastern Kentucky

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Several mulching agents were evaluated for their economic feasibility and revegetative responses on surface mines in eastern Kentucky. The most widely used soil amendments are wood fiber mulches. Wood fiber mulch, along with a seed and fertilizer mixture, is suspended in water for a one-step revegetative effort. Alternative mulches, such as processed municipal waste, bark, general sawmill residues, and straw and hay with asphalt binders, were evaluated for their economic feasibility. Each mulching system's equipment, labor, and daily area of application were evaluated. Costs per acre indicated that processed bark was the least expensive to apply on outslopes and hollow fills. The machinery for applying mill residue was more complex and required that the mulch be processed before its application with a truck-mounted thrower unit. In the two most heavily mined regions of eastern Kentucky, bark resources were available in sufficient quantity to revegetate 2956 acres annually at the recommended rate of 45 yd^3/acre. Almost all these mill residues required processing to improve quality, reduce equipment breakage, and increase ease of handling.

More than 90 percent of the nation's coal came from deep mines as recently as 30 years ago. Today, more than 50 percent of all coal produced in the United States is produced by surface mining. The federal government's proposed energy program calls for a 67 percent expansion in the coal industry, and the amount of coal mined is projected to rise to more than one billion tons/year by 1985.

The increased rate of mining and the recently enacted Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) require the rapid development of improved surface-mine-revegetation techniques. Environmental performance standards in P.L. 95-87, such as those defined under the sections on prime farmland, post-mining land use, approximate original contour, topsoil segregation and storage, revegetation, and protection of the hydrologic system, require that coal extraction must be planned and monitored in such a way that the post-mining conditions are as good as or better than the premined land conditions. The first four environmental standards may be achieved through good planning during the premining phase and sound engineering practices both during and after mining, whereas the latter two elements are biological in nature.

This paper addresses results of research aimed at improving conditions for effective revegetation of mined sites. A series of studies at the University of Kentucky indicate that the microenvironment of the surface spoil is greatly enhanced when some type of insulating mulch is applied, which improves the chances of success for initial revegetation efforts.

Currently, a simultaneous application of seed, fertilizer, and a processed wood fiber mulch (WFM) is used almost exclusively for revegetation of areas disturbed by surface mining in eastern Kentucky. Kentucky state law requires only that mulch be applied to the outslopes and hollow fills, where outslope means the face of the spoil or embankment that slopes downward from the highest elevation to the toe of the moved material, and hollow fill refers to a fill structure that consists of any material other than coal processing waste and organic material that is placed in the upper-most reaches of a hollow for either temporary or permanent storage.

The application of tree bark or sawmill waste, other composted organic residues, and hay or straw on disturbed sites can increase vegetative cover and reduce erosion losses (1). The environmental problems associated with disposal of sawmill residues and processed municipal waste make these mulches attractive for use in surface-mine reclamation.

Area application of these waste products has not been practical until recently because equipment capable of applying these materials had not been developed (2). This obstacle has been eliminated by the recent development of a truck-mounted power thrower constructed by the Estes Aero-Spread Equipment Company of Winchester, Kentucky.

METHODS

Time studies at the University of Kentucky were conducted with two 2500-gal Finn hydroseeders and compared with those attained with the Estes truck that applied unprocessed bark, processed bark, and composted municipal waste (3). Straw and hay (with asphalt binder) mulching system production rates were compiled through interviews with reclamation personnel that use these materials as a mulching medium. These studies formed the basis for determining the costs and production rates of each system evaluated.

Depreciation of the equipment was computed by using the straight-line procedure over its expected life. In computing hourly machinery costs, an operation year is assumed to consist of 180 days. The 180-day period allows 10 percent equipment down time and assumes that no revegetative efforts are conducted during the winter months of December, January, and February.

Other important costs that are not included in this study are the costs of site preparation prior to seeding, fertilizer, and seed. These were not considered part of the analysis because of the inherent variations in soil structure, topography, types of surface mining, and management decisions that concern final land use. These should be treated as fixed costs because the cost of seed, fertilizer, and site preparation is essentially common to each site.

RESULTS

Wood Fiber Mulch

Kentucky law requires that mulches be applied at rates that are consistent with the revegetation plan. Suggested rates for application of WFM on outslopes and hollow fills are 1500 lb/acre. Mulching may not be required on areas not subject to erosion. Two 2500-gal Finn hydroseeders that were used on two different mining sites were evaluated to determine the average daily area that could be mulched. Data from both locations were combined. Travel time to available water was important, but the factor most limiting production was the time necessary for the two-man crew to lift and load the 1100 lb of mulch, fertilizer, and seed required for each trip. Average water-filling time was 6.86 min. Discharge time for the mulch, fertilizer, and seed mixture was 11.98 min. Standard deviations were 0.43 and 0.80 min, respectively.

The average round-trip cycle time was 59 min when

Table 1. Equipment, depreciation schedule, and calculated cost of applying hydromulch at 1500 lb/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Dual axle truck (Mack)	45 000	7	6428	35.71	7.44
2500-gal hydroseeder (Finn)	13 600	7	1943	10.79	2.25
Hydromulch					165.00
Two operators (each at $10/h)					33.33
Total	58 600				208.02

[a]Cost calculated by using the 4.8 mulched acres/day derived through time studies.

an available water-supply point was within a 1-mile radius of the reclamation site. Each full load mulched 0.6 acre at a rate of 1500 lb/acre. A two-man crew could apply mulch, seed, and fertilizer to 4.8 acres in an 8-h work day. By using this production rate, the itemized cost of $208.02/acre was calculated for the application of WFM (see Table 1). The largest single cost item for this system of mulching was the price of WFM. The spring 1978 price of $220.00/ton was used in calculating this value.

Bark

When bark is applied as a mulch to outslopes and hollow fills in Kentucky, the state-suggested rate of application is 45 yd³/acre. This rate provides a protective insulating layer of approximately 0.32 in, and it is close to the recommended application rates of 30-50 yd³/acre suggested by Sarles and Emanual (1) and 35 yd³/acre suggested by Allison (4) to provide good erosion control and vegetative cover.

Unprocessed bark was applied with the Estes aero-spread truck in the fall 1977. The material was loaded directly onto the transport vehicles from a residue pile that was generated from a carbon-tip, rosserhead debarker. Application was slow because the larger particles tended to bridge between the slope sides of the aero-spread truck, which prevented the mulch from falling onto the conveyor belt that feeds the thrower assembly. Average discharge time was 0.95 yd³/min. The slow and erratic discharge times increased loader idle time and allowed only 3.8 acres/day to be mulched when the area was within a 0.5-mile radius of the loading point. The risk of large foreign materials that could damage the thrower unit was a constant threat. Seed mixtures were metered directly from a storage bin mounted above the thrower assembly and applied with the mulch. Fertilizer was mixed prior to loading or added during the loading operation. Itemized cost per acre for equipment, labor, and transportation for unprocessed bark totaled $110.35 (see Table 2).

Processing mill residues to increase production time and reduce equipment down time was investigated. Processing can be accomplished with a unit such as a hog or hammer mill at the sawmill site or with a portable unit transported from location to location. Interviews with sawmill operators in eastern Kentucky indicated a willingness to install the necessary processing units, but only if a firm could be contracted to purchase the residue at a price that was sufficient to cover its investment, expenses, maintenance, and management of such equipment.

A Farmhand 900B tub-grinder was evaluated for its potential use as a portable processing unit. A self-contained tub-grinder, powered by a 220-hp diesel engine, is commercially available, but the unit evaluated in this study was powered by an 8700 Ford, 115-hp farm tractor. A Michigan 45B front loader with a 2-yd³ bucket loader was used to feed the grinder unit. Particle size reduction decreased the input-to-output volume by 50 percent. An average output of bark at 1.52 yd³/min, or 91.36 yd³/h, was processed by the grinder. The processed bark mulch increased the Estes thrower capacity to 2.14 yd³/min with an SD of 0.86 yd³/min. Operation of the two units increased the area that could be mulched from 3.8 to 8.5 acres/day. With a stock pile of processed mulch within a 0.5-mile radius of the reclamation area, the itemized cost per acre was reduced to $83.12 (see Table 3).

Composted Municipal Waste

Disposal of solid and sewage waste is an increasingly serious problem in our cities. Although the idea of composting these wastes to yield a usable mulch through rapid action of thermophilic aerobic bacteria is not new, the application of these composts as mulches to surface mines is a recent development. The need to establish such uses to eliminate the problems associated with land fill and waste-incineration operations has led to the application of a composted mulch that consists of 67 percent solid waste and 33 percent raw sewage or water and sewage sludge on Kentucky surface mine areas. The material was composted by the Real Earth Naturizer plant in Norman, Oklahoma.

Composted municipal waste is of a sufficient texture that grinding or further processing is not required for application with the Estes Aero-Spreader. Recommended rates for application to disturbed sites have not yet been established by the Kentucky Bureau of Reclamation and Surface Mining. Preliminary data indicate that approximately 20 tons/acre is sufficient for good erosion control and vegetative response (5). At a volume of approximately 2.4 yd³/ton, this represents about 48 yd³/acre, or a mulch depth of 0.34 in.

Application time with the Estes Aero-Spreader was 2.24 yd³/min (SD = 0.80) when discharged through the thrower unit. This system could apply 20 tons/acre of Real Earth Naturizer to 8.5 acres/day when within a 0.5-mile radius of the loading point. Thrower discharge capacity was slightly lower for processed bark, but the additional 3-yd³/acre requirement made the area mulched per day the same as processed bark.

Application costs were $671.15/acre (see Table 4). Increased transportation cost and the $28.50/ton FOB plant were the inflating factors. Transportation cost was assessed by assuming that a composting plant was located within an 80-mile radius of the treatment site. Transportation cost was found by soliciting bid quotes from trucking firms. Plant locations that are farther away may require cost adjustments.

Straw and Hay with Asphalt Binder

The suggested rate of application of hay or straw with binder as a mulch in Kentucky is 1.5 tons/acre. However, competing uses of straw and hay within the Bluegrass areas of Kentucky have limited the amounts available as a mulch in the mountainous eastern Kentucky regions.

The application rates and other data were compiled from interviews with mining and contracting firms that use this mulching system. Results indicate that an average of 7.5 acres/day can be mulched at the 1.5-ton rate. Some 100 gal of an emulsion-

Table 2. Equipment, depreciation schedule, and calculated cost of applying unprocessed bark at 45 yd³/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Two-yard front loader (Michigan 45B)	42 000	10	4200	23.33	6.14
Estes Aero-Spreader[b]	28 000	7	4000	22.22	5.84
Bark transportation cost[c]					56.25
Two operators (each at $10/h)					42.11
Total	70 000				110.35

[a]Cost calculated by using the 3.8 mulched acres/day derived through time and motion studies.
[b]Single-axle Ford truck with thrower unit powered by a 300-in³ Ford gasoline engine.
[c]From actual spring 1978 total transportation cost of $1.25/yd³ for transportation not farther than 25 miles (one way).

Table 3. Equipment, depreciation schedule, and calculated cost of applying processed bark at 45 yd³/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Two-yard front loader (Michigan 45B)	42 000	10	4200	23.33	2.92
Estes Aero-Spreader[b]	28 000	7	4000	22.22	2.61
Farmhand tub-grinder[c]	27 000	7	3857	21.43	2.52
Bark transportation cost[d]					56.25
Two operators (each at $10/h)					18.82
Total	127 000				83.12

[a]Cost calculated by using the 8.5 mulched acres/day derived through time and motion studies.
[b]Single-axle Ford truck with thrower unit powered by a 300-in³ Ford gasoline engine.
[c]Farmhand 900B tub-grinder powered by a self-contained 200-hp diesel engine.
[d]From actual spring 1978 total transportation cost of $1.25/yd³ for transportation not farther than 25 miles (one way).

type binder must also be applied per ton of hay or straw to prevent it from blowing away from the site. Equipment requirements and costs per acre were $227.37 (see Table 5).

Twenty-five percent of the daily operating costs of a hydroseeder and crew were charged to the per acre cost for this system. This was necessary because mining firms that were interviewed used hydroseeders to apply seed and fertilizer rather than applying it manually.

CONCLUSIONS AND RECOMMENDATIONS

The cost of equipment was minor in all of the systems evaluated when it was reduced to cost per acre for application. The factors that had the greatest effect on overall cost were prices of the mulching material, transportation, and labor. Cost data for fuel, lubricants, or maintenance were not calculated for any of the systems.

A summary of equipment costs and application cost per acre for each mulching system investigated is given below:

Mulching System	Equipment Cost ($)	Mulch Application and Material Cost per Acre ($)
Hydromulching	58 600	208.02
Unprocessed bark	70 000	110.35
Processed bark	127 000	83.12
Composted municipal waste	70 000	671.15
Straw or hay	57 650	227.37

Table 4. Equipment, depreciation schedule, and calculated cost of applying composted solid municipal waste at 20 tons/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Two-yard front loader (Michigan 45B)	42 000	10	4200	23.33	2.92
Estes Aero-Spreader[b]	28 000	7	4000	22.22	2.61
Composted municipal waste[c]					570.00
Transportation cost[d]					76.80
Two operators (each at $10/h)					18.82
Total	70 000				671.15

[a]Cost calculated by using the 8.5 mulched acres/day derived through time and motion studies.
[b]Single-axle Ford truck with thrower unit powered by a 300-in³ Ford gasoline engine.
[c]Based on Real Earth, Ltd., quoted price of $28.50/ton free-on-board (FOB) price at the plant in Versailles, Kentucky.
[d]Cost from low bid quote of $1.60/yd³ for maximum one-way trip of 80 miles and assuming 2.4 yd³/ton.

The expansion of these data, which include varying rates of mulching, is given in Table 6.

Mulching with a hydroseeder was found to be very versatile and exhibited an effective range of coverage of up to 200 ft. The 2500-gal unit could lightly mulch, seed, and fertilize 4-5 acres/trip, depending on terrain and crew experience. On sites that did not require a specified mulching rate, a two-man crew could cover 32-40 acres/day. Poor sites that required 1500-lb WFM/acre reduced the capacity to 4.8 acres/day (see Table 7).

Processed and unprocessed bark could be applied at Kentucky's recommended rates for the lowest cost per acre. The aero-spread truck was also capable of effectively reaching a coverage range of up to 200 ft with processed bark. The decreased risk of damage to the thrower unit and the increased production rates with processed residues indicate that sawmill residues should be processed prior to application.

The Farmhand 900B tub-grinder processed the mill residues in sufficient quantities to keep a ready supply for the aero-spread truck. The tub-grinder also processed hay, sugarcane stalks, partially composted trash, and a mixture of chicken manure and bark. With proper screens it can also process a multitude of dry organic-waste materials.

Sawmills annually generate enough residue to mulch 2956 acres at the recommended rate of 45 yd³/acre in the two most heavily mined forest service survey units of eastern Kentucky (6). This material, which has been considered a problem in waste disposal, may begin to increase in value with its development as a mulching agent. Holding all other costs constant, the price per cubic yard that may be paid at sawmills within a 25-mile radius, and not exceed the cost of hydromulch application, is $2.78.

The cost of composted municipal waste ($28.50/ton FOB plant), including its transportation and availability, is currently more expensive than alternative mulches. However, the concept is good and some type of federal subsidy for firms that use processed waste from surrounding cities in their reclamation effort may be a possible answer to some of the envi-

Table 5. Equipment, depreciation schedule, and calculated cost of applying straw and hay at 1.5 tons/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
15-ton/h power mulcher[b]	13 000	5	2600	14.44	1.44
Dual-axle flat-bed truck	30 000	7	4286	23.81	2.38
2500-gal hydroseeder[c]	3 400	7	486	2.70	0.36
Dual-axle truck[c]	11 250	7	1607	8.93	1.19
Two operators[c]					5.33
Hay or straw mulch[d]					120.00
Binder (asphalt)[e]					54.00
Four operators (each at $10/h)					42.67
Total	57 650				227.37

[a]Cost calculated by using the 7.5 mulched acres/day derived through time and motion studies.
[b]Includes a Finn, Eagle model, 15-ton/h, and 50-gal/min asphalt-binder system.
[c]Charges of 25 percent of a Finn 25 000-gal hydroseeder to be used for the application of seed and fertilizer.
[d]Average cost of $80.00/ton for hay or straw delivered.
[e]Binder is applied at the rate of 100 gal/ton and cost $0.36/gal.

Table 6. Expanded cost per acre for applying varying rates of mulches.

Mulching System and Rate	Cost per Acre[a] ($)	Mulching System and Rate	Cost per Acre[a] ($)
Apply seed and fertilizer only	43.02	Hydromulch at	
Processed bark at		250 lb/acre	70.52
		500 lb/acre	98.02
45 yd^3/acre	83.12	750 lb/acre	125.52
70 yd^3/acre	129.30	1000 lb/acre	153.02
140 yd^3/acre	258.60	1500 lb/acre	208.02
Composted municipal waste at		Hay or straw at	
		1.5 tons/acre	227.37
20 tons/acre	671.15	3.0 tons/acre	454.74
40 tons/acre	1342.30		

[a]Price includes cost of mulch, transportation, straight-line depreciation of equipment, and cost of labor per acre of mulch application.

Table 7. Average daily acres of mulch applied for each mulching system.

Mulching System	Acres Mulched Daily (8 h)
Hydroseeder applying 1500 lb/acre of hydromulch	4.8
Estes spreader applying	
Unprocessed bark at 45 yd^3/acre	3.8
Processed bark at 45 yd^3/acre	8.5
Composted municipal waste at 20 tons/acre	8.5
Straw or hay applied at 1.5 tons/acre	7.5

ronmental problems of disposal of municipal waste.

The potential of hay and straw mulching systems is limited on surface mines in eastern Kentucky. Backing into or out of hollow fills presents a safety hazard to revegetation crews in mountainous terrain. Supplies of hay and straw are usually some distance from mining activity and multiple handling of each bale makes mulching with this system very strenuous.

No single mulch material exists in quantities great enough to satisfy the industry's needs except WFM. It is capable of producing acceptable levels of vegetation on many sites. However, it is not suitable in all cases. This necessitates consideration of revegetation systems that are capable of applying various mulching mediums so that the one best-suited for a particular situation can be used.

It may be necessary to consider blending mulches to attain specific chemical and physical properties and equalize cost structures. Research in this area has already begun in Kentucky. Combinations of bark or whole tree chips, industrial waste, and poultry manure are being evaluated. Other possible materials that should be tested include hay, straw, or leaves that are processed through grinder systems because of their rapid use and blending capabilities.

The objective of future research will be to meet mining-area needs for mulching mediums for revegetation while also solving the waste-disposal problems of surrounding communities. Mining firms should not consider a single mulching system as the solution to their complete revegetation needs. Combinations of mulches and mulching systems should be considered for cost of investment, cost per acre of application, revegetation achieved, and the overall environmental qualities produced by each.

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REFERENCES

1. R.L. Sarles and D.M. Emanual. Hardwood Bark Mulch for Revegetation and Erosion Control on Drastically Disturbed Sites. Journal of Soil and Water Conservation, Vol. 32, 1977, pp. 209-214.
2. D.M. Emanual. Hydromulch: A Potential Use for Hardwood Bark Residue. U.S. Department of Agriculture Forest Service, Upper Darby, PA, Research Note NE-226, 1976, p. 3.
3. D.L. Koon. Economic Analysis and Goal Programming Application of Soil Amending Mulches on Surface Mines in Eastern Kentucky. Univ. of Kentucky, Lexington, master's thesis, 1978.
4. R.C. Allison. Bark Utilization Project Report. School of Forest Resources, North Carolina State Univ., Raleigh, unpublished rept., 1976, p. 26.
5. D.L. Koon and D.H. Graves. Vegetative Responses of Grasses and Legumes Planted Under Differing Rates of Soil Amending Mulches on Kentucky Surface Mines. Proc., Symposium for Surface Mine Hydrology, Sedimentology, and Reclamation, Lexington, KY, 1979, pp. 1-5
6. J.T. Bones and C.J. Lohr. The Timber Industries of Kentucky. U.S. Department of Agriculture Forest Service, Upper Darby, PA, Resource Bull. NE-50, 1976, p. 26.

Survey of Native Prairie on Railroad Rights-of-Way in Minnesota

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A survey was conducted from September 15 to November 3, 1978, to identify railroad right-of-way with native prairie vegetation. A total of 2676 km (1663 miles) of right-of-way was sampled at 1.6-km (1-mile) intervals, and at each sampling point the right-of-way was characterized as either type A, high-diversity native prairie; type B, low-diversity native prairie; or type C, no native prairie present. The best-quality prairie, type A, was observed at 360 sampling points, which means that approximately 580 km (360 miles) of type A occurs on the surveyed right-of-way, or 22 percent of the total surveyed. Sixteen prairie corridors with concentrations of high-quality prairie were identified. These range from 21 km to 174 km (13-108 miles) long, with a total length of 875 km (544 miles). It is recommended that steps be taken to avoid major destructive impacts, conduct additional biological surveys, and appropriately manage native prairie or railroad rights-of-way.

Interest in Minnesota road and railroad rights-of-way has been stimulated by increased rail abandonment and the growing awareness that these are the only significant undeveloped areas in much of the prairie part of the state where cropland is most productive and costly. Figure 1 (1,2) shows the active and abandoned rail lines in Minnesota, excluding the Minneapolis-St. Paul area. Also shown are the rail lines surveyed in this study and the 16 prairie corridors recommended for protection. Figure 2 (1,2) shows which rail lines are abandoned or likely to be abandoned in the near future (note that abandonment is concentrated in the southern part of the state). Figure 3 (3) shows the cash rent paid for tillable land (note that values are highest in the southern part of the state, and higher in the prairie than in forested areas). Figure 4 (4) shows the vegetation of Minnesota at the time of early white settlement. The Minnesota State Planning Agency (1) reported to the legislature that railroad rights-of-way have high potential for recreation, wildlife management, and other public uses. Roadsides as a natural resource in Minnesota was the subject of a recent symposium (5) and a sizable body of literature is available on roadside-wildlife relationships (6,7).

Among the midwestern states to recognize the value of native prairie on rights-of-way are Illinois (8), where the natural areas inventory project carefully searched for prairie remnants and rights-of-way, and Michigan, where the National Railroad Passenger Corporation (Amtrak) and The Nature Conservancy are cooperating to protect prairie areas on the rail line southwest from Kalamazoo. Scientists who have studied or urged preservation of railroad rights-of-way include the following:

1. Iowa--Shimek (9);
2. Indiana--Betz (10) and Lindsey and others (11);
3. Michigan--Chapman and Pleznac (12), Kohring (13), Scharrer (14), and Thompson (15);
4. Ohio--King (16), Ramey (17), and Troutman (18);
5. Wisconsin--Curtis and Green (19), Curtis (20), Gould (21), Thomson (22), and Wilson (23);
6. Illinois--Adams (24), Douglas and others (25), Evers (26), Evers and Page (27), Goodnight and Koestner (28), Hankinson (29), Koestner (30), Long (31), Miller (32), Pepoon (33-36), Rapp (37), Shackleford (38), Stupka and others (39), and Vestal (40,41); and
7. North Dakota--Ralston and Dix (42).

Unlike most preserved natural areas that are isolated from each other, long stretches of nearly continuous native grassland on railroad rights-of-way allow for the natural processes of species and gene migration. Prairie preservation is best achieved where gene flow and vertebrate movements can occur along a prairie corridor (43). It might be possible to maintain transects of relatively natural vegetation across the entire east-west moisture gradient in the Great Plains, which would present an invaluable opportunity to study and monitor the dynamic relationship among tallgrass, midgrass, shortgrass, and western steppe vegetation.

The purpose of this study was to locate and assess Minnesota railroad rights-of-way that support native prairie vegetation. The survey was conducted on selected stretches of Burlington Northern rail lines and did not include many potentially interesting rights-of-way in southern Minnesota (see Figures 1 and 2). A detailed report that includes data collected at each sampling point is on file with The Nature Conservancy.

It was not the purpose of this project to assess vegetation other than prairie. Significant prairie remnants may have been missed because of the use of a sampling technique. It should not be assumed, therefore, that all areas on the surveyed rights-of-way with biological or environmental significance have been discovered.

SURVEY METHOD

The survey was conducted in early fall 1978 when native prairie grasses cure to distinctive golden colors. By conducting the survey in the fall, however, meant that many native forbs were inconspicuous. (A forb is a nongrasslike herbaceous plant. Native prairies are very diverse communities, usually with many more nongrass than grass species.) If native grasses were observed at the sampling points, a careful search was made for native prairie forbs.

Field work was conducted between September 15 and November 3, 1978. The surveyor, John Borowske, drove on roads that paralleled rights-of-way, stopping at 1.6-km (1-mile) intervals for sampling. In long stregches of uniform disturbed grassland with no apparent native prairie grasses, the interval between stops was extended to every second kilometer with the intermediary sampling point described as "no change."

At sampling points, the surveyor recorded data on right-of-way vegetation either from the roadside or while walking a transect perpendicular to the tracks. The right-of-way was described from the roadside if no native prairie was observed and if an accurate description could be made from that distance. Otherwise, the surveyor walked across the entire width of the right-of-way on a transect. Vegetation was sampled by using a belt transect approximately 30 cm (11.7 in) wide. If an accurate description could be made from a distance, the surveyor simply visualized a strip 30 cm wide that traversed the right-of-way. If it was necessary to walk the transect, the surveyor walked down the center of the transect and recorded data in an estimated 30-cm-wide belt.

In some cases fences, water, and private land made it difficult to reach the railroad right-of-way from the roadside. If the survey could be made accurately by using binoculars, this was done.

Figure 1. Active and abandoned rail lines in Minnesota, excluding the Minneapolis-St. Paul area.

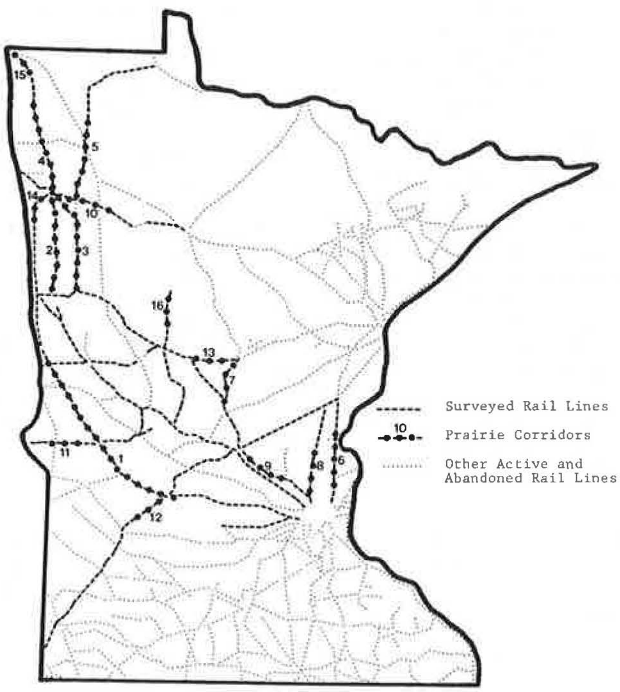


Figure 2. Minnesota rail lines abandoned and likely to be abandoned in the near future.

An attempt was made to use a trail motorcycle, but the rough surface of the rights-of-way made this method slow and unsafe. Problems of separation between road and right-of-way prevented data collection for about nine percent of the total kilometers

Figure 3. Cash rent paid for tillable land in Minnesota as an indication of land value.

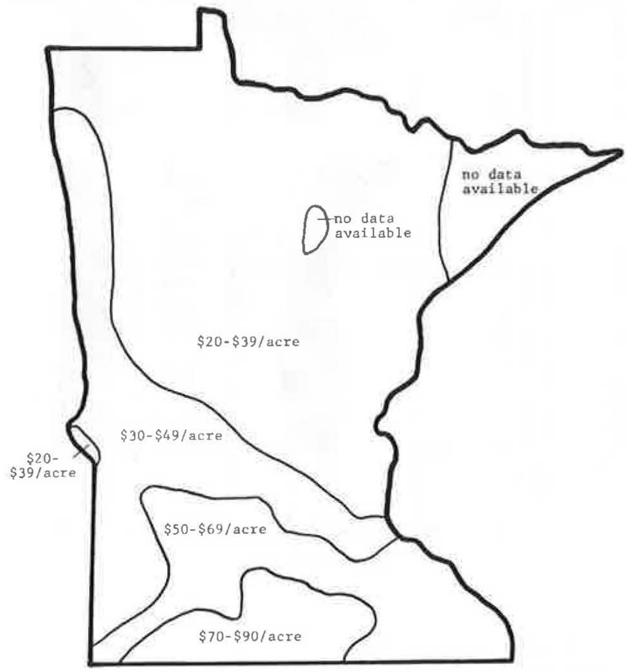


Figure 4. Vegetation of Minnesota at time of early white settlement.

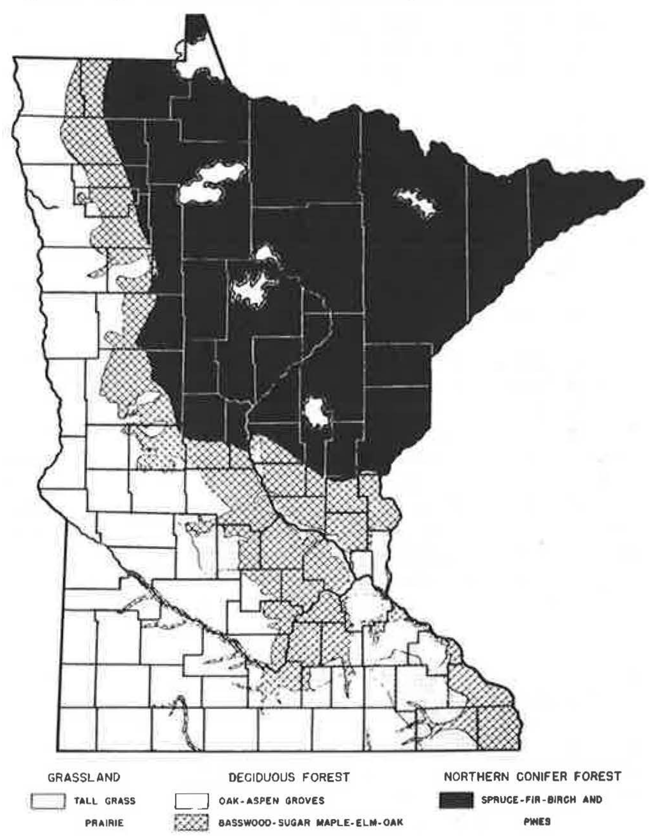
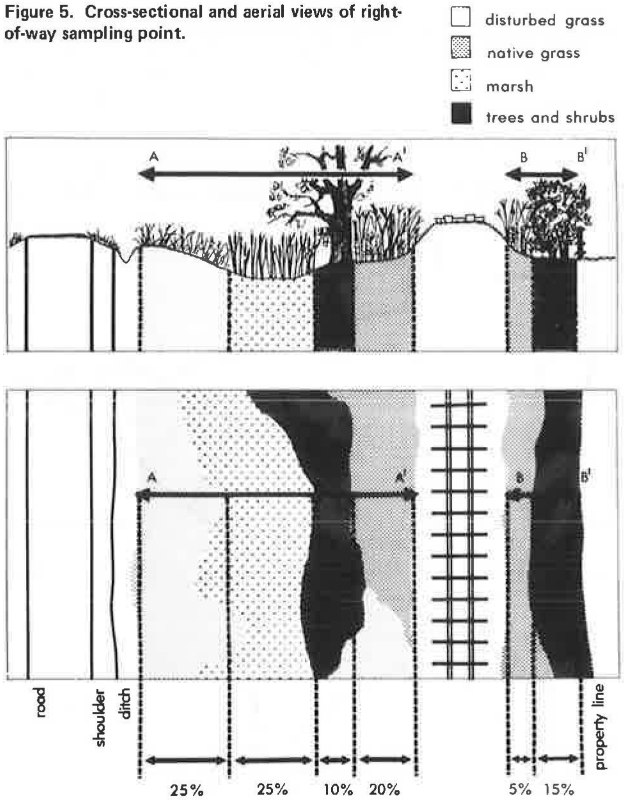


Figure 5. Cross-sectional and aerial views of right-of-way sampling point.



that might have been included in this survey.

The percentage of vegetation cover at sampling points was estimated for four categories: (a) native prairie, (b) disturbed grassland, (c) trees and shrubs, and (d) wetlands. Figure 5 shows the cross-sectional and aerial views of a sample right-of-way (note that the vertical scale is exaggerated, and that the road ditch and rail bed were excluded from the survey). If the road and railroad rights-of-way were contiguous, the area examined was from the back slope of the road ditch to the far edge of the right-of-way as defined by a fence line or other obvious change in land ownership or use. Data were recorded for only the railroad right-of-way if it was separated from the road right-of-way. The area taken up by unvegetated ballast was discounted in estimating the percentage of cover.

The following information was recorded for each category of vegetation:

1. Native prairie--(a) Percentage of right-of-way covered by native prairie vegetation (grasses and forbs); (b) presence and relative abundance of the following prairie indicator grasses: big bluestem, little bluestem, Indian grass, prairie June grass, side-oats grama, and prairie cordgrass; and (c) diversity of native prairie forbs along a transect (recorded as high diversity if five or more species, low diversity if less than five);
2. Disturbed grassland--(a) Percentage of right-of-way covered by plants associated with disturbed soil conditions, and (b) presence and relative abundance of the following common Eurasian species that are characteristic of disturbed sites: smooth brome, quackgrass, and bluegrass (Poa spp.);
3. Trees and shrubs--(a) Percentage of right-of-way covered by trees and shrubs, (b) whether tree and shrub growth was sparse or dense, and (c) presence of aspen, other hardwoods, coniferous trees, willow, and other shrubs; and
4. Wetlands--(a) Percentage of right-of-way covered by wetlands, and (b) presence of submerged vegetation, emergent vegetation (e.g., cattails), and wet meadows.

Information was also recorded on other adjacent land uses: crop or cultivated, pasture, wooded, highways or roads, and residential.

Each sampling point was characterized as type A, B, or C, based on the presence and quality of native prairie vegetation, as follows:

1. Type A: High-diversity native plants--(a) Major prairie grasses present on the right-of-way and (b) a high diversity of native prairie forbs present on the right-of-way;
2. Type B: Low-diversity native prairie--(a) Major prairie grasses present on the right-of-way and (b) a low diversity of native prairie forbs present on the right-of-way; and
3. Type C: No native prairie present--No native prairie observed on the right-of-way.

Prairie corridors are stretches of 21 or more kilometers (13 miles) with relatively continuous type A native prairie in the right-of-way. One corridor is only 25 percent type A, but it was included because it goes through a very intensively cultivated part of Minnesota. The amount of type B right-of-way, in which major prairie grasses were found but native forb diversity was low, was also considered in the identification of prairie corridors.

RESULTS

The surveyor collected data at 1663 sampling points spaced at 1.6-km (1-mile) intervals along railroad rights-of-way. The prairie types were divided as shown in the table below:

Prairie Type	No. of Sampling Points	Percentage of Total
A	360	21
B	411	25
C	892	54
Total	1663	

Prairie corridors number 16 and total 575 km (544 miles) (see Figure 1). The longest corridor, from Breckenridge to the town of Kandiyohi, southeast of Willmar, is 174 km (108 miles). The shortest is 21 km (13 miles) (see Table 1). The 16 corridors listed in Table 1 include 79 percent of the high-diversity native prairie surveyed.

The seven prairie corridors in northwestern Minnesota include 49 percent of all corridors identified in this survey. Corridors 2, 14, and 15 are highly significant because they represent remnants of the level Lake Agassiz Lacustrine Plain (inside the beach ridges), in which there is only one known protected prairie preserve in Minnesota. The other corridors in this area are interesting transects that include sections of lake plain, beach ridges, and till (44). Corridor 10 spans a transect from prairie to aspen parkland.

Corridors 16 and 13 traverse areas of jack pine barrens and prairie openings. Corridor 7 is a transect from prairie and oak savanna areas to jack pine barrens. Corridors 6, 8, and 9 are on sandy soils deposited as outwash. The vegetation in these areas was originally oak savanna with prairie openings.

Except for one 24-km (15-mile) portion, corridors 1, 11, and 12 are all within the most fertile cropland soils in the state (3, Map I). The length of

Table 1. Prairie corridors or stretches of relatively consistent good-quality prairie in Minnesota.

No.	Prairie Corridor	Highway	Total Kilometers[a]	Type[b] (%) A	B	C	No Data[c]
1	Breckenridge-Kandiyohi	MN-9	174	50	31	17	2
2	Crookston-Glyndon	MN-9	98	41	21	21	17
3	Crookston-Dale	MN-102, 32	97	41	29	17	13
4	Crookston-1.6 km north of Stephen	US-75	77	42	42	14	2
5	Holt-4.8 km south of Marcoux	MN-32	68	64	5	10	21
6	4.8 km north of Forest Lake-3.2 km north of Rush City	US-61	48	64	13	10	13
7	Little Falls-Brainerd	MN-371	43	56	22	18	4
8	1.6 km south of Cambridge-6.4 km south of Andover	MN-65	37	65	0	0	35
9	Elk River-1.6 km north of Clear Lake	US-10	35	68	23	9	0
10	Erskine-11.3 km east of Crookston	US-2	35	41	41	9	9
11	Alberta-Graceville	MN-28	32	25	40	5	30
12	Willmar-Clara City	MN-23	31	63	26	11	0
13	Staples-1.6 km east of Pilliger	MN-210	27	47	23	12	18
14	Nielsville-6.4 km north of Eldred	US-75	26	50	44	6	0
15	St. Vincent-3.2 km north of Hallock	US-75	26	63	25	6	6
16	6.4 km south of Menahga-8.1 km south of Park Rapids	US-71	21	38	46	8	8

Note: 1 km = 0.62 mile.
[a]Total kilometers = 875.
[b]Average percent by prairie type: A = 51; B = 27; C = 11; and no data = 11.
[c]No data figures are parts of the right-of-way that could not be observed because of construction or other barriers.

corridor 1, and the possibility that additional native grassland may occur that continues west across North Dakota and Montana, makes it a very high priority for protection.

RECOMMENDATIONS

Several recommendations are given for additional study and management of railroad rights-of-way in Minnesota. They include the following:

1. A preliminary prairie survey on all railroad rights-of-way should be completed. A shorter sampling interval than that used in this study is suggested in the southern part of Minnesota where little native prairie is known to survive.
2. Steps should be taken to ensure that prairie is not inadvertently or needlessly destroyed in the course of road and rail maintenance, or by incursion from adjacent landowners.
3. Efforts should be made to maintain and enhance native grassland through controlled burning.
4. Rights-of-way should be used for vegetation monitoring and ecological research.

In order to accomplish the goals listed above, a great deal of cooperation is needed from the Minnesota Department of Transportation, railroad corporations, private landowners, scientists, resource managers, and others. Prairie rights-of-way are important biological resources and are worthy of additional study, protection, and management.

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REFERENCES

1. Reuse of Abandoned Railroad Rights-of-Way. Minnesota State Planning Agency, St. Paul, 1978, 87 pp.
2. W. Nielsen. Right-of-Way: A Guide to Abandoned Railroads in the United States. Old Bottle Magazine, Bend, OR, 1972, 124 pp.
3. Minnesota Cropland Resources. Minnesota State Planning Agency, St. Paul, 1979, 36 pp.
4. C.O. Rosendahl and F.K. Butters. Trees and Shrubs of Minnesota. Univ. of Minnesota Press, Minneapolis, 1928, 385 pp.
5. Roadsides as a Natural Resource: A Symposium Report. Minnesota Department of Transportation, St. Paul, 1978, 24 pp.
6. Highway-Wildlife Relationships: Vol. 1, State-of-the-Art Report. FHWA, Rept. FHWA-RO-76-4, 1975, 183 pp.
7. Highway-Wildlife Relationships: Vol. 2, Annotated Bibliography. FHWA, Rept. FHWA-RO-76-5, 1975, 417 pp.
8. J. White. Illinois Natural Area Inventory Technical Report: Vol. 1, Survey Methods and Results. Illinois Natural Area Inventory, Urbana, 1978, 426 pp.
9. B. Shimek. The Persistence of the Prairie. Univ. of Iowa Studies in Natural History, Vol. 11, 1925, pp. 3-24.
10. R.F. Betz. The Prairies of Indiana. In Fifth Midwest Prairie Conference Proceedings (D.C. Glenn-Lewin and R.Q. Landers, Jr., eds.), Iowa State Univ., Ames, 1978, pp. 25-31.
11. A.A. Lindsey, D.V. Schmelz, and S.A. Nichols. Natural Areas of Indiana and Their Preservation. Indiana Natural Areas Survey, Lafayette, 1968, 594 pp.
12. K.A. Chapman and R.J. Pleznac. A Survey of Prairie Preservation and Prairie Reconstruction in Michigan. Presented at Sixth North American Prairie Conference, 1978.
13. M. Kohring. Saving Michigan's Railroad Strip Prairies. Presented at Sixth North American Prairie Conference, 1978.
14. E.B. Scharrer. Relic Prairie Flora of Southwestern Michigan. In Proc., Second Midwest Prairie Conference (J.H. Zimmerman, ed.), Univ. of Wisconsin, Madison, 1972, pp. 9-12.
15. P.W. Thompson. The Preservation of Prairie Stands in Michigan. In Proc., Second Midwest Prairie Conference (J.H. Zimmerman, ed.), Univ. of Wisconsin, Madison, 1972.
16. C.C. King. A Right-of-Way Prairie Near Milford Center, Union County, Ohio. Presented at Sixth

North American Prairie Conference, 1978.
17. R.E. Ramey. A Right-of-Way Prairie Near Zimmerman, Greene County, Ohio. Presented at Sixth North American Prairie Conference, 1978.
18. K.R. Troutman. The Prairie Remnants of Marion, Crawford, and Wyandot Counties in North Central Ohio. Presented at Sixth North American Prairie Conference, 1978.
19. J.T. Curtis and H.C. Green. A Study of Relic Wisconsin Prairies by the Species-Presence Method. Ecology, Vol. 30, 1949, pp. 83-92.
20. J.T. Curtis. The Vegetation of Wisconsin. Univ. of Wisconsin Press, Madison, 1959, 657 pp.
21. F.W. Gould. Plant Indicators of Original Wisconsin Prairies. Ecology, Vol. 22, 1941, pp. 427-429.
22. J.W. Thomson, Jr. Relic Prairie Areas in Central Wisconsin. Ecological Monographs, Vol. 10, 1940, pp. 685-717.
23. T. Wilson. A Plant-Species Inventory and Evaluation of Some Prairie Remnants, Waukesha, Wisconsin. In Fifth Midwest Prairie Conference (D.C. Glenn-Lewin and R.Q. Landers, Jr., eds.), Iowa State Univ., Ames, 1978, pp. 39-45.
24. C.C. Adams. An Ecological Study of Prairie and Forest Invertebrates. Bull., Illinois State Laboratory of Natural History, Vol. 11, 1915, pp. 33-280.
25. C.L. Douglas, Jr., J.B. Fehrenbacher, and B.W. Ray. The Lower Boundary of Selected Mollisols. Soil Science Society of America Proceedings, Vol. 31, 1967, pp. 795-800.
26. R.A. Evers. Some Unusual Natural Areas in Illinois and a Few of Their Plants. Illinois Natural History Survey Biological Notes, No. 50, 1963, 32 pp.
27. R.A. Evers and L.M. Page. Some Unusual Natural Areas in Illinois. Illinois Natural History Survey Biological Notes, No. 100, 1977, 47 pp.
28. C.J. Goodnight and E.J. Koestner. Winter Home Ranges of Some Small Illinois Mammals. Journal of the Tennessee Academy of Science, Vol. 17, 1942, pp. 276-279.
29. T.L. Hankinson. The Vertebrate Life of Certain Prairie and Forest Regions Near Charleston, Illinois. Bull., Illinois State Laboratory of Natural History, Vol. 11, 1915, pp. 281-303.
30. E.J. Koestner. Some Recent Records of Central Illinois Mammals. Journal of the Tennessee Academy of Science, Vol. 16, 1941, pp. 46-47.
31. C.A. Long. Populations of Small Mammals on Right-of-Way in Prairie of Central Illinois. Trans., Illinois State Academy of Science, Vol. 61, 1968, pp. 139-145.
32. L.W. Miller. The Use of Prairie Relics in Teaching. Trans., Illinois State Academy of Science, Vol. 32, 1943, p. 102.
33. H.S. Pepoon. Peculiar Example of Plant Distribution: A Problem in Phyto-Geography. Trans., Illinois State Academy of Science, Vol. 8, 1915, p. 136.
34. H.S. Pepoon. Peculiar Plant Distributions. Trans., Illinois State Academy of Science, Vol. 9, 1916, pp. 128-137.
35. H.S. Pepoon. The Flora of the Right-of-Way of the Illinois Central Railway: Waddams to East Dubuque. Trans., Illinois State Academy of Science, Vol. 20, 1927, pp. 92-98.
36. H.S. Pepoon. Vegetation Along the Illinois Central Railroad. Trans., Illinois State Academy of Science, Vol. 20, 1928, pp. 72-79.
37. J.L.C. Rapp. List of Myriapoda Taken in Champaign County, Illinois, During the Fall and Winter of 1944-1945. American Midland Naturalist, Vol. 36, 1946, pp. 666-667.
38. M.W. Shackleford. Animal Communities of an Illinois Prairie. Ecology, Vol. 10, 1929, pp. 126-154.
39. R.C. Stupka, J.E. Brower, and J. Henriksen. New Northwestern Illinois Locality Records for the Western Harvest Mouse (Reithrodontomys megalotis dychei). Trans., Illinois State Academy of Science, Vol. 65, 1972, pp. 112-114.
40. A.G. Vestal. Invasion of Forest Land by Prairie Along Railroads. Trans., Illinois State Academy of Science, Vol. 11, 1918, pp. 126-128.
41. A.G. Vestal. Strategic Habitats and Communities in Illinois. Trans., Illinois State Academy of Science, Vol. 24, 1931, pp. 163-261.
42. R.D. Rahlston and R.L. Dix. Green Herbage Production of Native Grasslands in the Red River Valley--1965. Proc., North Dakota Academy of Science, Vol. 20, 1966, pp. 57-66.
43. D.M. Reed and J.A. Schwarzmeier. The Prairie Corridor Concept: Possibilities for Planning Large-Scale Preservation and Restoration. In Fifth Midwest Prairie Conference Proceedings (D.C. Glenn-Lewin and R.Q. Landers, Jr., eds.), Iowa State Univ., Ames, 1978, pp. 158-165.
44. W. Upham. The Glacial Lake Agassiz. U.S. Geological Survey, Monograph 25, 1895, 658 pp.