1224

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Rest Areas, Wetlands, and Hydrology

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Transportation Research Record 1224

Contents

Foreword

Six of the 12 papers in this Record are about wetlands and roadside vegetation, and 3 are on the design or evaluation of highway rest areas. Two papers describe the development of dimensionless hydrographs, and one reports on critical water velocities and fish passage through highway culverts.

Caiazza and Bartoldus and Heliotis describe the success of developing typical wetland ecology within 2 or 3 years in created wetlands. A technique for increasing the shoreline length of a highway fill crossing a wetland, as described by Parrish, was also ecologically successful in mitigating the effects of the use of a portion of a wetland area.

Busey describes a technique for successfully establishing a stand of Bahiagrass in Fort Lauderdale. Part of the success was attributed to one strain (RCP-1) of Bahiagrass. Shanahan and Smardon propose a manual for managing roadside vegetation that will encourage untrained local community groups and provide them with a starting point for organizing physical improvements to roadside areas.

The design of rest areas is covered by Fowler et al. Design factors include general location, spacing, specific site selection, buildings, mechanical equipment, plumbing, water and waste-water, energy sources, conservation, and lighting. An example design for 500,000 people/year is given. King and Perfater studied the use of 13 and 11 existing rest areas, respectively.

Both Sauer and Welle and Woodward describe the development of dimensionless hydrographs for small watersheds. This method establishes the general shape of the hydrograph, which can then be used for run-off predictions for various rainfall events.

Behlke et al. report on four field studies to determine critical water velocities and allowable time delays for fish at drainage structures. A design manual incorporating new culvert and retrofit recommendations for fish passge is scheduled for completion in 1989.

Factors Affecting Survival of Planted Materials in Marley Creek Constructed Freshwater Tidal Marsh, Maryland

CANDY COLGAN BARTOLDUS AND FRANCIS D. HELIOTIS

The Maryland State Highway Administration constructed a 0.8-hectare freshwater tidal marsh on Marley Creek, Anne Arundel County, as mitigation for wetlands filled during the Route 10 extension. Research was initiated in June 1987 at the completion of site construction to investigate aspects of the initial stages of marsh development. Vegetation was sampled in the constructed marsh and in a neighboring natural marsh by using a random sampling design to determine planted species survival, species occurrence, and vertical distribution. June and October 1987 data indicate that the survival rate of the planted species (*Scirpus americanus*, *Peltandra virginica*, and *Leersia oryzoides*) is not solely dependent on placement within the tidal range. Although *Peltandra virginica* and *Leersia oryzoides* were planted within the elevation ranges determined for these species in the natural marsh, they suffered over 50 percent and 90 percent mortality, respectively. The data suggest that other factors such as life history, pH, and soil properties are important in determining survival of planted materials. By October 1987, the site was rapidly colonized with 28 additional plant species, most of which were found within the observed naturally occurring tidal range.

State highway authorities are increasingly challenged to construct wetlands successfully to satisfy permit conditions issued pursuant to state and federal wetland protection laws. The permit usually stipulates conditions under which wetlands must be constructed to insure compensation for wetland loss. Often the conditions require an 85 percent survival of planted materials per unit area, as determined at the beginning of the second growing season (*1*). If this survival rate is not met, the applicant may be required to reconstruct the wetland. Thus, improper design or construction could result in considerable costs to the applicant.

Wetlands are not necessarily easily constructed, and the 85 percent survival rate is neither readily achievable nor scientifically based. Although guidelines for planting these sites are available (*1–5*), the science or technology of wetland construction is still new and experimental. Most of the literature concentrates on the techniques to establish tidal salt and brackish marshes. Although the practice of constructing marshes has become relatively commonplace, follow-up studies evaluating the factors influencing the success of these communities are sparse. There is a growing demand to identify the factors affecting the survival rates of planted materials and the colonization by invading species in constructed freshwater marshes.

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In June 1987, the Maryland State Highway Administration completed construction of a 0.8-hectare freshwater tidal marsh on Marley Creek, Anne Arundel County, as a mitigation project for impacts associated with the construction of the Arundel Expressway. Research was initiated at completion of site construction to investigate aspects of the initial stages (0–2 years) of marsh development. Reported in this paper are the results for the first growing season extending into the following spring (May 1987 through June 1988).

The objective of this study was to observe the vegetation dynamics of a constructed freshwater tidal marsh, specifically the revegetation process and the survival of planted materials. Elevation was used to evaluate the extent to which tidal inundation determines individual species distribution. To accomplish this, the relative elevation ranges of individual species were determined and compared for the constructed marsh and for a neighboring natural marsh located across the Marley Creek channel from the constructed marsh. Since the planted species were placed within elevation ranges found for these and other wetland species in the natural marsh, this study permitted the identification of additional factors influencing survivorship.

AREA DESCRIPTION

The study site encompasses the constructed and natural freshwater tidal marshes adjacent to Marley Creek (39°9′10″ N, 76°35′15″ W), Harundale, Anne Arundel County, Maryland. Marley Creek is an estuary in the Chesapeake Bay watershed that joins the Patapsco River just south of Baltimore. The study area is located approximately 8 km upstream from the Patapsco River and less than 1 km from the end tidal influence. The average width of the creek measured at the study site is 15 m. At the Route 10 bridge, Marley Creek drains an area of 20.99 km^2.

Tides are diurnal, with a mean tide level at 0.18 m; predicted mean and spring tides are 0.34 m and 0.4 m, respectively (*6*). Mean low water (MLW) is −0.01 m below the National Geodetic Vertical Datum (NGVD); mean high water (MHW) is 0.33 m above NGVD.

The natural marsh sediments are classified as mixed alluvial land that consists of soil materials ranging from sand to clay (*7*). Land excavated to construct the new marsh was classified as Matawan loamy fine sand, 2 to 5 percent and/or Muirkirk

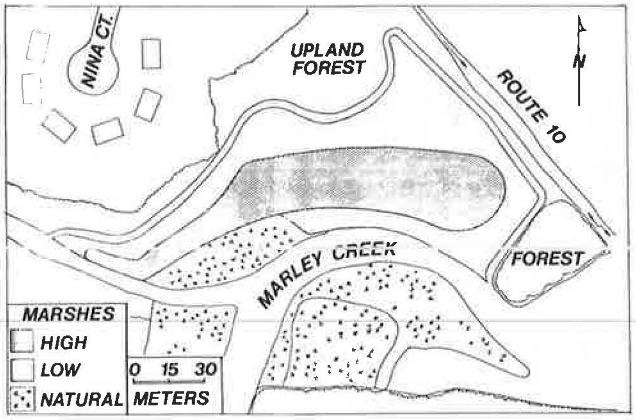

FIGURE 1 Marley Creek freshwater tidal constructed and natural marshes, Harundale, Anne Arundel County, Maryland.

loamy sand, 10 to 15 percent slopes. The upper horizons of these soils were removed to expose the underlying parent material of fine sandy mottled clay. Profiles at 1.02–1.52 m are described as very hard, firm, sticky and plastic, and strongly to very strongly acid (*7*). Measurements of soil pH taken September 1988 revealed a range of 3.6–6.2 for the constructed site sediments, in contrast to the constant 6.1 readings for the natural marsh sediments.

The Maryland State Highway Administration excavated what was originally forested upland to attain a freshwater tidal marsh (Figure 1). The original conceptual drawings were developed by Environmental Concern, Inc. (*8*). The constructed marsh was designed to have two zones, distinguished by elevation and by planted species. The plant species selected included those that (a) were naturally occurring in the area, (b) have been successfully used in wetland establishment projects, and (c) have been successfully developed and propagated in nurseries (*1*). The high marsh was to be graded to elevation 2.0 ± 0.20 ft above NGVD and planted with Olney threesquare (*Scirpus americanus*) and rice cutgrass (*Leersia oryzoides*). Arrow arum (*Peltandra virginica*) was planted in the low marsh that had a design grade of 1.2 ± 0.2 ft NGVD. The study area (Figure 1) includes the 0.8-hectare constructed marsh and the neighboring natural freshwater tidal marsh system. Grading was completed in May 1987; plantings were made between May 11 and 15 and June 9 and 13, 1987.

METHODS

The study area (including constructed and natural marsh) was sampled using a 6.1-m grid system. To provide data amenable to statistical data analysis, sample sites were located by using pairs of random numbers as coordinates in measuring with a tape from reference stakes. At least one point was located within each of 300 grids and permanently marked with reinforcing steel (rebar), which served to define the center point of a 1-m^2 circular sample quadrat. All vascular plant species (including seedlings) were recorded in each quadrat during July and October 1987. Species names follow Gleason and Cronquist (*9*). The numbers of live and dead planting units of *Scirpus americanus*, *Peltandra virginica*, and *Leersia oryzoides* were recorded in each quadrat during the July 1987 sampling.

Survival of *Peltandra virginica* was measured by taking a monthly census of 1,000 initial cohorts in permanent plot during the first growing season (June through October 1987) and the following spring (May 1988). Since the planting unit of *Scirpus americanus* was comprised of three to five plants per plug, individual cohorts could not be distinguished in the field; therefore, a proper census of survival of individuals could not be assessed. The rapid spread of *Scirpus americanus* also precluded the identification of individual planting units and measurement of survival for these units after July 1987. Survival for *Scirpus americanus* was measured for individual planting units as determined in the July 1987 quadrat sampling and related to elevation data.

Elevations were determined within each quadrat to the nearest 1.5 cm by transit and stadia board referenced to a Maryland Department of Transportation benchmark. More than one reading was taken depending on the quadrat surface relief (topographic conditions). Elevation data on the constructed site consisted mostly of one reading since the grading was relatively uniform, whereas elevations were read for each individual species on the natural marsh because of the microrelief.

RESULTS AND DISCUSSION

By July 1987, approximately 1 to 2 months after planting, the percent survival of *Scirpus americanus*, *Peltandra virginica*, and *Leersia oryzoides* were 65, 68, and less than 10 percent, respectively. Although *Peltandra virginica* incurred additional losses throughout the first growing season, most individual plants that survived by October 1987 overwintered and sprouted in May 1988. With the exception of one patch, which is completely devoid of vegetation, losses in *Scirpus americanus* were spatially compensated for through its rapid growth and attainment of 100 percent cover in many plots. The 65 percent survival is an underestimation because much of the *Scirpus* that seemed to die during the hot midsummer months lay dormant and sprouted later in September and October when the conditions were less severe. *Leersia oryzoides* suffered the greatest mortality rate apparently because of a combination of factors, including soil properties, reflectance of the soil, competition, and vandalism.

Several factors were expected to affect the population dynamics of species planted at the Marley Creek marsh. Critical factors identified for coastal wetland and dune restorations include wind and/or water transport and erosion, severe storms, available soil water, soil water salinity, soil nutrients, tide, drought, sudden temperature flucuations, ice damage and scouring, accretion, human activities, root damage by animals, weak planting stock, improper handling and/or storage of planting stock, and poor transplanting procedures, such as shallow planting and inadequate firming of sand around transplant base (*1, 10–12*).

Figure 2 illustrates the survival curve of *Peltandra virginica*. A referral to the aforementioned list of factors would show that apparently none of these contributed significantly to the demise of this planting effort. The low marsh was graded to meet design criteria and planted with fertilizer to insure suf-

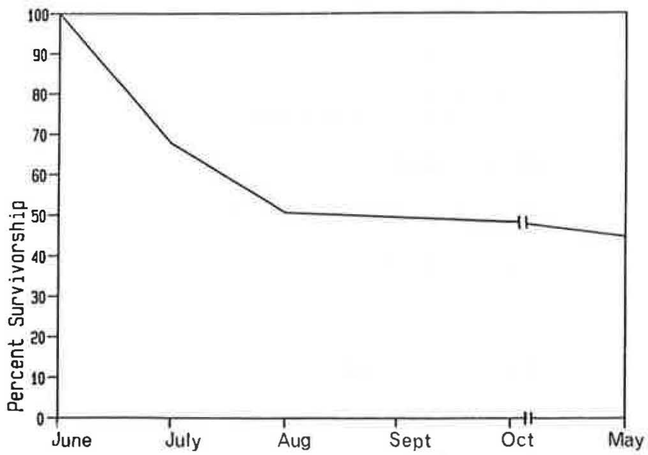

FIGURE 2 Percent survival of planted *Peltandra virginica* as a function of time (June 1987–May 1988).

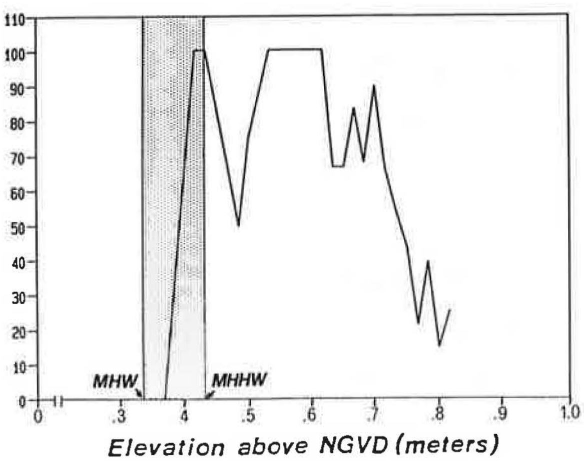

FIGURE 3 Percent survival of planted *Scirpus americanus* as a function of elevation above NGVD (July 1987).

ficient nutrient availability. Comparisons to the distribution of this species with respect to elevation in the natural marsh confirmed that the constructed low marsh elevations were within the range for the naturally occurring *Peltandra virginica* (see Figure 4b). Levels of mortality at various elevations within the low marsh revealed no significant preference of planted *Peltandra virginica* for any particular elevation. The mortality of *Peltandra virginica* cannot, therefore, be attributed to planting elevation. There were minimal losses due to vandalism (i.e., plants pulled out) and erosion of sediments from the high marsh edge into the low marsh. It appears that a major factor influencing survival may be the sediment properties such as particle size and pH, which are yet to be analyzed in detail. Initial measurements indicate a fine sandy mottled clay with a pH as low as 3.6.

Measurements of percent survival for *Scirpus americanus* (Figure 3) suggest that planting elevation may have affected its potential success in getting established in the constructed marsh. *Scirpus americanus* is not present in the natural marsh; therefore there was no basis for comparison within the study

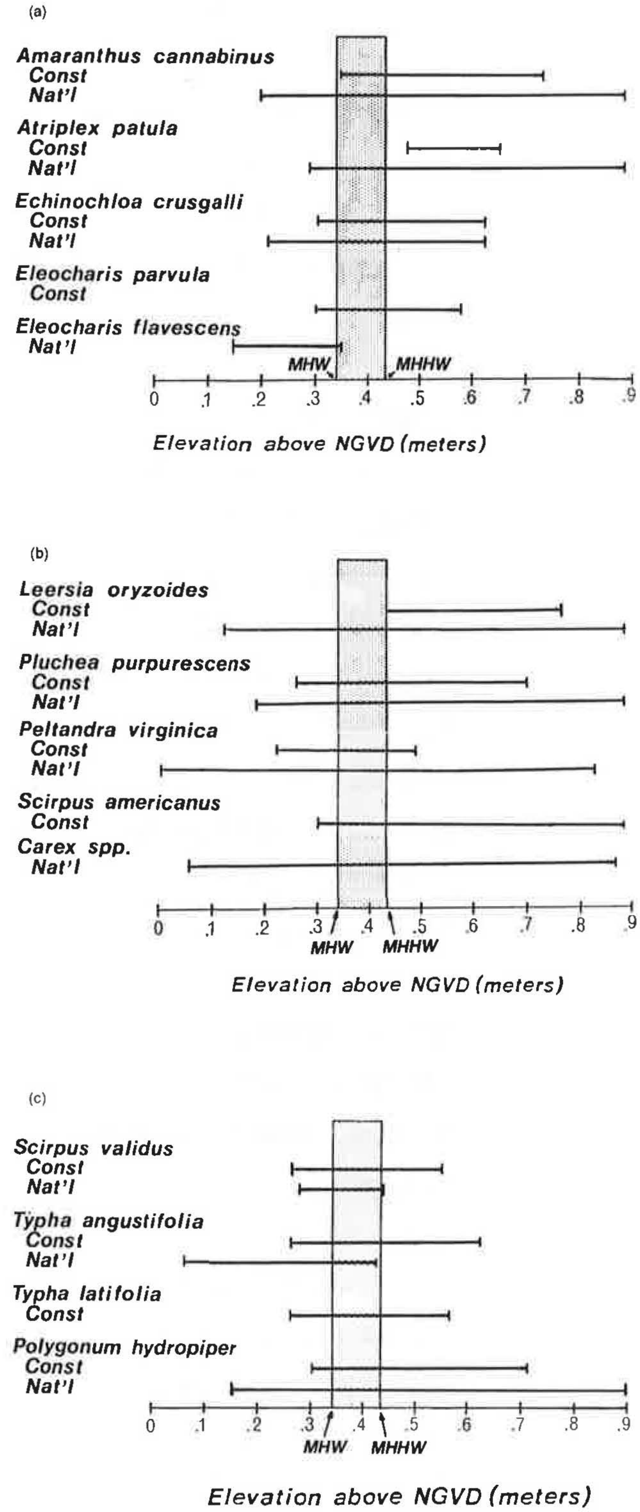

FIGURE 4 Elevation of plant species at Marley Creek constructed (Const) and natural (Nat'l) marshes. (a) *Amaranthus cannabinus, Atriplex patula, Echinochloa crusgalli, Eleocharis parvula, Eleocharis flavescens*; (b) *Leersia oryzoides, Pluchea purpuresceus, Peltandra virginica, Scirpus americanus,* Carex spp.; (c) *Scirpus validus, Typha angustifolia, Typha latifolia, Polygonum hydropiper.*

TABLE 1 PLANT SPECIES THAT COLONIZED MARLEY CREEK CONSTRUCTED MARSH BY OCTOBER 1987

Scientific Name	Common Name
Amaranthus cannabinus	Water Hemp
Aster subulatus	Annual Salt Marsh Aster
Atriplex patula	Marsh Orach
Carex spp.	Sedge
Cyperus Iria	Umbrella Sedge
Cyperus ovularis	Umbrella Sedge
Cyperus polystachyos	Umbrella Sedge
Cyperus retrorsus	Umbrella Sedge
Cyperus rivularis	Shining Cyperus
Cyperus strigosus	Straw-colored Cyperus
Cyperus tenuifolius	Umbrella Sedge
Echinochloa crusgalli	Barnyard grass
Eclipta alba	Eclipta
Eleocharis flavescens	Spike-rush
Eleocharis parvula	Dwarf spike-rush
Hibiscus moscheutos	Rose Mallow
Juncus acuminatus	Tapertip Rush
Juncus effusus	Soft rush
Osumunda regalis	Royal Fern
Panicum dichotomiflorum	Panic Grass
Pluchea purpurascans	Annual Salt marsh Fleabane
Polygonum hydropiper	Common Smartweed
Polygonum Persicaria	Smartweed
Pontedaria cordata	Pickeralweed
Sagittaria latifolia	Big-leaved Arrowhead
Scirpus validus	Soft-stemmed Bulrush
Typha angustifolia	Narrow-leaved Cattail
Typha latifolia	Broad-leaved Cattail

area to determine its normal elevation range under natural conditions. With the exception of a low value around 0.45 NGVD, the *Scirpus* generally maintained 100 percent survival between 0.40 and 0.60 NGVD and then followed a pattern of increased mortality with increased elevation. The low value at 0.45 NGVD appears to reflect the soil conditions in one patch of the marsh that remained devoid of vegetation throughout the first growing season.

Leersia oryzoides was planted within elevation ranges for which it was found in the natural marsh (Figure 4), yet it suffered the greatest mortality of all the species. The high mortality of *Leersia oryzoides* cannot be attributed to planting elevation and associated parameters (e.g., hydroperiod). Some losses were because of vandalism: vandals threw some of the plants out of the flats before planting, and it is assumed that the added shock may have resulted in the death of these few after planting. Initial observations suggest that reflectance of the sediment surface may have been a major contributor to the high mortality rates. The *Leersia* was primarily planted in a patch of light-colored, almost white sediments. In an adjacent area where the sediments were relatively darker, *Leersia* survived. When highly reflective aluminum tags were placed under a couple of these plants, they died within 2 to 3 days, suggesting that this species may be very sensitive to the high reflectance property of the light sediments.

The high mortality of *Leersia oryzoides* also may be attributed to sediment characteristics of the constructed marsh. Although *Leersia* is found at elevations well above mean high high water (MHHW) in the natural marsh, the substrate of fine silts remain saturated, providing sufficient water availability. In constrast, the sand-clay substrate of the constructed marsh at comparable elevations is not always saturated and appears to be more dependent on precipitation events than on the tidal influence. In terms of elevation, the potential distribution of *Leersia oryzoides* may be significantly more narrow on the constructed site because of the sediment properties.

In addition to the planted species, the elevation ranges of major invading species were also recorded and compared with distributions at the natural marsh (Figure 4a–c). With the exception of *Scirpus validus*, plant species invading the constructed marsh occupied a more narrow range. This narrow range may reflect the germination requirements of the individual species; that is, the seeds germinated where the moisture and temperature conditions were most suitable. If this is the case, then during the following growing season one might expect a shift in distribution as determined by differences in storm events, tide cycle, and temperature at seed set. The recorded distributions may also be more permanent and represent the realized niche breadth under various sediment conditions. In providing more saturated conditions, the silt substrate of the natural marsh may widen the potential elevation distribution range.

Included in Figure 4 is a comparison of *Scirpus americanus* and *Carex* species. The purpose of this comparison is to demonstrate that the natural marsh surface extends well above the MHHW level of the tides and yet it is still a wetland. Although the constructed wetland was graded, in part, higher than the design grade, the distribution of *Scirpus americanus* illustrates that these elevations are within the range found under natural conditions. Table 1 provides a list of all 28 plant species that colonized the constructed wetland within the first growing season.

CONCLUSIONS

Although elevation may be an important factor in the design and construction of a freshwater tidal marsh, other factors may have a significant role in determining the survival of planted materials. Comparison of a natural system with a constructed marsh revealed that differences in sediment properties, including grain size, reflectance, and pH may limit the potential distribution for both planted and invading species in the constructed marsh. Therefore, it is recommended that potential physical limitations of the sediment base be evaluated if, in the planning of marsh construction, the sediment base differs in composition from that of neighboring natural marshes. If an area is to be excavated to parent material, information should be gathered regarding the physical properties of these sediments.

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Special thanks go to Ed Garbisch for his support and encouragement during all facets of this research.

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Participatory Process for Managing Roadside Vegetation

DEBORAH M. SHANAHAN AND RICHARD C. SMARDON

New York State has adopted a manual containing a checklist that provides a replicable means by which local community groups can nominate roads for scenic designation by the state. The authors propose a similar approach to managing roadside vegetation. The comprehensive, yet simple, format consists of guidelines and a series of forms organized in workbook style. This format helps record the information necessary for evaluating management alternatives and improves communication between scenic conservationists and roadway crews.

The Scenic Byways' 88 Conference in Washington, D.C., showed that many states are involved in grass roots activity to protect and manage scenic roads. These roads are the byways that William Least Heat Moon termed "Blue Highways," stretching over 3 million miles in the form of two-lane roads in the United States. How do we protect and manage such linear landscapes? This is the theme of this paper.

In previous Transportation Research Records we reported on current projects to manage vegetation along the Blue Ridge Parkway (*1*) and the use of citizen involvement to visually improve commercial strip highways (*2*). In this paper we discuss two participatory processes that relate to scenic roads. The paper briefly summarizes a manual that provides straightforward guidance in identifying scenic roads in New York State and focuses on a process for managing roadside vegetation—one of the most important landscape elements.

CURRENT SCENIC ROADS PROGRAMS NATIONWIDE

Almost every state in the United States has taken some type of action to recognize its scenic roads. Twenty-three states have established programs to designate them and three more are considering such programs. Fifteen of the states without formal programs have an official list of historic or scenic roads. Several of the remaining states have no program or list because it is generally believed that since so many of their roads are scenic, it would be difficult to choose among them (*3*).

How scenic roads are managed influences how successful they are as public amenities. The governmental level at which the scenic road is managed depends on the provisions of the state program. Some states manage all scenic roads; others keep the jurisdiction unchanged after the road has been designated as scenic. Some programs provide maps and other promotional information; some identify the routes with special signs. Scenic beauty has been preserved by the acquisition of easements, the removal of billboards, and the removal or screening of junkyards. Recreational opportunities have been enhanced along many roads with facilities such as scenic overlooks, rest stops, and trails (*3*).

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NEW YORK'S SCENIC ROADS PROGRAM

Article 49 of the New York State Environmental Conservation Laws permits the preservation of scenic resources including those along roads. Interest in establishing a scenic road program grew in the 1960s, but ebbed in 1970 with the abolishment of the Natural Beauty Commission. Communities in the Hudson River Valley continued their efforts, nominating roads by using existing methods for evaluating roadside scenery. Their activities are largely responsible for the current state program initiated three years ago. Virtually all of New York State's designated scenic roads are near the Hudson. The program's dependence on local initiation, coupled with a nomination method that required a moderate understanding of the principles of aesthetic perception, may have kept other communities from participating in the program.

In 1987 the Department of Environmental Conservation (DEC) in cooperation with the State University of New York remedied the situation by developing a simple nomination method contained in *A Manual for Designating Scenic Roads* (*4*). The intent was to eliminate the need for expertise in aesthetics, allowing volunteers to play a large role in nominating roads. The manual includes a checklist (Figure 1), a step-by-step procedure for nominating roads, and the criteria that the state uses for designation. It also contains an illustrated glossary and suggested letters and maps to clarify scenic terms and provide help in organizing information. This approach provides a replicable format to which statewide designation criteria can be applied, yet it allows local initiation and implementation of the process.

The decision to allow local, as opposed to centralized, initiation of the selection of scenic roads has several benefits. Assuming that this system eliminates the need for establishing "circuit-riding" teams of evaluators, the opportunity for communities to nominate scenic roads on their own initiative—rather than waiting on a list—suggests that many roads could be nominated throughout the state within a short time. The total mileage of scenic roads is not an issue; rather the issue is that communities be actively involved in the nomination process and in charge of management of their respective scenic roads. In exchange for conformity and cooperation in nominating and managing scenic roads, communities receive the recognition of an official State Scenic Roads Program.

SURVEY CODE

√ Visible component

(√) Vegetation screens component

• Component is in right-of-way

COUNTY ______ TOWN ______
DATE ______ WEATHER ______
ROAD ______
DIRECTION ______ MILE ______ OF ______

TEAM MEMBERS ______

Positive Sub-Total ______
less Negative Sub-Total ______
= Total Scenic Elements ______

NOTES:

POSITIVE COMPONENTS

A. WATER & LANDFORM FEATURES

1. Lake, Pond, Marsh or Wetland
2. River or Brook
3. Waterfall
4. Cliff, Boulder, or Rock Outcrop
5. Hill or Mountain
6. Other, or Special Regional Feature ______

B. LANDSCAPE COMPOSITION & EFFECTS

1. Enframed, Enclosed, or Valley View
2. Panoramic or Distant View
3. Ephemeral Effect (Sunset, mist, reflection)
4. Seasonal Effect (Ice formations, brilliant foliage)
5. Other Natural Effect ______

C. VEGETATION

1. City Park
2. Agricultural Pattern (orchard, contour plowing)
3. Field & Forest Edge
4. Woodland, or Tree Pattern (Species mix, hedgerow)
5. Mass of Wildflowers or Ferns
6. Other (Heritage tree, leaf tunnel effect) ______

D. STRUCTURES

1. Picturesque Farmsteador Unusual Building
2. Historic Structure or Archeological Site
3. Covered or Other Bridge
4. Stone Wall or Wooden Fence
5. Cemetery
6. Distant Village, or Village Edge
7. City Skyline
8. Other (Roadside art, fountain) ______

E. ROAD CHARACTERISTICS

1. Road Conforming to Landscape
2. Road Pattern (Cobblestone, brick, gravel)
3. Rustic Drainage Mechanism

POSITIVE SUB-TOTAL ______

NEGATIVE COMPONENTS

A. LANDSCAPE SCARS

1. Lumbering Scar or Slash
2. Erosion
3. Gravel or Sand Mining Operation
4. Utility Line, Corridor, or Substation
5. Angular Road Cut or Fill

B. STRUCTURES

1. Strip Development
2. Incompatible Town Bldg (Style, material, lot size)
3. Incompatible Rural Bldg (Non-farm, non-residential)
4. Incompatible Fence or Wall (Scale, style, material)
5. Dilapidated Building
6. Dilapidated Fence, or Wall
7. Gas Station or Auto Repair Shop
8. Outdoor Auto Sales or Large Parking Lot
9. Junkyard or Landfill
10. Storage Tanks
11. Obtrusive signage (size, too many, flashing)
12. Stark Drainage System (Straight rows of rip-rap, protruding culvert)

C. OTHER

1. Litter
2. Heavy Traffic
3. Polluted Water
4. Structures Blocking View

NEGATIVE SUB-TOTAL ______

FIGURE 1 Scenic roads evaluation form.

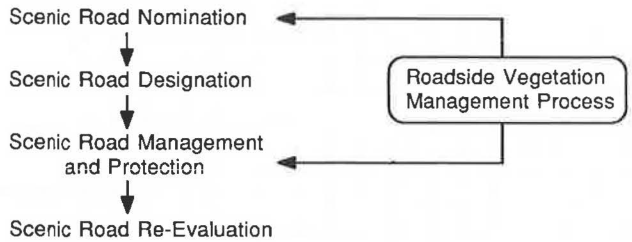


FIGURE 2 Interrelationship between scenic road designation and vegetation management processes.

MANAGING VEGETATION ALONG THE SCENIC ROADS

Like the selection process, the management of scenic roads in New York State is a local responsibility. Furthermore, the DEC reevaluates scenic roads every four years to determine whether or not they still meet the selection criteria. These two factors encourage the preparation of a management plan for each scenic road section to preserve and enhance its scenic resources. The designation manual lists components for such plans, placing emphasis on responses to roadside development pressures. On a more immediate level, however, management should address maintenance to keep the roadway itself attractive and the scenery visible. A vegetation management plan would fulfill these requirements. On some roads, vegetation management planning might begin before their nomination file is submitted to DEC (Figure 2). For example, the Scenic Roads Evaluation Form in Figure 1 provides a code for indicating components screened by vegetation. Guidelines would be useful for determining how much vegetation must be removed to effectively open the view and whether removing that vegetation would reduce the scenic quality of the roadside vegetation.

A review of the literature reveals that, although it is generally recognized that road maintenance requires a professional approach and adequate budget (*5*), historically neither requirement has been consistently fulfilled (*6,7*). Almost 100 years ago, New York used volunteer labor to maintain roads (*8*), but the details of penalties for refusing to work imply a lack of popular enthusiasm.

Where highway departments lack professional or technical staff (as in small communities) a companion to the designation manual—one that deals specifically with vegetation management—would be particularly helpful. If both manuals were similar in approach and method of use, some of the information collected during the scenic road designation process could be used in developing the vegetation management plan. Then the planning process could become a continuation of the designation process.

The management of roadside vegetation that might obscure or enhance scenery lends itself to public participation. The work can be time-consuming yet sporadic; in addition, good weather conditions may not correspond to the work schedules of the highway staff. Under these kinds of circumstances volunteers may best be able to provide the kind of flexibility that this work requires. The potential for confusion among highway workers at the state, county, or local level and a changing cadre of volunteers, however, would require a management process that recognizes the need for a highway supervisor to take the lead at the appropriate jurisdictional level. In the proposed process (*9*), a citizens' committee uses a workbook to perform the survey of the roadside, help develop the management objectives, communicate the recommendations and guidelines of the committee to the supervisor, and evaluate the finished work (Figure 3). Supervisors would maintain their authority over and status in relation to the work force.

The volunteers need to identify the issues and arrive at a comprehensive list of objectives for the roadside. What do

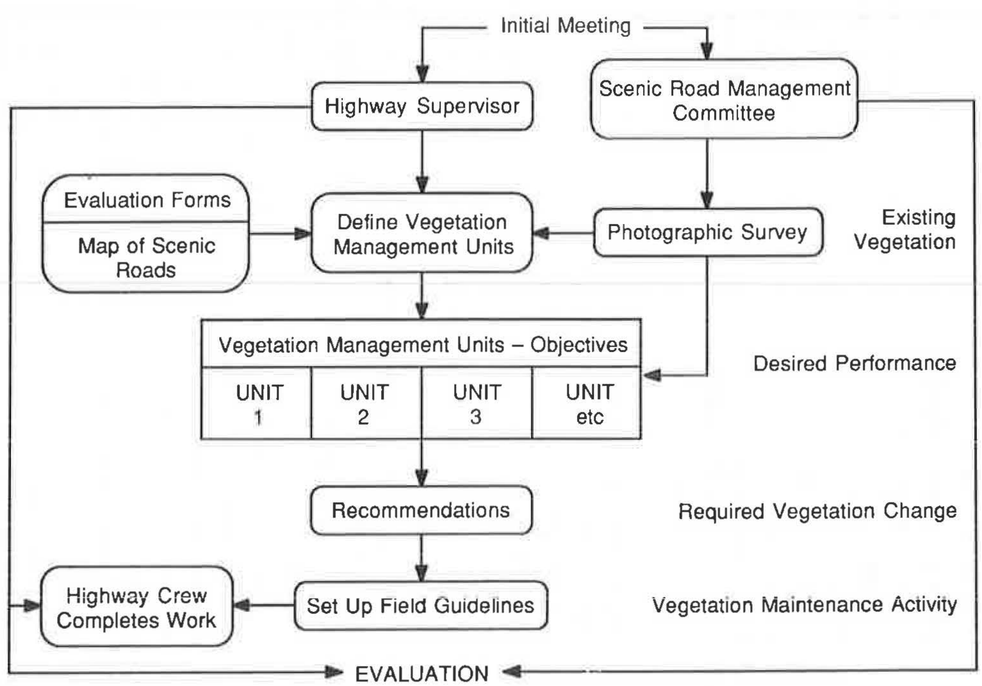


FIGURE 3 Vegetation management process.

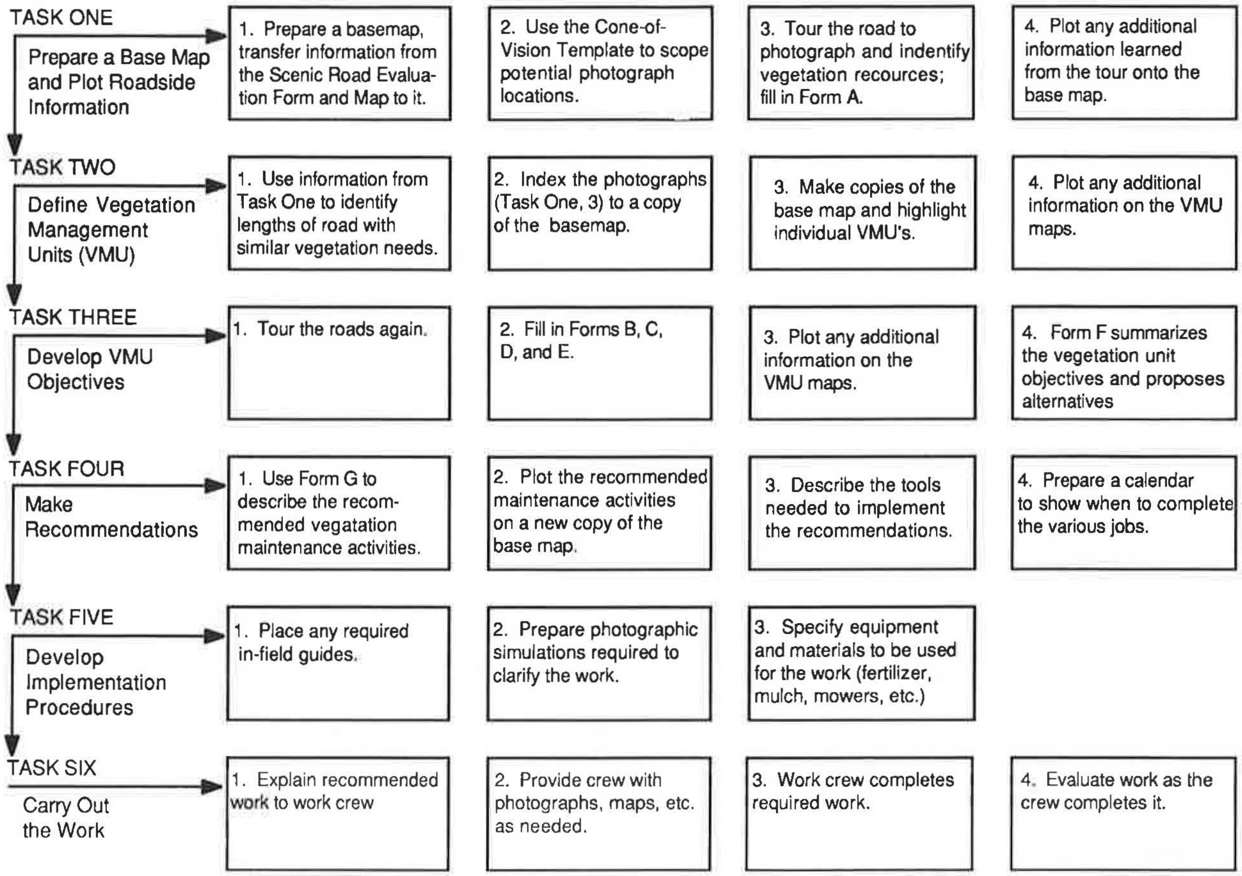


FIGURE 4 Organization of tasks in the vegetation management process.

they do and how do they do it? The two-part workbook (*9*) developed at the State University of New York, Syracuse, contains a series of forms and a set of guidelines that address potential roadside issues. The forms are completed as part of six tasks that make up the vegetation management system. Instructions for completing each task and filling out and using the information on each form are written in a step-by-step format. Any step that might be unfamiliar has a page reference to an explanation in the guidelines section of the workbook where details and careful work are emphasized. The guidelines also clarify most of the common maintenance tasks and explain their effects on scenery.

The main consideration in the development of the workbook was that resulting management plans should not conflict with the process and criteria in the *Manual for Designating Scenic Roads*. Beyond that, the workbook has six general goals.

1. The workbook should provide both an overview and complete details of the entire management process. In small communities there may be nobody among the participants with an adequate understanding of all the visual, environmental, and safety functions of the roadside. A diagram of all the activities involved in the management process and their relationship to each other helps to identify critical activities and can easily be modified into a flowchart and timetable to ease the transition from the planning to the action phase (Figure 4). The individual steps in the process describe how to fill out the forms, what information is useful, and where to obtain it. The chart also lists the equipment required and refers to sections of the guidelines that explain in detail how to complete complicated procedures.

2. The workbook should help participants in the process determine the visual and environmental issues and the potential conflicts of the roadside. The parties actively involved in managing or living near a length of road may have conflicting or vague objectives. A series of questionnaire forms helps to identify those conflicts (Figure 5). Some questions relate to the illustrated guidelines or to activities and questions completed on previous forms; others require making observations while driving or doing research on public documents. The guidelines help to evaluate and resolve conflicts in the collected information thus facilitating decisions on visual, environmental, or vegetation objectives for each section of road.

3. The workbook should emphasize the difference between the visual experience of drivers and those of stationary or slow-moving observers. Since driving is dynamic, the process requires the collection of some information on the road at traveling speeds. Several forms contain questions that relate road conformation to views and speed, reinforcing the need to consider safety. For desk work, tools such as a cone-of-vision template help interpret mapped information from the traveler's point of view (Figure 6).

FORM B — VISUAL ISSUES

VMU # _____ Form # _____

Issues

1. Describe the beginning and ending landmarks that define the length of the road where the view is visible, or where it would be visible if vegetation were removed.

____

____

2. Locate the viewing distance (p. 14): Foreground _____ Mid-ground _____ Background _____

3. Viewer position (p. 14): Normal _____ Viewer Superior _____ Viewer Inferior _____

4. Must the driver turn his head more than 10° to see the view (field check TASK ONE, Step 2) _______

5. Is the view at the beginning of a curve? ______________ in the middle of a sharp curve? __________

6. Is the view visible elsewhere on the road? _____________ VMU# _________ Form B# ___________

7. How does the vegetation itself contribute to the view? (Eg., focal point, frames or blocks view)

Positive ____

____

Negative ____

____

8. Describe any seasonal differences in vegetation that significantly affect scenic quality:

Positive ____

Negative ____

9. Adjacent land use(s) (Residential, Park, Commercial, etc.):______________________________

10. Adjacent land cover(s) (Lake, Fields, Orchards, Wooded, etc.): ___________________________

Objectives

Based on the answers to the above questions, briefly describe how vegetation management could modify or enhance the scenery in this unit.

____

____

____

____

____

____

____

____

____

____

FIGURE 5 Sample forms.

FORM F — VEGETATION UNIT OBJECTIVES

VMU # _____

General questions

1. Briefly describe the vegetation management unit. ______

2. Who maintains the right-of-way vegetation now? (County, local, private, etc.) ______

3. Briefly describe current maintenance practices ______

4. Are changes to vegetation likely to be controversial? ____ Describe ______

5. List any comments or questions from adjacent landowners regarding maintenance practices

6. List any comments or questions that motorists have concerning the view or road conditions

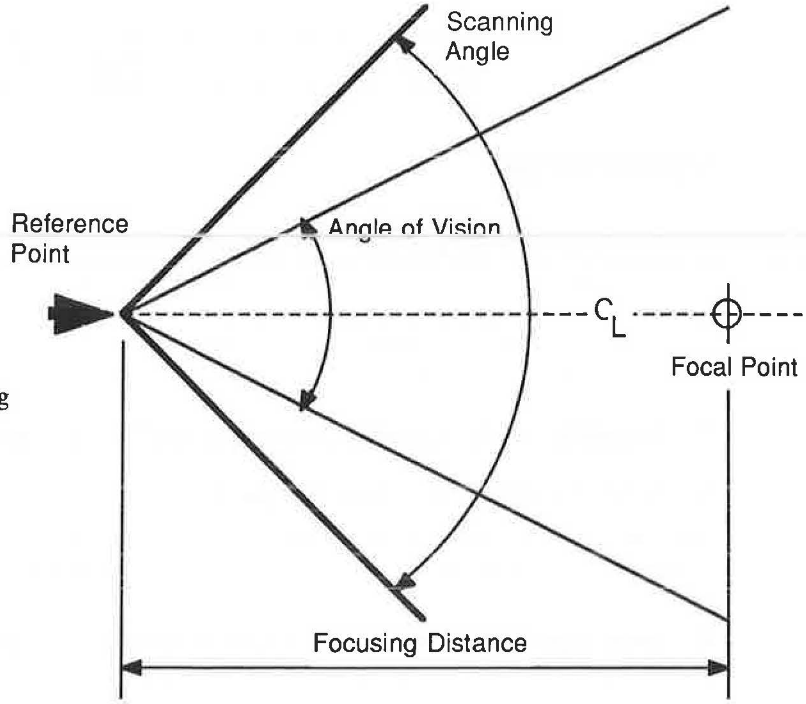
Summary and Recommendations

1. From the "objectives" on **Forms B, C,** and **D**, describe any conflicts that exist among the visual, environmental, or vegetation objectives.

2. Recommended alternatives and specifications :

3. Are changes in current practices necessary? ______

FIGURE 5 ***(continued)***



Design Speed	Focusing Distance	Angle of Vision	Scanning Angle
25 mph	600 ft	100°	120°
30	800	90	110
40	1100	75	95
50	1400	60	80
60	1800	40	60

FIGURE 6 Diagram and table for constructing a cone-of-vision template.

4. The workbook should give maintenance crews and volunteers descriptions and illustrations of maintenance and data collection methods. Some of the guidelines are modifications of ones provided by the state highway department; the guidelines encourage maintenance of scenic roads similar to that of other roads. Many of the grass-cutting and brush-trimming guidelines and all those relating to design, visibility, and safety have been specifically written for use on scenic roads. Where necessary, small sketches illustrate difficult concepts (Figure 7). Specific data collection methods such as photography are described in detail. The workbook provides a sample form for recording the camera location of photographs and explains a simple storage and retrieval system for them.

5. The workbook should encourage communication and collaboration among all parties involved in roadside management. Although roads will most likely be nominated by a town or county, they can be nominated at any level of government. The process requires that the highway supervisor from the governing area in which the nomination is initiated coordinate the management process. The supervisor meets with community volunteers and heads the lead agency that reviews proposed roadside maintenance activities of highway departments at various government levels. Because they consolidate data from other sources, the forms help the supervisor to understand problems or coordinate maintenance activities.

6. The workbook should provide highway supervisors with a descriptive and visual plan for roadside maintenance. A base map provides a visual record of activities that are completed along the roadside. The guidelines describe the preparation of a base map, and the workbook recommends information to be added to it from various forms (Figure 8). The book provides a permanent record of important scenic components that are the basis for management decisions, and it can be annotated to identify areas that require changes.

DISCUSSION OF THE WORKBOOK

The proposed workbook is not a compilation of research on proven methods of roadside management. It is, however, a response to an expressed need for the cooperation of the crews who maintain roadside vegetation to do their work to enhance scenic quality. The workbook offers a system of support to both supervisors and workers, especially if they lack formal training related to vegetation or aesthetics. The book has the potential to be the subject of research that inquires into various aspects of its usefulness: Is the workbook easy to use? What has been the impact of the workbook on visual quality of the road, safety, and the function of the roadside as wildlife habitat?

Finally, there are other possible uses for this workbook. Obviously, the book could be used for any roadside, whether or not it is scenic. With modifications, it could also be used to develop aesthetic, environmental, and vegetation improvement goals for urban or rural greenspaces and for land owned by condominium associations or shopping malls. The major function of the book is to provide local community groups with a starting point for organizing physical improvements of public areas regardless of the expertise of the members of these groups.

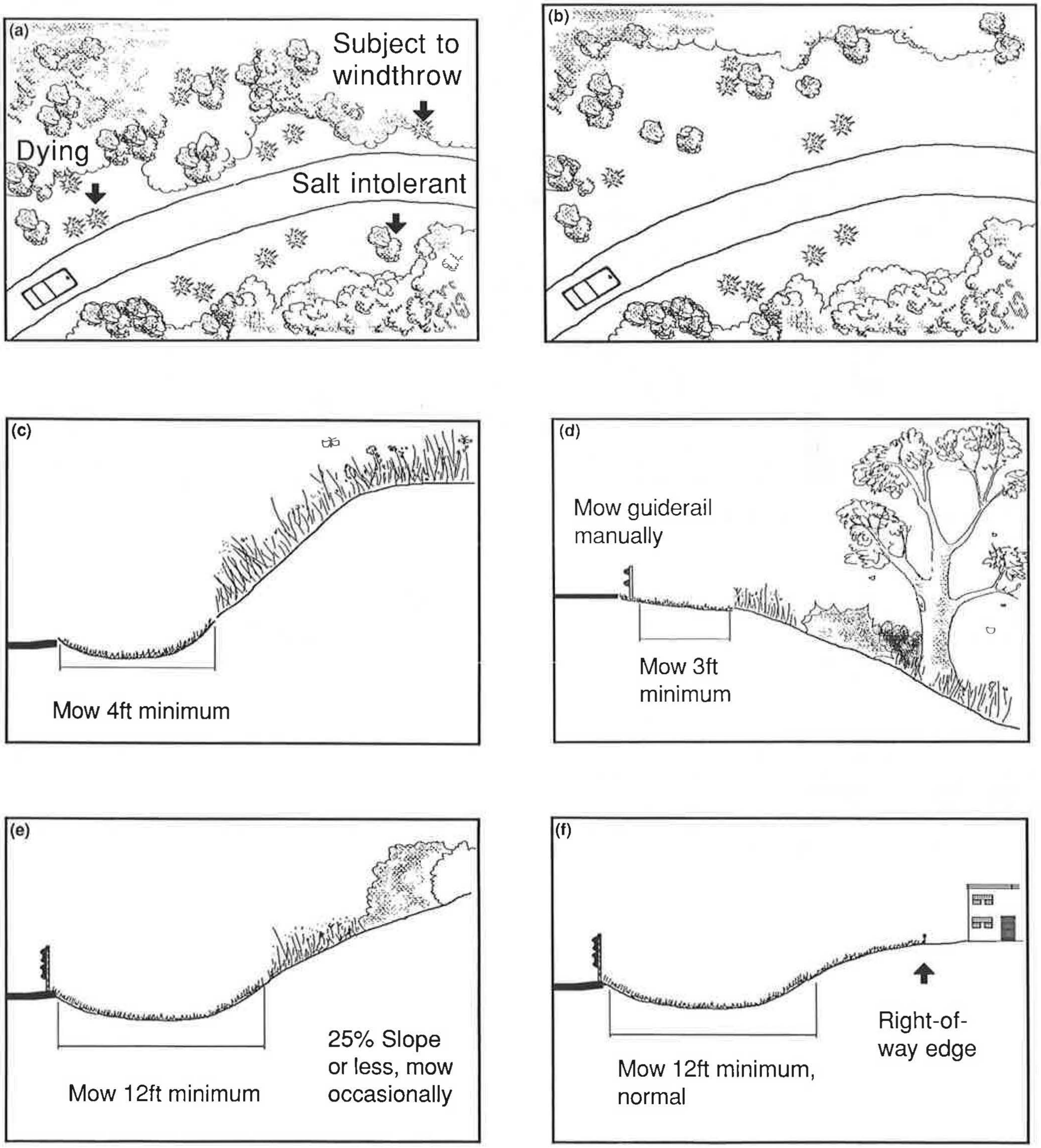


FIGURE 7 **Sample guideline illustrations. (a) Choosing trees to remove for a feathered edge, (b) feathered edge, (c) mowing on steep cuts, (d) mowing on steep fills, (e) mowing in rural areas, and (f) mowing in urban zones.**

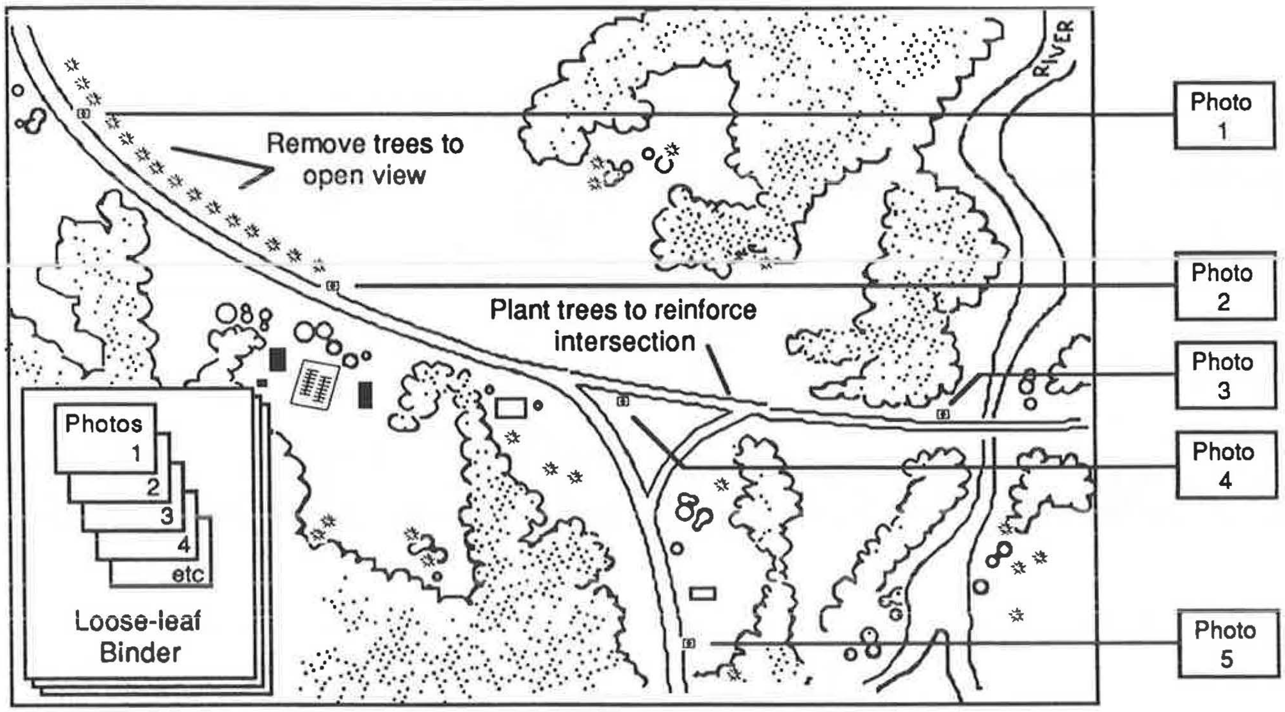


FIGURE 8 Base map with keyed photographs.

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Evaluation of a New Method of Restoring a Salt Marsh by Channelization of a Highway Spoil Barren

Bruce A. Pruitt, Percy B. Middlebrooks, Jr., and Fred K. Parrish

A bare coastal Georgian spoil area located in a smooth cordgrass (*Spartina alterniflora* Loisel.) salt marsh was channelized by using an amphibious rotary ditcher to evaluate its use in marsh restoration. The method has been found to offer an inexpensive and rapid, yet safe, technique of wetland mitigation in salt marshes that exhibit the proper hydrological and elevational characteristics. Amphibious rotary ditching has been found to have less of an impact on the marsh than excavation, which usually requires large earth-moving equipment, earth mats, site access, and traffic control. The surcharge is dispersed evenly to either side of the ditcher onto the marsh; thus, an upland disposal site is not required. In this case, the impact from the rotary ditcher's tracks and side-cast material to the existing salt marsh communities surrounding the spoil was temporary. Recovery and even enhancement of existing *S. alterniflora* communities has been rapid. Compared with an unchannelized (reference) spoil area, the marsh restoration channel has increased tidal frequency, duration, and flushing during ebb tide. In spite of drought, *S. alterniflora* coverage on the channelized spoil zone more than doubled over the first 2 years after the construction of the channel. Remote sensing using aerial photography has revealed a 42 percent decrease in unvegetated area on the channelized site.

The value of wetlands is now known and appreciated (*1*). In 1973 it was estimated that the total life support value per acre of salt marsh equaled $83,000 [income-capitalization value per acre at an interest rate of 5 percent (*2*)]. In 1986 it was estimated that fish production and waste assimilation values of wetlands were $10,333 and $6,225 per acre, respectively (*3*).

With the addition of two lanes to Torras Causeway, which connects St. Simons Island to the mainland in Glynn County, Ga., filling of some of the adjacent salt marsh could not be avoided. To mitigate this wetland loss, the U.S. Army Corps of Engineers and the reviewing agencies recommended (a) restoration of the spoil sites paralleling the causeway to smooth cordgrass (*Spartina alterniflora* Loisel.) marsh, (b) retention and modification of some of the existing bridges for fishing piers with access, and (c) construction of a paved bicycle path parallel to the causeway. *S. alterniflora* has been used extensively on the East Coast to stabilize intertidal spoil disposal sites (*4*).

The most widely accepted method in the past of stimulating marsh restoration was removal of a sufficient amount of spoil from the surface of a disposal site to reduce elevations and increase the frequency of tidal inundation. Recent investigations suggest that, in addition to tidal frequency and duration, the retention time of standing water after a high-tide cycle can influence the productivity of a salt marsh (*5*). Standing water can reduce the availability of oxygen to plant roots and rhizomes, but, even more devastating, it may increase soil salinities as a result of evaporation. This investigation explores the use of a different restoration technique to achieve an increase in the frequency of tidal flooding and a decrease in the retention time after a high-tide cycle.

In both Glynn and Chatham counties on the coast of Georgia, the Mosquito Control Department has employed an innovative method of ditching mosquito breeding areas. This method entails the use of an amphibious rotary ditcher that is able to simultaneously traverse and ditch areas of unstable substrates such as salt marshes. Depending on the composition of the substrate and the speed and design of the rotary ditcher, depths of 3 to 4 ft can be achieved with a single pass. Over several years of using this method of mosquito control, the Mosquito Control Department in both counties noted not only a reduction in mosquitos in recently ditched sites but, in some instances, an enhanced growth of salt marsh vegetation along and adjacent to the ditches (J. Carter, personal communication, 1985). Investigation of the potential of amphibious rotary ditching in salt marsh restoration had not been fully explored before this study. The investigation was designed to address the following questions:

1. Has channelization increased tidal frequency and duration?
2. Is channelization able to promote and maintain *Spartina*?
3. Will channelization provide additional growth and habitat diversity to the existing short *Spartina* found on the spoil fringe area and the marsh restoration channel (MRC) connectors?

SITE DESCRIPTION

Located on the coast of Georgia in Glynn County (Figure 1), the mitigation site parallels Torras Causeway, which connects St. Simons Island to the mainland at Brunswick. During construction of the original causeway in 1950, spoil from the

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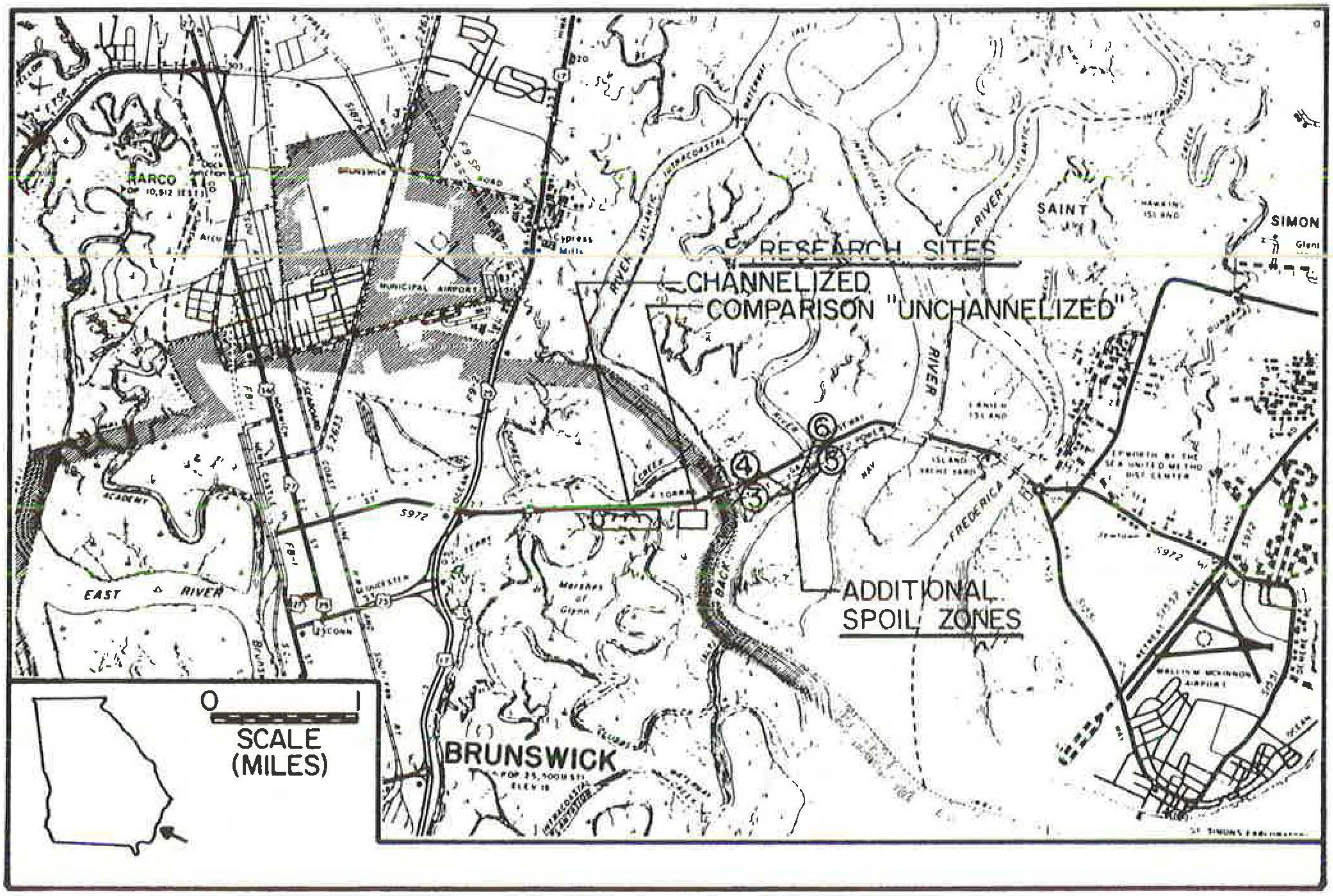

FIGURE 1 Project location (Torras Causeway, Glynn County, Georgia).

demucking process of the future roadbed was surcharged on the salt marsh adjacent to the highway. The spoil elevated the marsh and had an adverse effect on the smooth cordgrass (*S. alterniflora*) communities. *S. alterniflora* is the most frequent plant species in the salt marshes of Georgia (*6*). Because of the elevated condition, normal patterns of tidal frequency and duration of the spoil areas were interrupted, and the marsh was not able to regain its previous state of productivity. Salinity, tidal inundation, soil type and drainage, and competition by other species influence plant distribution within salt marshes (*7*). The resulting salt pans or salt barrens (*6*) have persisted for years, and soil salinities have become elevated evidently because of evaporation of standing water from an occasional spring high tide. Six spoil areas have been identified adjacent to the causeway and will require restoration as part of the mitigation (Figure 1).

MATERIALS AND SAMPLING METHODS

Channelization of the MRC began on August 28, 1985, but because of equipment failure, ditching was not completed until October 10, 1985. Approximately 1.5 km (0.93 mi) of channelization was completed, which included the main MRC (approximately 2,800 ft long); secondary MRCs (approximately 100 ft long); and the east, west, and intermediate connectors to the natural tidal creeks (Figures 2 and 3). Mean channel dimensions immediately after channelization ranged from 1.28 to 1.43 m (4.2 to 4.7 ft) wide and 0.7 to 0.79 m (2.3 to 2.6 ft) deep. The majority of the side-cast material was discharged 4 to 5 m from the rotary ditcher to either side of the MRC.

MRC Geomorphology

The MRC was monitored at predetermined stations for changes in width and depth due to erosion and deposition. Width and depth measurements were made to the nearest centimeter by using standard wooden meter sticks. The MRC width was measured from edge to edge of the MRC banks, and the depth was measured at the center while using an additional meter stick positioned level with the MRC edges.

MRC erosion-deposition stations were grouped for analysis on the basis of station location, soil composition, and presence or absence of vegetation. Additional categories included stations that received rhizomatous damage from the rotary ditcher during channelization and the mouths of the east and west connectors and the secondary MRCs.

Permanent Quadrats

A total of 16 permanent quadrats (PQ) were installed after channelization was completed. Twelve quadrats (PQ-0, PQ-00, PQ-1 through PQ-10) were located on the channelized

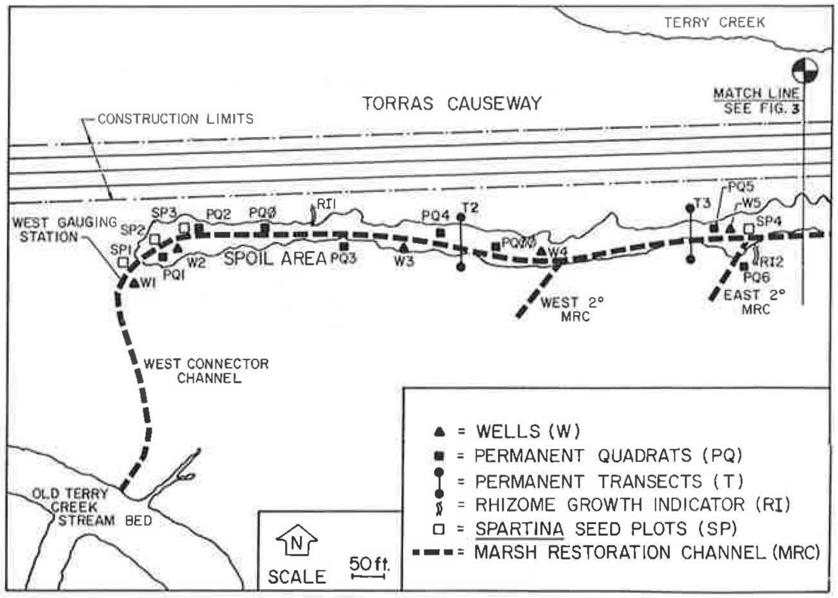

FIGURE 2. Channelized site (mitigation site 1): west connector.

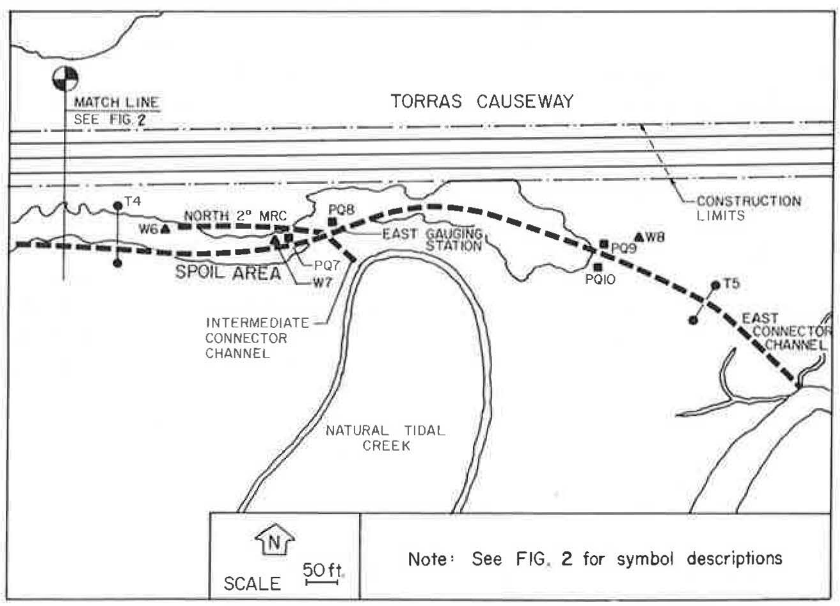

FIGURE 3 Channelized site (mitigation site 1): east and intermediate connectors.

research site and four quadrats (PQ-11 through PQ-14) were located on the unchannelized research site. The quadrat location was permanently marked by installing a 0.5-in.-diameter schedule 40 polyvinyl chloride (PVC) pipe that was approximately 4 ft long. A 1-m^2 quadrat frame was positioned with the permanent PVC marker in the southwest corner of the frame. The quadrat frame was assembled from precut 0.5-in.-diameter schedule 40 PVC pipe and 90° elbows.

Rhizomatous Growth Indicator Plots

Two rhizomatous growth indicator plots were permanently positioned April 10, 1986, on the channelized research site. Wood stakes and surveyor's flagging were used to create a line of demarcation between *S. alterniflora* vegetation and unvegetated spoil. Any growth that obviously resulted from rhizomatous mitigation across the line of demarcation was noted during subsequent sampling excursions. Plant taxa, numbers, and heights were measured and logged.

Random Quadrats

Random quadrat sampling was conducted in the fall of 1986 and 1987. In fall 1986, random quadrat sampling was initiated on October 18 and was completed on October 19 and November 4. All random quadrat sampling was completed on Octo-

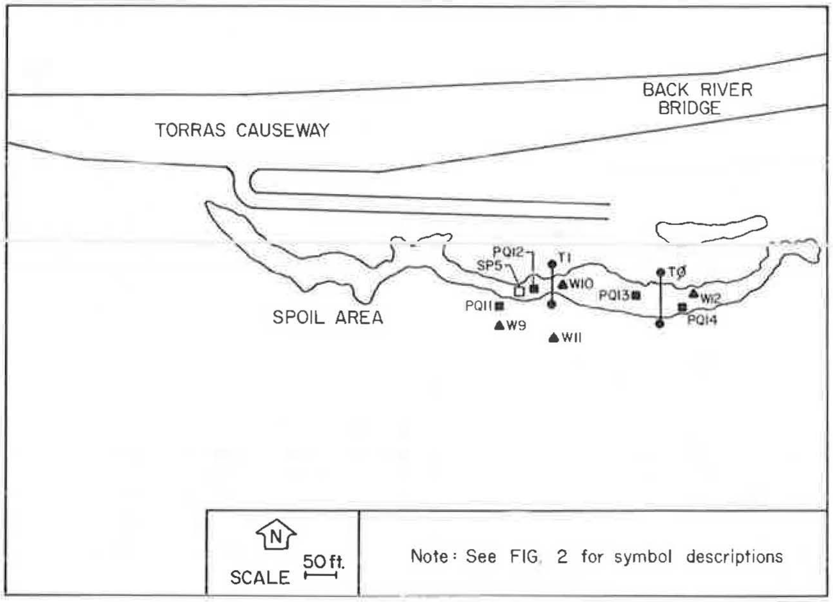

FIGURE 4 Unchannelized comparison site (mitigation site 2).

ber 31 during the fall 1987 period. The protocol of Kibby et al. (*8*) was followed for analysis of the random quadrats. A 0.2-m^2 quadrat was constructed from 0.5-in.-diameter schedule 40 PVC pipe and 0.5-in.-diameter schedule 40 PVC 90° elbows. Fiddler crab burrows were counted within each quadrat before vegetation was harvested. The vegetation was snipped at ground level, put into a plastic bag, and placed on wet ice for laboratory analysis. Before weighing, plant height measurements were logged. Live and dead plants of each species were weighed separately by using a trip balance. The observed wet plant weights were converted to dry weights by using conversion factors reported by Kibby et al. (*8*).

Remote Sensing

Remote sensing by aerial photography supplied by the Georgia Department of Transportation was conducted to plot changes in the unvegetated surface area of the spoil zone. The causeway was flown over and photographed on May 5, 1984 (17 months before channelization), April 23, 1987 (18 months after channelization), and December 19, 1987 (25 months after channelization). An outline of the unvegetated surface was transferred manually to tracing paper. A Hewlett-Packard computer digitizer was used to determine the unvegetated surface area. The computer was programmed to digitize to the nearest one-thousandth of a square mile. The scales on the photography were estimated from measuring the causeway width.

Hydrology

A high-tide hydrological study was conducted on October 30, 1987. The time of arrival of sheet flow onto the comparison site was noted (Figure 4). Flow velocity, width, and depth were measured at three places in the MRC: the west connector, the east connector, and the intermediate connector (Figures 2 and 3). Flow measurements were made over a high-tide cycle at 10-minute intervals by standard stream gauging equipment. The measurement procedure outlined by Buchanan and Somers (*9*) was followed for flow data acquisition and discharge determination. Modified from Buchanan and Somers, the formula

$$Q(f) \text{ or } Q(e) = \text{sum}[(a)(v)(k)]$$

represents the computation where $Q(f)$ and $Q(e)$ are the total discharge in cubic feet per second (CFS) during flood and ebb, respectively, a is an individual cross-section area, and v is the corresponding mean velocity of the flow normal to the cross-section area. The constant (k) is the conversion factor from CFS to the interval between measurements. The constant k assumes that the flow increased or decreased at a constant rate.

RESULTS

MRC Geomorphology

Figures 5–7 compare arithmetic mean width and depth values of the MRC in vegetated muck (along the west connector) with unvegetated spoil. In Figure 5, ratios of mean width to depth ($W{:}D$) are plotted to illustrate an overall indication of erosion or deposition of the MRC, or both. An increase in the ratio can occur as a result of an increase in MRC width, a decrease in MRC depth (indicates deposition), or both. Between October 1985 and April 1987, mean $W{:}D$ increased significantly in the spoil zone in unvegetated areas. A comparison of Figures 6 and 7 shows that the initial instability of the west connector MRC (vegetated muck) was not caused by an increase in MRC width, but instead was because of a decrease in MRC depth (note sharp decrease in mean depth between September and October 1985). Dense *S. alterniflora* rhizomes are responsible for soil stability and the retention

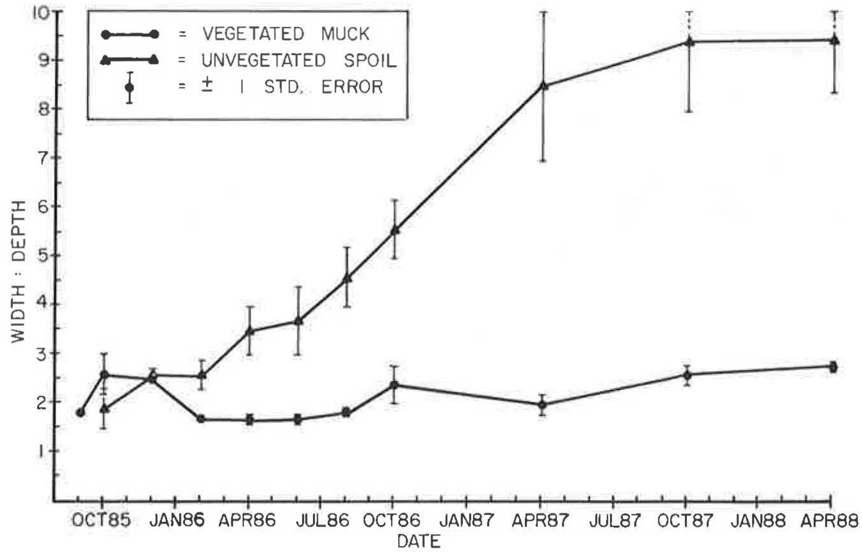

FIGURE 5 Mean channel width-to-depth ratios in vegetated muck and unvegetated spoil.

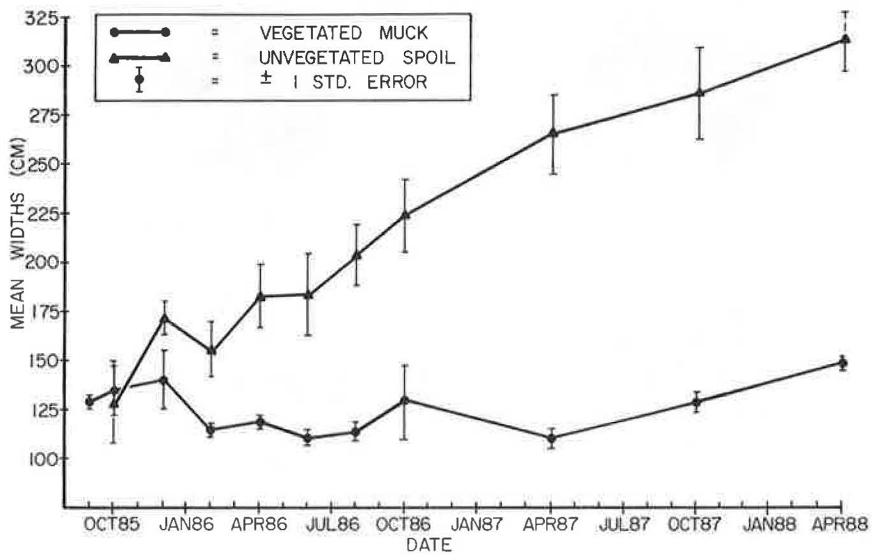

FIGURE 6 Mean channel width in vegetated muck and unvegetated spoil.

of the original cross-sectional profile of the west connector. With the exception of one length of channel in which the rotary ditcher damaged the rhizomes while attempting to make a sharp turn, track damage to *S. alterniflora* adjacent to the west connector occurred only aboveground during ditching.

Permanent Quadrats

Six of the eight permanent quadrats located on the channelized site that had no growth in April 1986 had *S. alterniflora* growth in December 1987. Permanent quadrats PQ-0 and PQ-00 were positioned during the April 1986 sampling period in areas beside the MRC and adjacent to short-form *S. alterniflora*. Both PQs had no visual growth in April, but in the June 1986 sampling period, just 2 months later, 29 and 4 *Spartina* plants (live and dead total) were recorded, respectively, in those PQs. By December 1986, *S. alterniflora* had increased to 27 and 57 plants in PQ-0 and PQ-00, respectively. By December 1987, *S. alterniflora* had increased to 197 and 146 in PQ-0 and PQ-00, respectively.

Rhizomatous Growth Indicator Plots

Two boundary plots were positioned April 10, 1986 to monitor the growth of *Spartina* resulting from rhizomatous migration. There was no growth on one side of the boundary line in April, but by June 21, 1986, 18 and 21 plants were observed across the east and west boundary plots, respectively. By August 19, 1986, the plants had increased in number to 60 and 49 plants in the east and west plots, respectively. By

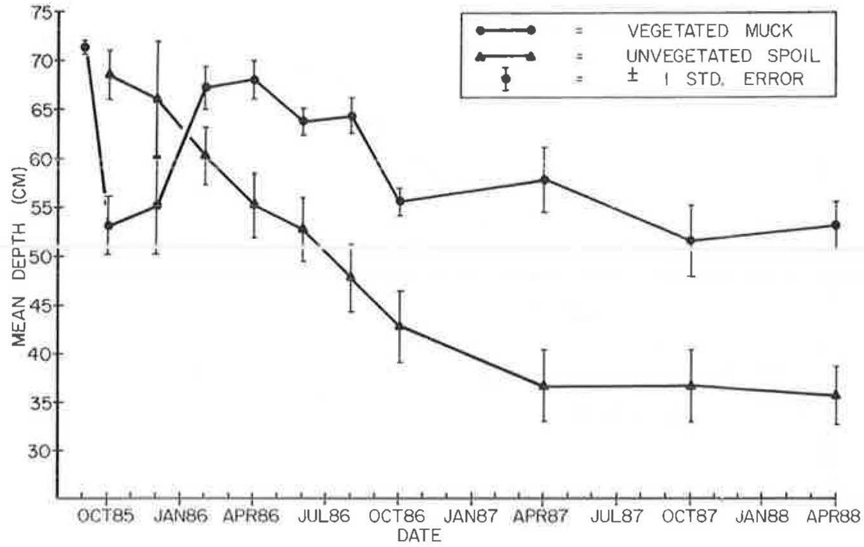

FIGURE 7 Mean channel depth in vegetated muck and unvegetated spoil.

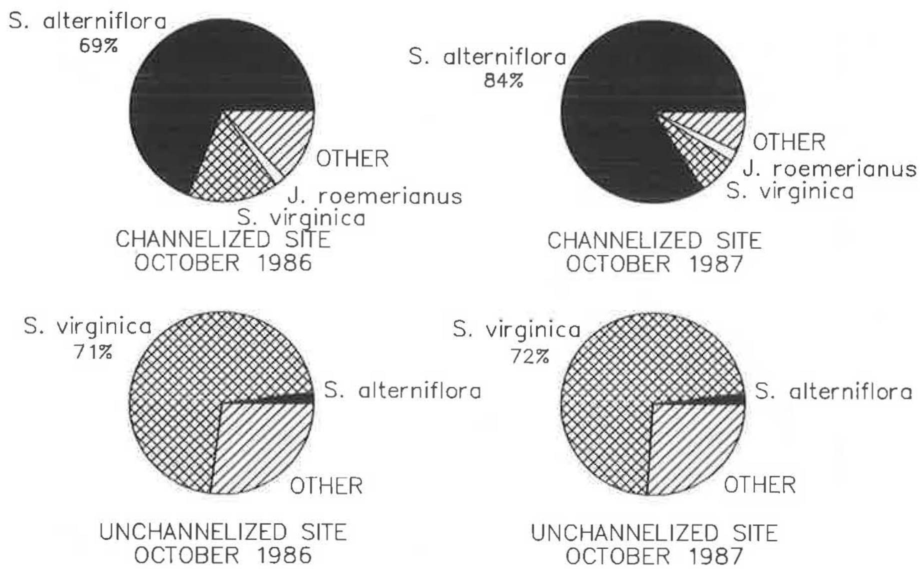

FIGURE 8 Relative plant abundance (by weight) from random quadrat sampling.

October, *Spartina* had further increased in numbers to 138 and 114 plants in the east and west boundary plots, respectively. Average height in the east plot increased from 21.7 to 22.0 to 29.9 cm during the three sample periods. Average height in the west plot increased from 14.2 to 16.0 to 22.3 cm during the three sample periods. All new growth in both plots was monospecific *S. alterniflora*.

Random Quadrats

Random quadrat sampling was conducted between October 1986 and October 1987 for net primary productivity (NPP) and estimated end-of-season total (EOST; above-ground live and dead). EOST for *S. alterniflora* more than doubled (factor of 2.4) over the entire channelized spoil zone between October 1986 and October 1987. As a consequence, bare ground surface area was reduced by a factor of 0.5 over the same period. Parallel increases were observed in fiddler crab burrow count (factor of 2.4) and *S. alterniflora* seed head production (factor of 1.8). Relative abundance (by weight) of *S. alterniflora* increased from 69 percent in October 1986 to 84 percent in October 1987 (Figure 8). However, relative abundance of *S. virginica* decreased from 16 percent to 7 percent during the same period.

In contrast, unvegetated surface area on the comparison site increased by a factor of 3.3 between October 1986 and October 1987. In addition, no improvement in *S. alterniflora* seed head production was observed. Relative abundance of *S. alterniflora*, *S. virginica*, and *B. maritima* remained essentially unchanged.

Spatial variation in the rate of restoration was observed

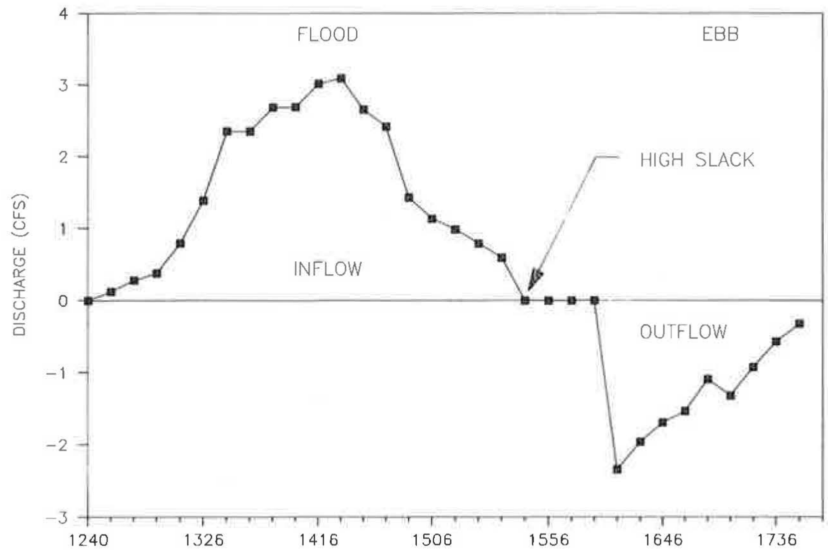

FIGURE 9 Tide cycle hydrograph from the west connector gauging station on October 30, 1987.

between the east and west sections of the channelized site. Causeway station 61 + 50 was the approximate center of the spoil zone. *S. alterniflora* on the west section (< 61 + 50) increased by a factor of 3.4 between October 1986 and October 1987. *S. alterniflora* on the east section (> 61 + 50) increased by a factor of 2.6 during the same time period.

Remote Sensing

A comparison of aerial photographs from May 1984, April 1987, and December 1987 revealed a reduction in unvegetated surface area on the channelized site. Between May 1984 and April 1987, a 25.2 percent decrease in unvegetated surface area was noted. Also, a comparison of photographs from May 1984 and December 1987 revealed a 42.1 percent decrease in unvegetated surface area. In contrast, a 57.0 percent increase in unvegetated surface area was measured between May 1984 and December 1987 on the unchannelized comparison site.

Hydrology

General

The channelized spoil zone was surveyed for elevations on August 19, 1985. The elevations varied along the bare spoil zone from 3.56 to 4.11 ft above mean sea level (MSL). Reported tides at the mouth of Frederica River range from 7.2 ft (mean) to 8.4 ft (spring) above mean low sea level [MLW (*10*)]. Based on an MSL elevation of 3.6 ft at the mouth of Frederica River and an elevation range of 3.56 to 4.11 ft above MSL, a tide of 7.16 to 7.71 ft above MLW was required to flood the spoil zone.

The following results are based on the hydrologic study of October 30, 1987. Even though the volume of estuarine water displaced in the MRC will vary according to different tidal cycles based on tidal amplitude, wind speed, and wind direction, the October 1987 study represents the general flow patterns during a typical high-tide cycle. The predicted tidal amplitude during the study was 7.3 ft (above MLW) which is only 0.1 ft higher than the average tidal amplitude of 7.2 ft reported at the mouth of Frederica River.

West Connector

Between 12:40 and 15:36, approximately 109,000 gal of seawater during flood tide flowed past the west connector gauging site to the spoil site (Figure 9). At approximately 13:56, the water left the banks of the MRC at the gauging station and flooded the adjacent marsh; thus the volume of seawater measured between 13:56 and 15:36 is a conservative estimation of the actual volume available. The flood tide continued until high slack occurred at the gauging site at 15:46. Between 15:56 and 16:06, seawater was observed to flow out the MRC, but the flow in the MRC was too slow to measure. From 16:26 to 17:46, 53,000 gal of seawater was measured until the flow in the MRC was reduced at 17:46 to 2 in. deep by 0.25 ft wide and was too low to measure accurately.

East and Intermediate Connectors

The east end of the spoil zone represents a much more complicated hydrologic regime. Between 12:24 and 15:15, approximately 155,000 gallons of seawater flowed during flood tide past the east connector gauging site onto the spoil zone (Figure 10). During this period, only 8,000 gal of seawater was introduced through the intermediate connector from the natural tidal meander adjacent to the east connector (Figure 11). However, 31,000 gal of seawater was lost during flood tide out the intermediate connector for a net loss of 23,000 gal from the MRC into the natural tidal meander. The direction of flow in the intermediate connector changed twice during the flood tide: from northwest (into the MRC) to southeast (into the natural tidal meander) to northwest again. High slack tide occurred at 15:25 at the east gauging sites.

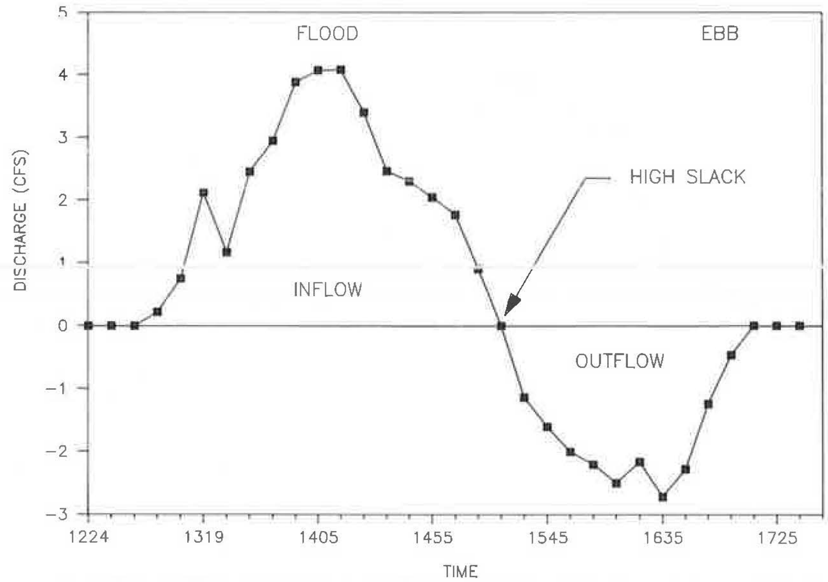

FIGURE 10 Tide cycle hydrograph from the east connector gauging station on October 30, 1987.

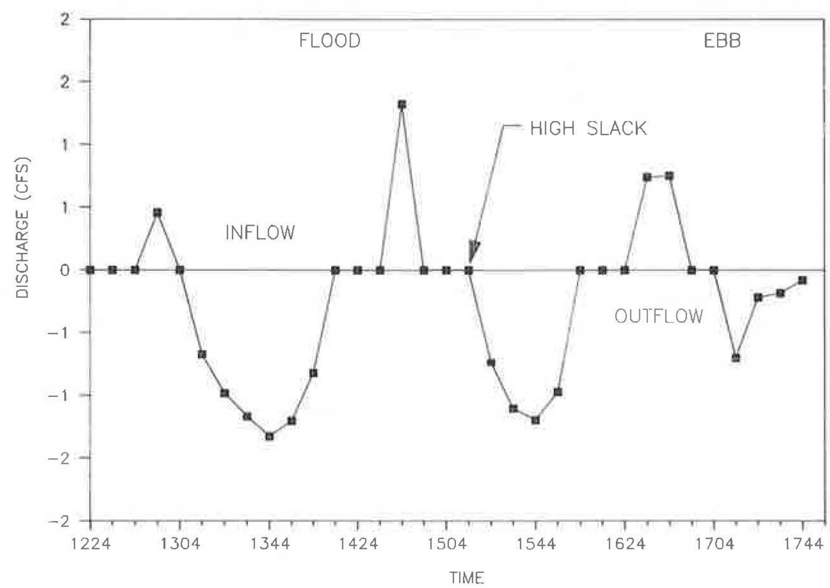

FIGURE 11 Tide cycle hydrograph from the intermediate connector gauging station on October 30, 1987.

During ebb tide, approximately 82,000 and 27,000 gal of seawater left the spoil zone via the east and intermediate connectors, respectively. Flow patterns in the intermediate connector during the ebb tide were observed to be just the opposite as were noted during the flood tide: from southeast to northwest to southeast.

Tidal asymmetry was noted in both the west and east gauging stations with tidal discharge (in CFS) during flood being greater than ebb. Pethick (*11*) reported that flood velocities on average in a natural tidal creek were 30 percent higher than those on the ebb.

Comparison Site

Aboveground estuarine water reached the comparison site approximately 2 hours later (14:40) than the MRC gauging sites. Even though interstitial flow is possible, estuarine water was not observed in any of the four sample wells located on the comparison site until the wells were filled from the aboveground flow. Bayliss-Smith et al. (*12*) reported that on upper marshes the majority of tides are below-marsh. When an infrequent over-marsh tide does occur on the comparison site, estuarine water has been observed to remain on the surface of the comparison site and in the sample wells between high tides.

DISCUSSION OF RESULTS

Analysis of permanent quadrat data, rhizomatous growth indicator plots, random quadrat data, and remote sensing has indicated that the MRC was successful in stimulating *S. alterniflora* growth, *S. alterniflora* seed-head production, and fiddler crab activity on the spoil site. The MRC not only increased tidal frequency and duration, it also reduced standing water and improved soil drainage after tidal cycles. Soil drainage has been found to be important in reducing soil anaerobiosis and increasing redox potential resulting in increasing *S. alterniflora* productivity (*13*). Also, soil flushing and drainage are essential in reducing free sulfides and salts (*14*), which can concentrate in toxic amounts causing plant mortality.

The amphibious rotary ditcher caused only temporary damage to existing soils and vegetation. Recovery of *S. alterniflora* that was damaged below ground was slow, but *S. alterniflora* that suffered only stem damage recovered rapidly. However, regardless of the degree of damage, enhanced growth of *S. alterniflora* adjacent to the MRC and damaged by the tracks was eventually evident. Also, no permanent damage from the side-cast material from the amphibious rotary ditcher was observed. Side-cast material could have even contributed to the enhancement of *S. alterniflora* growth to either side of the MRC. Based on random quadrat data, the estimated end-of-season total growth of *S. alterniflora* more than doubled in 1 year.

A parallel increase in fiddler crab activity, as measured by the number of burrows, was also observed. Burrowing was observed on the bare areas on the channelized site before *S. alterniflora* colonization occurred. It is hypothesized that burrowing may be responsible for "conditioning" the soil before revegetation occurs. Katz (*15*) found that a population of the fiddler crab, *Uca pugnax*, can turn over approximately 18 percent of the upper 15 cm of sediment in a salt marsh. Katz also noted that burrowing increased the surface area of the marsh by 59 percent. Also, Allen and Curran (*16*) noted that burrowing resulted in a great deal of bioturbation. Montague (*17*) reported that fiddler crab burrows improve the growth of *S. alterniflora* by an average of 25 percent. The resulting increases in soil turnover, surface area, and bioturbation act to decrease subsurface anaerobiosis and improve the rate of redissolution, resuspension, and export of concentrated salts and sulfides, which may inhibit growth of *S. alterniflora*.

As compared with the unchannelized site, the MRC not only increased tidal frequency and duration, but also reduced standing water and improved soil drainage after tidal cycles. Even though the comparison site is located closer to the Back River (Figure 1), aboveground estuarine water reached the comparison site approximately 2 hours later than estuarine water reached the channelized site. In addition, standing water and water in sampling wells were observed on the comparison site long after the high-tide cycle.

Soil drainage has been found to be important in reducing soil anaerobiosis and increasing the redox potential that results in increased *S. alterniflora* productivity (*13*). Also, soil flushing and drainage are essential to reducing free sulfides and salts (*14*) which can concentrate to toxic amounts, causing a reduction in plant productivity or even mortality.

No hydrologic impact to adjacent natural tidal meanders from estuarine water entering or leaving the MRC via the east connector is suspected. The high-tide study addressed the closest natural tidal meander that could be affected hydrologically by the MRC (see Figure 3 at the intermediate connector). Stream capture by the MRC during ebb tide is not suspected.

The degree of erodability along the edges of the MRC depended on the soil composition, the degree of exposure to run-off, and the presence or absence of vegetation. For instance, the unvegetated sandy spoil located closest to the causeway was much more susceptible to erosion than the vegetated muck located on the west connector. Little or no bank erosion, as indicated by the MRC width measurements, was observed in muck stabilized with *S. alterniflora*. The extensive *S. alterniflora* root and rhizomatous mass on the west connector was responsible for the reduction of soil erodability and the retention of the original MRC morphology. During the first 3 months after channelization (October through December 1985), some sediment export was observed in the west connector. By January 1986, the mean channel depth of the west connector had nearly returned to its original depth profile. The MRC geomorphological data from the October 1987 sampling period may indicate a reduction in the rate of erosion-deposition in both the unvegetated spoil zone and the vegetated muck areas. New *S. alterniflora* growth within and adjacent to the MRC on the spoil zone is probably contributing to the reduction in the rate of erosion.

The unchannelized, comparison site remained visually unchanged with a reduction in *S. alterniflora* growth and vitality within the spoil zone. Interstitial salinity was observed to be significantly higher on the unchannelized site than on the channelized site. Growth of *S. alterniflora* is inversely related to the interstitial salinity of the soil (*18*). Sea salts were apparent on the unvegetated, comparison site causing crusty surface conditions and restricting growth to only salt-tolerant plants, such as *S. virginica*, along the fringe of the spoil zone. Even a reduction of salt-tolerant plants was observed on the comparison site during the summer and fall of 1986. The drought of 1986 probably contributed to the mortality. In contrast, an increase in growth and seed-head formation of *Spartina* on the channelized site was recorded during the same drought.

The following design considerations are recommended for future use of amphibious rotary ditching in salt marsh restoration:

1. Survey the potential restoration site for elevations.
2. Coordinate ditching with periods of low tidal amplitude (preferably neap tides during solstice) and growing seasons to allow for channel settling and stabilization and reduction of sediment export.
3. Make use of the best combination of rotor speed, rotor depth, and track speed of the ditcher to reduce subsurface damage to existing vegetation. Use only experienced equipment operators.
4. Before staking the channel path on site, mark the path on aerial photographs to determine the route of least impact to existing plant and animal communities.

5. Map ditcher access to the site and to each channel starting position to reduce superficial aboveground damage.

6. When possible, limit ditching to sandy substrates and avoid soft muck.

7. Connect the channel to the largest supply of estuarine water and the most direct route to the ocean.

8. Introduce meanders into the channel where possible.

9. Have personnel experienced in the use of rotary ditching in salt marsh restoration on-site to supervise channelization.

10. Establish a monitoring program after channelization. Have personnel with a background in wetland ecology monitor and report on the success or failure of the project.

Although the technique has certain limits, the use of rotary ditching as a method to obtain salt marsh creation and restoration has potential. The degree of success depends on elevation, tidal amplitude, access to natural tidal streams, and the soil type(s) of the area to be restored. Areas that are above the mean high water during spring tides (MHWS) probably would have only a limited rate of success when rotary ditching is used alone. When elevations are above the MHWS, the use of a combination of rotary ditching with excavation probably would have the best results. First, the elevation of the restoration site could be reduced by excavation. Next, the restoration site could be connected to a tidal stream(s) by channelization with rotary ditching, which would reduce the impact to existing salt marsh communities. Channelization would ensure proper flushing and drainage of the site into the tidal stream(s) and reduce the potential for mosquito breeding, anaerobiosis, and concentration of free sulfides and soluble salts in toxic amounts.

In addition to salt marsh restoration, amphibious rotary ditching has potential in the restoration of inland freshwater systems. However, this area needs further investigation.

ACKNOWLEDGMENTS

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Investigation of a Shoreline Enhancement Technique for Wetlands Impact Mitigation

FRED K. PARRISH

An attempt was made to mitigate the impact of highway construction on a wetland (beaver pond) margin by enhancing the shoreline of the roadfill. One hundred 20-ft-long fingerlike extensions 10 ft wide were constructed 10 ft apart along the roadfill. The extensions increased the pond-roadfill margin by a factor of three. Willows were planted on the southeastern edge of the fingers. Despite repeated draining of the pond by county surveyors and two successive drought years, the procedure appeared successful. Transects were compared in three areas: an improved section with fingers; an unimproved section of roadfill; and a "control" across the pond from the roadfill. Sampling of the pond margin communities over a 3-year period revealed up to 89 percent the number of benthic invertebrates in the improved area as in the control and only 44 percent of the benthos in the unimproved area as in the control area. Trees occurred on the fingers at a rate 2.3 times greater per unit of shoreline than in the unimproved area, and over half were volunteers. Fish used the improved area about four times as much as the unimproved area. A community comparison index showed the shoreline tree community in the improved area to have about six times the habitat value of the unimproved area. Recommended modifications of the shoreline include making the fingers longer and wider and the sloughs wider and deeper, and providing erosion control and less slope to prevent excessive sedimentation.

The economic importance of wetlands is now generally known and appreciated (*1*). In the construction of the West Austell Bypass (the C.H. James Parkway) located in southwest Cobb County, Georgia, it was necessary to pass through the northeast side of the Powder Springs Creek floodplain (Figure 1), which was inundated as a result of beaver dam construction. Because of roadway fill placement in this wetland habitat, wetland mitigation was provided in accordance with U.S. Army Corps of Engineers' Section 404 regulations and Executive Order 11990, which require the "consideration" of wetland mitigation when such lands are affected by federal-aid highway projects.

Enhancement of the highway fill shoreline was considered an innovative approach to ameliorating the impact on this wetland. Al Tate, at the time in the Georgia Department of Transportation (GDOT) Environmental Section, suggested the procedure. The enhancement technique consisted of incorporating a series of 20-ft-long fingerlike serrations, 10 ft wide, spaced about 10 ft apart, projecting into the wetland. The object was to increase the shoreline area, a border between two ecological systems (an ecotone), that is important as wildlife habitat, and as a source of nutrients (*2–4*).

The objective of this study was to determine whether the shoreline enhancement technique was an effective way of enhancing fish and wildlife habitats and increasing diversity over the habitat values that normally result from a standard fill slope. Additional benefits would be to refine the design of shoreline enhancement methods to (a) reduce construction costs, (b) increase habitat and wildlife productivity benefits, and (c) reduce impacts on the existing wetland.

After completion of construction, the author was asked to evaluate the results. Evaluation of the technique was to be part of the mitigation at this particular site.

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METHODOLOGY

Site Description

The wetland chosen for this study was a beaver pond lying along Powder Springs Creek in the southern part of Cobb County, Georgia (Figures 2 and 3). The pond was separated from the creek by a low island, approximately 25 to 100 ft wide, which extended upstream about 2,200 ft (Figure 4). The island was covered with a mature stand of bottomland trees (red maple, *Acer rubrum*, predominated), shrubs, and vines. Privet (*Ligustrum* sp.) was abundant and provided food for the beavers.

The small stream draining the area cut across a bend in Powder Springs Creek. Its size varied from only 2 ft across and about 6 in. deep in places (as in October 1987) to the full extent of 25 acres. It was dammed by beavers in a channel 3 ft deep, about 25 ft from Powder Springs Creek. As the water level in the impoundment rose, the beavers heightened the dam to the top of the stream channel, then built extensions out along the island. Where water overflowed the island upstream, the beavers built ancillary dams.

The pond varied from about 400 to 500 ft wide, covering 25 acres when the beaver dam was at its highest and after rainfall. The maximum depth was about 8 ft. Because of the number and condition of dead trees that were observed standing in the water, the pond was estimated to be about 20 years old. Figure 1 is an aerial view of the pond and fingers taken in 1985 immediately after construction of the roadbed and mitigation fill fingers. Figures 2 and 3 are views of the pond from the roadfill taken in 1987.

The area apparently has been used extensively for outdoor recreation for years. During hunting season, gunfire was frequently heard. The remains of deer that had been field dressed were observed twice. Well-worn trails and an improvised boat launching facility were present (Figure 4). Fishermen were

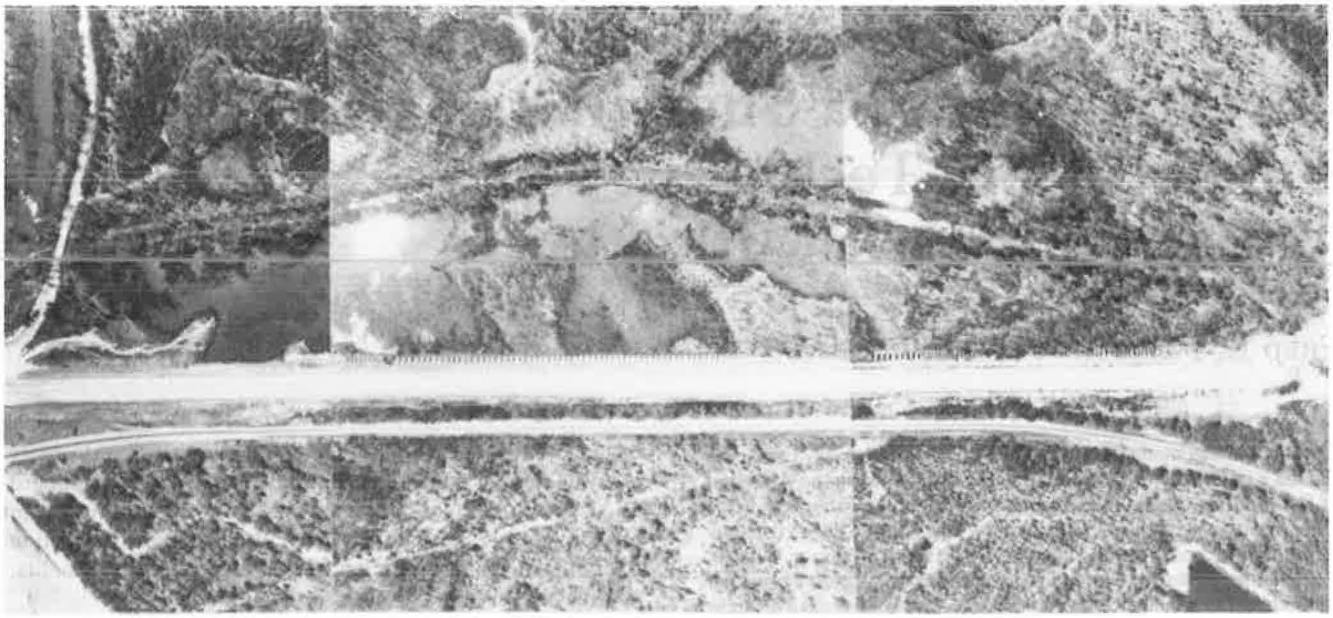

FIGURE 1 Aerial photograph of the site taken April 4, 1985.

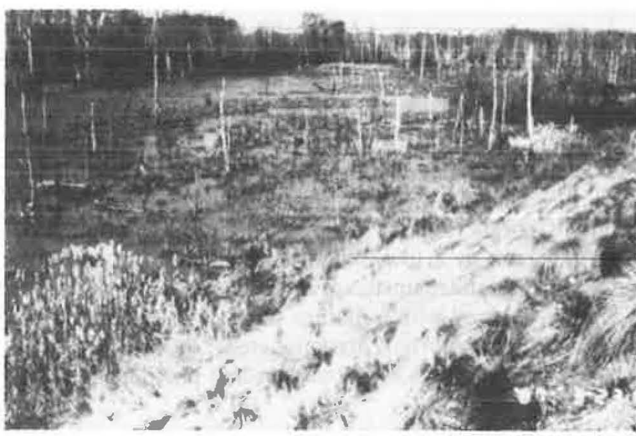

FIGURE 2 View of pond from roadfill taken March 1987. U 1, U 2, and U 3 are between the clumps of cattails. Note absence of trees after 2 years. Compare with Figure 6 taken September 16, 1986, 6 months earlier and after only 18 months. C 4 is across the pond, upper left in photograph.

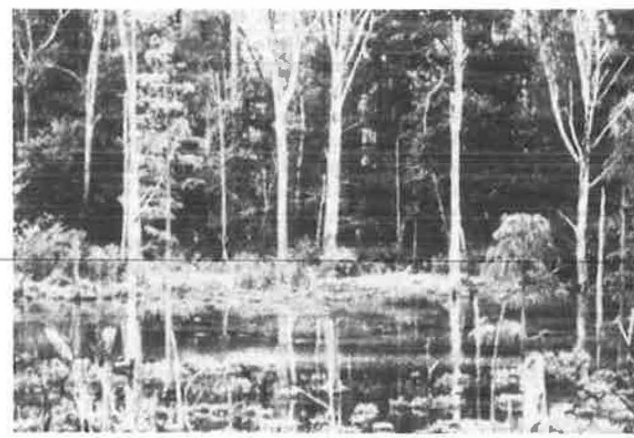

FIGURE 3 Telephoto view across pond. C 3 is visible. Note the four baldcypress trees. The specimen on the left is about 30 ft high, suggesting that the pond has a history of wet and dry periods, and that the pond is several years old.

seen on nearly all collecting trips. Local fishermen told us that trophy largemouth bass were occasionally caught.

Construction

The original construction plans (Figure 5) for the mitigation area required the following but were later modified. The original plans included the following:

1. About 100 fingerlike projections 20 ft long and 10 ft wide.
2. Ten-ft-wide sloughs between the fingers (making a distance of 20 ft from one finger centerline to the next).
3. Slopes of 2:1 on the sides of the fingers (the same as the roadfill).
4. Where the toe of the finger extended into saturated wetland soil, connection of the sloughs to the pond by a 5-ft-wide canal.
5. A water depth in the sloughs of 4 ft.

Deviations from the original plans included the following:

1. The 10 fingers southeast of the culvert (shown in Figure 4) measured about 12 ft wide center to center, whereas the remainder measured 17 ft center to center.
2. The width of water between fingers was 1 to 4 ft.
3. The depth of water in the sloughs was from 8 in. at the inner end of the slough to about 18 in. at the pond or canal.

Shortly after construction in 1984 and before this study began in March 1985, the beaver dam was apparently breached,

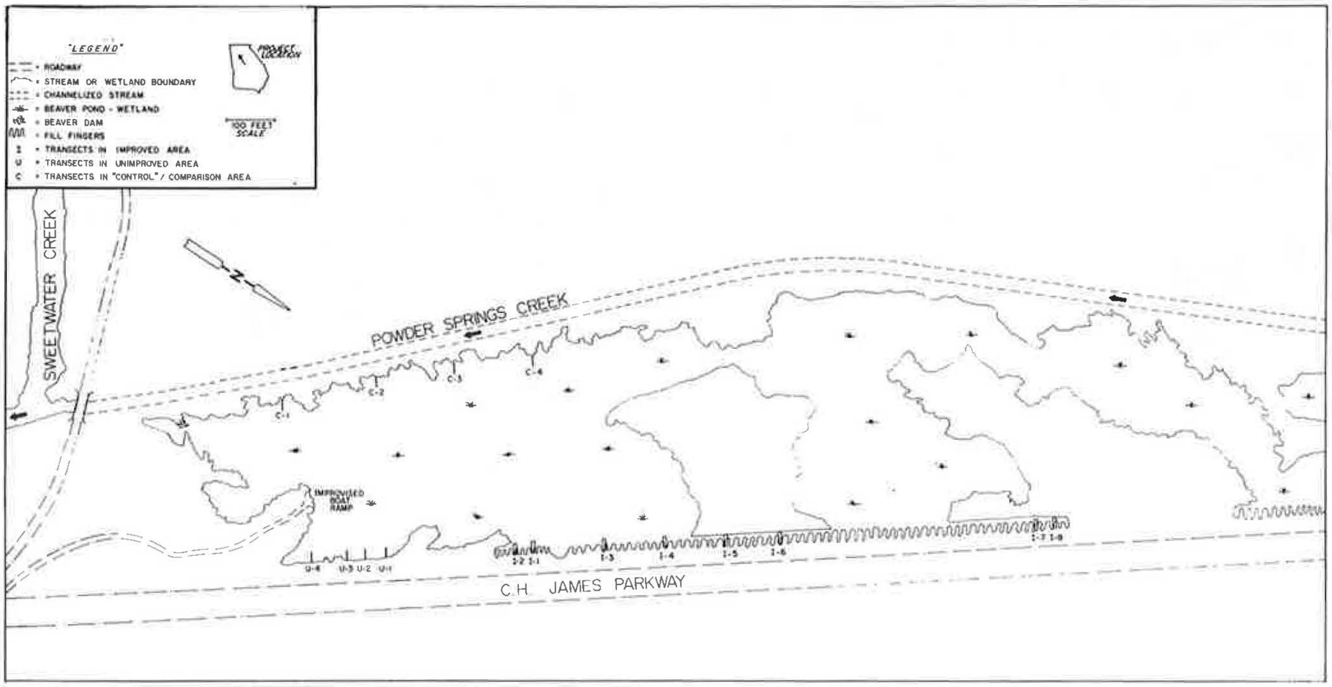

FIGURE 4 Outline of wetland showing location of fingers, transects, beaver dam, and improvised boat ramp.

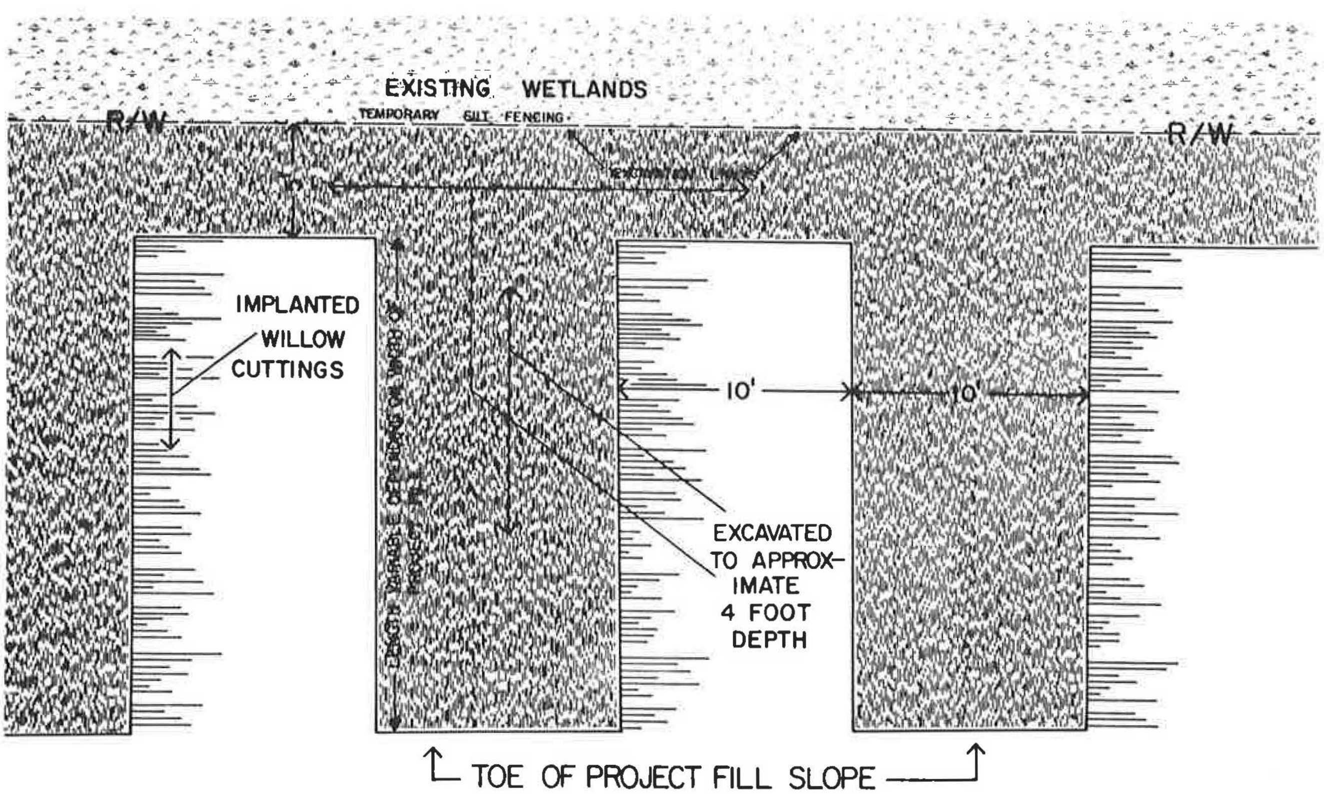

FIGURE 5 Diagram of fingers as originally designed for Powder Springs Creek Wetland.

FIGURE 6 Fingers in early March 1985. Weeping love grass is just coming up. B. Pruitt is standing on finger to the left of I 7. Note low water in slough, only about one-fourth of which is submerged. By end of March, when this study began, water was about 18 in. deep.

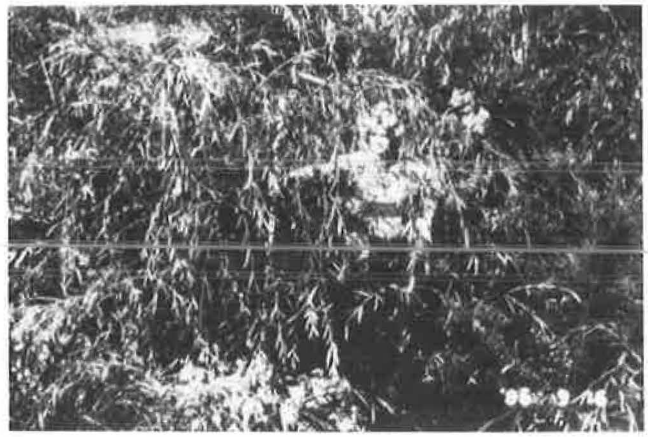

FIGURE 7 I 7 in September of 1986—18 months after Figure 5. Assistant B. J. Soteres is holding a surveyor's rod 6.6 ft (2 m) long at the base of a weeping willow tree.

making the water shallower and the width of the water narrower in the sloughs, and extending the length and width of the fingers (Figure 6). Sediment from the roadfill and finger edges was up to 32 in. deep in the sloughs. Thus, when the water level in the pond was down by 14 in., many sloughs were dry and most had only a few inches of water for less than one-fourth of their length.

Silt fencing was placed along the GDOT right-of-way in the wetland area before construction to protect the pond. It was designed to extend to the bottom in areas abutting directly on the pond and at least 2 ft above the water level. Fallen trees, however, knocked the silt fencing down in a number of places, allowing access by fish into the finger sloughs and entrance of suspended solids into the pond. Beaver, muskrats, and otters crossed the fencing at will. A den was found dug into one of the fingers before the fencing was removed.

A total of 72 fingers were constructed in the study area. The additional cost of constructing the fingers was $8,503.00.

Planting

The roadfill and fingers were seeded with weeping love grass (*Eragrostis* sp.) and interstate lespedeza (*Lespedeza stipulacea*) shortly after construction. These plants were just in evidence (Figure 6) when this study began in March 1985. The roadfill and finger banks had not yet completely stabilized.

Willow seedlings were planted in March 1985, two per linear foot, in a ditch at least 12 in. deep and 4 in. wide on the southeast side of each finger. After planting, soil was tamped and watered to saturation. A total of 2,612 willows were transplanted. Survival and compliance with specifications were checked in April 1985 by a GDOT engineer. The cost of planting the willow seedlings was $3,000.00.

Physical-Chemical Determinations

Critical environmental parameters were measured to determine if any extraordinary factor precluded normal habitat colonization.

During the quarterly sampling periods, samples from the water column were taken from selected transects, immediately placed on ice, and transported to the GDOT laboratory for determination of biochemical oxygen demand (BOD), turbidity, pH, suspended solids, alkalinity, nitrates, nitrites, and oil and grease. Determinations of air and water temperatures, dissolved oxygen, and illumination were made in the field. Temperature and oxygen were determined by using a Yellow Springs Instrument Co. (YSI) model 51A meter that was checked for accuracy against a laboratory calibrated GDOT YSI model 51A meter. Illumination was determined at waist height and arm's length with a General Electric type 214 light meter. Water samples were taken to the Extension Pesticide Laboratory at the University of Georgia at Athens in June 1985 and January 1986 for pesticide analysis.

Biological Sampling

Biological evaluation was divided into two major parts. The first part was an intensive descriptive survey of the Powder Springs Creek wetland at the project site. This part of the study compared the benthic, fish, and plant communities in the shoreline enhancement segment of the fill with the same communities in a segment of project fill without enhancement and those in a control area of wetland not affected by highway construction. The second part of the study was to pursue those aspects of community composition found to be the most informative in the first phase.

The first phase of the study began in March 1985. Four 2-m-wide by 10-m-long transects were laid out in each area: the control (C 1-4), the unimproved (U 1-4), the improved area facing the water (I 1-4), and the improved area constructed in the previous upland (I 5-8) (Figure 4).

In each transect, macrophytes and vertebrates were inventoried and four replicate ponar samples were taken to determine macroinvertebrate community composition. Macrophytes were field identified, and representative specimens were pressed for later reference; pictograms were made illustrating distribution. Fish were collected by using an electric shocker, identified, and then released. Invertebrates were preserved in ethanol and carried to the laboratory for identification and analysis.

Data Analysis

The original plan was to inventory and then compare the biotic communities, using representative transects, in the shoreline and pond margin communities in the improved, unimproved, and comparison (control) sites. Biologists have developed several methods of evaluating and quantifying ecological resources (*4–9*) that meet the criteria of being both mathematically acceptable as well as biologically sound to avoid what Slobodkin (*6*) characterized as taking biological nonsense to mathematical certainty. Of these, habitat assessment using biological communities is commonly used.

The widely used procedure developed by the U.S. Fish and Wildlife Service (USFWS) called Habitat Evaluation Procedure [HEP (*10–13*)] is also widely criticized for several reasons, one of which is its subjective nature (what makes one species "better" than another). HEP assumes that habitat quantity and quality for a species or guild can be numerically described. In use, values (on a scale of 0 to 1) are assigned to the environmental factors (for example, vegetation cover) responsible for the presence or absence of selected species or guilds. A summation or comparison, or both, of these values for a habitat results in the Habitat Suitability Index (HSI). The HSI is then multiplied by the habitat space available to give Habitat Units (HU). Habitat Units between different locales can then be compared.

A technique used more and more frequently in recent years is the comparison of one community's composition in species and numbers with another's (*9*). Biological communities are composed of numerous species, each with its own environmental requirements, containing numerous individuals, with varying tolerances to deviations in those requirements. If these requirements are not met, the species probably will not endure long in that habitat. On the other hand, if a species can get into a habitat and survive, it will usually endure. As a result, community analysis can be used to determine ambient environmental conditions. In some cases, and this study was one, community composition appeared more sensitive than human testing.

Of the numerous community comparison procedures, Pontasch and Brusven (*14*) found the average chi-square test of Parrish and Wagner (*15*) most reliable in tracking benthic community recovery after an oil spill. The average chi-square procedure averages the similarity of frequency distribution (chi-square) of each species in an experimental ("observed") as compared with a comparison community ("expected"). One form of the equation is

$$\overline{\chi}^2 = 2[\sum_{i=1}^{n} (O_i - E_i)^2/E_i]/N$$

where E_i is the mean of the individuals in a taxon in the two communities being compared; O_i is the number of individuals in one community; and N is the total number of individuals in both communities.

The result is a number on a linear scale of 0 (identical) to 1 (totally different). Replicate samples from the same community usually give an average chi-square value of 0.1 ± 0.05.

Odum (*3*) lists the trends to be expected in the development of mature ecosystems. Some of these trends include weblike foodchains (adding complexity and stability to the system), high species diversity (a variety of species present), large organisms, long life cycles, and well-organized stratification (in conjunction with the others, adding different ecological niches). In most areas, a climax community will have a higher general HSI than a prior successional stage. Given these trends, the average chi-square "distance" between dominant community components can become a measure of relative habitat suitability the closer an experimental or stressed community matches with a natural climax community.

FINDINGS

Summary

The success of enhancing the pond margin was demonstrated, although from the beginning sampling in the pond margin ran into difficulty. The beaver dam backing up the pond was breached by county surveyors before the study began in 1984. Although the dam was rebuilt, it was breached again on September 3, 1985. The year of 1986 brought a severe drought. The dam was utterly destroyed by dynamiting about March 10, 1987 and was never rebuilt. As a result, the most meaningful information was derived from a habitat evaluation of the tree component of the pond margin community (see the sections on plants and community comparison below). This quantification was supported by the macroinvertebrate and fish data that were collected. Physical-chemical and macroinvertebrate data highlighted sedimentation problems and revealed nothing in the water column that precluded normal colonization by organisms.

Physical-Chemical Parameters

No pesticides were detected that would adversely affect the biotic communities. Ambient physical and chemical parameters were usually within expected ranges.

Air and water temperatures, dissolved oxygen, and illumination were measured in June 1985; December 1985; March 1986; July 1986; September 1986; and January 1987. Most readings were within the tolerance limits of fish and benthos (5–10 mg/L) except during times of extreme low water when compacted vegetation lowered the oxygen (0.5–1 mg/L).

Laboratory determinations of BOD, turbidity, pH, suspended solids, alkalinity, nitrates, nitrites, and oil and grease were determined in March 1985, June 1985, December 1985, July 1986, and September 1986. All readings were within acceptable limits for fish and benthos (e.g., pH about 6.5–7) except during extreme low water, at which time the dying compacted vegetation raised the (5-day) BOD to about 7 mg/L. Temporary high pH values (pH 9.48) and alkalinities (20.6 mg/L) occurred once as a result of hydroseeding of the roadfill slope. Frequent high levels (>80 mg/L) of suspended solids occurred as a result of transport from upstream as well as erosion from the roadfill. During low water it was often impossible to collect samples without stirring up bottom sediments.

During one period of low water, sediments deposited in the sloughs were examined. A terrace approximately 5 ft long and up to 32 in. deep extended outward from the roadfill toe into the slough, filling about one-fourth the slough length.

Several sloughs were filled by collapse of the roadfill bank or by roadbed drainage. The accumulation of sediments meant that one-fourth of the slough was normally shallow and, with low water, dry. The shallow water and dry condition negated the planned methodology.

Fish

Two important trends appeared. The first trend was that gamefish used the sloughs in approximately equal numbers in the areas facing the pond and in the sloughs connected by canals but constructed in former upland areas. The second trend was that, so far as could be determined, bedding fish appeared to favor the improved site (see planting section in methodology).

In March 1985, more gamefish were found in the improved areas (five) than in either the controls (zero) or the unimproved area (three). In May 1985, a special trip was made to the site to count the number of fish beds. None were seen in the unimproved or control areas. Six were seen in the improved area. These six belonged to either largemouth bass (*Micropterus salmoides*) or green sunfish (*Lepomis cyanellus*) since adults of these species were seen in association with the nests. In June 1985, 28 gamefish were collected in the improved area, one was collected in the unimproved area and four were collected in the control area.

More gamefish were found in the improved area (22) in September and December than were found in the unimproved area (6). The control area was inaccessible in September because of rapid water flow through the breached dam. In March 1986, only one gamefish, a chain pickerel (*Esox niger*), was found in the control area, eight bluegills (*Lepomis macrochirus*) and nine warmouth bass (*Lepomis gulosus*) were collected in the improved area, and one each of bluegill, pickerel, and warmouth were collected in the unimproved area.

Fish collected during the June 1986 sampling period included seven gamefish (green sunfish, warmouths, and bluegills) in the improved area; a small large mouth and a green sunfish in the unimproved area; and no gamefish in the control area. Three fish nests were found in the improved area, one in the unimproved, and none in the control. Almost certainly, the low water level added to the negative effect of the slough's siltation to reduce the numbers of fish present.

The fish collected in this study are largely territoral in nature (*16,17*). Most will inhabit shallow open water but prefer nearby shelter and "structure" to hide from predators and to use as a reference for the maintenance of territorial boundaries. The substrate also provides a source of invertebrate food (*18,19*).

Other Vertebrates

Qualitative observations on other vertebrates revealed a steady increase in use of the improved area by birds, small mammals, and humans. No such increase was seen in the unimproved area.

Macroinvertebrates

A total of 3,401 macroinvertebrates in 85 taxa were collected and identified. Of these, there were 1,200 individuals in 58 taxa in the control area, 522 individuals in 45 taxa in the unimproved area, 984 individuals in 38 taxa in the improved area facing the pond, and 695 in 52 taxa in the sloughs connected by canals. The improved area facing the pond had 82 percent of the number found in the control, the improved sloughs connected by canals had 58 percent, whereas the unimproved area had only 44 percent of individuals occurring in the controls.

Many benthic species show marked habitat preference, and much can be learned from the taxa present in a given ecosystem. A qualitative discussion of the benthos is included in the full report but is not included here because the frequent drying of the pond precluded usable benthic data.

Plants

As can be seen in the aerial photograph (Figure 1), the fingers in the winter of 1984–1985 were bare clay. When this study began in March 1985, newly seeded weeping love grass and interstate lespedeza were just coming up (Figure 5). A survey for other plant species revealed only a few scattered dandelions (*Taraxacum officinale*).

By early 1987, because of the obvious low survival of the planted willows and continued difficulties obtaining adequate aquatic invertebrate samples, it was decided, in conjunction with the GDOT, that a survey of the species and size of colonizing trees would be most useful. In October 1987, trees on alternate fingers (36 of 72) and on the 200-ft margin of unimproved roadfill were field identified, the number in each species was counted, and their heights were determined to the nearest foot. All willows that occurred were counted together because it was not possible to distinguish between planted and volunteer individuals on the finger ends and the roadfill toe. The data are summarized in Table 1.

One hundred nineteen willows [in two species: weeping willow (*Salix babylonica*) and black willow (*Salix nigra*)] were found on the 36 fingers. Doubling this, to estimate survival for all 72 fingers, gives a total of 238 transplants that survived of the 2,612 individuals originally planted, a 9 percent survival rate. However, the actual survival rate was not this good since about one-fourth of the trees were on the northwest facing slope of the fingers and appeared to be volunteers.

By comparison, 137 individuals in nine species other than willows were found on the 36 fingers counted. Doubling this to estimate recruitment for the 72 fingers gives 274. Considering all individuals of all species, a total of 512 trees in 11 species is estimated to occur on the fingers; an average of 7.1 trees per finger. The mean of means for the willow tree height was 6.7 ft; the mean of means for the other trees was 3.4. The difference probably represents one season's growth for willow seedlings.

In deriving an "average" community of the fingers for community comparison, the following figures can be derived from the data given. More than three species occurred on 21 of the 36 fingers counted. Six species had more than 12 individuals. Therefore, an average of at least six species would be expected on three or more fingers. For 200 linear feet of roadfill (12 fingers) a total of 85 trees in at least six different species could be expected. It is important to note that over half the tree community considered in the habitat evaluation were volunteers.

In the unimproved area, a 6-ft-wide transect along the 200-

TABLE 1 SUMMARY OF NUMBER AND HEIGHT OF TREES IN OCTOBER 1987

IMPROVED SITE; number on 36 alternate fingers of the 72 total.

SPECIES \ HEIGHT (in feet)	1	2	3	4	5	6	7	8	9	10	>10	TOTAL NO'S	AVE HT.
PLANTED?													
Weeping willow	1		5	16	18	7	20	8		3	(18')	79	5.7
Black willow		1	1	2	8	6	10	6	3	1	(15',25')	40	7.7
VOLUNTEERS													
Pines		10	17	10	2							39	3.1
Sweetgum	7	13	16	5	1							42	2.3
Red maple	3	14	1	1								19	2.0
Tulip popular		1										1	2.0
Winged sumac	1	2	2	1		1						7	3.0
Sycamore	1	7	5		8	1	1		1			24	3.8
Alder		1		1	1							3	3.7
Ash						1						1	6.0
Hickory (pecan?)					1							1	5.0
TOTAL VOLUNTEERS												137	
GRAND TOTAL												256	

****

UNIMPROVED SITE; 200' along roadfill (12 finger shoreline equivalent).

SPECIES \ HEIGHT (in feet)	1	2	3	4	5	6	7	8	9	10	>10	TOTAL NO'S	AVE HT.
Black willow			1	3		1						5	4.2
Pines				1								1	4.0
Sweet gum		1	1									2	2.5
Alders				1	1							2	4.5

ft shoreline was surveyed for comparison. Ten trees in four species were found. Again, the situation is not simple. The aerial photograph taken after construction and before tree recruitment (Figure 1), shows that the tall black willows already were present; omitting these trees leaves five or six individual trees in the unimproved area. (All ten trees were included in the community comparison calculation so as not to bias the results.)

Community Comparison

The unimproved area was 200 ft long. In a 6-ft-wide transect along the entire 200-ft pond-roadfill toe margin, ten trees in four species were found (Table 1). A 6-ft-wide transect of 200 ft of pond-finger shoreline in the improved area would include 3.3 fingers. On these, one could expect to find 23.43 trees (average 7.1 trees per finger [see the section on plants]) in about six different species. Dividing the 23 trees among the six most numerous species in the proportion found in the survey gives the following "average" community: eight weeping willows, four black willows, four pines (*Pinus* sp.), four sweetgums (*Liquidambar styraciflua*), two sycamores (*Platanus occidentalis*), and one red maple (*Acer rubrum*).

There are two components of this habitat assessment to be considered. First, did the tree planting or the making of space for trees enhance unit lengths of shoreline? Second, was the construction of fingers, by increasing enhanced shoreline, an effective means of increasing habitat values?

It is important to recognize the difference between shoreline length and roadbed length. In the unimproved area, the straight roadbed and shoreline are of equal lengths—200 ft. In the improved area, because of the finger extensions, the shoreline is approximately three times the roadbed length, e.g., along 200 ft of roadbed there occur 12 fingers with a shoreline distance of about 600 ft. Two hundred feet of shoreline in the improved area includes 3.3 fingers, a roadbed length of about 65 ft.

A comparison of the average community found in the improved area with the community actually found in the unimproved area gives an average chi-square "distance" of 0.48. That the improved area contains more individuals and a variety of species approaching the climax community, indicates, according to Odum (*3*), that the habitat value of the improved area is about two times greater per linear foot of shoreline than that of the unimproved area. Furthermore, the finger complex makes the shoreline three times greater than the linear distance of roadbed in the improved area. This finding means that each linear foot of roadbed in the improved area has six times the habitat value of a linear foot of roadbed in the unimproved area.

Intuitively, this number seems about right: there are over twice as many trees and half again as many species along the improved roadbed. The numerically derived relative habitat values generally agree with those of other field observations, such as the increased occurrence of fish and fish nests and the increased numbers of benthos. Undoubtedly, as the area matures, these figures will change, but at present they demonstrate the increase in habitat value of the enhanced shoreline.

CONCLUSIONS AND RECOMMENDATIONS

The study of the wetland in Cobb County, Georgia, yielded the following conclusions and recommendations:

- The finger concept worked well in improving the pond margin habitat, resulting in a relative habitat value about six times greater than that for the unimproved area (compare Figures 2 and 7). With modifications, even greater enhancement may be possible.
- Nearly all the sloughs between the fingers are filled or partially filled with sediment derived from erosion of the roadfill or as a result of being (in two places) channeled from the roadbed. Recommendations are that fill be anchored as soon as possible and that the angle of the slopes be less (*20*). The water depth in the sloughs needs to be 3 ft after anticipated sedimentation to prevent rapid vegetation build up. Lewis (*21*) recommends at least 3 ft.
- If water depth in the sloughs had been deeper and wider, the addition of shelter, snags, or old Christmas trees would have been appropriate and would have added to invertebrate and fish production (*18,19*). The foodweb through fish, birds, and mammals (including humans) is dependent on the organisms beneath them. Increasing herbivorous invertebrate and fish production makes additional energy and nutrients available to the organisms above.
- The fingers and sloughs should be about 20 ft wide and 25 to 30 ft long. These dimensions would help prevent rapid filling, probably would lower construction costs, and would be as attractive or more attractive to aquatic organisms. Trees colonizing fingers of these dimensions would still spread enough to shade sloughs and fingers, yet be close enough to be influenced by the proximity of water.
- Natural seeding of hardwoods in a locale surrounded by hardwoods appears to occur rapidly enough that planting may not be necessary. Only one season's growth was gained by planting, and the survival rate was low (<9 percent). If planting is done, however, it is recommended that black willow seedlings be specified in the future and that they be planted 4 ft apart. A survival of one or two per finger along with natural colonization is all that the fingers will ultimately support; after a few years, the tree crowns will spread and provide the desired shade.
- Fish appeared to use the sloughs and connecting canals preferentially over the unimproved and control areas. Wider sloughs as recommended would more closely match the larger fishes' territorial requirements.
- An alternative to planting trees that would colonize naturally would be to plant wildlife food-producing trees that would add diversity (*22,23*). A planting schedule of one or two trees for every five fingers would be less expensive and still be habitat enhancing.
- Some government or private agency that will guarantee the integrity of the site needs to have control of all land on which publicly funded mitigation is practiced (The Austell site is privately owned, although it is in the floodplain.) Mitigation is too important and too expensive to waste.
- As demonstrated here, mitigation procedures are more effective if they are tailored to the particular site. Several other practices would have been appropriate at the Austell site, such as:

(1) cleaning out the pond—which is rapidly filling with vegetation—during low water to extend its life;

(2) paving or adding gravel to the boat launching site;

(3) obtaining the land and turning it over to the Department of Natural Resources or Georgia Conservancy to help prevent frequent drainage; and

(4) terracing the slopes of the roadfill and fingers to make the area more attractive to waterfowl (*24*) and not necessarily encroaching on additional wetland acreage.

- Biologically oriented mitigation procedures such as this one, the project at Augusta, Ga., and the Torras Causeway in Brunswick, Ga., need to be monitored over a period of at least 5 years to build an adequate data base for future practices. This need not be more expensive. An intensive 1- or 2-year study followed by an annual survey over a period of years would not cost more but would provide better, longer term data.

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Ecological Functions of a Created Freshwater Tidal Wetland

NICHOLAS CAIAZZA

A 3.1-acre freshwater tidal wetland was created in 1986 along Rancocas Creek in Burlington County, New Jersey, to partially compensate for wetland losses associated with a nearby bridge construction project. An existing upland site was graded to an elevation that provides for inundation of the created marsh during mean high tide with between 1.0 and 2.2 ft of water. Three perennial species, *Peltandra virginica*, *Sagittaria latifolia*, and *Pontederia cordata*, were planted in the created marsh in the spring of 1986. Vegetation was sampled in September 1986 and 1987. Fish and benthic invertebrates were sampled in September 1987 and August 1988. Wildlife use of the marsh was observed and recorded throughout the study period. Sediment depth was sampled in June 1988. Unplanted, volunteer vegetation has become well established throughout the wetland. The created marsh exhibits an ecosystem structure consistent with a developing freshwater tidal wetland in which the following functions are being performed: primary productivity and food chain support, fish and wildlife habitat, sediment trapping, nutrient transformation, and flood storage. These functions help support neighboring aquatic and terrestrial ecosystems, serve to maintain surface water quality, and help to protect nearby development from flood damage.

Man-made wetlands have become a common component of the American landscape in recent years. This type of development has been primarily a result of conditions imposed on applicants for federal (mostly the U.S. Army Corps of Engineers Sections 404 and 9 permits) as well as various state permits and authorizations to develop in wetlands.

Wetlands commonly have been credited with performing a number of natural functions, most of which have direct value to society (*1*). When wetlands are filled and built on, such functions as wildlife habitat, flood control, and water purification are permanently diminished or even entirely lost, and resource or permitting agencies are increasingly demanding the creation of wetlands to compensate for these lost functions.

Much has been written, however, concerning several unsuccessful attempts to create functional wetlands. Examples range from outright failure to establish wetland vegetation (*2, 3*) to quantitative studies comparing natural and artificial wetlands for various floral, faunal, and sediment characteristics (*4*). The ultimate indicator of success is often considered to be how well the created wetland replicates the one destroyed, that is, to what extent the original wetland functions and values are replaced (*5*).

The New Jersey Department of Transportation (NJDOT) is becoming increasingly involved in wetland creation to help mitigate the impact to wetlands after the development of various roadway construction projects. In 1986, the NJDOT completed construction of a new, high-level bridge to replace an existing, deteriorated structure carrying U.S. Route 130 over the Rancocas Creek in Burlington County, New Jersey. Construction of the new bridge, near the confluence of the Rancocas with the Delaware River, required the filling of 2.3 acres of freshwater tidal wetland dominated by *Zizania aquatica* (wild rice), *Sagittaria latifolia* (arrowhead), *Polygonum* spp. (smartweeds), and *Peltandra virginica* (arrow arum) (Figure 1). Permits were issued for the construction by the U.S. Army Corps of Engineers and the New Jersey Department of Environmental Protection. As a condition of these permits, the agencies required that a total of 4.45 acres of freshwater tidal wetlands be created in the project area as mitigation for the loss of existing wetland values. The wetlands were constructed at two sites: Site 3 in 1984 (1.35 acres) and Site 1 in 1986 (3.1 acres). Existing substrate at both sites was sand, which was graded down to provide for inundation during high tide of between 1.0 and 2.2 ft of water. Both creation sites are inundated by high tide twice daily and drain completely at low tide. (The central portion of Site 1 is slightly higher in elevation to facilitate drainage into a peripheral tidal ditch, thus avoiding ponding at low tide.) The sites were planted with three perennial wetland species: *Peltandra virginica*, *Sagittaria latifolia*, and *Pontederia cordata* (pickerelweed).

Both sites have exhibited a successful establishment of vegetation, and all permit conditions are considered completely satisfied. But additional questions can be asked. In what ways are these created marshes functioning as wetland systems? Are they more than merely assemblages of wetland flora, spacially and hydrologically isolated, as some past attempts have been described?

MATERIALS AND METHODS

In an attempt to determine what wetland functions can be confidently attributed to a created wetland (specifically Site 1), NJDOT ecologists performed the following studies during the summers of 1986 through 1988.

Vegetation Survey

A total of 27 one-square-meter sample quadrats were located at random on the marsh in September 1986 and again in 1987. The number of individuals of each plant species was recorded at each quadrat, along with the percent areal cover for each species.

New Jersey Department of Transportation, 1035 Parkway Avenue, Trenton, N.J. 08625.

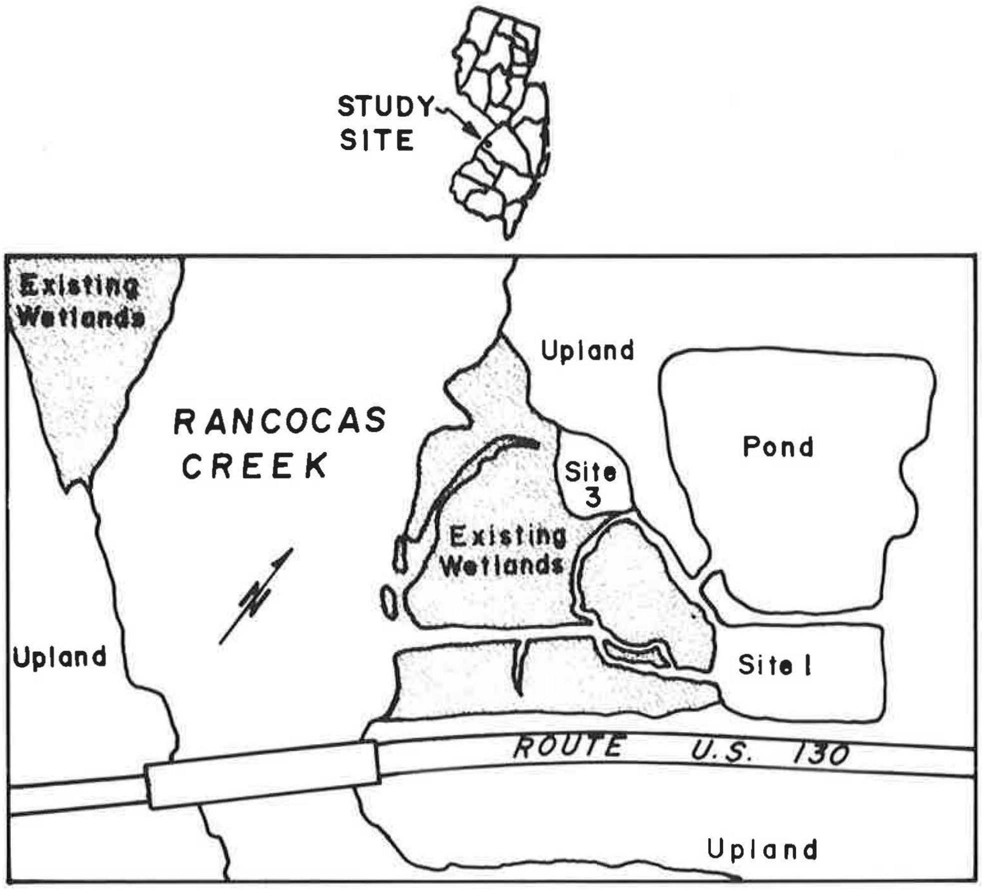

FIGURE 1 Study area showing the two created marsh sites (Sites 1 and 3).

Fish and Wildlife

Benthic macroinvertebrates were qualitatively sampled in September 1987. Portions of the peripheral tidal ditch and the marsh surface were closely observed, and individuals of all invertebrate species noticed were hand captured and immediately preserved in a 10 percent formalin solution and taken back to the laboratory for identification. In August 1988, benthic macroinvertebrates were again sampled at three tidal ditch and two marsh sites. Three samples were taken at each site by using a standard lightweight Ekman dredge and preserved in a 10 percent formalin solution. All samples were washed through a No. 30 U.S. standard sieve in the laboratory, and individual specimens were isolated and identified from the residue.

Fish were also sampled in September 1987 with a handheld seine net. Fish were netted along random sections of the tidal ditch surrounding the marsh at low tide. Representatives of all fish species collected were immediately preserved in a 10 percent formalin solution and taken back to the laboratory for identification.

All bird species observed during field visits for sampling of vegetation, sediment, or any other reason throughout the study period were recorded. Some periods of observation occurred from an adjacent upland, before entering the marsh, to minimize disturbance.

Observations of mammals and signs of their presence were also recorded during all field visits.

Sediment Depth

The depth of sediment deposited over the original sand substrate of the created marsh was measured at 21 sites in June 1988. Soil pits were dug at each sample site into the original sand layer, and a vertical surface was carefully carved out to expose the sand-sediment boundary without compaction or distortion of the layers. The boundary between original sand and sediment deposited on the marsh since its creation was easily discernible because of an abrupt change in color and texture. The depth of deposited sediment was directly measured with a plastic metric ruler.

RESULTS

Table 1 shows the dominant plant species of the created marsh in 1986 and 1987. Data have been converted to frequency (the number of quadrats in which the species is found, expressed as a percentage of the total number of quadrats), density (the number of individuals per square meter), and average absolute cover (the average of the areas of each quadrat covered by the species, as a percent). The table shows that unplanted, volunteer species have become well established. *Polygonum hydropiper* and *Ludwigia palustris* (water-purslane) maintained their dominance over both years. Of the planted species, only *Peltandra virginica* remains among the dominants. *Pontederia cordata* and *Sagittaria latifolia* both showed less

TABLE 1 DOMINANT PLANT SPECIES OF THE CREATED MARSH

Species[a]	Frequency (%)[b]	Density[b]	Average Cover (%)[b]
1986 (Total No. of Species, 19)			
Polygonum hydropiper	44	2.3	8
Ludwigia palustris	33	18.2	7
Peltandra virginica	44	0.9	5
Polygonum lapathifolium	19	0.6	1
Panicum sp.	30	0.4	1
1987 (Total No. of Species, 15)			
Polygonum hydropiper	100	110.4	72
Peltandra virginica	52	1.1	8
Ludwigia palustris	26	14.0	7
Polygonum arifolium	37	0.6	2
Polygonum sagittatum	15	0.8	1

[a]Species listed are those that showed an average cover ≥ 1 percent.
[b]See Results section of text for definitions of frequency, density, and average cover.

than 1 percent cover in 1986 and 1987. Late in the 1987 growing season, when the vegetation sampling was done (September), *Polygonum hydropiper* could be observed covering most of the marsh, and the density and average cover results for 1987 reflect the fact that by the end of the second growing season, there were few bare patches left on the marsh.

Macroinvertebrates found using the created marsh included the following: isopods (*Asellus* sp.), amphipods (*Gammarus fasciatus*), one species of freshwater snail (*Physa* sp.), three species of freshwater clam (*Anodonta* sp., *Sphaerium* sp., and *Pisidium* sp.), eastern crayfish (*Cambarus bartoni*), and chimney crayfish (*C. diogenes*). The snails were common on the marsh, particularly along the tidal ditch.

Several individuals of the following fish species were netted in the created marsh in September 1987: *Fundulus diaphanus* (banded killifish), *F. majalis* (striped killifish), *F. heteroclitus* (mummichog), *Ictalurus nebulosus* (brown bullhead), and *Lepomis macrochirus* (bluegill sunfish). Although these fish were netted from the peripheral tidal ditch built around the marsh, large schools of such fish have been observed on the marsh at intertidal periods or in marsh depressions during low tide.

Birds and mammals (or their signs) observed on the created marsh and its borders are the following:

Birds:

Great blue heron	(*Ardea herodias*)
Snowy egret	(*Egretta thula*)
Canada goose	(*Branta canadensis*)
Mallard	(*Anas platyrhynchos*)
Killdeer	(*Charadrius vociferus*)
Mourning dove	(*Zenaida macroura*)
American goldfinch	(*Carduelis tristis*)
Song sparrow	(*Melospiza melodia*)
Eastern kingbird	(*Tyrannus tyrannus*)
Common grackle	(*Quiscalus quiscula*)
American robin	(*Turdus migratorius*)
Red-winged blackbird	(*Agelaius phoeniceus*)

Mammals:

Muskrat	(*Ondatra zibethica*)
Raccoon	(*Procyon lotor*)
Red fox	(*Vulpes fulva*)
Groundhog	(*Marmota monax*)

Killdeer are commonly seen foraging on the marsh at low tide in early and midsummer when bare patches of mud remain. Canada geese are the most commonly seen waterfowl on the marsh, and adults and goslings regularly feed on the marsh at low tide. Muskrat and raccoon tracks are often seen in the marsh sediment, particularly along the ditch surrounding the marsh. Groundhogs burrow into areas of the berm and upland surrounding the marsh and are able to come onto the marsh at low tide.

The entire created marsh is covered by a layer of silty, very dark gray sediment that has been deposited since it was opened to tidal inundation in the spring of 1986. Figure 2 shows the depth of sediment at 21 sample sites on the created marsh. Although the results exhibit some variability (the range is 0.6 to 16.0 cm), two general trends in deposition of sediment can be seen. One is that deposition appears to be greater near the peripheral tidal ditch than in the interior of the marsh, which is a phenomenon supported by previous studies. Freshwater and saline tidal wetlands commonly exhibit slightly elevated levees along creek margins, where a large portion of sediment carried over the marsh by overflowing tides is deposited (*6,7*). The second trend that is visible in Figure 2 and readily evident from a visit to the marsh is that the southern portion (approximately one-third) of the marsh is covered by a deeper sediment layer. Walking in this area can be difficult at low tide as heavy, wet sediment clings to one's boots. This locally high deposition rate is presumably due to specific hydrologic conditions associated with the southern portion of the marsh.

DISCUSSION OF RESULTS

The Rancocas Creek created marsh possesses a developing ecosystem structure and provides several important wetland functions. The following discussion primarily highlights those functions indicated by the results of the study.

Productivity, Food Chain Support, and Fish and Wildlife Habitat

Simpson et al. (*8*) report that peak above-ground standing crop values for freshwater tidal wetlands have a range of 566–

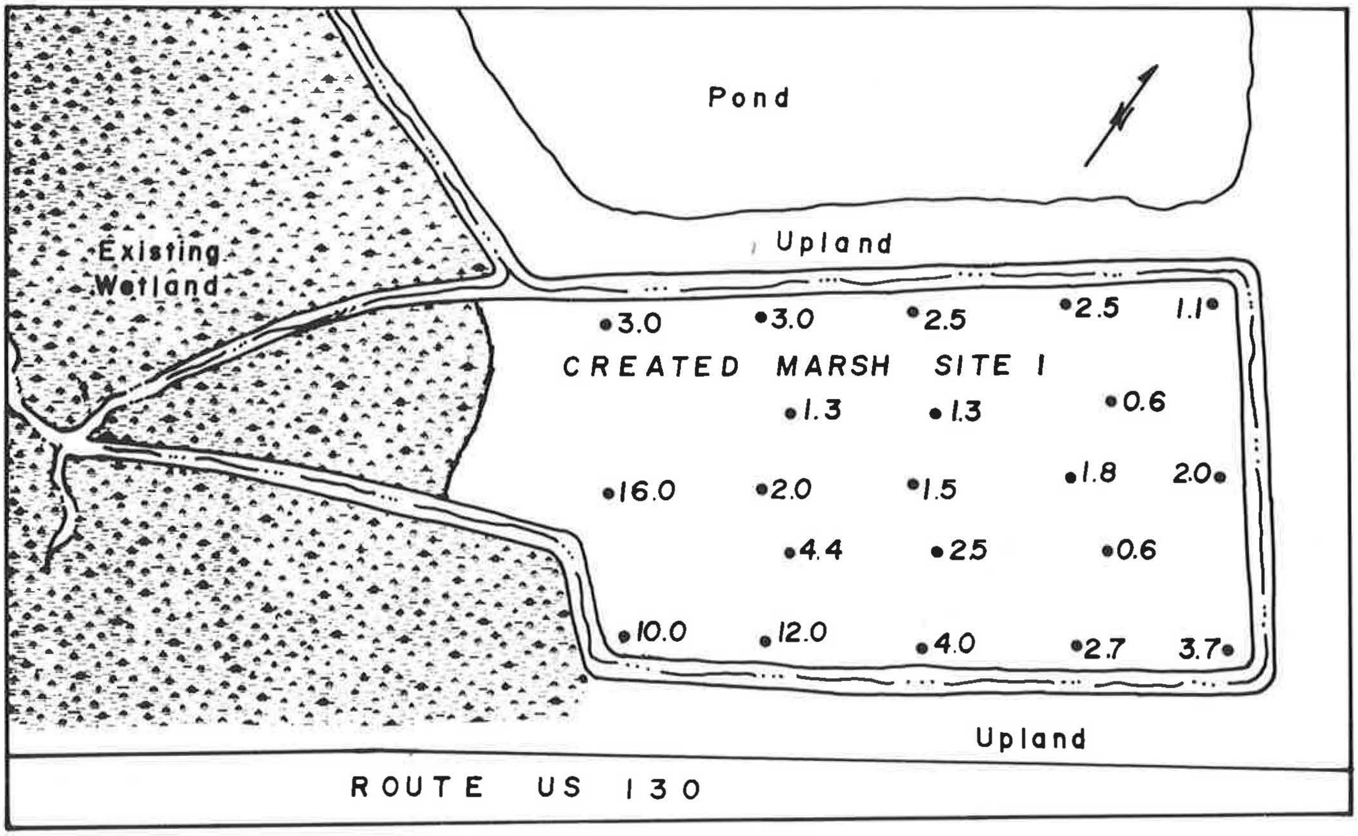

FIGURE 2 Created marsh Site 1 showing 21 sediment-depth sample locations. Values represent depth of sediment in centimeters.

2,312 g/m^2. Compared with other wetland or terrestrial ecosystems, freshwater tidal wetlands can be highly productive.

The created marsh Site 1 is obviously exhibiting primary productivity during the growing season. By September 1987, emergent annual and perennial plant species provided good cover throughout the marsh, as confirmed by the data from Table 1. Although accurately quantifying primary productivity in freshwater tidal wetlands can be difficult for several reasons (*9*), there are some productivity studies in the literature to which comparisons can be made. Odum et al. (*9*) summarized the results of several primary productivity studies for freshwater tidal wetlands in the mid-Atlantic region. The authors grouped the results for various vegetation types, or communities, stating that "density of vegetation and species composition . . . greatly influence production estimates" (*9*, p. 41). The two vegetation types discussed that most closely relate to the vegetation of created marsh Site 1 were arrow arum-pickerelweed and smartweed-rice cutgrass. The average above-ground peak standing crop for an arrow arum-pickerelweed marsh according to Odum et al. is relatively low (671 g/m^2), whereas the smartweed-rice cutgrass peak standing crop value (1,207 g/m^2) is among the moderate to higher averages reported for freshwater tidal marsh plant communities. Given the high frequency, density, and cover values for 1987 shown in Table 1 (particularly for the smartweed *Polygonum hydropiper*), it can be assumed that the created marsh productivity is similar to that given for the smartweed-rice cutgrass community. The Rancocas Creek-created marsh productivity would certainly be higher than a typical marsh entirely dominated by *Peltandra virginica* (arrow arum), whose leaves are composed primarily of water and aerenchymatous tissue (*9*), providing less dry weight biomass for a given degree of cover than species with more structural tissue (*8*). Doumlele (*10*) gave above-ground biomass and cover values for dominant species in a *Peltandra virginica* freshwater tidal marsh in Virginia for 5 months of the growing season. Annual production for the wetland was 775.74 g/m^2, with *Peltandra virginica* accounting for 423.4 g of that while exhibiting 38.7 percent cover. For all other species reported there was a combined cover of 16.9 percent. The average cover for *Polygonum hydropiper* alone in the Rancocas Creek created marsh for 1987 was 72 percent, which when compared to the Doumlele data also indicates a relatively high productivity. So, although a single, quantitative estimate of productivity for the Rancocas Creek created marsh cannot be given, it can be concluded that after only two growing seasons, the marsh's productivity is well within the expected range for natural marshes along the mid-Atlantic coast.

Freshwater tidal wetlands support mostly detritus-based food chains (*8*), and the Rancocas Creek created marsh is an example of this. As the end of the growing season approaches, the created marsh shows a high standing crop, as evidenced by the data in Table 1, but by midwinter the marsh is essentially a mud flat at low tide, stripped of all macrophytic vegetation. The daily tidal action of the created marsh flushes much of the dead plant material quickly out of the marsh, where it becomes available to support the aquatic food chains of the Rancocas Creek and Delaware River. Plant detritus that remains on the surface of the marsh and creek beds is consumed by benthic invertebrates, such as isopods, amphipods, insect larvae and snails, which in turn become food for various fish, birds, and mammals. Some direct grazing of vegetation does occur on the created marsh, however. *Polygonum* sp. seeds, considered important food for waterfowl and some songbirds (*11*), are plentiful on the marsh surface or floating at high tide in late summer. Muskrat are known to feed extensively on above- and below-ground parts of many plant species, including *Peltandra virginica* (*9*), and muskrat activity is evident in the created marsh. Canada geese are often seen on the created marsh feeding off the marsh surface at low tide, and the tidal ditch surrounding the entire marsh provides open water for ducks and wading birds to feed from even at low tide.

The fish species netted along the Rancocas Creek created marsh are all among the most common found in mid-Atlantic freshwater tidal marshes (*9*). The two species of killifish found are eaten by numerous larger fishes and wading birds (*9*), and as such are important food web components. In a recent study of fish use in tidal freshwater marshes and streams in Virginia, mummichogs and banded killifish were two of the most common fish netted (*12*). The authors concluded that the tidal freshwater marsh studied was heavily used by juveniles and may be an important nursery area, and that "marshes located at the upper reaches of tidal creeks support greater densities of fishes than marshes farther downstream" (*12*, p. 42). The Rancocas Creek created marsh is itself in a tidal headwater location, and its position in a well-developed creek system (Figure 1) coupled with its own peripheral ditch (Figure 2) probably serve to make it more productive for fish than a fringe marsh along a river (*12*).

Sediment Trapping and Nutrient Cycling

Accretion of clays and silts generally occur in freshwater tidal marshes (*9*). Accretion rates of mid-Atlantic freshwater tidal marshes are not well documented in the literature, where more attention has been focused on salt marshes. Hatton et al. (*13*) reported sediment accretion rates in a freshwater tidal marsh in Louisiana of 10.6 mm/year at a levee site and 6.5 mm/year in the backmarsh. Orson (unpublished presentation to New Jersey Academy of Science, Annual Meeting, 1988) reported an annual accretion rate for recent years of 1.2 cm/year in a freshwater tidal marsh along the Delaware River in New Jersey. Unpublished data from the natural Rancocas Creek freshwater tidal marsh near the U.S. Route 130 bridge (Orson, personal communication, 1988) show a similar sedimentation rate.

As reported, sediment depths at the Rancocas Creek created marsh show some variability, with a mean for all samples of 3.7 cm (coefficient of variation = 1.07). Less variability is shown by breaking up the results into two groups: levee sites along the peripheral tidal ditch (mean = 5.2 cm; coefficient of variation = 0.9) and interior sites (mean = 1.8 cm; coefficient of variation = 0.65). Regardless of the data variability, an average accretion rate of 1.2 cm/year for area marshes as reported by Orson is within the range found at the created marsh of 0.6–16.0 cm over an approximate 2-year period (0.3–8.0 cm/year).

Nutrient cycling in freshwater tidal marshes is a complex process varying seasonally (*6*). Generally, the marshes tend to import nutrients associated with plant uptake during the spring and summer. Nutrient export occurs during the fall as detritus washes off the marsh. In this manner, freshwater tidal marshes act primarily as nutrient transformers (*9*). Based on the plant productivity of the Rancocas Creek created marsh, and the detrital export washing into the Rancocas Creek at the end of the growing season, it is acting to transform nutrients from inorganic, oxidized forms to reduced compounds, usable by consumers. A significant degree of net nutrient retention may also be occurring in the created marsh, as nutrient-laden sediments are accreting on the surface as reported.

Flood Storage

The Rancocas Creek created marsh is within the 100-year floodplain of Rancocas Creek, according to the National Flood Insurance Program, Flood Insurance Rate Maps. The upland berm surrounding the marsh is at least 4 ft higher than the elevation of an average high tide on the marsh, providing additional storage for storm tides within the marsh. Flood storage is valuable in the project area, where development has encroached on several areas of the Delaware River floodplain.

In conclusion, the Rancocas Creek created marsh is a young but functioning wetland, with a developing ecosystem structure. Important environmental functions provided by the marsh include primary productivity and food chain support, fish and wildlife habitat, sediment trapping, nutrient transformation (and perhaps retention), and flood storage. These functions help support neighboring aquatic and terrestrial systems, since the created marsh is neither hydrologically nor biologically isolated. Those functions that serve to improve surface water quality, such as sediment trapping and nutrient retention, have great social importance in the area, since municipal water supply intakes (most notably the city of Philadelphia's) occur downstream.

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Genotype Selection and Seeding Rate in Bahiagrass Establishment

PHILIP BUSEY

Bahiagrass (*Paspalum notatum* Flügge) is a widely used roadside cover for the humid subtropics, but it can be slow and difficult to establish. Field tests were performed to determine optimum seeding rate and selection of genotype. Under weedy, nonirrigated conditions, Rapid Coverage Polycross (RCP-1) bahiagrass had higher establishment ratings in the second growing season than 'Pensacola' and 'Argentine.' For acceptable establishment, seeding rates of 17 and 12 g m^{-2} (150 and 100 lb/acre) would be required for Argentine and RCP-1, respectively. Pensacola establishment was unacceptable at any seeding rate, up to 19 g m^{-2} (170 lb/acre). Under weed-free conditions, and in the absence of millet (*Panicum* sp.) acceptable 2-month establishment required 13 and 16 g m^{-2} (120 and 140 lb/acre) seeding rates, respectively, for Argentine and Pensacola. Under weed-free conditions, high (>13 g m^{-2}) seeding rates conferred no advantage to long-term (9-month) performance. Millet interseeded with bahiagrass was deleterious to bahiagrass germination and subsequent establishment ratings. In spaced-plant evaluations, Rapid Coverage Polycross (RCP-2, or increase generation from RCP-1) had 12 percent and 61 percent faster lateral growth compared with Pensacola and Argentine, respectively. RCP-2 was superior to RCP-1 in visual coverage ratings. A dwarf bahiagrass, P3C1, which had shorter culms and finer texture than all other genotypes, had lateral growth equal to Pensacola.

Bahiagrass (*Paspalum notatum* Flügge) turf is widely used on highway rights-of-way in the humid subtropics. There it provides erosion control and aesthetic benefits. Bahiagrass has higher root mass per ground area and a higher ratio of root to shoot mass than several other species of warm-season grasses, e.g., bermudagrass, centipedegrass, and St. Augustinegrass (*1*). It is well adapted to low fertility (*2*) and is resistant to seasonal drought. In the Republic of China, bahiagrass has reduced the annual soil loss to $1.5 \cdot 10^2$ g m^{-2} compared with $1.56 \cdot 10^4$ g m^{-2} (70 tons/acre) under clean culture (*3*).

Grass root systems are capable of increasing the shear resistance of soil, which is important for the stabilization of highway slopes. Roots of some grass species produce threefold increases in soil shear resistance within 7.5 months after seeding (*4*). Although bahiagrass contributes to safety and other environmental goals along southeastern United States highways, and elsewhere, its establishment from seeding is often a failure. Improved specifications for bahiagrass seeding are needed to reduce construction and maintenance expenses.

Beneficial seeding practices such as mulching improve seedling stands of several turfgrass species. Straw mulch is at least as adequate as, and easier to apply than, many other materials (*5–7*). Mulch can be broadcast and cut in cross-slope at 450 g m^{-2} (2 tons/acre). Deep (9 to 25 mm, ⅜ to 1 in.) drilling and packing (pressing in) of seed in soil provides optimum bahiagrass germination, especially in sand soils during dry periods (*8*). Best bahiagrass establishment results from summer seedings [June through August (Busey, unpublished data)]. Postharvest dormancy is known to vary among bahiagrass genotypes (*9–11*) and may assist in the success of off-season seedings. Proper postseeding fertilization is important for bahiagrass establishment. A 9-week postseeding fertilization with 4.9 g of N m^{-2} (44 lb of N per acre) significantly improves turf quality, compared to no fertilization, when evaluated 22 months after seeding (Busey, unpublished data).

Recommended bahiagrass seeding rates are 0.3 to 49.3 g m^{-2} (2 to 436 lb/acre) (*12–14*), but 5.6 g m^{-2} (50 lb/acre) is often used in highway grassing. It is not known which rate is optimum. Bahiagrass is comparatively slow in its log-phase growth (*15*), which may contribute to the difficulty of seed establishment and problems of competition from weeds. Bahiagrass is often seeded in combination with a fast-growing cover crop, such as millet (*Panicum ramosum* L.) or annual ryegrass (*Lolium multiflorum* Lam.), but poor results have been observed from the use of millet (Busey, unpublished observations).

Cultivars "Argentine" and "Pensacola" are frequently used on highways. A proposed cultivar, RCP (Rapid Coverage Polycross) has been developed based on "general combining ability" (a genetic term) for rapid coverage ability (Busey and Henry, unpublished data). The comparative establishment of genotypes is not known. The objective of this study was to develop optimum seeding rates and selection of genotypes for bahiagrass establishment.

MATERIALS AND METHODS

Experiments were conducted at Fort Lauderdale Research and Education Center, Davie, Broward County, Florida. Field experiments were conducted on Hallandale fine sand, a siliceous, hyperthermic, Typic Psammaquent. Plots were occasionally spot treated with hydramethylnon (Amdro[R]) to control fire ants (*Solenopsis invicta* Buren), to facilitate data collection, but other pesticides were not used during the studies. Plots were free of preexisting bahiagrass and were individually broadcast-seeded from weighed allocations. Bahiagrass establishment was rated visually in field plots (10 = highest possible density, uniformity, and absence of weeds; 7 = acceptable; 1 = worst possible density, etc.), and other data were collected.

Experiment 1: Establishment under Weedy Conditions

Seven seeding rates of three bahiagrass genotypes (Argentine, Pensacola, and RCP-1) were seeded on 13 August 1986. Rates

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TABLE 1 ESTABLISHMENT RATINGS OF BAHIAGRASS GENOTYPES AND SEEDING RATES UNDER WEEDY CONDITIONS

		Evaluation time, days after seeding					
		First season	Second growing season				
Genotype		98	250	298	324	438	Mean
RCP-1		5.3 a[z]	5.6 a	6.1 a	6.7 a	6.7 a	6.3 a
Argentine		4.4 b	4.7 b	5.5 a	6.3 a	5.0 b	5.4 b
Pensacola		4.0 b	3.2 c	4.0 b	4.7 b	4.5 b	4.1 c
Seeding rate							
g.m-2	pounds/acre						
19.2	171	6.4 a	6.6 a	6.7 a	7.6 a	7.4 a	7.1 a
12.8	114	5.4 b	5.2 b	5.7 ab	6.7 ab	6.1 bc	5.9 b
8.5	76	4.9 bc	5.2 b	6.3 a	6.7 ab	6.5 ab	6.2 b
5.7	51	4.1 cd	4.1 c	5.1 bc	5.6 bc	5.0 cd	4.9 c
3.8	34	3.9 d	3.6 cd	4.6 c	5.3 c	4.4 de	4.5 cd
2.5	23	3.6 d	3.9 cd	4.6 c	5.2 cd	4.7 de	4.6 c
1.7	15	3.5 d	3.0 d	3.5 d	4.2 d	3.8 e	3.6 d
Mean squares:							
Genotype		18.5	59.4	50.5	24.0	29.1	49.9
Seeding rate		21.5	27.1	21.6	46.6	56.2	24.9
Error		1.5	1.5	1.7	1.8	1.7	1.4

[z] Values are visual ratings, means of 6 replications; 10=maximum possible; 1=least. Values with a letter in common are not significantly different by the Waller-Duncan k-ratio t-test, k=100, P = ca. 0.05.

were 1.7 to 19.2 g of seed m^{-2} (15 to 171 lb/acre) in a 1.5× geometric series. The 21 resulting factorial combinations plus a control (nonseeded) treatment were replicated in six randomized complete blocks. Seed had been harvested by commercial growers in 1984 (Argentine and Pensacola bahiagrasses) or by hand in 1983 at the Fort Lauderdale Research and Education Center (RCP-1 bahiagrass). Seed were not scarified and were stored in a refrigerator (5°C). Tests done in 1984 by professional laboratories revealed proportions of pure, live seed (percent germination × percent pure seed) of 75 percent, 91 percent, and 90 percent for Argentine, Pensacola, and RCP-1, respectively; and 61 percent and 38 percent dormancy ("hard seed") for Pensacola and RCP-1, respectively. Because Argentine seed were hand-peeled, dormancy data were not available. A 1985 field study (Busey, unpublished data) revealed that acid scarification on these seed lots did not affect establishment. Thus, by the time the seed were used in the present study, they were effectively nondormant. Seeding rates were based on gross weight. Individual seed weights were 2.58, 1.51, and 1.69 mg for Argentine, Pensacola, and RCP-1, respectively.

Plots were 1.5 m by 1.2 m (5 ft by 4 ft). Soil pH was 6.0 to 6.5, and plots were not irrigated, were mowed three times in the first year, and received no pest control. Before tillage, the field area had a dense stand of torpedograss (*Panicum repens* L.), a competitive, perennial grassy weed. Grass and weeds were mowed, and plots were rototilled to 16 mm (0.6 in.). Debris was removed, the area was leveled with a hand rake and broadcast-seeded, and seed were gently raked in. Plots were mulched with 454 g m^{-2} (2 tons/acre) small-grain straw, and run over with a cultipacker. Plots were fertilized 5 weeks after seeding, with 5.0, 0.6, and 2.1 g m^{-2} N, P, and K, respectively (44, 11, and 22 lb/acre of N, P_2O_5, and K_2O, respectively), with additional micronutrients, and 78 percent of the N was water soluble, primarily ammoniacal. Establishment ratings were taken on five dates of evaluation (3 to 15 months after seeding), and cultivars and seeding rates were compared by analysis of variance, within dates (Table 1).

TABLE 2 BAHIAGRASS GENOTYPE CHARACTERISTICS

Genotype	Unmown foliage height	Leaf width	Culm height	Culm number	Plant diameter	Visual cover rating[z]
	(mm)	(mm)	(mm)		(mm)	
RCP-2	144 c[y]	7.10 c	763 c	136 c	408 a	8.7 a
RCP-1	137 bc	6.71 b	752 c	135 bc	378 ab	8.0 b
Pensacola	129 b	7.00 bc	759 c	95 b	364 b	7.9 b
P3C1	108 a	6.30 a	544 a	162 c	362 b	6.3 c
Argentine	101 a	9.14 d	672 b	29 a	253 c	5.7 c
Mean squares:						
Genotype	6973	24.16	176740	54185	69706	30.5
Error	501	0.38	4743	4734	5015	1.5

[z] Visual rating, 10=maximum possible; 1=least; 7=acceptable.

[y] Values with a letter in common are not significantly different by the Waller-Duncan *k*-ratio *t*-test, *k*=100, P = ca. 0.05.

Because seeding rates and dates of evaluation were continuous variables, regression was a more appropriate means to study their effect than analysis of variance (*16*). Establishment ratings were estimated by a multivariate model, involving stepwise regression of linear effects, days after seeding, seeding rates, and quadratic and interactive sources of variation, for each genotype. To simplify the interpretation, four dates of evaluation (April through October 1987) were averaged as split plots in time, and genotype responses to log seeding rates were analyzed by using a linear model.

Experiment 2: Establishment Under Weed-Free Conditions

Red millet (*Panicum* sp.) and bahiagrasses were seeded together in various rate combinations on 25 August 1987. Seeding rates for each species were 0, 6.5, 12.9, 19.4, and 25.8 g m^{-2} (0, 60, 120, 180, and 240 lb/acre), in all combinations, making 25 factorial treatment combinations. Treatments were repeated for two cultivars (Argentine and Pensacola) in three completely randomized replications; hence there were 150 plots. Seed of cultivars (1985 and 1986 harvests) were commercially scarified and fungicide treated and had a pure live seed proportion of 72 percent and 82 percent for Argentine and Pensacola, respectively. Seed weights were 3.09, 1.64, and 5.42 mg per seed for Argentine, Pensacola, and millet, respectively.

Plots were 1.5 by 1.5 m (5 by 5 ft). The field area had been fumigated (methyl bromide) to control weeds. (Because of its high cost, soil fumigation would be inappropriate for highway use.) The pH was between 7.2 and 7.6. Plots were rototilled to a depth of 50 mm (2 in.), left rough, and seeded. Plots were raked level, mulched with 450 g m^{-2} (2 tons/acre) of small grain straw, and run over with a cultipacker. Plots were fertilized with 9.9, 1.1, and 4.1 g m^{-2} of N, P, and K, respectively (88, 22, and 44 lb/acre of N, P_2O_5, and K_2O, respectively), with additional micronutrients, and 78 percent of the N was water soluble, mostly ammoniacal. This fertilizer was split into two application groups, applied at 3 and 6 weeks postseeding. Plots were irrigated 6 mm (0.25 in.) every other night, except during rainy periods, for the first 6 months. Seedling emergence and root and shoot biomass were determined 8 weeks after seeding with a 100-mm-(4-in.) diameter core randomly taken to a depth of 150 mm (6 in.) from one replicate of each treatment. Establishment ratings were taken visually at 2 and 9 months postseeding. Stepwise regression was used to develop a model for genotype response to seeding rates.

Experiment 3: Genotype Characteristics

Bahiagrass genotypes (Table 2) were compared in a spaced planting. RCP-2 consisted of the second-generation bulk increase (first generation from polycross nursery) of RCP-1. P3C1 consisted of the third-generation bulk of a dwarf population under selection. All seeds were germinated at the same time in a greenhouse, seedlings were transplanted in September 1987 to a temporary field area, and healthy plants of each genotype were again transplanted in December 1987 to a space-planted trial in the same areas as Experiment 2. Plots were irrigated every other night, except during rainy periods, for the first 3 months after seeding. There were 20 complete blocks, and plots were 1.2 by 1.2 m (3 by 3 ft).

In March 1988, each plant was measured for diameter lateral spread, unmown leaf height, and leaf width. Culm (seedhead) height at anthesis (mean of tallest three per plant) and number per plant were recorded weekly from 18 May through 28 June 1988. Because of the seasonally variable number of culms per plant, the culm height for each plot was the seasonal mean weighted for the number of culms produced during each week. Coverage was estimated visually in July 1988. Genotype means were compared by analysis of variance.

RESULTS

Experiment 1: Establishment Under Weedy Conditions

RCP-1 bahiagrass achieved higher establishment ratings than Argentine or Pensacola on most dates of evaluation (Table 1). Bahiagrass establishment was highly dependent ($r^2 = 0.56$, $P < 0.0001$) on days after seeding, seeding rates, blocks, cultivars, and several quadratic and interactive sources of variation. Predicted establishment ratings for treatment means were

$$Y_A = -2.77 + 0.362*B - 0.00736*B^2 + 0.0371*T - 0.0000542*T^2 \quad (1)$$

$$Y_P = -2.29 + 0.406*B - 0.01031*B^2 + 0.0205*T - 0.0000222*T^2 \quad (2)$$

$$Y_R = 1.17 + 0.155*B + 0.00060*B^2 + 0.0182*T - 0.0000189*T^2 \quad (3)$$

where

Y_A, Y_P, and Y_R = predicted second growing season establishment ratings for Argentine, Pensacola, and RCP-1, respectively,
B = bahiagrass seeding rate (g m^{-2}), and
T = time since seeding (days).

These formulae explained 78 percent, 89 percent, and 78 percent of the variance of treatment means for Argentine, Pensacola, and RCP-1, respectively. Longer intervals after seeding and higher seeding rates generally resulted in higher establishment ratings.

A simpler, linear regression of genotype second-growing-season establishment on log-transformed seeding rates (Figure 1) resulted in

$$Y_A = 2.879 + 1.446*\ln(B) \quad (4)$$

$$Y_p = 1.701 + 1.384*\ln(B) \quad (5)$$

$$Y_R = 4.497 + 1.021*\ln(B) \quad (6)$$

These formulae explained 62 percent, 68 percent, and 52 percent of the variance of treatment means for Argentine, Pensacola, and RCP-1, respectively. According to these formulae, seeding rates of 17 g m^{-2} (150 lb/acre) for Argentine and 12 g m^{-2} (100 lb/acre) for RCP-1 would be required to achieve acceptable (rating ≥ 7.0) establishment in the second growing season. Pensacola would not achieve acceptable establishment at any seeding rate within the range of rates tested. The higher establishment ratings of RCP-1 bahiagrass compared with Argentine and Pensacola (Figure 1) were most noticeable at low seeding rates.

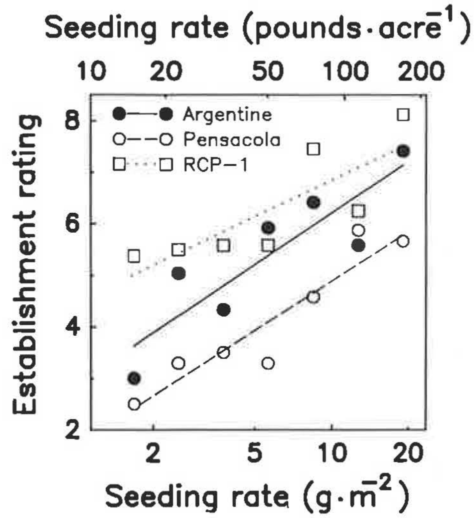

FIGURE 1 Bahiagrass establishment response to bahiagrass genotype and seeding rate under weedy conditions: second growing season.

Experiment 2: Establishment Under Weed-Free Conditions

Higher emergence of seedlings was observed for Pensacola than for Argentine (5,220 vs. 2,620 m^{-2}). Considering the smaller seed size for Pensacola compared with Argentine, and the differing pure live seed proportions, this calculated to comparable germinations for Pensacola and Argentine, 69 percent and 65 percent, respectively. The millet seeding rate had a deleterious effect on bahiagrass germination percentages and reduced bahiagrass germination by about one-third over the range of millet seeding rates used.

Early (2-month) bahiagrass establishment ratings were highly determined ($r^2 = 0.74$ and 0.80 for Argentine and Pensacola, respectively) by bahiagrass seeding rate (Figure 2), millet seeding rate (Figure 3), and second- and third-order interactions:

$$Y_P = 1.05 + 0.579B - 0.0128B^2 - 0.031BM + 0.000484BM^2 + 0.000527B^2M \quad (7)$$

$$Y_A = 1.10 + 0.628B - 0.0129B^2 - 0.290BM + 0.000375BM^2 + 0.000553B^2M \quad (8)$$

where

Y_P, Y_A = predicted second growing season establishment ratings for Pensacola and Argentine, respectively,
B = bahiagrass seeding rate (g m^{-2}), and
M = millet seeding rate (g m^{-2}).

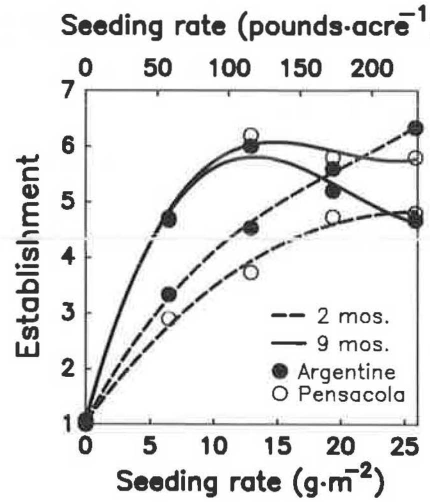

FIGURE 2 Bahiagrass establishment response to bahiagrass genotype and seeding rate under weed-free conditions.

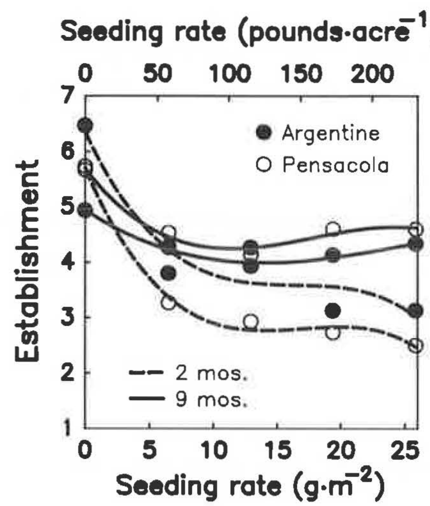

FIGURE 3 Bahiagrass establishment response to millet seeding rate under weed-free conditions.

Acceptable early bahiagrass establishment (rating ≥ 7) was predicted only for high bahiagrass seeding rates (13 g m^{-2}, 120 lb/acre, for Argentine; and 16 g m^{-2}, 140 lb/acre, for Pensacola) and where no more than 2 g m^{-2} (17 lb/acre) millet would be used. In the range of acceptable seeding rates, millet would always be deleterious.

Bahiagrass stand dry weights were highly associated with visual establishment ratings. Argentine and Pensacola revealed a similar relationship between establishment rating and stand dry weight (data not presented). Acceptable 2-month establishment (rating ≥ 7) was associated with stand dry weights ≥ 110 g m^{-2} (980 lb/acre). Argentine achieved higher stand dry weights than Pensacola. Each increase of 1 g m^{-2} millet seed would require a 3 g m^{-2} increase in bahiagrass seed to compensate for the deleterious effects of millet.

The 9-month establishment ratings revealed a dramatic curvilinear relationship (Figure 2). Maximum bahiagrass establishment was predicted for both Argentine and Pensacola in the bahiagrass seeding rate range, 10–15 g m^{-2} (90 to 130 lb/acre) and higher rates were deleterious. The deleterious effect caused by millet was less conspicuous for the 9-month rating (Figure 3) than for the 2-month rating.

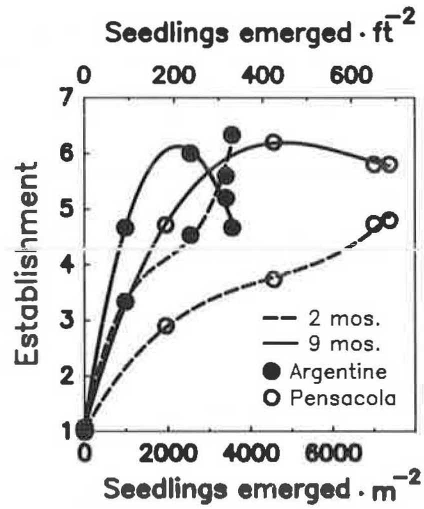

FIGURE 4 Bahiagrass establishment response to bahiagrass seedling emergence under weed-free conditions.

The most predictive criterion of bahiagrass establishment was seedling emergence (Figure 4). Maximum 9-month establishment ratings were observed at 2,000 and 4,000 emergent seedlings m^{-2} for Argentine and Pensacola, respectively. These seedling densities resulted in marginal establishment (rating about 6), and higher densities were not beneficial.

Experiment 3: Genotype Characteristics.

RCP bahiagrass (generations RCP-1 and RCP-2) had rapid lateral spread (Table 2). RCP-2 was faster spreading than Argentine and Pensacola and equal to or faster than RCP-1. These rates indicated that no decline in fitness had occurred during advance of generations. RCP-1 was not different from Pensacola in any respect. RCP bahiagrass was relatively tall (unmown height) compared with other genotypes and about the same texture (leaf width) as Pensacola. The dwarf bahiagrass, P3C1, had moderate coverage rate and was superior to Argentine, but not different than Pensacola. The dwarf had significantly finer leaves and shorter culm height than all other genotypes and had unmown height as short as Argentine. The dwarf, P3C1, also had the largest number of seedheads. These results are encouraging evidence of breeding progress for rapid coverage and dwarf habit.

CONCLUSIONS AND RECOMMENDATIONS

These studies, in combination with a review of previous work, result in a model and a method for bahiagrass establishment. Bahiagrass has slow biomass accumulation (*15*), poor seedling competition, and slow vegetative spread. Successful establishment may be viewed as a process of developing sufficient biomass reserve to endure cool and dry periods, when bahiagrass growth ceases. Everything must be done to gently promote the bahiagrass, while using proper timing of practices (e.g., mowing and fertilization) to deter weed encroachment but not injure the bahiagrass. Millet (*Panicum* spp.), because of its deleterious effects, should not be used at high rates, although it has commonly been used as a companion crop. The effect of millet is so deleterious that it should be further studied for possible allelopathy, which might be operable at low seeding rates.

Genotype selection is important in bahiagrass establishment. Argentine and RCP-1 had superior establishment compared with Pensacola. From 13 to 17 g m^{-2} (120 to 150 lb/acre) Argentine seed would be needed, depending on conditions, and 16 g m^{-2} (140 lb/acre) Pensacola would be needed under weed-free conditions. RCP-1 can be planted at 12 g m^{-2} (100 lb/acre), even under weedy conditions, to achieve acceptable establishment. RCP-1 and RCP-2 have an advantage because they have faster lateral growth rates than Argentine, based on spaced plant evaluations. Higher bahiagrass seeding rates are beneficial, especially in weedy conditions, and their effect is most apparent in the first season of growth. Seeding rates needed to achieve acceptable establishment in the second season and in weed-free conditions may be reduced considerably with no reduction in ultimate establishment ratings.

The effectiveness of proper seeding rate and genotype selection is dependent on other practices that have been found to be effective. Seeding should be done during warm, rainy months; no supplemental watering is needed. Seed should be distributed evenly, incorporated 9 to 25 mm (3/8 to 1 in.) deep, mulched with small-grain straw at 450 g m^{-2} (2 tons/acre), and firmly rolled after seeding to create good seed to soil contact. If there is any slope, the mulch should be cut in across slope with blunt coulters (*5*).

Seeded areas should be fertilized to provide maximum nutrient release to young seedlings. Soluble nitrogen sources can be used but should be in a complete formulation, including micronutrients (iron, especially). The application of fertilizer postseeding is more expensive than fertilization at the time of planting because it requires a second visit to the site by the grassing contractor. About 4.5 g of N m^{-2} (40 lb of N per acre) is effective, and higher rates should not be used in any single application. Regular mowing should be initiated as soon as weeds begin to shade the bahiagrass seedlings (about 6 weeks), but mowing height must not be less than 80 mm (3 in.).

Inspection 3 to 9 weeks after seeding (assuming warm weather and adequate soil moisture) should reveal a minimum of 1,000 to 2,000 seedlings m^{-2} (100 to 200 per ft^2), although this is not a guarantee of successful longterm establishment, if other procedures are not followed. One should be unable to take a step without touching a seedling. Seedlings should produce one leaf per week of growth, and a major onset of tillering (development of basal offshoots) and development of thick roots should be observed 8 weeks after seeding. Seedling stands may subsequently be observed to go into 1 or more weeks of wilt, and still survive, but they remain tender and susceptible to shading by weeds and scalping. Until seeded areas are 1 year old, a secure basis for their acceptance cannot be made.

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Operation and Motorist Usage of Interstate Rest Areas and Welcome Centers in Virginia

MICHAEL A. PERFATER

This study was conducted to examine existing conditions at Virginia's Interstate rest areas and welcome centers and to assess what impact additional services, such as vending machines, might have on the service delivery of these facilities. A selected sample of seven rest areas and four welcome centers were visited in October 1986, May 1987, and August 1987 for a 1- to 2-day period for the purpose of obtaining data. Traffic counts, vehicle occupancy, length of stay, restroom and amenity usage, and parking lot occupancy rates were all recorded. Videotapes were made to record the general condition of the facilities. Stopping motorists were asked to respond to a mailbox survey, and interviews were conducted with rest area custodians. The impact of vending machines, which were installed at seven sites in May 1987, was also assessed. The study generally revealed that the Interstate traveler is dependent on rest areas and welcome centers. It also pointed out the need for the refurbishment of some facilities and the need for additional facilities, especially women's restrooms. Vending machines were found to be enthusiastically received by the public, to generate approximately 30 percent more refuse but little in the way of litter, to incur some vandalism but only while attendants were not on duty, and to generate a substantial amount of revenue for the Virginia Department of Transportation and Virginia State Department for the Visually Handicapped.

The origin of today's rest area system was a provision in the Federal-Aid Highway Act of 1938 that stated "the States with the aid of Federal Funds may include . . . such sanitary and other facilities as may be deemed necessary to provide for the suitable accommodation of the public." The intent of the Act was to increase motorist safety and comfort by providing facilities for stopping and resting. Subsequent Federal-Aid Highway Acts, the Highway Trust Fund, and the Highway Beautification Act of 1965 gave authority, funding, and substance to the rest area program. Ultimately, each state prepared a master plan for the development of rest areas. The primary guidelines used to prepare these plans were the FHWA's "Instructions for Highway Beautification Cost Estimate," the AASHTO guide on safety rest areas (*1*), and FHWA Policies and Procedures Memoranda 80-1 and 90-3.

Using these guidelines, the Virginia Department of Transportation (VDOT) developed a master plan for constructing rest and welcome facilities on Virginia's Interstate highway system. The plan established sites and building designs for these facilities and included amenities such as picnic tables, drinking fountains, trash receptacles, and walkways positioned around brick buildings containing restrooms. At the state borders, these buildings were combined with tourist information centers operated by the Virginia Department of Economic Development's Division of Tourism.

Rest areas and welcome centers in Virginia were designed and constructed to meet the needs of travelers based on 20-year traffic projections. Since most of them were built during the late 1960s or early 1970s, many have been, or very shortly will have been, in operation for 20 years. During this period, traffic speeds and conditions as well as vehicle types and sizes have changed. Driving habits have also changed because of the increased mobility of certain segments of the population, such as senior citizens, the handicapped, and young families. These factors have put increased demands on rest areas and welcome centers. To assess how these facilities are meeting those demands, a study was undertaken to determine baseline conditions for the safe and efficient operation of Virginia's Interstate rest areas and welcome centers. This paper presents the results of that study.

METHODOLOGY

The study consisted, for the most part, of fact-finding visits to a selected sample of Virginia's rest areas and welcome centers. Since manpower and funding limitations did not permit an evaluation of all such facilities in the Commonwealth, a representative sample of the 28 interstate rest areas and 9 welcome centers that are currently in operation was chosen (Figure 1). Mainline traffic volume, geographical location, physical condition, and other site-specific features were used to determine which sites would be selected for study.

Eleven sites were chosen for evaluation, four of which are combination rest areas and welcome centers (Table 1). At each site, the following tasks were performed by a five-member study team between the hours of 8 a.m. and 5 p.m. for a 2-day period in the fall of 1986, for a 1.5-day period during the spring of 1987, and for a 1-day period during the summer of 1987:

1. Length of stay and occupancy rates were documented for vehicles entering the sample sites during daylight hours.
2. Frequency of use of restrooms, picnic tables and grills, telephones, and other site-specific amenities was determined. Hourly occupancy counts were also made of both passenger car and truck parking lots.
3. A videotape was made of each site to record the condition of the grounds and appurtenances. The outside shoulder of the mainline 2 miles downstream from each site was also videotaped to document litter accumulation.

Virginia Transportation Research Council, P.O. Box 3817 University Station, Charlottesville, Va. 22903.

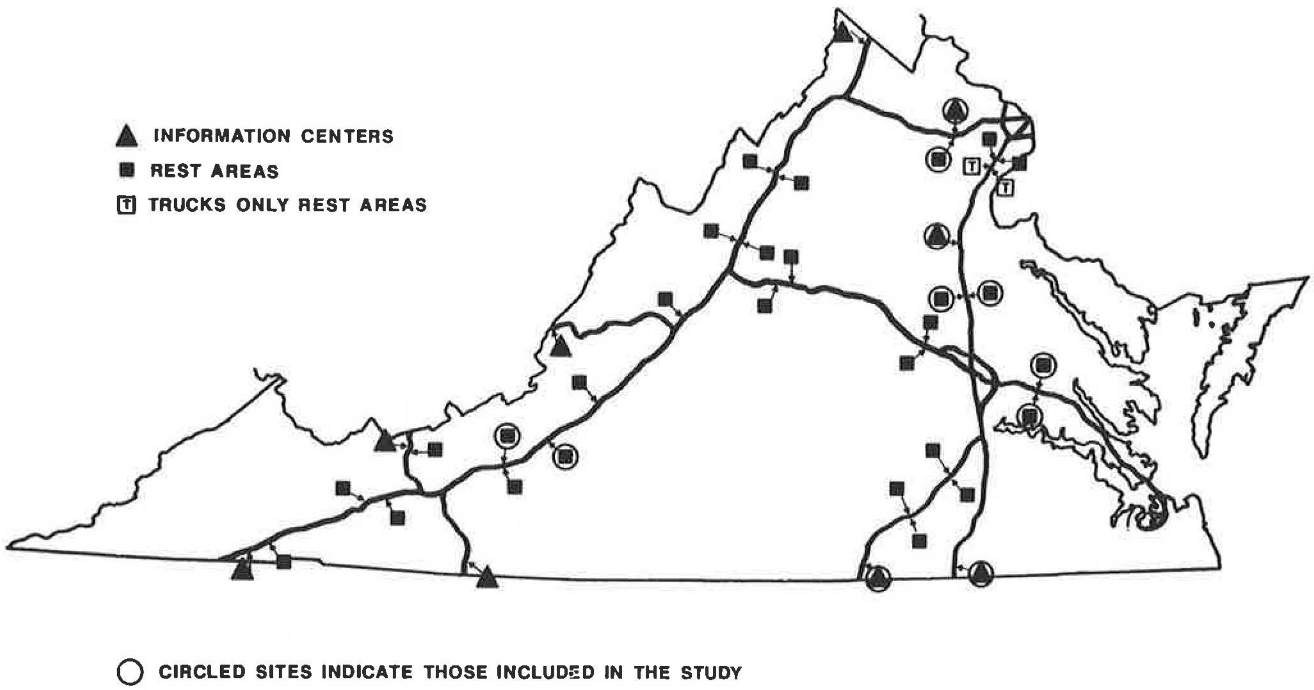

FIGURE 1 Commonwealth of Virginia Interstate rest areas and information centers.

TABLE 1 REST AREA SAMPLE SITES

Site No.	Classification	Year Built	Location[a]
1	Rest area	1968	I-81 SBL 0.8 mi S of Rt. 177 near Radford
2	Rest area	1979	I-81 NBL 0.9 mi N of Rt. 603 near Ironto
3	Welcome center	1965	I-95 NBL 0.1 mi N of Va./N.C. state line
4	Welcome center	1966	I-85 NBL 0.7 mi N of Va./N.C. state line
5	Rest area	1977	I-64 EBL 2.4 mi E of Rt. 609 near New Kent
6	Rest area	1977	I-64 WBL 1.1 mi W of Rt. 155 near New Kent
7	Rest area	1965	I-95 NBL 3.4 mi N of Rt. 207 near Ladysmith
8	Rest area	1965	I-95 SBL 2.6 mi S of Rt. 609 near Ladysmith
9	Welcome center	1968	I-95 SBL 1.8 mi S. of Rt. 17 near Fredericksburg
10	Rest area	1965	I-66 EBL 1.5 mi E of Rt. 234 near Manassas
11	Welcome center	1965	I-66 WBL 0.3 mi W of Bull Run

[a]SBL, southbound lane; NBL, northbound lane; WBL, westbound lane; EBL, eastbound lane.

4. Special problems, special conditions, and any history of vandalism were documented mostly through on-site observation and discussions with custodial staff.
5. Prestamped, mail-back questionnaires were distributed to stopping motorists. They contained both site-specific questions and ones relative to motorists' stopping habits, frequency of use of the rest area system, and overall opinion of it. A copy of the questionnaire is available from the author and can also be found in a published report by the author (*2*).

In addition, 24-hour traffic counts of vehicles entering all rest area and welcome center lots over a 7-day period were made just before each data-gathering visit.

SERVICE DELIVERY CHARACTERISTICS OF SAMPLE SITES

Vehicle Occupancy Rates

Research team members stationed at the exit ramps recorded the occupancy of a sample of the entering vehicles. Table 2 shows the average occupancy rates for these vehicles. (Num-

TABLE 2 OCCUPANCY RATES OF VEHICLES ENTERING REST AREAS AND WELCOME CENTERS

Vehicle Type[a]	Rest Areas[b]	Welcome Centers[b]
Passenger car (10,256)	1.80	1.90
Light truck (455)	1.25	1.30
Tractor-trailer (1,688)	1.05	1.05
Recreational vehicle (424)	2.05	2.10
Bus (50)	24.00	28.60
Motorcycle (74)	1.20	1.30

[a]Numbers in parentheses are no. of vehicles.
[b]Values are no. of occupants per vehicle.

bers in parentheses denote the number of vehicles in the sample.) Occupancy rates for all classes for vehicles were found to be about 15 percent higher during the summer than in the spring and fall.

Length of Stay

To determine the duration of the usual rest area visit, a member of the research team was stationed at the entrance ramp equipped with a lap-top computer into which the license plate number and classification of each entering vehicle and the time of day were entered. Another member of the research team entered the same data as each vehicle left the rest area. Using a computerized method by which license plates of the entering vehicles were matched with those of exiting ones, the duration of the rest area visit by vehicle class was determined. Vehicles that tend to remain the longest at rest areas are the larger ones—tractor-trailers, recreational vehicles, and buses. Tractor-trailers and recreational vehicles tend to remain longer at rest areas than at welcome centers, whereas the opposite is true for passenger cars. All classes of vehicles, with the exception of buses, tend to remain at rest areas and welcome centers longer in the summer than in any other season. For the 6,300 passenger cars for which license plate matches were achieved, the average length of stay was 9.1 minutes. In the summer, this stay was extended to almost 10 minutes. For large vehicles, the average length of stay was about 15 minutes.

In-State: Out-of-State Ratio

The license plate retrieval process also provided a means for gathering information regarding the in-state versus out-of-state mix of vehicles entering rest facilities. Table 3 shows that the ratio of in-state to out-of-state passenger cars is essentially identical for rest areas and welcome centers. Seasonal variations from this trend were minimal for all vehicle types except for passenger cars. During the spring and summer travel seasons, welcome centers had a higher influx of out-of-state users, whereas rest areas tended to attract more in-state passenger cars.

Parking Lot Occupancy

To assess the adequacy of parking facilities at each of the subject sites, the number of spaces in both truck and passenger lots was inventoried, and hourly counts were made of the vehicles occupying these lots. None of the lots was ever found to be full at the time these counts were made. Truck lots were, on average, at 41 percent of capacity, and the passenger car lots were at 32 percent of capacity between 8 a.m. and 5 p.m. on weekdays. Welcome center lots exceeded this average by 4 percent and 10 percent, respectively. As one might expect, summer travel raised these occupancy rates some, especially for the passenger car lots; but these increases also were meager—on average, less than 5 percent.

Although during data-gathering periods all lots were found to be adequate to meet demand, there was some evidence that during certain specified periods, demand exceeded capacity. Photographs taken before 8 a.m. by rest area custodians showed trucks parked both along the exit ramps and, at some sites, on the mainline. Custodians attested that such occurrences were not infrequent, especially between 10 p.m. and dawn, and attributed them to the tendency for truckers to ignore the posted 2-hour parking limitation. Commentary received from truck drivers, motorists, and VDOT staff supported the custodians' claims that truck drivers are reluctant to heed the 2-hour limit, especially at night. Enforcement of this limit is difficult, especially since it does not have a high priority with the Virginia State Police. Increasing or removing the limit completely might only magnify the problem. Although larger truck parking lots or separate trucks-only rest areas are viable options, the availability and cost of land adjacent to the interstate renders either of these alternatives a costly one.

Some overcrowding in the passenger car and truck parking lots also occurred on weekends and holidays. Although data were not gathered during these periods, random visits to selected sites on weekends revealed some parking capacity problems in the passenger car lots. These occurrences appeared to be the result of the number of vehicles entering rest areas during

TABLE 3 IN-STATE VERSUS OUT-OF-STATE PROPORTION OF VEHICLES ENTERING REST AREAS AND WELCOME CENTERS

Vehicle Classification	Welcome Centers (%)		Rest Areas (%)	
	In-State	Out-of-State	In-State	Out-of-State
Passenger car	42.5	57.5	41.5	58.5
Light truck	59.8	40.2	51.5	48.5
Tractor-trailer	16.9	83.1	25.4	74.6
Double trailer	25.0	75.0	0	100.0
Recreational vehicle	9.8	90.2	8.6	91.4
Bus	53.9	46.1	18.2	81.8
Motorcycle	38.6	61.4	46.7	53.3

these peak periods rather than from nonobservance of the 2-hour parking limit. Isolated instances of shoulder parking were observed, and there was some queuing for parking spaces. Although such occurrences did not appear to present a significant safety problem in those areas in which they were observed, the potential does exist for safety problems should the situation worsen.

Amenity Usage

Rest areas and welcome centers provide a variety of amenities for use by the motoring public including restrooms, paved walkways, benches, drinking fountains, and pay telephones. Many include vending machines, recreational facilities, and rest areas for pets, and most include picnic tables (many of which are covered) and cooking grills. In addition, rest areas contain a display of the map of Virginia, whereas welcome centers are staffed by individuals who provide maps and other tourist information.

The amenities used most often by most travelers are the restrooms. On average, about 66 passenger vehicles and 16 trucks and recreational vehicles enter rest areas and welcome centers hourly. Applying the occupancy rates mentioned previously in this report, this amounts to roughly 141 people per hour. Of these, an average of 87 per hour (62 percent) use the restroom facilities. The following data show the systemwide use of restroom facilities for all sites observed:

	Welcome Centers	*Rest Areas*	*Avg*
Males/hr	58.0	44.5	49.3
Females/hr	46.2	33.4	37.9
Total/hr	104.2	77.9	87.2

These frequencies are roughly 40 percent higher during the summer season and on weekends and holidays. As shown above, the greatest percentage of restroom users are males. Nevertheless, observations at most sites revealed that long lines outside women's restrooms were not uncommon during peak stopping periods. Accounts received from rest area custodians and observations by the author on weekends and holidays revealed that this phenomenon becomes pronounced during peak periods. Studies have shown that the length of stay for women in restrooms is typically longer than that for men. Although possibly attributable to a number of factors, the most likely reason for queuing at women's restrooms is that the absence of urinals slows things down. If this is true (and one would assume it is), women's restrooms in rest areas may need to contain more comfort facilities than the men's restrooms. In the late 1960s, the Bureau of Public Roads developed the *Design Guide for Interstate Safety Rest Areas With Comfort Stations*, which, to this writer's knowledge, continues to be used as the principal reference for designing comfort facilities. This guide includes a formula for computing the number of comfort facilities necessary in a rest area. For example, if the formula calls for two urinals and two toilets in the men's restroom, then the adjoining women's restroom will receive four toilets. The longer lines at women's restrooms lead one to believe that this formula may no longer be applicable

All sites visited by the research team contained picnic facilities. On average, 7 percent of these facilities were in use during daylight hours. As expected, usage of these facilities was highest during the summer; but even then, they were never found to be at or near capacity.

Finally, telephone usage was documented at each site in the sample. Each site contained between one and four public pay telephones where, on average, about eight calls per hour were made. In general, more calls were made from rest areas than welcome centers, and the rate of usage was slightly higher in the summer than the spring or fall.

Traffic Volumes

In the rest areas, although passenger car volume averages were highest in the fall of the year, overall volumes were highest during the summer. However, sites 8 (Interstate 95 [I-95 southbound]) and 10 (Interstate 66 [I-66 eastbound]), which are located on commuter-oriented Interstates, actually showed lower volumes in summer than in the fall. The welcome centers showed a similar pattern: traffic volume remained fairly constant at the I-66 welcome center (again a commuter-oriented facility) but was highest at the other sites in the summer. Using average daily mainline traffic counts that are taken periodically by the VDOT as a basis, an average of about 12 percent of the mainline passenger cars can be expected to stop at rest areas. This number will, of course, be dependent on several variables, including proximity to other rest areas, location (welcome centers at state borders tend to attract a slightly higher volume of passenger car traffic), and facilities offered.

The volume of truck traffic also tended to be slightly higher during the summer. The percentage of mainline trucks entering rest areas was found to be higher than that for passenger cars. An everage of 23 percent of the mainline trucks stopped at the 11 sites. This percentage varied from 40.6 percent to 10 percent and was the highest at the I-64 and I-66 sites. High percentages of mainline trucks stopping at these sites could be the result of the lack of commercial truck facilities on these routes.

Staffing and Costs

General maintenance of rest areas and welcome centers is the responsibility of a rotating three-person custodial staff. Each site has at least one custodian on duty between the hours of 6 a.m. and 10 p.m. seven days per week. (These hours vary at some locations.) At certain rest areas in the Commonwealth, the Department employs custodians on a 24-hour basis to help curtail loitering and other undesirable activities. The responsibilities of the custodial staff include cleaning, refuse disposal, repairs, painting, mowing, and general maintenance. At 23 locations, custodians are VDOT employees, whereas at 14 locations, these services are provided by private contractors.

In fiscal year (FY) 1987 (1 July 1986, through 30 June 1987), the cost of operating Virginia's Interstate rest areas and welcome centers was $4,151,949. Figure 2 shows how those expenditures were distributed. Annual expenditures per site averaged $109,261 and ranged from a low of $63,530 to a high of $167,287 for FY 1987. These costs are dependent on a number of site-specific characteristics of the rest area, not the least of which is the sophistication of the water and sewage treatment systems.

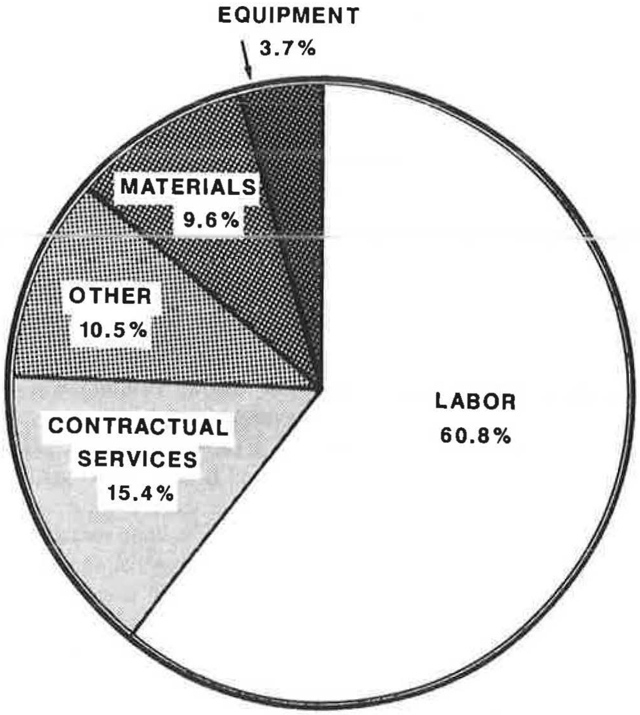

FIGURE 2 FY 1987 rest area expenditures.

Vending Machines

Section 153 of the 1978 Surface Transportation Act authorized the establishment of a Federal Demonstration Project to permit the installation of vending machines in rest areas on the Interstate highway system (*3*). The states of California, Connecticut, Georgia, Kentucky, and Massachusetts were chosen to participate in the project. Each was required to evaluate the project based on public acceptance, possible economic benefits, and any problems related to litter and vandalism. After 1 year of operation, these states reported public reaction to be generally positive toward vending machines and found litter and vandalism problems to be insignificant. Based on these findings, the Surface Transportation Assistanct Act of 1982 allowed states the option of placing vending machines in rest areas and required that the operation of such facilities be offered to the Randolph-Shepard Agencies (RSA) in those states (*4*). To date, 21 states have installed vending machines in at least one rest area, and the RSA participates in the vending machine operation in 19 of these states. In some states, the RSA installs and maintains the machines and receives all of the profits, and in some, the state highway agency installs and maintains the machines and allots some or all of the profits to the RSA.

In 1984, the VDOT entered into an agreement with the state Department for the Visually Handicapped, designating it as the procurement agency for vendors. Profits were to be shared between the two agencies, and it was anticipated that the VDOT's share of the profits would offset the cost of construction, operation, and maintenance of the vending facilities. A sum of $278,000 was appropriated to construct refreshment center buildings at nine rest area and welcome center locations (Figure 3).

Seven of the nine rest facilities containing vending machines were included in this study. An attempt was made to assess the impact of these facilities during the period between installation and the summer data-gathering trip conducted in late August. This assessment included the documentation of litter and refuse accumulation, incidences of vandalism, public acceptance, and vendor performance. This assessment was accomplished through on-site observations, interviews with rest area custodians, and conversations with the resident engineers within whose jurisdictions these particular sites fell.

The public has been enthusiastic about the vending operation. Initially, machines at all sites were kept in operation for 24 hours, and at several sites, vendors remained on duty to fill them continually during the daylight hours. It was not uncommon, especially during the summer, to find many machines empty each morning before the vendor's arrival. During the first 3 months of operation, the machines collected nearly $88,000. After 1 year of operation, enough profits were realized to recoup all the construction costs for the buildings housing the vending machines.

Visits to the sites containing vending machines revealed that a few changes have occurred as a result of the vending installations. Each of these will be discussed briefly.

Litter and Refuse

An examination of videotapes made of sites before and after vending machine installation revealed no substantial accumulation of additional litter. Custodians reported that, generally, refuse increased anywhere from 30 to 50 percent, depending on the site, once vending machines became operational. However, they did not feel that this additional accumulation resulted in substantial additional work at most sites. At several sites custodians reported that tiny cellophane wrappers were being discarded on the grounds and in the parking lots. Retrieval of these wrappers, they said, was time-consuming since they had to be picked up by hand rather than with a litter stick. Anti-litter reminders affixed throughout the rest area grounds and the distribution of automobile litter bags were suggested as means of reducing the accumulation of such litter both within the confines of the rest areas as well as on the interstate mainline.

Use of Other Facilities and Amenities

The impact of the vending services on the use of specific facilities and amenities at rest areas is difficult to assess. Custodians and other residency personnel feel that the vending concession has generated an increase in the use of picnic tables. This occurrence could not be substantiated during this study because of the absence of sufficient before-and-after data during like seasons. Studies in other states have shown some increase in the average length of stay in rest areas after installation of vending machines (*5*, *6*). Whether or not this activity is occurring in Virginia will be verified in a follow-up study to be conducted in late 1988.

Vandalism

Although no occurrences of vandalism were documented during the initial few months of operation, some vandalism began

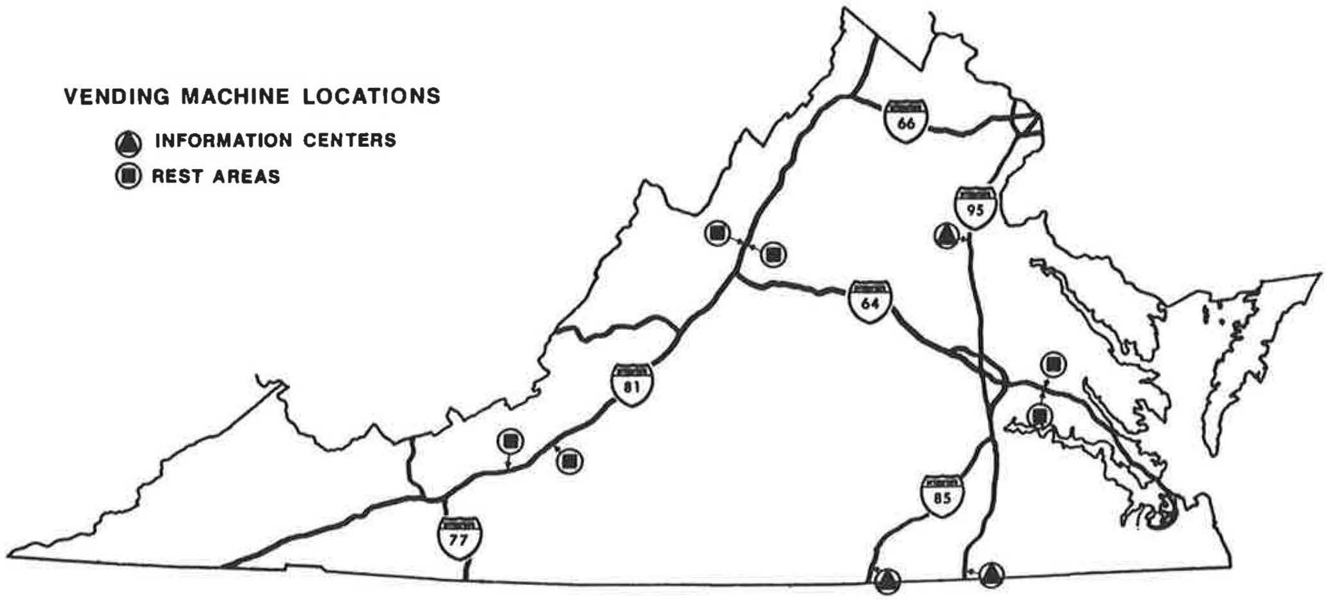

FIGURE 3 Commonwealth of Virginia Interstate rest areas and information centers with vending machines.

to take place at two sites during the fall and winter. It appears that vandalism may be minimal during peak travel seasons when rest areas and welcome centers are at their busiest. As visitation declines, however, the machines may become more vulnerable. Most break-ins occurred at night, which suggests that the presence of an on-duty custodian may be a deterrent to vandalism. Studies in other states corroborate this finding (*2*). Those states either closed the vending machine buildings while an attendant was not on duty or they employed attendants on a 24-hour basis.

VDOT is presently seeking ways to deal with vandalism. At some sites, vending machine buildings are now locked while no attendant is on duty. However, this alternative has resulted in some criticism from motorists who feel that accessibility to the vending machines on a 24-hour basis is important, since it is often during the wee hours of the morning that drivers need a quick pick-me-up.

Miscellaneous Operations

One of the minor problems anticipated at the outset of the vending machine program in Virginia was the method by which change would be made accessible to motorists. The hypothesis was that VDOT custodial and tourism staff would be inundated with requests from motorists to make change. Although the installation of change machines that will take a dollar bill curtailed many such requests, shortly after the installation of the machines, custodial and tourism staff were still frequently requested to make change. The installation of signs stating that employees in the rest areas and welcome centers do not have change have helped eliminate most, but not all, such requests.

A similar concern was anticipated regarding the refunding of money lost in malfunctioning vending machines. In anticipation of the fact that requests for refunds would be made to rest area staff, each vendor posts a sign in the vending machine building containing an address to which refund requests can be made. According to many of the custodians interviewed, the public is not satisfied with this procedure, since postage of $.25 is required to obtain a $.50 refund. This dissatisfaction was at times outwardly leveled at either the custodial staff or the vending machines. A refund method used by the North Carolina Department of Transportation may result in less frustration than the method used in Virginia. Inside each vending machine building is a box provided by the vendor into which refund requests can be placed. These are picked up periodically by the vendor, and refunds are then mailed to the individual making the refund request.

RESULTS OF REST AREA USER SURVEY

Survey Distribution Method

At each of the 11 sample sites, self-addressed, prestamped questionnaires were distributed to stopping motorists. The questionnaires contained 16 questions regarding specific facilities, the rest area system in general, travel behavior, and demographic information. During the spring, summer, and fall visits, 7,543 questionnaires were distributed and 1,945 were returned.

User Profile

The average age of respondents entering the sample sites was 52.73 years, and 38 percent of those responding were 60 years of age or older. Fifty-eight percent were non-Virginians, and 2 percent were classified as local (meaning they resided within the jurisdiction of the subject rest area or welcome center). A question regarding stopping frequency revealed that nearly 70 percent of motorists stop between every 1.5 and 3 hours, with the average stop being made about every 2.5 hours.

TABLE 4 PROFILE OF USE OF REST AREA AND WELCOME CENTER AMENITIES

Amenity Used	Percentage of Respondents[a]
Restroom	97.2
Water fountain	43.7
Travel information	20.2
Parking lot	16.3
Trash cans	15.6
Telephone	11.5
Picnic table	8.6
Paths and grounds	7.2
Pet rest area	4.0
Benches	3.8
Cooking grill	0.3

[a]N = 1,937. A total of 4,423 responses were tabulated because of the allowance of multiple responses to the question; therefore, percentages do not total 100.

TABLE 5 ADDITIONAL REST AREA AMENITIES DESIRED

Amenity	Percentage of Respondents[a]
Vending machines	34.8
Nothing	29.9
Paper towels	19.9
Gas, food, hotel information	14.7
Additional rest rooms	14.5
Better water fountains	10.4
Hot water	8.4
Weather and road condition information	7.4
Larger truck lot	7.0
Larger car lot	5.1
Additional telephones	4.9
Restaurants	4.7
Children's play equipment	4.7
Diapering table	3.9
Pet watering troughs	3.2
Motor home dump stations	2.6
More picnic equipment	2.1
More landscaping	0.9

[a]N = 1,832. Percentages do not total 100 because of multiple responses.

Reason for Stopping and Usage Patterns of Amenities

Respondents were asked their principal reason for stopping at the rest area or welcome center. Eighty-two percent of those stopping at rest areas and 72 percent of those stopping at welcome centers did so principally to use the restrooms. The remainder of the respondents stopped to rest (7 percent), picnic (2 percent), obtain travel information (4.3 percent), make a telephone call (2 percent), or for miscellaneous purposes (3.3 percent).

Survey respondents were asked to indicate the amenities they used during their stop. Table 4 presents a profile of that usage. Although 20 percent of the total sample obtained travel information during their stop, of those stopping at welcome centers, almost half obtained travel information compared to 8 to 10 percent of those stopping at rest areas. Facilities used the least are benches, cooking grills, and pet rest areas.

Respondents were given the opportunity to suggest additional amenities for the rest area at which they stopped or to any other rest area along the interstate system. Table 5 presents a profile of these suggestions.

As the table shows, the additional amenity desired most by the greatest majority of the respondents is vending machines. A significant number of respondents suggested that paper towels be made available in the restrooms. A significant number of respondents also suggested that rest areas include information about the motorist services (gas, food, and lodging) that are available along the interstate route. Finally, a significant number of respondents, the majority of whom were female, pointed out the need for additional restroom facilities.

Survey responses indicate that overall, motorist opinion of rest facilities in Virginia is quite high. Eighty percent of the survey respondents rated them as good or excellent, whereas only about 4 percent rated them as poor.

SUMMARY AND CONCLUSIONS

As part of the effort to improve motorist safety and comfort, the VDOT has constructed 28 rest areas and 9 welcome centers along its interstate system. The first such facility opened in 1964 on Interstate 81 in Botetourt County; the last opened in 1983 on Interstate 95 in Prince William County. Concomitant with its plans for developing additional rest area sites, representatives from the Department's Environmental Division perceived a need for an assessment of the service delivery characteristics of the existing sites, many of which were built more than 20 years ago. This study examined existing conditions at selected sites and assessed what impact the provisions of new services might have on that service delivery. This paper presents the results of that assessment.

On average, 1,600 passenger cars and 421 tractor-trailer trucks or recreational vehicles enter Virginia's rest areas and welcome centers daily. During peak periods, which are typically weekends and holidays, these daily volumes can rise to 2,800 and 650, respectively. At welcome centers, passenger car traffic volumes are about the same as they are at rest areas, whereas truck traffic volumes tend to be roughly 20 percent lower at welcome centers than at rest areas. The highest traffic volume at all sites generally occurs in the summer, and roughly 58 percent of the passenger cars stopping at these facilities are from out of state. The data showed that about 6 to 10 percent of the mainline passenger car traffic and 10 to 12 percent of the mainline truck traffic stop at rest areas and welcome centers. At some sites, especially those on Interstates 64 and 66, as many as 22 percent of the mainline trucks stopped at rest areas on selected days. These occurrences may be due to the absence of commercial truck facilities on both of these routes.

On average, passenger cars and large trucks entering rest areas and welcome centers year-round contain 1.85 and 1.05 occupants, respectively. These rates are slightly higher during the summer. Based on the previously mentioned traffic volumes, this means that, on average, in excess of 3,500 persons can be expected to use rest areas and welcome centers on a typical day. During the summer, on holidays, and weekend peak periods, this number can exceed 7,000. The average duration of stay for these vehicles was found to be 9.1 minutes for passenger cars and about 15 minutes for large trucks and recreational vehicles. The average stopping interval for the latter vehicle class did not include overnight stays. Since data were gathered only during the daylight hours, a precise determination as to the frequency and duration of overnight stays could not be ascertained. Early-morning observations by the research team as well as reports received from rest area custodial personnel, however, indicated that stays in excess of the 2-hour limit are frequent during nocturnal hours. At some sites, extended stays were found to result in trucks parking along entrance and exit ramps as well as the interstate mainline, thus creating a safety hazard. The VDOT appears to be faced with a dilemma here. The extension or removal of the 2-hour limit might compound the problem. A better solution might be the enlargement of truck parking lots or the construction of additional trucks-only rest areas, or both. The latter alternative has proven successful in one area of the Commonwealth and would likely be welcomed by the trucking industry. Another alternative might be the reduction of the 2-hour limit to, say, 30 minutes, which might be more easily enforced by the Virginia State Police.

Restrooms are the most frequently used amenity at rest areas and welcome centers. Even though the greatest percentage of restroom users are males, the women's restrooms were the ones found to be at or exceeding capacity most often. Length of stay for females in restrooms appears to be longer than that for men. Although this phenomenon might be attributable to several factors, the most likely reason is simply that urinal usage is faster than toilet usage. Consequently, women's restrooms may need more comfort facilities than men's restrooms. In this regard, specifics set forth in the Bureau of Public Roads design guide appear questionable and may need updating.

General maintenance and upkeep of all but 14 of the Commonwealth's rest areas and welcome centers is the responsibility of custodians employed by the VDOT. Each site usually has one custodian on duty between 6 a.m. and 10 p.m.

In late 1987, vending machines operated on a 24-hour basis were installed at nine rest area and welcome center locations. Public acceptance thus far has been enthusiastic. Custodians reported a 30 to 50 percent increase in refuse and some additional accumulation of litter on the rest area grounds but, in most cases, not a sufficient amount to warrant additional manpower. Requests for custodial assistance in making change and recovering money lost in machines were frequent until signs were erected informing patrons that custodians were not responsible for these services.

During the first summer of operation, no cases of vending machine vandalism were documented. However, as peak travel periods subsided, vandalism began to occur at two sites. Since these break-ins occurred when attendants were not on duty, the VDOT has been forced to close the vending buildings at these two locations when attendants are not on duty. This action has resulted in some criticism from the public, who desire 24-hour accessibility to the vending machines. Many alternatives exist for coping with the vandalism of vending machines. Studies in other states have shown that having an attendant on duty for 24 hours seems to help (*5*, *6*). Other alternatives that have been tried include vandal-proof machines, partial or total closure of the vending operation, and alarm systems.

A survey distributed to motorists stopping at rest areas and welcome centers revealed that the typical user is 52 years of age or older and stops about every 2.5 hours. The most common facilities used are restrooms, water fountains, and travel guides. At welcome centers especially, the availability of travel information is very important to the interstate traveler. When asked what additional amenities they would like to see included at rest areas, more than one-third of those responding listed vending machines. Motorists' opinions of Virginia's rest area and welcome center facilities is quite high, and more than one-third of the respondents felt that additional facilities are needed system wide.

The importance of rest areas and welcome centers to the interstate traveler cannot be overstated. They provide an indispensable means for enhancing motorist safety and comfort. Changes in population growth and the diversity of the driving public have resulted in increased demands on these facilities. These demands can be met only if steps are initiated to ensure that these facilities provide the services needed by today's interstate travelers. It is hoped that information gathered during this study will assist decision-makers in initiating such steps.

ACKNOWLEDGMENTS

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Compilation and Evaluation of Rest Area Issues and Designs

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A research study was conducted to determine the required design for rest areas with particular emphasis on comfort stations. Many sources of information were used: personal visits with Department of Transportation rest area professionals in six states, telephone surveys of officials in twelve other states, visits to other agencies that maintain comfort stations, literature surveys, complaint and commendation letters received from users of Texas rest areas, rest area surveys, visits with legal counsel for the Texas Department of Highways and Public Transportation, and visits to Texas rest areas and interviews of maintenance personnel. A summary of current design criteria is presented for site size, location, spacing, and lighting; building design and layout; interior building design; plumbing fixtures; and operations and maintenance. Recommendations are made for design in these areas. An example design of a rest area is presented.

The initial stimulus for highway roadside rest area development came in the form of a provision of the Federal-Aid Highway Act of 1938, which stated that "the States, with the aid of Federal funds, may include . . . such sanitary and other facilities as may be deemed necessary to provide for the suitable accommodations of the public."

While this act is considered to mark the birth of the highway roadside rest area in the United States, rest area growth did not really begin until passage of the Interstate Highway Act of 1956. However, the major impetus for the construction of highway roadside rest areas was the passage of the Highway Beautification Act of 1965, together with the establishment of the Highway Trust Fund.

Today's rest area user has come to expect more than just a place to rest, and the Texas State Department of Highways and Public Transportation (SDHPT) initiated this research project to determine the rest area design, operations, and maintenance criteria required to serve the needs of the highway traveler. Six reports have been issued (*1–6*). Two of the reports discuss energy sources and water and wastewater design. These topics are not discussed in this paper because of space limitations.

SOURCE OF INFORMATION

State Surveys

Meetings were held with the professionals involved in the design, operation, and maintenance of highway roadside rest areas in six states: California, Georgia, Louisiana, Oregon, Texas, and Washington. The meetings provided answers to questions concerning rest area design that were prepared in advance of the meeting. Other topics germane to rest area design, operation, and maintenance were also discussed. Drawings, plans, and specifications for rest areas in each state were provided. These meetings were followed by a tour of several of the rest areas in each of these states. In addition, rest areas were inspected in the state of Mississippi.

Comprehensive telephone surveys were conducted with the professionals involved in the design, maintenance, and operation of highway roadside rest areas in 12 states: Arkansas, Colorado, Florida, Illinois, Minnesota, Nebraska, New Mexico, North Carolina, Oklahoma, and Pennsylvania.

Separate meetings were held with the representatives of three SDHPT districts. District personnel responded to an extensive questionnaire. Each of the meetings was followed by a visit to a district rest area and an interview with the rest area attendant, who responded to another set of prepared questions from a second questionnaire.

Other Agency Surveys

Texas Department of Parks and Wildlife

A meeting and several subsequent discussions were held with the professionals involved in the design, operation, and maintenance of all state park facilities in the Texas Department of Parks and Wildlife. Answers were provided for a detailed list of questions concerning park facilities—primarily comfort stations and related utilities and services.

In addition, an inspection tour of 13 Texas Parks and Wildlife installations was conducted for the purpose of providing a large sample of this agency's handling of problems similar to those encountered in the design, operation, and maintenance of highway roadside rest areas. Most of the parks were relatively remote areas, and there are many similarities involved in the construction and maintenance of these and highway rest area facilities.

U.S. Army Corps of Engineers

An inspection tour of five U.S. Army Corps of Engineers public use areas along the shores of Lake Somerville, near Somerville, Tex., was conducted to view their park facilities and comfort stations. A secondary purpose of this trip was to compare the site-built comfort stations that are being replaced by factory-manufactured restrooms.

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Legal Counsel

Meetings were arranged with both the Texas Attorney General's office and the highway department's legal counsel to discuss critical items of concern regarding rest area design, construction, operation, and maintenance.

Literature Review

An extensive search was conducted to identify all available literature that might be pertinent to the research. Unfortunately, most of the 67 books and papers that might be pertinent were written during the period that marked the major thrust in highway roadside rest area construction, namely, the mid-1960s to the early 1970s, and these do not all reflect the current state of rest area design.

Factory-Manufactured Restrooms

The Restroom Facilities Division of Intex Corporation in Ennis, Tex., was visited to observe the manufacturing process and the finished products for the consideration of alternative comfort station designs and construction techniques. This plant designs and manufactures a line of commercial restrooms that are primarily targeted for park installations.

Review, Compilation, and Summary of Complaint and Commendation Letters

All letters were reviewed from the traveling public regarding highway roadside rest areas that were received by SDHPT between January 1984 and July 1985. The complaints were categorized and summarized, and specific comments were itemized.

Rest Area User Surveys

A rest area interview form was developed after extensive research and discussion, and two field surveys of rest area users were conducted. The surveys not only involved interviewing roadside rest area users, but they also included the collection and compilation of data on such items as:

1. the percentage of highway traffic diverting to the rest area during each hour of the survey period;
2. the number of vehicles diverting to the rest area during each hour of the survey period;
3. average duration of visit by category of those vehicles diverting to the rest area during each hour of the entire 24-hour test period;
4. hourly percentage breakdown by category of those vehicles diverting to the rest area during each hour of the entire 24-hour test period;
5. user responses to questions posed on the rest area interview form;
6. additional comments and suggestions of rest area users; and
7. rest area facilities used.

RESEARCH FINDINGS

The underlying fundamental approach used in the research effort was to determine the guidelines and recommendations of those practicing professionals who have devoted a significant portion of their careers to the design, operation, and maintenance of roadside rest areas.

Although pertinent information obtained from other agencies was considered where applicable together with the literature review and surveys, the major thrust of the research concentrated on the practices and recommendations from the states. By using this approach, it was possible to learn what not to do, as well as what should be done in the design, operation, and maintenance of highway roadside rest areas.

Spacing Criteria

The research sought to determine the highway roadside rest area spacing criteria used by each state, both currently and when the program was initially established. In addition, state officials were asked if they were satisfied with the current criteria and, if not, what criteria they would recommend.

Virtually all states used the criteria of 30 miles apart or 30 minutes' driving time between rest areas as their spacing goal at the initiation of the program. (The 30-mi or 30-minute criterion is synonymous with the 60 MPH speed limit that was prevalent in most states at the time.) Only five of the states surveyed actually achieved this goal by July 1986. One-hour driving time between rest areas or 50 to 60 mi apart is the current spacing criterion for the majority of states.

Overall Design Criteria

All of the states surveyed, except four, are using a formula developed by the Oregon Department of Transportation that starts with the average daily traffic. Although all the states surveyed use a format similar to this, there are some rather minor variances in the factors used. For example, some states assume that the ratio of males to total restroom facility users is 0.5, whereas others use a factor of 0.4 for design purposes.

Several states reported realistic results using the factors developed by the state of Oregon as compared with results of all follow-up surveys. This is the only specific design procedure mentioned with any degree of regularity.

Site Size and Selection Criteria

Site

Although the size of rest area sites inspected varied from 3 to more than 80 acres, the majority fell into the 20- to 30-acre range. Most states dedicate rather spacious sites and devote considerable effort in designing and maintaining the landscaping. Large varieties of trees and other plantings are carefully placed. In most instances it is obvious that the states are trying to make their rest areas "show places" in an effort to create a favorable impression on the traveling public.

The site selected should facilitate an attractive layout of all buildings, picnic shelters, and other facilities without conveying a feeling of "crowding." In other words, there should be some open areas between structures, which themselves should not be crowded together. The site should not be long and narrow like an airport runway. The ideal site would have equal side dimensions and permit the use of divided parking to separate small and large vehicles, which is the practice in nearly all states.

Site Selection

In addition to the need to find a spacious site, there are other important considerations involved. Some of these include

- Source and quality of water supply;
- Availability of electric power;
- Annual rainfall data for evaporative lagoons;
- Soil classification or percolation test for septic systems with leach fields;
- Proximity to commercial sewage treatment facilities for direct connection;
- Level and proximity of acquifer for on-site sewage treatment facilities;
- Proximity to major metropolitan areas (all states interviewed would not build a rest area near a major metropolitan area because of the vandalism problem);
- Presence of a buffer zone between the rest area and any nearby community; and
- Availability of emergency services such as firefighting and rescue from nearby communities.

Lighting

Most of the states place more emphasis on the importance of illumination of rest areas than perhaps any other area of engineering, with the possible exception of restroom ventilation. While some states use three different types of lighting (high-pressure sodium for parking and roadway areas, metal halide on building exteriors, and fluorescent in building interiors), two different forms are more predominantly used: fluorescent inside buildings and metal halide (typically mercury vapor) at all exterior locations. Several of the states indicated a plan to replace all parking area and roadway metal halide fixtures with high-pressure sodium fixtures.

The main point made by all states is that it is important that all building interiors are well lighted with no dark corners, and that the path from the farthest parking space to the restroom facilities is not just well lighted but very brightly lighted. Lighting is one of the main security measures against unwanted attacks and molestations of the traveling public.

Building Design and Layout

Several features were found to be in common use by most states. Some of these are listed below:

1. A mechanical room containing pipe chases, furnace, and vent stacks is located between the men's and women's restroom facilities. Several rest areas inspected use this room to facilitate back-bolting mirrors and plumbing fixtures through the wall to make removal more difficult for vandals.
2. Both natural and mechanical ventilation in restrooms is necessary to eliminate noxious odors.
3. All states but one provide entrance doors on restroom facilities. Most of the doors are made of heavy metal and, in some cases, have plastic overlays to eliminate denting and scratching of the metal with the subsequent unsightly rusting problems.
4. All but two of the states visited provided dual restroom facilities to minimize the inconvenience to the traveling public when either the men's or women's restrooms was out of service for cleaning or maintenance. Of those states surveyed by telephone, all but six had dual facilities, whereas three of these accomplished nearly the same goal by employing both male and female attendants at every rest area to allow both facilities to remain partially open during cleaning. Most of the states provided separate structures, but one accomplished the same goal by providing two pull-down overhead doors to subdivide each restroom during cleaning or maintenance.

One of the states visited said that consideration was given to providing dual facilities, but that their rest area spacing is such that it was not deemed necessary. This is the only state that actually has an average spacing of 30 mi. This state also has designed some Interstate highway roadside rest areas so that traffic that exits the interstate and turns into the rest area has access to two restroom facilities in either direction.

5. Natural lighting in the form of clerestories and skylights is used extensively by most states even in existing construction, but it is planned for even a higher degree of use in all new construction.

Plumbing Fixtures and Accessories

Some of the more consistent recommendations for plumbing fixtures and accessories are

- Wall-hung toilets and urinals with concealed mounting attachment bolts;
- Flush valves mounted behind permanent construction; and
- Electric hand dryers rather than paper towel dispensers (several of the states stressed the fire hazard when paper towels are used).

Most of these were consistently observed during the rest area inspection tours. On the other hand, there were significant inconsistencies in the recommendations for other items such as stainless steel vs. glazed mirrors, water saver toilets, and waste receptacle design.

All state rest areas observed used vitreous china plumbing fixtures; however, representatives surveyed by telephone from two of the twelve states indicated that some rest areas had stainless steel plumbing fixtures.

Interior Building Specifications

Since the design of rest areas is a dynamic, ongoing activity, the interior design of the restroom facilities is affected perhaps more than most aspects of highway roadside rest area design. Not only are there significant variations in interior design among the states, but there are variations in the interior design of rest areas within a state.

Because of this variation, this summary will cover only those consensus aspects of current interior design.

1. All states use some form of ceramic tile in current construction.
2. Most states use a ceramic tile wallcovering for the interior walls and toilet partitions. One state is using structural glazed tile. Stainless steel toilet partitions generally are considered to be the only preferred alternative.
3. All states except one use full-height toilet partitions and doors in both men's and women's restrooms.
4. Although they are considered the most vandal resistant, the use of stainless steel toilet partition doors was observed in less than half of the rest area installations.
5. Electrical receptacles (110-volt outlets) are normally provided in both the men's and women's restrooms as a convenience to the traveling public.

Rest Area Operation and Maintenance

The organization and management control of highway roadside rest area operations and maintenance varies widely among the states; however, there were certain areas of similarity.

1. Although most states consider the ideal rest area custodial coverage to be 24 hours per day, 7 days per week, the general consensus is that the minimum coverage provided should be 12 hours per day, 7 days per week; however, coverage of 16 hours per day, 7 days per week is even more desirable. The majority of the states surveyed provided a coverage equal to or in excess of this minimum criteria.

It was generally felt that rest area attendants must be present on all 7 days of the week to maintain a satisfactory level of cleanliness and to keep all equipment in satisfactory working order. A lower level of coverage is insufficient to attain this level and ultimately will result in vandalism from public dismay over either the state of cleanliness or malfunctioning equipment.

2. Some states require attendants to wear an identifying uniform. It is felt that this improves the overall level of custodian dress, improves the public's perception of the custodian, and adds to the general feeling of security in the form of an identifiable presence.
3. Custodial personnel are typically responsible for building and ground cleanliness and maintenance. In a small rest area, they are sometimes responsible for grass cutting, but in very large rest areas, the highway maintenance crews handle the mowing of the grass.
4. Most states handle rest area custodial duties with state employees. Two states use contractors at a few selected locations. A number of other states indicated they had tried contractors but received poor results and subsequently abandoned this approach. It seems that there was continual bickering over who was supposed to do what. Those states researched via the telephone generally were positive about the use of contract personnel for rest area maintenance.
5. Routine maintenance is typically handled by the custodian or other maintenance specialists within the highway district. Repairs such as rewinding a burnt-out motor are always handled by outside firms.
6. Most states steam clean the restroom facilities two or more times per year, and one state includes built-in steam cleaning equipment in the construction of all rest areas.
7. All states prohibit overnight parking in rest areas. Although all admit that this rule is not rigidly enforced (most of them report having to enforce it on a few occasions), they do not really have a problem with "squatters."

Although state highway roadside rest area operation and maintenance organizations differ substantially, there is general agreement that the overall management and control of rest area performance would be considerably enhanced if the design, construction, operation, and maintenance were the responsibility of one midlevel manager in the state highway department. One state reported that although this centralized level of authority had not been totally achieved, the state compensated for it by forming a headquarters design review team that periodically inspects rest areas, roadways, drainage, lighting, and various other services and files a report for any remedial action required. This state seemed to feel that this approach is effective and that any discrepancies noted are typically acted upon immediately by the district engineer.

Special Services

Special services provided at state rest areas vary from only pay telephones to a complete array of vending machines for snacks, soft drinks, newspapers, and maps. Some states place rest areas in conjunction with, adjacent to, or near recreational areas and places of historical or geological interest. In some cases, these areas of interest are explained by "displays" at the rest area, and sometimes this is in conjunction with a viewing area.

Heavily used recreational areas nearby should provide separate parking or the rest area parking spaces will be monopolized by the recreational users to the detriment of the rest area parking needs of the traveling public. One state passed a bill that charged an annual fee of $10 for the use of state-constructed parking lots near recreational areas, and success was reported with the program. Two states have for sometime awarded permission to various charitable organizations for disbursing free coffee to the traveling public, and they heavily endorse providing this service.

Most states provide (as a minimum) some type of traveler information service concerning local areas of interest. One state constructs and maintains rather complete traveler information gazebos similar to those found at major airports, at selected rest areas, and advertising space is sold to the business community.

Recreational Vehicle Dump Stations

Most states are experiencing operational problems with recreational vehicle (RV) dump stations. Several states have begun separating RV dump station sewage treatment facilities from restroom sewage treatment facilities.

The primary problem appears to be the heavy use of formaldehyde in RV sewage holding tank cleaning solutions. The chemical "shocks" the sewage treatment system with a heavier concentration than it can handle. This problem primarily manifests itself near the end of a weekend in certain rest areas during which large numbers of travelers stop to dump their tanks. All states interviewed would like to see RV dump stations eliminated at highway roadside rest areas, and one state has initiated a program to eliminate all of them within 5 years.

One state is required by law to provide RV dump stations at all highway roadside rest areas in the state, but the legislature passed a bill charging all licensed RV owners $1.00 per year. According to those responsible for rest area design, construction, operation, and maintenance, this fee has proved adequate to pay for all these services for RV dump stations with separate sewage treatment facilities.

Only one state reported any incidents of deliberate dumping of toxic wastes into rest area RV dump stations.

Joint-Use Rest Areas

Several states are actively pursuing the concept in which a highway rest area is built in conjunction with commercial enterprises; these enterprises then become responsible for the operation and maintenance of rest area facilities, as well as the financing of all or part of the rest area construction costs. In some states not presently considering this concept the subject had been discussed among members of the state rest area management team and may be considered sometime in the future. In general, the idea seems a plausible way to reduce state rest area construction, operation, and maintenance costs. Since current federal legislation prohibits commercial enterprises on highway rights-of-way, the realization of this concept would require a change in legislation or providing the facilities off the system, perhaps at an interchange.

Rest Area Vandalism

Upon the initiation of this project, rest area vandalism was thought to be a major problem, with more questions pursued on this subject among states than any other subject. Two factors under discussion among the other states deserve special mention:

1. Virtually all states report (*1*) that the major reason for excessive vandalism in rest areas near large metropolitan areas is not only because of their ready availability to large population segments but also because of the typically large homosexual communities in large cities. Without providing for 24-hour-a-day security in these rest areas, it is virtually impossible to eliminate this problem. For this reason, coupled with the fact that similar commercial and public facilities are available nearby, consideration should be given to closing all rest areas adjacent to (within 50 to 60 mi of) metropolitan areas.
2. A buffer zone between the rest area and any nearby community is essential and should not be violated during the life of the rest area to prevent problems with nearby residents.

Vandal-resistant design and vandalism problems are addressed in many of the design criteria. These recommendations came forward only in response to specific design problems. However, when the more general question, "Do you have a major problem with vandalism?" was asked, the respondents said no, and in all but one state this was verified by the fact that vandal-related repairs represented less than 2 percent of the total annual rest area operations and maintenance budget. In some instances, vandal-related repair costs were less than 1 percent of the total annual rest area operation and maintenance budget.

Most of the states accept all or part of the blame for vandalism. Numerous times, the following statement was made: "If we do a good job in design, construction, and maintenance of all rest area facilities, we would not have a vandalism problem, except for those rather rare instances when a habitual vandal enters the premises intent only on destruction" (*1*, p. 9). One state even offered a further clarification by stating, "If we install all the required facilities and if the equipment does what it is supposed to do the way it is supposed to do it, we will not have a vandalism problem" (*1*, p. 9).

This summary of state rest area official responses to the vandalism issue is essentially the unanimous opinion of all states visited and surveyed by telephone, except for one state. Vandalism takes many forms, some of which are reported elsewhere (*2*).

REST AREA GUIDELINES AND RECOMMENDATIONS

Specific recommendations and guidelines for the design, operation, and maintenance of highway roadside rest areas were developed after a detailed review of all drawings, plans, specifications, photographs, interview reports, and other materials, together with detailed discussions among SDHPT representatives and others involved in this project. One of the best sources of information was the experience and practice of other states. Texas, however, has unique requirements, and the recommendations made in this report attempt to recognize these needs.

Site

1. Use the ideal rest area spacing, usually 50 to 60 mi. No site should be closer than 50 to 60 mi from a major metropolitan area.
2. Base overall design guidelines for determining the number of users on current procedures recognized by many states, supplemented by data and experience in Texas.
3. Use the ideal site size, 20 to 30 acres, with 10 acres considered the absolute minimum. The site should be relatively square and should facilitate an attractive layout of all buildings, picnic shelters, and other facilities, with sufficient open spaces to prevent a feeling of crowding.
4. Use divided parking areas to provide separate parking areas for small vehicles (e.g., automobiles and pickup trucks) and for large vehicles, (e.g., all other trucks, buses, and RVs).

Lighting

1. Provide a high level of illumination in the parking areas, on the walkways to the restrooms, on the buildings around

the outside of the building in the immediate vicinity, and inside the building. High-pressure metal vapor lighting is recommended in all locations, not only because of its effectiveness, but because of its superior bulb life and low maintenance cost. An acceptable alternative would be fluorescent fixtures with vandal-resistant covers in the men's and women's restrooms, or a combination of both.

2. Provide strong natural lighting using skylights and clerestories.

Site and Ancillary Facilities

1. Use concrete picnic tables and benches set on concrete pads.
2. Provide picnic shelters, charcoal boxes, and waste receptacles at all table locations.
3. Use concrete trash receptacles outside and inside the building.
4. Provide utility sink, drinking fountain, and outdoor water spigot in conjunction with the restroom building.
5. Construct a separate gazebo-type structure for use as an information-communication center. Install telephones and provide for an informational display complete with a state highway map and description of nearby points of interest.

Restroom Building Design and Layout

1. Construct essentially square or rectangular restroom building units with no recessed or hidden corners, and with a mechanical room between the men's and women's restrooms. Design men's and women's restrooms with vaulted (cathedral) ceilings to allow natural light into the rooms.
2. Construct dual men's and women's restroom units.
3. Provide an effective flow-through (low ingress-high egress) natural ventilation system supplemented with mechanical exhaust fans.
4. Provide solid core laminated plastic clad exterior doors in steel frames on all restroom entrances.
5. Provide a central forced air heating-cooling system to condition restroom units.

Plumbing Fixtures

1. Use wall-hung vitreous china toilets and urinals "back-bolted" through the walls.
2. Use push-button operated flush valves, with the valves mounted behind permanent construction.
3. Use vitreous china lavatories in conjunction with spring-loaded faucets.
4. Provide central liquid soap dispensing, with a translucent tank to permit monitoring the fluid level.
5. Use antitheft-type toilet tissue holders (two per stall).
6. Use a compressed air hand dryer (without heating coils) in each restroom.
7. Provide a stainless steel sanitary napkin disposal unit in each toilet stall in the women's restroom.
8. Provide a toilet seat cover dispensing unit in every toilet stall in the rest area.
9. Use heavy-duty glazed mirrors back-bolted through the wall in each restroom.

Interior Building Design and Specification

1. In all restrooms, use full-height toilet partitions suspended 12 to 15 in. above the floor to permit easier floor cleaning.
2. Use stainless steel-clad toilet partition panels and doors on all toilet partitions.
3. Use ceramic tile on the floors in all restrooms.
4. Use ceramic tile on all building walls in all restrooms to a height of 7 ft, 2 in.
5. Provide one or more 10-volt electrical outlets in all restrooms.

Operations and Maintenance

1. Wash down all rest area restrooms with either a portable steam cleaning nozzle or high-pressure hot (160°+ F) water spray containing strong cleaning chemicals. This type of cleaning should occur at least quarterly and more often if there are odors or visible accumulations of dirt or other residues that cannot be removed by normal cleaning means. The permanent installation of steam or hot water cleaning equipment is not recommended because (a) the system is expensive (about $10,000 per building) and (b) the portable systems can be used to clean the interior as well as the exterior, including sidewalks and picnic tables.
2. Establish custodial presence 24 hours per day 7 days per week; in most cases a minimum of 16 hours per day, 7 days per week, should be provided. The attendants should be provided with uniforms. Wearing uniforms should be mandatory while attendants are on duty.

Example Design

An example site plan is shown in Figure 1. Separate parking areas, restroom facilities, information kiosk, and picnic facilities are shown. Future restrooms are shown by dashed lines on the right. Figures 2 through 5 show the comfort station design. Each comfort station, which includes two men's and two women's restrooms, will serve 500,000 people per year. The facilities have well-defined entrances and exits, an escape route in each unit, and a central maintenance and equipment room between units. A roof with a wide overhang covers the units. Ceramic tile is used on the walls and floors; stainless steel partitions are suspended to provide for easier cleaning.

CONCLUSIONS

Rest areas are an important aspect of the Interstate highway system. The design of rest areas involves many aspects: location, spacing, site, buildings, mechanical equipment, plumbing, water and wastewater, energy sources, conservation, and lighting. This paper summarizes the results of a survey and makes recommendations for the design of rest areas.

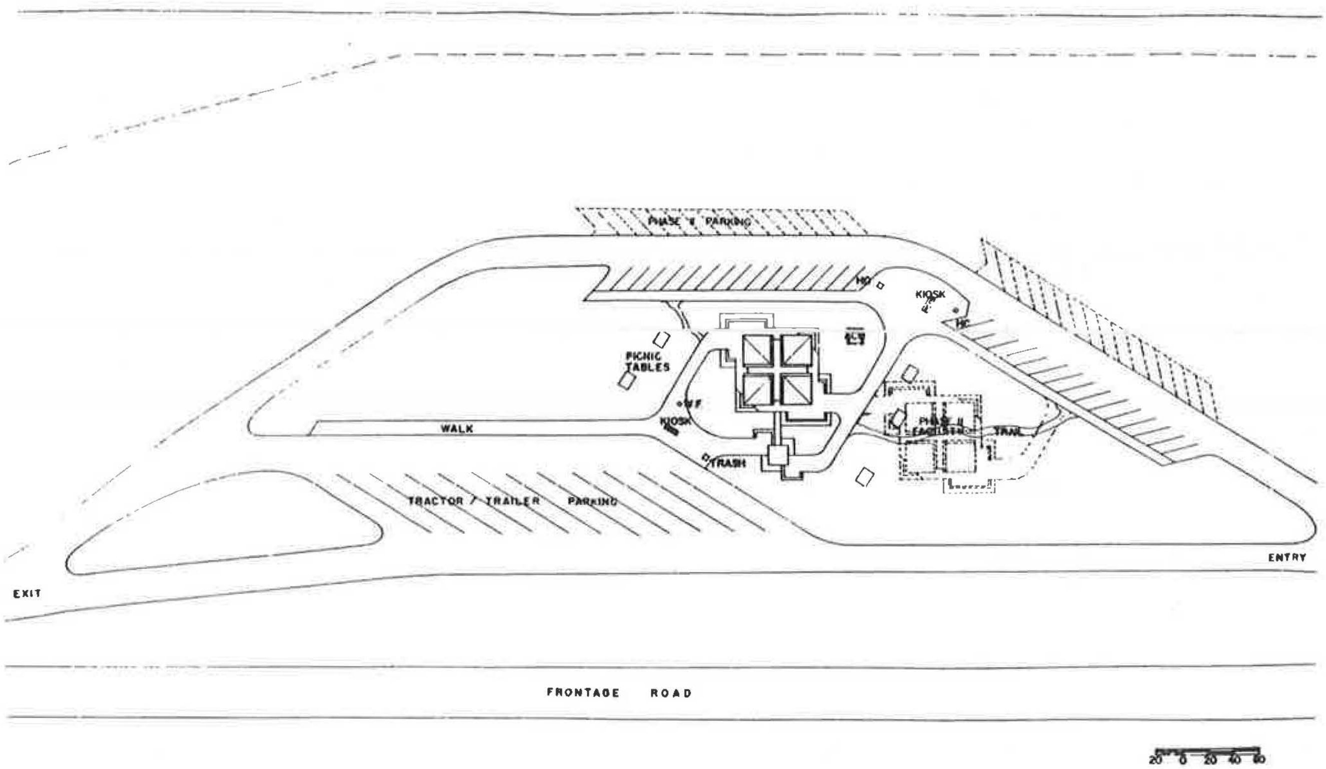

FIGURE 1 Rest area site plan.

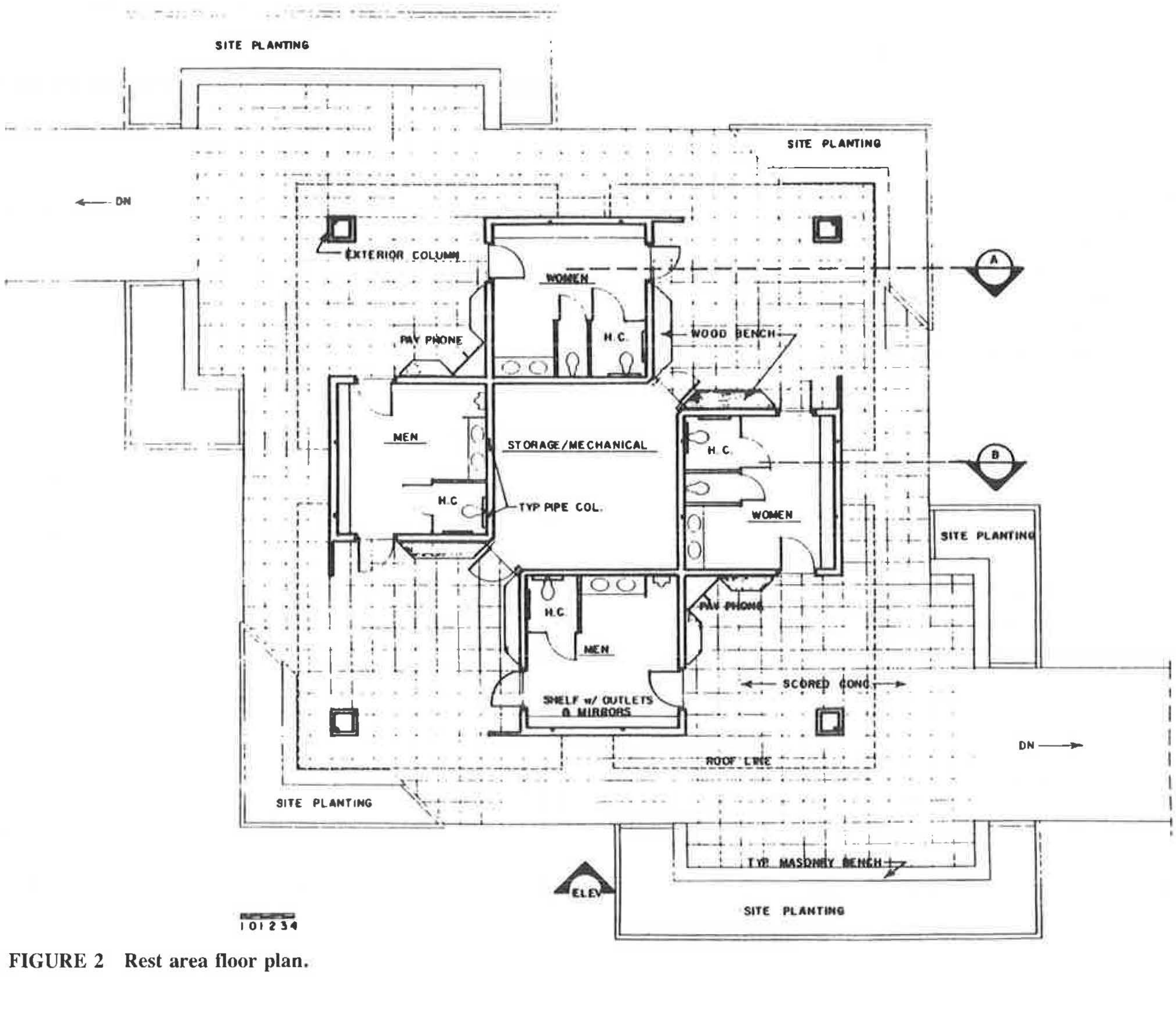

FIGURE 2 Rest area floor plan.

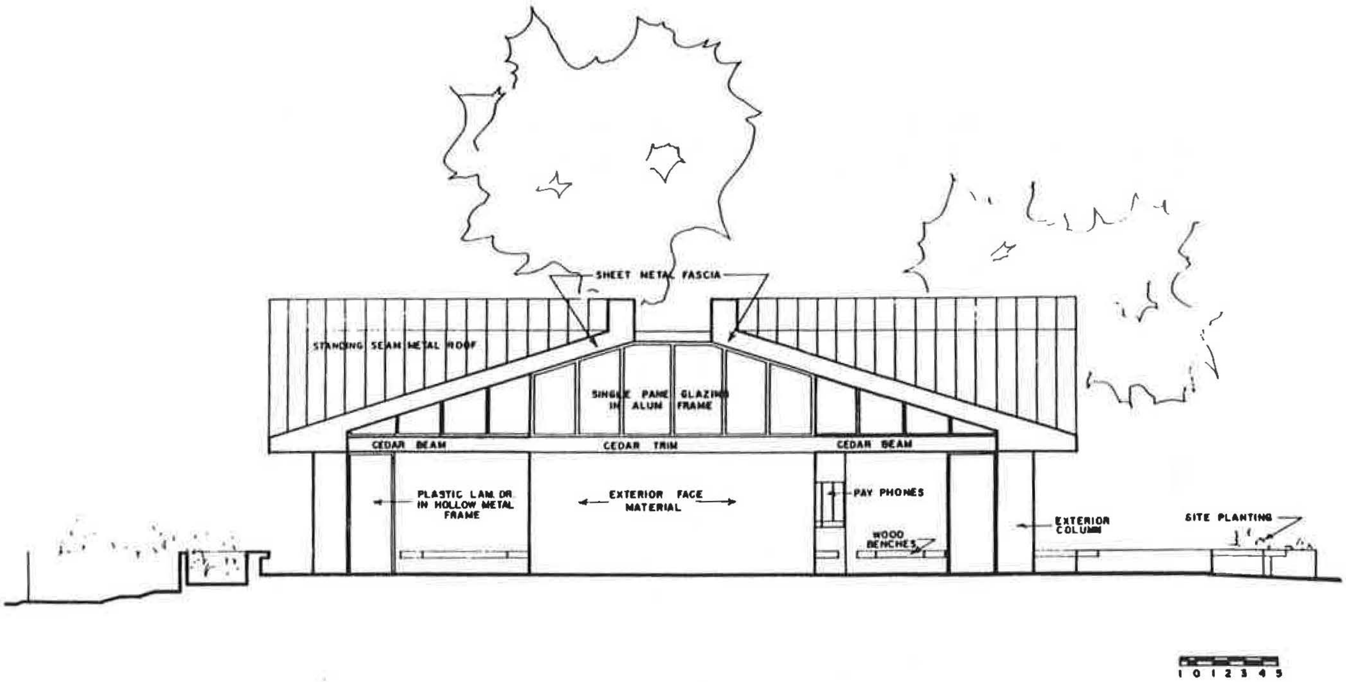

FIGURE 3 Comfort station elevation.

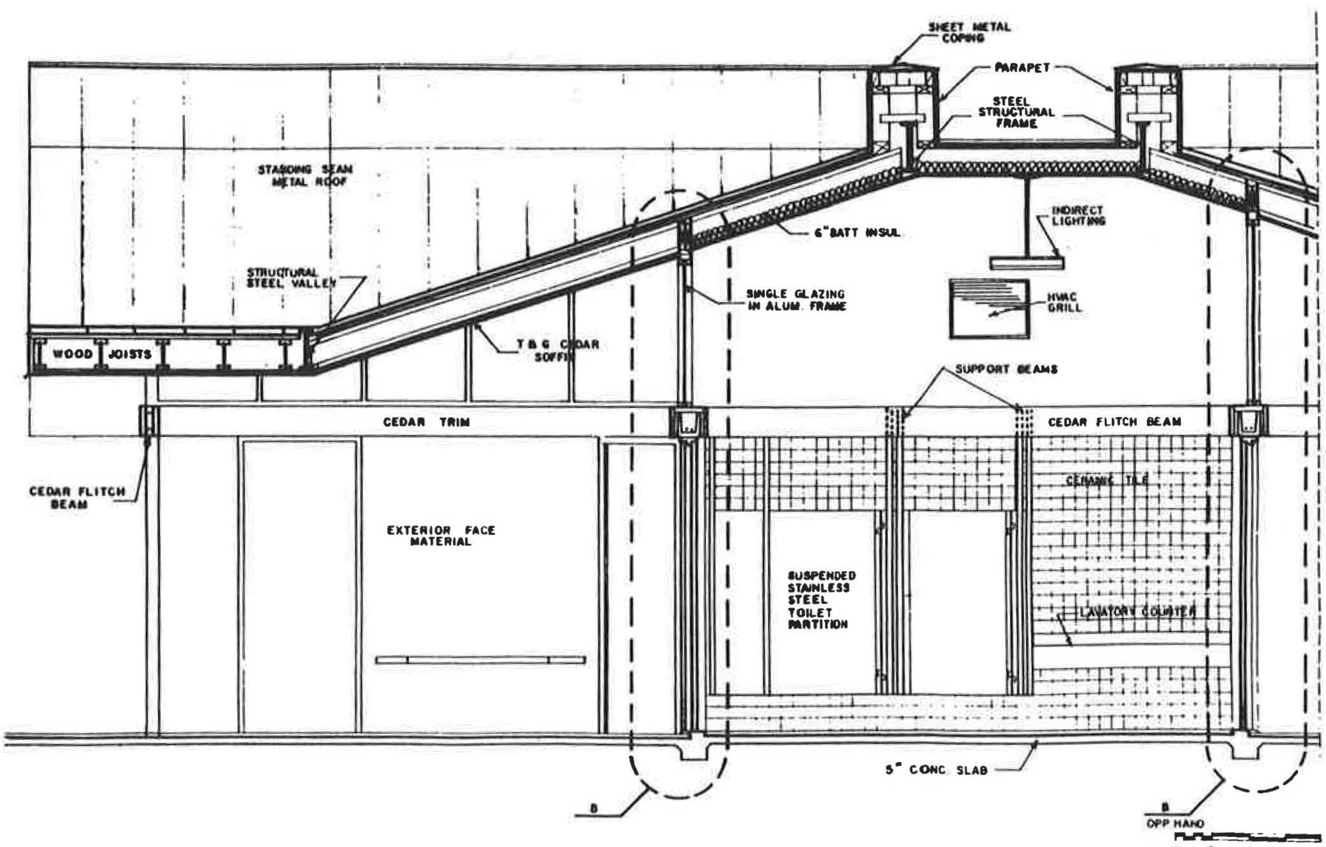

FIGURE 4 Comfort station building, section A.

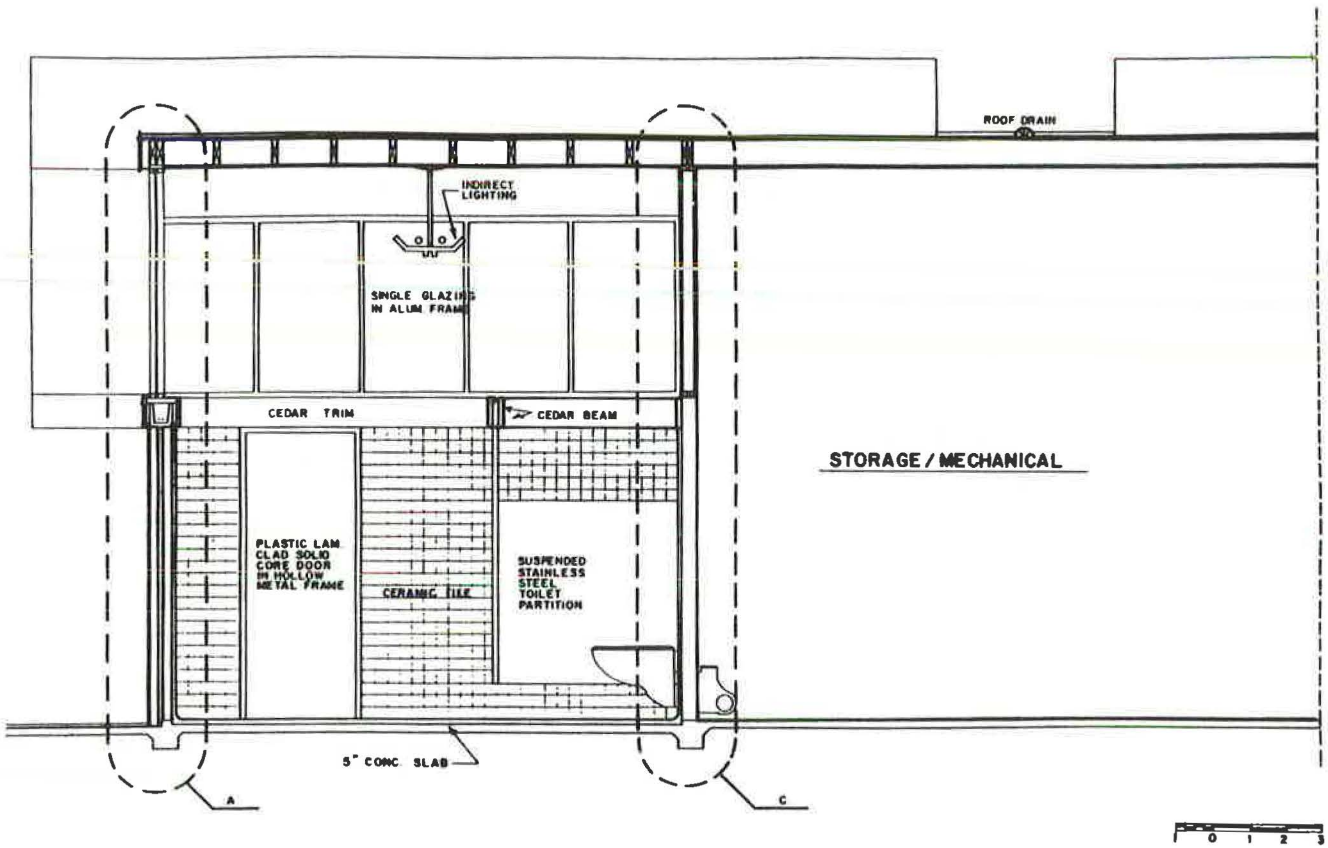

FIGURE 5 Comfort station building, section B.

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Field Observations of Arctic Grayling Passage Through Highway Culverts

CHARLES E. BEHLKE, DOUGLAS L. KANE, ROBERT F. MCLEAN, AND MICHAEL D. TRAVIS

Potentially important, miscellaneous, qualitative observations of four field studies of spawning migrations of arctic grayling (*Thymallus arcticus*) through highway culverts are discussed. Problems associated with culvert outlets, inlets, and barrels are described together with observed methods that fish use to negotiate culverts. The importance of location where fish actually swim in culverts is discussed. Limited observations of effects of culvert skew on culvert barrel flow patterns indicate such skew can make fish passage less difficult. The necessity of recognizing red muscle and white muscle power and energy capabilities of fish attempting to pass through culverts is indicated. Observations of fish attempting to enter a small fish ladder and a difficult culvert indicate that water-produced noise may attract fish to relatively small passage devices. Fish are observed to resort to leaping to enter difficult passage situations.

The Arctic grayling (*Thymallus arcticus*) was selected by the Alaska Department of Fish and Game as the design species for developing fish passage structure guidelines at highway stream crossings for low swimming performance fish (Group I). Arctic grayling were selected because of their ubiquitous distribution throughout Alaskan waters and their relative importance as a sport fish. Although the literature contains some information on the observed swimming performance of Arctic grayling through drainage structures (*1–3*), unanswered questions remained regarding (a) the critical water velocities within culvert barrels that grayling could successfully ascend under various conditions, (b) the length of time delay that grayling could withstand at drainage structures without affecting subsequent reproductive success, and (c) other hydraulic forces within culvert drainage structures (in addition to profile drag) that may also affect fish passage. To attempt to answer these questions, four field studies were initiated by the Alaska Interagency Fish Passage Task Force between 1985 and 1988.

These studies were designed to yield quantitative data related to fish energy and power delivered by grayling passing through two different culverts. Two of these studies have been reported (*4,5*). Reports for the other two are being written. During the course of the studies, several miscellaneous but potentially important phenomena were observed. These observations were made at two culvert sites and at a beaver dam where a small fish ladder had been introduced to aid fish in moving upstream past the dam. These limited observations are qualitative in nature but are reported here in the hope that others may profit from them and, through their observations and research, may add to the data base.

Fish take the path of least total resistance while swimming in culverts. To minimize the propulsive force necessary to move ahead, they choose paths where water velocities, water surface slopes, and water accelerations are reduced. The forces created by each of these, and the necessary power and energy produced by fish to overcome these effects are reported elsewhere (*5–7*). However, those involved in design of culverts should be aware that these parameters are deterrents to fish attempting to pass through culverts. We have observed fish attempting to avoid each of these situations. Since these situations usually appear collectively in culvert inlets and outlets, attempts to minimize all of these adverse conditions are encouraged.

Most hydraulic model studies of culverts have been directed toward identifying the effects of culvert inlet shape, slope, cross-section shape, or other geometric variables on discharge through culverts. Since fish swim along paths of least resistance, water velocities, accelerations, and pressure gradients (resulting from sloping water surfaces) in the zone in which the fish actually swim are important and should be analyzed. Mean cross-section water velocities in a culvert may have little meaning except as possible indicators of water velocities where the fish elect to swim within the culvert. However, water velocity is only one of the parameters that affect fish passage.

The distribution of water velocity in culvert barrels is extremely important to fish swimming through this zone of rather uniform flow in a relatively shallow sloping structure. Water velocity measurements by Katopodis et al. (*8*) and by us (Figure 1) show that water velocities near the boundary of a culvert are smaller than mean cross-sectional velocities at any point in the culvert. Our observations indicate that fish hug the culvert boundaries. Detailed study of the data of Katopodis et al. and Figure 1 reveals that, in culverts that are roughened only by corrugations but not by baffling or other artificial roughness (to reduce local water velocities), the zone of slowest water in a partially full culvert occurs at the intersection of the water surface with either side of the culvert. Recently, from working on a platform in a 9.5-ft-diameter culvert that was flowing approximately 2.5 ft deep, we were able to observe this location within the culvert and document that it was where the fish were swimming upstream.

During times when entrance to the culvert was difficult, fish negotiated the culvert outlet at the edge of the culvert

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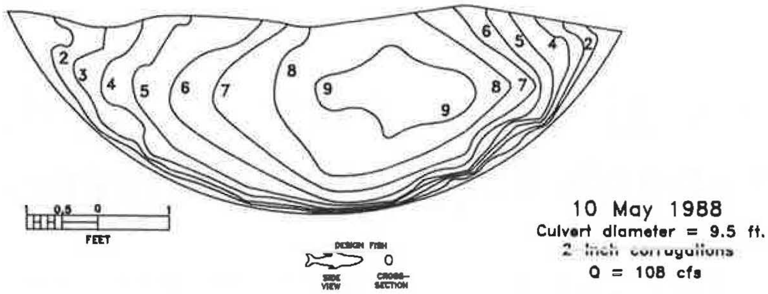

FIGURE 1 Water velocity cross section (ft/second) of Fish Creek Culvert, Denali Highway, Alaska.

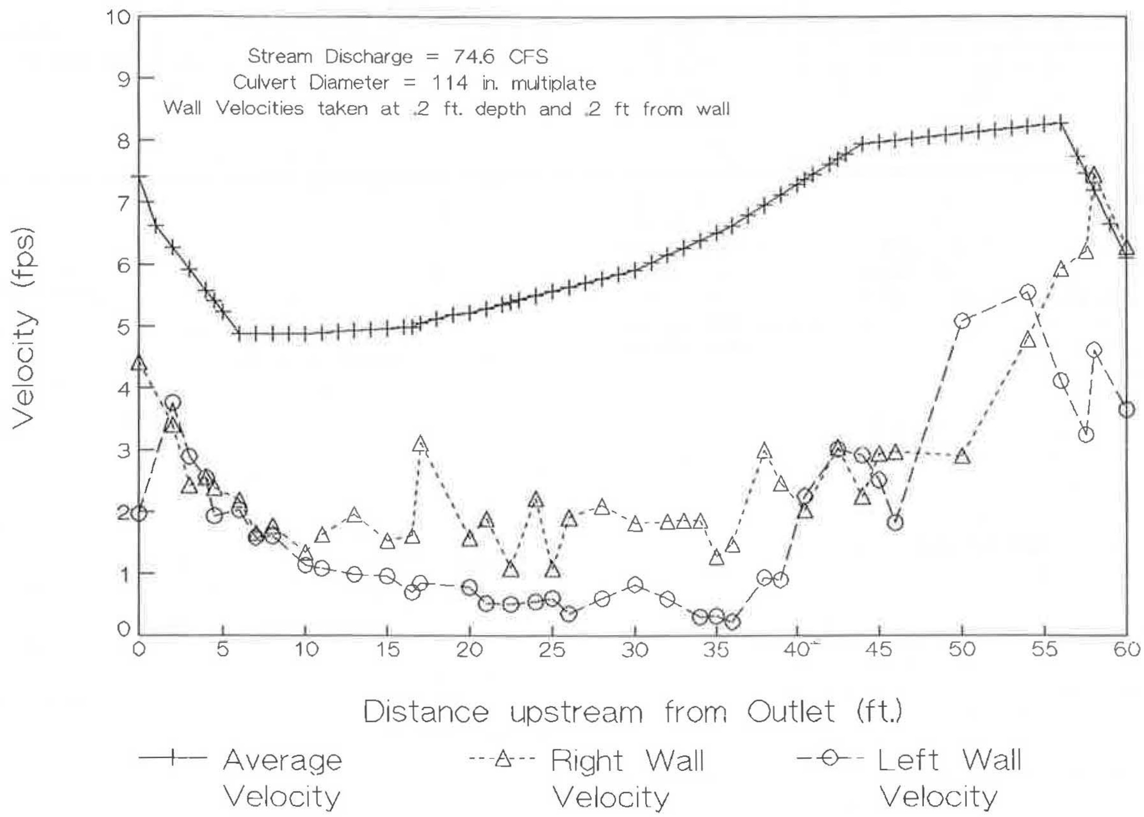

FIGURE 2 Culvert wall velocities of Fish Creek Culvert, May 15–16, 1988.

close to the water surface. Later, when discharges decreased, fish also entered the outlet at the invert and other locations across the bottom of the culvert. During higher discharges, when smaller fish were not able to pass through the culvert, only large fish were able to exit the culvert at the edge of the culvert close to the water surface. All of these occupied zones were areas of least total resistance to the fish.

In most situations, fish swim with their bodies oriented with bellies downward and backs upward. However, most fish swimming at the edge of this culvert and close to the water surface were not oriented vertically but were oriented normal to the sloping culvert wall with their bellies very near the wall.

In other studies by Tilsworth and Travis (*4*) and by us (*5*) of another culvert, most grayling were observed to enter the culvert hugging the invert, although many entered the culvert at the sides of the culvert too. This was a situation in which high-velocity flow, water acceleration, and relatively steep sloping water surfaces existed. Because the culvert diameter was 5 ft, it was not possible to enter the culvert to observe where the fish actually swam in the barrel of the culvert.

The effect of a skewed culvert inlet is important from the perspective of fish passage. Figure 2 indicates water velocity measurements for both edges of the 9.5-ft-diameter culvert mentioned previously. Corrugations were 1-3/8 in. deep and 6 in. apart. Velocity measurements were taken 0.2 ft from the culvert wall at a depth of 0.2 ft, and they are compared with the mean cross-sectional velocity in the culvert at various longitudinal locations. Water approached the inlet of this culvert from an angle of approximately 30° from the axis of the culvert. Clearly, the effect of this entrance skew was felt completely through the 60-ft length of the culvert. Fish clearly preferred the side of the culvert with lesser water velocities.

How much farther downstream this skew would have affected flow if the culvert had been longer is open to conjecture.

This culvert was constructed of bolted corrugated metal plates with the nut end of the bolts projecting inside the culvert. Some fish were observed to swim very close to the line of protruding nuts and bolts. Another culvert, where the axis of the culvert was skewed approximately 45° from the approaching flow, appeared to show a similar effect through a 60-ft culvert, although it was not possible to enter this culvert to obtain actual water velocity measurements. While skew is not desirable from the water passage viewpoint, it appears to show considerable promise for fish passage through large-diameter culverts.

The appropriate parameters for quantifying this effect presently appear to be s/B and Vo/V, where s is longitudinal distance downstream from the culvert inlet, B is the water surface width at location s, Vo is the water velocity at the edge of the culvert close to the water surface where the fish swim, and V is the cross-sectional average water velocity at location s. Water surface widths (B) for the culvert of Figure 2 varied along the culvert but averaged approximately 8 ft, so at the culvert outlet $s/B = 60/8 = 7.5$. The effect of skew was observed to exist throughout the length of this culvert. We are working on better quantifying this effect, since it is apparent from Figure 2 that the effect of skew is more pronounced where water velocities in the culvert were slower, thus suggesting a possible Froude number dependency.

The concept that fish swim with virtually constant velocity with respect to the ground as they move through culverts appears to be incorrect for many fish. Fish were observed to be "treading water" close to the side of the culvert at several locations of low water velocities in the culvert of Figure 2. It can be shown (*6,7*) that this type of motion leads to more total energy expenditure in passing through the culvert than if the fish swims at constant velocity, but there appears to be a power-energy trade-off that fish choose to make. We observed smaller grayling, burbot, and dolly varden also resting in the fashion outlined above. Interestingly, a single sculpin (approximately 2 in. long) was able to swim in and out of the corrugations and, by remaining very close to the wall, move upstream faster than grayling several times its length. How the sculpin fared in faster water closer to the inlet is unknown.

Fish have two separate muscle systems—red (aerobic) and white (anaerobic) muscles—to propel themselves. Red muscles are used for slow, long-duration swimming, and white muscles are utilized for fast, short-duration swimming. The red muscle system operates in an aerobic mode, and the white muscle system operates in an anaerobic mode. The latter is confined to short periods of output followed by long periods of rest (*9*). The red muscle and white muscle power and energy capabilities of fish (if known) must be kept in mind for culvert design. We have observed grayling obviously struggling hard in a white muscle mode as they entered culverts. However, when they had passed the difficult culvert outlet conditions, they switched to a larger amplitude and much slower tailbeat frequency, which is typical of the red muscle mode of swimming.

If fish completely deplete their white muscle capability at their entrance through the outlet of a culvert, they can switch to red muscle propulsion to swim through the barrel. But if water conditions at the culvert inlet are too difficult, the fish probably will not have sufficient white muscle capability to swim out of the culvert. We have seen fish that had difficulty entering a culvert fail the white muscle test in their attempts to leave a difficult culvert. Long rest periods are required to reconstitute white muscle capabilities. But culverts, in which white muscle efforts may be required most, provide little opportunity to rest in the barrel long enough to reconstitute these capabilities.

Our experiences with how water attracts upstream-migrating fish to specific water locations leads us to believe that this relationship should be an area of future research. We recently observed grayling reacting to a high beaver dam that they were unable to negotiate. Many leaped futilely at the water falling over a small spillway section that carried most of the streamflow over the dam. Some also entered a small side channel that carried only 3 percent of the total streamflow. At the upper end of the side channel, this small flow dropped down a 0.6-ft waterfall. Several fish ascended this small waterfall but were unable to get past the dam because of further difficulties.

When a small fish ladder was introduced to carry fish from the upstream end of the waterfall to the pool above the beaver dam, fish quickly utilized the route. After a few hours, they completely ceased leaping at the main channel spillway that was then carrying 94 percent of the total flow. When the same ladder was located so it extended, with no waterfalls, into the main channel scour pool from the pool above the dam, no fish entered it. Fish appeared to have difficulty finding the entrance to the ladder without the presence of a small waterfall to announce the ladder's location.

At another culvert, where fish passage was temporarily blocked by high stream discharges, many fish leaped from the scour pool at a water jet approximately the diameter of a pencil that was emitting from a bullet hole in the side of the full-flowing, 5-ft-diameter culvert. It appears that splashing water such as that from the small waterfall and that created by the bullet hole jet may have a considerable attracting effect for spawning migration fish. This type of attraction may be more important than other attraction methods in which attraction to a passage device is important.

Although leaping can be a very efficient mode for fish to move upstream past difficult vertical obstructions, it is our observation that grayling leap only as a last resort. This observation is a departure from the rule that fish select the easiest way to move from one location to another.

In the 9.5-ft-diameter culvert previously referenced, high-velocity, supercritical flow existed for 20 ft downstream from the inlet because the culvert was relatively steep there. This flow resulted in formation of surface waves that did not attenuate rapidly in the downstream direction. Several small grayling swimming close to the surface at the more favorable side of the culvert were observed to be dislocated rather severely by these waves. Clearly, situations that set up moving waves in culverts are the enemy of small fish, because waves can sweep them away from the low-velocity flow near the boundary, out into higher-velocity flow, which can sweep them out of the culvert.

Any culvert that flows with hydraulically supercritical flow contains water velocities too fast for most small species of fish to negotiate in the culvert barrel. For this reason and because of the attendant transient waves associated with high-velocity flow, culverts should be designed with outlet or downstream pool control.

SUMMARY AND FUTURE WORK

We are incorporating many of the observations from our present study into the preparation of a culvert design manual for the upstream passage of fish. These observations are also being used in the development of retrofit strategies for existing culverts that are incapable of passing upstream-migrant fish. A design manual that incorporates new culvert design recommendations is scheduled for completion late in 1989.

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Dimensionless Hydrograph Method of Simulating Flood Hydrographs

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The dimensionless hydrograph method is a simple, easy-to-use technique for simulating an average, or typical, hydrograph that corresponds to a given peak discharge. The method has been successfully tested and applied to both rural and urban streams in the states of Georgia, Tennessee, Alabama, South Carolina, Ohio, Missouri, and Arkansas. Most studies found that the dimensionless hydrograph developed for the Georgia study, which is nearly identical to a theoretical dimensionless hydrograph developed nationwide for urban streams, will apply to streams in the other study areas. Only in the Coastal Plain area of South Carolina and the lowlands of west Tennessee were dimensionless hydrographs found to be significantly different. An important parameter for the use of the dimensionless hydrograph method is the basin lagtime. Each of the studies developed regression equations that relate lagtime to basin characteristics. The other parameter needed to apply the method is peak discharge. The accuracy of the dimensionless hydrograph method varies from state to state, but in general the width at 50 and 75 percent of the peak discharge had standard errors in the range of 20 to 40 percent. For large floods at ungauged sites, the standard errors were between about 30 and 60 percent and represented the combined errors using lagtime regressions, peak discharge regressions, and the dimensionless hydrograph. The report also contains hydrograph width relations that can be used to determine the elapsed time that a specified discharge would be exceeded. Some investigators included regression equations for estimating flood volumes; however, flood volumes also can be computed by integrating the area beneath the simulated hydrograph, or by applying an equation that yields virtually the same result as the integration method.

The design of transportation structures, flood detention structures, and other flood control structures requires an estimate of flood peak discharges, flood hydrographs, and flood volumes for specified design probabilities. The U.S. Geological Survey (Geological Survey) has cooperated with state highway departments, the FHWA, and other state and federal agencies to provide flood data and flood frequency analyses to meet the needs of design engineers. Much of the past work has been for the purpose of providing flood peak information. Recently, however, the Geological Survey has been working on projects to develop methods of estimating flood hydrographs and flood volumes. Projects have been completed for Georgia, Alabama, Ohio (urban), and central Tennessee. Projects are nearing completion in South Carolina, Ohio (rural), Missouri, Arkansas, and east and west Tennessee. A nationwide urban hydrograph project has also been completed. Each of these studies uses a similar approach that provides a simple, easy-to-use dimensionless hydrograph that can be converted to a design hydrograph for any design peak discharge. In some of these studies, methods are also provided for estimating flood volumes.

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The purpose of this paper is to describe the dimensionless hydrograph method and to compare the results obtained in the states in which projects have been completed or are under way. Results from the states of Georgia, Alabama, Tennessee, South Carolina, Ohio, Missouri, and Arkansas will be compared. The nationwide urban hydrograph results will also be compared with the individual state results. Comparisons will be made of the dimensionless hydrograph, hydrograph width relations, lagtime equations, and volume equations.

The results from uncompleted studies in South Carolina, Ohio (rural), Missouri, Arkansas, and east and west Tennessee are preliminary and subject to revision.

DESCRIPTION OF METHOD

The dimensionless hydrograph method is specifically designed to be easy to use and to produce a typical hydrograph that represents average runoff for a specified peak discharge. The hydrograph peak discharge will be exactly the same as the peak discharge for the design recurrence interval, i.e., a 50-year or 100-year discharge. There are three essential parts to the dimensionless hydrograph method: (a) the peak discharge for which a hydrograph is desired, (b) the basin lagtime, and (c) the dimensionless hydrograph itself.

The peak discharge can be an actual observed peak if it is desired to fit an average hydrograph to some known peak. In this case, the analyst should be aware that the fitted hydrograph will not necessarily reproduce the actual hydrograph, nor is it intended to. The resultant hydrograph will simply be an average hydrograph that represents average conditions. On the other hand, most design applications will use a peak discharge representative of some specified recurrence interval. Peak discharges of this type can be determined independently. The Geological Survey has defined regression equations for this purpose throughout the United States. These equations are based on actual streamflow records and log Pearson type III frequency distributions. They are available through published reports and soon will be available through computer programs. Other methods of defining the peak discharge to be used in the dimensionless hydrograph method are acceptable and are the choice of the analyst.

Basin lagtime is defined as the elapsed time, in hours, from the center of mass of rainfall excess to the center of mass of the resultant runoff hydrograph. This is the most difficult estimate to make for the dimensionless hydrograph method

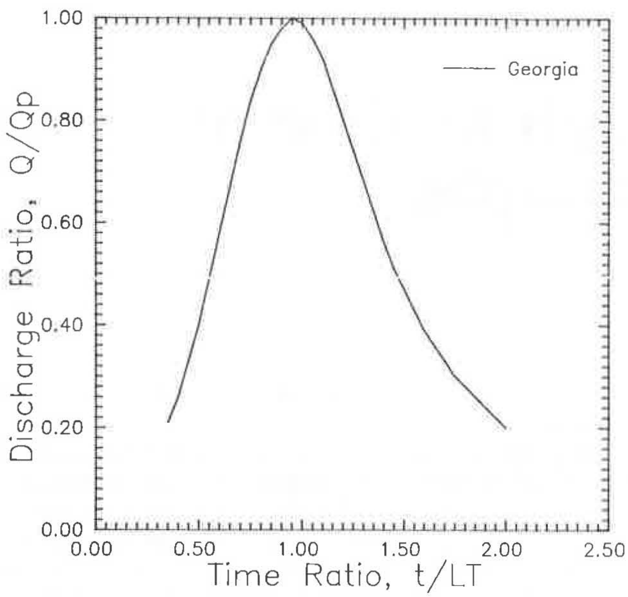

FIGURE 1 Dimensionless hydrograph for Georgia.

because lagtime is highly variable, depending on numerous basin conditions such as basin size, basin and channel slope, soil conditions, cover, basin storage (reservoir, swamps, and detention ponds), urbanization, channel conditions, channel modifications, and other factors. Generally lagtime is considered to be constant for a given basin, and not variable with the size of the runoff event. Most of the Geological Survey hydrograph projects have followed this concept and use a constant lagtime for all floods for a given basin. It has been observed, however, that in some basins lagtime will vary with the size of the runoff event. In these cases, lagtime will decrease as the size of the runoff event increases. The uncertainty in estimating lagtime, even for gauged basins, is large, and consequently most of the error in the estimated hydrographs results from the errors in lagtime. Regression equations have been developed for the areas of each of the Geological Survey studies, including some urban areas, and these equations can be used to estimate lagtime for ungauged basins.

The third, and final component needed to use the dimensionless hydrograph method, is the dimensionless hydrograph ordinates. Figure 1 is a plot of the dimensionless hydrograph defined for use in the state of Georgia by Inman (*1*). Note that the ordinate scale is a dimensionless ratio of discharge (Q) to peak discharge (Qp), and the abscissa scale is a dimensionless ratio of time (t) to lagtime (LT). This dimensionless hydrograph was developed by analyzing several hundred actual flood hydrographs and reducing them to unit hydrographs and finally to the dimensionless hydrograph as described by Inman (*1*). A paper describing the procedure was presented in 1986 to the Transportation Research Board and has been published (*2*).

A feature, and advantage, of the dimensionless hydrograph method is that it does not require any kind of rainfall or rainfall excess analysis. The derivation of the dimensionless hydrograph was based on a generalization of rainfall duration by considering duration as a fraction of lagtime. By comparing synthesized hydrograph widths based on different values of duration with observed hydrograph widths, it was found that the optimum value of duration (minimum standard error) was equal to one-half the value of lagtime for most of the study areas. Consequently, the dimensionless hydrograph method contains an indirect consideration of rainfall duration that will produce an average hydrograph for the selected peak discharge. On the other hand, it cannot be expected to reproduce actual flood hydrographs because the actual rainfall is not considered in the computations. Removing rainfall and rainfall excess computations from the dimensionless hydrograph method makes the method simple and easy to apply.

Application of the dimensionless hydrograph to derive an average, or typical, hydrograph for a specified peak discharge, Qp, is a simple case of multiplication. The hydrograph discharge ordinates, in cubic feet per second, are computed by multiplying each of the discharge ratios, Q/Qp, times the peak discharge, Qp. Likewise, the time, in hours, for each discharge is computed by multiplying the time ratios, t/LT, times the basin lagtime, LT. The resultant hydrograph will have a peak discharge equal to the specified, or design, peak discharge and can be assumed to be typical for that recurrence interval.

COMPARISON OF DIMENSIONLESS HYDROGRAPHS

The first Geological Survey statewide dimensionless hydrograph study was made by Inman (*1*) using streamflow data from 355 flood events recorded at 80 gauging stations in Georgia. These data included sites located in all parts of the state, including mountains, coastal plains, and urban areas. Inman (*1*) found that the optimum value of rainfall duration was one-half of lagtime. Testing and verification of the dimensionless hydrograph involved the use of 138 additional storm events at 37 different gauging stations. Because it involved the use of an extensive data base for the development and testing of the dimensionless hydrograph, this study is considered the primary basis of comparison for other studies. In fact, several of the other studies have adopted the Georgia dimensionless hydrograph for use in their states.

A nationwide urban hydrograph study was made by Stricker and Sauer (*3*) using a theoretical approach. In that study, unit hydrographs were computed for 62 urban gauging stations located in Georgia, Pennsylvania, Tennessee, Colorado, Missouri, Oklahoma, Oregon, and Texas. The method of Clark (*4*) was used to derive a theoretical unit hydrograph for each station. These unit hydrographs were transformed to a generalized rainfall excess duration of one-third lagtime and then reduced to dimensionless terms. The duration of one-third lagtime was an arbitrary choice. However, a comparison of the final dimensionless hydrograph to the Georgia dimensionless hydrograph (Figure 2) shows that the two hydrographs are similar and, in fact, are almost identical. The nationwide urban hydrograph is slightly more narrow, and this is probably because it is based on a duration of one-third lagtime as opposed to the one-half lagtime of the Georgia hydrograph. The application of either of these hydrographs will produce similar results, and for practical purposes they are considered equal.

The Tennessee hydrograph project was divided into two parts, one for central Tennessee and the other for east and west Tennessee. In the central Tennessee study, Robbins (*5*) used a small, distributed data base and the analytical techniques developed in Georgia to derive an average dimen-

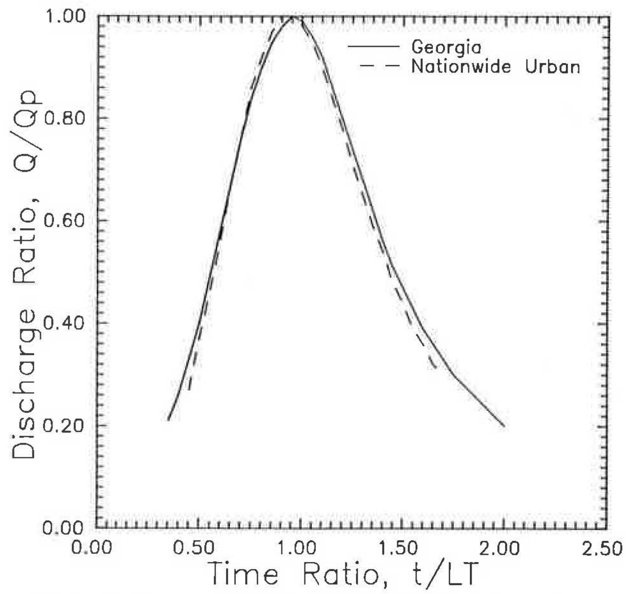

FIGURE 2 Comparison of Georgia and nationwide urban dimensionless hydrographs.

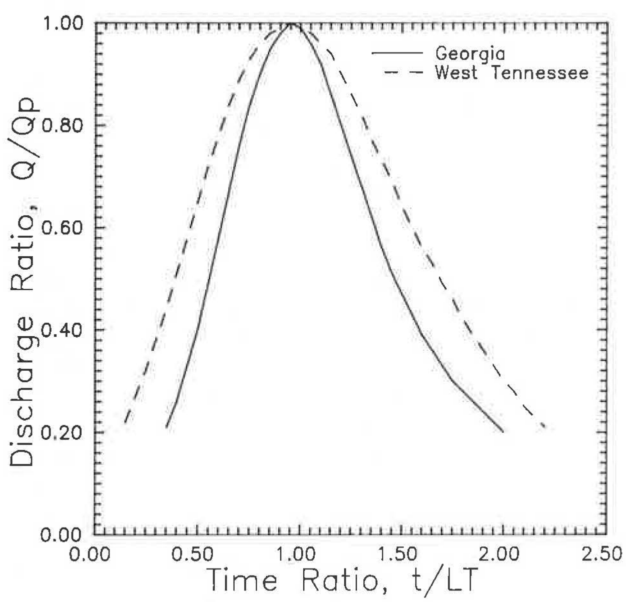

FIGURE 3 Comparison of Georgia and west Tennessee dimensionless hydrographs.

sionless hydrograph. He compared and tested this dimensionless hydrograph with the Georgia dimensionless hydrograph and found that it was essentially the same. Consequently, he adopted the Georgia dimensionless hydrograph for use in central Tennessee. In the second Tennessee study (Gamble, unpublished data), it was also found that the Georgia dimensionless hydrograph was applicable to east Tennessee streams. They used a selected data base to compute an average dimensionless hydrograph that was found to be nearly identical to the Georgia hydrograph. The situation was different, however, in west Tennessee where the dimensionless hydrograph was found to be considerably wider than the Georgia hydrograph. Figure 3 is a comparison of the west Tennessee dimensionless hydrograph, developed from 38 flood events at 10 gauging stations, with the Georgia dimensionless hydrograph. The reason for the departure from the basic dimensionless hydrograph developed in Georgia may be related to the topography of west Tennessee, where relief is much less than in east and central Tennessee and most of Georgia. In addition, considerable channel modifications that affect runoff distribution have been performed on the west Tennessee streams.

In the Alabama study, Olin and Atkins (*6*) developed dimensionless hydrographs by using the Georgia method with data from 76 flood events at 27 rural gauging stations. They also made similar computations for 44 flood events at 10 urban stations. These stations were selected because they were representative of all hydrologic areas in Alabama. Both the rural and urban dimensionless hydrographs compared closely with the Georgia dimensionless hydrograph, and that hydrograph was adopted for use in Alabama.

In South Carolina, 188 flood events recorded at 49 rural gauging stations throughout South Carolina were used to develop regionalized dimensionless hydrographs. Bohman (unpublished data) found a significant difference in the dimensionless hydrographs for each of three regions—the Blue Ridge province, the Piedmont province, and the Coastal Plain province south of the fall line. Only in the Piedmont province did he find that the dimensionless hydrograph was nearly the same as that for the Georgia dimensionless hydrograph, and even so, he opted to use the hydrograph derived from the South Carolina data. See Figure 4 for a comparison of this Piedmont dimensionless hydrograph to the Georgia hydrograph. In the Blue Ridge he found that the dimensionless hydrograph was more narrow than the Georgia hydrograph, and that the optimum duration was one-third lagtime rather than one-half lagtime. The shorter duration may account, at least partially, for the more narrow width of the Blue Ridge hydrograph. See Figure 5 for a comparison of the Blue Ridge hydrograph to the Georgia hydrograph. In the Coastal Plain south of the fall line, the dimensionless hydrograph was found to be considerably wider than the Georgia hydrograph (see Figure 6).

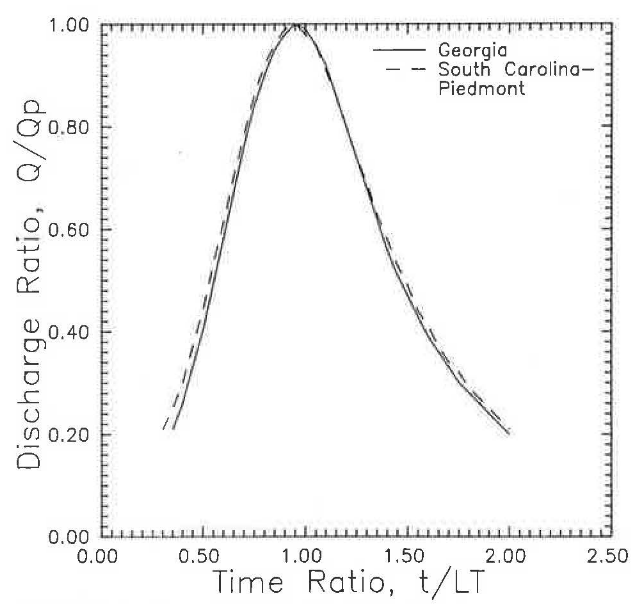

FIGURE 4 Comparison of Georgia and South Carolina Piedmont dimensionless hydrographs.

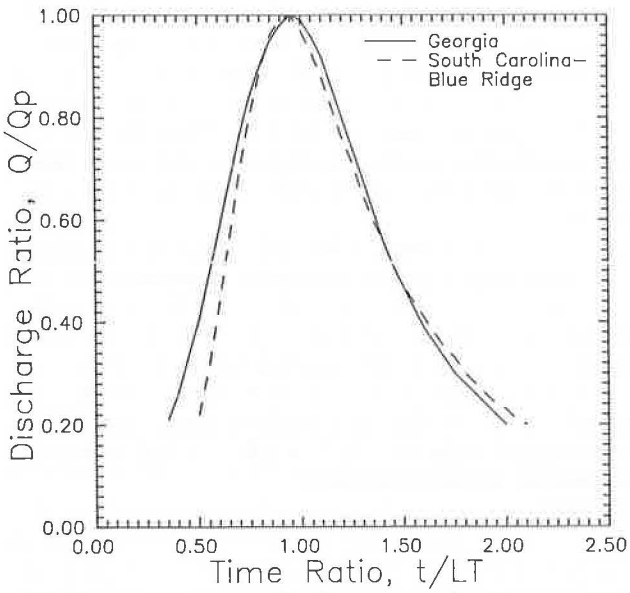

FIGURE 5 Comparison of Georgia and South Carolina Blue Ridge dimensionless hydrographs.

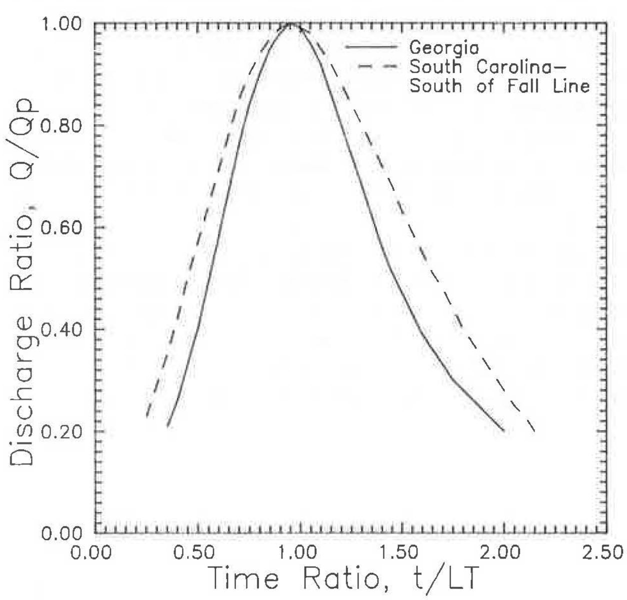

FIGURE 6 Comparison of Georgia and South Carolina, south of the fall line, dimensionless hydrographs.

Like the west Tennessee study, this may reflect the flat slopes and small topographic relief. In addition, there is considerable surface storage in the Coastal Plains area, as well as many channel modifications. All of these factors may combine in some way to result in comparatively wide hydrograph shapes. Although it was decided to use three separate dimensionless hydrographs for South Carolina, the use of the Georgia hydrograph could be used with acceptable standard errors. There would, however, be a bias in the Blue Ridge province and the Coastal Plains province if the Georgia hydrograph were used.

Investigators in Arkansas took a somewhat different approach to develop an average dimensionless hydrograph for 18 gauging stations throughout the state (Neely, unpublished data).

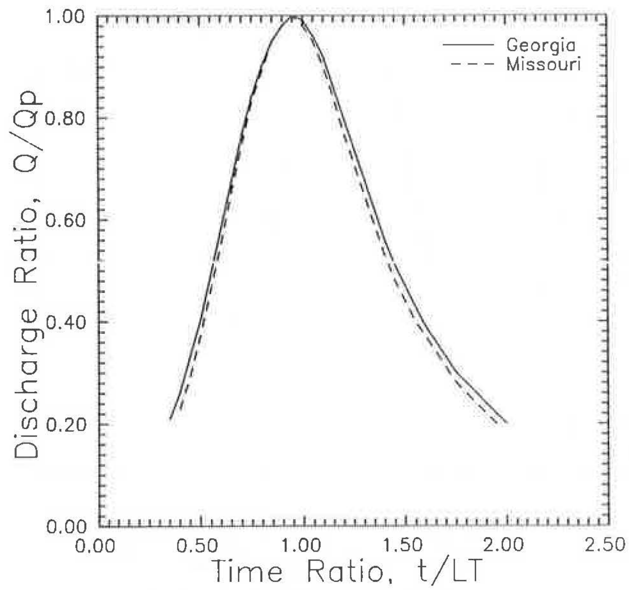

FIGURE 7 Comparison of Georgia and Missouri dimensionless hydrographs.

They reduced actual flood hydrographs to dimensionless terms rather than first defining unit hydrographs as done in the other state studies. Even so, they found that the average dimensionless hydrograph as defined for the 18 stations was essentially the same as the Georgia hydrograph, so they decided to use the Georgia hydrograph for Arkansas because it is defined from considerably more data. The Arkansas data were obtained only from rural gauging stations.

An urban hydrograph study in Ohio by Sherwood (*7*) has been completed, and another Ohio study for small rural basins is in progress (Sherwood, unpublished data). In the urban study, he found that the dimensionless hydrograph developed by Stricker and Sauer (*3*) for the nationwide urban flood study was applicable to Ohio urban sites. This hydrograph is similar to the Georgia hydrograph as seen in Figure 2. In the study for small rural basins, he used 96 flood events from 32 gauging stations to verify that the Georgia dimensionless hydrograph is applicable in Ohio.

Preliminary results from the hydrograph project under way in Missouri (Becker, unpublished data) indicate that the dimensionless hydrograph developed from data in Missouri compares closely with the Georgia dimensionless hydrograph; however, the dimensionless hydrograph developed from the Missouri data will be used. Figure 7 shows a comparison of the Missouri hydrograph to the Georgia hydrograph.

Table 1 shows the ordinates for the various dimensionless hydrographs. The ordinates have been purposely aligned so that the maximum ratio of *Q*/*Qp* coincides for each hydrograph.

COMPARISON OF EQUATIONS FOR ESTIMATING BASIN LAGTIME

An important factor in the dimensionless hydrograph method is basin lagtime. As already mentioned, this is a difficult factor to estimate for a drainage basin. For gauged basins, lagtime can be estimated from observed records of rainfall and runoff.

TABLE 1 DIMENSIONLESS HYDROGRAPH ORDINATES

Time ratio t/LT	Discharge ratio, Q/Qp						
	GA	NWU	W-TN	SC-BR	SC-P	SC-SF	MO
.15			.22				
.20			.27				
.25			.32			.23	
.30			.38		.21	.29	
.35	.21		.44		.25	.35	
.40	.26		.51		.30	.42	.23
.45	.33	.27	.58		.37	.50	.29
.50	.40	.37	.65	.22	.44	.57	.37
.55	.49	.46	.72	.31	.53	.64	.46
.60	.58	.56	.78	.43	.61	.71	.55
.65	.67	.67	.84	.56	.70	.78	.65
.70	.76	.76	.89	.69	.78	.85	.74
.75	.84	.86	.93	.80	.86	.90	.83
.80	.90	.92	.96	.89	.92	.94	.89
.85	.95	.97	.98	.96	.96	.97	.95
.90	.98	1.00	.99	.99	.99	.99	.98
.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	.99	.98	.99	.97	.98	.99	.98
1.05	.96	.95	.98	.93	.96	.98	.95
1.10	.92	.90	.96	.88	.91	.95	.90
1.15	.86	.84	.94	.82	.86	.92	.84
1.20	.80	.78	.90	.76	.80	.88	.77
1.25	.74	.71	.86	.71	.74	.84	.71
1.30	.68	.65	.82	.65	.69	.80	.65
1.35	.62	.59	.77	.60	.63	.76	.59
1.40	.56	.54	.73	.56	.58	.72	.53
1.45	.51	.48	.69	.51	.53	.68	.48
1.50	.47	.44	.64	.47	.49	.63	.44
1.55	.43	.39	.60	.44	.44	.59	.40
1.60	.39	.36	.56	.41	.41	.55	.37

(*Continued on next page*)

TABLE 1 (*continued*)

Time ratio t/LT	Discharge ratio, Q/Qp						
	GA	NWU	W-TN	SC-BR	SC-P	SC-SF	MO
1.65	.36	.32	.53	.38	.37	.51	.34
1.70	.33	.30	.49	.35	.34	.48	.31
1.75	.30		.46	.33	.32	.44	.28
1.80	.28		.42	.30	.29	.40	.26
1.85	.26		.39	.28	.27	.37	.24
1.90	.24		.36	.26	.25	.34	.22
1.95	.22		.33	.24	.23	.31	.20
2.00	.20		.30	.23	.21	.28	
2.05			.28	.21		.25	
2.10			.25	.20		.23	
2.15			.23			.20	
2.20			.21				

[GA=Georgia, NWU=Nationwide urban, W-TN=West Tennessee, SC-BR=South Carolina Blue Ridge, SC-P=South Carolina Piedmont, SC-SF=South Carolina south of fall line, and MO=Missouri]

Even so, there is a great deal of uncertainty because one must compute the time of the center of mass of rainfall excess and the corresponding time of the center of mass of direct runoff, which vary from storm to storm. Numerous factors enter into these computations, such as the magnitude and distribution of rainfall excess, infiltration, and extraction of base flow from the total runoff hydrograph. The subjective nature of these factors makes interpretation difficult and can lead to errors in the computed lagtime. For ungauged basins, the problem is even more difficult. Generally, lagtime for ungauged basins is estimated from equations or graphs that relate lagtime to basin parameters such as drainage area size, length, slope, vegetal cover, storage in reservoirs and swamps, and, in some cases, even size of runoff event. Standard errors are, however, generally large. In addition, there seem to be regional differences that cannot be accounted for with the usual array of measurable basin parameters. Consequently, it becomes necessary to segment the estimating equations and graphs by region. Table 2 is a listing and comparison of the various equations developed by regression analysis for the hydrograph studies.

In all of the equations except Ohio (rural) there is a measure of basin size, either drainage area or main channel length. For rural basins in Ohio the size of the basins was limited to a maximum of 6.5 mi^2; consequently, size did not prove significant in the regression with lagtime. It was found that main channel slope, percent of forest area in the basin, and percent of storage in the basin were the significant factors for estimating lagtime in rural areas up to 6.5 mi^2 in Ohio. Main channel slope also proved significant in a number of the other equations, both rural and urban. In the Arkansas and South Carolina studies, it was found that the peak discharge of a flood hydrograph is related to the lagtime of that hydrograph. In each of these studies, the equations show that for a given drainage basin, the flood hydrographs with large peaks have shorter lagtimes than flood hydrographs with small peaks. This difference can be logically explained because, in many drainage systems, the main channel tends to meander within a flood plain that is comparatively straight. Consequently, as the size of the flood increases, the flow path shortens and velocities increase, which result in shorter travel times and thus shorter lagtimes. In the South Carolina study, equations were developed for average basin lagtime and for discharge adjusted lagtime. Both sets of equations are shown in Table 2, but standard errors were computed only for the average lagtime equations.

For urban basins, the parameters for estimating lagtime are essentially the same as those for rural basins, except that the equations contain some measure of urbanization. Most of the equations use the percent of basin covered by impervious surfaces for the urbanization index. The nationwide urban equation developed by Sauer et al. (*8*) also contains the basin development factor (BDF) as well as several other parameters. In the urban studies in Ohio and Missouri, it was found

TABLE 2 EQUATIONS FOR ESTIMATING BASIN LAGTIME (*LT*) IN HOURS

State/Area/Region	Equation	Standard Error, in percent
ALABAMA		
North of fall line	$LT=2.66\,A^{.46}\,S^{-.08}$	32
South of fall line	$LT=5.06\,A^{.50}\,S^{-.20}$	31
Statewide, urban	$LT=2.85\,A^{.295}\,S^{-.183}\,IA^{-.122}$	21
TENNESSEE		
East	$LT=1.26\,L^{.825}$	47
Central	$LT=0.94\,L^{.86}$	39
Central, urban	$LT=1.64\,L^{.49}\,IA^{-.16}$	16
West	$LT=0.707\,A^{.73}$	43
West, urban	$LT=2.65\,A^{.348}\,IA^{-.357}$	39
GEORGIA		
North of fall line	$LT=4.64\,A^{.49}\,S^{-.21}$	31
South of fall line	$LT=13.6\,A^{.43}\,S^{-.31}$	25
Atlanta urban	$LT=161\,A^{.22}\,S^{-.66}\,IA^{-.67}$	19
SOUTH CAROLINA (avg. basin LT)		
Blue Ridge	$LT=3.71\,A^{.265}$	7
Piedmont	$LT=2.66\,A^{.460}$	26
Inner Coastal Pl.	$LT=6.10\,A^{.417}$	34
Lower Coastal Pl. Region 1	$LT=6.62\,A^{.341}$	26
Region 2	$LT=10.88\,A^{.341}$	
SOUTH CAROLINA (Qp adj. LT)		
Blue Ridge	$LT=7.21\,A^{.322}\,Qp^{-.112}$	--
Piedmont	$LT=3.30\,A^{.614}\,Qp^{-.120}$	--
Inner Coastal Pl.	$LT=7.03\,A^{.375}\,Qp^{-.010}$	--
Lower Coastal Pl. Region 1	$LT=6.95\,A^{.348}\,Qp^{-.022}$	--
Region 2	$LT=11.7\,A^{.348}\,Qp^{-.022}$	

(*Continued on next page*)

TABLE 2 (*continued*)

State/Area/Region	Equation	Standard Error, in percent
OHIO		
Small rural	$LT=16.4\ S^{-.78}\ (F+10)^{.38}\ (ST+1)^{.31}$	35
Small urban	$LT=1.07\ L^{.54}\ S^{-.27}\ (13-BDF)^{.42}$	48
ARKANSAS		
Rural	$LT=256\ A^{.90}\ (P-30)^{.61}\ Q100^{-.65}\ Qp^{-.16}\ S^{-.25}$	33
Memphis urban	$LT=2.05\ A^{.35}\ C^{-.87}\ IA^{-.22}$	24
MISSOURI RURAL		
Equation 1	$LT=2.79\ L^{.39}\ S^{-.195}$	26
Equation 2	$LT=1.46\ A^{.27}$	26
MISSOURI URBAN		
Equation 1	$LT=0.87\ L^{.60}\ S^{-.30}\ (13-BDF)^{0.45}$	23
Equation 2	$LT=0.32\ A^{.50}\ (13-BDF)^{.37}$	22
NATIONWIDE URBAN		
Equation 1	$LT=0.85\ L^{.62}\ S^{-.31}\ (13-BDF)^{.47}$	76
Equation 2	$LT=.0030\ L^{.71}\ (13-BDF)^{.34}\ (ST+10)^{2.53}\ RI2^{-.44}\ IA^{-.20}\ S^{-.14}$	61

[A=drainage area, in sq.mi.; S=main channel slope, in fpm; L=main channel length, in mi.; Qp=peak discharge, in cfs; F=percent forest area; ST=percent of surface storage in basin; P=mean annual precipitation, in inches; Q100=100-year recurrence interval peak discharge, in cfs; IA=percent of basin covered by impervious surfaces; BDF=basin development factor; RI2=2-year 2-hour rainfall intensity; and C=channel condition (unpaved 1, fully paved 2)]

that the BDF was significant for estimating urban lagtimes. There is marked similarity among the Missouri, Ohio, and nationwide urban (equation 1) lagtime equations.

The BDF is a measure of drainage modifications, such as main channel enlarging and straightening, channel lining, storm drains, and curb and gutter streets. Each of these modifications is evaluated in the upper, middle, and lower third of the drainage basin and assigned a value of 0 if they are not prevalent and a value of 1 if they are prevalent (50 percent effective). The individual values are summed to define the BDF, which can range from 0 to 12. A detailed description of the BDF and its computation is given by Sauer et al. (*8*).

In Arkansas, a different approach was used to compute lagtimes from observed rural flood events. Researchers had already tested and confirmed that the Georgia dimensionless hydrograph was applicable to Arkansas streams, so they used this hydrograph to compute an equivalent lagtime that would reproduce observed hydrograph widths at 50 and 75 percent of the peak discharge of actual flood events. This method may be the most practicable approach of all because it eliminates the need to analyze rainfall data and to compute the center of mass of rainfall excess and corresponding runoff. It is also interesting that researchers were able to regionalize equivalent lagtime throughout the state with one regression equation, even though Arkansas has considerable variation in topography. Most probably this calculation was possible because the equation contains an estimate of the 100-year flood, which is made on a regional basis. It is likely that the Arkansas regression equation for lagtime may be applicable in other areas outside of Arkansas because of the inclusion of the 100-year peak discharge. This possibility is planned for further testing.

As can be noted from the equations in Table 2, there is considerable variability among the statewide studies. Even within a given state, lagtime varies greatly between adjacent regions. The humanmade changes occurring in urban areas create an even greater effect on lagtime. It is evident there is a need to find other parameters, or other methods, to explain the variability.

HYDROGRAPH WIDTH RELATIONS

The dimensionless hydrograph can be changed into a hydrograph width relation by computing the width of the dimensionless hydrograph at selected values of the dimensionless discharge ordinates. Table 3 gives the dimensionless width ratios, W/LT, for each of the dimensionless hydrographs. Figure 8 is a plot of the same values. These relations are useful to estimate the elapsed time for which a given discharge will be exceeded. For example, suppose it is desired to know how long a roadway will be inundated during a specific design flood, such as a 100-year flood. If the over-topping discharge (Q) is known, then the ratio of this discharge to the 100-year discharge can be computed. This ratio (Q/Qp) is used to enter the hydrograph width relation to find the ratio W/LT. Mul-

TABLE 3 HYDROGRAPH WIDTH RELATIONS

Discharge Ratio, Q/Qp	Width ratios, W/LT						
	GA	NWU	W-TN	SC-BR	SC-P	SC-SF	MO
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.95	.22	.22	.34	.18	.22	.30	.19
.90	.32	.32	.49	.27	.32	.43	.29
.85	.40	.40	.60	.34	.41	.55	.37
.80	.48	.46	.70	.42	.50	.65	.44
.75	.55	.53	.80	.48	.57	.74	.51
.70	.62	.59	.90	.54	.64	.83	.58
.65	.68	.66	.99	.61	.71	.92	.65
.60	.76	.72	1.09	.68	.79	1.02	.71
.55	.83	.80	1.19	.74	.87	1.11	.79
.50	.91	.86	1.29	.84	.95	1.22	.86
.45	1.00	.95	1.40	.92	1.04	1.32	.94
.40	1.09	1.01	1.52	1.02	1.14	1.43	1.03
.35	1.20	1.12	1.64	1.12	1.24	1.53	1.14
.30	1.33	1.23	1.78	1.26	1.38	1.65	1.26
.25	1.4	--	1.93	1.41	1.55	1.79	1.41

[GA=Georgia, NWU=Nationwide urban, W-TN=West Tennessee, SC-BR=South Carolina Blue Ridge, SC-P=South Carolina Piedmont, SC-SF=South Carolina south of fall line, and MO=Missouri]

tiplying the W/LT ratio times the estimated lagtime (LT) for the basin will yield an estimate of the inundation time, in hours.

FLOOD VOLUMES

Flood volumes corresponding to the hydrographs computed by the dimensionless hydrograph method can be computed by extending the rising and falling limbs of the hydrograph to zero flow, and then integrating the area beneath the hydrographs. Volumes computed in this manner, like the hydrograph itself, are simply an average, or typical, volume for the design peak discharge. It can be assumed that the recurrence intervals of such volumes are at least similar to the recurrence intervals of the peak discharges. However, there have been no statistical confirmations of this. The equation for computing an integrated volume is as follows:

$$V = a(Qp)(LT)/(A)$$

where

V = flood volume (in.),
Qp = peak discharge (ft^3/sec),
LT = basin lagtime (hr),
A = drainage area, (mi^2), and
a = conversion constant.

Values of a for the various dimensionless hydrographs are as follows:

Area	*a*
Georgia	0.00169
Nationwide urban	0.00159
West Tennessee	0.00218
South Carolina	
Blue Ridge	0.00166
Piedmont	0.00176
South of fall line	0.00202
Missouri	0.00161

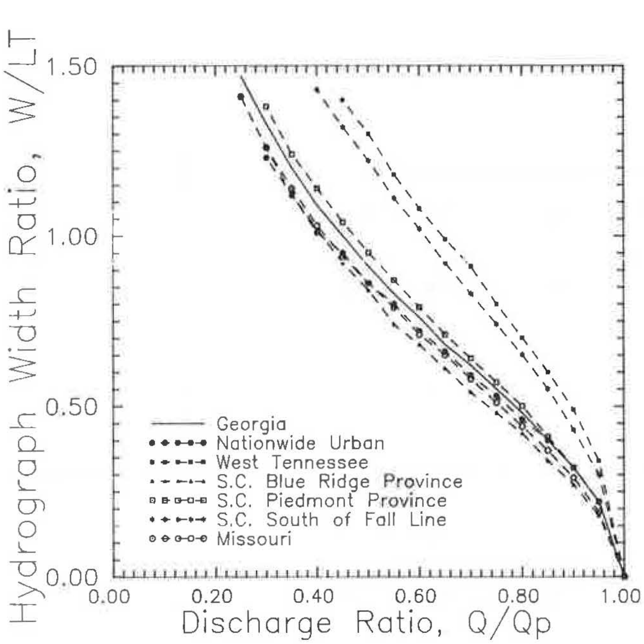

FIGURE 8 Hydrograph width relations.

In some of the state studies, the investigators developed regression equations to estimate flood volumes. The regression equations for Tennessee and South Carolina are shown in Table 4. The form of these equations is the same as those shown above, and the exponents are near 1; however, they will yield somewhat different values of runoff that will not agree with the integrated volume beneath the simulated hydrograph. The Ohio regression equation of urban volumes is somewhat different, in that it includes main channel slope and basin development factor in place of lagtime. This equation is also shown in Table 4.

In the Ohio rural study (Sherwood, unpublished data), a different approach was used for estimating runoff volumes. He computed volumes for selected time durations, such as 1 hour, 2 hours, 4 hours, etc. Maximum values of each of these were computed for each year of record, and a frequency analysis was made to determine recurrence intervals. Regression analysis was then used to relate the various recurrence interval volumes to basin characteristics.

ACCURACY OF SYNTHESIZED HYDROGRAPHS

Testing of the dimensionless hydrograph method can be done by comparing observed hydrographs to synthesized hydrographs. As explained in an earlier part of this report, the dimensionless hydrograph method cannot be expected to reproduce actual hydrographs because it does not directly account for rainfall, rainfall excess, and rainfall distribution. The method yields only an average or typical hydrograph for a specified peak discharge. Consequently, the accuracy tests are really an indication of average departure of actual floods from the average hydrograph shape. The tests were made by comparing the observed widths, in hours, to the synthesized widths, in hours, at two selected ratios of Q/Qp (0.50 and

TABLE 4 REGRESSION EQUATIONS FOR FLOOD VOLUMES

State/Area/Region	Regression Equation	Standard Error, in percent
TENNESSEE EAST	$V=.00234\,A^{-.953}\,Qp^{.947}\,LT^{.956}$	22
CENTRAL	$V=.0013\,A^{-1.06}\,Qp^{1.05}\,LT^{1.03}$	32
WEST	$V=.0035\,A^{-.881}\,Qp^{.866}\,LT^{.968}$	24
SOUTH CAROLINA BLUE RIDGE	$V=.003780\,A^{-.911}\,Qp^{.888}\,LT^{.879}$	10
PIEDMONT	$V=.002418\,A^{-.798}\,Qp^{.880}\,LT^{.896}$	21
INNER COASTAL PLAIN	$V=.003854\,A^{-.926}\,Qp^{.990}\,LT^{.721}$	14
LOWER COASTAL PLAIN REGION 1	$V=.002652\,A^{-.953}\,Qp^{.978}\,LT^{.882}$	15
REGION 2	$V=.002872\,A^{-.953}\,Qp^{.978}\,LT^{.882}$	
OHIO, urban	$V=.0633\,A^{-.74}\,Qp^{.69}\,S^{-.54}\,(13\text{-}BDF)^{.30}$	52

TABLE 5 STANDARD ERRORS OF ESTIMATED HYDROGRAPH WIDTHS SIMULATED WITH THE DIMENSIONLESS HYDROGRAPH METHOD

	Calibration		Verification		Large Floods	
	Discharge Ratio, Q/Qp					
	0.50	0.75	0.50	0.75	0.50	0.75
State/Area/Region	Standard Error, in percent					
GEORGIA	32	36	39	44	52	57
NATIONWIDE URBAN	--	--	--	--	--	89
TENNESSEE						
EAST	a	a	35	35	56	70
CENTRAL	a	a	21	25	44	39
WEST	34	42	--	--	49	47
SOUTH CAROLINA	--	--	--	--	32	37
BLUE RIDGE	14	18	20	30	--	--
PIEDMONT	29	36	31	31	--	--
SOUTH OF FALL LINE	18	23	15	23	--	--
ALABAMA	a	a	24	24	32	34
OHIO (small rural)	a	a	31	35	--	--
OHIO (small urban)	b	b	--	--	--	--
ARKANSAS	a	a	--	--	41	39
MISSOURI	--	--	--	--	--	--

[a=used Georgia dimensionless hydrograph, no calibration standard errors computed; b=used Nationwide urban dimensionless hydrograph, no calibration errors computed; and --=not computed or not available]

0.75). In addition, the tests were made for three different sets of data. The first test was based on the data used to develop the basic dimensionless hydrograph and used measured basin lagtimes and observed peak discharges. The second test also used measured basin lagtimes and observed peak discharges, but was performed on data not used in the original development of the dimensionless hydrograph. The third, and final, test was designed to provide a measure of the accuracy of estimating hydrographs for large floods at ungauged sites. In this test, the largest flood of record was selected at each gauging station, and the recurrence interval of the peak discharge was computed from the observed peak flow records. With this recurrence interval a peak discharge was then estimated from the applicable regression equations for the area. Lagtime was estimated from the regression equations developed for this purpose, and the hydrograph was then synthesized from the dimensionless hydrograph. Synthesized hydrograph widths at discharge ratios of 0.50 and 0.75 were compared with the observed widths at the same discharge. This test provides an estimate of the combined error of using regression estimates for peak discharge and lagtime together with the dimensionless hydrograph. In addition, it is applied only to large floods, which is the primary purpose of the dimensionless hydrograph method. A summary of the error analyses is given in Table 5. It should be noted that some investigators did not perform all of the tests. Also, those investigators who used the Georgia dimensionless hydrograph did not do the first test but needed only to verify the method and apply it to large floods. The verification tests indicate standard errors of hydrograph widths of 15 to 44 percent. Standard errors for the large-flood tests were between 32 and 89 percent. Most of the verification standard errors are equal to or less than 35 percent, and most of the large-flood standard errors are equal to or less than 57 percent.

LIMITATIONS

The dimensionless hydrograph method was developed and tested for both urban and rural conditions and found to work equally well in both. The data used were mostly for basins having drainage areas between about 0.1 and 500 mi^2 for rural basins. For urban basins, the upper drainage area limit is about 50 mi^2. The method probably should not be used outside these limits. The Ohio studies were made only for small drainage areas, both urban and rural, having upper limits of drainage area of 4.1 mi^2 for urban and 6.5 mi^2 for rural basins.

The methods should not be used for regulated streams, streams with significant channel modifications, and streams where significant detention storage occurs. Also, the method should not be used if the intent is to reproduce an actual flood event, especially where complex rainfall distributions are observed.

SUMMARY AND CONCLUSIONS

In summary, the several studies that have been conducted using the dimensionless hydrograph method have shown that for most areas, including both rural and urban conditions, a single dimensionless hydrograph (Georgia) can be used to synthesize an average, or typical, hydrograph for a specified peak discharge. Dimensionless hydrographs for west Tennessee and the Coastal Plain of South Carolina are notable exceptions. A very important parameter is basin lagtime, which is difficult to estimate accurately. Regression equations relating lagtime to basin characteristics can be used for this purpose, but these relations are variable in the various study areas.

Hydrograph width relations were developed for most of the study areas. These relations can be used to estimate the elapsed time that a specified discharge will be exceeded for a specific flood event. Again, the elapsed time represents average conditions.

Flood volume regression equations were developed for some of the study areas and can be used to determine the average volume of flow corresponding to a specified peak discharge. Another method of doing this is to integrate the area beneath the flood hydrograph, or to apply an equation that yields essentially the same volume as the integration method. The integration method and the regression equations may show somewhat different results.

ACKNOWLEDGMENTS

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Dimensionless Unit Hydrograph for the Delmarva Peninsula

P.I. Welle and D.E. Woodward

The Soil Conservation Service uses a dimensionless unit hydrograph to develop storm hydrographs for hydrologic evaluation of small watersheds and for hydrologic design of conservation measures. An average dimensionless unit hydrograph has been used extensively nationwide with reasonable success. However, in flatlands such as the Atlantic coastal plains, stream gauge analysis indicates that another shaped dimensionless unit hydrograph that is significantly different from the average should be used. An average dimensionless unit hydrograph for coastal flatlands was developed by using the techniques in the U.S. Army Corps of Engineers HEC-1 computer program. An average C_p value for the Snyder unit hydrograph was determined from seven events on four streams. The flatland unit hydrograph was then used to generate peakflow frequency curves with reasonable success at the four stream gauge sites plus one additional site.

The Soil Conservation Service (SCS) uses a dimensionless unit hydrograph to develop storm hydrographs for hydrologic evaluation of small watersheds and hydrologic design of soil and water resource management practices. These practices include both agricultural and urban stormwater management.

An average dimensionless unit hydrograph has been used extensively by the SCS throughout the country with reasonable results. However, in certain unique areas such as the Delmarva Peninsula of the Atlantic coastal plain, the observed storm hydrographs from stream gauges indicate that the hydrograph shape in this area is significantly different from that of the average SCS unit hydrograph.

A dimensionless unit hydrograph that is representative of some of the flat topography has been developed and is currently being used by SCS personnel in the Delmarva Peninsula. This paper describes the technique used to develop the Delmarva unit hydrograph.

WATERSHED DESCRIPTION

As part of the Atlantic Coast Flatwoods major land resource area, the Delmarva Peninsula has local relief of less than 3 m (10 ft) with considerable available surface storage in swales and depressions. Although many soils require drainage before they can be used for crops, crops grown on some of the sandy soils need irrigation during droughts. The mean annual precipitation is 117 cm (46 in.), including 38 cm (15 in.) of snowfall (*1*).

The four watersheds studied are widely distributed geographically and have at least 20 years of continuous stream gauge records (Figure 1). These watersheds have drainage areas of approximately 12–155 km^2 (5–60 mi^2). The average land slopes of 2 to 5 percent or less are typical of the Delmarva Peninsula.

BACKGROUND

The standard SCS unit hydrograph was derived from natural unit hydrographs of watersheds varying widely in size and geographic location (*2*). However, most of these watersheds are in the Midwest where local relief may be 15–30 m (49–98 ft) with little or no surface storage. Since these physical characteristics are not typical of those in the Delmarva Peninsula, a unit hydrograph unique to the watershed characteristics of the study area was developed.

In the standard SCS unit hydrograph, shown in Figure 2, 37.5 percent of the volume is under the rising side. The peak rate of flow equation for this standard SCS hydrograph is

$$q_p = \frac{2.08QA}{T_p} \quad \left(\frac{484QA}{T_p}\right) \tag{1}$$

where

q_p = peak discharge in cubic meters per second (cubic feet per second);
Q = volume of runoff in centimeters (inches);
A = drainage area in square kilometers (square miles); and
T_p = time to peak in hours.

The constant, 2.08, is a shape and unit conversion factor. Later reference to this factor will be as a dimensionless unit hydrograph peak factor. This constant can be converted to the percent of volume under the rising side of the hydrograph by multiplying by 18.

The dimensionless form of a unit hydrograph, where the axes are q/q_p and T/T_p, is used in the SCS Computer Program for Project Formulation—Hydrology (TR-20) (*3*). The TR-20 computer program has the capability of developing a flood hydrograph given the rainfall histogram, watershed characteristics (T_c, drainage area, and curve number), and a dimen-

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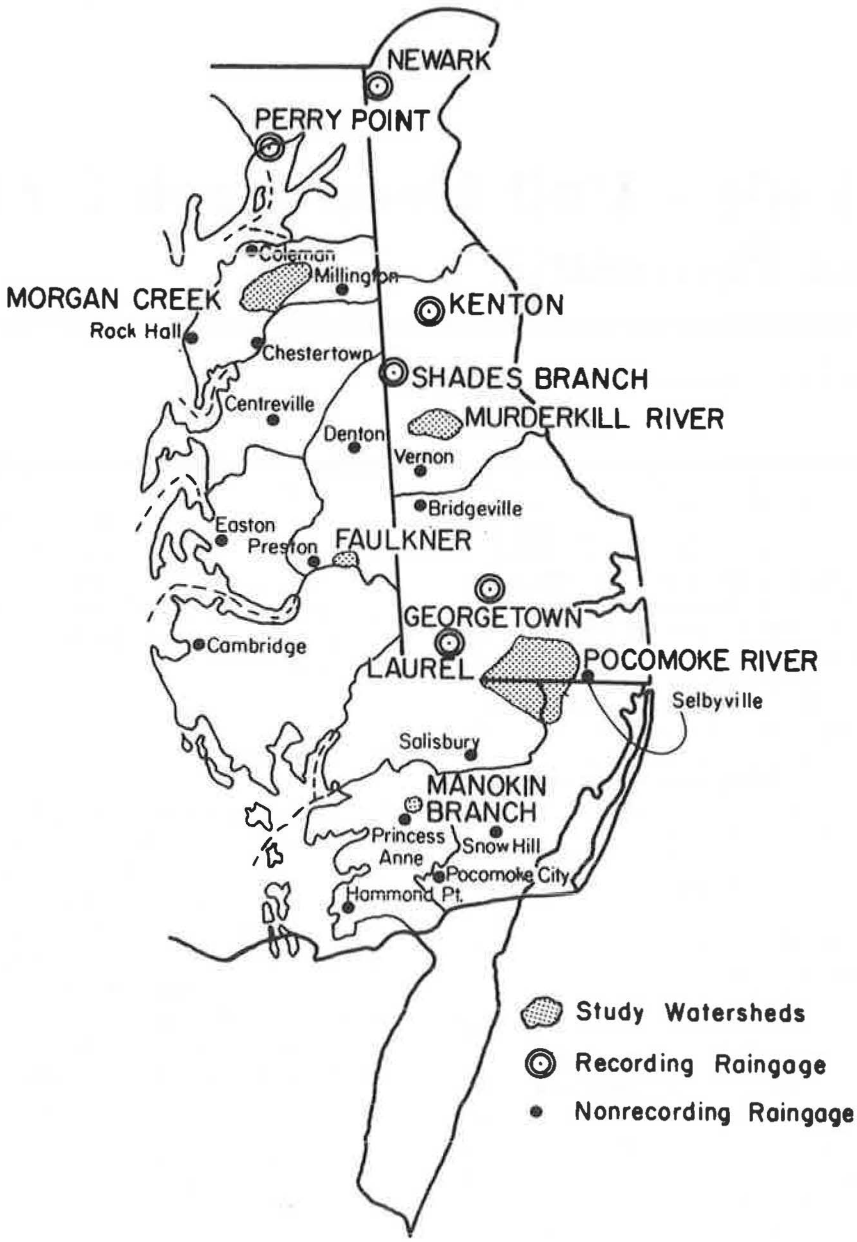


FIGURE 1 Locations of watersheds and climatological stations.

sionless unit hydrograph. The TR-20 computer program cannot be used to develop unit hydrographs.

BASIC DATA

Rainfall and runoff data were obtained for three storms on two agricultural watersheds and two storms on two other watersheds (Table 1). Locations of the watershed and climatological stations are shown in Figure 1. A total of 10 flood hydrographs were used to develop the dimensionless unit hydrograph. Two additional storms on the Murderkill River watershed were used during the verification portion of the study. The rainfall and runoff data used were compiled and published by the National Weather Service (NWS) and U.S. Geological Survey (USGS). The data were used in 1-hour intervals. The closest available recording precipitation gauges were used. Nonrecording precipitation gauges within a 32-km (20-mi) radius of the watershed were used to weight the total rainfall volume. With the exception of the September 1960 storm on the Pocomoke River, 3 cm (1.2 in.) or more of runoff occurred for each event.

ANALYSIS

The computer model selected for this study is the Flood Hydrograph Package (HEC-1) (*4*). Selection was based on the model's capability of developing a unit hydrograph given a rainfall histogram, a recorded flood hydrograph, and the watershed characteristics. The unit hydrograph is computed by the Clark method by using two unit hydrograph variables

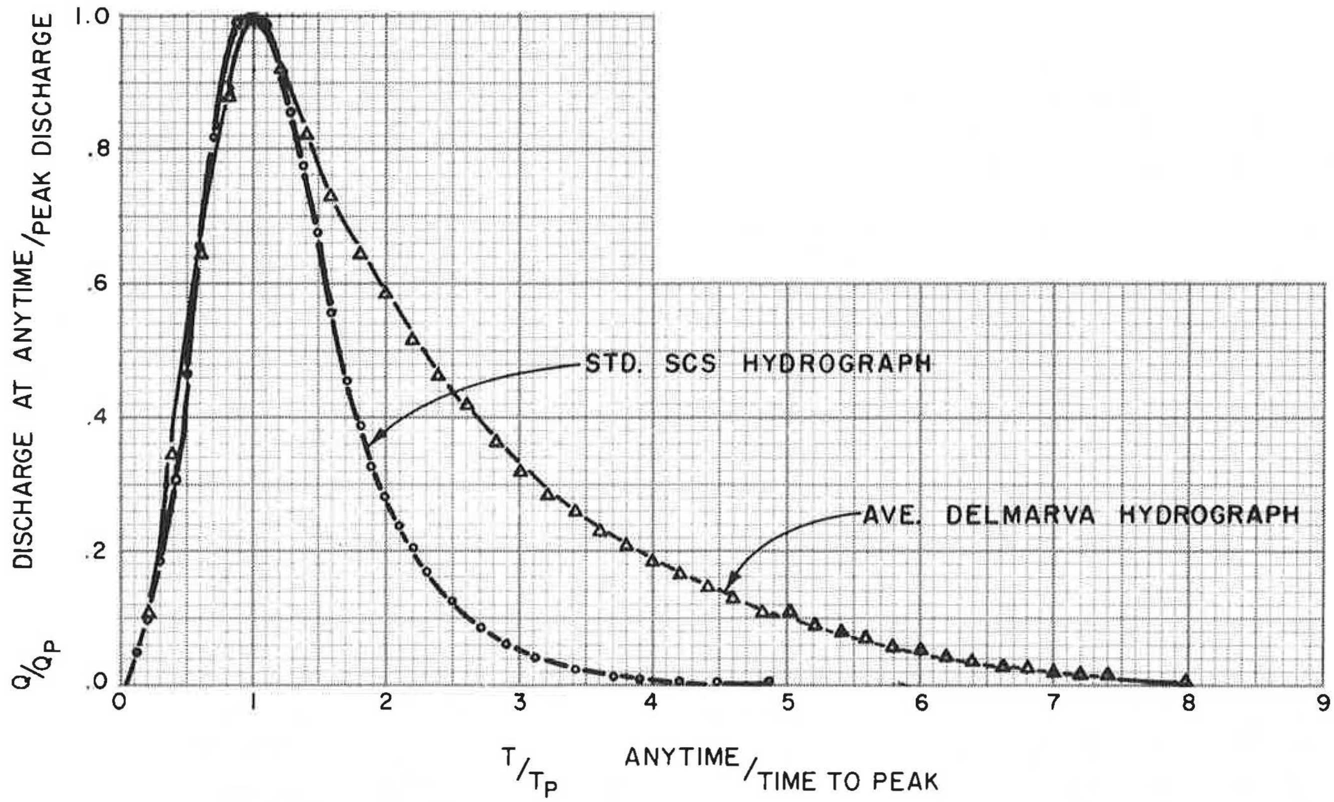


FIGURE 2 Dimensionless unit hydrographs.

TABLE 1 WATERSHED CHARACTERISTICS AND SELECTED FLOODS

Watershed	Drainage Area (km^2)	Land Slope (%)	Flood Runoff Data: Aug. 12–13, 1955 Peak (m^3/sec)	Aug. 12–13, 1955 Volume (cm)	Aug. 24–26, 1958 Peak (m^3/sec)	Aug. 24–26, 1958 Volume (cm)	Sept. 11–12, 1960 Peak (m^3/sec)	Sept. 11–12, 1960 Volume (cm)
Faulkner Branch at Federalsburg, Md.	18.4	2	12.2	4.85	11.9[a]	5.84	18.4	6.48
Manokin Branch near Princess Anne, Md.	12.4	2	6.54	4.88	—	—	5.18[a]	3.76
Morgan Creek near Kennedyville, Md.	32.9	5	17.6	3.10	23.3	3.43	43.6[a]	5.72
Pocomoke River near Williards, Md.	157.0	2	17.5	3.20	—	—	5.80	0.66

[a]Not used in developing average Delmarva dimensionless unit hydrograph.

and four loss-rate variables as calibration coefficients. Full optimization of all six variables was performed. In a few cases, the results were improved by specifying starting values for the optimization of these variables.

Originally, it was planned to use the procedure described in the HEC-1 Users Manual to individually fix each loss-rate variable and then reiterate the computations until all variables were selected. After finishing two of these iterations, however, it was recognized that only optimized loss-rate variables and no average unit hydrograph would be obtained. Therefore, HEC-1 was used to compute a unit hydrograph and Snyder's coefficient (C_p) for each storm (see Table 2).

The mean value of C_p was 0.40 with a standard deviation of 0.18. The seven unit hydrographs with C_p values within approximately one standard deviation of 0.40 were selected for averaging. These unit hydrographs could not be readily averaged because they were tabulated by using different intervals. The seven unit hydrographs were made dimensionless and averaged to obtain a unique dimensionless unit hydrograph with a dimensionless unit hydrograph peak factor of 1.22 (284). This average dimensionless unit hydrograph can be used as input in TR-20. SCS has developed a relationship between T_p and time of concentration (T_c) for the unit hydrograph.

TABLE 2 HEC-1 OPTIMIZATION RESULTS

Location of Stream Gauge	C_p by Storm Year: 1955	1958	1960
Morgan Creek	0.45	0.41	0.78[a]
Faulkner Branch	0.34	0.23[a]	0.44
Manokin Branch	0.52	—	0.09[a]
Pocomoke River	0.33	—	0.42

[a] Not used in developing average dimensionless unit hydrograph. Mean C_p (n = 10) is 0.40; standard deviation, 0.17. Mean C_p (n = 7) is 0.42; standard deviation, 0.06.

$$T_p = \frac{D}{2} + 0.6\ T_c \qquad (2)$$

where

T_p = time to peak of unit hydrograph in hours,
D = duration of rainfall excess in hours, and
T_c = time of concentration in hours.

This relationship was developed from analysis of hydrographs from small watersheds.

The TR-20 computer program generates the flood hydrograph by convolution of the incremental unit hydrographs. Time of concentration is a user-defined variable in the TR-20 computer program. This procedure of flood hydrograph development provided reasonable results. The simulated and actual storm hydrographs are shown in Figures 3–6.

VERIFICATION

Although the TR-20 computer program is not intended to reproduce an historic event, it was used to determine if the average Delmarva unit hydrograph gave better results than the standard SCS unit hydrograph. The hydrographs are shown in Figures 3–6 and the peak discharges are shown in Table 3. The peak discharge obtained using the average Delmarva unit hydrograph more nearly approximates the observed peak discharge in every case except one.

Using the actual computed unit hydrograph for each storm improved the results for only two of the seven storms that were used to develop the average Delmarva unit hydrograph.

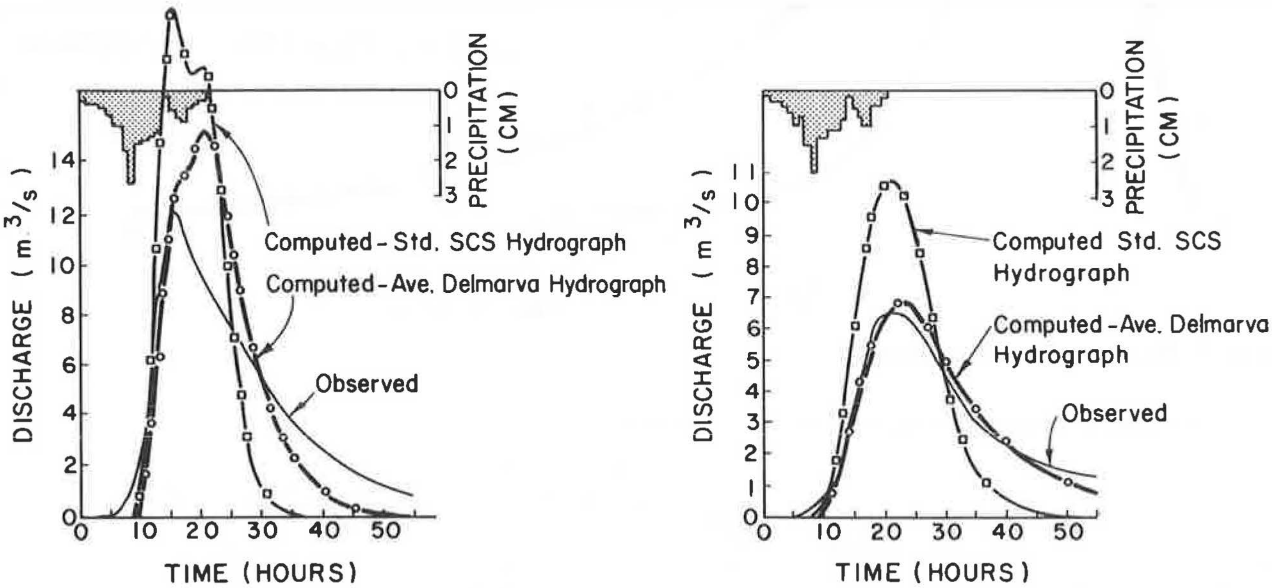


FIGURE 3 Actual storm hydrographs: *Left*, 1955 storm, Faulkner Branch; *right*, 1955 storm, Manokin Branch.

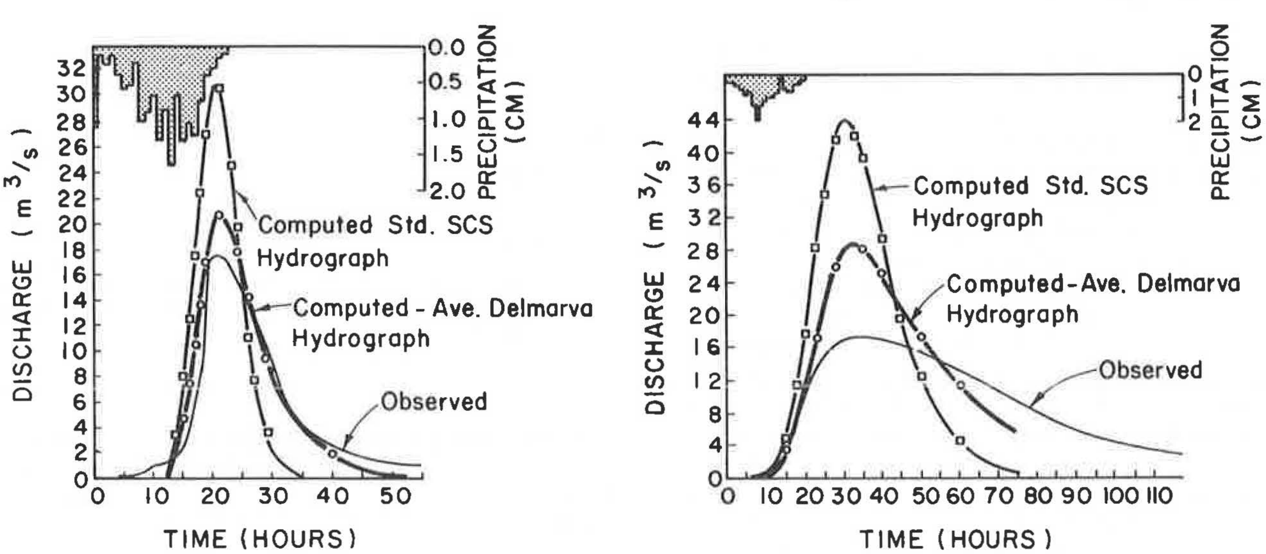


FIGURE 4 Actual storm hydrographs: *Left*, 1955 storm, Morgan Creek; *right*, 1955 storm, Pocomoke River.

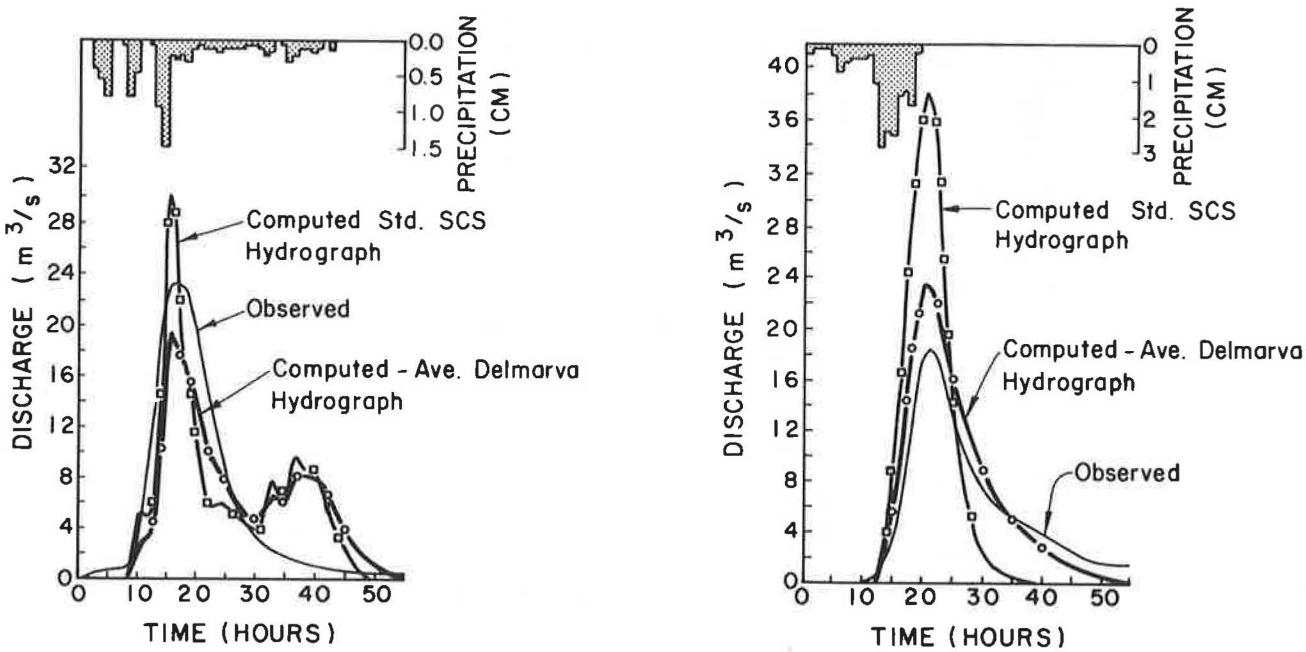


FIGURE 5 **Actual storm hydrographs: *Left*, 1958 storm, Morgan Creek; *right*, 1960 storm, Faulkner Branch.**

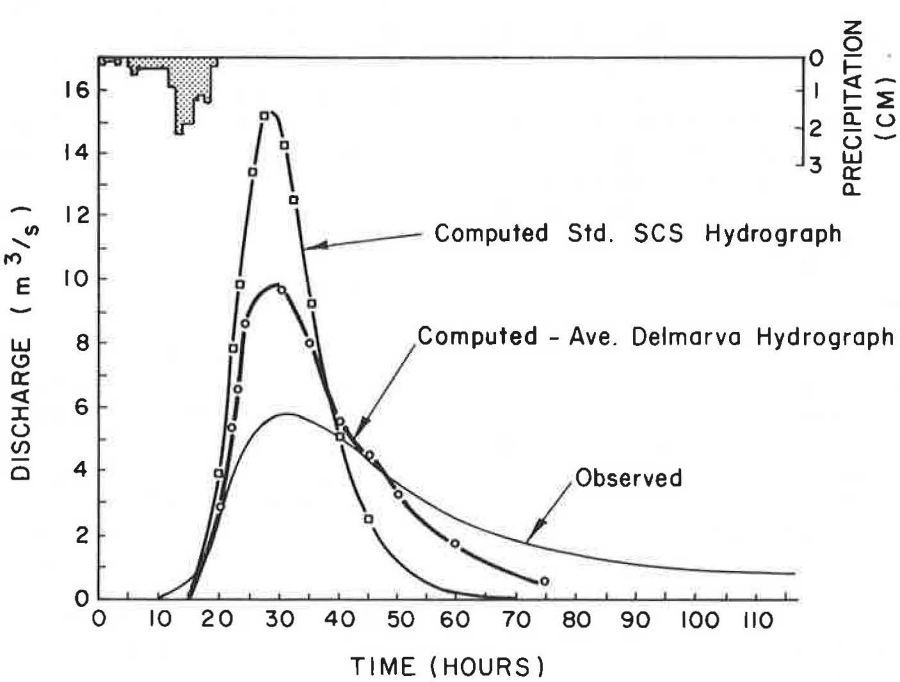


FIGURE 6 **Actual storm hydrographs: 1960 storm, Pocomoke River.**

TABLE 3 PEAK DISCHARGES FOR HISTORIC EVENTS

	Storm Peak Discharge (m^3/sec)			
Watershed	Observed	Actual Hydrograph[a]	Average Delmarva Hydrograph[a]	Standard SCS Hydrograph[a]
Faulkner Branch				
1955	12.2	14.2	15.3	20.1
1958[b]	11.9	—	18.7	29.4
1960	18.4	24.1	23.5	38.5
Manokin Branch				
1955	6.54	7.93	6.80	10.8
1960[b]	5.18	—	23.80	27.5
Morgan Creek				
1955	17.6	21.8	21.0	31.1
1958	23.3	22.1	19.5	30.6
1960[b]	43.6	—	28.0	45.0
Pocomoke River				
1955	17.5	25.2	28.7	43.6
1960	5.80	9.91	9.91	15.3
Murderkill River				
1960[b]	22.8	—	34.5	58.3
1967[b]	58.9	—	75.3	129.0

[a] TR-20 results.
[b] Not used in developing average Delmarva dimensionless unit hydrograph.

The maximum variation of peak discharges using the average Delmarva unit hydrograph and the actual storm unit hydrograph was 14 percent. This value indicates that the average Delmarva hydrograph provides results as reasonable as those from the actual hydrograph.

The TR-20 computer program was used to compute a peak flow frequency curve for each station studied. The TR-20 uses standard hydrograph generation techniques and 24-hour precipitation values for selected return periods (i.e., 2-, 10-, 25-, 50-, 100-year) to determine peak flows at selected return periods. As shown in Figures 7 and 8, the peak flow frequency curves computed by the average Delmarva hydrograph are much closer to the peak flow frequency curves published by Simmons and Carpenter (5) than are the curves computed by the standard SCS hydrograph.

These comparisons indicate that in most cases the average Delmarva hydrograph still produces peak discharges that are higher than those observed. These values are to be expected since the Type II rainfall distribution was used. Type II is a maximized distribution based on design considerations rather than on meteorological factors (*6*). To provide unbiased results, the TR-20 models were not calibrated against either the actual storm hydrographs or the USGS peak flow frequency curves. Thus, the estimated times of concentration and runoff curve numbers used may not be representative, which may account for part of the differences. In addition, the hydraulic rating curves developed by SCS for the Pocomoke River appear to be significantly different from those of USGS. The reasons for the difference were never determined. However, it appears that different downstream conditions were assumed.

Data from two storms on the Murderkill River Watershed, a watershed not used for development of the average Delmarva hydrograph, provided an independent validation of results. Figure 9 shows that the computed peak discharges are within 20 percent of those observed. The computed hydrograph shape for the single burst storm on September 11–12, 1960 matches the observed hydrograph shape very closely. The lack of similarity of hydrograph shapes for the August 3–4, 1967 storm is probably due to the inapplicability of the TR-20 computer program to multiple burst storms and the variation between actual rainfall on the watershed and rainfall recorded at the climatological stations. The peak flow frequency curves for the Murderkill River (Figure 10) also indicate the superior performance of the average Delmarva hydrograph.

CONCLUSIONS

Use of the Delmarva dimensionless unit hydrograph will allow more accurate hydrologic evaluation of small watersheds and, therefore, more appropriate design of conservation practices and structures, including stormwater management practices on the Delmarva Peninsula. However, other factors such as rainfall distribution, runoff potential (as reflected in the runoff curve number), and watershed characteristics, such as the time of concentration, also must be accurately estimated to obtain reasonable results.

This same approach is being used for development of dimensionless unit hydrographs for the entire Atlantic coastal plain. The study was extended to the coastal plain region of New Jersey. However, the variability in the available data precluded the development of a dimensionless unit hydrograph for New Jersey.

McCuen and Bondelid (*7*) analyzed the same flood events for the same stream gauges on the Delmarva Peninsula by another technique. They assumed that the proportion under

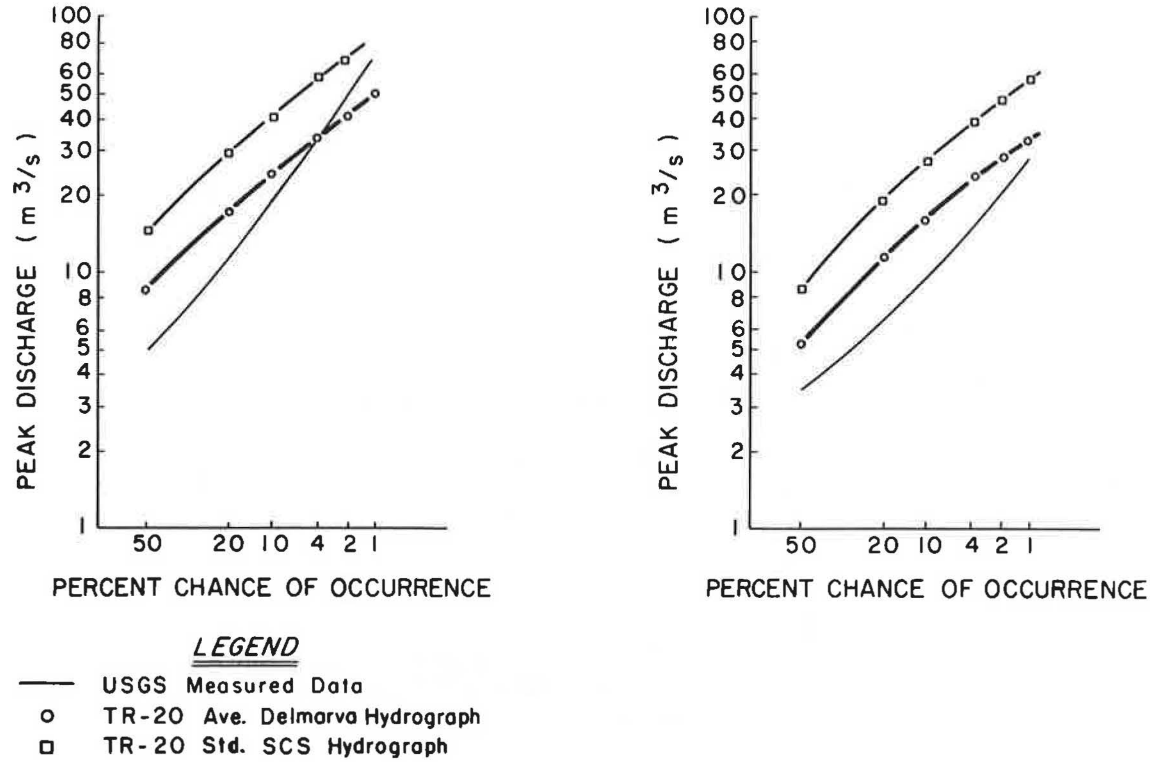


FIGURE 7 **Peak flow frequency curves:** ***Left*****, Faulkner Branch;** ***right*****, Manokin Branch.**

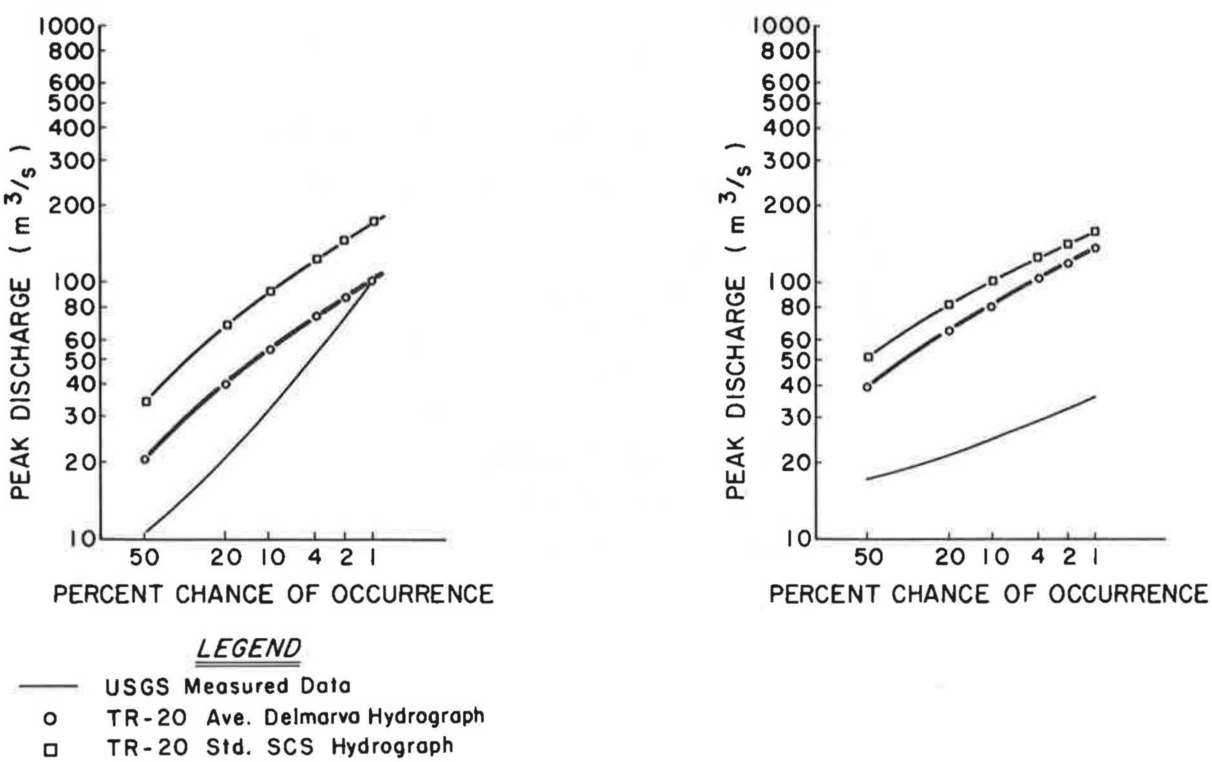
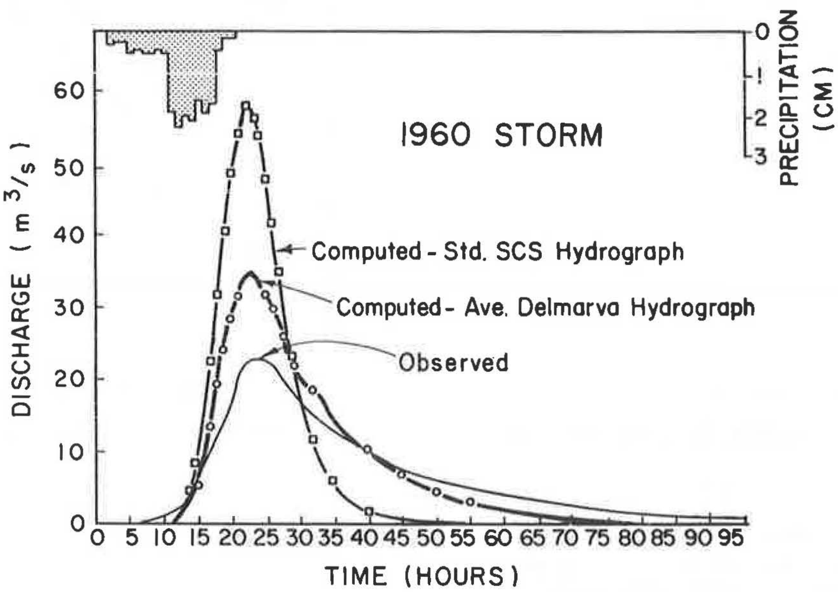


FIGURE 8 **Peak flow frequency curves:** ***Left*****, Morgan Creek;** ***right*****, Pokomoke River.**



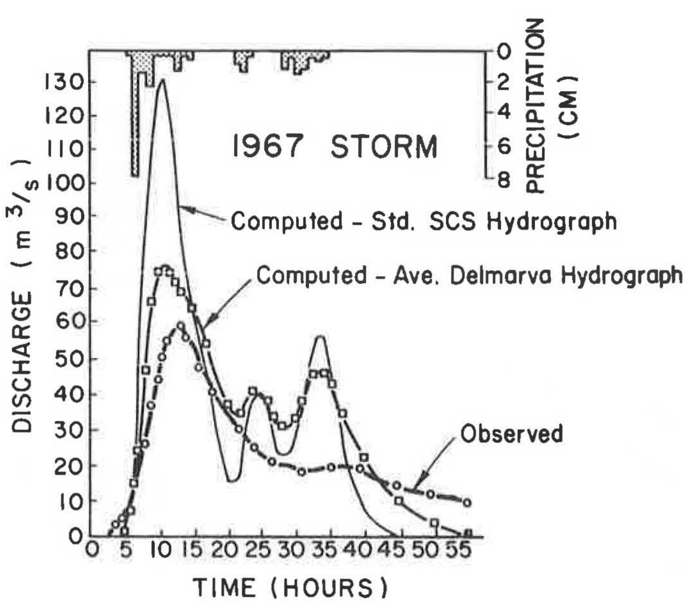


FIGURE 9 Actual storm hydrographs: Murderkill River.

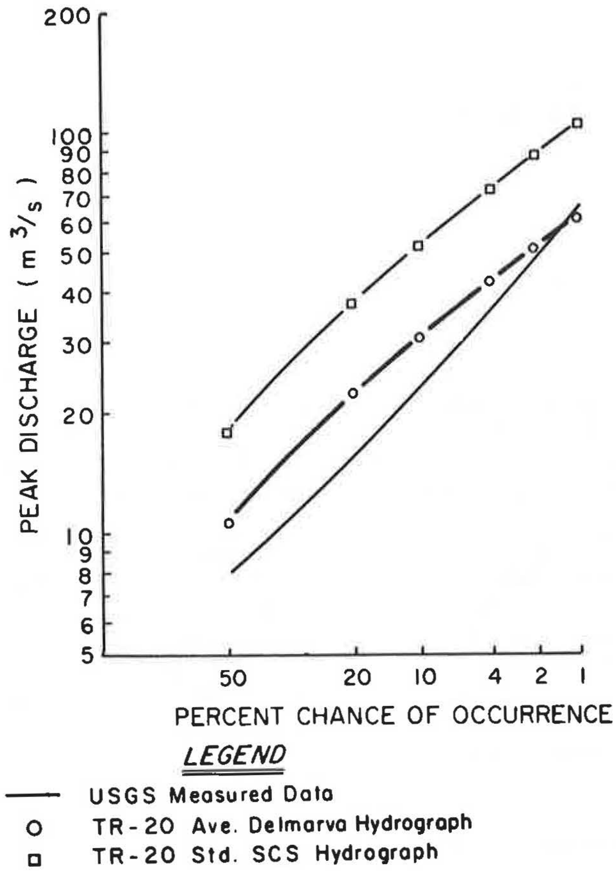


FIGURE 10 Peak flow frequency curves: Murderkill River.

the rising limbs of the time area curve and the dimensionless unit hydrograph are equal. Their conclusions are consistent with the conclusions of this paper: that a standard factor of 2.08 was too large for coastal watersheds.

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Profile of Highway Rest Area Usage and Users

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A profile of rest area usage patterns and of rest area user attributes is presented based on interviews at 13 rest areas in five states, on a nationwide telephone survey, and on unpublished data furnished by a number of states. These data show that rest area usage, as a function of mainline traffic, varies widely and averages 10.3 percent. Trucks and recreational vehicles are more likely to enter rest areas than are passenger automobiles. The demographic characteristics of the rest area user population are closely matched to those of the long trip driving population with a slight overrepresentation of older drivers. Toilet use and resting-stretching together account for more than 80 percent of all the stated reasons for stopping at rest areas. The average time in a rest area is somewhat longer than 10 minutes, with a pronounced increase in length of stay at lunchtime. Recreational vehicles and trucks generally stay for longer periods. Rest areas, and public financing thereof, have the overwhelming approval of the user population. However, there are some perceived security problems associated with rest area use at night.

The last reported nationwide study of rest area usage was made in 1971 and 1972 under the auspices of the FHWA (*1*). In the intervening years there have been considerable changes in a number of the factors that, reasonably, could be considered to have a major impact on usage patterns. These factors include the following:

- Population demographics, especially age distribution and family size. Between 1970 and 1986 the percentage of the population 65 years or older increased from 11.2 to 14.0, whereas the percentage 17 years or younger decreased from 32.7 to 25.0. In the same period, the average household size decreased from 3.14 to 2.67 members (*2*).
- Automobile ownership and use. Between 1970 and 1987 the total number of privately owned passenger automobiles increased by more than 50 percent to a total of almost 138 million (*3*). At the same time total vehicle miles of travel on the rural interstate system increased by 116 percent. The increase for other rural arterial highways was 31 percent (*4,5*).
- Automobile design and characteristics. There have been considerable changes in automobile design and characteristics. Of special interest, as directly affecting the need for a vehicle stop, is average fuel consumption. For passenger cars, fuel consumption increased from 13.5 mi/gal (mpg) in 1970 to 18.3 mpg in 1986 (*3*). Although this increase was partially offset by reduced fuel tank sizes, a corollary of vehicle downsizing, the net result was still a considerable increase in total miles per tankful. This trend can be expected to accelerate since newer models show considerably higher fuel economy. From 1978 to 1986 the sales weighted fuel economy of passenger cars increased from 19.7 mpg to 27.9 mpg (*6*). Also worth mentioning is that the market penetration of factory-installed automobile airconditioning, a prime determinant of the comfort of long-distance automobile travel, increased from 60.1 percent in 1970 to 85.2 percent in 1987 (*4,5*).

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In view of these considerations, an update of rest area usage patterns appears to be indicated. This update is the subject of the present paper. The material presented is mainly based on data collected by KLD Associates as part of NCHRP Study 2-15 (*7*). Data were collected at 13 rest areas in five states and supplemented by a nationwide telephone survey of 500 randomly dialed respondents as well as by data collected by individual states.

REST AREA USAGE

The 1971–1972 nationwide study of rest area usage (*1*) found that the percentage of mainline traffic entering ranged from 1.0 to 27.4 percent. Fifty of the 54 rest areas checked ranged from 3.0 to 14.9 percent with a weighted average of 7.6 percent. Eighty percent of these were passenger cars.

Traffic counts at nine of the rest areas in which field studies were performed showed a range of entering traffic between 5.5 and 17.7 percent, with a weighted average of 10.3 percent.

	Percentage		
	Entering	*Of Total Entering*	*Of Mainline Total*
Cars	9.4	76.3	83.5
Recreational vehicles	16.7	10.2	6.3
Trucks	13.8	12.7	9.5
Other	11.8	0.9	7.8

A number of states have published rest area usage studies or have made the results of such studies available. These results are as shown in Table 1. A smaller number of studies have reported on traffic composition. The few that do, e.g., Michigan, invariably report that the rest area population shows a considerably higher proportion of commercial and recreational vehicles (RVs) than does the mainline traffic stream.

The proportion of passing traffic that will enter a highway rest area is a function of traffic stream characteristics, such as composition and distribution by trip purpose and by trip length; general area characteristics, especially the frequency, distance to, and accessibility of alternate stopping opportunities; and temporal factors such as season, day of the week, and hour of the day. However, no general model exists by which these factors can be combined to predict rest area usage. As a standard, Reierson and Adams (*8*) recommend basing

TABLE 1 STATE STUDIES OF REST AREA USAGE

State	Year	No. in Sample	Percent Entering	Comments
California	1981	16	2.1–21	
Kansas	1983	29	5.6–21	
Michigan	1985	7	4.6–31	Weekdays
Michigan	1985	7	7.7–32	Weekends
Montana	?	16	5–50	Federal-aid interstate (FAI) routes
Montana	?	16	1–25	Non-FAI routes
Nebraska	1987	8	5.1–15	
New York	1980	14	4.9–29	I87 only
Utah	1977–1978	2	13.8–17	Welcome centers
Virginia	1987	11	8.9–3.5	
Washington	1985	28	0.8–12	FAI routes
Washington	1985	10	2–11	Non-FAI routes

expected usage on the percentage estimated from usage counts of existing rest areas. The traffic data assembled for the present study indicate that no simple algorithm will explain usage differences between rest areas.

FHWA Technical Advisory T5140.8 (see reference *8*) gives use percentage figures as a function of route characteristics and rest area spacing. The formulae are of the type $P = C \times DSL$, where P is the proportion of mainline traffic entering the rest area; DSL is the actual distance between rest areas in miles; and C is a constant depending on route characteristics (interstate—0.0024; primary, recreational—0.0016; primary, rural—0.0011). These formulations do not include traffic stream or area characteristics except insofar as these are reflected in the three highway types for which coefficients are defined. For a 50-mi spacing, the recommended P value for the design of an interstate rest area is thus 12 percent, a figure that appears to be in line with the values shown in Table 1. This procedure, however, does not account for the many factors, most of whose influence has, so far, not been quantified, which leads a significant proportion of rest areas to show usage percentages in excess of 20 percent. Although available data are somewhat limited, there is every indication that rest area usage, in many cases, is higher than would be predicted using the FHWA formulation.

The same FHWA document also recommends that parking be provided on the assumption that 25 percent of the entering traffic will be trucks or RVs. According to the latest data (*5*) trucks and buses constitute over 36 percent of total rural interstate vehicle miles of travel (VMT). The assumed entering truck traffic volume thus appears to be too low. This conclusion is supported by Michigan data quoted earlier and by visual observations of rest areas, which consistently indicated, especially during certain hours of the day, that truck and RV parking facilities approached or exceeded capacity much more often than did automobile parking areas.

Several approaches are possible to use these data and relationships to estimate total rest area usage.

1. The expected number of stops for each average daily traffic (ADT) class has been computed by using ADT data by highway classification described elsewhere (*5*); average rest area spacing from a survey of 46 states (*7*); and the FHWA formulae for percentage entering. The overall estimate for yearly rest area use for the United States as a whole is thus as follows: Interstate highways, 402×10^6; and other primary highways, 208×10^6 (total, 610×10^6).

2. Data on total annual VMT on long trips (i.e., >100 mi) from Nationwide Personal Transportation Study (NPTS) data (*9*) and on average distance between stops (138 mi) and preference for rest area stops (59.8 percent) from a telephone survey (*7*) showed that the expected annual total number of rest area stops can be computed as 648 million.

A rough check on these orders of magnitude can be obtained by using data from one state. In 1985, researchers in Washington recorded a total 8,322,602 vehicles entering all of its interstate rest areas. According to U.S. DOT (*5*), Washington drivers, in 1985, accumulated a total VMT, on rural interstate highways, of $2,625 \times 10^6$ miles or 1.70 percent of the United States total. If Washington is considered representative of the United States, then extrapolating from the state total and adjusting for differences in average interstate rest area spacing (United States, 44.4 mi; Washington, 35 mi) would yield a national total of 386 million vehicles using interstate rest areas.

There is, thus, a good basis to support an estimate of over 600 million vehicles entering rest areas each year in the United States.

DEMOGRAPHIC ATTRIBUTES OF REST AREA USERS

User demographics, discussed in this section, are based on visual observation of 1,630 rest area users. Of these, 817 were interviewed to obtain additional information. Vehicle occupancy data are based on the visual observation of approximately 10,000 vehicles entering the rest areas during the periods of data collection. The percentage of out-of-state vehicles ranged from 16.3 to 79.0 and averaged 32.8.

Vehicle Occupancy

Occupancy data for all vehicles entering rest areas are summarized in Table 2. This table shows the range of both vehicle occupancy and percent single occupancy for the 13 rest areas studied.

Two percent of all vehicles and 2.3 percent of all passenger cars contained persons with apparent ambulatory handicaps, whereas 5 percent of all passenger cars contained pets. These percentages varied widely between individual rest areas with maximum values of 4.2 and 8.9 percent, respectively.

TABLE 2 VEHICLE OCCUPANCY

	Avg Vehicle Occupancy (%)			Single Occupancy (%)		
Vehicle Type	High	Low	Mean	High	Low	Mean
Passenger car	2.5	1.7	2.3	53.2	12.5	26.6
RV	9.0	2.0	2.8	26.7	0	13.2
Truck	1.5	1.0	1.3	100.0	64.3	77.9
Other	4.4	1.4	2.2	68.8	0	45.5
All	2.4	1.6	2.2	58.9	12.5	32.8

TABLE 3 DISTRIBUTION OF REST AREA USERS BY AGE AND SEX

Age Group	Male	Female	Total
<20	0.2	0.4	0.2
20–29	11.1	15.5	12.4
30–39	21.2	23.5	21.8
40–49	34.2	31.4	33.4
50–59	16.9	15.1	16.4
60–69	13.5	12.3	13.1
>70	3.0	1.8	2.6
<65	91.2	94.2	92.1
>65	8.8	5.8	7.9

Age and Sex

Data on the age and sex of rest area users are shown in Table 3. The parameters of the distribution by age are shown below:

	Male	*Female*	*All*
Mean	43.7	41.5	43.0
Median	43.5	40.0	40.0
Percent >64	8.8	5.8	7.9

The ratio of male to female rest area users was almost exactly 7:3. NPTS data (*9*) show that male drivers account for 74 percent of all trips in excess of 75 mi.

Of all cars entering the rest areas, 19.2 percent of all vehicles and 21.5 percent of all passenger cars contained children with an apparent age of 12 years or less. The average number of children in vehicles containing any children was 1.8. NPTS data show that children are present on 21.6 percent of all miles driven on personal trips in excess of 100 miles.

The general agreement of the rest area user population with the long trip driving population is also shown by a comparison of the cumulative distribution by age of rest area users, of licensed drivers, and of the long trip driving population. Some parameters of these distributions are given below:

	Mean	*Percent >64*
Rest area users	43.0	7.9
Licensed drivers (1985)	43.2	11.9
NPTS data	42.0	5.8

Trip Characteristics

The distribution of trip lengths (in miles) on which the interviewed travelers were engaged had the following parameters: mean, 332; standard deviation, 329; standard error, 11.5; median, 260; mode, 280; minimum, 9; and maximum, 2,500.

The number of trips of over 100 mi taken by respondents ranged from one per year to one per day. The median response was all, 10; cars, 6; RVs, 5; and trucks, 250.

The distribution of trip purpose for trips with known purposes is business, 35 percent; pleasure, 54 percent; and other, 11 percent.

For the 10 rest areas at which this information could be collected from most of the respondents, the proportion of business trips showed considerable spread being highest, as expected, near major urban aggregations.

USE OF REST AREA FACILITIES

Observation of rest area users showed that only seven of the possible uses of services and facilities accounted for 5 percent or more of the total, as follows:

Use	*Percent*
Toilet	85.1
Rest and stretch	50.5
Water fountain	13.6
Eat	8.0
Telephone	7.2
Check or repair car	6.5
Consult map	5.0

Differences in facility use on the basis of sex, age, vehicle types, presence of children, or trip purpose were only significant insofar as telephone use was concerned. This difference could be traced to the high rate (almost 25 percent) of telephone use by business travelers who were mostly male, relatively young, and unaccompanied by children. As the above percentages show, most rest area users take advantage of more than one facility or service during their stop. Insofar as the principal reason for stopping was concerned, two uses, toilet use and resting-stretching, accounted for over 80 percent of all stops. Only three others were cited by more than 2 percent of all rest area users. The exact percentages for these five uses were

Use	*Percent*
Toilet	49.3
Rest and stretch	32.3
Telephone	4.7
Water fountain	3.2
Eat	2.3

Detailed, disaggregated analyses of these data showed the following:

- There appears to be no major effect of time since last stop on rank ordering or on usage frequencies. The frequency with which telephone use is mentioned appears to be inversely correlated with time since last stop probably because business travelers tend to stop with shorter intervals.

• There is no significant difference in the distribution of primary stopping reasons between the sexes except for telephone use.

• Analyses by age group (10-year intervals) and by the over- and under-65 distribution revealed no significant differences except for higher telephone use by younger travelers.

• The presence of children in a vehicle leads to significantly higher percentages of food-related primary stopping reasons but to significantly lower telephone usage.

• Business travelers, as previously indicated, listed telephone use as the primary reason for stopping to a significantly greater degree than did travelers for other purposes. Business travelers also cited toilet use as a significantly less important reason for stopping. This may be because of the shorter interval between stops of this type of traveler.

• Insofar as vehicle class is concerned, truck occupants showed significantly higher percentages for telephone use and significantly lower percentages for toilet use and for the food- and drink-related items.

In interpreting data on the primary reason for stopping and on the other uses of rest area facilities, a number of points must be kept in mind:

1. Data collection, for the most part, was accomplished during daylight hours and under generally good weather conditions. Data collected on the few days with rain and cool weather showed a sharp decrease in the percentage of respondents citing resting and stretching as the primary reason for stopping. However, it should be noted that most travelers will take an opportunity to rest even if stopping for other reasons.

2. No data collection was done under such extreme climatic conditions that weather (extreme heat or heavy precipitation), roadway surface, or visibility conditions would be an impetus for stopping.

3. Data on food and drink bought at rest areas are constrained by the fact that vending machines, the only legally permissible means of dispensing food and drink in Interstate highway rest areas, were available at only 6 of the 13 areas in which data were collected.

TIME IN REST AREA

Data on time in rest area were collected by a check-in–check-out, license plate-matching procedure. These data were also obtained, by direct questionnaires, as part of a parallel, random-dialing, nationwide telephone survey.

The parameters of the distribution of time in rest areas for the two surveys are shown in Table 4. The cumulative distribution for the rest area data is shown in Figure 1.

The times given by the respondents to the telephone survey are significantly higher than those obtained from actual measurements at rest areas. It is probable that the telephone survey data are less reliable since:

• They involve the memory of the respondents of an event that may be as much as 1 year in the past.

TABLE 4 DISTRIBUTION OF TIME IN REST AREAS

Parameter	Rest Area Interviews	Telephone Survey
No. of rest areas	9	—
No. of data points	2,885	447
Mean (min)	11.4	19.2
Standard deviation (min)	12.87	26.7
Standard error (min)	.24	1.27
Median (min)	8	15
Mode (min)	5	15
Minimum	0 hr 01 min	0 hr 02 min
Maximum	3 hr 31 min	6 hr 0 min
Time in rest area (%)		
> 15 min	19.0	31.8
> 30 min	6.8	8.1
> 60 min	0.9	2.0

• There was a definite tendency to round up to the nearest 5- or 10-minute interval. A total of 94 percent of all replies were even multiples of 5 minutes.

• There is a possible tendency to report the last "substantive visit" to a rest area and suppress quick drive-through stops.

The pattern of extended stays in rest areas is detailed in Table 5. Disaggregate analyses by a number of pertinent variables showed the following:

• The mean time, by rest area, ranged from 9.5 to 14.1 minutes, and the median time ranged from 6 to 9 minutes.

• Analysis by vehicle class shows that RVs stay almost 75 percent longer in rest areas than other vehicle types (19.5 minutes vs. 11.0 minutes) and also have a two- to three-times-higher probability of an extended stay.

• The time that a vehicle enters the rest area has a significant effect on the length of stay. There is a pronounced lunchtime peak; almost one-third of all vehicles entering between noon and 1:00 p.m. stay more than 15 minutes.

• There is no difference between weekday and weekend travelers.

• There are significant differences between in-state and out-of-state registered vehicles, with out-of-state vehicles staying longer.

Data from studies of seven rest areas and four welcome centers in Virginia indicate the average length of stay to be as follows:

	Length of Stay (min)	
Vehicle Type	*Rest Area*	*Welcome Center*
Automobile	9	10.5
Tractor-trailer	16	13
Bus and RV	18	18

ATTITUDES AND OPINIONS

Both surveys included questions concerning overall quality ratings of specific rest areas and of rest areas in general. A number of states, as part of rest area surveys, have, in the past, elicited such opinions from motorists. These state surveys generally resulted in favorable ratings, with complaints

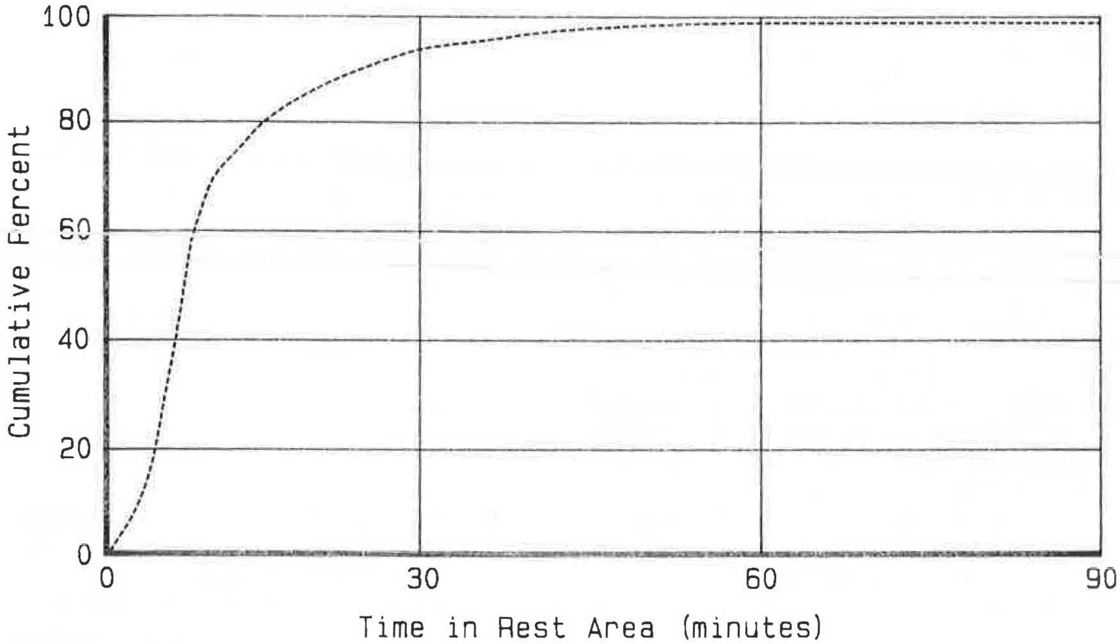

FIGURE 1 Cumulative distribution of time in rest area.

TABLE 5 EXTENDED STAYS IN REST AREAS

Parameter	Percent of Vehicles Exceeding Stated Time (min) 15	30	60
Entering hour			
Before 8 a.m.	11.0	3.0	1.0
9 a.m.	16.6	3.7	0.9
10 a.m.	12.4	3.5	0.6
11 a.m.	19.9	6.1	0.7
12 noon	30.2	14.7	2.3
1 p.m.	20.8	8.3	1.2
2 p.m.	21.3	6.3	0.5
3 p.m.	13.5	5.8	—
4 p.m.	18.5	5.6	0.8
5 p.m.	14.4	4.5	—
After 6 p.m.	9.9	2.0	—
Vehicle class			
Car	17.5	6.3	0.8
RV	45.3	21.1	4.2
Truck	25.0	6.7	0.4
Other	21.4	—	—
Day			
Sat., Sun.	17.6	6.3	0.8
Other	19.6	7.0	0.9
Registration			
In state	16.7	5.7	0.8
Out of state	29.2	10.7	0.9

usually limited to specific perceived defects in maintenance or the absence of specific facilities (e.g., vending machines).

Comfort and Safety

The present study also elicited generally favorable comments about comfort and safety. Because of the various settings of the two surveys, the format of the information obtained was somewhat different. The interviews included a specific question concerning apparent security and safety as well as requests for respondents' opinions concerning both the specific rest area and rest areas in general. Since 99 percent of all respondents indicated that they felt safe and secure during the day, this part of the question was not analyzed further.

However, more than one-third of all interviewees expressed reservations about stopping at night. The percentage that definitely feel safe at night ranged from 42 to 62 among the five states. In three rest areas, one each in Michigan, New York, and Virginia, less than half of the respondents felt safe. Particularly low percentages were recorded, as could be expected, by older travelers and by women, whereas high percentages were registered by truck drivers and business travelers.

Further analysis relating vehicle occupancy to perceived insecurity showed the following percentages (eliminating no opinion responses) of respondents who felt unsafe or insecure.

	All Respondents *N*	*Percent*	*Women Only* *N*	*Percent*
Single adult, no children	271	31.4	39	57.1
Single adult with children	16	53.8	5	100.0
More than one adult	530	43.5	160	49.3

In considering these response percentages, it should be realized that the classification single adult, no children included most of the truck drivers interviewed.

In the telephone survey respondents were asked to rate the last rest area visited on an 11-point scale ranging from very bad (0) to excellent (10). Separate responses were requested for in- and out-of-state rest areas. The mean ratings, for all respondents, was 7.4 for in-state rest areas and 7.2 for those out of state. There is no statistical significant difference between these means. When responses were stratified by census regions, respondents from the northeast rated their within-state rest areas significantly lower than did respondents from the other three regions.

However, no conclusions should be drawn from this highly subjective process except to note the general overall approval of rest areas.

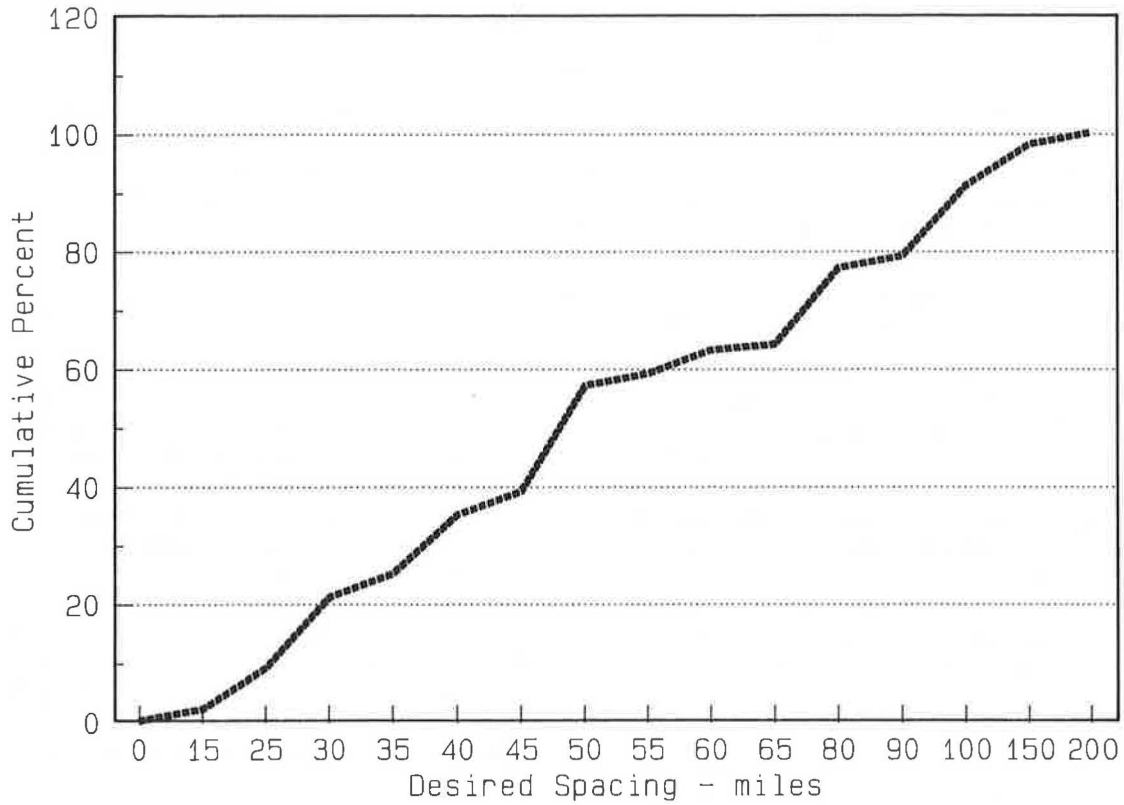

FIGURE 2 Desired rest area spacing.

Frequency and Spacing of Rest Areas

Respondents to the rest area interviews, asked about the adequacy of the current number of rest areas, responded as follows: too few, 41.9 percent; about right, 54.0 percent; too many, 0.5 percent; and no opinion, 3.7 percent.

In general truck drivers, RV users, business travelers, and older persons would like more rest areas. The preferred rest area spacing, in miles as expressed in the two surveys, is given below.

	Interviews	*Telephone*
No. of responses	778	460
Mean	63	66
Standard error of the mean	1.31	2.14
Median	50	50
Mode	50	50
Maximum	250	300
Minimum	10	5
Percent ≤		
50 mi	56.7	59.1
75 mi	71.0	73.3
100 mi	91.4	91.3

Figure 2 shows the cumulative distribution of the preferred spacing from the rest area interview data.

The degree of agreement between the two data sets is striking. Insofar as defined subgroups of the two samples are concerned, the only significant difference on the interview sample was that RV users were willing to accept a longer rest area spacing. The telephone survey revealed a significant regional difference. Respondents from the northeast preferred a significantly lower spacing, whereas respondents from the west preferred longer spacings. These differences can probably be attributed to different average trip lengths between these regions.

It would, however, appear to be a mistake to interpret these data as indicating an optimum rest area spacing for the interstate system. The responses were made in terms of individual trip-making behavior and indicated the minimum stopping interval of drivers. At currently prevailing highway speeds, the preferred distance intervals translate into time intervals of slightly more than 1 hour. Any individual driver probably would not like to stop more often.

From another point of view, however, such a spacing would imply a maximum delay of 1 hour or more after a decision to stop has been made. Although the question was not posed in these terms, such a delay is probably not acceptable, especially when the principal reason for rest area stops is considered and in view of the fact that over 80 percent of respondents indicated that decisions on where to stop were made on the basis of convenience.

Private Business in Rest Areas

Table 6 summarizes the attitudes of respondents to both surveys to six different types of private business activities in highway rest areas. The difference between the two response sets is striking and hard to explain. The only difference was the relative placement of this question within the two surveys. For the interviews the question was asked before the topic of rest area financing was introduced; in the telephone survey this order was reversed. Another possible explanation is that there may have been some confusion in the minds of tele-

TABLE 6 PRIVATE BUSINESS ACTIVITIES IN REST AREAS

Business Type	Percent Response to Interviews			Percent Response to Telephone Survey		
	Yes	No	Uncertain	Yes	No	Uncertain
Restaurant						
Fast food	30.8	61.6	7.6	56.6	42.0	1.4
Sit down	29.9	62.4	7.7	50.8	47.8	1.4
Gas and other automotive services	30.1	61.4	7.8	67.8	31.0	1.2
Shopping						
Travel-related goods	28.0	63.9	8.1	47.5	50.1	2.4
Local handicrafts and souvenirs	27.4	64.8	7.8	41.4	57.5	1.4
Advance hotel reservations	29.3	62.7	8.0	57.3	39.5	3.2

phone survey respondents about the difference between highway rest areas and toll road service plazas.

The telephone survey added vending machines to the list of potential private business involvement with the following results: vending machines dispensing food and drink, 86.0 percent approval; and vending machines dispensing other items, 58.8 percent approval.

This question was not asked during the interviews since the presence of existing vending machines in some, but not all, of the rest areas would have biased the results.

Financing Rest Areas

A number of questions, on both surveys, explored attitudes concerning financing the construction and operation of rest areas. A general question whether rest area construction and operations should be paid for by tax revenues, asked on the telephone survey only, received a positive response of over 95 percent.

All respondents were asked to indicate the amount they would be willing to pay as a user fee for each visit. The wording of the question was slightly different on the two surveys:

- In the rest area interviews, respondents were asked to indicate the maximum amount that they would pay from a preselected list (ranging from $0.25 to more than $3.00).
- In the telephone survey, respondents were asked to name an amount without any guidance or constraint.

Although only 39 and 50 percent, respectively, of the respondents had indicated that they were willing to pay a user fee to prevent rest area closings, 46 and 84 percent, respectively, indicated that they would pay some fee if such a fee were actually imposed. The average maximum amount that respondents would be willing to pay, together with the standard error of that average, is shown below. Omitted from the computations of these parameters are respondents who did not answer, who indicated that they were not sure, or who stated that the amount would depend on the services offered, or on other factors. These parameters were computed in two separate ways: once for all respondents and once for only those who gave a definite non-zero response.

Type of Survey	*No.*	*Mean ($)*	*Standard Error ($)*
Telephone			
All responses	440	0.82	0.047
Non-zero amount only	368	0.98	0.052
Rest area interview			
All responses	587	0.36	0.026
Non-zero amount only	269	0.78	0.044

There were some differences in these amounts between demographically defined subgroups; however, these were relatively small and not consistent between the two surveys. It is, however, worth noting that there were no significant differences, in the rest area interviews, when these data were stratified on the basis of the principal reason for stopping.

The differences between the surveys in both the proportion that would pay a user fee and in the amount of that fee is probably correlated with the difference between the two samples in the willingness to pay taxes. It is possible that the rest area users, who were in a facility clearly identified as a governmental function, believed that the user fees would be imposed as an addition, and not as an alternate, to taxes.

SUMMARY PROFILE

The data summarized in the preceding sections indicate that the following generalizations can be made about rest area users:

- Almost every rural freeway user on a long trip (i.e., in excess of 100 miles) is a potential user of highway rest areas.
- Drivers, who stop at an average interval of about 130 mi or somewhat more than 2 hours would prefer rest areas to be spaced about 50 mi apart.
- Demographically, the rest area user population closely approximates the driving population, especially that engaged in longer trips, with possibly a higher participation by older drivers.
- The proportion of mainline traffic that enters a given rest area is highly variable depending on traffic stream, driver, trip, and area characteristics and on competing stopping opportunities. This proportion may range from less than 1 percent to almost 50 percent. The overall average is about 10 to 12 percent, with the proportion of trucks and RVs entering the rest area generally significantly higher. There appears to be a longterm secular upward trend in this proportion.
- Approximately 20 percent of all vehicles entering rest areas contain children; 2 percent include visibly ambulatory handicapped occupants; and 4 percent of all travelers are accompanied by pets. The average occupancy of passenger vehicles entering rest areas is 2.3.
- The average time spent in rest areas ranges from 10 to 12 minutes per vehicle with a significant increase at lunchtime. Except at lunchtime, less than 20 percent of travelers remain in a rest area for more than 15 minutes. RVs remain for significantly longer times.
- Use of toilet facilities and resting, stretching, and exercising are, by far, the most significant reasons for stopping at

rest areas. Considerably smaller but still significant proportions of entering traffic do so to eat or drink, use the telephones (primarily business travelers), check or repair their vehicles, or consult a map. No other rest area service or facility is used by more than 5 percent of entering traffic.

- An overwhelming majority of all rest area users believe that these facilities represent a valid public service that should be financed by public funds. There was, however, considerable ambiguity whether private business, even if travel related, should be allowed in rest areas.

ACKNOWLEDGMENT

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