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Contents

Foreword

The papers in this Record cover various aspects of environmental analysis for transportation systems. In the first paper, Hamilton creates a system for classifying and ranking environmental impacts on the Interstate highway system. In the next paper, Lindeman and Wilt explore the effectiveness of revegetating a black rush marsh in Florida. Elevation was a critical factor in the success of this marsh revegetation effort. Maestri addresses the continuing problem of pollution from highway storm water runoff in his paper. He suggests that there are three effective measures that can be used to mitigate this problem: vegetation controls, detention basins, and retention measures. In the final paper, Hansen, Palmer, and Khan discuss the increasing problem of providing urban access to large combination trucks. A utility theory based methodology for evaluating access alternatives is described.

Identification and Ranking of Environmental Impacts Associated with the United States Interstate Highway System

H. ROGER HAMILTON

Environmental impacts associated with the development and use of the Interstate highway system are identified, grouped into categories, and ranked by relative significance. The development and use of the Interstate highway system has resulted in several environmental impacts. Although many of these impacts are intuitively recognized, they have not been formally identified or ranked in any systematic way by their relative significance or magnitude. Classification and ranking systems are presented.

Man has traveled since his nomadic beginning when he followed the migratory routes of animals. These travel routes evolved into roads, which we may define as routes of overland communication between established communities (*1*).

A number of significant events have combined to expand the definition of a road beyond being simply a route from one place to another. Industrial advances, increased population, increased disposable income, more leisure time, significant technological accomplishments, and an increasingly complex society have resulted in the development of many roads in the United States. Roads have become an integral part of the landscape and a part of life for virtually every American.

As highway travel in this country increased, the interdependence of utility, safety, beauty, and economics led us to the concept of divided highways. The first such roads were built in the 1930s and the Interstate highway system was begun in 1956. The National System of Interstate and Defense Highways, as it is called in the generic legislation, is to be some 42,500 mi long when it is completed. About 1,000 mi remain to be built (*2*).

According to Hindley (*1*), the Interstate system will represent only 1 percent of the total U.S. road mileage when completed. However, the system will carry at least one-fourth of the nation's total traffic flow. Interstate highways link 43 state capitals and serve 90 percent of all cities with populations greater than 50,000, in addition to about one-half of the rural population.

Although roads have become a natural component of our lives, certain environmental impacts are associated with the system of highways. Those impacts are identified in this paper and it is shown how they can be grouped and ranked.

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PROBLEM STATEMENT

With the invention of the internal combustion engine and mass production of the automobile as catalysts, the proliferation and expansion of the network of highways in the United States have resulted in several environmental impacts. Although these impacts may intuitively be recognized, they have not been formally identified or ranked in any systematic way by their relative significance or magnitude. Additionally, a system for classifying impacts has not been developed.

HYPOTHESIS

Environmental impacts of the Interstate Highway System can be identified and ranked using a scheme of relative importance, significance, or magnitude. It is also possible to place the impacts into definable categories so that relationships can be identified.

DISCUSSION

An attempt is made in this paper to discuss, at least in general terms, the environmental impacts of the Interstate highway system. For the purposes of discussion the term "impact" is treated synonymously with "effect." Put another way, an attempt is made to identify the environmental changes that have occurred as a result of the development and operation of the Interstate highway system.

The following assumptions are made in conducting this study.

1. For the most part, impacts associated with all roads and road systems can be applied to the Interstate highway system. (Some differences in impacts and their relative ranking can be expected because of the differences in location, relative size and volume, and type of traffic use.)
2. Certain impacts are more relevant to the Interstate system than to other roads because of the strategic location of the Interstate highways.
3. Impacts vary in magnitude (scale) and consequence. They can be large or small, beneficial or detrimental.

4. Permanent impacts are more significant than temporary impacts.
5. Impacts can be grouped by function or source.
6. It is possible to identify and describe impacts that are secondary, tertiary, or even further removed, but which have their genesis in the Interstate highway system.

Any alteration of the landscape of the magnitude of the massive highway system obviously causes certain changes or impacts. Some of these impacts are more permanent than others; some are quite significant whereas others are not; and some are generally accepted as beneficial whereas others are considered detrimental.

An additional dimension to the perception of impacts arises when the intended or consequent beneficiary is considered. For example, a section of Interstate highway that connects two major metropolitan areas is of obvious benefit to the people who use that access on a regular basis for commerce and pleasure travel. However, the same stretch of road is probably less beneficial, and perhaps detrimental, to the individual who resides in another region of the country and seldom or never uses the road but contributes to its construction and maintenance through taxes. The same might be true of the individual who owned or was employed by a restaurant or other service type of business located on a previously busy highway that was bypassed by the development of the new Interstate highway.

The Interstate system of highways, although quite small relative to the extent of roadways in the nation, is strategically located so that special impacts can be associated with that system.

Certain impacts are readily apparent when the Interstate system of highways is visualized crisscrossing the nation in north–south and east–west grids. Visual impacts of the long ribbons of roads and their attendant strip developments in and near population centers are immediately evident. Further, the rather permanent nature of the physical presence of the roads and their associated developments are obvious. The highway commercial strip environment will be around as long as the automobile persists as a major transportation mode (*3*).

We have lost the night. Illumination by vehicles on the nation's roads, and the communities and strip developments they serve, has changed the visual quality of our once-dark continent to one splashed with light. Certain areas are now lighted virtually 24 hours a day. The significance of illumination of our landscape is particularly evident to travelers who cross the country at night by air.

Another conspicuous impact is the noise caused by the large volume of traffic pounding the pavement at high speeds. Interstate highways, with their facility for commercial transportation in the form of large trucks and buses coupled with maximum allowable speed limits, are particular sources of noise pollution. Construction and maintenance equipment and activities provide additional sources.

Cook and Van Haverbeke (*4*) have found that proper placement of certain species of shrubs and trees can result in significant reductions in noise pollution. Other mitigating features have been incorporated into high-volume traffic areas in congested regions to reduce noise levels adjacent to the highway. On I-495 around Washington, D.C., for example, sound barriers that resemble fences about 15 ft high have been erected on either side of the highway. These barriers are made of a variety of materials including wood and steel and appear to be fairly effective in containing noise in the highway corridor.

The alteration of vegetation brings with it a host of additional impacts. Vegetative communities form important building blocks for a vast array of environmental processes, functions, and situations. Among them are wildlife habitat values, soil erosion control, and uptake of pollutants and contaminants. The search for low-maintenance plant species that are effective as soil erosion control agents has led to the importation of exotic species such as kudzu (*Pueraria thunbergiana*) and the genetic development of new varieties such as crown vetch (*Coronilla varia*).

Indiana researchers are experimenting with planting shrubs on highway rights-of-way to offset wildlife habitat losses caused by intensive farming, urbanization, industrialization, and other land use practices associated with a rapidly urbanizing society. Roach and Kirkpatrick (*5*) discovered that the planting of shrubs along Indianan four-lane highways provided a habitat that attracts a greater number and diversity of wildlife, primarily birds. Use of these areas by rabbits was more than that of grassed areas. Road-kill data indicate that highway rights-of-way can be developed to increase wildlife productivity without attendant increases in mortality. Maintenance costs associated with mowing are greatly reduced when the grassy areas are converted to shrubs or other vegetation that does not require that treatment.

Formation of borrow pits as a result of the removal of sand, gravel, and fill material for use in highway construction results in wildlife habitat modification. Existing or preconstruction habitat is destroyed or altered and additional habitat is created. Specific management prescriptions can enhance these habitats significantly (*6*).

The extent of the effects of habitat loss because of the construction of I-95 in northern Maine is not fully understood. However, some species have adapted to the new habitats created by this highway development. Other species that are naturally adapted to forest habitat are avoiding the I-95 corridor (*7*).

Yellow sweet clover (*Melilotus officinalis*) volunteered as a ruderal species along a highway that had been recently relocated in conjunction with the construction of Libby Dam in Montana in 1973. The clover reached heights of approximately 8 ft and was browsed heavily by mule deer (*Odocoileus hemionus*). Increased road kills of mule deer were reported, but the cause was linked closely with the action of the deer crossing the road to gain access to the river on their migration route. Construction of the relocated road had occurred at the base of a mountain and the deer traveled from the higher elevations to the river, returning daily.

When the U.S. highway system was composed primarily of gravel roads, the width of the right-of-way—owned, easement, or both—was usually one chain or four rods (66 ft). The advent of the Interstate highway system in the 1950s resulted in expansion of those rights-of-way to a minimum of 300 ft with a median strip of variable widths. Grass was almost always used on the unpaved portions for soil erosion control. Later concerns for overall aesthetic appearance and reduction in maintenance costs led to the planting of perennial woody shrubs and trees to supplement natural vegetation.

Several studies have concluded that significant savings in costs of maintaining the rights-of-way can be achieved, and, indeed, potential profits can be realized by converting these areas to commercial forestry operations (*8*).

Impacts on the environment result from both the construction and operation of the highway system and from the vehicular traffic that uses the roads. Noise pollution has already been discussed. Another impact occurs in the form of chemical emissions from all vehicles.

Traffic on the highways introduces a number of contaminants and pollutants into the immediate area. Runoff from the highway surface carries these potentially harmful pollutant loads to nearby surface waters. Constituents typically include boron, lead, zinc, nitrogen, phosphorus, and ammonia (*9*).

Concentrations of heavy metals and other pollutants from vehicles on Interstate highways have been the object of considerable concern and, consequently, a great deal of research over the past several years. Yousef et al. (*10*) report that the use of detention or retention ponds was quite successful in locking up these noxious elements in the upper layer (approximately 5 to 6.8 cm) of the bottom sediments. Their work was conducted at sites on I-4 and US 17-92 in central Florida. Additional work in central Florida on I-4 showed that grassy swales were effective in reducing concentrations of heavy metals (*11*). Water quality changes caused by highway construction were found to be temporary, and, once the construction was completed, the water quality tended to return to its preconstruction conditions (*12*).

These findings partially coincide with similar observations by the author of several major Corps of Engineers construction projects throughout the nation. Terrestrial scars with their attendant soil erosion and vegetative losses occur during major construction activities. However, with proper care, the scars quickly heal and adverse ecological impacts are mitigated. Obvious visual impacts and effects on certain vegetative and wildlife communities are more permanent.

The literature appears to concentrate on the forms of impacts that have been discussed here. There are, however, other impacts that have received only limited or no attention from the scientific community. The identification of impacts becomes quite complicated when one considers the far reaching consequences of some of the actions that result from development of a means of transporting people and things from one point to another are considered.

Land has been lost from agriculture and other productive uses to the highway system. The total amount of land is probably not as significant as are its location and function and the impacts of the linear corridors created by road construction.

The significance of an Interstate highway route is often more related to its location than to how much land will be taken. The values of archaeological sites, minerals, critical habitats for wildlife species, and other important features associated with a proposed highway route can outweigh the use of the corridor as a road, resulting in a change of the planned route. The relocation of the planned route for I-29 in Louisiana, for instance, allowed continued access to mine extensive lignite deposits. The location of I-85 across Georgia and South Carolina permitted easy access so that millions of Americans could enjoy recreational opportunities at Lake Sidney Lanier and Hartwell Lake.

Population concentrations in the urban areas linked and serviced by the road system open a vast array of secondary and induced impacts. Los Angeles, California, represents the classic example of a modern urban area built around the automobile. It has been estimated that one-third of the metropolitan area is taken up by road surface, one-third by parking facilities, and one-third by living space (*1*). Regardless of the statistical validity of these data, the fact remains that significant land resources are devoted, either directly or indirectly, to the use of motor vehicles in Southern California and the rest of the country.

The concept of neighborhoods has changed with easy access to friends living several miles distant now possible. Distances once considered major journeys are now routinely traveled. Our mobile society has a different set of socioeconomic, cultural, and political values compared with those of previous generations, due in large part to the ease of transportation caused by the highway system. The migration from the inner cities to suburbia following World War II was accelerated by a growing population and great advances in technology. The explosion of the automobile market and improved highways were certainly important aspects of this major cultural change.

The morphology of cities has been altered dramatically by the Interstate system. Traditional neighborhoods have been split. Pedestrian access to, from, or across the multilane roads is limited or nonexistent. The result is fragmentation and isolation of once integral areas in many major cities.

With the advent of the Interstate system and the expansion of the commercial trucking and busing industries, alternative means of travel and shipping provided competition for commercial airlines, railroads, and barges. Economic and environmental impacts in all of these areas could be attributed, at least in part, to improved roads. This unprecedented mobility has permitted, paradoxically, both a decentralization and a recentralization of social activities. Metropolitan life-style has spread into the countryside because of easy access to areas beyond the city limits. The development of suburban areas with shopping centers that have ample parking space, larger centralized schools and hospitals, and other automobile-oriented features has resulted in the decentralization of activities from the metropolis to the suburb (*13*). Each of these new directions comes equipped with a myriad of environmental, economic, and social consequences.

Secondary and induced impacts in the form of sand, gravel, and limestone mining for road construction and the mining of iron ore and other raw materials for the manufacture of vehicles, construction equipment, and other supplies continue to result in environmental impacts on the landscape. Additionally, these activities have produced impacts on the national economy and employment rates.

RELATIVE RANKING OF IMPACTS

The foregoing discussion has established that our system of Interstate highways continues to create a variety of changes in our environment. These changes vary extensively in their relative permanence, magnitude, and importance. Individual impacts can be considered beneficial or detrimental, depending on perspective and whether the action that causes the impact results in a gain or a loss.

The major environmental impacts of the Interstate highway system are shown in the following list. Because of the complexity of the subject, the list can be expanded to capture the level of detail desired. An attempt is made to categorize several impacts under activities that are descriptive of those impacts as a group. These 18 major group headings are used in further analysis in the interest of simplicity, brevity, and consistency.

Direct Impacts

1. Visual
   (a) General aesthetics
   (b) Illumination at night
2. Noise level increase
   (a) Construction and maintenance
   (b) Public use
   (c) Impacts on man
   (d) Impacts on wildlife
3. Air pollution
   (a) Construction and maintenance
   (b) Public use
4. Water pollution
   (a) Construction and maintenance
   (b) Public use
   (c) Surface water runoff
5. Land loss from other use
   (a) Road corridor
   (b) Shoreline at bridge crossings
   (c) Support activities (e.g., maintenance yards, and so on)
   (d) Acquisition, storage, and transportation of materials
   (e) Manufacture, storage, and sales of equipment
6. Land alteration
   (a) Borrow pits
   (b) Cuts and fills
   (c) Soil profile mixing
7. Vegetative modification
   (a) Erosion control
   (b) Wildlife habitat impacts
   (c) Mowing
   (d) Development of new varieties
   (e) Introduction of exotic species
   (f) Use of herbicides
8. Soil erosion
   (a) Increased erosion
   (b) Decreased erosion
9. Wildlife
   (a) Habitat loss
   (b) Habitat creation
   (c) Alteration of habitat for indigenous species
   (d) Interference with migration routes
   (e) Interference with access to water or other nearby habitats
   (f) Road kills
   (g) Interruption in travel routes
   (h) Improved access to wildlife by man
   (i) Isolation of populations and communities
10. Wetlands loss or alteration
   (a) Dredging and filling
   (b) Drainage
   (c) Encroachment because of improved agriculture and development
11. Cultural resources
   (a) Archaeological sites
   (b) Historical sites
   (c) Site destruction
   (d) Site discovery

Indirect Impacts

1. Litter and other solid wastes
   (a) Landfill requirements
   (b) Recycle
2. Strip mines
   (a) Sand and gravel
   (b) Limestone
   (c) Iron ore and other raw materials
   (d) Soil disturbance
   (e) Vegetation loss
   (f) Reclamation
   (g) Water pollution

Induced Impacts

1. Strip development
   (a) Commercial
   (b) Residential
2. Urban development alteration
   (a) Decentralization
   (b) Recentralization
3. Auto manufacture
   (a) Manufacturing plants
   (b) Dealerships
   (c) Repair shops
   (d) Supply of raw materials
   (e) Other support facilities
4. Junk cars
   (a) Storage
   (b) Transportation
   (c) Recycling
   (d) Other disposal (incineration, landfill, and so on)
5. Petroleum production
   (a) Production
   (b) Processing
   (c) Delivery
   (d) Use
   (e) Disposal

In order to assess the overall, generic environmental impact of the highway system, it is important to first assess the individual impacts. Once the individual pieces of the puzzle are identified and placed into logical groupings, the puzzle itself will begin to take form. Two alternative approaches for accomplishing this process are presented.

The first logical step in this process is to combine similar impacts into functional groups (see Table 1). In this display (Alternative 1), the impacts that were broadly identified in the list previously shown are associated with one or more classes. These classes, which represent a further refinement of the list, are defined as follows:

- Class I: Physical impacts are physical alterations to the environment such as vegetative changes and soil movement.
- Class II: Sensual impacts are those that affect the five human senses, but are primarily concerned with visual and auditory perceptions.
- Class III: Conceptual impacts directly alter the life-styles and sociological make-up of our society. Time and space have different conceptual values for the current generation from those they had for generations that did not have the relatively easy transportation associated with our system of four-lane roads. This class is intended to identify those impacts that have had an effect on our conceptual values.

In Table 1, direct, indirect, and induced impacts are shown that are the result of highway construction and operation and the movement of vehicles on the highways. These types of impacts are defined as follows:

- Direct impacts are the direct result of construction and operation of the roads. The use of the highways by motor vehicles is also a source of direct impacts.
- Indirect impacts are caused by the acquisition, storage, and transportation of materials used in the construction and operation of the Interstate highway system.
- Induced impacts result from accelerated activities caused by the operation and use of the Interstate highway system.

Some impacts can be placed in more than one class, illustrating the complex nature of the impacts of the highway system and their interrelationships.

Also identified in Table 1 is a classification of each impact as permanent or temporary. For this study, permanent impacts are those that extend from one generation to another. Temporary impacts may also be long-lived, but it is reasonable to expect that they could be neutralized under normal conditions of national priorities and adequate funding. Temporary impacts may also be those that are short-lived on a site-specific basis. For example, erosion is constant nationwide, but it is normally controlled at a given site in a short time.

Those impacts that are considered to be permanent and classified as having the characteristics of all three classes of impacts under Alternative 1 are

- Strip development,
- Urban alteration,
- Auto manufacture, and
- Petroleum manufacture.

Permanent impacts that appear in two classes are

- Visual,
- Vegetative modification,
- Strip mines,
- Land loss, and
- Land alteration.

Numerical values can be assigned to the impacts that have been identified using the scheme shown in Table 2. Under this

TABLE 1 CLASSES AND TYPES OF IMPACTS: ALTERNATIVE 1

	Class				
			III		
Impact	I Physical	II Sensual	Conceptual	Permanent	Temporary
Direct					
Visual		X	X	X	
Noise level increase		X		X	
Wildlife	X				X
Wetlands	X				X
Land loss	X	X		X	
Soil erosion	X	X			X
Vegetative modification	X	X		X	
Air pollution	X	X			X
Water pollution	X	X			X
Land alteration	X	X		X	
Cultural resources			X	X	
Indirect					
Litter	X	X	X		
Strip mines	X	X		X	
Induced					
Strip development	X	X	X	X	
Urban alteration	X	X	X	X	
Auto manufacture	X	X	X	X	
Petroleum production	X	X	X	X	
Junk cars	X	X			X

TABLE 2 A SYSTEM FOR RANKING IMPACTS: ALTERNATIVE 1

Rank	Permanent	Temporary	Three Classes	Any Two Classes	Any One Class
1	X		X		
2	X			X	
3	X				X
4		X	X		
5		X		X	
6		X			X

TABLE 3 RELATIVE RANKING OF IMPACTS: ALTERNATIVE 1

Rank Number	Impact
1	Strip development
	Urban alteration
	Auto manufacture
	Petroleum production
2	Visual
	Land loss
	Vegetative alteration
	Land alteration
	Strip mines
3	Noise level increase
	Cultural resources
4	Litter
5	Soil erosion
	Air pollution
	Water pollution
	Junk cars
6	Wildlife
	Wetlands

ranking system, the results shown in Table 3 would be achieved. One conclusion from this analysis might be that those impacts with lower rank numbers are more significant and should, therefore, receive attention before the higher-ranked impacts.

The identification and classification scheme is applied to the entire Interstate highway system in a broad, general sense and does not account for regional or local circumstances. Ecological, cultural, socioeconomic, and political variations occur across the nation and the significance of impacts depends heavily on these considerations.

No priorities or values were assigned to the three classes of impacts. This could be done, but, in this instance, the judgment was made that all three classes should receive equal weight. Also, emphasis was given to permanent impacts. The implementation of such a classification and ranking scheme so that priorities of research efforts could be assigned to problem areas must include decision points at which the determination should be made to attack a problem area of a permanent or temporary nature. The methodology should also be appropriately tested before implementation.

The foregoing is an example of how impacts can be grouped and ranked. It is also possible to organize the impacts in other ways. Alternative 2, depicted in Table 4, presents an additional scheme that could be used to arrange impacts in groups of functions that include the construction, maintenance, and use of the roads. A final group in this scheme includes impacts resulting from development adjacent to the Interstate roads.

This alternative method is further refined to identify those impacts that are permanent and those that are more temporary. In this example, air and water pollution resulting from construction lasts only through and, perhaps, until shortly after the construction activity. Strip mines and land and urban alteration are permanent results of the construction activity.

It is possible to rank the relative impacts under the criteria established in Alternative 2 by using the assumption that permanent impacts that meet the most criteria are the most significant. The results of such an analysis are displayed in Table 5.

RESULTS

A review of the literature did not reveal that all environmental impacts associated with the Interstate highway system have been identified and grouped into logical categories. No system of ranking or assignment of significance to individual or groups of impacts was discovered.

Two alternative systems have been devised to group and rank the impacts. Under Alternative 1, impacts are identified and grouped into categories based on functions. Impacts are identified that are direct, indirect, or induced and are further categorized based on their physical, sensual, or conceptual functions. They are also judged to be either permanent or temporary.

A quantitative scoring system was devised based on the permanent or temporary nature of the impact and the number of functional qualities each possesses. Permanent impacts with all three functional classes receive a rank score of 1. Temporary impacts with only one class assignment are ranked as 6. The lower the rank score under Alternative 1, the greater the significance of the impact.

Under this ranking system, impacts associated with urban development, population concentration, and the induced impacts of building more vehicles and developing petroleum products to power them are the most significant of all those that were identified. Temporarily disrupted wetlands and wildlife are the least significant.

Alternative 2 arranges impacts in groups of activities associated with the highway system itself. They are construction, maintenance, public use, and adjacent development. These impacts are also identified on their relative permanency. The scoring system used for Alternative 1 is also applied in Alternative 2.

The results of the analysis under Alternative 2 differ somewhat from those of Alternative 1. This variation is due to the consideration of the source of the environmental impact in Alternative 2 as opposed to the class of impact in Alternative 1.

Results of the analysis in Alternative 1 would be of use in attacking problems that could be associated with physical alteration of the natural resources or perceptual or socioeconomic problems. Alternative 2 could be helpful in identifying the source of impacts so that appropriate corrective action could be taken.

TABLE 4 IMPACTS GROUPED BY SOURCE: ALTERNATIVE 2

Impact	Source of Impact: Road Construction P	Road Construction T	Road Maintenance P	Road Maintenance T	Road Use P	Road Use T	Development of Adjacent Lands P	Development of Adjacent Lands T
Direct								
Visual	X				X		X	
Noise level increase		X		X	X		X	
Wildlife		X		X	X		X	
Wetlands		X					X	
Land loss	X						X	
Soil erosion		X						X
Vegetative modification	X		X				X	
Air pollution		X		X	X		X	
Water pollution		X		X	X		X	
Land alteration	X						X	
Cultural resources	X						X	
Indirect								
Litter		X		X	X		X	
Strip mines	X		X					
Induced								
Strip development	X						X	
Urban alteration	X				X		X	
Auto manufacture					X			
Petroleum production		X		X	X			
Junk cars					X			

NOTE: P = permanent, T = temporary.

TABLE 5 RELATIVE RANKING OF IMPACTS: ALTERNATIVE 2

Rank Number	Criteria	Impact
1	Permanent impact of 4 sources	None
2	Permanent impact of 3 sources	Urban alteration
		Visual
		Vegetative modification
3	Permanent impact of 2 sources	Land loss
		Land alteration
		Noise level increase
		Litter
		Air pollution
		Water pollution
		Wildlife
		Strip development
		Strip mines
		Cultural resources
4	Permanent impact of 1 source	Auto manufacture
		Petroleum
		Junk cars
		Wetlands
5	Permanent impact of 0 source	Soil erosion

CONCLUSIONS

Some environmental impacts associated with the system of Interstate highways have been identified by previous studies, but a comprehensive list that has been grouped and ranked has not been found. Research emphasis has been placed on problems associated with air and water pollution resulting from vehicular emissions and vegetative modifications along with soil erosion and wildlife changes and their effects on plant communities. Some attention has been given to visual and noise problems. These areas are generally the most noticeable and are thus the most likely to be funded for research.

Additional impacts, some of which appear to be significant, are caused by construction and maintenance activities as well as public use of the four-lane roads. These impacts have been identified and arranged into more generic groups in the interest of simplicity.

This action, combined with the application of the ranking system to those impacts, allows problems and opportunities associated with the construction and operation of the highways to be identified. By using two analysis schemes (Alternatives 1 and 2), this information can be effectively used in the identification and investigation of problems in a logical and systematic way.

It was not the intent of this study to assign positive or negative values to the impacts. It is noted that a given impact could be viewed either way by different individuals or groups. It is now possible, however, to begin work to identify the benefits of and detriments to the highway system and to formulate problem statements.

In summary, environmental impacts associated with the development, maintenance, and use of the Interstate highway system have been identified. These impacts have been grouped in several different ways, each having a specific application, and they have been ranked by their relative significance in accordance with a system that has been devised. It is possible to group the impacts in a variety of categories as an aid to problem identification and development of strategies for problem solution, mitigation, or other management applications.

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Effectiveness of Mitigation Techniques at the Alafia River Crossing

WIN LINDEMAN AND JAMES R. WILT, JR.

Mitigation activities are frequently required on highway construction projects. Explored in this paper is the effectiveness of revegetating a black rush *(Juncus roemerianus)* marsh in Florida. The results of a 6-yr monitoring effort are reported. Based on the results, it is concluded that elevation was the critical factor in the success or failure of this marsh revegetation effort.

The extension of I-75 by the Florida Department of Transportation (FDOT) from north of Tampa to Naples and on to Miami began in the mid-1970s. A portion of this Interstate crossed the Alafia River just west of Riverview (see Figure 1). Located in central Hillsborough County, this 31-mi-long river originates in the western part of Polk County and empties into Hillsborough Bay near Gibsonton. The Interstate crosses this tidally influenced river approximately 3.5 mi east of its mouth. At this location the Interstate is a six-lane rural design. Twin concrete bridges 1,552 ft long cross the river at about 34 ft above mean high water. The floodplain was bridged to an elevation of +6 ft or more to minimize potential adverse impacts on this sensitive ecological area.

PRECONSTRUCTION ACTIVITIES

During the development of the final design for the Interstate, environmental permits were required from a number of permitting agencies. These included the U.S. Army Corps of Engineers, the U.S. Coast Guard, the Florida Department of Environmental Regulation (FDER), and the Tampa Port Authority. These permits were obtained in 1978 before construction took place and, among other things, specified

1. No fill (temporary or permanent) to be placed in the wetlands;
2. No dredging for access of work barges;
3. The use of temporary timber work mats; and
4. An on-site, post-construction inspection to determine if restoration measures would be necessary in the tidal marsh.

In cross section, the bridge and approaches showed a transition from a pine-palmetto flatwood north of the bridge at an elevation of +12 ft through a natural marsh edge habitat of palmetto (*Serona repens*) and cabbage palm (*Sabal palmetto*) (*1*) at +5 ft. Crossing a black rush (*Juncus roemerianus*) marsh approximately 425 ft wide at an elevation of +1 ft, the bridge finally reached a natural berm (approximately 3 ft high) of alluvial deposition. The berm is vegetated with palmetto, cabbage palm, and grasses for about 50 ft to the edge of the Alafia River. Two small tidal creeks cross the black rush marsh under the bridges. On the south side of the river, the bank climbs rapidly to an elevation of +6 ft within 60 ft of the river's edge (see Figure 2). This rapid transition into a pine-palmetto flatwoods condition minimized any adverse impact on the aquatic environment south of the river. Because of this, all mitigation activities required by the permits focused on the north side of the river, specifically the black rush marsh.

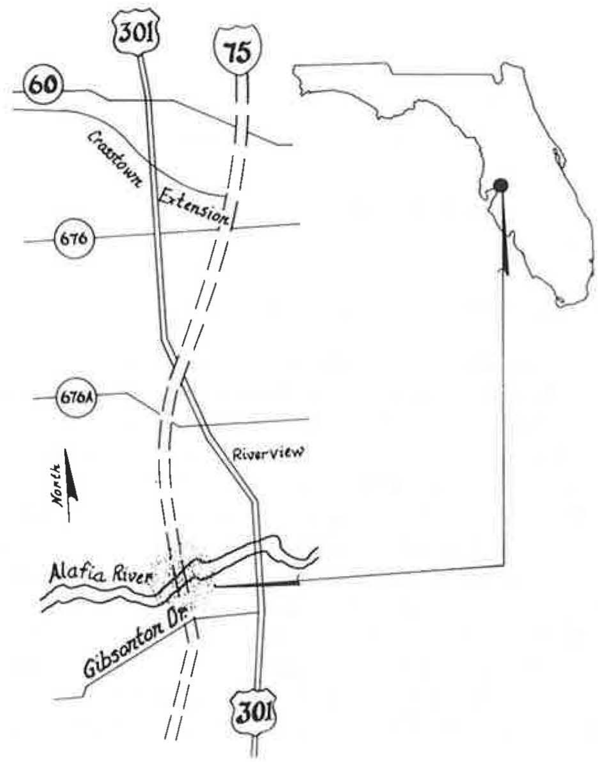

FIGURE 1 Project location map.

As noted earlier, the original permits received in 1978 provided for temporary timber mats to be placed over the black rush marsh. The black rush was to be burned before the placement of the mats and the mats were to be removed after construction was complete. Any areas where culverts were to be placed had to be restored to original contour and vegetative cover. The FDOT was required to arrange an on-site postconstruction meeting with FDER to determine if restoration measures would be necessary in the tidal black rush marsh. If restoration was deemed necessary after the meeting, the

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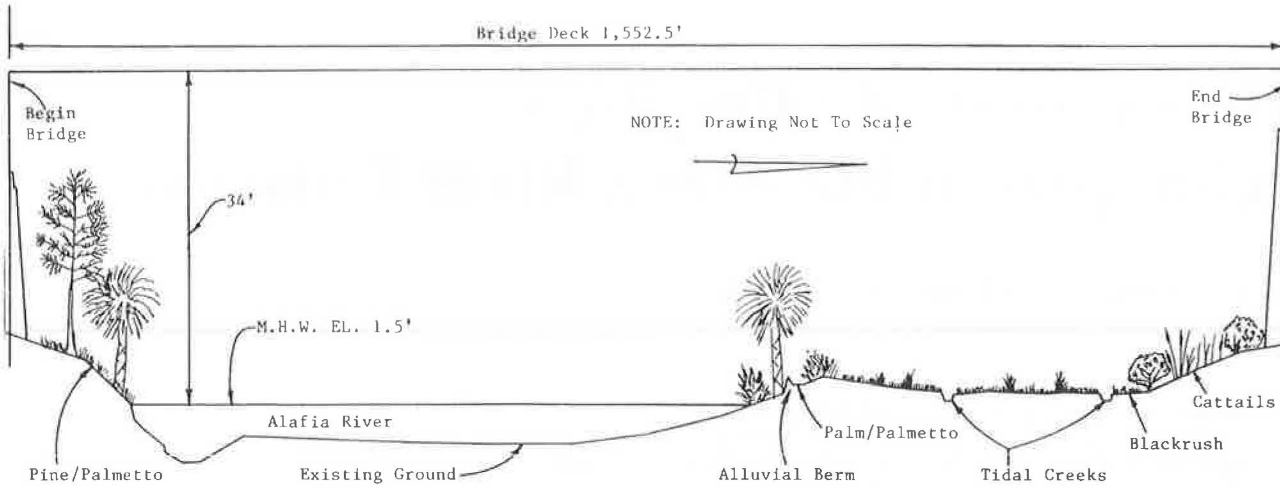


FIGURE 2 Alafia River floodplain cross section.

FDOT was responsible for the development of a restoration plan that would be approved by the FDER.

CONSTRUCTION ACTIVITIES

The construction contract was awarded in September 1979 to the Wiley N. Jackson Company. Work began in January 1980 and the contractor quickly proposed several permit modifications to allow for easier, lower cost construction techniques. However, these construction methods would result in greater impacts to the river's floodplain environment. The proposed modifications requested in the spring of 1980 featured a timber loading platform on the north bank of the Alafia River and a 425-ft-long, 60-ft-wide temporary access road across the black rush marsh, also on the north side of the river (see Figure 3). Two temporary 18-in. culvert pipes were to be installed in the two tidal creeks to maintain the tidal flushing these creeks provided. Additional finger fills were provided east and west of the temporary access road.

The access road was to be placed on Mirafi filter fabric after the area of black rush to be covered was burned to ground level. Because of the wet conditions encountered during construction, this was not possible. As an alternative, the black rush was cut off near ground level and covered with the fabric. Approximately 4 ft of fill material was placed on top of the fabric and the edges of the fabric were rolled back to minimize soil erosion into the marsh.

Adjacent to the main access road, 11 finger fills were constructed to allow access for the bridge construction equipment and materials. These finger fills employed the same techniques for fill placement that the contractor used on the main access road. The permit modification required that all disturbed areas were to be restored to original contour and revegetated with black rush clumps a minimum of 6 in. square. The revegetation plan was to be coordinated with the FDER before its implementation.

REVEGETATION ACTIVITIES

As construction of the bridge was nearing completion, the FDOT developed a revegetation plan that was approved by the permitting agencies. The details of the plan can be found in Figure 4. Although the FDOT did not guarantee any success rate, it did agree to monitor the site for at least 2 yr and report the results to the FDER. The results of the monitoring program will be discussed later in this paper and are summarized in Figure 5.

The contractor began the revegetation plan in September 1981 by first removing the fill material and the filter fabric from the finger fills as required. The contractor used a back hoe with a modified bucket to avoid tearing the fabric. The overlay of fill material was carefully removed until the filter fabric was reached. Before uncovering the filter fabric, a test hole was created on one fill pad to determine the condition of the fabric and the black rush under it. It was noteworthy to find that the fabric under the fill was in nearly original condition, whereas the edges of the fabric exposed to the sun were brittle and easily torn. The black rush and supporting muck soil were compressed as much as 12 to 18 in. in some locations. As the fabric was uncovered, the edges were rolled toward the center to minimize the loss of the fill material.

Following specific criteria for the removal of the fill and filter fabric at each individual location, the fingers were replanted as required by the revegetation plan. The first step in this process involved the restoration of the fill site in accordance with the plan. This involved various techniques including backfilling with a variety of materials (see Figure 4) and matching contours as specified in the plan.

The next step was to identify a donor site for the replacement black rush. Because undisturbed areas of black rush marsh were available within existing rights-of-way, this did not pose a serious problem. To minimize the potential impact on these undisturbed areas, the contractor was required to restrict the width of his clearing for donor plants. The contractor also used random patterns and spread the collection of donor plants over a fairly large area. To collect the plants, workers first cut a path 2 to 3 ft wide through an area of black rush up to 75 ft long. A gasoline-powered weed cutter with a saw-toothed blade was used to cut off the upper portion of the plants, leaving about 12 to 18 in. of stem. Using a hand shovel, random 6-in. squares of black rush were dug and transported to the revegetation areas. Here, operating from planks to avoid sinking into the

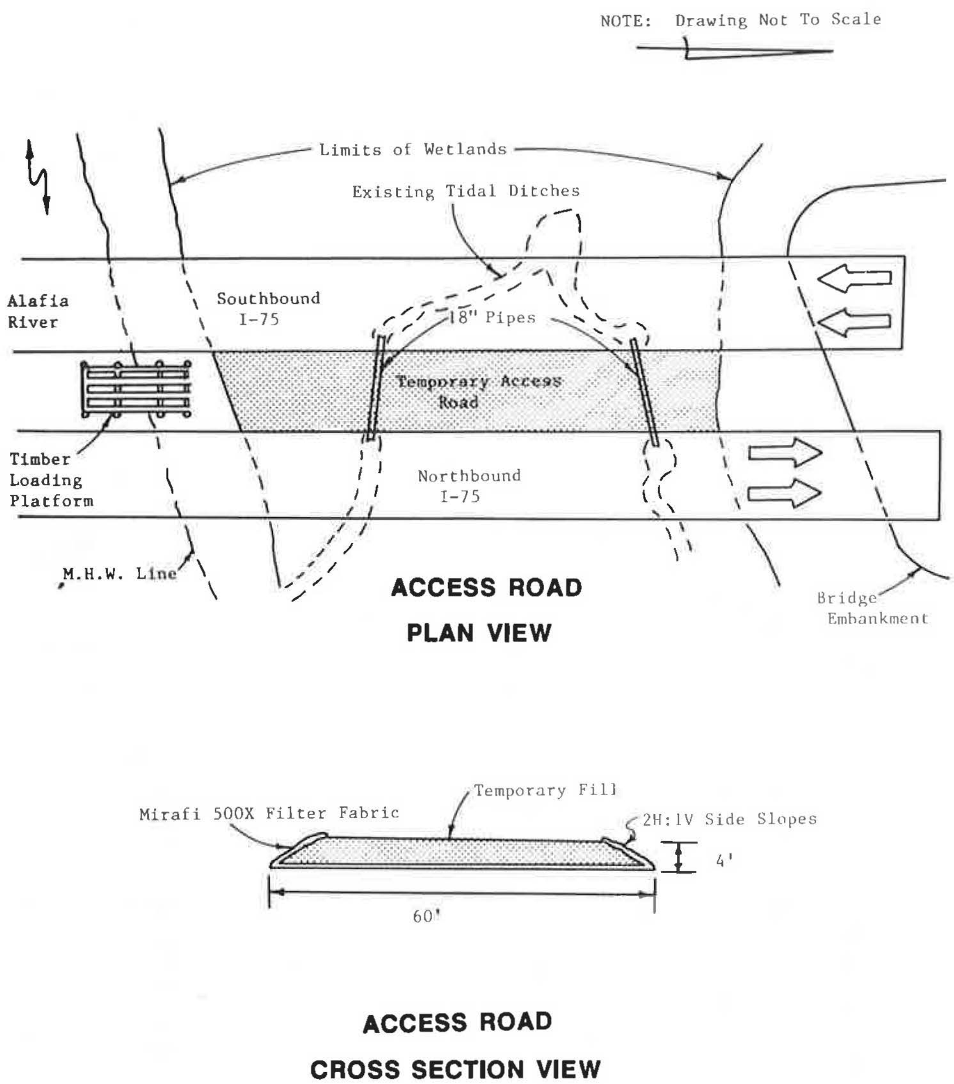


FIGURE 3 Modified permit sketch.

muck, the workers placed the plugs of black rush into holes created by the use of post-hole diggers. The plants were generally placed on 3-ft centers within the areas called for in the revegetation plan.

After the revegetation of the finger fills was completed, the main access road was removed and replanted. The process followed was the same as for the finger fills, with removal starting near the river and working northward. The revegetation work was completed by November 1981.

Based on field reviews conducted in 1981, 1982, 1983, 1986, and 1987, the relative success of the revegetation plan can be evaluated. As seen in Figure 5, Area 1 shows generally good recovery. This area was restored to original contours but was not revegetated. A diversity of plant species covers the area transitions from north to south. On the northern edge are found grasses, dog fennel (*Eupatorium capillifolium*), wax myrtle (*Myrica cerifera*), and brazilian pepper (*Schinus terebinthifolius*). As the area becomes wetter, cattail (*Typha domingenis*) and black rush dominate (*2*). Total vegetative coverage is better than 60 percent and would probably be better if it were not for livestock creating paths and trampling vegetation.

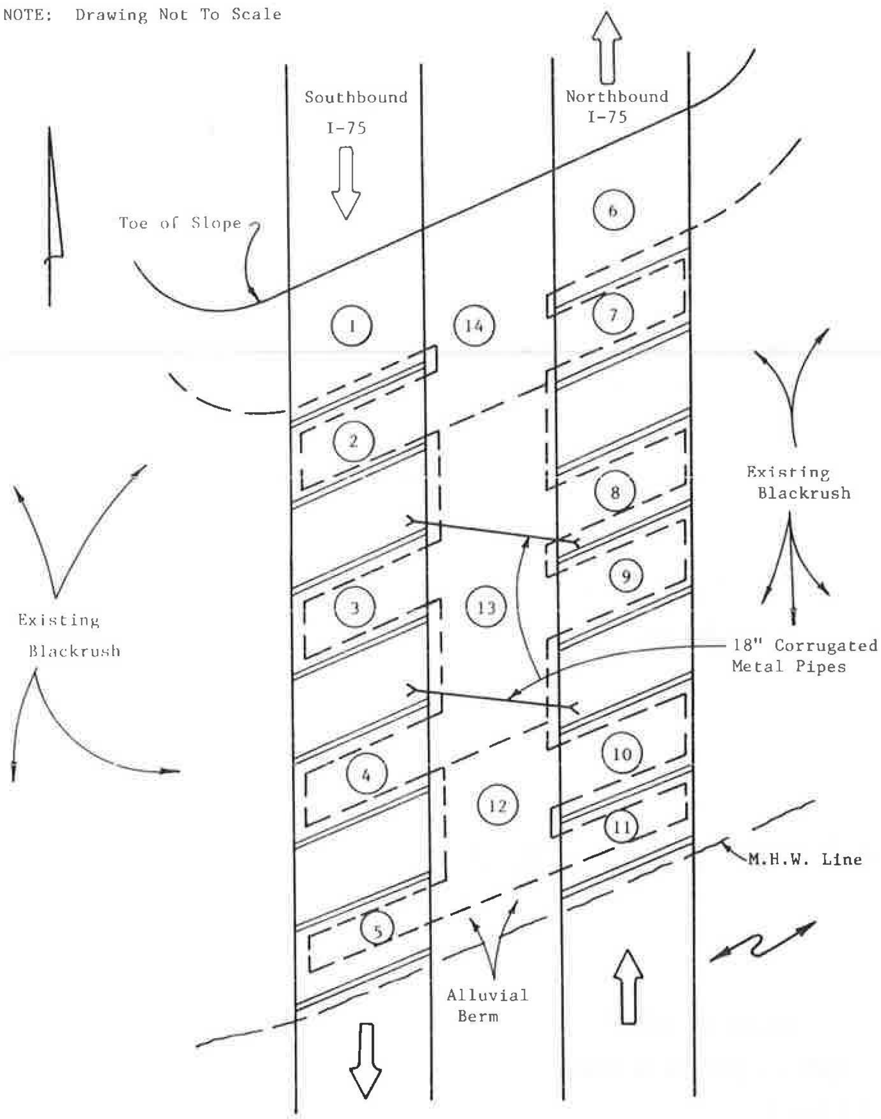
Area 2 contains one of the two tidal creeks with cattails, alligator weed (*Alternanthera Philloxeroides*), willows (*Salix* spp.) (*3*), and ferns present along with black rush. This area was not backfilled but was planted with black rush, which covers about 30 percent of the area.

Like Area 2, Area 3 also contains one of the tidal creeks and was not backfilled, nor was it replanted. Less than 10 percent of black rush establishment has occurred. Some fern and alligator weed are present but little other vegetation is found. Open water, even at low tide, occupies 80 to 85 percent of the area.

Black rush, 4 to 5 ft tall, covers more than 90 percent of Area 4. After backfilling to natural contours, the area was replanted with black rush.

Approaching the alluvial berm separating the marsh from the Alafia River, less than 15 percent coverage by black rush is seen in Area 5. This area has approximately 6 in. of the original fill left on top of the filter fabric. No revegetation was attempted in this area. The black rush that does exist is shorter (typically 3 ft high) than the surrounding plants.

Viewed from the toe of the slope southward on the northbound bridge (east side), Area 6 is very similar to Area 1. Edge



Area	Proposed Activity	Revegetation
1	Remove filter blanket and backfill with mixture of organic material and topsoil to match natural surrounding contours	None
2	Leave as presently excavated	Black rush on 3 ft centers
3	Leave as presently excavated	None
4	Backfill with sand (low organic content) to match natural surrounding contours	Black rush on 3 ft centers
5	Leave filter blanket with approximately 6 in. of existing fill remaining on top of it	None
6	Remove filter blanket and backfill with mixture of organic material and topsoil to match natural surrounding contours	Black rush on 3 ft centers
7	Backfill with topsoil to match natural surrounding contours	None
8	Backfill with topsoil to match natural surrounding contours	Black rush on 3 ft centers
9	Remove fill from filter blanket and roll back blanket without damaging existing root system	None
10	Remove fill from filter blanket and roll back blanket without damaging existing root system	Black rush on 3 ft centers
11	Leave filter blanket with approximately 6 in. of existing fill remaining on top of it	Black rush on 3 ft centers
12	Remove filter blanket and backfill with sand (low organic content) to match natural surrounding contours	Black rush on 3 ft centers
13	Remove filter blanket and backfill with topsoil to match natural surrounding contours	Black rush on 3 ft centers
14	Remove filter blanket and backfill with mixture of organic material and topsoil to match natural surrounding contours	Black rush on 3 ft centers

FIGURE 4 Revegetation plan.

plants such as dog fennel, brazilian pepper, wax myrtle, and palmetto are dominant. Livestock paths crisscross the area. After the backfilling and contouring of this area were completed, black rush was planted. No surviving black rush could be found.

Area 7 was backfilled and contoured but not replanted. Revegetation is slow, with less than 30 percent coverage in black rush. Alligator weed and some cattail was found.

After backfilling and contouring were completed, Area 8 was replanted with black rush. About 70 to 80 percent of the area is now covered with black rush 3 to 5 ft tall.

Following removal of the fill, the filter fabric was carefully removed from Area 9 so that existing black rush root stock was not damaged. No additional plants were introduced. The results show less than 10 percent revegetation in this area although some young plants (1 to 2 ft high) are in evidence.

After the fill and filter fabric were removed, Area 10 was replanted with black rush. No backfilling or contouring took place before the planting. Less than 20 percent coverage of 4- to 5-ft tall black rush has taken place.

Approaching the alluvial berm on the east side of the project, better than 80 percent revegetation with 3.5- to 4-ft tall black rush can be seen in Area 11. Like its western counterpart (Area 5), this area was left with about 6 in. of fill material on the filter fabric. The difference appears to be because Area 11 was replanted, whereas Area 5 was not.

Area 12 is one of three segments of the main access road. This area nearest to the river was backfilled and contoured before being replanted with black rush. Today, a dense coverage of black rush 4 to 5 ft tall exists.

Like Area 12, Area 13 was backfilled and contoured before replanting. Approximately 80 percent of the area is covered with 4- to 5-ft tall black rush and bisected by the two tidal creeks.

The last area to be revegetated was Area 14. This transition area from marsh to upland at the northern end of the bridge was backfilled and contoured. Black rush was replanted and shows a vegetative gradation. Black rush marsh gives way to cattail, dog fennel, brazilian pepper, and wax myrtle. The area adjacent to the toe of the slope is disturbed by livestock paths and contains vines and grasses.

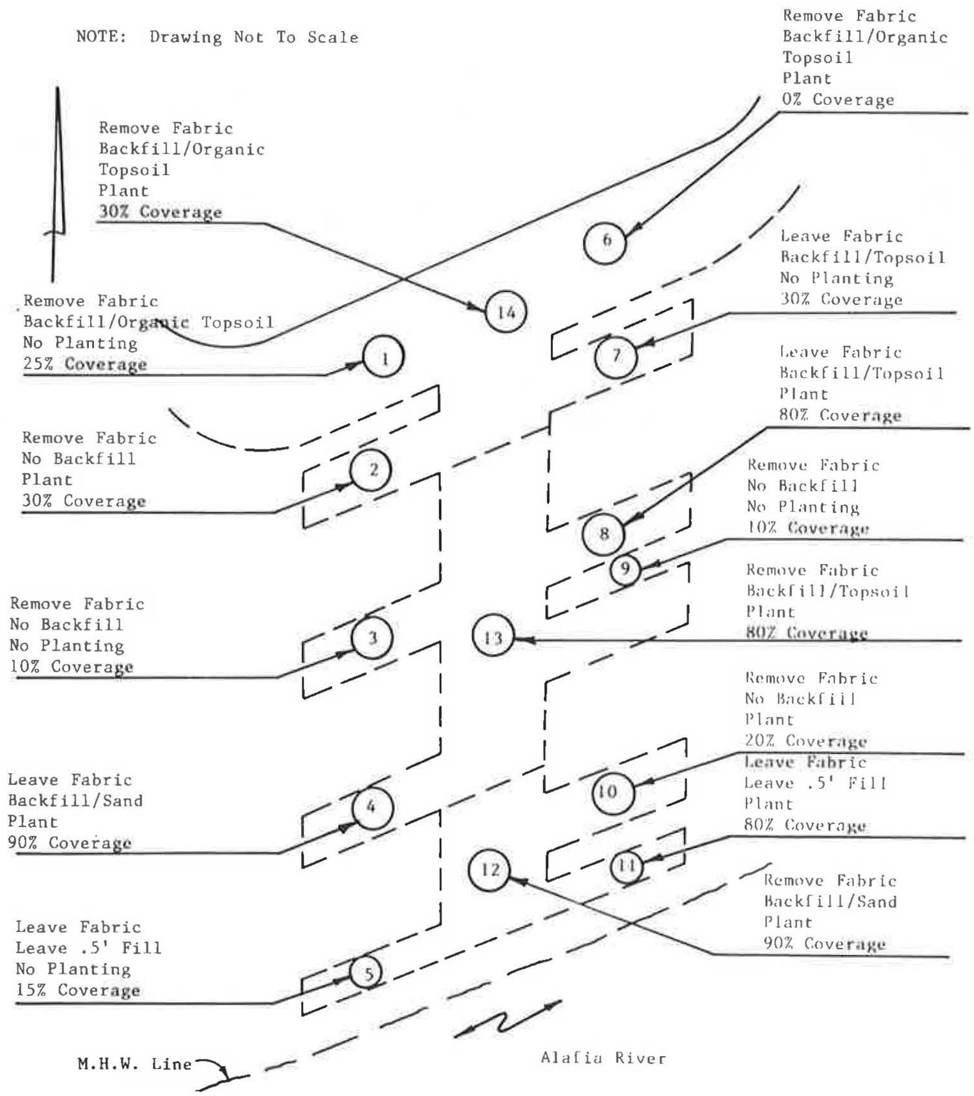


FIGURE 5 1987 summary of activities and results.

As a final point, the donor sites were monitored to determine if any adverse impacts would result. After 6 yr of growth, it is nearly impossible to distinguish the donor areas from the adjacent growth.

CONCLUSIONS

Based on the results of 6 yr of monitoring this mitigation effort in a tidal marsh, several conclusions can be drawn.

1. Reestablishment of the preconstruction contours is critical to the success of revegetation of a tidal black rush marsh. Backfilling (independent of soil type) and contouring before replanting seemed to be the controlling factors in a successful effort. Those areas where backfilling of some type did not take place generally resulted in less than 20 percent black rush coverage. The transition areas (1, 5, 6, and 11) also showed the effects of elevation changes. The black rush does not appear to survive as well when the elevation increases by 12 in. over the preconstruction level of the marsh.

2. Supplemental planting will increase the rate of coverage significantly when combined with backfilling and contouring. A comparison of Areas 2 and 3, 5 and 11, 7 and 8, and 9 and 10 illustrates this conclusion. Whether planting on 3 ft centers is necessary for coverage could not be determined, although it is the accepted norm.

3. Removal of the filter fabric does not appear critical to the successful reestablishment of a black rush marsh if the area is contoured and revegetated. This principle is well illustrated by examining Area 11.

4. The use of areas next to the project for donor sites did not have any adverse impact on the viability of the marsh. No evidence of the removal of these donor plants is evident if care is taken in their selection and removal.

5. After 6 yr, the replanted black rush is generally as tall and full as those specimens found in the undisturbed areas.

6. Finally, it appears that replanting will generally be required in this type of marsh setting to ensure reasonable coverage. Areas 7 and 8 illustrate this concept, although temperature and rainfall may play an important part.

SUMMARY

The use of revegetation by using plugging is an acceptable method to aid in the reestablishment of a black rush marsh. Before replanting, backfilling and contouring to preconstruction conditions is critical. The use of available topsoil or fill material is adequate to provide for plant growth in this type of marsh environment. Donor sites near the project site, if selected at random, will not be adversely affected.

ACKNOWLEDGMENT

The contributions of Sherry Swinford to this paper must be noted. Her knowledge of the project and her assistance with the graphics were invaluable.

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Managing Pollution from Highway Storm Water Runoff

BRUNO MAESTRI, MICHAEL E. DORMAN, AND JACK HARTIGAN

Guidelines to reduce the impacts of highway storm water runoff have been developed to address both management practices and mitigation measures. The research is a part of the Federal Highway Administration's ongoing program, "Nonpoint Source Pollution from Highway Storm Water." Provided in this paper is a synopsis of interim guidelines for the design of management measures for the removal of pollutants from highway storm water runoff. Three general types of management measures have been determined through previous FHWA studies to be effective in treating highway runoff: vegetative controls (overland flow and grassed channels), detention basins (wet detention basins and wetlands), and retention measures (retention basins, trenches, and wells). Interim design guidelines have been developed based on the experience of the project team and a thorough review of available literature. Field and laboratory studies are currently under way to verify the design procedures and assumptions presented in this paper.

The Clean Water Act (PL 95-217), as amended, sets forth national policy and national water quality programs to restore and maintain the chemical, physical, and biological integrity of water resources. To realize the objectives of the act, the following were established as national goals: (a) that the discharge of pollutants into the navigable waters be eliminated; (b) that, wherever attainable, an interim goal of water quality that provides for recreation in and on the water be achieved; (c) that a major research and demonstration effort be made to develop the technology necessary to eliminate the discharge of pollutants into the water resources; and (d) that federal agencies cooperate with state and local agencies in minimizing pollution.

The Federal Highway Administration (FHWA) has under its purview protection of the environment from pollution by highway sources under the Clean Water Act and other federal laws. The FHWA, in response to these laws and the potential impact on water resources from highway runoff, initiated a cooperative federal and state research program to identify and quantify the effects of highway runoff and to develop management practices for the protection of water resources. The FHWA approached the problem in a four-phase contract research program, as follows:

1. Identify and quantify the constituents of highway runoff,
2. Identify the sources of these pollutants and migration paths from the highway to the receiving water,
3. Analyze the effects of these pollutants in receiving waters, and
4. Develop the necessary analytical tools and abatement/treatment criteria and guidelines for minimizing objectionable constituents.

The first three phases are complete.

The fourth phase is currently being addressed by three research projects. The first research project is complete and constitutes a literature review and state-of-the-art synthesis of storm water best management practices (BMP) applicable to highway systems (*1–4*). The second research project is the subject of this paper and will evaluate retention, detention, and overland flow for pollutant removal from highway runoff based on laboratory and field testing. The third research project will improve on the existing procedures for estimating pollutant loadings from highways.

Summarized in the paper are FHWA interim guidelines (*5*) for the design of retention, detention, and overland flow management measures for pollutant removal from highway runoff. The guidelines assume that the need for controlling pollution from a specific highway site has been established, using guidelines such as those presented by Dupuis and Kobriger (*6*). Effective and ineffective management measures are presented, along with ratings for pollutant removal effectiveness and highway applicability. Presented in the paper are general management techniques and a synopsis of design procedures for site-specific management measures.

SOURCES OF HIGHWAY POLLUTION, CHARACTERISTICS, AND IMPACTS

Highway operation and maintenance can contribute an array of pollutants to surface and groundwater resources. Highway runoff may contain solids, heavy metals, nutrients, oil and grease, bacteria, and other pollutants. The impacts of highway runoff pollution on receiving waters' aquatic ecosystems are extremely site- and runoff-event specific. The objective of a highway runoff pollution management program is to reduce the total pollutant loading that enters receiving waters from highway runoff. The emphasis of the management program is on total runoff, not individual events. Although all highway runoff contains pollutants, the pollutant loading does not always necessarily constitute a problem for receiving waters.

Pollutants accumulate on highway surfaces, roadside areas, and rights-of-way from highway use, maintenance, natural sources, and deposition of air pollution. The concentrations of these pollutants are highly variable by site, and are affected by

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numerous factors such as traffic characteristics, climate, maintenance, adjacent land use, and others.

Highway pollutants, such as solids, heavy metals, and organics (found in fuels and motor oils) have been found to correlate directly with traffic volume. Other pollutants (herbicides and nutrients) are found in highway runoff mainly as a result of highway maintenance activities and adjacent land-use contributions. Management techniques for the control of traffic- or maintenance-related pollutants are, therefore, different. Maintenance-related pollutants are better controlled through the use of general measures, such as herbicide and fertilizer application management (*7*). Traffic-related pollutants are more applicable to site-specific control measures and are the focus of this paper.

The extent to which a pollutant is susceptible to movement from the highway source to the environment will vary based on the chemical nature of the pollutant, its physical-chemical properties such as water solubility and vapor pressure, and its tendency to adsorb to organic matter or sediment (see Table 1). The actual processes that remove or degrade will depend not only on the properties of the pollutant already mentioned, but on the management practices being used to mitigate loading. Certain measures will not provide the time or environment to allow a particular removal process to occur. Of the major transport processes, the combination of sorption and settling will be the key removal mechanisms applicable to highway runoff. Many of the constituents will be in particulate form and will settle. Further, organic chemicals and heavy metals in solution will tend to adsorb to suspended sediments and then settle. Biological action, both degradation and assimilation by microbial and rooted vegetation populations, will be the most applicable transformation process.

Highway runoff pollution may affect water quality of receiving waters through shock or acute loadings and through chronic effects from long-term accumulation within the receiving water. The significance of these impacts is very site specific, and will depend heavily on the highway and receiving water characteristics. Recent research (*6, 8, 9*) indicates few significant impacts for highways with less than 30,000 average daily traffic (ADT). Potential impacts are generally short-term, localized acute loadings from temporary water quality degradation, with few, if any, chronic effects.

Dupuis et al. (*8*) monitored highway runoff pollution impacts on receiving streams at three sites with ADT volumes of 7,400, 25,500, and 15,600. Laboratory bioassays were also conducted with the highway runoff for ADTs up to 135,000. Dupuis et al. concluded that

1. There were no apparent water quality impacts during storm events;
2. Benthic invertebrate faunal population distribution, abundance, and composition were unaffected by the runoff;
3. Periphyton communities showed no discernible impacts; and
4. Bioassays with undiluted highway runoff showed no acute effects on test organisms. Some sublethal chronic effects were observed; however, the use of undiluted runoff makes this a worst-case situation not likely to occur in any receiving water.

In a study of the effects of highway runoff on receiving waters, Dupuis and Kobriger (*6*) summarized the findings of several bioassay studies of highway runoff. Runoff from high traffic highways [one highway at 185,000 ADT (*10*) and one at 50,000 ADT (*11*) did have toxic effects on aquatic biota. Runoff from lower ADT rural highways did not cause discernible toxic stress to aquatic biota].

From these studies and other literature reviewed, the following conclusions can be reached regarding highway runoff pollution potential:

1. Highway runoff does have the potential to adversely affect the water quality and aquatic biota of receiving waters;
2. The significance of these adverse effects is variable by highway, receiving water, and runoff event;
3. Runoff from urban highways with high ADT volumes may have a relatively high potential to cause adverse effects; and
4. Runoff from rural highways with low ADT volumes has a relatively low potential to cause adverse effects.

TABLE 1 PRINCIPAL POLLUTANT FATE PROCESSES BY MAJOR MANAGEMENT MEASURES

	Management Measures			
Pollutant	Vegetative Controls	Detention Basins	Infiltration Systems	Wetlands
Heavy metals	Filtering	Adsorption Settling	Adsorption Filtration	Adsorption Settling
Toxic organics	Adsorption	Adsorption Settling Biodegradation Volatilization	Adsorption Biodegradation	Adsorption Settling Biodegradation Volatilization
Nutrients	Bioassimilation	Bioassimilation	Absorption	Bioassimilation
Solids	Filtering	Settling	Adsorption	Adsorption Settling
Oil and grease	Adsorption	Adsorption Settling	Adsorption	Adsorption Settling
BOD	Biodegradation	Biodegradation	Biodegradation	Biodegradation
Pathogens	Not applicable	Settling	Filtration	Not applicable

DESIGN CONTEXT

Mitigation measures should be designed to take advantage of the following characteristics of highway runoff: (a) nonpoint pollution discharges from frequent minor storms are more critical than discharges during infrequent major storms, (b) first-flush conditions result in relatively high pollutant concentrations during the initial stages of storm runoff, (c) loadings of heavy metals and other toxicants tend to be of greater concern than loadings of nutrients and biological oxygen demand (BOD), and (d) critical pollutants such as heavy metals tend to appear primarily in a suspended form.

Because frequent storms tend to cause runoff primarily from paved areas, they tend to produce highly concentrated discharges of highway runoff and reduced dilution by upstream runoff. As a result, most urban runoff pollution management programs rely on controls for minor storms with relatively short recurrence intervals (e.g., less than 1 yr), rather than the relatively infrequent major storms (e.g., 10-, 25-, and 100-yr events) that serve as performance standards for flood management programs. Mitigation measures are typically designed to control most storms that occur each year. For example, in many sections of the United States, mitigation measures designed to control storms producing less than 1.0 in. of rainfall will control nonpoint pollution discharges from about 90 percent of the storms each year. Runoff from the more significant storm events that are not controlled tends to exhibit significant flows from nonurban areas that can dilute discharges from paved areas.

"First flush" effects refer to conditions under which a large percentage of the total storm pollution load is produced by a relatively small percentage of the runoff volume during the initial stages of runoff. As a result, the initial stages of runoff can exhibit relatively high pollutant concentrations that may induce shock-loading conditions and short-term contraventions of water quality criteria in receiving waters. Conversely, mitigation measures that can isolate first flush loadings for "treatment" may take advantage of smaller storage capacities than measures that must treat all runoff flows. Field studies have shown that the significance of first flush conditions is positively related to the amount of pavement in an urban watershed. Consequently, first flush conditions should be prevalent for most highway runoff settings. Further, first flush effects are attributed primarily to the washoff of particulates from paved areas, meaning that first flush runoff tends to exhibit relatively high loadings of suspended pollutants. Finally, heavy metals tend to exhibit a more pronounced first flush effect than other pollutants.

Heavy metals and other toxicants in highway runoff tend to be of greater concern than other nonpoint pollutants such as nutrients. This is because paved areas tend to produce the highest per-acre loadings and concentrations of heavy metals, because of contributions from vehicular traffic. Likewise, paved areas tend to exhibit less significant sources of nutrient loadings than unpaved areas.

Because most heavy metals and other toxicants in highway runoff tend to occur in suspended form, mitigation measures that achieve high removal efficiencies for suspended solids should also achieve significant removal efficiencies for heavy metals and other critical constituents. However, solids-settling design should account for the fact that the majority of suspended loadings in highway runoff is associated with fine silt particles characterized by relatively low settling velocities.

GENERAL MEASURES FOR EFFECTIVE MANAGEMENT

Certain general measures for managing highway storm water runoff pollution are applicable to virtually all highway situations. These measures are not directed toward site-specific problems, although they can be used in conjunction with effective site-specific measures. The practices cited are relatively low cost and can be incorporated into existing highway design procedures and maintenance programs. They are intended to be used wherever practicable without the necessity of identifying a specific highway runoff pollution problem.

Typically, the pollutant load from highways is transported by storm water runoff from the pavement along curbs. Most of the pollutant load in the runoff is carried as suspended solids or adsorbed to suspended solids. Therefore, management measures are usually intended to reduce the volume of particulates available for transport by runoff or to filter and settle out suspended solids. The measures, which fall into these two categories, are presented as follows (*5*):

1. Curb elimination: Future design or reconstruction of highways should omit the use of curbs for delineation and storm water runoff control where practicable. Where curbs are necessary for traffic control or other reasons, consider partial removal (i.e., leave gaps instead of a continuous curb) to allow air transport of pollutants from the highway. However, partial elimination of curbs should be done with caution, as discontinuous curbs may be a traffic hazard.
2. Litter control: Existing litter control programs and regulations were designed primarily for aesthetic and safety objectives. However, they also achieve pollutant-reduction benefits through limitation of potential pollutant sources.
3. Deicing chemical use management: Proper storage and handling of deicing chemicals coupled with sound application practices will provide significant reduction for potential ground and surface water contamination. Covered storage and handling facilities designed to prevent washoff and loss of deicers coupled with good housekeeping will effectively mitigate potential pollution from these facilities. Attention to optimum application rates of chemicals along with maintenance calibration of spreading equipment will eliminate excessive deicer application.
4. Pesticide/herbicide use management: Use of pesticides and herbicides by state highway agencies (SHAs) are typically limited in scope and have strict controls on application, employee training, and so on. The benefits of these controlled-use programs are shown by the low percentage of total pollutant load attributed to pesticides or herbicides. The pesticide/herbicide controls exercised by SHAs should continue.
5. Reduction of direct discharges: Avoid direct discharges of highway runoff to receiving waters (including ground water) wherever practicable. This would include collection and conveyance through closed conduits. Highway runoff should be routed through an effective management measure, or a combination of them, before discharge to receiving waters.

6. Reduction of runoff velocity: Lowering the runoff velocity to a nonerosive level reduces the ability of the flow to transport particulates, especially bed load, and encourages sedimentation. This can be accomplished by reducing gradients, installing velocity-reduction devices such as drop structures and baffles, and using grassed waterways. There will be some situations, however, where higher velocities may be required to provide for timely drainage of the highway surface and roadside areas, and where devices used to reduce gradients could be a roadside hazard.

7. Establishment and maintenance of vegetation: Vegetation along highway rights-of-way is generally established and maintained for aesthetic purposes and erosion control. Vegetation, particularly dense grass cover, also provides pollutant-reduction mechanisms (filtration, sedimentation, and infiltration) for highway runoff.

These mechanisms can be enhanced by

- Establishing dense grass cover wherever practicable.
- Minimizing the number of grass cuttings per growing season to increase the grass height and resistance to flow. Note that there is a limit to the effectiveness of this; at some height (variable by species) and flow depth, the grass will lie flat and become a less effective pollutant-removal measure. The determination of the optimal number of cuttings should be based on local experience.
- Leaving grass cuttings on the ground to act as additional filter material to encourage velocity reduction and to provide mulch.

INEFFECTIVE MANAGEMENT MEASURES

Several storm water runoff pollution management measures occasionally recommended as BMPs were found to be ineffective in reducing pollutant loads in highway runoff. These ineffective measures are (*5*)

- Street cleaning: Street cleaning is accomplished either by sweeping or street flushing. Although the practice has aesthetic benefits, it is not effective for highway runoff pollutant management.
- Catch basins: A catch basin combines a storage chamber for particulates with a drainage inlet for intercepting storm water runoff. However, the finer solids associated with most of the pollutant load are not effectively removed.
- Dry detention basins: Dry detention basins are used for flood abatement and drainage structure cost economy. Storm water runoff peak flow rates are reduced by storing floods and releasing the water from storage at a lesser rate over a longer period of time. Detention time is generally only a few hours and inadequate to permit settling out of the smaller fractions of suspended materials associated with pollutants.
- Porous pavements: Porous pavements consist of a relatively thin coat of open-graded asphalt over a base of crushed stone. The stone temporarily stores water until it percolates into the subbase material or moves laterally into a drainage channel. Potential pollutant removal occurs as the water infiltrates through the subbase. Because a key aspect of highway design is to maintain a dry subbase for structural stability, use of porous pavements is limited to parking areas and low traffic volume highways.
- Filtration systems: Filtration systems are used extensively as temporary sediment control measures during construction and vegetative cover establishment periods. Commonly used filtration systems include straw bales, sand bags, filter cloth fences, gravel, and sand filters. Filtration systems are generally used to filter out larger fractions of suspended sediments and to cause some deposition upstream of the installation. Finer solids are not effectively trapped and, therefore, highway runoff pollutant removal potentials are low.

MANAGEMENT MEASURES, EFFECTIVENESS AND APPLICABILITY

Management measures were rated (*1, 5*) on the basis of their pollutant removal effectiveness for specific pollutants, relative capital costs, land requirements, and operation and maintenance costs. Ratings are based on information gathered from the review of literature. Efficiencies inferred from other than specific data in the literature are identified. Qualitative ratings are used because effectiveness is dependent on the design of the management measure and site-specific factors that determine runoff characteristics and pollutant loads. The ratings are shown in Table 2.

All measures found effective require space for construction and maintenance. Because the need for mitigation is usually associated with high traffic volumes, and high traffic volumes occur in or near urban areas, the costs of management measures can be high. In many locations, the most practical and cost-effective approach to storm water runoff management may be cooperation with local government in installations that serve the purposes of both levels of government. Shown in Table 3 is the applicability of the specific management measures for use in different highway configurations.

The primary management measure for highway runoff pollution is vegetative controls because of their relatively low costs (compared to the other measures) and their widespread applicability. However, considering that storm water runoff management for pollution abatement is principally needed in high-traffic corridors, vegetative controls may be impractical in many locations. The second choice for a management measure is wet detention. Detention typically costs more than vegetative controls and less than infiltration systems or wetlands. Infiltration systems and wetlands are variations on detention, and are considered as special subsets of detention.

Combinations of measures may be used to compensate for certain site limitations and to increase pollutant-removal effectiveness. An example would be use of infiltration wells in a detention basin to increase pollutant removal while decreasing long-term runoff storage requirements. Another example is the use of overland flow to filter suspended sediments from runoff upstream from an infiltration basin or trench.

IMPLEMENTATION OF SITE-SPECIFIC MEASURES

Site-specific management measures can be used singly or in combination to address highway runoff pollution problems. They are presented based on their relative effectiveness, adaptability to highway design and right-of-way, ease of operation, and minimum maintenance (*12*).

TABLE 2 EFFECTIVENESS RATINGS OF MANAGEMENT MEASURES

Management Measure	Type	Pollutant Removal Effectiveness: Particulates	Heavy Metals	Pesticides	Organics	Relative Capital Costs/ Acre[a]	Additional Land Requirements	O & M Costs: Routine	Nonroutine
Curb elimination	Post deposition	H	H	N/A	H	L	M to H	0	0
Litter control	Source	L to H	L to H	L to H	L to H	L	0	0	0
Controlled use of deicing chemicals	Source	N/A	H	H	H	L	0	0	0
Controlled use of pesticides/herbicides	Source	N/A	H	H	H	L	0	0	0
Grassed channels	Post runoff	H	H	M	H	L	L	L	L
Overland flow	Post runoff	H	H	M	H	L	M to HL	L	L
Dry detention basins	Post runoff	L to H	L to H	L to M	L to M	M	M	L	L
Wet detention basins	Post runoff	H	H	H	H	H	H	L	L
Infiltration systems	Post runoff	H	H	H	H	M to H	L to M	H	H
Wetlands	Post runoff	H	H	M to H	M to H	M to H	M to H	L	L
Street cleaning	Post deposition	L to H	L	L	L	L	0	H	0
Catchbasins	Post runoff	L	L	L	L	M to H	L to M	H	H
Porous pavements	Post runoff	H	H	N/A	H	L to H	0	M	M
Filtration systems	Post runoff	L to M	L	L	L	L	0	M	M

NOTE: Ratings: H = high, M = medium, L = low, 0 = none, N/A = not applicable.
[a]Based on additional capital costs required for nonpoint pollution management per acre.

TABLE 3 APPLICABILITY OF POLLUTION MANAGEMENT MEASURES TO HIGHWAY CONFIGURATIONS

Management Measure	Planned Highway Construction: Interchange	Elevated Highway	At-grade Highway	Depressed Highway	Existing Highway Retrofit: Interchange	Elevated Highway	At-Grade Highway	Depressed Highway
Vegetative controls								
Grassed channel	High	Low	High	Low	Medium	Low	High	Low
Overland flow	Medium	Low	High	Low	High	Low	High	Low
Detention basins	High	Medium	Medium	Low	Medium-High	Medium	Medium	Low
Infiltration measures								
Basin	High	Medium	Low	Low	Medium-High	Medium	Medium	Low-Medium
Trench	Low	Medium	Medium	Medium	Medium	Low-Medium	Medium	Low-Medium
Well	Medium	Low	Low	Low	Low-Medium	Low-Medium	Low	Low
Wetlands	Medium	Low	Low	Low	Low-Medium	Medium	Medium	Low

Vegetative Controls

Vegetative controls involve the use of vegetated surfaces to manage storm water runoff pollution from highways. Vegetative controls are also common management practices for erosion and sediment control. The natural capability of vegetated surfaces to reduce velocity of runoff, enhance sedimentation, filter suspended solids, and increase infiltration can be used to remove runoff pollutants.

Vegetative controls include

1. Grassed channels, or waterways, which are ditches, channels, or swales with a cover of grass designed to inhibit erosion and enhance settling of suspended solids; and
2. Overland flow, which is an application of the filter strip concept, in which strips of grass are designed for sheet flow to filter pollutants from the runoff and increasing infiltration.

These vegetative controls are highly effective management measures for highway runoff pollution and are the primary management measures for most highway runoff situations. Vegetative controls are adaptable to a variety of site conditions, are flexible in design and layout, and are the least costly management measure. Their use is recommended wherever practical. Vegetative controls can be used as sole management measures or in combination with secondary measures (e.g., detention basins, infiltration systems, and wetlands). Grass is the most common vegetation used and is more effective at pollutant removal than shrubs, trees, or other vegetation.

The development of vegetative controls, whether grassed channels or overland flow over grass cover, involves design for pollutant removal and stability and the establishment and maintenance of grass cover. Use of vegetative controls is influenced by the following factors: topography, soils, space, climate, and erosion. The design process is summarized as follows:

1. Estimate runoff flow rates for design runoff event;
2. Estimate grade of proposed channel or overland flow;
3. Select a grass cover suitable for the site;
4. Determine maximum permissible flow depth for the grass cover and slope to be used;
5. Estimate channel or overland flow dimensions;
6. Determine flow velocity;
7. Determine whether design flow is less than maximum permissible flow (stable) or greater than maximum permissible flow (unstable);

8. Reduce flow depth by increasing bottom width or using flatter side slopes, or both, if channel or overland flow is unstable. Maximum noneroding depth can be increased by decreasing the slope;

9. Determine whether provisions for erosion protection are necessary during establishment of grass cover; and

10. Establish and maintain continuous grass cover.

Detention Basins

Where it is impractical to use vegetated roadside ditches, wet detention basins are the most practical and effective storm water runoff management measure for pollution abatement. Detention is a highly effective management measure for controlling storm water runoff quality, if sufficient detention time is provided. Performance of wet detention basins, or those that maintain a permanent pool of water, has been found to range from poor to excellent, depending on the size of the basin relative to the size of the drainage area served and on storm characteristics of the area. The principal mechanism for the removal of particulate forms of pollutants in wet basins is sedimentation, but some basins exhibit substantial reductions in soluble nutrients such as soluble phosphorus, and nitrate and nitrate nitrogen. This may be attributable to biological processes in the permanent pool.

Any particular detention basin will exhibit variable performance characteristics depending on the size and characteristics of the storm and the storm water runoff being processed by the basin. Therefore, a procedure for estimating the long-term average performance of a basin is a more practical tool than a procedure for analyzing individual storm events. Driscoll (*13*) reported a procedure based on a probabilistic analysis methodology used to compute long-term average performance from the statistical properties of detention basin inflows. The analysis assumes that overall performance is due to the combined effect of removals under dynamic conditions as flows move through a basin and under quiescent conditions between storms. The methodology was tested against observed performance and monitored storm events from the Environmental Protection Agency's Nationwide Urban Runoff Program (NURP) data base of 5 to 30 or more separate storm events at each of 13 detention basins.

The following adaptation of the methodology reported by Driscoll can be used to estimate long-term efficiency of wet detention basins or to estimate the dimensions or proposed basins to achieve desired removal rates. This presentation assumes a permanent pool in the detention basin. It is not applicable to dry basins, and cannot be used to size basins for peak flow attenuation. Infiltration of water from the retained pool would increase performance under both dynamic and quiescent conditions.

The design procedures for wet detention basins are outlined as follows:

1. Determine rainfall characteristics;
2. Determine runoff coefficient;
3. Determine settling velocities of particulates;
4. Determine distribution of pollutants in runoff;
5. Estimate the dimensions of proposed basins to achieve desired removal rates;
   - Estimate dynamic removal efficiency and estimate quiescent performance;
   - Develop a chart to estimate percentage of total suspended solids removal versus basin surface area;
6. Design basin configuration to minimize potential for short-circuiting; and
7. Design all basin bank slopes at 3:1 or flatter, maintain grass cover where practicable.

Rainfall and runoff characteristics, settling velocities for suspended solids in runoff, and the distribution of particulates and pollutants in each size range are needed to design wet detention basins to achieve pollutant-removal objectives.

Wetlands

Wetland is a general term for land where the water table is at or near the surface, or the land is inundated by relatively shallow water, or supports aquatic vegetation. Saturation is the dominant factor in soil development and species composition. Wetlands are complex ecosystems often occurring at the interface between terrestrial and aquatic systems. They are generally characterized by high floral productivity and nutrient needs, high decomposition rates, low oxygen content in the sediments and substrates, and large adsorptive surfaces in the substrate.

Wetlands can provide a highly effective management measure for highway runoff pollution, assimilating large quantities of suspended and dissolved materials from inflow. However, development of wetland treatment systems is a complex process that is not well defined. Differences in geographic location, climate, hydrologic parameters, and wetland type significantly affect pollutant removal effectiveness. In many areas, wetlands are not a practical alternative.

Wetland treatment systems are a variation on detention, removing runoff pollutants primarily through sediment retention and vegetative uptake. Wetland designs differ from conventional detention systems by being shallower, using vegetation as a pollutant-removal mechanism, and emphasizing slow-moving, well-spread sheet flow within the wetland. Wetland treatment systems are applicable in place of standard detention basins where the water table is at or near the surface and there is sufficient space for a shallow basin, or where there is an existing natural wetland.

Infiltration Systems

An infiltration system is a runoff management method whereby surface runoff is temporarily stored, allowing it to infiltrate the ground. Infiltration systems are used in several areas of the United States as an alternative method for the disposal of storm water runoff. An infiltration drainage system can consist of one or several types of installations, and can be used alone or in combination with conventional systems of disposal. Infiltration techniques include open basins, infiltration trenches, and infiltration wells.

Infiltration systems can provide effective management of highway runoff pollution, provided that certain requirements are met. An effective infiltration system requires (a) soils or subsoils that are moderately to highly permeable, (b) a groundwater table a minimum of 10 ft (3 m) below the bottom of the infiltration point, (c) a runoff inflow relatively free of suspended solids; and (d) sufficient storage for the design runoff event during the infiltration period.

Infiltration systems are typically designed as management measures to control storm water runoff or recharge groundwater resources, and reduction of pollutant loads in runoff is a byproduct. A general design procedure has been developed that can be adapted to specific site characteristics.

HIGHWAY APPLICATIONS

In applying management measures to specific highway runoff situations, it may be desirable to combine two or more measures. Combinations of measures may increase pollutant-removal effectiveness, allow for filtration of suspended solids, or be used to overcome site factors that limit the effectiveness of a single measure. Although each of the four cost-effective measures previously discussed can be used alone, combinations of measures are recommended where practicable.

Vegetative controls are the only management measure providing pollutant abatement while the runoff is conveyed from point to point. Therefore, vegetative controls should be used to convey highway runoff wherever possible. Such controls should serve as the runoff collection and conveyance system, both as a single management measure and as a link between different measures.

Vegetative controls can be used in combination with other effective management measures to increase pollutant removal, provide filtering of suspended solids for infiltration systems, and reduce erosion and scour at inflow discharges to infiltration basins, detention basins, and wetlands. Combinations are particularly advantageous where the desired length of grassed channel or width of overland flow is unobtainable.

Detention basins may be used in combination with vegetative controls to provide storage of runoff or sediment removal before infiltration basins or wetlands. The primary consideration in the use of infiltration systems for pollutant removal from highway runoff is the vulnerability of the system to sediment. Except for basins receiving relatively sediment-free runoff, infiltration systems require additional highway runoff management measures (vegetative controls or detention basins) to provide adequate runoff storage and sediment removal before infiltration. Thus, infiltration systems are usually an add-on feature to other management measures.

Wetlands can be used in combination only with vegetative controls or detention, not with infiltration. Typically, wetlands would receive inflow from vegetative controls or a detention basin and discharge (if there is an outlet) to vegetative controls. Wetlands should not be used before infiltration basins, as accumulated sediment or decaying plant matter are often flushed from wetlands in the spring. The sediments and particulate matter could clog the infiltration basin. In addition, conditions favorable to wetlands, such as a high water table and impervious soils, are unfavorable to infiltration measures.

CONCLUSIONS

The primary mitigation measures identified as effective for control of pollution from highway runoff are vegetative controls, wet detention basins, infiltration systems, and wetlands. These measures, used singly or in combination, along with application of the general guidelines, can provide major reductions in pollutant loadings resulting from highway runoff.

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Planning Urban Access for Large Combination Trucks

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In Canada and the United States, as a result of liberalized regulations of freight motor vehicle weights and dimensions, there will be increasing pressure to provide urban access to large combination trucks. Although studies have recently been completed on vehicle performance, the effects of oversize vehicles under open highway conditions, and the identification of the highway network for their operation, it is essential at this time that a better understanding of the problems of urban access and possible solutions be acquired. Described in this paper is research conducted in the sociotechnical criteria and methodology for the definition and assessment of urban access policy alternatives. The criteria include the ability of oversize vehicles to use urban truck routes and terminals as well as the effects of such vehicles on urban access routes. To augment data available from published and unpublished sources, a questionnaire survey of transportation departments of urban areas, provinces, and states in North America was carried out. In this paper, following background summary, urban access issues are introduced and a utility theory-based methodological framework for the evaluation of access alternatives is described. Access policy options are defined and evaluated. Results of the evaluation process provide new insights into the development of solutions to the urban access problem. In conclusion, the innovative nature of the evaluation model, as well as some guidelines for the planning of urban access are highlighted.

A major government-industry cooperative research effort, coordinated by the Road and Transportation Association of Canada (RTAC) and the Canadian Conference on Motor Transport Administrators (CCMTA), examined the effect of variations in truck weights and dimensions on vehicle stability and control and on pavement loadings (*1*, *2*). The testing phase of the study has recently been completed. In addition to stability and pavement response studies, preliminary research results on industry impacts have been reported (*3*).

Presently, work is under way to develop regulatory principles. The first level of priority has been assigned to apply revised size and weight scenarios in regulating the tractor semitrailer and various configurations of double trailers (i.e., *A*-train, *B*-train and *C*-train doubles). Recommendations are expected to include a program of upgrading highway facilities.

Next in line would be regulations for extended length vehicles, namely rocky mountain doubles, turnpike doubles, and triple trailers. The rocky mountain doubles are double trailer combinations, with the lead trailer being 45 to 50 ft (13.7 to 15.2 m) followed by a short pup trailer of 26 to 28 ft (7.9 to 8.5 m). Turnpike doubles are twin 45 to 50 ft (13.7 to 15.2 m); trailers and triples are a combination of 26 to 28 ft (7.9 to 8.5 m) pup trailers. In all cases, trailer width is restricted to 8.5 ft (2.6 m).

In the Canadian provinces of Alberta, British Columbia, Manitoba, Quebec, and Saskatchewan, at present, special rules and regulations apply for operating extra-length combination vehicles. These include specific permits applicable on specified routes. The conditions and routes allowed vary for different types of equipment.

In the United States, longer combination trucks are at present operating in 12 states and on 6 additional state turnpikes (*4*). The feasibility of a nationwide network for longer combination vehicles has been investigated pursuant to Sections 138 and 415 of the Surface Transportation Assistance Act (STAA) of 1982. Among other unresolved issues associated with a long combination vehicle network, local access is believed to be the most troubling aspect of the network (*4*).

In Canada, as well as in the United States, available evidence suggests that the trucking industry is switching to vehicles with the larger dimensions for truckload type of traffic and to longer combination vehicles based on the use of wider (8.5-ft) pup trailers for less-than-truckload operations (*3*, *5*). There is every indication that whenever and wherever regulations permit rocky mountain and turnpike doubles and triple trailers, the trucking industry will seize the opportunity to increase its use of such large trucks.

URBAN ACCESS ISSUES

Canadian road motor regulators and municipal governments have not so far clarified the extent to which large combination trucks are to be granted access to existing terminals and other points of loading or unloading. It is, however, commonly assumed that large combination vehicles will be granted a certain degree of urban access. In the United States, the STAA (1982) includes a provision for "reasonable access." According to this provision, " . . . states may not deny reasonable access to vehicles of the weights and linear dimensions authorized by the STAA (1982) between the National Network and terminals or service facilities" (*5*).

Clearly, there are opposing pressures at work. Trucking interests, especially those that are potential users of large combination trucks, are interested in access to their terminals and other major generators of shipments. Also, they are interested in avoiding any extra costs associated with urban access and reducing delays in serving major hub terminals. On the other

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hand, the urban community wants to avoid adverse impacts of urban access provided to such vehicles. The allocation of incremental costs of urban access routes for oversize vehicles is an unsettled issue.

For policy analysts and planners, the complex task is to balance the urban access (i.e., associated productivity gains in goods movement) against effects of urban access (e.g., costs of road improvements, safety, traffic disruption, and environmental impacts). Trade-offs are to be investigated between staging areas (for combination vehicle breakup) with virtually no urban impacts and options for permitting urban access beyond major highways.

It is assumed here that interchanges for the oversize truck entrance or exit either are adequate or will be modified. Our interest here is in urban access routes that link staging areas or existing or new terminals with major intercity highways.

METHODOLOGICAL FRAMEWORK

Previous authors have recognized the need for research in urban access issues and called for tools that treat these multidimensional socio-technical issues *(4, 5)*. In order to address the urban access problem, a methodological framework was defined (see Figure 1).

At the outset, characteristics of oversize combination vehicles (in terms of offtracking, backsway, braking, and blocking motorists' view) were noted. In the second step, the current practice of providing urban access for the existing large combination trucks was reviewed and outstanding problems were noted. The review of the practice of providing urban access included staging areas as well as access routes and terminals. Typical sources of information include recent reports on this subject *(6–8)*.

In the third step, a survey of transportation departments of urban regions and provincial and state transportation departments was carried out to obtain supplemental information about current practices of providing urban access and existing as well as anticipated problems. From the findings of Steps 1 to 3, a synthesis of future (potential) issues and value structure was carried out in Step 4. Access options were also defined in Step 4.

A utility theoretic evaluation model was defined in Step 5 for establishing the relative desirability of the various access options. In Step 6, applications of survey results and the utility-theoretic model were illustrated in the form of evaluating four access options, and inferences were drawn for urban access of large combination trucks. Highlights of the overall research project are presented in this paper.

SURVEY OF TRANSPORTATION DEPARTMENTS

A questionnaire type of survey was initiated to elicit current practice toward oversize vehicles, together with any changes in the parameters that the various agencies intended to implement or considered should be implemented to accommodate these vehicles.

The questionnaire was designed to obtain factual data as well as to quantify values of access criteria and related factors. Specifically, the questionnaire requested information on the maximum size of vehicle allowed in the area, the degree of urban access permitted, vehicle condition, hitching methods used, weight restrictions, truck routes (including traffic disruptions), accidents, damage to pavement and street furniture, geometrics for urban truck routes, signalization, terminals, and environmental impacts. In addition to seeking responses to questions posed, copies of appropriate documents were requested in cases where guidelines or policies (other than those of the national or provincial and state manuals) were available.

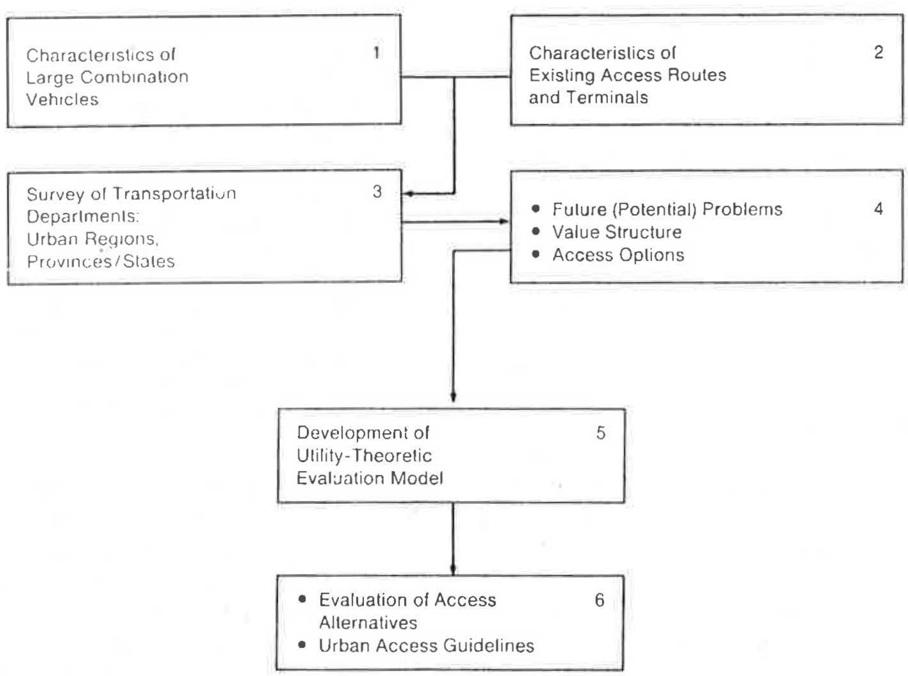

FIGURE 1 Methodological framework.

Questionnaires were sent to the chief executive officer of urbanized region transportation departments and provincial or state transportation departments, or both. The choice of urban regions was based on their location within a network of highways that is presently served, or could be served in the future, by large trucks. It was made clear in the questionnaire that "oversize" vehicle referred to vehicles greater than 90 ft (27.4 m) long and 8 ft (2.44 m) or greater width. The cover letter stated that through their cooperation, the research should result in a better appreciation of problems and opportunities for the accommodation of these vehicles on access routes and terminals.

Out of more than 200 questionnaires that were mailed out, a total of 58 responses were received (provinces/states 24, urban areas 34). The design of the questionnaire permitted responses on various modules by different divisions within a transportation department. A number of agencies, because of lack of information, did not respond to parts of the questionnaire. Also, because of the unusual length of the questionnaire (48 questions, 17 pages) and the detailed nature of the questions asked, the level of response from urban areas was rather low. Despite the modest response level on some modules of the questionnaire, this information base is the most comprehensive source of information on urban access factors known to the authors, including values expressed by transportation experts with urban and provincial or state government agencies in North America. Thus, the survey results noted as follows provide further insights into the urban access problem.

SURVEY RESULTS: PROBLEMS AND PROSPECTS

Factors for the design and evaluation of truck routes have been of interest to researchers and practitioners alike in the past. In the context of urban access for large combination trucks, their definition and relative importance is of special significance. Through a number of questions asked, a list of such variables has been compiled (Table 1). These consist of three types of factors: (a) truck transportation productivity improvement factors, (b) factors that define the cost of access routes (will probably be borne jointly by the urban and provincial/state governments), and (c) urban impacts on road users and residents.

Agencies surveyed were asked to show the importance of criteria on a scale of 1 (extremely unimportant) to 7 (extremely important). The results shown in Table 1 suggest that policy and planning experts have a balanced view of urban access issues. The top three criteria fall into the urban impact category (i.e., limiting large trucks to major commercial or industrial routes, safety, and traffic disruption).

Ranks 4 and 6 go to access route cost variables, and truck productivity factors receive Ranks 5 (access to terminal) and 11 (truck delays). It appears that providing access to terminals is accorded sufficient importance. Environmental impacts, because of their low levels, are not rated high compared with safety and convenience factors.

As for existing criteria for truck terminal location and planning, there do not appear to be many guidelines that have to be followed by common carriers except, of course, zoning regulations (Table 2). In general, terminals are not required to be within the defined distance of currently designated truck routes. This implies that part of existing urban access routes may be on roads that are not designed to handle even tractor semitrailer traffic adequately. Also, a very high percentage of transportation departments do not provide truck routes to any location requested by a terminal operator.

Existing terminals may have difficulty in accommodating future truck traffic requirements. Respondents suggest that in

TABLE 1 CRITERIA FOR THE EVALUATION OF LARGE TRUCK URBAN ACCESS ALTERNATIVES SURVEY RESULTS

Criteria	Rank	Rating (scale of 1 to 7)	Standard Deviation
Truck transportation productivity			
Provide access to terminal	5	5.14	1.46
Minimize truck delays	11	3.41	1.37
Access route cost			
Minimize pavement damage	4	5.30	1.43
Minimize cost of geometric improvements	6	4.70	1.29
Urban impact			
Avoid the use of local collectors (prevent trucks from entering residential areas)	1	6.52	0.73
Maximize safety	2	6.26	1.05
Minimize urban traffic disruption	3	5.48	1.44
Minimize noise	7	4.52	1.27
Minimize vibrations	8	4.18	1.47
Minimize air pollution	9	3.91	1.38
Minimize visual pollution	10	3.87	1.55

NOTE: Twenty-three agencies responded to this question.

TABLE 2 SELECTED SURVEY RESPONSES: TERMINALS

	Response	Percentage
Existing terminals		
Are terminals required to be within defined distance of currently designated truck route? (23 agencies responding)	Yes No	13 87
Are new truck routes provided to any location requested by a terminal operator? (18 agencies responding)	Yes No	17 83
Are terminals required to make provision for expansion? (14 agencies responding)	Yes No	7 93
Do you have regulations which prohibit queueing outside the terminal on the access road? (26 agencies responding)	Yes No	15 85
Are oversize vehicles allowed to park outside the terminal? (16 agencies responding)	Yes No	50 50
Are there any provisions of parking control regulations which specifically relate to oversize trucks? (26 agencies responding)	Yes No	23 77
Future terminals		
Will the location of terminals near main highways be an essential criterion in the near future? (17 agencies responding)	Yes No	53 47
Have you considered the "common carrier" Co-op terminal? (21 agencies responding)	Yes No	95 5
Do you intend to evaluate the possibility of establishing a "common carrier" Co-op terminal? (21 agencies responding)	Yes No	0 100

most urban areas, terminals are not required to make provision for expansion and there are no regulations that prohibit queueing outside the terminals on access roads. About one-half of responding agencies indicate that oversize, vehicles are allowed to park outside terminals. In fact, more than two-thirds of agencies stated that there are no provisions of parking control regulations that specifically relate to oversize trucks.

There are indications that the presence of large vehicles will influence future planning for terminals (Table 2). Over one-half of the respondents expect that the location of terminals near main highways will be an essential criterion of urban access. Comments received indicate that new terminals could be appropriately located in industrial parks in the vicinity of major highways. There is, however, little support for the common carrier "cooperative" terminal concept.

Survey responses on truck routes indicate that existing regulations are not strict enough for controlling the urban travel of large trucks (Table 3). Over one-half of the responding agencies indicate that truck routes are not restricted for use by certain specific sizes or gross weights of vehicles. Although truck routes are marked by proper signs, there are infractions of the designated truck-route system.

TABLE 3 SELECTED SURVEY RESPONSES: TRUCK ROUTES

	Response	Percentage
Existing practice		
Are truck routes in urban areas restricted for use by certain specific sizes or gross weights of vehicles? (28 agencies responding)	Yes No	43 57
How are truck routes marked through urban areas? By sign? (24 agencies responding)	Yes No	63 37
Are there any infractions of the designated truck route system? (25 agencies responding)	Yes Probably No	80 8 12
Future routes		
Have the urban truck routes in your area been reviewed for use by oversize vehicles? (27 agencies responding)	Yes No	59 41
Have or will any special geometric criteria be introduced for the design of urban truck routes in future? (18 agencies responding)	Yes No	33 67
Have or will any change be made to the signalization at intersections along truck routes to allow for oversize trucks to clear the intersection? (28 agencies responding)	Yes No	14 86

A majority of agencies have reviewed truck routes in their areas. Interestingly, a majority of respondents have not or will not introduce special geometric criteria for the design of urban truck routes. Also, a very high percentage (86 percent) of respondents indicate that urban areas have not or will not make changes to the signalization at intersections along truck routes to allow for oversize trucks to clear the intersection. This appears to indicate that access of oversize combination trucks at existing terminals located in a highly dispersed manner is not necessarily regarded as a viable solution to the urban access problem (Table 3).

Survey responses that fall into the urban impacts category are shown in Table 4. Eighty-nine percent of respondents have not modified or introduced any extra safety precautions on urban truck routes owing to the introduction of oversize vehicles.

TABLE 4 SELECTED SURVEY RESPONSES: URBAN IMPACTS

	Response	Percentage
Have you modified or introduced any extra safety precautions on urban truck routes because of the introduction of oversize trucks? (28 agencies responding)	Yes No	11 89
Do you consider that tractor trailer combinations significantly increase congestion on urban road network? (31 agencies responding)	Yes No	65 35
On the urban street network, are you experiencing damage which may be attributable directly to the use of increased (oversize) truck sizes? (22 agencies responding)	Yes No	41 59
Do you anticipate any increase in the rate of damage occurrence in 5 years time? (16 agencies responding)	Yes No Probably Unknown	31 37 13 19
Do you anticipate any increase in environmental pollution (noise, emissions, visual, other . . .)? (25 agencies responding)	Yes No	36 64
Do you have any regulations governing environmental pollution which were formulated or revised to apply to oversize trucks? (25 agencies responding)	Yes No	4 96

Sixty-five percent of the responding agencies expect that tractor-trailer combinations will significantly increase congestion on urban networks. A majority of respondents are not experiencing damage to pavements and road furniture attributable directly to oversize trucks. The reason stated for this observation is the low volume of large trucks presently using urban roads. However, a reasonably high proportion of agencies anticipate an increase in the rate of damage occurrence in the next 5 years (Table 4).

Sixty-four percent of respondents do not expect an increase in environmental pollution (i.e., noise, emissions, visual pollution, and so forth) attributable to large combination trucks. Almost all (96 percent) agencies indicate that they do not have any regulations governing environmental pollution that were formulated or revised to apply specifically to large trucks (Table 4).

Responding agencies prefer truck routes that loop outside a city with specific access points (see Table 5). Next in the order of preference is the type that loops within the urban area, and the hub and radial type of truck route (which generally accommodates heavy urban traffic volumes) was assigned the last rank. Respondents also indicate that urban transportation authorities consider large trucks, including combination vehicles, to be reasonably well maintained (Table 5).

ACCESS OPTIONS

Four options can be defined for providing large combination truck service to urban areas that are connected by major highway networks. The first option is to allow oversize trucks

TABLE 5 SELECTED SURVEY RESPONSES: IMPORTANCE OF CRITERIA

	Average Score (scale of 1 to 7)	Standard Deviation
Truck Routes[a]		
What type of truck route layout do you operate and favor for an urban area served predominantly by oversize trucks?		
Loop outside city with specific access points	6.15	0.99
Loop within city	3.95	2.22
Hub and radial	2.90	1.85
Urban Impacts[b]		
From your experience are the vehicles well maintained and in good condition?		
Trucks (straight)	4.81	0.68
Tractors	4.90	0.70
Trailers	4.86	0.65

[a]13 agencies responding.
[b]21 agencies responding.

to use the shortest route available to reach terminals. In such a scenario, most terminals requiring access are those that are already in existence. Such terminals are not necessarily clustered in a limited number of locations very close to highway interchanges. This option, in general, would follow the current practice of reaching truck terminals.

A second option would require that terminals be located within a short distance (e.g., up to 5 km) from major interchange points. The use of distance as the only criterion may not permit access to a reasonable proportion of existing terminals. Also, there is hardly any assurance that appropriate sites could be found in the vicinity of interchanges for the development of new terminals.

A third option is to locate terminals within industrial parks that are situated along major highways. In most instances, these sites are within 5 to 8 km of major interchanges and are generally accessible by major roads. Because of their highly commercial and outlying nature, any access road improvements can be implemented without unreasonable cost. However, this option would require the establishment of design and operational standards that are best suited for long combination trucks.

Finally, a fourth option for providing urban access to large combination trucks is that of staging areas on or adjacent to the intercity network's right-of-way (i.e., major interchanges). However, such sites, although difficult to find within the urban part of the right-of-way, are meant only as break-up points and are not intended to serve as terminals. This option is the most restrictive in terms of serving urban areas but avoids the use of combination vehicles on urban roads.

In this paper, these access alternatives (i.e., policy options) are assessed by using a utility-theoretic evaluation model described as follows. Results of the survey of transportation departments are also used in the example application.

UTILITY-THEORETIC EVALUATION MODEL

Urban access policy decisions require trade-offs between the degree of urban access offered to long combination trucks and the extent of urban impacts, including the cost of building or modifying major urban roads. The higher the degree of access, the lower the motor carriers' cost of serving an urban area, and therefore the higher the truck transportation productivity. On the other hand, the higher the degree of urban access, the greater the extent of urban impacts, including higher urban road costs.

A utility-theoretic model conceptualized by Khan in an earlier paper can be further developed here and applied to the urban access problem (*9*). A previous application of utility theory to a simpler truck route choice problem was carried out as a graduate research thesis at Carleton University (*10*).

In Figure 2, the urban community's indifference between the value of large truck access and its impacts is represented by curve *I*. For given resources (i.e., monetary and other), technical trade-offs that are possible between urban access provided and resulting urban impacts are represented by lines T_1, T_2, . . ., and so on. A specific *T* line defines a given magnitude of resources. Point *A*, which is the point of tangency between a given *I* curve and T_1 line is the optimal degree of access for T_1 level of resources. Of course, a higher magnitude of resource expenditure, such as shown by T_2, would enable a higher optimal level of access. On the other hand, if urban access higher than *A* level is allowed and resource expenditures are defined by T_1, the extra urban impacts are more than enough to offset the extra welfare from increased access. In such a case, the urban area moves to a lower indifference curve.

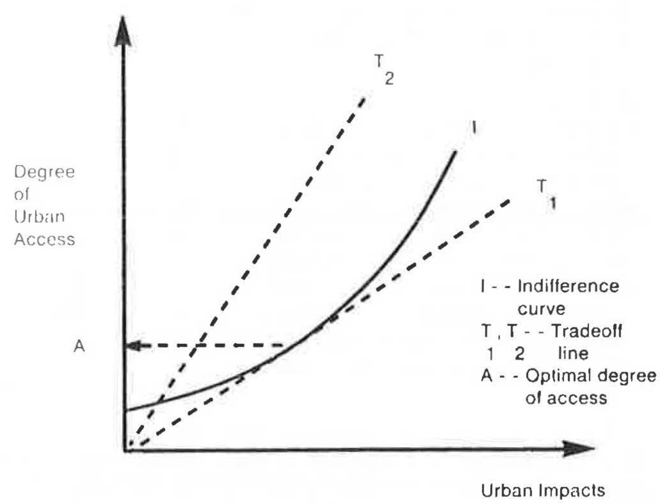

FIGURE 2 Urban access versus impacts.

From an urban community perspective, low-cost trucking services provide benefits to all the production and consumption sectors and up to a certain degree of urban access, social benefits outweigh social costs. Also, conceptually, the optimal degree of urban access is at a location where net benefits are the highest (Figure 3). The social choice of the oversize truck urban access policy is conceptualized in Figure 4. On the

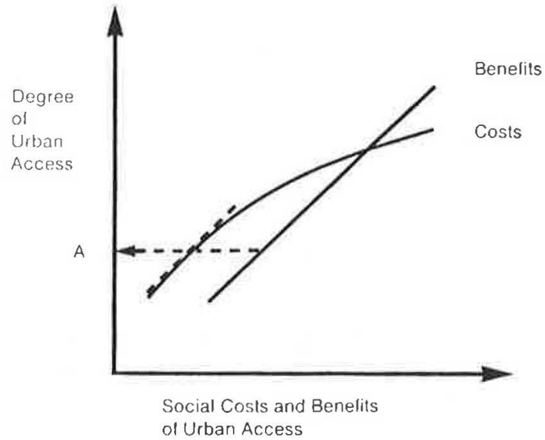

FIGURE 3 Costs and benefits of urban access.

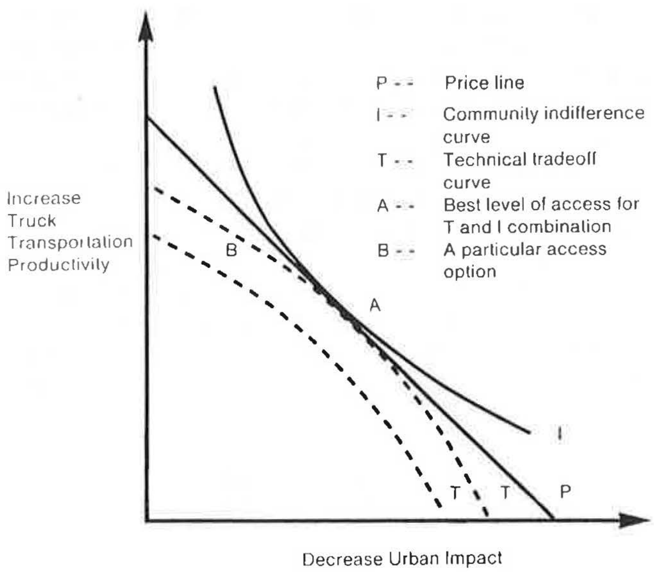

FIGURE 4 Social choice of urban access.

assumption that equity or distributional aspects can be taken into account, as described later in this paper, the access choice problem is based on the identification of the best possible combination of truck transportation productivity and urban impact outputs for a given level of resource inputs. As shown in Figure 4, this is the urban access level *A* that is the point at which the technical trade-off curve, *T*, is tangent to the community indifference curve, *I*.

Community value structure and the extent of physical and monetary impacts associated with the various levels of access determine the optimality point. For example, in environmentally sensitive congested urban areas, optimal degree of urban access may turn out to be the minimal level of access provided in the form of staging areas. On the other hand, for relatively newer urban developments with well-positioned industrial areas and relatively unconstrained urban road rights-of-way, the best option might turn out to be access to terminals located within industrial parks. In order to assist transportation planners and policy analysts, the utility-theoretic methodology, described later in this paper, can be used to establish the best access level that would reflect local conditions as well as value structure.

In considering urban access options, the question of the incidence of costs and benefits cannot be ignored. Although traditional approaches to urban transportation policy decisions have tended to emphasize economic efficiency and productivity and ignore the distributional aspects of urban impacts, there is, however, the increasing sensitivity to the equity question at this time. Despite the recognition of the goal of distributional efficiency, available methodology cannot accommodate the complexity of the access problem for a various reasons. First, for a number of urban impacts, objective measures do not exist. Second, market prices are not available for a number of impacts. Third, direct aggregation of quantifiable costs and benefits in any form without weighting the costs and benefits for the impact groups would be inappropriate. Clearly, there is a need for an innovative approach to help decision makers decide on the degree of urban access to be provided to oversize trucks.

It is assumed that urban access alternatives are to be evaluated by using criteria such as those listed in Table 1. These are designated as $cr_1, cr_2, \ldots, cr_g, \ldots, cr_q$. Two conflicting criteria are shown in Figure 5. The outputs (representing various levels of criteria attainment) are aggregated on an urban network basis and weighted for the relevant impact groups. The community indifference curves (I_1, I_2, I_3), assumed linear in this model for operational reasons, express the relative importance of the criteria—defined by weights, w_g. All possible alternatives, $a_1, a_2, \ldots, a_m$, are defined by the technical trade-off curves shown as T_1, T_2, and T_3. A given trade-off (constant resource) curve, say T_1, would represent a subset of all possible alternatives. The outputs and trade-off curves can be expressed in relative value units (e.g., utils or dollars), as described in the following paragraphs.

In this formulation of the utility-theoretic model, it is assumed that uncertainties do not exist in the estimation of access costs and truck transportation as well as urban impacts. Access

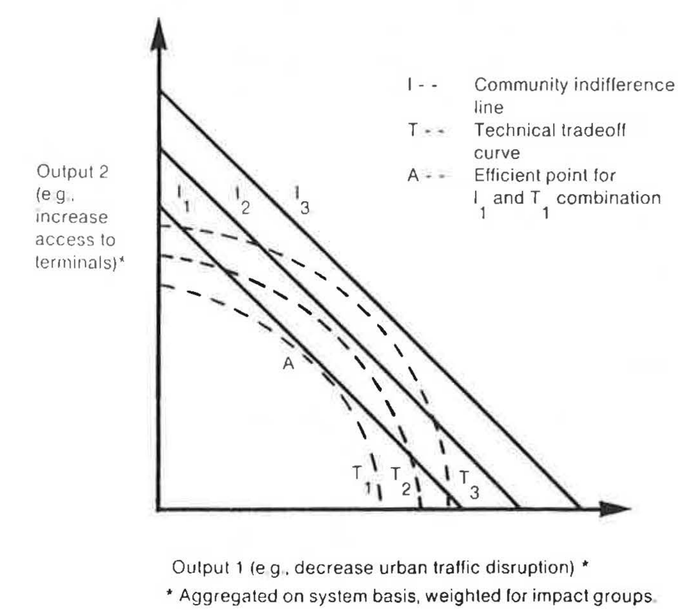

FIGURE 5 Combination of economic and distributional efficiency criteria in access policy evaluation.

alternatives are defined by their outcome states, for any affected component of the urban community, including interest groups (e.g., commuters, other motorists, urban residents, and so on). The outcome states are defined by combining the various levels of criteria attainment (through the use of "and" ^ "not" ~ symbols):

$$o_1 = \text{cr}_{11} \wedge \text{cr}_{21} \wedge \ldots \wedge \sim (\text{cr}_{12} \wedge \text{cr}_{22} \wedge \ldots) \wedge \sim (\ldots.)$$

$$o_2 = \ldots$$

where

cr_{11} = $y_1\, \text{cr}^1_{11} + y_2\, \text{cr}^2_{11} + \ldots + y_x\, \text{cr}^x_{11}$;

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cr_{gh} = $y_1\, \text{cr}^1_{gh} + y_2\, \text{cr}^2_{gh} + \ldots + y_x\, \text{cr}^x_{gh}$;

cr^x_{gh} = the hth level of impact of criterion g on group x (e.g., travel delay to urban motorist group x);

y_x = a weight, reflecting the importance of the impact group x with respect to the criterion g, and can be determined from community's preference expressed as ranks or weights; and

cr_{gh} = the hth level of criterion g, weighted for all impact groups.

It should be noted that urban areas may not wish to weigh impacts according to impact groups. In such a case, only one value of cr_{gh} would be applicable.

The worth or value of an urban access alternative a_m can be found by determining the value of its outcome state o_m to the society. This involves the estimation of the weighted impacts (the criteria attainment levels) for all the groups. Two steps are required for obtaining the final answer. In the first step, the state of the system is to be found that is likely to occur as a result of the implementation of the access alternative. All outputs that correspond to the criteria are estimated through a variety of technical means that range from sophisticated models (e.g., traffic interruption, noise pollution) to subjective assessments.

Following the estimation of outcome or impact state for access alternatives, the second basic step is taken in the form of evaluation of the resultant states. The value of outcome states in relative value units is found by using value functions and applying criteria weights:

$$U(a_m) = U(o_m) = w_1 u_1\, (\text{cr}_{1h}) + w_2 u_2\, (\text{cr}_{2h}) + \ldots + w_g u_g\, (\text{cr}_{gh})$$

where

u_g = a numerical function on the gth criterion;

cr_{gh} = the hth level of criterion g;

$u_g(\text{cr}_{gh})$ = the value of the hth level of cr_g measured by numerical function u_g, in units of measurement that may be different from the original units of cr_g; and

w_g = criteria weight determined from the community or the decision maker's preferences.

Value functions are used for the transformation of criteria-attainment estimates measured in their original but diverse scales (including subjective scales such as 1 to 7) to relative values or utils measured on a 0 to 1 scale. Value functions may be of the following form:

$$u_g(\text{cr}_{gh}) = s_g v_g(\text{cr}_{gh}) + b_g \qquad \text{for all } \text{cr}_g,\ g = 1, 2, \ldots, q$$

where $v_g(\text{cr}_{gh})$ is the original value of cr_{gh}, and s_g and b_g are constants.

The $U(o_m)$'s can be expressed in units of any criterion (e.g., dollars) by transformation. For example, the following transformation is allowed:

$$U(o_m) \text{ in units of } \text{cr}_g = 1/s_g\, w_g\, [U(o_m) \text{ in relative value units}] - b_g/s_g$$

The weights y_x and w_g can be obtained from an expression of values by representatives of the urban community. The mechanism that can be used is that of expressing preferences through rating, ranking, or other methods by elected officials, their policy experts, and representatives of special interests. It should be noted that criteria weights shown in Table 1 were obtained from transportation experts and do not represent the views of elected officials or of special interest groups.

Through value functions and criteria weights, the urban community's valuation of each outcome state can therefore be expressed as a single quantity: $U(o_m)$. These establish the ranking of states according to their desirability. In Figure 5, Point A represents the most cost-effective alternative for the I and T combination.

EVALUATION OF URBAN ACCESS ALTERNATIVES: MODEL APPLICATION

Four urban access alternatives defined earlier are evaluated here through the application of the utility-theoretic model. Eleven criteria as well as their relative weights shown in Table 1 are used for establishing the relative desirability of access alternatives. In this example application of the model, the access alternatives are not being evaluated for any specific urban area. Instead, on the basis of the knowledge of average conditions in North America and the findings of the survey reported earlier, criteria achievement levels are estimated and weighted by using weights obtained from the survey (Table 6). Although there is a substantial degree of realism in the example application presented here, the main objective is to illustrate how urban areas could use the methodology advanced here to evaluate their urban access policies.

The criterion of providing access to terminals is completely met by Alternatives 1 and 3 and the policy of limiting urban access to staging areas (Alternative 4) is in the lowest attainment level. Alternative 2 would allow about 60 percent of the terminals to be reached by oversize vehicles. As for the criterion of minimizing truck delays and associated costs, the use of staging areas would be the least effective option and locating terminals in industrial parks would be the most effective.

From the trucking industry perspective, access to terminals is important for productivity reasons. Less-than-truckload type

TABLE 6 EVALUATION OF URBAN ACCESS ALTERNATIVES CRITERION ACHIEVEMENT LEVEL u_g (cr_{gh})/ WEIGHTED VALUE w_g u_g (cr_{gh})

Criteria	Alternative 1 Shortest Route	Alternative 2 Terminals Within 5 km Distance	Alternative 3 Terminals Within Industrial Parks	Alternative 4 Staging Areas
cr1 Provide access to terminal	1.0/5.14	0.6/3.08	1.0/5.14	0.0/0.0
cr2 Minimize truck delays	0.85/2.9	0.8/2.73	1.0/3.41	0.0/0.0
cr3 Minimize pavement damage	0.7/3.71	0.75/3.98	0.8/4.24	1.0/5.3
cr4 Minimize geometric improvements	0.7/3.29	0.7/3.29	0.85/4.0	1.0/4.7
cr5 Avoid local collectors	0.8/5.22	0.9/5.87	0.95/6.19	1.0/6.52
cr6 Maximize safety	0.75/4.7	0.8/5.01	0.9/5.63	1.0/6.26
cr7 Minimize urban traffic disruption	0.75/4.11	0.8/4.38	0.85/4.66	1.0/5.48
cr8 Minimize noise	0.65/2.94	0.7/3.16	0.75/3.39	1.0/4.52
cr9 Minimize vibrations	0.65/2.72	0.7/2.93	0.75/3.14	1.0/4.18
cr10 Minimize air pollution	0.65/2.54	0.7/2.74	0.75/2.93	1.0/3.91
cr11 Minimize visual pollution	0.65/2.52	0.7/2.71	0.75/2.9	1.0/3.87
Utility of alternative $U(a_m)$	39.79	39.88	45.63	44.74

of service, which could potentially use triple trailers, is a heavy user of terminals. For truckload type of service, major loading or unloading points are generally located in industrial parks. In newer developments, most manufacturing facilities, warehouses, and other generators of large loads (that would be carried in large trailers) are located in industrial areas within 3 to 5 mi (5 to 8 km) of major highways. It is hardly surprising that major new truck terminals are increasingly being located within industrial parks.

In incremental terms, pavement damage would not be an issue if oversize trucks were not permitted beyond staging areas. Properly designed roads providing access to industrial parks or terminals in the vicinity of major highways would be more effective in minimizing pavement effects than other routes. As for the minimization of the cost of geometric improvements, the worst performer is the option of allowing access on the shortest route basis. The alternative of using staging areas involves no geometric changes to truck routes.

Vehicle turning performance is a critical factor for establishing the adequacy of geometric design features for existing or new roads. The turning space required increases with an increase in trailer length or number of trailers. In general, longer vehicles with fewer articulation points have higher offtracking characteristics (*4*). Offtracking is more serious for turnpike doubles than for triples (*6*). At urban intersections with restrictive rights-of-way, rocky mountain doubles and turnpike doubles would have to encroach on opposing traffic lanes to make the right-hand turn (*4*). In the case of intersecting roadways with two lanes each (e.g., minor arterials, local collectors), longer combination trucks would not be able to make left turns without using the space of opposing traffic (*4, 6*).

Although in theory local collectors are not included in truck routes, there are instances where large trucks may have to use segments of such roads to reach terminals. In this respect, the alternative of using the shortest route would involve the highest incidence of the use of minor arterial and local collectors.

In relative terms, safety problems would be the most pronounced should a policy of allowing terminal access on the shortest route basis be adopted. Safety problems could arise because of vehicle offtracking, braking time, trailer sway (in the case of triple trailers), blocking the view of motorists, and the difficulty oversize trucks have in making emergency maneuvers. In cases where oversize vehicles may have to run over curbs in unexpected maneuvers, there would be a problem of instability.

Traffic disruption would not be an issue if the option of staging areas is selected. On the other hand, the highest level of traffic disruption would be encountered in the case of using the shortest route option. Large combination trucks take more time and space to turn and therefore would impede traffic.

As for environmental impacts, the best option is, of course, that of limiting urban access to staging areas only. The order of desirability of other options in minimizing environmental impacts is Alternative 3 (terminals within industrial parks), Alternative 2 (terminals within 5-km distance), and—the least attractive alternative—allowing access on the shortest route basis (i.e., Alternative 1).

Results shown in Table 6 suggest that the alternative of providing access to terminals within industrial parks has the highest utility and the alternative of limiting access to staging areas is almost equally attractive. On the other hand, the policy of using the shortest route to existing terminals is the least attractive option. The policy of limiting access within a 5-km distance without regard to the type of areas or the type of roads available is marginally better than the shortest route option.

CONCLUSIONS

Owing to the substantial potential urban impacts of oversize trucks, it is essential that relevant sociotechnical factors and the welfare of interest groups be included in access policy decisions.

Transportation departments in North America, who responded to the questionnaire survey, have expressed a balanced view of urban access issues by recognizing the importance of urban impacts as well as terminal access. However, in general, urban impact factors are accorded higher importance than providing access to terminals.

An outstanding need for methodology for making trade-offs between the benefits of providing urban access to large combination trucks and urban impacts is met through the utility-theoretic evaluation model. This tool is the most appropriate mechanism for treating the urban access criteria and enabling the quantification and use of community values.

Major guidelines for providing urban access are noted as follows:

- Terminals in outlying industrial parks should be made accessible. Such industrial parks are generally situated on outer loops or rings, within a 3- to 5-mi (5- to 8-km) distance from highway interchanges. With properly designed access facilities and terminals located in industrial parks, the 3-mi (5-km) distance criteria used by a number of jurisdictions could be relaxed.
- Access roads to terminals located within industrial parks should be developed with geometric standards that are best suited for oversize trucks.
- Providing access to dispersed urban truck terminals through existing truck routes cannot be regarded as a feasible solution. Most existing urban routes cannot handle oversize trucks without safety and traffic disruption problems.

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