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16. Abstract <p>This report documents the activities and accomplishments of the first year of a two-year research effort designed to predict the impact of an interruption in service of the GIWW (Gulf Intracoastal Waterway) to the Texas highway system. The research is to consider the kinds of disruptive events possible, their probability, the location and duration of the events, and resulting impacts on safety, the environment, and the Texas roadway system.</p>			
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**CLOSURE OF THE GIWW AND ITS IMPACT
ON THE TEXAS HIGHWAY TRANSPORTATION SYSTEM
INTERIM REPORT**

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Research Report 1283-1
Research Study No. 0-1283

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IMPLEMENTATION STATEMENT

The implementation of results is expected to take the form of a contingency plan that enables the Texas Department of Transportation to evaluate interruption of service scenarios for both short and long term interruptions in service along the Gulf Intracoastal Waterway in Texas. The contingency plans will be based upon a type of input-output model developed to evaluate service interruption type and location, and to predict likely consequences.

DISCLAIMER

The material presented in this paper was assembled during a research project sponsored by the Texas Department of Transportation. The views, interpretations, analyses, and conclusions expressed or implied in this report are those of the authors. They do not represent a standard, policy, or recommended practice established by the sponsors. **NOT INTENDED FOR CONSTRUCTION, BIDDING OR PERMIT PURPOSES.**

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA				
in ²	square inches	645.2	centimetres squared	cm ²
ft ²	square feet	0.0929	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
mi ²	square miles	2.59	kilometres squared	km ²
ac	acres	0.395	hectares	ha

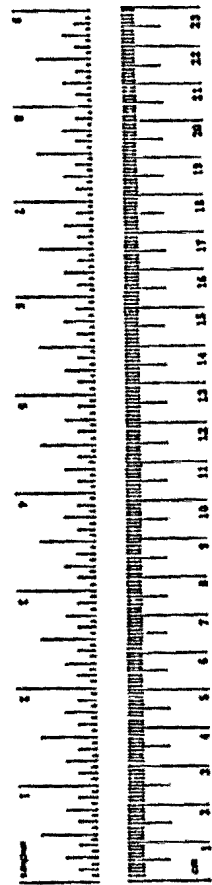
MASS (weight)				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft ³	cubic feet	0.0328	metres cubed	m ³
yd ³	cubic yards	0.0765	metres cubed	m ³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



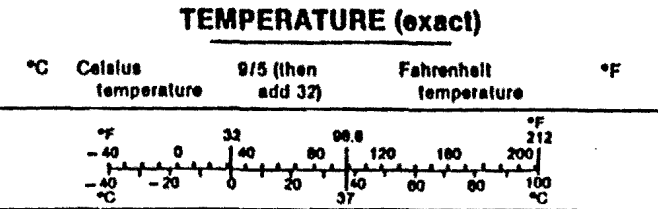
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA				
mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
km ²	kilometres squared	0.39	square miles	mi ²
ha	hectares (10 000 m ²)	2.53	acres	ac

MASS (weight)				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³



These factors conform to the requirement of FHWA Order 5190.1A.

METRIC CONVERSION CHART

SUMMARY

This report documents the activities and accomplishments of the first year of a two year research effort designed to predict the impact of an interruption in service on the GIWW to the Texas highway system. The research is to consider the kinds of disruptive events possible, their probability, the location and duration of the event, and resulting impacts on safety, the environment, and the Texas roadway system.

Predicting a loss of navigation along the Texas portion of the Gulf Intracoastal Waterway and planning for the subsequent shift of freight to the Texas highway system requires information on several broad areas. Among these are:

1. Modal freight shifts - switching commodities from one type of carrier to another,
2. Current commodity flows - both the type of goods and material moved and their origins and destinations,
3. Inland navigation in general and navigation on the Texas portion of the GIWW in particular,
4. Traffic flow analysis models,
5. Risk/hazard identification,
6. Past GIWW closings and comparative interruptions in service on other inland waterways, and;
7. Texas Gulf coast evacuation plans.

A literature review was undertaken to examine relevant material for information on methodology, analytical techniques, similar past research, and data availability as it relates to the current study.

In order to estimate the likelihood for closure along the Gulf Intracoastal Waterway, information about the risks and hazards of this area must be collected and analyzed.

The preliminary analysis of risk suggests three predominant areas of concern:

1. structural problems of the canal,
2. natural and other disasters, and;
3. a lack of approval and financial resources for necessary projects and maintenance due to political/environmental agendas.

The transportation system serving the Texas coastal zone includes elements of every mode of freight transportation: highway, rail, air, pipeline, ship, and barge. In addition, three of the top four economic sectors in Texas (petroleum refining, petroleum production, and agriculture) are located in this region of Texas. Each of these sectors is heavily dependent upon transportation for their value, and it is no accident, given the transportation options which exist, that firms have chosen to locate along the Texas gulf coast.

The impact model, developed to assess the effects of a closure in the GIWW, will combine data from several different sources through a series of stepwise calculations to arrive at a set of bottom line impacts which will include projected increases in maintenance costs, accidents, roadway congestion, energy usage, and pollution. The impact assessment will focus on three areas:

1. the impact a significant freight shift to the Texas highway system would have on energy consumption and energy-related environmental implications,
2. the potential impact of a shift in hazardous materials to the Texas highway system, and;
3. the direct impact on the highway system itself: maintenance and rehabilitation costs, highway capacities and congestion, and traffic pattern changes.

1.0 STUDY OVERVIEW

The Gulf Intracoastal Waterway (GIWW) serves as a vital link between Texas' oil, chemical, and mining industries, the state's deep water ports, and important midwestern markets. Extending over 400 miles along the Texas coast and connecting with other waterway networks throughout southern and middle America, the GIWW plays a major role in the economic life of the state. The U.S. Army Corps of Engineers estimates that approximately 20 percent of Texas gross state product is tied to water transportation. Other studies have reported that as much as three quarters of Texas' goods are shipped by water. Commodity flow data for 1989 indicates that over 80 million tons of material was transported along the Texas reach of the canal.

Water transport is among the most energy efficient modes available. Commercial and industrial firms located along the GIWW are, therefore, able to ship and receive large volumes of bulk commodities at relatively low cost. The significance of the canal to Texas has been demonstrated through revenues generated, through jobs created, and through business activity encouraged by the availability of cost efficient and wide ranging water transportation.

In 1986, almost 20,000 Texans were employed directly by the water transportation industries. Coastal mining and manufacturing firms, which are heavily dependent on low-cost water transportation, had almost 127,000 employees on their payrolls. The value of payrolls and expenditures of the chemical, petroleum refining, oil and gas extraction, and non-metallic mineral industries located in the coastal region have an important impact on the State. These four industries combined produced an economic impact of almost \$37 billion in 1986, not including over \$400 million collected in tax revenues.

Recently, the significance of the GIWW to Texas has taken on additional importance. Interest and concern have surfaced over the potential impact of an interruption in service on the canal. Severe erosion and possible encroachment by the Gulf of Mexico at Sargent Beach, Texas, have focused

attention on the waterway and the vast quantity of material moved on the system. The prospect of an unforeseen interruption in service on the GIWW, and the resulting search for alternative transportation modes, has alerted the Texas Department of Transportation (TxDOT) to the potential threat to the integrity of the Texas highway system.

This research is designed to predict the impact of an interruption in service on the GIWW to the Texas highway system. The investigation will consider the kinds of disruptive events possible, their probability, the location and duration of the event, and resulting impacts on safety, the environment, and the Texas roadway system. The material contained in this interim report reflects the efforts of the first year of study and investigation, and presents the schedule for the second and final year of project development.

2.0 LITERATURE REVIEW

The purpose of the literature review is to examine relevant material for information on methodology, analytical techniques, similar past research, and data availability as it relates to the current study. Predicting a loss of navigation along the Texas portion of the Gulf Intracoastal Waterway and planning for the subsequent shift of freight to the Texas highway system requires information on several broad areas. Among these are:

1. Modal freight shifts - switching commodities from one type of carrier to another,
2. Current commodity flows - both the type of goods and material moved and their origins and destinations,
3. Inland navigation in general and navigation on the Texas portion of the GIWW in particular,
4. Traffic flow analysis models,
5. Risk/hazard identification,
6. Past GIWW closings and comparative interruptions in service on other inland waterways, and;
7. Texas Gulf coast evacuation plans.

The number of factors involved in the present research and the corresponding number of disciplines makes it impractical to present every pertinent report. Therefore, this review will not encompass all of the literature but, rather, will focus on those studies and reports that are representative of the material reviewed and clearly relevant to the task at hand: developing a predictive impact model for the Texas portion of the GIWW.

2.1 MODAL FREIGHT SHIFT STUDIES

The broad issue of modal diversion has resulted in a number of studies. Two lines of research in particular demonstrate methodology for predicting and evaluating impacts from a termination of

navigation along the Texas portion of the Gulf Intracoastal Waterway. The first of these two research areas addresses abandonment of rail lines and the second examines the effects from the imposition of waterway taxes on the nations inland waterway system. The body of research resulting from these studies mirrors many aspects of the present project. Because of the design of these studies and their regional focus, they provide a useful inventory of methods for modal shift prediction and analysis.

Theory

Several factors influence shippers in selecting which transportation mode to use. Research in this area is important in establishing valid expectations regarding which mode or modes may be selected in the event of a closure on the GIWW. The major factors considered are cost, level of service (speed and reliability), and the capacity provided by each mode.

According to a 1977 National Cooperative Highway Research Program (NCHRP) Research report (1), there are three basic costs involved in the transportation process: terminal costs, line-haul costs, and inventory costs. Terminal costs include handling costs associated with readying the shipment for transit as well as costs associated with billing. Line-haul costs are those which arise from carrying the shipment from its origin to its destination. These costs include the expense of running and maintaining the moving stock, costs associated with constructing and maintaining any required right-of-way, and costs associated with overhead. Inventory costs result from the cost of money tied up in unsold goods.

Daughety and Inaba (2) derive a model for choice of freight transportation mode from the basic economic concept of profit maximization. Shippers choose the quantity shipped to a given market by a given mode with maximization of profits as their goal. The resulting quantity/mode/market bundles are functions of the price of the product in a given market, the transport rate to a given market by a given mode, and the cost to the firm of producing a given quantity of output.

Whether the shipper or carrier bears the cost of higher shipping rates depends on the elasticity of demand for transportation. Elasticity of demand is an economic concept referring to the change in demand for a good or service brought about by a change in price (3). An inelastic demand implies that demand will not change significantly as price changes, even if the price increases substantially. Conversely, elastic demand suggests that demand for a good or service may evaporate if price increases even slightly. When shippers have few, if any, transportation alternatives, they bear more of the costs of a transportation rate increase than the carriers. If they have several alternatives, the carrier must absorb the cost.

In research related to the concept of elasticity of demand, Cosby et al. (4) illustrate the importance of market factors in determining the effects of a rate increase on water transportation. Cosby's research examined the impact of increased taxation on inland waterways. The authors submit that two economic factors determine the demand for transportation: the demand for the product being shipped and the cost and quality of the transportation service. The extent to which a higher transportation rate can be passed on to customers depends on the demand for products they produce. In a related study by Pryce (5), the presence of marine transport is found to keep rail prices 10 to 12 percent lower than those charged where no competition exists.

The degree of profitability and competition within an industry will partly determine whether a transportation rate increase is potentially devastating to the industry and the firms within that industry. In addition, under robust economic conditions, rate increases will be easier to absorb. The extent of the impact from user charges, as discussed by Cosby et al. (4), or, as in the present research, from the loss of a transportation alternative, will depend upon the market structure of the various users and the competing modes of transportation available.

Analytical Techniques

Statistical analysis provides a means to define the factors that impact a shipper's choice of transport mode. Systematic studies of modal choice behavior have yielded valuable insight into the factors that impact carrier and mode choice by shippers. Statistical methods are a critical tool used in

making an accurate assessment of the relative importance of factors in the ultimate selection of a transport mode. The literature cites several different statistical techniques that have been used for this purpose. The three primary techniques are multiple linear regression, logit analysis, and discriminate analysis. Each of these approaches may be used to judge the relative importance of factors such as a product's characteristics (perishable, bulk, etc.), market characteristics (amount of competition in the industry or market), the service characteristics of a carrier or transportation mode (speed, reliability, flexibility), and transport rates on mode selection.

Jelavich (6) illustrates the basic statistical modeling of modal choice by using multiple linear regression. When different transport options exist, the total amount shipped by one mode divided by the total amount shipped by all modes gives the probability of a good moving by that mode. If information is available about the characteristics of shipments and these vary systematically by transport mode, shipment-specific probabilities can be calculated that depend on the features of the shipment and features of the alternative transport modes. Because the dependent variable is a probability, it can only take on values between 0 and 1. Hence, ordinary least squares regression is not considered the best technique, though Jelavich uses it. The fact that the dependent variable only assumes restricted values is the basis for logit models, as described by Greene (7).

Jelavich's analysis examines the shipper's choice between rail, truck, and an all-inclusive "other" transport mode. Selection ratios of rail/truck, rail/other, and truck/other are used as dependent variables for estimation. Data used are from the 1972 *Census of Transportation, Census of Manufacturers*, and ICC's *Freight Commodity Statistics*.

The independent variables used by Jelavich are:

1. rail rate per ton-mile of commodity,
2. truck-rate per ton-mile of commodity,
3. the cost difference between rail and truck,
4. average length of haul by mode,
5. percent of shipments weighing over 90,000 pounds,

6. mean of weights of shipments under 90,000 pounds,
7. a variable equal to one if a commodity's value added per ton equals or exceeds \$500/ton but is less than \$1500/ton,
8. a variable equal to one if a commodity's value added per ton equals or exceeds \$1500/ton,
9. a variable equal to one if over one-half of the goods shipments weigh in excess of 30,000 pounds, and;
10. value per ton of the shipment.

Rate variables did not play much of a role in this model. Value of shipment, weight, and average haul length were found to be the major determinants of modal choice, with longer, heavier hauls going to rail and high-value goods going to truck.

Daughety and Inaba (2) use a logit model in considering the case of a country grain elevator that ships corn to various markets. The corn can be sold in different markets and transported by several different modes. Variables used in their estimation of modal choice are:

1. grain market price,
2. quantity,
3. transport rate,
4. whether the shipper paid the transport rate,
5. destination,
6. mode, and;
7. the distribution of delay times.

The modes examined were truck and rail. Actual transport rates were not obtained but predicted by ordinary least squares regression analysis from data collected on shipment size, rate paid, and distance shipped. The analysis yielded relative valuations of modal characteristics that could then be used for predictive purposes. For example, net price alone did not affect choice probabilities, but net price multiplied by quantity did affect choice probabilities. This may be important to GIWW

users shipping bulk goods. In addition, the model can incorporate the alternative of not selling the inventory at all, and holding until more favorable market circumstances exist.

Discriminant analysis is an alternative statistical method for predicting modal choice. In discriminant analysis, a linear function is established to separate a set of observations into predetermined populations or groups. A set of observations that possess the most similar characteristics is assigned to a population grouping. Sasaki (8) outlines the theoretical underpinnings of discriminant analysis and tests its predictive powers in the two-mode case of barge and rail transportation of coal. Discriminant analysis bases the separation of modes of transportation on the dissimilarity of common variables and their order of importance. In this case, the cost of coal, the price of rail and barge transport, and average transit time vary significantly. The model accurately classifies 95 percent of the sample and is found acceptable by the authors in predicting the mode of transportation a user will select.

Rail Abandonment

The abandonment of unprofitable rail lines has occurred with alarming frequency over the last 10 to 15 years. Most abandoned lines are lower volume branch lines serving agricultural entities. Branch line abandonments offer a unique, real world experiment on the behavior of transportation users when faced with the requirement to choose an alternative mode. The parallels with the current study are readily apparent; loss of the GIWW would force users to make decisions on the next best transportation alternative.

Weinblatt et al. (9), in a study designed to estimate the effects of railroad abandonment, first estimated the probability of closure for certain rail lines and then divided their study area into 4 segments depending on these probabilities. Data for the analysis was collected from users of rail lines.

Analysis of the effects of abandonment on each rail user began with the grouping of shipments by commodity and volume. Costs for each shipment group were then estimated for the transport

alternatives that appeared to be realistic possibilities.

Five transport alternatives were considered:

1. trans-shipment (i.e. multi-modal shipment) by rail and truck,
2. truck (directly from origin to destination),
3. barge (with trans-shipment by truck and, possibly, rail),
4. trailer on flat car, and;
5. truck (to a closer market or from a closer source of supply).

On the basis of these cost estimates it was determined which transport alternative(s) would most likely be used for each group of similar shipments if present rail service was discontinued. This determination relied on several factors:

1. alternatives already in use for similar shipments,
2. handling characteristics,
3. likely availability of equipment for trans-shipping,
4. estimated cost of the alternatives,
5. value of the commodity, and;
6. the alternative which the rail user thought would be selected.

Additional alternatives examined were:

1. probability of relocating the business and the expected cost of this,
2. probability of a facility being closed, and;
3. expected decline in business volume at present location.

Estimated sales volumes of the affected products with the expected increase in transport costs for continued operation were examined, as well as an evaluation of the ability of the firm to pass these increased costs along to its customers or suppliers. Many of these same considerations would be brought into play were the GIWW to close for an extended period of time.

A more recent study of rail line abandonment by Taylor et al. (10) also follows an ad hoc analysis. The first step in their study was to identify rail lines that might be abandoned on the basis of estimated rail line revenues and operating costs. Transportation cost has the primary impact in this analysis, although, as presented in the theory section, this is not necessarily the only important factor. Additional consideration was given to a possible loss of quality of service from seasonal movements over roads constrained by weight limits or closures, resulting in lost market opportunities. The loss of competition between rail and truck modes and resulting changes in the dynamics of rate or fee negotiation was also examined.

Transportation alternatives if a rail line closes were:

1. truck transport to another rail site,
2. truck transport to barge transportation, and;
3. truck transport to or from the final destination or origin.

The first two cases include double handling expenditures as well as trucking costs.

The authors identified commodities that would be trans-shipped, with grain being the principal commodity that moves by rail service. Grain transportation costs were then detailed. Since the cooperative grain elevator is a multi-plant firm, its closest alternative facility with rail service would probably be charged the same rate. The additional costs comprise the expense to truck to the alternative elevator plus those of the alternative elevator throughput. They arrive at an average increase per bushel of grain of 10 cents (5 cents trucking and 5 cents handling) by reviewing earlier studies. This cost is multiplied by the annual volume to be moved to identify total cost increases. This figure is modified for some elevators because of a readily accessible and low-cost transportation alternative (truck or barge).

For other commodities, discussions with firms shipping each product, supplemented by a review of recent studies, gave a basis for cost impacts. These costs were then applied to each line segment on the basis of its commodities and trucking distances to the nearest alternative railhead.

User Charges on Waterways

Many studies have been undertaken to examine impacts of some type of taxation on water transport. Increases in the cost of water transport via increased taxes should, it is expected, decrease the competitive position of the waterborne mode and, consequently, decrease user demand. The decrease in demand caused by increased costs will, correspondingly, improve the competitive position of other transportation modes, creating a modal shift situation accessible to documentation and study. While the current research does not parallel these studies in terms of causation, it does yield insight into effects and into the reasons underlying alternative mode selection.

A study specific to Texas, *Some Economic Effects of User Charges on Texas' Coastal Waterways* (4), takes a general approach to the phenomenon and bases its predictions for the effects of increased taxes on economic principles. The authors maintain that loss of traffic on the waterway from user charges depends on the market structure of the various users and on the competing modes of transportation available. Because commodities carried by firms using the GIWW vary from high value petroleum products and chemicals to relatively low value bulk commodities, a wide range of market structures exist.

A further spur to diversity is the wide variation in form, structure, and size of operations. The greatest effects from changes in transport rates would be on high-volume high-value shipments of fuels, chemicals, and crude petroleum. It is expected that the potential increases in shipping rates could lead to traffic loss on the GIWW and higher energy costs for the general consumer. The implication is that transportation of some portion of these goods would shift to rail and/or truck.

For the segment of the GIWW from Corpus Christi to Brownsville, the major commodities are petroleum products, chemicals, and crude petroleum (68 percent in 1976). Petroleum products and crude petroleum have pipelines as the major alternative transport mode. The authors postulate that modal diversion may occur in the long-run if the tax on water transportation creates an uneconomical situation for continued waterborne shipments.

Another specific commodity/area discussed deals with shipments of sand and gravel from Victoria, Texas. These shipments moved to Houston (in 1982) by both barge and truck in a competitive situation. It is suggested that with an increase in costs to ship the material by waterway, a complete shift to the Texas highway system could occur.

The report stresses that in any analysis of the Texas GIWW, firm- specific and segment-specific effects will play an important role. The increase in costs for high-volume, low-value commodities and for lower-volume, lower-value commodities could remove certain firms from competition.

On the national level, *Modal Traffic Impacts of Waterway User Charges: Volume II, Distribution Systems Analysis* (11) is one of a series of studies conducted to examine the modal traffic and carrier impacts of imposing waterway user charges on the U.S. shallow and deep-draft navigation system. This volume describes the distribution system for a particular commodity/industry group and estimates the impact of cost recovery tolls on barge traffic by evaluating potential changes in transportation mode, routing, materials' source, and production technologies.

Impact of Modal Shifts

Central to the goals of this study are instances or investigations of the impact of modal shifts on the environment or transportation system. Newstrand (12), in *Environmental Impacts of a Modal Shift*, examines the impacts of a modal shift in a "what if scenario"; what if the transportation needs of select goods moving by water were met by other forms of transportation. The analysis dealt specifically with the routine transport of goods along Minnesota's river and Great Lakes transportation system. This resulted in reports on 4 specific case studies: a mining company to its distributors; a petroleum refinery to distribution centers; a coal loading facility to power plants in four cities; and the movement of wood and paper products between three ports.

All goods were assumed to travel on either truck or train if water travel was not available. An impact analysis for a cargo shift from barge to truck was made for each case and an analysis for a barge to rail shift was made for those movements where a rail alternative exists or the construction

of a rail link was considered feasible. Based on the modal impact factors shown in Table 1, the author estimates the impacts of modal shifts. However, as will be discussed later in this review, these factors need to be interpreted carefully.

Table 1. Modal Impact Factors

MODE	FUEL USED Ton Miles/ Gal	EMISSIONS Pounds/Gal	ACCIDENT RATE
Truck	60	.31	76.6/100 million miles
Rail	204	.69	1/51,310 miles
River	514	.37	1/600 million ton miles
Great Lakes	607	.37	1/2.59 billion ton miles

Source: Newstrand, 1991.

The study estimates that a barge to truck modal shift in these four transportation corridors would result in:

1. an annual increase in fuel use of 926 percent,
2. an increase in exhaust emission of 1,920 percent,
3. the need to dispose of 2,746 additional truck tires each year,
4. daily truck traffic increases of 1,333 vehicles in the corridors, and;
5. an annual increase in probable accidents of 610 percent.

For those two movements where rail is a viable alternative, the cumulative impacts were estimated to be:

1. an annual increase in fuel use of 331 percent,
2. annual increases in exhaust emissions 470 percent, and;
3. an annual increase in probable accidents of 290 percent.

Effects of Heavy Trucks on Texas Highways (13) estimates increased costs of road maintenance resulting from a hypothetical change in truck weight limits. While the interests of the present study

are in increased truck traffic, this study examines highway maintenance impacts from an increase in the average weight of trucks. The present effort can draw from this work in the establishment of current and future truck traffic distributions under different scenarios. In addition, in the present study we will estimate, as they did, the dollar costs required to perpetuate the state highway system in an acceptable condition while carrying projected traffic volumes under different scenarios.

The major approach of *Effects of Heavy Trucks on Texas Highways* (13) involved the estimation of the comparative maintenance and rehabilitation costs of perpetuating the state highway systems under current weight limitations and on future use under different weight conditions. The authors use data from the *Truck Weight and Vehicle Classification Study*, by the Planning Survey Division, Texas Highway Department, 1960 through 1971, and 1973 to 1975 from the Federal Highway Administration. The data represent vehicle (empty and loaded) weight intervals sampled at designated highway locations around the state. The REHAB computer program (an abbreviation standing for rehabilitation) was used to project pavement rehabilitation costs.

Stowers 1983 paper (14), also presents results from a study evaluating the impacts of a change in truck traffic on roadways. In this work, several alternative changes to federal limits on truck length and weight are investigated. The impacts of these changes on truck productivity, modal diversion, freight costs, pavement and bridge costs, safety, energy, air quality, and noise are estimated.

The scenarios examined consist of a base case, and 5 categories of changes in federal truck length and weight limits. The base case serves as a benchmark against which benefits and costs for the various scenarios are compared. All impacts are expressed in terms of changes from the base case. In order to provide a uniform basis for comparing scenarios to the base case the present value of cumulative changes in costs were calculated for each scenario.

Truck productivity increases because allowable tonnage and volume per trip increase. Fewer trips and vehicle miles traveled (VMT) will be required to carry the same amount of freight. This improvement in truck productivity reduces costs. The savings accrue to truckers, shippers, receivers,

and consumers. The portion each group receives depends primarily on the competitiveness of the affected markets.

The authors find choice of mode only moderately sensitive to shipping costs compared with other components of overall distribution costs and quality of service. A change in truck weight limits was found to principally affect shipping costs. Improvements in truck productivity create the potential for diversion of freight to trucks from other modes the most significant movement would occur between truck and rail. Changes in truck costs could also have a slight effect on barge traffic.

Higher axle weight limits tend to accelerate pavement wear, even though they reduce truck miles by allowing higher average payloads. The authors find an increase between 4.8 percent and 14.4 percent in maintenance and overlay costs for Federal-aid highways, while bridge impacts could result in an increase between 2.8 percent and 17.1 percent.

Intermodal Freight Competition

The literature review of intermodal freight competition yields information on the transportation services providing freight movement in Texas. Rates, capacities, relative efficiency and safety, and commodities carried are compared for water, truck, rail, and pipeline transportation systems.

Information about rates charged by freight carriers has become less available since deregulation of the railroad and trucking industries in 1980. The relative position of rates, however, seems to have remained fairly constant, with rail and barge in more direct competition, their rates are fairly close, while truck rates are generally higher.

The economic advantage of water transport for bulk goods is mitigated to some extent by its lack of flexibility, as contrasted to the door-to-door service offered by other modes of transportation. Thus, to remain competitive, towing service must be offered at a considerably lower cost than other modes competing within the natural trade area offered by the inland waterways. On the other hand, the presence of marine transport keeps rail prices 10 to 12 percent lower than those charged where

no competition exists (5). The rail industry views waterways as having an unfair competitive advantage and, along with environmental interests, has forced the implementation of cost-recovery measures on the inland waterway system. The battle was waged for two years in Congress with the first user-fee in the history of the inland waterway network signed into law in 1978 (15).

In the Cosby study (4) some tentative conclusions about waterway user charges are drawn. Water freight carriers were asked how much their rates would have to increase before competitors took away business; they responded on average, 25 percent. With a rate increase of approximately 15 percent, a tonnage decrease of approximately 5 percent was forecast. In a similar study by Pryce (5), the difference between water transport and the least cost alternative for grain shipment was estimated at \$2.50/ton. The savings for chemicals was \$13.10/ton and for food and kindred products \$10.15/ton. Costs are full origin to destination charges, including collection at terminal, transfer and handling, modal rates, and distribution to the ultimate destination.

Cost-Efficient Cargo Distribution Among Transportation Modes (16) provides detailed rate information for chemical shipments to and from the Texas coastal zone by specific origins/destinations for rail, truck, and barge. Table 2 from the report gives an example of transportation rates for chemicals by rail, barge, and truck. Area specific rates for some commodities, including petroleum, are also available from Anderson's *Modal Traffic Impacts of Waterway User Charges, Volume II: Distribution Systems Analysis* (11).

Table 2. Typical Transportation Rates for Chemicals

From: CORPUS CHRISTI To:	RAIL (\$/ton)	BARGE (\$/ton)	TRUCK (\$/ton)
New Orleans	\$41.80	\$ 7.25	\$46.80
St. Louis	\$56.20	\$14.15	\$80.00
Beaumont	\$27.20	\$ 3.75	\$21.20
Houston	\$24.60	\$ 2.50	\$17.60
Port Arthur	\$28.80	\$ 3.55	\$21.20

Source: Phillips, 1976

Shipments of chemicals, fuel and lubricants, and primary iron and steel products between Corpus Christi, Houston, Beaumont/Port Arthur, New Orleans, and St. Louis are examined to determine if their distribution is undertaken in an efficient manner. The authors use a linear programming model to determine the least cost movements of these goods by rail, truck, and/or water transport. Their results show that the current distribution scheme could be improved to reduce total distribution costs and still satisfy the demand requirements for each city.

In this analysis it was found that barge and truck modes are highly complementary, while rail transportation behaves more as a substitute service. According to the model developed, the most efficient distribution occurs when barges move goods over long hauls, while trucks are employed for short hauls, with rail moving the overflow of quantities beyond existing barge and truck carrying capability. The authors show through statistical analysis that barge rates must be raised substantially before any type of quantity reallocation comes about. Freight transfers from barge to truck would occur in their analysis when barge rates were increased to \$10.33. At this point, the volume moved to truck increases from 570,000 tons to 869,000 tons. Over the price range of \$10.33 to \$14.85, a sizeable shift in the volume from barge to truck occurs.

2.2 COMMODITY FLOW REPORTS

Commodity Flow Data

In order to project the diversion of goods and material from the GIWW onto the Texas highway system, it is necessary to have detailed data on the movement of commodities along the Texas reach of the canal. Commodity category, amount (in tons), month of shipment, point of origin, and destination are key elements of the information necessary to accurately estimate those goods diverted to alternative modes. The Waterborne Commerce Statistics Center, Water Resources Support Center, of the U.S. Army Corps of Engineers, collects and reports waterborne commodity flow data on an annual basis from throughout the United States.

The data published by the Waterborne Commerce Statistics Center, *Waterborne Commerce of the United States*, is reported for discrete reaches of the canal in aggregate, so as to not reveal proprietary commercial data. In addition, whenever the aggregate data is composed of less than three commercial entities, the commodity classification is reported as "special items" to ensure that confidentiality is maintained. However, special arrangements were made for this study to allow access to detailed origin-destination records. These data provide dock-to-dock information for each shipment made during the calendar year.

Modal Energy Database for Transportation (17) provides a convenient reference for tabular information about commodity transport in Texas gathered from several sources. Table 3 gives information on pipeline movements of petroleum shipments in Texas.

In addition, information from *Waterborne Commerce of the United States* is compiled here with data on waterborne commodity movements for Texas. Table 4 presents this information.

Data from *Texas Railroad Facts 1990* are also presented in previously mentioned in Modal Energy Database for Transportation with information on commodities shipped by rail in Texas. This information is presented in Table 5.

Table 3. Texas Pipeline Shipments

YEAR	TOTAL PETROLEUM TRANSPORTED		CRUDE PETROLEUM
	Million Tons	Billion Ton-Miles	Billion Ton-Miles
1972	95.5	51.9	31.1
1973	104.2	58.0	34.5
1974	96.9	55.8	33.4
1975	95.2	54.9	31.2
1976	92.3	50.9	29.9
1977	92.7	51.3	30.7
1978	111.3	66.4	40.8
1979	98.9	61.5	37.6
1980	118.7	75.8	46.8
1981	109.8	69.9	41.3
1982	119.0	75.1	44.5
1983	143.4	88.7	53.0
1984	141.7	87.8	51.4
1985	124.5	76.5	45.3
1986	117.7	72.0	41.7
1987	111.6	68.7	40.0
1988	134.6	83.0	49.0

Source: Burke, et al., 1991.

Table 4. Commodities Shipped By Water in Texas, 1988

COMMODITY	GALVESTON DISTRICT (tons)	TEXAS GIWW (tons)	GIWW (fraction of total)	TOTAL (tons)	COMMODITY (fraction of total)
Agriculture & Food Products	15,874,462	1,225,137	7.2%	17,099,599	4.7%
Chemicals & Related Products	55,371,674	28,804,669	38.8%	84,176,343	23.1%
Forestry & Paper Products	760,551	97,086	11.3%	857,637	0.2%
Machinery	610,766	92,023	13.1%	702,789	0.2%
Metals, metal products & ores	10,640,969	2,400,435	18.4%	13,041,404	3.6%
Miscellaneous	3,194,060	215,526	6.3%	3,409,586	0.9%
Petroleum & coal products	189,317,258	44,657,529	19.1%	233,974,787	64.1%
Radioactive material	1,389	0	0.0%	1,389	0.0%
Sand, gravel, stones, rocks	3,236,905	2,517,362	43.7%	5,754,267	1.6%
Scrap & waste material	3,070,107	1,056,263	25.6%	4,126,370	1.1%
Textiles & textile products	110,436	2464	2.2%	112,900	0.0%
Transportation equipment & parts	462,299	2861	0.6%	465,160	0.1%
Shells	939,125	473,477	23.5%	1,412,602	0.4%
Total	283,590,001	81,544,832	22.3%	365,134,833	

Source: Texas Railroad Facts, 1990.

Table 5. Top Five Commodities Shipped By Rail, 1988

COMMODITY	STCC CODE	TONS	CAR LOADS
Chemicals & Allied Products	28	60,144,464	717,405
Coal	11	54,314,525	531,837
Farm Products	1	42,376,801	504,632
Food & Kindred Products	20	21,131,008	372,404
Nonmetallic Minerals (except fuels)	14	20,595,898	241,369

Source: Texas Railroad Facts, 1990.

Another source for information about commodity movements in Texas is a preliminary report, *Commodity Movements on Texas Highways* (18). It provides current information on the movement of seven broad categories of commodities shipped across Texas roads by regions.

Relative Capacity of Transportation Modes

Capacity, as used in this report, measures the number of tons that can be transported in a given vehicle. An alternative definition, used in some reports, includes consideration of the support facilities required for vehicle operations.

Barges

Waterborne transport on inland waterways is most often accomplished by loading goods and material onto one of several types of barges. Barge sizes range from 175 to 300 feet in length and from 26 to 54 feet in breadth. Capacity varies with the type of barge used and with the type of commodity being transported. Table 6 presents dimension and capacity data for the three dominant barge types.

Table 6. Dominant Barge Types

CATEGORY	TYPE	LENGTH (feet)	BREADTH (feet)	DRAFT (feet)	CAPACITY (tons)
Open Hopper	Standard	175	26	9	1000
	Jumbo	195	35	9	1500
	Super Jumbo	250-290	40-52	9	2500-3000
Covered Hopper	Standard	175	26	9	1000
	Jumbo	195	35	9	1500
Liquid Chemical & Petroleum	Standard	150-300	50-54	9	1900-3000

Source: Newstand, 1990

Currently, a barge tow on the GIWW is restricted by navigation regulations to a length of 1,180 feet and a width of 55 feet. Thus, tow size is restricted to five, 195 feet by 35 feet barges, or three, 290 feet by 50 feet barges in single file. Fifteen to 40 barge tows are used on other rivers, and the larger barges in use on these waterways are effectively restricted from use on the GIWW.

Trucks

Truck configuration is not as standardized as that of barges. The *1987 Census of Transportation* contains statistics on the characteristics of non-personal/recreational trucks registered in the state of Texas. Four defining aspects of a truck are length, gross vehicle weight, truck type, and axle configuration. Statistics describing the distribution for truck lengths indicate that over 15 percent of the trucks on Texas roads are 16 to 20 feet, almost 40 percent are 20 to 28 feet, and approximately 27 percent are 45 feet or longer.

The average weight (empty weight of the vehicle plus the average weight of the load carried) of trucks registered in Texas is distributed evenly across weight categories with the exception of the 6,000 to 10,000 pound class with 25 percent and the 60,000 to 80,000 pound class with about 16 percent of vehicles. Another identifiable factor for trucks is the truck type and axle arrangement. Data for Texas suggests that almost 58 percent of trucks on Texas highways are single unit-double axle vehicles. The next largest category, at 16 percent, is made up of single tractor trailers with

five or more axles.

Rail

Freight cars are also less standardized than barges but more standardized than trucks. The 1988 edition of the Association of American Railroads *Railroad Facts* gathers national data on the railroad industry. Average freight car capacity by type is not available in this publication, but in 1987 the overall average was 86.6 tons. The average freight train consisted of 71 cars. The average weight of a carload of freight was 66.6 tons, and the average freight train load was 2,644 tons.

Uniform conversion factors for barge, rail, and truck do not seem to be in use across studies. Table 7 shows the capacity values used from two representative studies.

Table 7. Mode Capacities

BARGE (tons)	RAIL CAR (tons)	TRUCK (tons)	TRUCK LOADS (per Barge)
1500	100	22	68
2150	143.4	35.8	60

Source: Eastman (19), and the Gulf Intracoastal Waterway in Texas, 1988

The capacity relationship between modes depends on several factors. Barge characteristics vary depending on which U.S. waterway system they travel on, with lock dimensions, channel widths and bends in the river affecting vessel options. The numbers presented in Table 7, for the Texas portion of the GIWW, are applicable on the Texas GIWW, but not necessarily elsewhere. Due to factors cited above, a national factor is not necessarily applicable to any individual waterway. In addition, the unit capacity for rail and truck is likely to increase over time, making the ratios only accurate at a point in time.

Efficiency

Efficiency is traditionally defined as the ratio of output to the inputs required to generate that output. Given this definition, the transportation mode using the fewest resources to produce the same level of service may be regarded as the most efficient. However, according to the *NCHRP Synthesis 43: Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation* (1), some comparisons of freight transportation energy efficiency are misleading. In many cases, the relative energy efficiency of different modes is determined by simply comparing the number of ton-miles hauled per gallon of fuel. Little or no attention is given to the shipment and commodity characteristics of the freight being carried by the various modes. This practice can give the impression that modes compete in identical markets and that any ton of freight is the same for any commodity. Consideration needs to be given to the fact that up to half the travel by some trucks, rail cars, and barges takes place when the vehicles are empty.

Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation (1) provides a comparison of energy efficiencies for basic types of freight transportation modes in terms of their design, operating, and use characteristics. The report compiles estimates of these from various sources. Table 8 gives a range of estimates for energy efficiencies.

Estimates from Eastman (19) were used in the previously mentioned impact analysis study (12). However, care should be taken when using these estimates. The author uses net ton miles of transportation produced as a measure of output because for rail and water the average density is nearly the same. Note that this is not true for truck transport. Eastman warns:

"...caution must be exercised in drawing hard and fast conclusions from these comparisons because of differences in cargo densities and the different services offered by the three modes. This is particularly true of water and truck comparisons, which include for truck but not for water, labor-intensive pickup, delivery, and consolidation services that involve the handling of low-density freight."

Table 8. Energy Efficiency for Intercity Freight Transport Modes

MODE	Ton-Miles per Gallon	British Thermal Unit per Ton-Mile	Source
Heavy-duty truck (combinations)	123-67	1110-2023	DOT/NASA ⁽¹⁾
	51	2679	TSC ⁽²⁾
	85	1600	DOT/EPA ⁽³⁾
Railway	212	650	Smith ⁽⁴⁾
	206	670	Hirst ⁽⁵⁾
	418-251	330-550	DOT/NASA ⁽¹⁾
	204	676	TSC ⁽²⁾
Waterway	280	500	Mooz ⁽⁶⁾
	214	655	Smith ⁽⁴⁾
	206	680	Hirst ⁽⁵⁾
	275	509	TSC ⁽²⁾
Pipeline	302	450	Hirst ⁽⁵⁾
	206	660	TSC ⁽²⁾

Source: NCHRP Synthesis 43 (1)

- (1) "Transportation Vehicle Energy Intensities." *Report No. DOT-TST-13-74-1/NASA TMS-64, 404*, U.S. Department of Transportation and National Aeronautics and Space Administration, 1974.
- (2) Pollard K., D. Hiatt, and D. Rubin. "A Summary of Opportunities to Conserve Transportation Energy." *Report No. DOT-TSC-OST-75-22*, Transportation Systems Center, U.S. Department of Transportation, 1975.
- (3) "Study of Potential for Motor Vehicle Fuel Economy Improvement : Truck and Bus Panel Report." *Report No. 7*, U.S. Department of Transportation and Environmental Protection Agency.
- (4) Smith, M.L., "Energy Consumption comparison Between Waterway and Railroad Transportation." Missouri Pacific System, St. Louis, 1974.
- (5) Hirst, E., "Energy Intensiveness of Passenger and Freight Modes: 1950-1972." *Report No. ORNL-NSF-EP-44*, Oak Ridge National Laboratory, 1973.
- (6) Mooz, W.E., "The Effect of Fuel Price Increases on Energy Intensiveness of Freight Transportation." *Report No. R-804-NSF*, Rand Corp., 1971.

2.3 TRAFFIC FLOW ANALYSIS MODELS

One of the central issues in evaluating potential impacts from a closure of the GIWW is the capacity of impacted roadways to handle additional traffic flow. Traffic flow analysis deals with understanding and quantifying the movement of people and goods. Traffic flow analysis, as a discipline, is a multi-dimensional area involving mathematical and computer modeling, historical studies of traffic pattern changes, and roadway planning.

Transportation Engineering: An Introduction by C. Jotin Khisty (20) outlines the basic tools and considerations of traffic flow analysis. Khisty describes eight basic variables used in traffic flow analysis:

- | | |
|------------|--------------|
| 1. speed | 5. spacing |
| 2. volume | 6. occupancy |
| 3. density | 7. clearance |
| 4. headway | 8. gap |

Traffic density is of particular importance to the current study. It is defined as the number of vehicles occupying a given length of roadway, averaged over time, usually expressed as vehicles per mile (VPM). Urbanik (21) in Texas Hurricane Evacuation Study focuses on highway capacity and develops simplified techniques for determining capacity for planning purposes in the coastal zone. Highway capacity is a measure of the effectiveness of various highways in accommodating traffic. According to Urbanik, highway capacity can be defined as the maximum number of vehicles having a reasonable expectation of passing over a given section of roadway during a given time.

Traffic flow models can be used for the analysis of speed, vehicle flow, and density relationships. If a linear relationship is assumed, as pioneered by Greenshields in A Study of Traffic Capacity (22), the mean speed of vehicles can be expressed as a constant proportion of the average density of vehicles. The flow of an uninterrupted traffic stream is the product of the density and the speed. The point of maximum flow corresponds to "optimal density."

As field measures of speed, flow, and density became available, several researchers, such as Greenberg in An Analysis of Traffic Flow (23), evolved traffic flow models based on actual curve fitting and statistical testing. These flow models assume that the density-space relationship is not linear. Today the cutting-edge of traffic flow modeling incorporates three dimensional space, as discussed by Gilchrist and Hall (24), and chaotic behavior, as discussed by Disbro and Frame (25).

While capacity and level of service are important parameters in traffic flow analysis, another quantitative method uses delay as a measure of the impact of congestion on the traffic stream. Using delay also provides a way to evaluate user benefits and costs. Clive et.al. (26), use this method to evaluate congestion and delay at light rail transit grade crossings. Molina et.al. (27) also concentrate on evaluating delay. In their report, Passenger Car Equivalencies for Large Trucks at Signalized Intersections, they determine the delay effects of a truck on a queue of vehicles. The presence of large trucks at signalized intersections was shown to have a detrimental effect on the intersection's capacity to handle traffic.

In order to evaluate the effects of increased traffic flow diverted from the GIWW, an assignment of this traffic to a specific route must be made. Of potential use in this regard, the Texas Travel Demand Package, described in How to Read the Output Tables of the Texas Large Network Assignment Model (28), is a series of computer programs designed to generate, distribute, and assign roadway trips. The Texas Travel Demand Package, though designed to be applied to urban areas, can be applied to non-urbanized areas as well.

2.4 RISK/HAZARD IDENTIFICATION

In order to estimate the likelihood for closure along the Gulf Intracoastal Waterway, information about the risks and hazards of this area must be collected and analyzed. The preliminary analysis of risk suggests three predominant areas of concern:

1. structural problems of the canal,
2. natural and other disasters, and;
3. a lack of approval and financial resources for necessary projects and maintenance due to political/environmental agendas.

This section will examine the available literature on these risks and the documentation related to them.

Structural Problems

Safety on the GIWW is a prime concern for Texas because over 80 percent of the commerce on the canal consists of crude petroleum, petroleum products and industrial chemicals: the most hazardous cargoes moving in marine commerce. In the previously mentioned study, *Some Economic Effects of User Charges on Texas' Coastal Waterways* (4), the following assessment is made of the 1983 status of the GIWW:

"The entire GIWW was dredged to 12-feet by 125-feet in 1949 and has been maintained at those dimensions. Technology in marine transportation has made these dimensions obsolete creating unsafe conditions and causing the GIWW to lag behind other waterways in the number of barges that can be put in one tow. The shallow depth also limits how heavily barges can be loaded."

"A growing problem on the GIWW and in the ports is congestion due to the steadily increasing flow of commodities, larger vessel sizes, and increased recreational use. The growth in tonnage that has been transported safely in the past is primarily due to technological improvements in vessels and equipment. It is the general consensus of those directly involved in the inland navigation industry that further advances in technology can no longer be depended upon to carry the brunt of increasing traffic. Further efficiencies in the marine transportation industry must come from improvements in port layouts and other facilities."

The National Waterways Study (29) developed an approach for evaluating safety problems on the waterways based on categorizing problems by root cause. With 60 percent of all reported accidents involving lack of vessel control, safety problems were defined in terms of their contribution to this lack of vessel control. Waterway segments with high levels of accidents were found to have common characteristics: bridges, locks, bends, intersections with other channels, and/or a narrow channel width.

Bridges and locks increase congestion and the risk of accidents by obstructing or delaying traffic.

Bridges were the most common factor found in areas where accidents occurred. *The National Waterways Study (29)* places bridge safety problems into two categories: major structural and minor structural. Major structural problems require solutions such as the alteration, replacement or removal of specific bridges deemed to be hazardous to navigation. Minor structural problems at bridges require the placement of navigational aids or minor protective measures such as dolphins or fender systems. Lock safety problems involve solutions to reduce hazardous navigation conditions in the vicinity of a given lock. Hazards at locks can include heavy traffic, terminals, bends, dangerous currents and shoals, as well as the lock configuration itself. Restrictive channel dimensions and frequent shoaling, which makes a channel unreliable, increase the risk of loss of vessel control by increasing the problems operators must deal with. Other factors contributing to safety problems include traffic growth, increases in vessel delay at locks, increasing tow sizes and high levels of hazardous cargoes.

Five measures were used to determine safety problems:

1. historical record of accidents;
2. narrow bridge clearance, horizontal and/or vertical;
3. lock approach, channel configuration and dimensions;
4. density of traffic, measured in absolute tons;
5. amount and share of hazardous commodities, measured in tons and percent.

The National Waterways Study (29), identified the following structural problems along the canal in Texas:

Safety Problems

- Houston Ship Channel: shoaling, heavy traffic, restrictive bends at Baytown.

Major Channel Congestion Problems

- Port Arthur terminals: heavy traffic at intersections, hazardous cargo.

Bridge Safety Problems

- Galveston: minor structural
- Freeport: minor structural

- Caney Creek: minor structural
- Matagorda: minor structural
- Aransas Pass: minor structural
- Freeport Harbor: minor structural

Lock and Dam Safety Problems

- Freeport: Brazos River floodgates
- Matagorda: Colorado River locks

A study by the U.S. Coast Guard, cited in the 1976 Texas Department of Transportation Report on the GIWW (30), labeled the GIWW between the Mississippi River and Galveston Bay as the most hazardous waterway in the United States. While most of the safety problems are concentrated in the segment between New Orleans, Louisiana and Port Arthur, Texas, the portion of the waterway coincident with the Sabine-Neches Waterway, in Texas, was listed as one of the most dangerous sections of the GIWW. Of the casualties occurring along the GIWW from 1970 to 1974, 36 percent were attributed to the channel restricting the maneuverability of the tow or the towing vessel. Three of five oil spills were at least partially due to channel restrictions (30).

In the summer of 1990 significant oil spills occurred on or around some Texas water transportation facilities. On July 28, a chain of three northbound barges maneuvering near Redfish Island in the busy Houston Ship Channel collided with a departing 601 foot Greek tanker. A bottleneck of traffic occurred in the ship channel following the accident. Port officials, noting that about 60 vessels were stalled waiting to get in or out of the channel, estimated the disruption in shipping was costing \$1.5 million per day.

After the oil spills in 1990, Texas Water Commissioner B.J. Wynne addressed the need for effective oil spill management in Texas. Galveston, sitting on the western edge of the GIWW, is vulnerable to spills, especially in the ship channel. Texas is exposed, not only in Galveston Bay and that estuarine environment, but all along the Texas Gulf coast where millions of gallons of oil and petroleum products travel up and down the GIWW. Commissioner Wynne is quoted in

Texas Shores (31) as estimating state-wide oil and chemical spills at about 1,800 per year; about 1,000 include oil or partially refined products.

However, on another waterway, William Newstrand (32) reviews cargo and spill data, vessel and fleet characteristics, and spill response techniques and finds that water transportation of liquid cargoes poses little threat to the river environment in Minnesota. During the 1984 to 1987 period, the waterborne freight industry lost only about 4,400 gallons of liquid cargo in navigation and non-navigation related spills out of the nearly 3.4 billion gallons it carried in Minnesota.

The Texas Department of Transportation, the state sponsor of the GIWW, has recommended to the Texas legislature the following structural changes:

1. widening the channel from the Sabine River to Corpus Christi Bay to 250 feet,
2. increase the depth of this section to 16 feet,
3. straighten the Sabine River to Corpus Christi reach where possible and ease and widen curves, and;
4. consider converting the Brazos River floodgates to full locking facilities.

The Brazos River floodgate, mentioned as item 4 above, can complicate or temporarily halt traffic flow through awkward alignment with the GIWW at the crossing of the river. The alignment was originally intended to accommodate canal traffic using tow lines to pull barges. The inherent drift of the barge accounts for the design characteristics seen in the facility today. Traffic can also be hampered if the river current exceeds two miles per hour. That rate of flow limits tows to one loaded or two empty barges, and with flow greater than about four miles per hour, navigation is impossible.

Hurricanes

Between the years 1871-1973, forty-three hurricanes made landfall on the coast of Texas. Since 1890, Texas has dealt with 24 major hurricanes that have claimed nearly 3,500 lives, cost billions of dollars in damages and stolen miles of beach front property. On average, the Texas coast

endures a hurricane every other year and a tropical storm every third year. Still, the average occurrence of hurricanes is relatively useless in determining whether a hurricane will occur in any given year. The vulnerable season for hurricanes on the Texas coast begins in June and lasts through October.

There are three *Hurricane Contingency Planning Guides* for the state of Texas. All were developed by Carlton Ruch of Texas A&M University. Ruch is contracted by the Division of Emergency Management (DEM) to produce these planning guides. The DEM utilizes Ruch's *Hurricane Contingency Planning Guides* (33) in the event of a hurricane. Ruch also has written brochures outlining contingency plans for specific counties and municipalities. The Division of Emergency Management is under the supervision of both the Governor's Office and the Department of Public Safety. For hurricane planning purposes, the Texas coast is divided into five zones. These zones are used by Ruch and the DEM to serve as the official guidelines for the State of Texas and the Department of Public Safety in the event of a hurricane. Table 9 lists the five hurricane zones by their names and counties.

Within each of these zones, areas are divided further into Evacuation and Contingency Zones. Evacuation zones are the most vulnerable, while contingency zones are less vulnerable, adjacent zones.

Henry and McCormack (34) in *Hurricanes on the Texas Coast* divide the coast into 50-mile segments. They compute the probability of tropical storm and hurricane occurrence during any one year period for each segment to show variability along the coast and to estimate frequency of damage. The computed segment percentages are smaller than those given for the entire Texas coast because of the much shorter coastline involved. Figure 1 presents data from the Henry and McCormack study. Data summarizing the average number of years between significant storms are presented in terms of two classes of storms: (1) all hurricanes; and (2) only extreme hurricanes. One occurrence in five years represents a 20 percent probability of storm occurrence.

Table 9. Texas Gulf Coast Hurricane Zones

ZONE	COUNTIES INCLUDED
1 - Sabine Lake	Hardin Jasper Jefferson Newton Orange
2 - Houston-Galveston	Brazoria Chambers Fort Bend Galveston Harris
3 - Matagorda	Calhoun Jackson Matagorda Victoria
4 - Corpus Christi	Aransas Kenedy Klegberg Nueces Refugio San Patricio
5 - Brownsville	Cameron Willacy

Source: Ruch, 1986

In the study of hurricanes, it is significant to note that when a storm makes landfall in any one of the 50-mile segments, it is considered to affect the segment to the right. A hurricane is considered to affect all segments within 50 miles of the eye. An extreme hurricane influences the area 100 miles to the right and 50 miles to the left of the eye. Significant storms which come within 50 miles of the coast are also considered to affect coastal segments.

Erosion

Erosion, along with subsidence, is eating away the land buffer that protects much of the Texas portion of the GIWW from wave and current action of the Gulf of Mexico waters. Some portions of the GIWW have as little as 600 to 900 feet left to protect it from open water. Most seriously

threatened is a ten mile strip of coastline near Sargent, Texas. The U.S. Army Corps of Engineers is currently addressing the problem through the planned construction of a barrier sea wall.

If erosion rates at Sargent Beach continue as they have for the last three years barge traffic to southern Texas could be cut off by 1995. Erosion has caused the shoreline to recede more than one-half mile. While the average erosion rate along the Texas shoreline is about 10 feet per year, Sargent Beach will probably lose as much as 60 feet this year. Furthermore, a breach could occur soon if a major hurricane were to strike the coast. Hurricane Gilbert which hit land 425 miles south of Sargent Beach, engulfed about 15 feet of the beach during a two-day period (35).

Political

More than thirty separate federal agencies have influenced national water resource/transportation policy. The U.S. Coast Guard, the U.S. Army Corps of Engineers and the U.S. Maritime Administration are the principal federal agencies involved in inland marine commerce.

Another federal agency affecting all water resource projects is the Environmental Protection Agency. The restrictions imposed by this agency have had dramatic effects on all navigation projects. In addition, the Office of Management and Budget contributes to the availability of funds for all civil-work projects. Final approval for all civil works projects rests with the U.S. Congress which authorizes and funds projects and approves, modifies, or rejects the budgets of federal agencies.

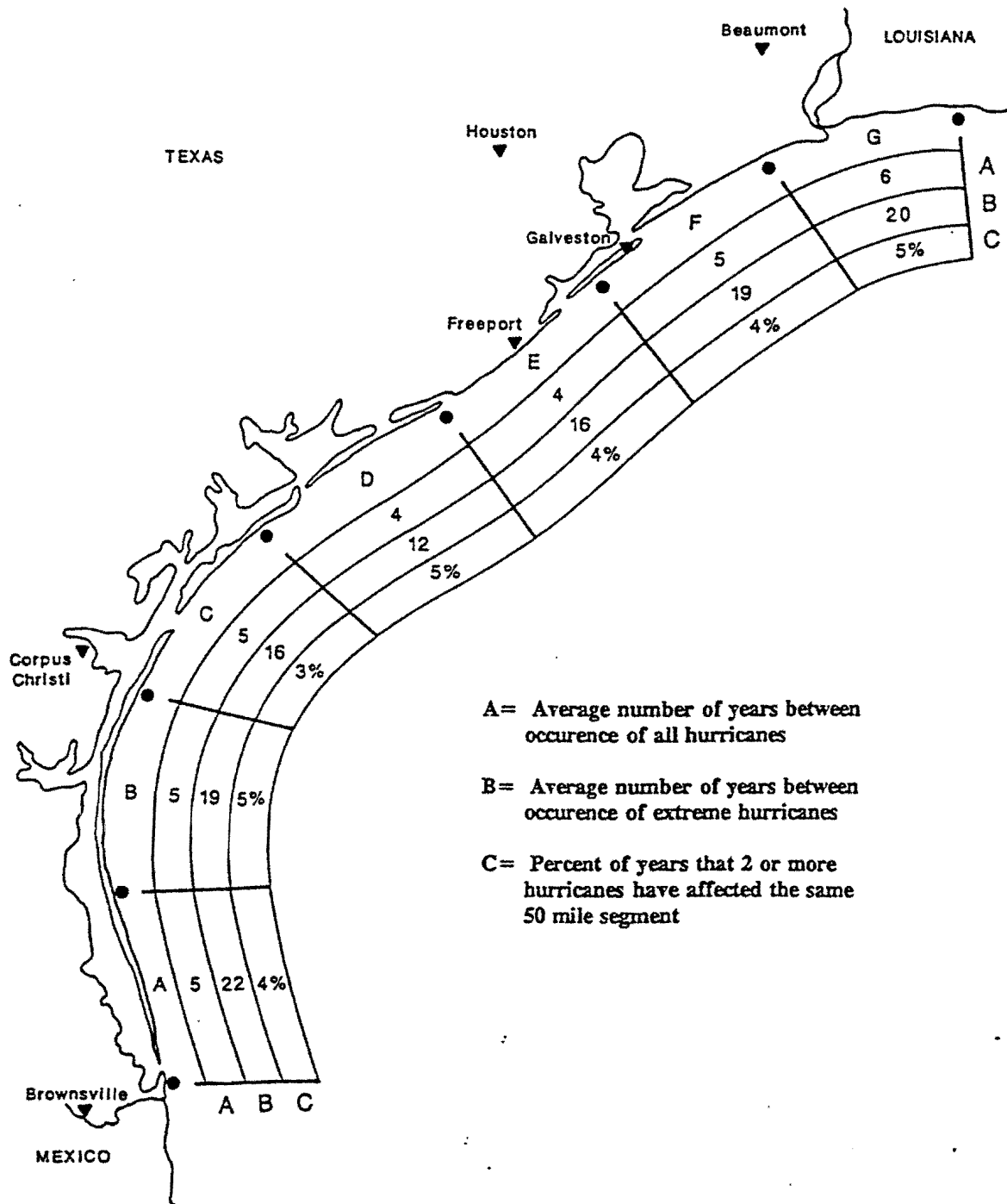


Figure 1. Texas Gulf Coast Hurricane Experience
(From Ruch, 1986)

In Texas, a number of executive agencies, most only under nominal control of the governor and responsible for a single specific resource, are involved in waterway matters. For example, the General Land Office manages submerged lands, the Railroad Commission regulates the oil industry, the Department of Parks and Wildlife enforces policy for coastal fisheries, and the Texas Water Commission monitors water quality. According to Hunt (36), there is currently, no state department of natural resources or environmental protection.

In addition to the above agencies, the Texas Department of Health, the Texas Water Development Board, The Texas Department of Agriculture, and the Texas Department of Transportation also have jurisdiction over various issues that affect those reaches of the GIWW which span the Texas coast.

Financial

The continued success of the GIWW lies in maintenance and future improvements to the system. Some improvements, such as widening the canal at key points, are desired to insure its competitive position among the available modes of transportation. The responsibilities, steps, and processes in modernizing the GIWW are quite lengthy and complicated and may soon rest, at least in part, with the state.

Between 1975 and 1983 a required federal indemnity policy prevented Texas' participation as nonfederal sponsor in dredging projects on the GIWW. For those nine years, the impasse restricted Texas from spending monies budgeted to acquire the necessary property for disposal of dredged materials. During that period in Texas, the Legislature reduced funding to the amount necessary to cover only administrative costs. The restriction was resolved in March 1983; but, the state continued to omit needed appropriations (38). Recommendations to the legislature in 1988 included consideration of methods of financing additional expenses for relocation of the waterway in certain areas.

The *National Waterways Study* (29) also addresses issues involving funding problems for our inland waterways system. Recent legislation and regulations have increased intervention by opposing economic interests. Litigation over navigation projects' compliance with these new regulations has further delayed modernization. A recurring issue in litigation concerns the incremental nature of navigation project evaluation. The existing planning process is often unable to cope with rapidly changing technology and market shifts. Incorporation of state and local governments as well as public concerns and aims, which, in many cases are not the same as national needs, may delay projects designed to address national goals.

The federal government is moving away from a project by project evaluation and is working toward an overall plan for the nation's waterways. Variance among national, state, and local goals has delayed or halted projects important to national economic objectives (29). One strategy proposed by the *National Waterways Study* would provide funds for major structural actions by federal abandonment of shallow draft navigation segments with high ratios of costs per ton-mile of commercial traffic. All ports and side channels with less than one million tons of annual traffic would also be dropped. The Corpus Christi to Brownsville portion of the GIWW has historically carried the lowest volumes on the GIWW in Texas moving approximately 2 million tons, or 2.5 percent of Texas GIWW traffic in 1988. The distribution of traffic along the segments of the waterway has remained fairly constant through the years.

The inland waterway system is no longer totally subsidized by the federal government. In 1978 the Inland Waterway Revenue Act was passed which imposed a four cent per gallon fuel tax on tow boats and tugs moving commerce on 26 specified shallow-draft navigation channels. The tax was to increase in three increments to ten cents per gallon in 1985.

Another piece of landmark legislation was the Water Resource Development Act of 1986. The bill established the rules for the cost-sharing principle agreed to in 1978. This act increased the ten cents per gallon barge fuel tax over a ten year period until it reaches a maximum of 20 cents per gallon in 1995. The tax is scheduled to become 17 cents a gallon on January 1, 1993. It also

established a "Users Board" to advise the Corps on construction, operation, and maintenance priorities in funding levels for the Inland Waterway System. It required a minimum non-federal share of 25 percent for flood control projects and limited the federal share to 50 percent for operations and maintenance of channels deeper than 45 feet. In addition, the bill imposed a four percent tax on the value of cargo loaded or unloaded in American ports.

Environmental

The 1984 publication of the *Gulf Intracoastal Waterway in Texas* (38) highlighted some inherent problems that arise when environmental concerns become a part of the planning process for the GIWW. The route of the Gulf Intracoastal Waterway leads through some of the most productive, yet sensitive areas of the Texas coast. As a result, several state and federal agencies administer the regulations necessary to protect the wetlands during water management projects.

The counties adjacent to the Gulf Intracoastal Waterway in Texas are home to several endangered and threatened species. Texas coastal counties are Orange, Jefferson, Chambers, Galveston, Brazoria, Matagorda, Calhoun, Refugio, Aransas, San Patricio, Nueces, Kleberg, Kenedy, Willacy, and Cameron. While not all of these species are found along the path of the waterway, several are.

The following species are found on state and federal endangered and threatened species lists for the coastal counties:

Fish:

River goby
Oppsum pipefish
Paddlefish
Blackfin goby

Plants:

Black lace cactus
Slender rush-pea

Reptiles and Amphibians:

Green sea turtle
Hawksbill sea turtle
Leatherback sea turtle
Loggerhead sea turtle
Kemp's ridley sea turtle
Texas scarlet snake
Black striped snake
Speckled racer
Sheep frog

Northern cat-eyed snake
Black-spotted newt
Smooth green snake
Mexican tree frog
Texas tortoise
Texas horned lizard
Snapping alligator turtle
Timber rattlesnake
White lipped frog
Rio Grande lesser siren
Texas indigo snake

Birds:

Arctic peregrine falcon
Bald eagle
Brown pelican
Piping plover
Whooping crane
Attwater's greater prairie-chicken
Reddish egret
White-faced ibis
Wood stork
Botteri's sparrow
White-tailed hawk
Aplomado falcon
Black-capped vireo
Black hawk
Gray hawk
Zone-tailed hawk
Swallow-tailed American kite
Golden-cheeked warbler
Rose-throated becard
Tropical parula
Sooty tern
Beardless northern tyrannulet
Pygmy owl
Bachman's sparrow
Eskimo curlew

Mammals:

Coati
Jaguarundi
Ocelot
Yellow southern bat
Coues rice rat

In planning the future of the GIWW, the Endangered Species Act of 1973 requires that a biological assessment of areas affected by projects of major federal action be made to identify those species which may be affected.

At the Federal level, information on endangered/threatened species is provided by the Ecological Services Field Offices of the U.S. Fish and Wildlife Service. State classifications are available from the Texas Parks and Wildlife Department Texas Natural Heritage Program, Resource Protection Division.

In 1983, in response to perceived danger to sensitive ecosystems, the Texas Department of Parks and Wildlife asked the State Attorney General to take legal action to stop dredging on one portion of the GIWW. This resulted in a need for disposal sites for dredged material situated where damage to the ecosystem would not occur. Soon thereafter, the Gulf Intracoastal Waterway Advisory Committee was organized by TxDOT to enable the state to act as a coherent unit in addressing the maintenance needs of the GIWW. The immediate objective was to acquire environmentally responsible disposal sites. The future goal was to devise a plan for the waterway as "a guide for exercising the State's continuing responsibility as the nonfederal sponsor as set forth in applicable State and Federal legislation and regulations."

The Gulf Intracoastal Waterway Advisory committee is composed of the following state agencies:

1. Texas Department of Transportation
2. Office of the Governor
3. General Land Office
4. Texas Parks and Wildlife Department
5. Texas Natural Resource Conservation Commission
6. Texas Historical Commission
7. Texas Antiquities Committee
8. Texas Department of Commerce

Since waterway plans may impact private industries or may be perceived as a threat to

conservationism, additional industry and conservation groups are invited to attend GIWW meetings to serve as resource organizations.

Among these are:

1. Texas Shrimp Association
2. Gulf Coast Conservation Association
3. Texas Ports Association
4. Lone Star Chapter of the Sierra Club
5. National Audubon Society
6. Texas Natural Resources Information System Task Force
7. National Marine Fisheries Service
8. U.S. Environmental Protection Agency
9. U.S. Fish and Wildlife Service
10. The Sportsmen's Clubs of Texas
11. PISCES (Professional Involvement Seafood Concerned Enterprises)
12. The U.S. Army Corps of Engineers
13. The Gulf Intracoastal Canal Association
14. King Fisher Marine Service, Inc.
15. House Transportation Committee
16. Texas A&M University/Sea Grant Program
17. Texas Agricultural Extension Service
18. Hollywood Marine, Inc.
19. Texas Water Development Board
20. Brownsville Navigation District
21. AGC of Texas
22. Texas Waterway Operators Association

Fourteen resource agency heads answered this question for *Texas Shores* magazine (39): "What do you see as the top three or four issues facing coastal Texas in the 1990's?" The most

mentioned topics were lack of freshwater flows, wetlands protection, toxic chemicals, and coastal fisheries conservation. Most respondents mentioned "reduced availability of adequate fresh water flows into the state's bays and estuaries." The General Land Office and U.S. Department of Agriculture Soil Conservation Service recognized shoreline erosion as a problem along with the National Hurricane Center for barrier islands. Both U.S. Senators from Texas, responding to the same question, focused on the costs of managing waterway problems. Both spoke of "wetlands protection," as did most of those interviewed. With the exception of the Texas Ports Association, which recognizes maintenance of the GIWW as important, no one expressed any concern for the GIWW.

Decisions impacting the GIWW, are made at all levels of government: federal, state and local. Hunt (36) examines state level interest groups and their influence on coastal water issues, specifically Galveston Bay. Texas interest group populations are identified and their tactics and effectiveness are explored. This is not, however, a straight-forward process because bay issues tend to lack durability, the decision-making structure is fragmented, and public record keeping on group activities was found to be less than adequate.

Interest groups are organized around the eight major uses of the Galveston Bay area:

1. transportation,
2. petroleum production,
3. industrial production,
4. waste disposal,
5. commercial fishing,
6. sport fishing,
7. recreation, and;
8. preservation as an ecological system.

From these groups, five major types of interest groups emerge; business, commercial fishing, sporting and recreation, environmental, and government.

Interest groups use a variety of means to achieve their goals. These include lobbying, public information campaigns, electioneering, litigation and forming coalitions. In the Sargent Beach situation, the Victoria Economic Development Corporation established the "Coalition to Save the Gulf Intracoastal Waterway" with the stated purpose of aiding the U.S. Army Corps of Engineers in developing a solution to the eroding beach (40). City, county, port, business and industry officials along with organizations concerned with the GIWW formed the coalition. They held workshops about the problem and raised \$16,000 to commission an economic impact study for the area. The head of the Committee to Save the Gulf Intracoastal Waterway stated "before you can go anywhere in the state or up on the federal level, you have to have something that's quantified." Their tactics included informing the public about the importance of the waterway and what it would mean to the state if it were to shut down. The commissioned study proved to be a useful tool for the association. The group applied political pressure on lawmakers and federal officials to convince them to view the Sargent Beach situation as an immediate threat to national commerce.

The group's tactics were extremely successful. By June 1992 initial plans for the Sargent Beach protection project had been passed by the Board of Engineers for Rivers and Harbors in Washington, D.C. Authorizing legislation at the subcommittee level has been approved and construction is expected to start in late 1994, with completion in 1998. The Sargent beach project has moved much faster than most federal projects because of the intense and powerful lobbying efforts. It takes an average of ten to twelve years for major improvements to a waterway to be inaugurated, and the time span from study to authorization through construction averages 15 years or more.

The Texas GIWW traverses a great amount of environmentally sensitive, coastal land area. *Land Resources of Texas* (41) classifies Texas lands according to natural suitability and use conditions. Texas is grouped according to 71 resource units based on important ground water recharge, significant mineral resources, limiting physical properties, unique landscapes, dynamic physical processes, submerged coastal environments, and environments altered by man. Of particular

importance to this project, the resource units are also dichotomized by critical biologic habitats.

Table 10 depicts rough likelihood estimates that dredging along specified types of land resources could, if adequate care is not taken, adversely impact the environment.

Table 10. Potential Dredging Impact

TYPE OF LAND RESOURCE	APPROXIMATE LENGTH (miles)	PERCENT OF TEXAS GIWW	POTENTIAL DREDGING IMPACT (Likelihood = High, Medium, Low)
Brackish to salt-water marsh	83	19%	H
Coastal aquifers	38	09%	H
Tidally influenced open bay	37	09%	H
Marine grass flats	24	06%	H
Tidal inlets and tidal flats	2	.5%	H
Levee & crevasse deposits	2	.5%	H
Swamp	2	.5%	H
Restricted bay	61	14%	M
Subaqueous spoil	18	04%	M
Open bay	14	03%	M
Wind-tidal flats & tidal flats	6	01%	M
Inter-reef flats	3	01%	M
Expansive clay mud	2	.5%	M
Flood-prone areas	2	.5%	M
Created Land & Spoil	91	21%	L
Other	41	10%	-

Source: U.S. Army Corps of Engineers, 1992

Table 10 reveals that approximately 45 percent of the Texas reach of the GIWW crosses very sensitive areas where the probability is high that dredging could, without care, potentially impact the environment. An additional 24 percent of the Texas GIWW runs through land where the probability is moderate that dredging could impact the environment.

2.5 HISTORY OF HAZARDS AND CLOSINGS ALONG THE GIWW

The U.S. Coast Guard's Eighth District Local Notices to Mariners (42) were reviewed from 1982 through 1991 to develop a history of hazards and closings on the Texas portion of the Gulf Intracoastal Waterway. These weekly documents notify mariners about hazards that may be encountered along the waterway and also depict the placement of buoys and other navigation aids. The hazards can be grouped into four areas: repairs and maintenance, dredging activities, shoaling, and wrecks.

Table 11 shows the distribution of hazards by category along the Texas GIWW. On average, approximately 18 significant (and reported) hazards occur along the Texas GIWW each year. Maintenance and repairs activities (32.2 percent) are the most numerous hazard encountered by mariners along the Texas GIWW. This is almost double the rate for any other category of reported hazard. Shoaling (19.8 percent) is the next most frequent hazard reported, followed by accidents (18.6 percent), and dredging (14.1 percent).

Table 11. Hazards Along the Texas Gulf Intracoastal Waterway

HAZARD CATEGORY	NUMBER OF EVENTS, 1982-1991	PERCENT OF TOTAL RECORDED EVENTS
Maintenance & Repairs	57	32.2%
Shoaling	35	19.8%
Accidents	33	18.6%
Miscellaneous	27	15.3%
Dredging	25	14.1%
TOTAL	177	100%
Average per Year	17.7	

Source: Texas Department of Transportation, 1976

No hazard or accident which completely closed the Texas GIWW for any appreciable duration could be found. However, Table 12 displays closings of the Texas GIWW by year and duration in hours. All of the closings depicted in this table were due to planned repair or maintenance

activities. No closing lasted for more than 10 continuous hours. In the event of such a closing the waterborne traffic just piles up until passage is cleared.

According to Table 12, over the ten year period, an average of three to four closings per year (37 total) occurred on the Texas portion of the GIWW. These planned closings lasted an average of 104 hours. This is far short of any closing which would necessitate a significant shift in transportation modes.

Table 12. Number of Closures on Texas Gulf Intracoastal Waterway

YEAR	NUMBER OF CLOSURES	TOTAL DURATION (in Hrs)	AVERAGE DURATION PER CLOSURE (Hrs)
1982	6	1320.7	220.1
1983	2	110	55.0
1984	3	412.6	137.5
1985	1	8	8.0
1986	6	485.5	80.9
1987	11	722.8	65.7
1988	5	541.4	108.3
1989	0	0	.
1990	0	0	.
1991	3	244.3	81.4
TOTAL	37	3845.3	103.9

Source: U.S. Department of Transportation, 1982 - 1991

One of the primary responsibilities of the U.S. Coast Guard is to clear the waterway expeditiously. Interviews with information officers of the 8th U.S. Coast Guard District were conducted to determine if any anecdotal evidence of closures of long duration could be produced. Most of these officers were ten to twelve year veterans. The longest period of continuous closure was found to be four days, but that was along the Louisiana GIWW, a more heavily traveled route.

A closure along the Texas GIWW due to reasons of national security was also investigated. Most major ports in the United States has a U.S. Coast Guard contingent. The U.S. Coast Guard port commander has the authority to institute a military zone along the canal to ensure the safety and transport priority of vital military goods and material. The military zone, however, does not cover a significant area, perhaps a few hundred yards on either side of a military convoy. During the recent Gulf War, military zones were instituted along the Texas GIWW, but this did not close the waterway or otherwise affect canal operations. An interview with a U.S. Coast Guard officer revealed that, in his opinion, no closure would occur due to military involvement.

3.0 INVENTORY OF THE TRANSPORTATION NETWORK ALONG THE GIWW

The transportation system serving the Texas coastal zone includes elements of every mode of freight transportation: highway, rail, air, pipeline, ship, and barge. In addition, three of the top four economic sectors in Texas (petroleum refining, petroleum production, and agriculture) are located in this region of Texas. Each of these sectors is heavily dependent upon transportation for their value, and it is no accident, given the transportation options which exist, that firms have chosen to locate along the Texas gulf coast.

Of central concern to the current research is the waterborne transport that fuels much of the economic activity of the region. Barges loaded with more than 80 million tons of goods travelled the GIWW during 1989. About half of this traffic (39 million tons) crossed the Texas-Louisiana border and had to pass through the heavily congested locks in Louisiana. Figure 2 shows the quantity of goods moved on the Texas portion of the GIWW and on the central portion of the inland waterway system.

The remainder of this section of the interim report will examine some of the features of the other transportation networks found in the gulf coast region of the state. The discussion will focus on those modes which may serve as alternative carriers in the event of an extended closure in the GIWW.

3.1 RAIL

An extensive network of railroads, including almost 3,000 miles of main-line tracks, serves the coastal region of Texas. A total of 55 million tons of rail freight is estimated to originate in, terminate in, or pass through the coastal zone each year. However, none of the major rail corridors appear to be operating at capacity, and this basic capacity can be greatly increased through signalization and centralized traffic control if future needs require.

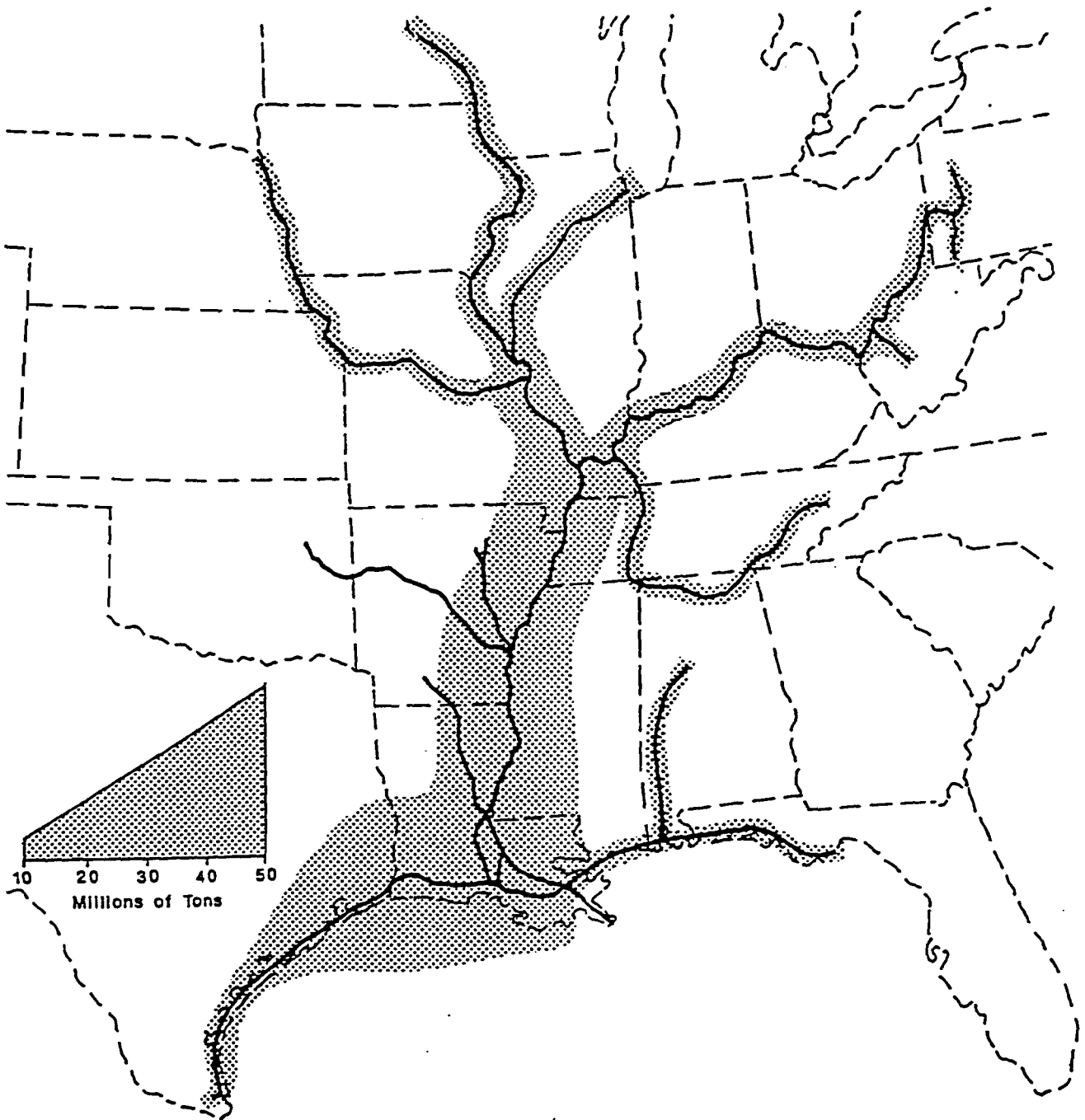


Figure 2. Inland Waterway Commodity Flow
(Updated from Holder, 1973)

Two trunk-line railroads, the Missouri Pacific/Union Pacific Railroad and the Southern Pacific, parallel the Texas Gulf Coast between Galveston and Brownsville. The Union Pacific Railroad serves the industrial areas of Freeport, Bay City, and Victoria Barge Canal; the Southern Pacific Transportation Co. serves Port Lavaca and Aransas Pass. Connections with the Union Pacific Railroad are made at Lolita by the Point Comfort and Northern Railway which serves the Point Comfort Industrial Complex; and at Brownsville by the Brownsville and Rio Grande International Railroad which serves the Brownsville Port area. The Port of Harlingen Railroad serves that port and connects with the Southern Pacific. The National Railways of Mexico connect these trunk-line carriers via a railroad bridge across the Rio Grande between Matamoros, Mexico and Brownsville, Texas.

All of the publicly owned waterfront terminals at the Port of Galveston are served by a terminal railroad known as Galveston Wharves. This railroad connects with and performs switching services for the following railroads serving Galveston and the port area: The Atchison, Topeka and Santa Fe Railway Co.; Burlington Northern Railroad Co.; Missouri-Kansas-Texas Railroad Co.; Missouri Pacific/Union Pacific; and the Southern Pacific.

The Texas City Terminal Railway Co., jointly owned by The Atchison, Topeka and Santa Fe Railway Co., Missouri-Kansas-Texas Railroad Co., and Missouri Pacific/Union Pacific Railroad Co., operates all terminal and switching service at the Port of Texas City. In addition to connecting with the above mentioned carriers, direct interchanges are also made with Burlington Northern; Galveston, Houston, and Henderson Railroad Co.; and the Southern Pacific.

All of the publicly owned, as well as some of the privately owned, waterfront terminals at the Port of Corpus Christi are served by terminal trackage owned by the Port of Corpus Christi Authority. This trackage is operated in turn by the Missouri Pacific/Union Pacific Railroad Company, the Southern Pacific and the Texas Mexico Railway Company, under an agreement which provides for the rotation of the operation.

Two terminal and switching lines, the Houston Belt & Terminal Railway Co. and the Port Terminal Railroad Association, serve the majority of the waterfront facilities at Houston and interchange with the five trunk line railroads serving the port: the Atchison, Topeka and Santa Fe Railway Co.; Burlington Northern; Missouri-Kansas-Texas Railroad Co.; Missouri Pacific/Union Pacific and Southern Pacific.

The Kansas City Southern/ Louisiana and Arkansas and the Southern Pacific serve the Port of Port Arthur, Texas. The port area of Beaumont is served by the Atchison, Topeka and Santa Fe Railroad; Kansas City Southern /Louisiana and Arkansas; Missouri Pacific/Union Pacific Railroad; and the Southern Pacific. The Missouri Pacific/Union Pacific Railroad and the Southern Pacific serve the Port of Orange, Texas.

Sixty to seventy percent of the major shippers in this area have direct access to rail. For the petro-chemical plants along the coast, many have on-site rail access. In 1988 the Texas Railroad Commission reported that the single largest commodity volume (in tons) transported by rail was the Chemical and Allied Products category with over 60 million tons transported. The second largest volume was coal, with over 54 million tons moved. Both of these commodities are transported by barge on the GIWW and would be expected to shift to alternate modes. Figure 3 shows the location of Texas coastal rail-lines.

3.2 PIPELINE

The concentration of pipelines in the Texas coastal zone is greater than in any similar size area in the world. Figure 4 shows the network of pipelines emanating from this region of the state. Crude petroleum products, and natural gas pipelines ranging from 6" diameter to 36" diameter criss-cross the entire area. The total capacity of liquid pipelines entering or leaving the coastal zone is sufficient to transport more than 150 million tons of crude oil and petroleum products each year.

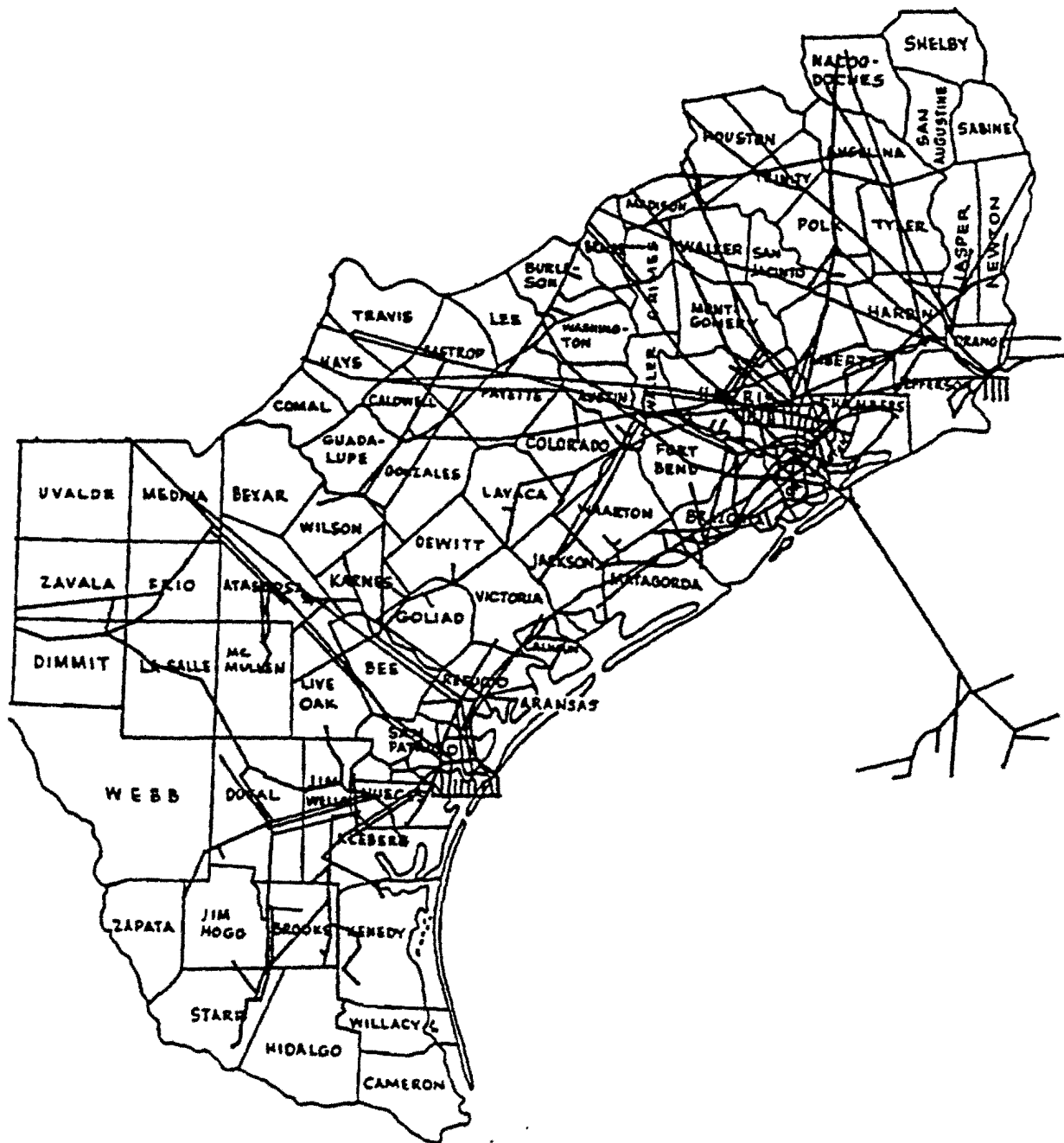


Figure 4. Texas Gulf Coast Pipeline Network
(From Wolbert, 1979)

Pipelines are subject to both state and federal regulation. On the federal level, legislation requires that crude-oil pipeline companies must make their pipelines available to all shippers, follow ICC guidelines, and file tariffs showing their complete rate structure. However, a company transporting its own production from its own wells, through its own lines, to its own refineries is not subject to ICC jurisdiction (43). Many states adhere closely to the ICC common carrier status, even though the pipelines may operate on an intrastate basis. Also, a variety of methods are employed by the states to determine whether a pipeline falls in the common carrier status or the private category. The eminent domain privileges are mostly dependent upon common carrier status.

Since the time of anti-monopoly legislation for the pipelines, the nature of the industry has changed. The tremendous outlay of funds for lines in more recent years and the fact that the volume of traffic required to fully realize economies of scale surpasses what a single refiner can provide has led to jointly owned and operated lines being commonplace. The economic incentive is to broaden the base of ownership and to solicit vigorously the traffic of those not interested in taking an ownership position.

U.S. Oil Pipelines (43) reports that in 1979 there were:

- Thirteen common carrier crude trunk lines competing for the movement of crude oil from the West Texas producing region to the Texas Gulf coast refining area, and;
- Nine such carriers battling for traffic from the East Texas producing region to the Texas Gulf coast refining area.

Since that time pipeline shipment of petroleum products has increased. Given the low rates, the incentive to share costs, and the existing network of pipelines, it could be expected that this mode would be pressured to accommodate as much of the shift in commodities as possible. It remains to be determined how much excess capacity exists and where access to the system is possible.

3.3 ROADWAYS AND TEXAS TRUCK TRAFFIC FLOW

Highways also provide a major corridor for freight transportation. Most of the 12,000 miles of highways crisscrossing the coastal zone are presently located in rural areas and operate at less than half their capacity. However, traffic volumes increase sharply as these highways approach urban or commercial centers.

For this report, it will be convenient to divide the 43 counties under study into an inland and coastal region. The coastal region is composed of the 13 coastal counties: Jefferson, Chambers, Galveston, Brazoria, Matagorda, Calhoun, Aransas, San Patricio, Nueces, Kleberg, Kenedy, Willacy, and Cameron. The inland region is made up of the remaining 30 counties likely to be impacted by a shift in cargo from waterborne transport to the Texas highway system.

Truck traffic data from 1990, developed by TxDOT, makes the usual truck traffic routes clearly visible. Volume data, as shown in Figure 5, indicates that the interstate routes carry the largest loads, followed by the U.S. routes, and third, the state routes. The interstate highways in Texas, however, do not offer proximate transportation along the gulf coast. Consequently, much of the traffic parallel to the coast is shifted to U S. highways.

In south Texas, between Cameron County and Nueces County, the north-south traffic is heavily reliant upon US 77. The inland region of the same area between Hidalgo and Jim Wells, however, is likely to depend upon US 281. Based on a 1990 traffic flow analysis of a 24-hour period, the truck flow for both roads averages approximately 2,500 vehicles per day.

The coastal counties between San Patricio and Brazoria, on the other hand, are connected by State Highway 35. The truck traffic is estimated to be about 750 per 24 hours. The inner counties lying between San Patricio and Victoria are connected by US 77, with truck average annual daily traffic (AADT) approximating 2,000 vehicles per day. In Victoria, however, US 77 joins with US 59 and runs to Fort Bend county.

At this juncture, the truck traffic increases to approximately 3,500 trucks over a 24 hour period.

Truck traffic converges in the Harris and Galveston county area. Within this area, there are a multitude of highway options. Interstate 10 runs east-west while Interstate 45 runs north-south. Other major roads which run through these counties are US 59, US 90, and State Highways 6, 35, 225, and 146. In this region, truck traffic is dominated by the Interstate system, followed by heavy usage of US 59. Although TxDOT data indicates a heavy conglomeration of traffic in this area, for the purposes of our studies, the congestion is not as bad as is indicated due to the irrelevant flow of traffic from the west.

Beyond this sector, moving toward the Louisiana border, traffic is concentrated on Interstate 10 and US 90. Along the Texas-Louisiana border (Orange, Jasper, Newton and Tyler counties), however, the predominate traffic flow is on US Highway 96 and US Highway 69.

4.0 MODEL DEVELOPMENT

The impact model, developed to assess the effects of a closure in the GIWW, will combine data from several different sources through a series of stepwise calculations to arrive at a set of bottom line impacts which will include projected increases in maintenance costs, accidents, roadway congestion, energy usage, and pollution. The impact assessment will focus on three areas:

1. the impact a significant freight shift to the Texas highway system would have on energy consumption and energy-related environmental implications,
2. the potential impact of a shift in hazardous materials to the Texas highway system, and;
3. the direct impact on the highway system itself: maintenance and rehabilitation costs, highway capacities and congestion, and traffic pattern changes.

The impact model will consider the type of interruption, the expected duration of an interruption, and the location of the interruption. The model, through a modal freight shift algorithm, will assess origin and destination data in conjunction with commodity categories to calculate tons of freight, number of trucks and axles, and total numbers of vehicles on proximate roadways. Bottom line impacts will be drawn from these derived values.

4.1 LIKELY INTERRUPTIONS

Several potential interrupting events or conditions have been cited in previous sections of this report. Among these are:

- structural; lack of maintenance of the physical integrity of the canal
- natural; uncontrollable natural forces such as weather (hurricanes), or erosion (as at Sargent Beach, Texas).
- political; unfavorable legislative or judicial action which would effectively render some portion of the GIWW unusable for transportation purposes. This would include the economic effects of burdensome taxation.

4.2 IMPACT ANALYSIS ZONES

The Texas portion of the GIWW runs along the Texas gulf coast for approximately 400 miles. Mile point assignments, employed on navigation charts and maps, begin at mile 266-West at the Texas-Louisiana border. New Orleans is considered the zero point on GIWW maps, hence the use of distance and direction from that location. Mile 683-West corresponds to the terminal point of the GIWW at Brownsville, Texas.

For the purposes of this study, preliminary impact analysis zones have been established based on the Texas Department of Transportation Districts. Five TxDOT Districts span the Texas coastline. In addition, given the considerable area covered by the districts, identifiable industrial clusters, and the highway systems, the use of sub-zones within some of the districts will enable more accurate prediction. Table 13 presents the preliminary impact zones and sub zones.

Table 13. Preliminary Impact Zones

TxDOT DISTRICT	IMPACT ZONE	SUB ZONE	GIWW MILE POINT (approximate)	LOCATION LABEL
20	1	1 2	270-305 305-320	Louisiana Border Chambers Co.
12	2	1 2	320-370 370-410	Galveston Bay Freeport
13	3	1 2 3	410-450 450-480 480-500	Matagorda Lavaca Bay San Antonio Bay
16	4	1 2	500-540 540-580	Corpus Christi Baffin Bay
21	5	1	580-670	Brownsville

Source: TTI Research

4.3 ROADWAY IMPACT MODELS

The following section summarizes some alternative models in consideration for quantifying and predicting the impacts of increased truck traffic on Texas roads. The models under consideration for data analysis in the project are:

1. RENU (short for rehabilitation and new axle loading); a commonly used and well-documented series of programs designed to assess several factors including weather, KIPs, and surface type,
2. Casavant's (1989) methodology from *Procedure for Predicting and Estimating the Impact of Rail Line Abandonments on Washington Roads* (44),
3. Evaluation of TxDOT maintenance contract costs for guardrails, rest areas, pavement marker, striping and seal coats,
4. Creation of a new/simple model developed from functions borrowed from RENU, and ;
5. Obtain base values for maintenance costs as found in the *Final Report on the Federal Highway Cost Allocation Study* (45).

Model 1

RENU is a self-sustaining and independent model developed from previous research and available for use in this study. A summary of RENU's input/output parameters suggests that the required data is obtainable, but is also very extensive. Tests of RENU are scheduled to allow for verification of the model parameters.

Although RENU's output is thorough, an algorithm for consideration of environmental effects on Texas highways has not been located. A possible solution is that the regions of concern all have a similar climatic condition thereby yielding a constant parameter that can be hard-coded. One of the variables that RENU requires is "Economic Prediction Information," or more specifically, base costs for highway rehabilitation. Although this information is inarguably valuable, its

usefulness seems to be better applied to Model 5.

Model 2

A model outlined by Casavant (44) for rail line abandonment, may suit the needs of this project. This model uses a simple function to compute cost increases to highway maintenance due to railroad abandonment. The function is as follows:

$$(M_o - M_n) = (T)(V)(L) \times [0.00251331]$$

where $M_o - M_n$ = increased annual highway maintenance cost
T = number of one-way trucks per year diverted from rail
V = average gross vehicle weight per round trip, and
L = length of haul

Factors potentially limiting the applicability of this model include the fact that the equation does not consider type of pavement, type of repair/rehab, highway number, or environmental impacts.

Model 3

The third possible model or approach is to use existing, readily obtainable information with which to develop a more relevant model and function. Currently, our resources include data from a seal coat project which includes the following parameters:

- District Number
- County Number
- Highway Type (US, SH, FM)
- Average Daily Traffic
- Contractor/State Force
- Gallons of Asphalt Used
- Total number of Cubic Yards of Aggregate
- Total Length of the Project

- Total Area Sealed
- Total Direct Cost of the Project
- Cost per Square Yard

Although the above information does not completely suit our needs, the availability of this data, and the chance that TTI may have other more pertinent information, makes this a viable option worth pursuing.

Model 4

Our fourth option is to create our own database from which the data analysis will be undertaken. This database will be based on functions provided by RENU. Function documentation is ongoing, but promises to be difficult because documentation for these pre-existing databases is either complex, incomplete, or both.

Model 5

The method introduced by the *Final Report on the Federal Highway Cost Allocation Study (45)* is based on one of the pieces of information needed to run RENU. Using the information for this model seems to be more feasible than its application to RENU. In addition, the simplicity provided by Model 5 may make the approach more functional than RENU with its inherent complexities.

The base value data presently on hand dates back to 1982 and is highly inaccurate. More recent costs must be obtained to pursue this approach. Furthermore, the base values must cover a wider range. It must account for the type of required maintenance, for example, to fill in pot-holes or resurface the entire road. Also, the type of pavement must be accounted for, as well as the extensiveness of the repair. The calculation procedure for this method is simple, but data collection can be rather detailed.

5.0 NEXT STEPS

Much of the data required for an analysis of the impacts of a closure in the GIWW has been obtained or is available through TTI or TxDOT sources. The remaining steps, therefore, involve the combination of these data in a manner which simulates the effects of an interruption in service along the GIWW on Texas highways . The simulation will focus on the highway impacts within each of the ten impact sub-zones defined in the previous section of this report.

In preparation for the simulation analysis, a preferred modal shift model will be selected from the available alternatives. The modal shift model will provide information on the quantity and types of goods likely to be added to the Texas highway system in the event of a closure of the GIWW. The model will derive the expected quantities added to the highway system through a process of elimination. The elimination process will estimate the goods first shifted to railroads, pipeline, and ocean transport. The calculation will also include an estimation of that quantity no longer produced or shipped due to the loss of transportation alternatives. The goods remaining after subtracting those handled by other means, can be allocated to the Texas coastal highway network.

The literature review identified several approaches to modal shift modeling. However, many of the approaches identified are not suitable for the current application due to their requirement for involved data collection and analysis. Extensive data collection and analysis is beyond the practical scope of the current research. Important criteria for model selection then will include limited data collection and analysis, model simplicity, and, most importantly, an intuitive logic associated with model assumptions.

Once the amount of material diverted into a given impact zone is derived, those roadways likely to carry the additional goods must be defined. The definition of impacted roads will be accomplished by examining State maintenance maps in conjunction with information on the centers of industrial activity along the GIWW. Those roadways likely to carry additional traffic based

on proximity to industrial locations and origin-destination data, will be selected for detailed analysis. The impact analysis will include roads from the FM, State, US, and IH classifications. Identified roadways will be examined in detail with the aid of roadway condition, volume, and maintenance data obtained from TxDOT's annual RI2-T log data tapes. This source contains data on AADT (for automobiles and trucks), surface and base type and condition, lane width, and other pertinent factors, referenced by control-section numbers.

The impact of truck traffic increases expected on selected roadways will be derived from the anticipated number of additional tons of material transported on Texas highways. These tonnage figures will be converted into the number of KIPS (thousand pound axle loadings) anticipated and the number of ton miles of transport expected to result from freight shifts to truck transport. The impact of these increases will be calculated for fuel use, environmental impact (i.e., increases in pollution), accident potential, roadway surface degradation, traffic congestion, and hazardous material transport.

The effects of an interruption in service on the GIWW will be assessed through a series of simulation runs. The simulation runs will extract information from origin-destination data files and roadway condition data files to arrive at the tons (by commodity) added to Texas highways. These figures will be calculated for each of the 10 impact zones defined in the previous section. The tonnage data will be computed for average (standardized) one-month time periods, allowing the user to extrapolate to any time period by adjusting for seasonal variations. Seasonal adjustment factors will be calculated from commodity flow data from 1989.

The resulting data will be presented in hard copy form with at least one simulation run performed for each of the ten impact sub-zones. The programs and data files will be kept available in the event that interruption simulations are requested for any other section of the coastal region.

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