Impact Assessment

Dredge and Fill Activities in Galveston Bay

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The single most obvious manifestation of human impacts on Galveston Bay is the physical modifications associated with excavation and disposal of sediments. After the close of the Civil War , increased shipping in the bay led to channelization, current training, and protective structures, which have continued to the present. Further, development of the Bay periphery has led to constructive dredge-and-fill activities not directly associated with navigation. The net effect has been a gradual alteration in the morphology of the Bay. While the actions of dredging and filling associated with a specific project are immediately evident at the site, the cumulative activity over the entirety of the bay is not so readily ascertained, and even less so is the variation of that activity over a time frame of years. The objective of this study is to quantitatively characterize dredge-and-fill activities throughout the bay as a function of time.

In the 19th Century, dredge-and-fill operations were dominated by navigation projects, primarily private though with an increasing Federal involvement in the last quarter of the century. Both the project objectives and the Federal-private mix changed during the early 20th Century. Further, the basic process of undertaking such projects was altered profoundly in the last half of the 20th Century with the increasing regulatory role of the government. This period commanded the bulk of this study effort, in compiling data from sources at the Corps of Engineers, *viz.* dredging records for federal projects and permit records for 404-regulated activities.

Early 20th Century Activities

In 1900, a Federal channel of nominal 12-ft draft spanned Galveston Bay, from the Bolivar inlet between the jetties, across Redfish Bar, through the cut at Morgans Point, and up Buffalo Bayou to the city of Houston at White Oak Bayou. This channel was pieced together from several autonomous projects, and the value of a single coordinated project was immediately apparent to both military and private interests. Moreover, the deepening of the bar as a result of the improvements at Bolivar inlet allowed vessels drawing 25-ft to Galveston, which predictably stimulated interest in a deep-draft (i.e., 25-ft) channel across the bay to Houston.

The problem of siltation ("deterioration") of dredged channels crossing the open bay was confronted since the 12-ft Galveston Bay Channel of the last century. This was obviously related to silt-loaded currents crossing the channel, so an equally obvious solution was to protect the channel by a structure on the upcurrent side. This approach led to the construction of two extensive dikes in the open waters of Galveston Bay. The first, part of the 25-ft project for the Galveston Bay Channel, was a 26,000-ft dike of timber pilings and brush extending from Morgans Point south along the eastern side of the channel.

Heretofore, disposal of spoil was undertaken somewhat cavalierly, usually sidecast in open water or placed in proximity to the project along inland streams. For the 25-ft channel, disposal, as well as minimization of maintenance, became a major concern. Part of the project design included identification of suitable spoiling tactics. The bay reach below Redfish Bar was to be spoiled to the west of the channel. For the upper bay reach above Redfish Bar, more problematic due to the cross-flow from the Trinity, spoil was to be placed to the east beyond the dike.

The first phase of this project, begun in 1900 after the great storm, consisted of construction of the pile-and-brush dike from Morgans Point to Redfish Bar and dredging of a 17.5 x 80 ft channel through the bay. The dike was completed in 1902, using 500,000 linear feet of timber and 6000 cords of brush. In 1903, dredging was begun to enlarge the channel across the bay to 18.5 x 150 ft. By 1910, the Federal project had achieved 18.5 ft, and in the Rivers and Harbors Act of that year was renamed the Houston Ship Channel. In 1914, dredging was completed to the authorized depth of 25 ft. The dike was plagued with deterioration, and in 1910, 11,500 ft was replaced with creosoted piles. The storm of 1911 destroyed all but the uppermost 7,500 ft. However, the spoil bank here, Atkinson Island, had now stabilized to continue to provide the same protective function as the old dike.

A new industry motivated the next channel expansion: the appearance of oil tankers in the world fleet after World War I. New project dimensions of 30 x 250 ft in Galveston Bay and 30 x 150 in the reach above Morgans Point were completed in 1926 (the bay reaches being completed in 1922). In the 1930s, the Houston Ship Channel was enlarged again, to 32 x 400, completed in 1937.

In 1900, Galveston Channel was approximately 30 x 1200 ft in dimension to about 51st street. This channel was extended at 30 x 700 ft to 56th St. in 1909, and further widened to 1000 ft in 1913. The channel to 43rd St. was deepened to 32 ft in 1929, and 34 ft in 1937. The harbor channel (i.e., the inner and outer bar channels between the jetties) was enlarged to 35 x 800 ft in 1922.

In close association with the development of the Houston Ship Channel was the creation of a channel to Texas City. The private 16-ft channel was assumed by the U.S. government, and included in the 25-ft channel network. This was completed in 1905, and extensive maintenance dredging was needed almost every year for the next decade. The Texas City Channel was laid nearly perpendicular across a natural scour channel known as Half Moon Channel. (In fact, there was some debate that the Houston Ship Channel should pass through Galveston Channel, then around the west side of Pelican Island and along Half Moon Channel, to take advantage of the naturally scoured depths). With sediment-laden currents regularly sweeping across Texas City Channel, the resulting high rate of siltation led to authorization of a timber pile dike along the north side of the channel, completed in 1915. This structure extended 28,200 ft out into Galveston Bay, and required 950,000 linear feet of timber pilings. While it definitely reduced siltation in the channel, maintenance on the structure was expensive, and several alternatives were tried in the 1920s, including mud shell, pontoons and sheet pile bulkheads. In 1931-34 a rubble mound dike was constructed, creating the present Texas City Dike configuration.

Meanwhile, the idea of an inland canal, which had been floated since 1818, gathered momentum with the creation in 1905 of the Interstate Inland Waterway League, an organization that gradually evolved into the Gulf Intracoastal Canal Association. As a Federal project, segments of a 5 x 40 ft inland canal were completed by the Army Corps of Engineers (USACE) by 1909, including, in Galveston Bay, the old canal through Karankawa Reef from West Bay to the Brazos. The abandoned original route of the Gulf Intercoastal WaterWay (GIWW) at Drum Bay is still apparent in the physiography of this area, though it has not been dredged since the early part of the century. The connection with the upper coast was finally completed in 1934 with the segment from East Bay to Sabine Lake. Also, the older strategy of running a canal from bay to bay was replaced with that of a landlocked channel paralleling the coast. The GIWW was enlarged to a 9 x 100-ft canal by 1942.

Federal Channel Projects since World War II (WWII)

At present, there are over 200 miles of federal channels in Galveston Bay (exclusive of the harbor channels). This includes 73 miles of deep channels (depths exceeding 36 ft), 76 miles of 12- to 15-ft channels, and over 60 miles of channels of depth less than 12 ft. In terms of bay area, these channels occupy some 6300 acres, of which 80% is deep-draft.

Most of the channel projects in the interior of the Bay have been dredged under contract to the USACE. Each contract is preceded by a before-dredging survey, and upon completion of the work, is followed by an after-dredging survey. Their difference for each sub-reach of the contract gives the volume of material removed, upon which payment is based. Data on dredged volumes for contract subreaches were made available to this study by the USACE Fort Point Area Office, all of which was keyboarded from Corps records, referenced to a uniform positioning system and accumulated by standard lengths along the channel projects. It was then further aggregated in time and space for analysis.

For example, Figure 1 displays dredging activity in the lower bay reach of the Houston Ship Channel accumulated by 5000-ft reaches for the period 1986-91. There have been two significant periods of dredging of virgin material. The first, beginning in 1949, is the enlargement of the Houston Ship Channel from a project depth of 32 ft to a project depth of 36 ft. The next was the enlargement to a project depth of 40 ft, begun in 1963. With respect to maintenance dredging, in the open-bay

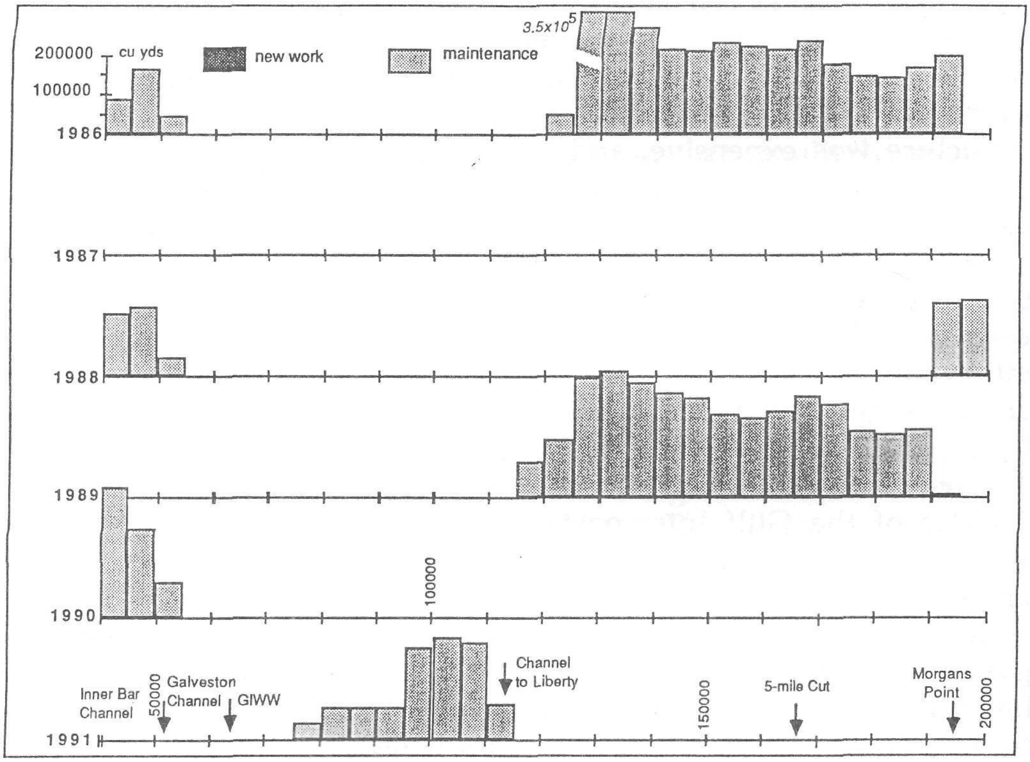

Figure 1. Dredging in 5,000-foot segments, Houston Ship Channel from entrance to Morgans Point.

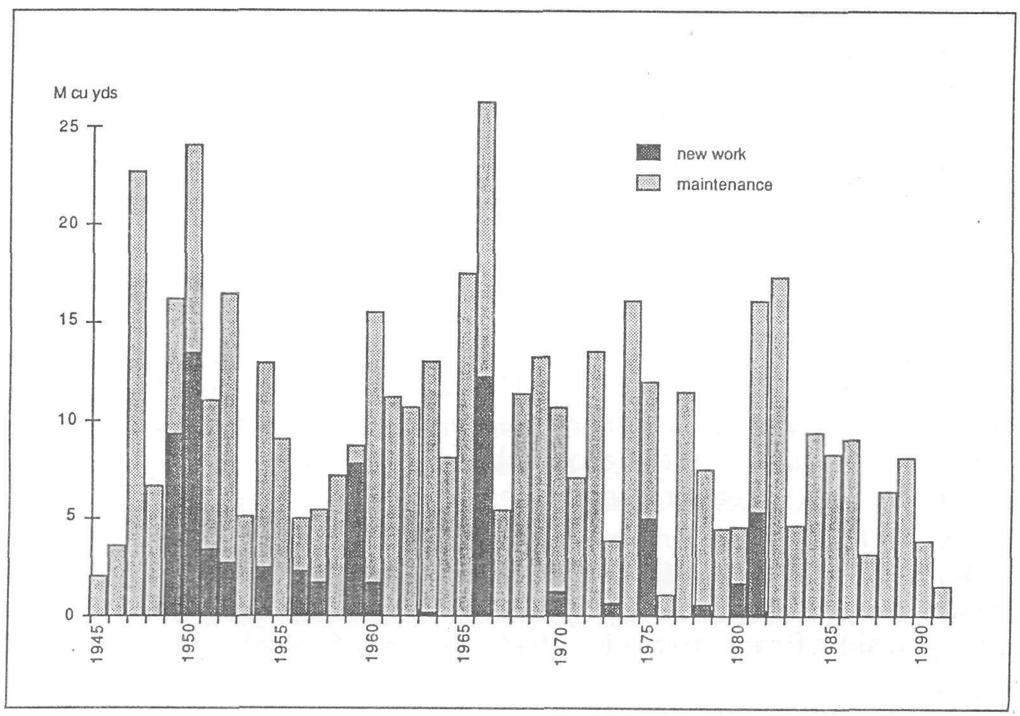

Figure 2. Total federal dredging in Galveston Bay, 1945-1991.

section, the reach in the upper bay requires greater maintenance than the reach in the lower bay. In the lower bay, the 30,000-ft reach from the entrance to above the end of Texas City Dike has required practically no maintenance dredging in the past 50 years. This reach transects the zone of convergence of flows into and out of the estuary, especially tides, a zone which is naturally scoured and, therefore, exhibits some of the highest natural depths in Galveston Bay. It appears that the higher currents in this zone prevent accumulation of silt in the channel.

One feature of Galveston Channel, immediate from this compilation of data, is the large maintenance dredging required in this channel. Its maintenance dredging has been a point of difficulty since early in the century. In the late 1930s, the Corps investigated movement of sediment in this area, and determined that Galveston Channel intercepts part of the ebb flow from the main body of Galveston Bay; in fact, much of the influx of sediment into West Bay seems to take place through Galveston Channel. Both normal tidal ebbs and sustained effluxes after northers were observed to drive a flow through Galveston Channel into West Bay.

Data were further aggregated by natural subreaches of each of the major projects that are differentiated by rates of dredging, for a more compact depiction of time variation of dredging activities. Complete presentation of this data for all of the federal projects on a year-by-year basis since 1945 is given in the final report (Ward, 1992). All of these projects are combined into baywide annual dredging, shown in Figure 2. Maintenance dredging, in contrast to new work, is presumably more closely related to physical processes of resuspension and siltation. Despite the high year-to-year variability of dredging in the individual projects, on a baywide basis the annual maintenance volume is remarkably consistent of about 8.5×10^6 cu yds. Moreover, the rate of maintenance dredging has been reduced by about 40% from pre-1970 to post-1970 periods, a reduction dominated by the confined reach of the Houston Ship Channel and the reach above Redfish Bar.

Prior to WWII, dredged material from projects within the interior of the bay requiring open-water disposal was freely sidecast, usually at the convenience of the dredger. Although the problem of re-dredging the same material was clearly recognized by the Corps, the economics of pipeline operation, especially in the open bay, did not offer alternatives. Since the 1960s (earlier in some areas of the bay), specific regions have been designated as disposal areas. As dredged material has accumulated, these regions have become shoal and even emergent. Some have been stabilized around their periphery by levees, and the strategy is to ultimately levee all open-water areas. While the record keeping on disposal of dredged material is not nearly as detailed as that for removal of dredged material, for the purposes of this project, the important action is the creation of the disposal area. From the standpoint of Galveston Bay, that area is essentially isolated and removed from the bay system. All told, there are about 25,000 acres of such designated disposal area in the Galveston Bay system, of which 23% is in the upper Houston Ship Channel area, 32% is in West Bay (including Galveston Channel and Texas City Channel), and 6% is in Trinity Bay. Open-water sites total about 9000 acres.

Section-404 Activities since WWII

There is a considerable range of dredge-and-fill operations not carried out by the Corps of Engineers, but rather by private interests and public agencies. These include port approaches and dock facilities, marinas and boat slips, drilling and well installation, pipelines, canals and channels, bridges and shoreface structures, bulkheads, revetment, dikes and levees, borrow excavations, land filling and grade elevation, and outfall structures. These and related activities are regulated through the approval and issuance of Section 10/404 permits. Almost any physical modification to a watercourse or its adjacent wetlands now requires a Section 10/404 permit. Galveston District USACE has a considerable body of records documenting this permitting activity, in the form of microfiche copies of file records on permits. The permitting traffic is immense, totaling 4,245 separate permits for 1940 through 1991 for the Galveston Bay area, averaging about 100 per year since 1950.

Galveston District made available to this project all of its file holdings on 404 permitting. In view of the large number of permits and the sheer bulk of the material on file for each permit, a two-pass approach to data compilation was employed. Pass One entailed a comprehensive inventory of all permits issued by the Corps for the Galveston Bay system, including date and number of permit, general location of the project (i.e., county and watercourse), and character of the work in one or several categories. Pass Two comprised a quasi-statistical subsampling, focusing upon those permits for work within or immediately adjacent to Galveston Bay, including the lower reaches of tributaries flowing directly into Galveston Bay or a principal subsystem of the bay, and involving specifically dredge or fill activities. The permit files were examined in detail to determine quantitative data on location, as latitude/longitude, volume and area of affected areas, and types of habitat displaced or created. Generally, most of this information is not presented as such in the permit file. Therefore, the project site had to be located on large-scale maps of the area and the position coordinates determined manually. At least one of volume and area had to be manually computed from construction drawings, sometimes both. Cumulatively, since WWII, 64×10^6 cu yds of dredging involving nearly 3000 acres, both maintenance and new work, have been permitted in the Galveston Bay system. This is an order of magnitude less than the federal channel projects, which have removed cumulatively since WWII 401×10^6 of maintenance and 81×10^6 cu yds of new work. On the other hand, the 404-permitted work tends to be concentrated in the near shore zone.

The time history of Section 10/404 permitting is shown in Figure 3, for the general region of Galveston Bay including all tributaries and inland operations. The broad trends in this permitting activity are indicated by the shaded lines. After WWII, the rate of permit issuance rose to about 70 per year, which was maintained, more or less, from the late 1950s to the early 1970s. Then, the rate of permits rose precipitously to about 180/yr by 1976. This is indubitably a response to the new 404 requirements of FWPCA (PL 92-500), and the formalization of the 404 process, but also due to economic expansion during this period. Beginning in the early 1980s,

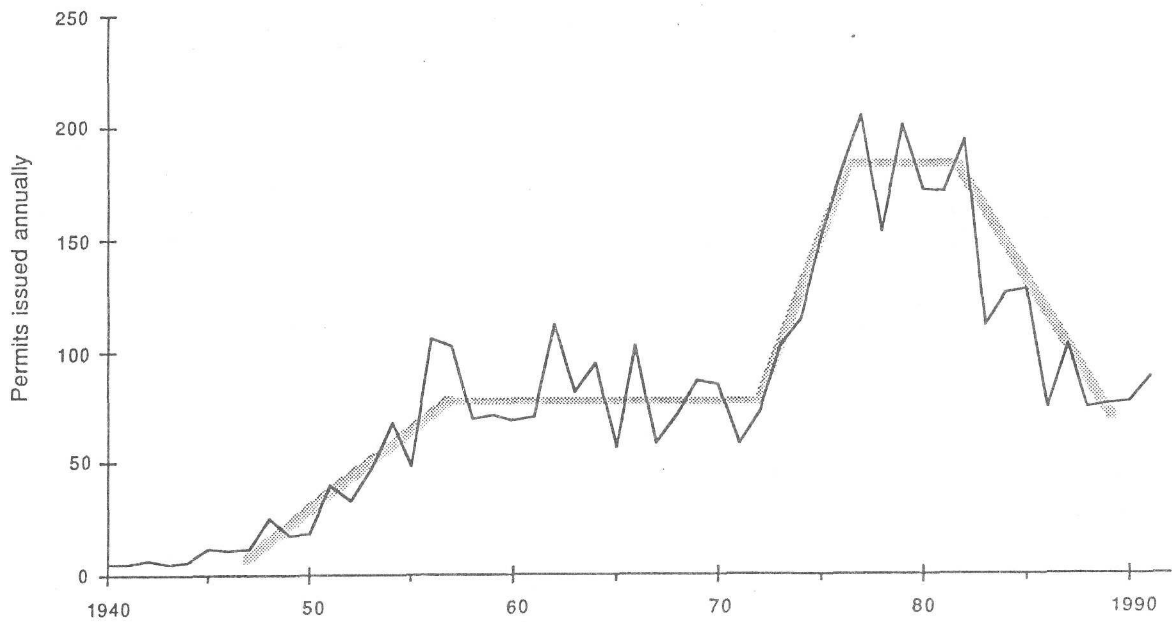

Figure 3. Section 10/404 permitting activity in Galveston Bay, 1940-1991.

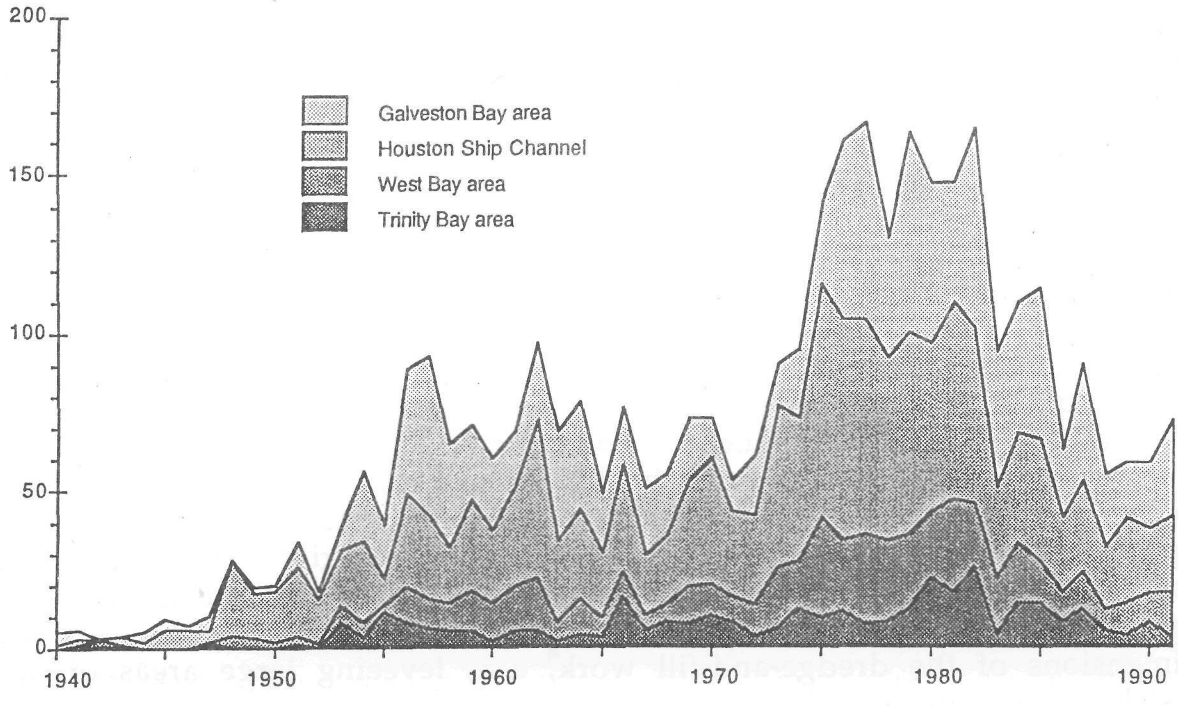

Figure 4. Annual section 10/404 permits by major areas of Galveston Bay.

the rate of permitting began to drop, ultimately by the late 1980s to a level on the order of that prior to promulgation of FWPCA regulations. This drop is probably driven by economics, a reaction to the sequence of economic calamities that have been visited upon the region since 1980, including the collapse of the oil market and its direct impact on offshore production, the southwest real-estate bust, and two nationwide recessions.

As a function of position in the bay, 404 activity tracks intensity of development, as might be expected, the Houston Ship Channel (including the side bays and the San Jacinto River) having the single highest density of permitting in the system. Moreover, the Houston Ship Channel, Galveston Channel (including Texas City Channel), and Clear Lake together account for about one-half of the permits issued for the entire system. Four large subsections are displayed in aggregate as a function of time for the period 1940-91 in Fig. 4. One is immediately struck by the coherence of the time signal in the different subregions of the bay. In fact, the linear correlation of annual permitting ranges 60-80%, which suggests that 404 activity in Galveston Bay is partially driven by a factor(s) that is uniformly exerted over the entire region. Economics would clearly be one such factor.

There is a major impediment to applying 404 data directly to the objectives of this study. A Section 10/404 *permit* is simply that: a license to carry out certain physical modifications bound by the parameters of the permit. Many permitted projects are never implemented, or are implemented on a scale smaller than allowed in the permit. Moreover, there is no information on which permitted projects are or are not actually implemented (apart from the negligibly rare District inspection reports). Data compiled by the Atlantic Marine Center of the National Ocean Service in Norfolk on status of 404-permitted projects that could impact navigation were analyzed: for the entire Atlantic seaboard, including the Texas coast, the rate of completion is about 30%.

Comments

The study from which this brief report is drawn presents various analyses of the above data. Other types of dredge and fill activity are considered as well, most importantly shell dredging. Also, the impacts of dredging and filling on habitat are evaluated. This study adopted the viewpoint that a dredging or a filling activity replaces one habitat with another. For example, dredging a channel through a shallow bay replaces shallow bay habitat with non-shallow. Disposal of the material in the open-bay can effectively replace bay habitat with shallow-water, or even upland, if the material becomes emergent. Habitat categories were morphologically based, e.g., pre-altered, bay-bottom, shallow bay-bottom, marsh, near shore, oyster reef, etc. For a few projects, the physical impacts of the project far exceeds the dimensions of the dredge-and-fill work, e.g., leveeing large areas of marsh, installation of "tide gates" (really saltwater barriers), and the closure of Turtle Bay. Much of the shoreline of Galveston Bay has been modified by 404-regulated activities, including bulkheading and revetting, which comprise a negligible proportion of the dredge-and-fill work in terms of volume. These and other aspects of dredge-and-fill impacts are discussed in the project final report.

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Natural Resource Damage Assessment: Background and Case Studies for Galveston Bay

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Background

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (also called the Superfund Act) set up a fund to clean up hazardous waste sites on the National Priorities List (NPL). Additionally, it required that damages be collected by government agencies from potentially responsible parties (PRPs) for injury to, destruction of, loss of, or loss of use of natural resources that occur as a result of their exposure to spills or releases of oil or hazardous substances. When CERCLA was amended and extended by the Superfund amendments and Reauthorization Act of 1986 (SARA), one provision was that the President designate natural resource trustees that would be required to seek restoration or monetary compensation (damages) for injuries to trust resources. Trust natural resources include land, fish, wildlife, biota, air, water, groundwater, and drinking water supplies that are under the protection and management of various trustee agencies. The President designated, through the National Contingency Plan (NCP), the Department of the Interior, Department of Commerce, and Department of Agriculture as the main Federal trustees. The Department of Commerce delegated its authority to one of its bureaus, namely the National Oceanic and Atmospheric Administration (NOAA). SARA also required that the governor of each state designate state trustees for natural resources. At various times over the next five years, the Governors of Texas named the Texas Water Commission, Texas Parks and Wildlife Department, and the Texas General Land Office as trustees. These agencies work as a group, since responsibility for many of the resources is shared between State and Federal agencies. They are vulnerable to the citizens' suit provisions of SARA if they do not perform these assessment duties on behalf of the public, which owns the resources that they manage.

CERCLA required that the Department of the Interior (DOI) develop the damage assessment methods. As a result of this requirement, DOI developed two types of procedures, the Type A and Type B Natural Resource Damage Assessment methodologies, as well as the rules for managing the assessments. The rules apply to spill incidents covered by CERCLA, the Clean Water Act (CWA), or the Oil Pollution Act of 1990 (OPA). One major change brought about by OPA was the transfer of responsibility for rulemaking for oil spill damage assessments from DOI to NOAA while DOI retained that authority for hazardous substance releases. The damage assessment rules allow for two fundamentally different types of damage assessments. The more complicated of the two, Type B assessments, are oriented toward the development of specific study protocols that follow scientific methods for each incident. The pathway of the oil or chemical from the source to the injured resource must be documented and the corresponding injury must be demonstrated as an adverse change, either long- or short-term, in the chemical or physical quality or viability of a natural resource. Injury also includes destruction or loss. Because Type B assessments are expensive and time consuming, Congress also required DOI to develop rules and methods for a simplified assessment option requiring minimal field observation called a Type A assessment. DOI decided to develop computer models and developed the first one for use in coastal and marine environments, the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME). This model is currently under revision and another one is under development for the Great Lakes (NRDAM/GLE). Another way of settling damage assessment cases is by negotiation. Often, a party responsible for an incident might be willing to construct some environmental restoration or enhancement project to compensate for injuries that it caused. This is an attractive way of handling cases when the time element and cost-effectiveness of the other alternatives are taken into consideration. Regardless of the method or methods used, any funds recovered from the responsible party must be used only to restore, replace, rehabilitate, or acquire the equivalent of the resources lost or injured in order that the resources again produce their pre-incident level of services.

Case Studies

It must first be pointed out that only aspects of completed cases or public aspects of ongoing cases can be discussed in this forum. The earliest case in the Galveston Bay area involving potential natural resource damages was related to the Motco *Superfund site in Lamarque near State Highways 3 and 146. The consent* decree provisions were negotiated by Brian Cain of the U.S. Fish and Wildlife Service before either the formal damage assessment rules or any State trustees were in existence. That settlement involved the creation of 31 acres of tidal wetland habitat from an upland area. The created habitat will, over time, compensate for estimated damages to wetland habitat adjacent to the site, which resulted from washout of *contaminants during flooding events such as Hurricanes Carla and Alicia.* No formal field studies or laboratory analyses, which would have cost a large amount of time and money, and likely not yielded a significant additional amount of information, were carried out.

The French Limited Superfund site on the San Jacinto River near Crosby has been settled in much the same way, without formal assessment studies. The parties responsible for that site have agreed to create approximately 22 acres of wetlands tidally connected to the San Jacinto River to compensate for presumed contamination of the river from washout of contaminants from the site during flood events.

The largest oil spill to take place in the Galveston Bay system since the rules have been available for damage assessments has been the *Apex* barges spill in July, 1990. Approximately 700,000 gallons of catalytic feedstock oil were released from two barges after they were struck by the *M/T Shinoussa* while the vessels were navigating the Houston Ship Channel just south of Redfish Island. In this case, the trustees signed a Memorandum of Agreement with the PRPs that outlined the damage assessment process. The PRPs agreed to partially fund a study of the oiled marsh at Houston Point to determine the need for restoration. The PRPs also agreed to partially fund the administrative costs associated with a Type A damage assessment. At this point in the case, a Damage Assessment Plan, which includes these and other provisions, has been through public and PRP review. Unfortunately, the PRPs have initiated discovery proceedings in U.S. District Court, which precludes the discussion of further aspects of the case in this forum. The trustees are hoping that a negotiated settlement can still occur in the case.

In September, 1991, a 10,000-gallon oil spill took place at the Amoco Pipeline terminal on the Gulf Intracoastal Waterway (GIWW) at High Island. A substantial amount of fringe marsh along the waterway and associated oxbows on and adjacent to the Anahuac National Wildlife Refuge was oiled. In addition to providing high quality nursery habitat for aquatic life, the fringe marsh provided erosion control. In early talks with Amoco personnel, it was decided that more damage would be done if attempts were made to clean the oil out of the marsh and instead it was decided to leave it alone. Fish and Wildlife Service personnel documented the areal extent of the marsh oiling and potential impacts on trust resources, and the possibility of a negotiated settlement was discussed with Amoco. The settlement agreed upon involved the replacement of an old non-functional water control structure at the Jackson Ditch intersection with East Bay Bayou, just off the GIWW. The structure's functions had been to regulate water levels on the refuge and prevent saltwater intrusion from the GIWW. Replacement of the structure will yield two main benefits: the enhancement of about 850 acres of marsh that had been deteriorating from saltwater intrusion; and protection of the refuge from any future oil spills that could take place on this part of the GIWW. Due to unusual weather conditions, only a small amount of oil from the 1991 spill was able to flow through the old structure onto the refuge. At this time the structure has been completed and is functioning.

In April, 1991, a 45,000,000-gallon release of phosphoric acid-gypsum process water with a pH of about 2.3 occurred at the Mobil Mining and Minerals Company plant in Pasadena. The material entered the Houston Ship Channel and acidified the channel for at least seven miles to such an extent that a substantial kill of aquatic organisms, mainly blue crabs and juvenile fish, occurred. Shortly after the spill, natural resource trustee representatives met with Mobil and presented them with several options that could be used to address their natural resource liability. Mobil agreed to begin a cooperative process that would lead to the completion of an environmental restoration project instead of formal damage assessment proceedings. Mobil has proposed a project that would involve wetland creation on a site that they own on the Houston Ship Channel near the site of the incident. The justification for this project is that additional wetland habitat in this area could serve as nursery habitat so that organisms of the type that were killed during the incident will be restored to the affected area. At the present time, the trustees are evaluating this project to determine if it should satisfy all or only part of Mobil's liability.

The Southeast Texas area should serve as a model of how the damage assessment process can work when there is cooperation between trustees and when there is a constructive working relationship with the PRPs. The process is designed to make the environment whole again by restoring it so that it again provides the levels of services it was producing before the spill or release. Following this line of reasoning, the process will not and can not be used in a punitive nature, but instead in a restorative one. When negotiated settlements can be accomplished like those such as mentioned above, they are a much more cost-effective and efficient way of addressing the issue of natural resource restoration, as opposed to using the more expensive, complicated, and time consuming methods outlined in the damage assessment rules.

Cumulative Project Impacts in Galveston Bay

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Cumulative impacts are incremental effects of projects which are added to the effects of other past, present, and reasonably foreseeable future projects. Forecasting cumulative impacts requires both a knowledge of and means for continually updating existing conditions, an understanding of the impacts of proposed projects, and knowledge of what is reasonably foreseeable as future development.

It has only been through the activity of the Galveston Bay National Estuary Program that existing condition information has been concentrated into a unified database. Yet, no program or activity has been developed that similarly concentrates upon *past* project impact information, and there are no formal programs that focus upon *future* development.

There are potential sources for past and future projects. Historical maps and recorded observations as well as photographs, drawings, and reports are likely stored in government archives, in university collections, or in the private files of research scientists and historians. These data could help establish a plausible "original" condition of Galveston Bay, though how far back one would want to characterize this original condition would depend upon a variety of factors. It is likely that one would want to settle on that period where there is the greatest amount of historical information that would allow for a reasonable characterization of that period where there was the least amount of human activity that adversely affected streams, creeks, bayous, wetland areas, and the main parts of the bay itself. From this "original" condition or from some other condition developed with different assumptions, the "list" of "all past projects" would be derived. Some projects could be identified indirectly through the physical changes they brought about. Perhaps the greatest single source of past projects and related impacts is the U.S. Army Corps of Engineers, Galveston District. Both this District's past district engineer reports concerning the federal navigation channel and related construction requirements and the information contained in its 404 permit program files would be necessary to identify past projects and their impacts.

Identifying future developments would require a similar effort. Here the idea would be to identify both private and public projects which would likely have some measurable effect upon the Bay and which have a reasonable probability of being implemented. Local community land use plans, development master plans, various municipal capital improvement plans, and the announcement of private projects or major public projects are sources for what would be reasonably foreseeable.

Once the past, present, and future conditions are established, a single project's incremental effects can be added to the effects of the past and future projects. Incremental and combinatory impact prediction can take a variety of forms. Physical models, mathematical models, and judgmental methods are the principal approaches used in impact prediction.

Physical models typically consist of small-scale models of those parts of the physical world one is interested in evaluating. The Delaware Estuary and San Francisco Bay models have been used to evaluate water-related impacts. The altered physical conditions that a project would create are understood to be the impacts or changes from the existing condition.

Mathematical models are somewhat varied in character. Some utilize algebraic or differential equations to permit analysis of impacts. Typically based upon scientific theory or law, techniques forecasting water quality effects utilize the Laws of Conservation of Matter. Air quality models also use the Law of Conservation of Matter to predict air pollutant changes. Another type of mathematical model utilizes statistical analyses of data from past activities which are used to forecast impacts. Still another type of mathematical model is known as a simulation model. These rely upon both physical laws and statistical relationships between phenomena. Simulation models attempt to represent the environment through developing mathematical equations for the various relationships known to be existing in the environment.

By far the most common approach used for impact prediction is expert judgment. This type of forecasting ranges from the single technical/scientific authority providing both quantitative and qualitative statements about a proposed change to the environment to an interdisciplinary group of experts who predict impacts through joint evaluation. One approach, known as the Delphi technique relies upon a group of experts who do not meet. Instead forecasts are individually made, summaries of all forecasts are then distributed to the group members and new forecasts are made. This iterative activity continues until consensus is reached or a decision that no consensus is possible is reached.

Now the prediction of impacts through whatever means or combination just described must be followed by an analysis of what is predicted. This analysis must rely upon established knowledge or upon consensus opinion about what is or is not harmful (threshold levels of pollutants for safe drinking water or water that allows for aquatic organisms to live).

This knowledge or consensus is usually expressed in policies established to protect resources that are under pressure. These policies can be of two types: limits and goals. Air quality policies often establish a limit for various attributes of air. Often these are expressed as standards for maximum levels of degradation. Sometimes limits cannot be identified such as in urban areas where natural capacities are not exceeded yet urban growth is ongoing. Growth management policies are a common response in areas where public sentiment to allocate growth and conserve resources is strong. Zoning regulations would be an example of this type of policy.

The degree to which impact forecasts exceed policy thresholds is indispensable to the concept of impact analyses. If a policy or regulatory limit is exceeded, then impacts are judged to be severe. Impacts which do not violate policies or approach important thresholds are judged to be acceptable if not insignificant.

Analyzing cumulative impacts in the Galveston Bay system is complicated by the fact that there are only a handful of policy/regulatory frameworks available with which to perform cumulative impact analyses. There are no comprehensive limit or goal setting policies which represent a process of determining the limiting factors for industrial, commercial, or residential growth on the Bay system. What does exist are federal regulatory processes covering threatened and endangered species, waters of the U.S. including wetlands, air quality, waste regulations, and water quality regulations. The limits set by regulations are the only available basis for cumulative impact analyses and some of these also require coordination processes (404 program), which often involves political determinations about acceptable magnitudes of impact.

The capacity limits to natural systems such as Galveston Bay should be captured by what some would call development constraints, performance standards, or policy thresholds. Carrying capacity is usually understood as the ability of a natural or man-made system to absorb population growth or physical development without significant degradation or breakdown. These limits, however, are often conjectural and typically fall into the category of value judgment. The process which develops comprehensive limit-setting policies is relatively new to the Houston-Galveston area. Because of this key elements of cumulative impact analyses in this area are still in the process of development.

Aquaculture: Managing the Environmental Impacts on Galveston Bay

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Aquaculture is the most rapidly expanding form of agriculture (20%/yr) in the United States (Treece, 1992). Aquaculture in Texas has lagged behind that of other southern states (e.g., Mississippi and Louisiana), but recent legislative action (Fish Farming Act of 1989) and the initiation of a leasing program through the Land Bureau has stimulated activity in Texas. The large consumer market for marine species, especially Gulf shrimp and redfish, has also resulted in increased activity in coastal areas like Galveston Bay. In the last five years, several commercial ventures located on Galveston Bay have been started for the purpose of growing shrimp, redfish, or oysters. All of these operations impact the environmental quality of the bay by increasing the biomass per unit volume of water. Some also pump large amounts of water through their operations and return organic-rich water to the bay. A rational plan for the siting of these aquaculture projects should be formulated in order to reduce conflicts with other industry and agricultural operations.

The three major management strategies for controlling the environmental impact of aquaculture in order of ascending cost are: (1) site selection; (2) input management; and (3) waste treatment or reuse (Piedrahita, 1992). Aquaculture projects should avoid locations where large amounts of industrial wastes or municipal sewage are discharged into the bay near their influent water source. They should avoid locations were agricultural runoff can result in pesticide contamination or high levels of nitrogen and phosphate in influent waters. They should also avoid locations where high levels of nitrate and phosphate in effluent waters can result in eutrophication of areas of the bay. As a result, siting is the most important aspect in controlling the environmental impact of aquaculture on the bay.

Input management plays a role in controlling both biotic and abiotic outputs from aquaculture. The use of exotic species and/or associated diseases can impact the native populations of similar species (i.e., marine shrimp). Management standards must be developed before any industry based on exotic species can become established. Water utilization, feeding, and fertilizing techniques must also be optimized on each site since improvements in the utilization of resources will reduce the waste levels in effluents (Lawrence and Lee, 1992). The control of inputs can be illustrated best by examining the feeding of pelleted diets to aquatic organisms. It is estimated that 30% of the feed offered is wasted before ingestion. Of the ingested diet, 55% is excreted in one organic form or another. Therefore, less than 15% of the food is assimilated into the cultured species. Improvements in diet palatability and nutrient composition (e.g., nitrogen and phosphorous) could reduce significantly pollutants in aquaculture effluents.

Water treatment and reuse is being considered since the water quality of aquaculture effluents is coming under greater scrutiny by regulatory agencies as the volume of these effluents increases with increasing aquaculture development. The most cost effective method to control the water quality of effluents is by reducing the inputs or improving the usage of inputs. Finally, water reuse is possible, but the high initial cost of building and high cost of operation for the required filtration devices limits the ability of commercial projects to operate profitably when reuse is the principle management practice.

In conclusion, aquaculture can play a role in the economic diversification of Galveston Bay and supplement decreasing fishery stocks. However, the expansion of aquaculture in Galveston Bay must proceed in a rational manner to insure the future viability of aquaculture in the region and to avoid negative impacts on other industries and communities in Galveston Bay, as well as, to the ecological balance of the estuary.

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