Appendix 1:
Estimates of Economic Value of Various Uses of Galveston Bay Based on Other Methodological Approaches

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Preface: Overview of Services Provided by the Bay

Galveston Bay provides many services to its surrounding residents, and these services are valued differently by each individual. The scope of these services is quite broad. Certain people, for example, might rely upon the sounds of waves to achieve a good night's sleep. Still others might appreciate refreshing bay breezes that they do not consciously attribute to the bay itself. Thus, this study can only attempt to capture some of the many diverse services provided by the bay.

The services selected for valuation in this appendix were chosen based upon the following criteria:

1. The ability to be measured and/or quantified,
2. The relative magnitude of a given service's value in comparison to other bay-provided services, and
3. The degree to which the service is available to the surrounding population as a whole.
4. The degree to which the service would be affected by a change in water quality.

The services chosen for valuation based on the above criteria are listed below:

1. Commercial fishing
2. Water-based recreational activity: recreational fishing and boating
3. Land-based recreational activity: hunting and trapping, camping, swimming and wading, sunbathing, hiking and sightseeing, picnicking, and bird-watching
4. Storm buffering

Valuations for waste assimilation services and erosion control were not included in our analysis due to insufficient information about the extent of these services in Galveston Bay. While this is not an exhaustive list of the services provided by Galveston Bay, we believe that these four capture the majority of the value that the bay provides to residents of the Greater Houston-Galveston Area. As noted in the main body of the report, we have not attempted to value commercial shipping activity on Galveston Bay since no changes are proposed that would limit shipping. For some of the services provided, we are only able to assign crude bounds to the values, while for others we have been able to make more refined estimates.

While wetlands contribute to many of the services listed above, they are also valued separately in Chapter II of this appendix. Although wetlands are actually inputs (directly or indirectly) to many of the services listed above, the value of wetlands is discussed separately to assist in policy decisions that may be made concerning the preservation of wetland areas. Since we are evaluating some of the final services that use wetlands as inputs (such as recreational fishing for species that may breed in wetlands) as well as providing a value for wetlands themselves, we must be careful to avoid double-counting wetland services. These double-counting concerns will be addressed within each of the valuation method applications.

The valuation methods used to arrive at the estimates of value for each of the uses described above will be discussed in the sections below. In Chapter I, we provide a net revenue analysis of commercial fishing, an assessment of recreational use values of Galveston Bay using benefit transfer methods, and an estimate of the value of wetlands for storm buffering, also using benefit transfer methods. These methods will be described within the context of their applications. In Chapter II, we present an approach for measuring the value of an acre of wetlands as it contributes to recreational fishing (marginal value). Finally, in Chapter III, we apply an embodied energy analysis approach to valuing the ecosystem productivity of Galveston Bay.

Appendix 1, Chapter I:
Estimates of the Economic Value of Recreational and Commercial Uses of Galveston Bay

I.1 Introduction

This chapter of Appendix 1 reports our estimates of the economic value of the following "bay-dependent" goods and services: commercial fishing (shellfish and finfish), recreational fishing, recreational boating, and land-based recreation (including hiking, picnicking, camping, hunting, trail walking/jogging, and bird watching). In addition to these activities, the value of wetlands as storm buffers in Galveston Bay is discussed and rough estimates are advanced, though much more research is required for more precise estimates of the economic value of this wetland function. The reader should be aware of two things when examining our estimates. First, unless otherwise specified, all estimates reported in this appendix are annual values and are reported in constant June 1993 dollars. Second, our estimates of the value of bay-dependent activities represent the economic value of a change in water quality that produces a change in recreational activity such that recreational usage rates drop from current levels to zero. This assumed adverse change in water quality is thus different from that measured by the contingent valuation study detailed in the main report. The responses to the contingent valuation questions measured willingness to pay for an improvement in the environmental quality of the bay. The improvement presented in the CV report would presumably lead to an increase in usage rates.

I.2 Commercial Fishing

I.2.1 Net Revenue Analysis Method and Assumptions Used for Valuation

Net revenue analysis was used to determine the net benefit of commercial fishing in Galveston Bay. The net revenue to the commercial fishing industry measures the benefit to commercial fishermen of being able to fish commercially in Galveston Bay. Net revenue to the commercial fishing industry is equal to the gross revenues of the industry minus the costs of commercial fishing. Gross revenues to commercial fishermen are the ex-vessel values of their landings. Ex-vessel value is not the retail value, but rather the price that is received at the dock from wholesalers, retailers, and restaurateurs. This value is lower than the retail price, which is the price that consumers pay seafood dealers. The ex-vessel values of the catches of many species of finfish and shellfish are reported to the National Marine Fisheries and Texas Parks and Wildlife Department.

The costs of commercial fishing are determined by several factors, such as the number of days per year spent fishing by commercial fishermen, the number of hours per day they typically fish, the rental values and depreciation costs of their boats and equipment, and their fuel expenditures. The net benefit of commercial fishing in Galveston Bay can then be expressed as:

Net Benefit = Ex-Vessel Value - Costs.

There is little published information on commercial fishing costs in Galveston Bay, and a formal survey to study these costs is beyond the scope of this project. A further complication arises from the need to separate commercial fishing harvests into bay and Gulf catches, since the State of Texas does not make this distinction in its data. There is a discussion in section I.2.3 below, however, of the gross revenues from commercial fishing with some approximate bounds on the net benefits of this activity that can be attributed to fishing activity in the bay.

The commercial fishing data for both finfish and shellfish that were used for our net revenue analysis of the economic value of commercial fishing in Galveston Bay were supplied by the National Marine Fisheries Service (NMFS) and the Texas Parks and Wildlife Department (TPWD). The NMFS data range from 1962 to 1991, while the TPWD data range from 1977 to 1987. Based on interviews with commercial fishermen in Galveston Bay, we have assumed that net revenue to commercial fishermen is between 10 and 20 percent of gross revenues. We have used this range to derive our estimates of the value of commercial fishing in Galveston Bay.

I.2.2 Trends in Commercial Fishing Catches

The time series data on commercial fishing from TPWD and NMFS allow us to identify trends in commercial landings from 1962 to 1991. The data show that since 1972, fluctuations in bay landings have occurred but no strong trend is apparent (Green, 1992). Over the period between 1972 to 1989, the average percentage composition (by weight) of all fish species landed from Galveston Bay was: shrimp, 52 percent; blue crab, 20 percent; American oysters, 23 percent; finfish, 5 percent (Green, 1992).

Finfish and shellfish landings depend on many factors. This makes it difficult to isolate a single reason for changes in landings. Decreases in finfish landings are caused by commercial and recreational fishing pressure, fishing regulations meant to decrease fishing pressure on declining stocks, and environmental events (for example, the 1983 freeze and the 1986 red tide) (Green, 1992). Fishing pressure is a measure of the total number of hours spent fishing by individual fishermen in Galveston Bay and is calculated in units of person-hours per year. Fishing pressure is also variable and depends on declines in fish availability, economic factors, and environmental events (Green, 1992). The difficulty in isolating any one cause of these fluctuations in catch rates is illustrated by the following example: After the 1983 freeze and the 1986 red tide, decreases in the weights of total finfish and total shellfish were observed; however, these decreases were not dramatic relative to decreases in other years. They do not offer conclusive evidence that the freeze and red tide played large roles in affecting the weight of landings of finfish and shellfish.

Though it is difficult to explain changes in landings, it is widely accepted that the main reason for decreases in red drum and spotted sea trout landings is over-fishing. The popularity of fish in the 1970s (and recipes for "blackened fish" in particular) appears to have caused a dramatic decline in the red drum population. According to Stroud (1985) and Green (1992), commercial landings of red drum showed increases during the 1950s, record landings in the mid-1970s, and decreases beginning in 1976. Recreational landings fell as well. The severity of the decline prompted enactment of traditional management strategies to rebuild the population. Ineffective attempts included possession, size and bag limits, commercial quotas, restrictions on the operations of nets, and license restrictions. In 1981, the Texas legislature banned the sale of red drum.

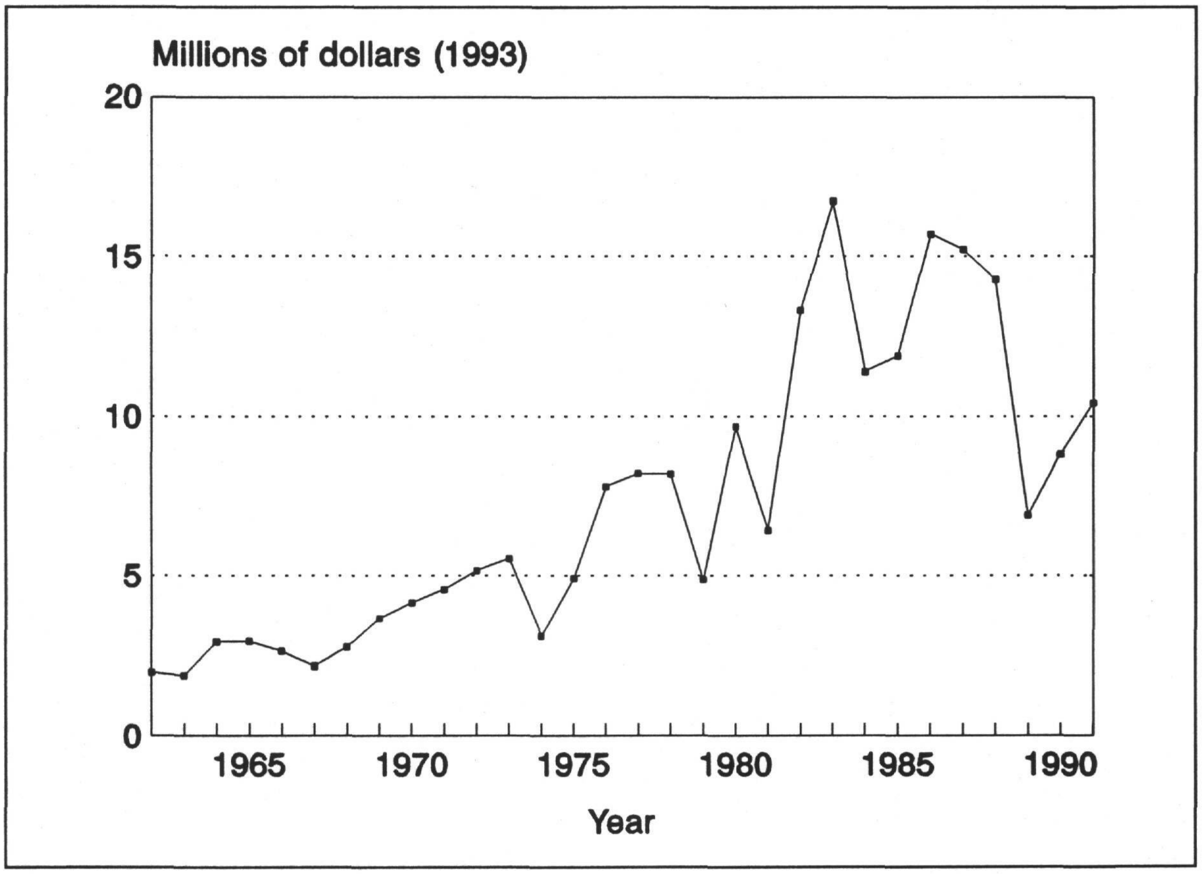
A similar story can be told about spotted sea trout. After experiencing record landings in the 1970s, the sale of spotted sea trout was banned (Green, 1992). In the years before the bans, spotted sea trout and red drum represented about 53 percent of the total finfish value. In the year prior to the ban, red drum landings had declined so dramatically that they contributed a relatively insignificant percentage to the total finfish landings. The increase in landings after 1981, shown in Figure A1.I.1, are probably best attributed to relative increases in the commercial catches of flounder, mullet and black drum that resulted from commercial fishermen switching their target species (Green, 1992).

Shellfish have not demonstrated as severe a decrease in landings as finfish. According to Green (1992), most shellfish species reproduce earlier in the season than recreationally and commercially important finfish species and do not live as long. They are therefore more resistant to fishing pressure. However, the pattern in shellfish landings is similar to that seen with finfishing. In the 1970s, shellfish landings reached a peak. After that, the levels of harvest and effort possibly exceeded the levels necessary to maintain maximum sustainable yield. Currently, shellfish fisheries are either at or over effort levels consistent with maximum sustainable yield from the estuary. In recent years, oyster and crab landings have decreased, and the shrimp fishery has become overcapitalized. Increases in commercial fishing pressure and technological changes (i.e., changes in fishing gear) are most likely responsible for the increases in shellfish landings.

I.2.3 Value of Current Commercial Fishing Activities

Figure A1.I.1 shows the ex-vessel values of commercial landings of finfish and shellfish from 1962 to 1991. Since the mid-1970s there has been a significant decline in the ex-vessel value of finfish, perhaps the result of decreased landings. After the peak value in 1978, fluctuations in ex-vessel value have followed fluctuations in the weight of commercial finfish landings, except in 1988. The ex-vessel value of commercial shellfish fails to exhibit a strong trend. The value of commercial shellfish is correlated with the weight of shellfish landings in all years except 1990 and 1991.

Figure A1.I.1:
Ex-Vessel Value of Commercial Landings
from Galveston Bay (1962-1991)



Based on the assumption that the profits to commercial fishermen are between 10 and 20 percent of gross revenues, the net revenue economic value of commercial fishing in 1991 was between $1-2 million.

I.2.4 Limitations and Uncertainties

Both TPWD and NMFS collected their information through site-intercept studies that consisted of interviewing fishermen after they complete fishing trips. The harvest and pressure estimates reported by fishermen in site-intercept surveys should be considered minimum estimates because there are areas where boats can be docked and to which the enumerators have no access, and because commercial fishermen may underreport their catch.

I.3 Recreational Fishing

Recreational fishing was valued using the benefit transfer method. Data on the number of recreational fishing days in Galveston Bay came from two sources, TPWD and our mail-only survey. After a brief explanation of the benefit transfer method, we report our valuation estimates. The estimates of the value of recreational fishing using TPWD data are reported first; the results using data collected in our mail-only survey are then discussed.

I.3.1 The Benefit Transfer Method

To directly determine the value of nonmarket services--i.e., most bay-related recreational services--is expensive and time-consuming. Considerable time and money can be saved by transferring the results of other valuation studies done at similar sites to Galveston Bay. For example, to estimate the value that Texans get from fishing for a day in Galveston Bay (the "policy site"), we might look at a study done at Albemarle Sound in North Carolina (the "study site") and make inferences from the value of similar recreational activities there.

There are two limitations to using benefit transfer techniques to estimate the value of nonmarket services at the policy site. First, one must assume that the study site is sufficiently similar to the policy site, particularly in terms of consumer preferences and environmental quality. Second, the benefit transfer method assumes that the policy site has the same market structure, substitute services, and access to those services as the study site. If a study site seems significantly different from the policy site in any of these three ways, the value determined at that study site may not accurately reflect the value at the policy site.

Either a single, unique value or a benefit equation can be transferred from study sites to policy sites. An example of a transferred benefit equation might be a valuation function developed for a study site using data from a contingent valuation study. Less flexible--and perhaps less accurate--is the transfer of single, unique values that represent the benefits of specific services at sites other than Galveston Bay. These values could be determined at the study sites in a number of different ways, including the use of net revenue analysis or the contingent valuation method. The term *user-day value* refers to the value of a typical visit to the recreation site for a representative day's activity. We use the median of the range of values from multiple studies identified for a particular service to value a user-day at Galveston Bay. The value of a user-day is expressed in dollars per user-day. Thus, to determine the net value of a particular service to Greater Houston-Galveston Area residents, the value is simply multiplied by an estimate of the number of user-days. Picnicking, for example, might have a median value of $13 per user-day--as determined by aggregating the results of picnicking evaluations across the country. If the annual number of picnic user-days was determined to be 20,000 for the area surrounding the bay, then the value of picnicking to local residents would be estimated at $13 * 20,000 = $260,000 per year. The research necessary to determine the number of user-days can comprise much of the benefit transfer effort.

I.3.2 Application of the Benefit Transfer Method to Galveston Bay

To employ the benefit transfer method to value recreational fishing and boating, we collected data on the annual number of user-days for each activity in the bay area. Estimated net economic value of a given activity is calculated as the product of the estimated number of user-days and the value of a user-day. The assumed values of different types of user-days used in this study were based on the results of Walsh et al. (1992).

Data on the number of recreational fishing, boating, and other land-based recreation days were obtained in two ways. First, existing data were gathered from Texas Parks and Wildlife Department (TPWD) and other agencies. Available data on past usage of the bay were collected (and are reported here to enable the reader to observe trends in usage). Second, we collected data on the recreational use of Galveston Bay in our mail-only survey. Though use questions were asked in both the mail-only survey and in the mail/in-person follow-up surveys, only responses to the mail-only survey were used to estimate the number of user-days in different types of recreational activities. The mail-only responses were selected because, though the sample receiving the mail/in-person follow-up survey was selected to be representative of the Greater Houston-Galveston Area in terms of socioeconomic characteristics, the sample cannot be expected to be representative in terms of recreational use of Galveston Bay. Two of the three clusters from which the mail/in-person follow-up sample was drawn, Baytown and Texas City, are both close to the bay. Residents of Baytown and Texas City can be expected to have higher levels of recreational use relative to the population of the five-county study area due to their proximity to the bay. Responses to the mail-only survey indicate that approximately 25 percent of the population of the five-county area use the bay for recreational boating and fishing at least once a year. The data on user-days from both the TPWD and the mail-only survey were used in a benefit transfer analysis, and the results are reported and compared in Section I.3.8 below.

I.3.3 Benefit Transfer Using TPWD Data for Recreational Fishing

The existing data on recreational fishing in Galveston Bay come almost exclusively from TPWD. As for commercial fishing, TPWD collects recreational fishing data through site intercept studies that interview fishermen as they complete fishing trips. The recreational fishing data includes fishing from private boats, party boats, and head boats. TPWD defines these types of recreational fishing as follows: "private-boat fishing" is fishing from a privately owned or rental boat without a guide; "party-boat fishing" is fishing from a boat, operated by a guide and crew, that carries no more than 10 people for a fee; and "head-boat fishing" is fishing from a boat, operated by a guide and crew, that carries at least 11 people for a fee (Campbell et al., 1991). TPWD reports on shore-based recreational fishing in the *1990 Comprehensive Outdoor Recreational Plan*.

Table A1.I.1 shows the annual number of days spent fishing from a boat in Galveston Bay from 1974-1990, based on TPWD figures. Fishing days are calculated by dividing the fishing pressure for recreational fishing, measured in person-hours, by the average length of a trip, in hours. The number of fishing days is calculated separately for each type of recreational fishing and summed. Fishing pressure and the number of hours in a recreational fishing day are reported in Campbell et al. (1991). The number of hours in a recreational fishing day used here is the average of the mean lengths of fishing trips reported for each year from 1974-1990 (Campbell et al., 1991).

The number of days spent fishing from banks and structures is based on the number of fishing days reported in the *1990 Comprehensive Outdoor Recreation Plan.* These figures require adjustment because they represent activity engaged in anywhere in Region 16, a thirteen-county area that includes the five-county study area. It also includes activity by the entire population of Region 16. Therefore, the numbers reported in the plan include recreational fishing in Galveston Bay by residents of Texas who live outside the study area, and they include recreational fishing by residents of the study area that is not dependent on the bay. For our analysis, we need data on the recreational fishing days taking place on Galveston Bay by residents of the study area only. The data from the Texas Outdoor Recreation Plan are adjusted by the proportion of the Region 16 1986 population living in the five-county study area (0.86). The numbers are also roughly adjusted for the amount of Region 16 activity that is dependent on Galveston Bay. The latter adjustment is based on a comparison of the number of recreational boat fishing days in 1990 calculated from data reported by Campbell et al. (1991) with the number of boat fishing days in 1990 reported in the *1990 Comprehensive Outdoor Recreation Plan.* This comparison indicates that approximately one third of the use in Region 16 depends on Galveston Bay. Thus, the numbers reported in the *1990 Comprehensive Outdoor Recreation Plan* were multiplied by 0.33 and 0.86. Adjusting TPWD's numbers assumes that the 86 percent of Region 16 recreational fishing is done by residents of our study area and one third of the activity in the region is dependent on Galveston Bay.

I.3.4 Trends in Recreational Fishing

Table A1.I.1 reflects trends in recreational fishing pressure, or effort, and the net economic value of recreational boat fishing from 1974-90. Factors that affect effort include economic factors (such as fuel prices), perceptions about the quality of the fishing experience (which depend on recreationers' perceptions of water quality), fish availability, and congestion.

Table A1.I.1 Total Annual Number of Recreational Boat-Fishing Days and the Annual Economic Value of Recreational Fishing (in $ Millions)

Year	Total annual number of recreational boat fishing days[1] (1,000 days)	Annual value of recreational boat fishing (Millions of 1993 dollars)[2]
1974-76	503	$13-20
1976-77	181	$5-8
1977-78	382	$10-15
1978-79	346	$9-13
1979-80	351	$9-13
1980-81	379	$9-14
1981-82	331	$8-13
1982-83	292	$7-11
1983-84	402	$10-15
1984-85	294	$7-11
1985-86	385	$10-15
1986-87	405	$10-15
1987-88	403	$10-15
1988-89	381	$10-14
1989-90	312	$8-12

[1] Campbell et al. (1991)
[2] Based on the 90 percent confidence interval on the value of a warm-water fishing day reported in Walsh et al. (1992)

I.3.5 Value of Current Recreational Fishing Activities

The net economic value of recreational boat-fishing in 1989-90, determined by the benefit transfer of the median value of a warm-water fishing day, is $8-12 million. This range is the product of the number of recreational fishing days in 1989-90 and the value of a warm-water fishing day reported by Walsh et al. (1992). We used a range of user-day values defined by the

90 percent confidence interval on the value of a warm-water fishing day reported in Walsh et al. (1992). In 1993 dollars, the range of values for a fishing day is $25-38. The value of warm-water fishing is used because it is the most conservative value listed for the various types of fishing.

The value of warm-water fishing from banks and structures is also determined by the benefit transfer of the same confidence interval. In 1990, the value of shore-based fishing in Galveston Bay was about $20-30 million and the value of fishing from structures was about $18-28 million.

I.3.6 Projected Values for Recreational Fishing

In the *1990 Comprehensive Outdoor Recreation Plan*, TPWD makes projections of the number of saltwater recreational fishing days in Region 16 in 1995 and 2000. These projections were adjusted as described in the previous section because they represent activity engaged in anywhere in the 13 counties and by the entire population of Region 16.

The net economic values of three types of recreational fishing in 1995 and 2000 in 1993 dollars are listed in Table A1.I.2. These values were determined by a benefit transfer of the 90 percent confidence interval on the value of a warm-water fishing day and are adjusted from the Texas Outdoor Recreation Plan as described in a previous section.

Table A1.I.2 Projected Net Economic Value of Recreational Fishing (in $ Millions, 1993)

Type of saltwater recreational fishing	1995 (Projected)	2000 (Projected)
Fishing from bank	$21-32	$22-34
Fishing from boats	$7-11	$8-11
Fishing from structures	$19-30	$22-34
All types of fishing	$47-73	$52-79

I.3.7 Limitations and Uncertainties in the Estimates of the Value of Recreational Fishing Based on TPWD Data

The value of recreational fishing from a boat reported in this analysis may be underestimated, while the value of recreational fishing from banks and structures and the future values of recreational fishing may be overestimated. The underestimate of the value of recreational fishing from a boat stems from the use of site intercept studies. As discussed in the commercial fishing section above, pressure estimates reported in site intercept studies should be considered minimum estimates for several reasons (McEachron and Green, 1984). First, there are areas where boats can be docked and TPWD has no access. TPWD has preliminary data that indicates pressure from these sources could be 25 percent greater than estimated (McEachron and Green, 1984). Second, TPWD only reports recreational fishing done from a boat and fails to take account of shore-based recreational fishing done from banks and piers, which has been reported to account for 33-36 percent of the recreational fishing landings from along the Texas coast (Campbell et al., 1991). In addition, the estimates of fishing pressure do not include nighttime private-boat and party-boat fishing (Campbell et al., 1991). As a result of the underestimation of fishing pressure, the number of recreational fishing days and the current economic value of recreational fishing are both biased downward.

Current values of fishing from banks and structures and future values of recreational fishing in Galveston Bay in 1995 and 2000 may be overestimated due to our assumptions of the relative importance of Galveston Bay versus other bays and the Gulf of Mexico. Though the projected fishing days were roughly adjusted for the proportion of activity taking place in the bay, it is unclear exactly how much the projected activity depends on Galveston Bay and how much depends on other Texas bays and the Gulf of Mexico.

I.3.8 Benefit Transfer of Recreational Fishing Values Using Data Collected from the Contingent Valuation Survey

Based on the recreational use of Galveston Bay reported by respondents in our mail-only survey, the total estimated number of fishing days from boats, banks, and structures in Galveston Bay in 1993 was about 4.5 million. This estimate is based on the mean number of fishing days per household per year in the Greater Houston-Galveston Area of 5.0[33], the number of households in the area, and a conservative assumption that nonrespondents[34] have one half the usage rates of respondents. This assumption adds uncertainty to our estimates of fishing days and the economic value of fishing.

Given the uncertainty both in the total number of person fish-days per year and the wide range in value per fish-day, we tried several combinations of plausible and conservative estimates of each to arrive at what we believe to be a reasonable, though wide, range for the economic value of recreational fishing on Galveston Bay: $75-150 million per year. If we assume that nonrespondents have one half the usage of respondents and use the upper and lower 90 percent confidence intervals on the value of a fishing day, then the range of the value of recreational fishing is about $110-160 million per year. Using the more conservative assumption that nonrespondents have a zero usage rate and the same 90 percent confidence interval, the range

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33 Based on our mail-only survey, 1.6 household members go on each fishing trip.

34 The mail survey had a 49 percent response rate.

becomes about $75-110 million. A range of $75-150 million allows for the possibility that nonrespondents have a usage rate between zero and one half the usage rate of respondents.

The estimate of the annual net economic value of recreational fishing obtained using the existing TPWD data ($44-60 million) and the estimate of the value using data from the household survey ($75-150 million) are about the same order of magnitude, though their intervals do not overlap. One possible explanation for the difference is the method of data collection. As noted, the TPWD data were collected by site intercept studies and, as explained above, were probably underestimates of the fishing pressure. The data collected in our household survey of residents of the Greater Houston-Galveston Area are likely to be a more accurate estimate of the number of recreational fishing days on Galveston Bay. Note, however, that data obtained from our contingent valuation survey only include households in the five-county region around the bay. There are many people who come from elsewhere in Texas to fish in Galveston Bay, and they were not counted in our survey results.

I.4 Recreational Boating

I.4.1 Assumptions Used in Valuation of Recreational Boating Activities

Like recreational fishing, recreational boating was valued using the benefit transfer method, with data on user-days from both TPWD and our mail-only survey. The results using data reported by TPWD are reported first; then the results using data collected in our mail-only survey are discussed. The range assumed for the value of a boating day used was $15-33 (1993 dollars). The lower estimate is the lower bound of the 90 percent confidence interval for motorized boating, the more conservative of the boating value options, reported by Walsh et al. (1992). We believe that the value of a recreational boating day based on the upper bound of the 90 percent confidence interval (over $50) is not conservative enough, so we used the median value for a motorized-boat day ($33) as our upper bound.

Galveston Bay provides opportunities for recreational boating activities including sport fishing, pleasure cruising, water-skiing, jet-skiing, sailing, sailboarding, canoeing, and kayaking. This study considers recreational boating as a whole, making no distinction between different boating activities. Note that, in order to avoid double counting, the economic value of recreational boating does not include the economic value attributed to recreational fishing from a boat. The value of this activity is included in the total economic value of recreational fishing discussed in the previous section.

I.4.2 Benefit Transfer of Recreational Boating Values Using TPWD Data

Our attempt to estimate the number of recreational boating days started with the gathering of data on the number of boat registrations, commercial marinas, and wet slips on Galveston Bay from state and federal sources. Texas law requires that all boats with a motor be registered with the Texas Parks and Wildlife Department (TPWD). This requirement applies to all powerboats and most sailboats, since larger sailboats usually require some type of motor for maneuvering inside marinas and navigation channels. Excluded from the requirement are unpowered trailer-launched sailboats, canoes, kayaks, and sailboards.

However, data of this nature are inadequate for economic valuation using the benefit-transfer method because they do not indicate the frequency of boat use. To illustrate, consider the following. A valid registration is required regardless of whether a boat is used once per week or once per year. Many of the boats used on Galveston Bay originate from outside of the five-county region. Marinas are not the only points of entry to the bay; and wet slips may be empty, or if occupied, boats may sit idle. It is also important to note that boats registered in the five-county region or docked at marinas in Galveston Bay may operate outside the bay in the Gulf of Mexico. However, the majority of boats are dependent upon the sheltered harbors and launch facilities inside Galveston Bay.

We used information on participation (i.e., number of boater-days) for saltwater pleasure boating as presented by TPWD in its *1990 Comprehensive Outdoor Recreation Plan*. Boater-days were reported for residents in a 13-county region along the Texas Gulf Coast, including the five counties in the study area. The annual number of boater-days has been adjusted to represent use only by residents of the five-county area by multiplying the number of boater days by 0.86. This correction factor was based on fact that the 1986 population in the study area (3.28 million) was 86 percent of the population in the 13-county study region (3.81 million).

I.4.3 Value of Recreational Boating Activities: Current and Projected Values

Table A1.I.3 shows the economic value of recreational boating in Galveston Bay for the years 1990, 1995, and 2000. In 1990, the economic value was between $15 and $32 million, and in 2000 the value is expected to be between $17 and $37 million.

Table A1.I.3 Economic Value of Recreational Boating Based on User-Days (Derived from TPWD's *1990 Comprehensive Outdoor Recreation Plan*)			
	1000s of User-Days	Unit Value (1993 dollars per day)[1]	Total Value (million 1993 dollars)
Year	Residents[2]	Range	Range
1990	967	$15-33	$15-32
1995	1046	$15-33	$16-35
2000	1125	$15-33	$17-37

[1] Walsh et al. (1992).
[2] Residents of five-county study area only.

I.4.4 Limitations and Uncertainties of Estimates of Economic Value of Recreational Boating

There are several limitations of these estimates of the economic value of boating activities on Galveston Bay. First, use estimates were made without distinction between boating in Galveston Bay and boating in the Gulf of Mexico or other coastal bays. However, as mentioned above, we assumed that many of the boats operating offshore are dependent on Galveston Bay for launching and docking. Therefore, even boats operating outside the bay receive some economic value from the bay, but an unknown portion of these boater-days occur in other coastal saltwater bays. Another source of bias is the unknown percentage of boats that use Galveston Bay but are launched elsewhere. Also, note that the economic value obtained by boaters from outside of the study area is not included in Table A1.I.3 because recreational boating data for this group were not available. Due to this fact, our estimate of the economic value of recreational boating may be an underestimate of the true value. The net effect of all these sources of bias on our results is unknown.

I.4.5 Benefit Transfer of Recreational Boating Values Combined with Data Collected in the Mail-Only Contingent Valuation Survey for Recreational Boating

Since the mail-only survey did not ask the number of household members who typically go on a boating trip, we used the mean number going on fishing trips (1.6 persons per household) with the assumption that both fishing and boating are often family activities. We also assumed that nonrespondents have one half the usage of respondents. The total number of person boat-days for the population of the Greater Houston-Galveston Area in 1993 is estimated to have been

1,350,000. If nonrespondents have a zero usage rate, the total number of person boat-days for the population of the area is 900,000.

The total value estimate for boating is between $20-44 million per year, using both the assumption that nonrespondents have one half the use of respondents and the conservative estimates of the value of a boating day. If we assume that nonrespondents, in fact, had zero usage of the bay for boating and that respondents accurately disclosed their usage rates, the range of recreational boating values is $13-30 million per year. Since most of the boating on the bay is nonmotorized and the value per day of nonmotorized boating ($23-105 in 1993 dollars) is greater that the value per day of motorized boating, we feel it is reasonable to extrapolate the range to $25-50 million per year (Walsh et al. 1992).

Though our estimates of the economic value of recreational boating based on the mail-only survey responses are greater than those based on TPWD data, the ranges overlap. In fact, assuming that nonrespondents in the mail-only survey had zero boating usage of the bay leads to nearly identical ranges. However, note again that our survey counts usage only by households in the five-county area, and does not include use by households who live elsewhere in Texas.

I.5 Land-Based Recreational Activities (Swimming, Hiking, Picnicking, Camping, Hunting, and Trail Walking/Jogging)

I.5.1 Problems with the TPWD Data for Land-Based Recreational Use

A serious obstacle to our valuation of land-based recreation was the fact that recreational use data for these activities are either not available at all or are not specific to Galveston Bay. The authors of a 1989 study completed for the National Oceanic and Atmospheric Administration (NOAA, 1989) acknowledged this problem. The NOAA study reports *direct expenditures* on recreational boating, hunting, swimming, camping, picnicking, and sightseeing, along with other water-based recreational activities in Galveston Bay. According to NOAA, the direct expenditures for these activities in 1986 for Galveston Bay were $122.4 million, 55 percent of the total expenditures for water-based recreation expenditures in all bay systems on the Texas coast.[35] If we net out the value of recreational boating that we estimated above, land-based recreation activities (including swimming) could be crudely estimated at $80-100 million per year.

We tried to improve on this estimate of land-based recreation by consulting other sources for use rates on Galveston Bay for these activities. Recreational use data were reported for Texas in the TPWD's *1990 Comprehensive Outdoor Recreation Plan*, but the usage data are for all of Region 16 and are not specific to Galveston Bay. Because many types of land-based recreation are not dependent on the bay and can take place nearly anywhere in the study area (e.g.,

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[35] Note that these estimates are for direct expenditure, not net economic value.

picnicking), it is impossible to say how much land-based recreation was done in the Galveston Bay area and how many days people from the study area recreated near the bay. Unlike recreational fishing and boating data, TPWD's data on land-based recreation could not be adjusted for use in a benefit transfer calculation. Due to this lack of existing data, we collected data on the use of Galveston Bay for land-based recreation in our mail-only survey and used these for benefit transfer calculations.

I.5.2 Benefit Transfer Valuation Using Data Collected in the Mail-Only Contingent Valuation Study for Land-Based Recreational Activities

Based on the mail-only survey, there were an estimated 1,620,000 use-days in 1993 in the Greater Houston-Galveston Area for the following activities combined: picnicking, camping, hunting and trapping, bird-watching, and hiking and walking on or along the shore of Galveston Bay. This estimate of usage assumes that nonrespondents had one half the use of respondents. This category omits swimming because many respondents failed to separate swimming done in Galveston Bay from swimming done in the Gulf of Mexico. When questioned about this, many respondents admitted aggregating swimming trips over both locations, though we confirmed that their reports of use rates for other activities were for Galveston Bay only. Significant bias could arise from such misreporting, so we deleted this category of recreational use from our valuation.

There are several ranges of values from Walsh et al. (1992) that could be applied to this category of recreation activity. These authors' range for "other recreation activities," in 1993 dollars, is approximately $15-35 per use-day. Camping, swimming and picnicking show ranges of approximately $9-61 per day. Walsh et al. (1992) report that the median value of a day involved in nonconsumptive fish and wildlife activities is $26 (1993 dollars). We used a conservative range of $10-30 per day.

If we assume that nonrespondents use the bay at a rate equal to half that of respondents, the value of other recreational activities is between $15-50 million per year. Again, note that our estimates are based only on use by households in the study area, and do not include the value of Galveston Bay for land-based recreation activities to Texans residing outside the study area.

I.5.3 Comments

It is worth noting that, although bird-watching was not valued separately in land-based recreation activities, the findings of a study by Eubanks (1993) indicate that it is a highly valued activity in Galveston Bay. In a 1991 survey of 458 active members of the Texas Ornithological Society, Eubanks found that the average annual expenditure for bird-watching on High Island in the bay was over $2000 per bird-watcher. Although this is not an "economic value" of a user day of bird-watching, it demonstrates that people are willing to pay large amounts to participate in this activity. In fact, in 1992 the average expenditure per bird-watching trip on High Island by locals, nonlocal U.S. citizens, and foreigners was, respectively, $45, $690, and $1670.

Without data on the number of days spent bird-watching in Galveston Bay, we cannot determine the economic value of this activity, but Eubanks' study does provide information of interest for policy. In his study Eubanks suggests that most of the 300,000 to 1.8 million active bird-watchers in the U.S. have never visited the Galveston Bay area. Of those surveyed at High Island in Galveston Bay, 35 percent were first-time visitors. Thus, a large potential may exist for expanding the present bird-watching "tourism market" in Galveston Bay. There are several areas where excellent bird-watching could be done, including High Island, Anahuac Wildlife Reserve, and others. It could boost economic activity during the tourism off-season because the peak bird-watching season is before the peak season for tourism in the Gulf of Mexico. The extent to which this market can be developed depends not only on promotional efforts and access to bird-watching sites, but also on overall environmental quality, including odor, debris on the beach and in the water, other visual aesthetics, and waterfowl abundance.

I.6 The Value of Wetlands as Storm Buffers

Wetlands reduce the hazards of hurricanes and other coastal storms by protecting coastal and inland properties from wind damage and flooding. As hurricanes pass over wetlands, they dissipate quickly due to reduced humidity and increased friction. Farber (1987) created a hurricane property damage function for wetlands in Louisiana to determine the wind damage costs per loss of one mile of wetlands in Louisiana. Farber's model used wetlands traversed by hurricanes as a specific damage-determining variable. Farber found that, based on 1980 costs and population, and discounting over 100 years at discount rates of 8 percent and 3 percent, the value of one acre of wetlands is $7 and $23, respectively. However, these estimates of the value of wetlands as storm buffers are not readily transferable to Galveston Bay. On the one hand, the value of wetlands along the Louisiana coast is likely to be greater than the value of wetlands in Galveston Bay because the waves and wind from the Gulf of Mexico are presumably more powerful and damaging than waves and wind from the bay. Also, the properties protected from damage are different in Louisiana and in Galveston Bay.

To estimate the benefits of storm protection provided by Galveston Bay, one can: (1) assume that the value of an acre of wetlands in Galveston Bay is some fraction of Farber's derived value per acre and determine the total value using acreage data, or (2) transfer his model substituting Galveston Bay-specific data. For illustrative purposes we assume that the value of wetlands in Galveston Bay for storm buffer protection is one quarter of Farber's per acre estimates of wetland values, or $1.75-5.75 per acre (in 1980 dollars). By updating these values to 1993 dollars, and using trend data on vegetated wetlands estimated for the Galveston Bay system for the years 1956, 1979, and 1989 (White et al. 1993), Farber's estimates can be adjusted and transferred to obtain the estimates in Table A1.I.4.

Table A1.I.4 Estimated Economic Value of Galveston Bay Wetlands for Protection from Hurricane Wind Damage

Year	Acres of Wetlands in Galveston Bay	Value of Wetlands (1993 dollars)
1956	170,400	$426,000-1,400,000
1979	146,000	$365,000-1,120,000
1989	138,600	$347,000-1,140,000

Farber's valuation of wetlands as storm buffers illustrates the damage to physical structures that might result in Galveston Bay if one mile of wetlands is lost. He uses an expected annual cost of the loss of one acre of wetlands (or benefit if the wetlands remain intact) that has been discounted over a 100-year period. It thus appears that wetlands in Galveston Bay probably provide some economic value to individuals in surrounding communities in terms of storm buffering.

An alternative to transferring the dollar value per acre calculated by Farber, is transferring his model and inserting Galveston Bay-specific data. Data could be obtained from vegetative maps, area maps, census data, and the Army Corps of Engineers (which conducts post-hurricane damage surveys and analyzes the hurricane path). This is a labor-intensive task that was not undertaken in this study. However, research in this area could provide the data needed to formulate a damage function model specific to Galveston Bay.

The storm protection provided by vegetation depends in part on the ecological health of the wetlands and on the new development near the bay. A healthy wetland system is required in order to sustain vegetation and, subsequently, to buffer any hurricane damage. Without the wetlands, damage costs would increase not only from wind, but also from flooding, and it can be safely assumed that flood damage is of greater magnitude since it comprises approximately 90 percent of the damage incurred during a hurricane. Since Farber's estimates include wind damage only, adding the flood damages would, presumably, increase the value significantly. Future development around the bay would increase these costs. Thus, damages would increase and the costs would have to be borne by the homeowners (either through direct damages or insurance costs).

I.7 Summary

The total annual economic value of the existing level of recreational fishing to users of the bay living in the Greater Houston-Galveston Area is estimated to be in the range of $75-150 million, and the total annual value of the existing level of boating to users of the bay is estimated to be in the range of $25-50 million. The annual economic value of other recreational uses of the bay to people living in the Greater Houston-Galveston Area is estimated to be in the range of $15-50 million. The total annual economic value of Galveston Bay for recreational uses is thus in the range of $115-250 million. So as not to imply unjustified accuracy, we suggest that the total annual economic value of the bay for recreational uses be considered in the range of $100-250 million. These are the values of a change in these recreational usage rates from current levels to zero.

The estimate of the economic value of fish harvested in the bay by commercial fisherman ($1-2 million) is very low in relation to the economic value of recreational uses. This estimate of the economic value of commercial fishing is not the total market value of fish harvested in the bay, but is rather the estimated profit of commercial fisherman, calculated by subtracting their costs from their revenues. It is important to note, however, that this is likely to be an underestimate of what commercial fishermen stand to lose if the water quality of Galveston Bay deteriorated to such an extent that no fish could be harvested in the bay. This is because such a decrease in the water quality in Galveston Bay would also damage fish nurseries and the productivity of the food chain that supports fish that are now caught in the Gulf of Mexico. However, if water quality remained unchanged and commercial fishing activities in Galveston Bay were curtailed, the value of the commercial catch in the Gulf would presumably stay the same or increase.

Appendix 1, Chapter II:
The Marginal Value of Wetland Systems for Recreational Fisheries in Galveston Bay

II.1 Introduction

This chapter of Appendix 1 presents an approach for estimating the value of an acre of wetlands for recreational fishing. We used this approach to develop an estimate of the value that wetlands contribute to recreational fishing in Galveston Bay. Such estimates of the value of wetlands can be used, for example, to show the economic benefits of a management plan that could slow or reverse the current rate of wetland loss.

II.2 The Marginal Benefit of Wetlands for Recreational Fishing: A Conceptual Framework

This section of Chapter II presents a theoretical approach to estimating the marginal value of an acre of wetlands in terms of its contribution to recreational fishing activity in an estuary. The approach partially follows that of Bell (1989).[36] The fish harvest from an estuary is assumed to be a function of both (1) environmental variables, such as the acreage of wetlands, and (2) the level of human effort devoted to recreational fishing, often measured in fishing days. If other factors are held constant, annual recreational fish landings will increase with an increase of fishing days and/or with an increase of wetlands acreage. A Cobb-Douglas production function can be used to approximate this relationship:

$$C(t) = A \cdot D(t)^{a} \cdot W(t)^{b} \qquad \text{(II.1)}$$

where $C(t)$ is fish landings in year t; $D(t)$ is recreational fishing days in year t; $W(t)$ is wetlands acreage in year t; A is a constant parameter; a is fishing effort elasticity of fish production; and b is the wetlands acreage elasticity of fish production. This treatment of wetlands in the production function implicitly assumes that changes in wetland characteristics other than total acreage (i.e., nutrient cycling, salinity levels, etc.) either do not have a significant influence on changes in recreational fish output over the time period being considered or are highly correlated with the total acreage.[37]

Recreational fishing days are also a function of users' fishing costs and level of fishing success or fish landings. This demand curve is assumed to have the following mathematical relationship:

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36 The production function and demand function used here were suggested by Bell (1989).

37 For an alternative to this Cobb-Douglas approach to modeling the wetlands-fishing relationship, see Lynne et al. (1981).

$$D(t) = B \cdot C(t)^n - V \cdot P(t)^m \tag{II.2}$$

where $P(t)$ is cost or price per recreational fishing day in year t; $B^*C(t)^n$ is the maximum number of fishing days that would be taken if the cost were zero; n is success elasticity of fish catch; m is price (or cost) elasticity; B and V are constants.

If we assume that $m = 1$, then from the demand function in year t, we have:

$$P(t) = V^{-1} \ (B \cdot C(t)^n - D(t)). \tag{II.3}$$

The total benefit from recreational fishing in year t will be:

$$Benefit \ (t) = \int_0^{D(t)} P \ dD = \int_0^{D(t)} V^{-1}(B * C(t)^n - D) \ dD \tag{II.4}$$

$$= V^{-1} \ (B \cdot C(t)^n \cdot D(t) - 0.5D(t)^2) \tag{II.5}$$

$$= V^{-1}(B \cdot A^{\,n} \cdot D(t)^{an+1} \cdot W(t)^{bn} - 0.5D(t)^2). \tag{II.6}$$

The marginal benefit from increasing the stock of wetlands by one acre in year t, (i.e., the marginal value of an acre of wetlands) will be :

$$MV(t) = \frac{\partial \ Benefit(t)}{\partial \ W(t)} \ ,$$

$$= bn \cdot V^{-1} \cdot B \cdot A^{\,n} \cdot D(t)^{an+1} \cdot W(t)^{bn-1},$$

$$= bn \frac{D(t) \cdot B \cdot C(t)^n}{V \cdot W(t)}. \qquad \text{(II.7)}$$

From equation II.2 we know that when $m = 1$, the number of fishing days, $D(t)$, will be zero at the choke price, and $P_0(t) = B^*C(t)^n/V$. In this case the marginal value of an acre of wetland would be:

$$MV(t) = \frac{bn \cdot P_0(t) \cdot D(t)}{W(t)}. \qquad \text{(II.8)}$$

Here $P_0(t)$ is the choke price, or the price at which there will be no demand for the good. Usually, it is the average cost, $P(t)$, and not the choke price, that is given in the results of other research. To use equation II.8, we still need to find a relationship between the choke price, $P_0(t)$, and the average cost, $P(t)$.

To estimate the relationship between $P_0(t)$ and $P(t)$, we assume that the cost of recreational fishing for an individual is proportional to the distance (or travel time) from the individual's residence to the recreational fishing site, i.e., $P=c^*h$, where h is the distance and c is a coefficient (for convenience of notation, the subscript t is omitted). When $h=h_0$, the cost reaches its choke price, i.e., $P=P_0$. When $h > h_0$, user days will be zero and c will be equal to P_0/h_0. We also assume that the density of users around the recreation site decreases as the distance to the site increases, and that the line density of the user population, denoted N, decreases linearly as the distance increases. We then have:

$$N = N_0 - (N_0/h_0) \cdot h, \qquad \text{(II.9)}$$

where N_0 is the maximum population density at the site when $h=0$. When $h=h_0$, which is the maximum distance to users, $N=0$, and users' cost reaches the choke value.

Then, the total cost to users per day will be:

$$TC = \int_0^{h_0} P \cdot N \, dh = \int_0^{h_0} c \cdot h \cdot (N_0 - (N_0 \cdot h)/h_0) \, dh = \frac{P_0 \cdot N_0 \cdot h_0}{6} \qquad (II.10)$$

The total number of users will be:

$$TN = \int_0^{h_0} N \, dh = N_0 \cdot h_0/2 \qquad (II.11)$$

Therefore, the average cost per day for one user will be $P=TC/TN=P_0/3$. Equation II.8 can be rewritten as:

$$MV(t) = \frac{3D(t) \cdot P(t) \cdot bn}{W(t)}, \qquad (II.12)$$

where n is the success elasticity; b is the wetland acreage elasticity of fishing production; $P(t)$ is the average cost of one person fishing per day; $D(t)$ is the total number of recreational fishing days; $W(t)$ is wetland acreage. When the average value of a an acre of wetlands for recreational fishing is $AV=P*D/W$, the marginal value, MV, will equal $AV*3bn$.

II.3 An Application to Galveston Bay

Estimation of the Production Function

The data on recreational fishing trends in Galveston Bay are listed in the Table A1.II.1. Fish landings and recreational days are based on data from Green (1992). Eight species of fish that are dependent on the existence of wetlands were selected to estimate a production function: Atlantic croaker, sand sea trout, spotted sea trout, black drum, sheepshead, gafftopsail catfish, Southern flounder, and red drum. Data on wetland losses are based on White et al. (1993), who provide estimates of wetland acreage around the bay at 171,700 acres in the 1950s, 145,500 acres in 1979, and 138,300 acres in 1989. Estimates of wetlands for the years in between actual measurements were obtained by interpolation. The production function, equation II.1 above, will be used to portray the relationship between recreational fishing and wetlands.

Table A1.II.1 Trends in Recreational Fish Landings for Eight Economically Important Wetland-Dependent Fish Species and Wetland Acreage on Galveston Bay

Year	Recreational Fishing Effort (1,000 hours)	Combined Total Fish Landings (pounds)	Wetlands Acreage (acres)
1976	2,859	2,367,000	148,000
1977	1,050	1,333,000	147,300
1978	2,180	1,845,000	146,500
1979	1,980	2,449,000	146,000
1980	2,000	1,585,000	144,800
1981	2,145	2,440,000	144,000
1982	1,900	1,375,000	143,000
1983	1,700	1,366,000	142,300
1984	2,100	1,061,000	141,600
1985	1,500	800,000	140,800
1986	1,900	1,444,000	140,100
1987	2,200	1,218,000	139,500
1988	2,520	1,354,000	138,900
1989	2,000	928,000	138,500

Source: Green (1992)

To estimate the production function, recreational fish landings were regressed on wetland acreage. The results are shown below (the *t*-values are shown in parentheses below their respective parameter estimates).

$$\ln C(t) = \underset{(-4.190)}{-129.928} + \underset{(2.873)}{0.697547} * \ln D(t) + \underset{(4.455)}{11.4769} * \ln W(t)$$

Adjusted R^2 = 0.6445
N = 14, F = 12.7732
Durbin Watson statistic = 2.4369
Autocorrelation = -0.21843

In terms of the R^2 and F statistic values, these results are quite good. The estimated coefficients are significant at levels of 5 and 10 percent.

From the parameter estimates above, the output elasticities are about 0.7 for fishing effort and 11.5 for wetlands input. The wetlands acreage elasticity is higher than expected. These results suggest that the loss of wetlands area has substantially reduced the recreational fishing productivity in Galveston Bay, and that fishing activity in Galveston Bay is tightly constrained by the shortage of wetlands.

Estimation of the Marginal Values of Wetlands for Recreational Fisheries

In 1989 the total recreational fishing effort in the Galveston Bay area for the eight wetland-dependent fish species examined here was about 2,000,000 person-hours, or about 333,333 days, assuming 6 hours per fishing day (Green, 1992). This estimate of recreational fishing activity is considerably lower than both the results from our mail-only survey and the TPWD data. This is in part because the recreational-fishing-activity estimates presented here only include finfish species that are dependent on wetlands. We used these data of fishing activity calculated from Green (1992) because they are the best time-series data available for the same period as wetland loss data. Using this data in our calculations will not affect the wetland acreage elasticity, since this depends only upon the relative magnitude of changes in fish catch and wetland acreage and not the absolute magnitudes of these indicators. However, the marginal value of an acre of wetland will be underestimated if the data on recreational fishing are lower than actual. This means that the economic value of an acre of wetlands presented here is a conservative estimate.

The total wetlands acreage in 1989 was 138,500 acres. We assumed a fishing success elasticity of 0.13 based on the work in Florida by Green (1984) and Glasure (1987). The success elasticity in Galveston Bay could be lower or higher than that in Florida. If so, our estimate of the marginal value of an acre of wetland would be too high or too low, respectively. From the estimated production function above, the fishing effort elasticity of fish landings is 0.7, and the wetlands acreage elasticity of fish landings is about 11.5. No attempt has been made to estimate production functions for the different species of fish separately; we have simply aggregated the landings of the eight fish species for which data were available in order to obtain an estimate of the total sport fish landings per year (by weight).

Based on results from our valuation of recreation uses of the bay given in Chapter I of this appendix, the average cost for recreational fishing in the Galveston Bay area was assumed to be $30 per day per person. This average cost for one recreational fishing day was shown above in section II.2.1 to be equal to one third of the maximum willingness to pay (the choke WTP). [Bell (1989) assumed that the ratio of the average to the maximum willingness to pay was higher, 0.5].

Given these assumptions, we estimate that the marginal value of an acre of wetlands in Galveston Bay in 1989 for recreational fishing is about 320 dollars per year according to formula 12 above. Using a discount rate of 4 percent, the net present value is estimated as $8,500 per acre. Table A1.II.2 lists all of the assumed and calculated values used in this calculation.

This estimate of the marginal economic value of an acre of wetlands is much higher than the existing market price (about $500 per acre) because it takes into account the loss to recreational fishing activities that occurs when an acre of wetlands is lost. Even though we expected the marginal economic value to be higher than the market price, the estimated magnitude of this differential is surprisingly large (i.e., the marginal economic value is more than ten times the market value).

Table A1.II.2 Assumptions and Results of the Calculation of Marginal Values of Wetlands to Recreational Fishing

Assumptions:	
Recreational Fishing Days:	D = 333,333 days per year
Wetlands Acreage:	W = 138,500 acres
Average Cost per User Day:	P = 30 dollars per day
Fishing Success Elasticity:	n = 0.13
Fishing Effort Elasticity:	a = 0.698
Wetlands Acreage Elasticity:	b = 11.477
Discount Rate:	r = 4%
Results:	
Marginal Value of Wetlands:	MV = 320 dollars per acre per year
Present Value of Wetlands:	NPV = 8,500 dollars/acre

II.4 Concluding Remarks

The estimates of the marginal value of wetlands presented here are the result of many assumptions. Although these assumptions seem to us to be reasonable, a number of these cannot be empirically verified. As such, the resulting estimates of the marginal value of an acre of wetlands to recreational fishing cannot be considered definitive. We believe, however, that they may be indicative of the order of magnitude of economic value that wetlands contribute to recreational fishing. If this is true, our results suggest that the economic value of wetlands for recreational fishing is *much* higher than the market value of wetlands. From an economic point of view, public regulation and/or purchase of existing wetlands would appear to be highly desirable because market forces are grossly underestimating their true economic value to society.

Note also that the marginal value of wetlands acreage calculated above reflects only the value of wetlands in producing recreational fishing opportunities in the bay. This marginal productivity value does *not* include the value of any other services to which wetlands contribute, such as wetland-dependent commercial fishing, recreational fishing in the Gulf for species that are dependent upon wetlands for part of their life cycle, or any other service, such as storm buffering, bird nesting, or wildlife feeding grounds. The value given is thus a very conservative estimate of the marginal economic value of an acre of wetland in producing environmental services.

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Appendix 1, Chapter III:
The Economic Value of Galveston Bay: An Embodied Energy Analysis

III.1 Introduction

Traditional economics assumes that measures of economic value should be based on individuals' preferences. An appropriate economic value can thus only be assigned to a certain service or commodity when the public is well informed. This places a heavy burden on economic valuation techniques for nonmarket goods, especially for environmental commodities and ecosystems' services, because the general public may be far from being well informed about the ecosystem's true contributions to their own well-being, and individuals may, therefore, be unable to value the ecosystem's services as accurately as they might if their understanding were greater.

Embodied Energy Analysis (EEA) was developed as an alternative approach to the nonmarket valuation techniques that are currently used by economists to assign dollar values to environmental goods and services. EEA is based on the notion that energy is the source and control of all things, values, and actions of both human beings and nature (Odum and Odum, 1976) and that energy flow can be used as a common denominator by which all systems can be quantified and evaluated in an unbiased manner (Hopkinson, 1978). Since the economic value of an ecosystem is related to its physical, chemical, and biological roles in the environment whether the public fully recognizes these roles or not, proponents of EEA argue that it is an important and legitimate task for scientists to analyze the structure and function of ecosystems and then use this to assess a value of an ecosystem (Costanza, 1989). Strictly speaking, EEA is not an *economic* valuation approach even though it generates dollar values; it does not attempt to measure individuals' preferences for an ecosystem's services.

In this chapter of Appendix 1, we briefly describe how the EEA approach is used to derive dollar estimates of the amount of economic work that could be done by an ecosystem. We then present our analysis of the "embodied energy" value of the Galveston Bay ecosystem. We conclude with a discussion of the limitations of using the EEA approach for calculating the value of an ecosystem.

III.2 Embodied Energy Analysis: An Overview of the Approach

There are six basic steps involved in an EEA. In this section, we describe each of these six steps in turn.

Step 1: Collect data on the gross primary production (GPP) of the ecosystem.

Embodied Energy Analysis is based on the gross primary production of an ecosystem. GPP is a measure of the amount of solar energy used by plants in the ecosystem to fix carbon into organic molecules. Carbon is the basis for the food chain that supports all life in the ecosystem, including fish and wildlife. GPP is a useful index of overall ecosystem energy capture. Generally, primary production data are either measured in units of energy or units of mass. If data are reported in units of mass, a conversion factor must be employed to convert the productivity data into units of energy used per unit of time.

Step 2: Convert the estimate of GPP to fossil fuel equivalents (FFE).

FFEs are estimates of the burning efficiency of the organisms engaged in primary production, compared with the burning efficiency of a barrel of oil. This conversion is accomplished by considering the fuel efficiency of each energy source. Gross primary production is a lower quality form of energy than fossil-fuel energy.

Step 3: Convert the FFE value into dollars.

FFEs are converted to dollars using a whole-economy-based ratio of economic value produced per unit of energy consumed. This is usually the ratio of GNP to total energy used in the economy (measured in FFEs). Proponents of EEA view this dollar value as the annual contributory value of the ecosystem.

Step 4: Calculate the present value of expected energy flows from the ecosystem.

The annual dollar value of the energy flow from the ecosystem is converted to a present value for the ecosystem using an assumed discount rate. This is simply the standard economic method (i.e., discounting) for collapsing a time stream of dollar values into a single estimate of value in the current period.

Step 5: Calculate the value of the energy stock of the ecosystem.

Instead of obtaining the flow of energy benefits over time, society may have the option of "mining," or harvesting, the energy of the ecosystem "all at once," or much more quickly than assumed in the valuation of flows described above. The dollar value of the existing stock of energy resources is measured in the manner described below in section III.3.6.

Step 6: Compare the flow and stock values.

Compare the dollar value obtained from the net present value calculation of the energy flow value with the dollar value of the stock. Because society is assumed to have a choice between consuming the total energy stock in the ecosystem now and consuming the flow of services from the ecosystem indefinitely in the future, EEA assumes that society should base its estimate of the value of the ecosystem on whichever of these estimates is greater.

EEA can be more precisely described using the following mathematical notation:

The value of the annual energy flow is given by

$$VF(i) = GPP(i) * ME(i) * EQ(i) * DC * AREA(i). \quad \text{(III.1)}$$

The present value of this annual flow is

$$PV(i) = VF(i) * (1+r)/r. \quad \text{(III.2)}$$

The value of current energy stock is given by

$$VS(i) = VF(i) * S(i). \quad \text{(III.3)}$$

$VF(i)$, is the annual energy flow. $GPP(i)$ is the gross primary productivity of ith component of the ecosystem measured in grams per square meter per year. $ME(i)$ is the conversion factor from mass to energy measured in Kcal per gram. $EQ(i)$ is the energy quality factor (a dimensionless, i.e., unitless number). DC is the conversion factor from energy to dollar value measured in dollars per Kcal. $AREA(i)$ is the area of the component of the ecosystem of concern measured in square meters. The discount rate is represented by r. Multiplying the annual energy flow, $VF(i)$, by the discount factor, $(1+r)/r$, in equation III.2 converts the annual flow to a present value. $S(i)$ is a factor that converts the value of annual GPP flow to a stock value by multiplying the annual flow by the factor $S(i)$, where $S(i)$ is based on the number of years it would take to regenerate the ecosystem if it were destroyed. According to E. P. Odum (1978), the value of $S(i)$ is about 10 for marshes.

III.3 An Estimate of the Embodied Energy Value of the Galveston Bay Ecosystem

III.3.1 Gross Primary Production of Galveston Bay

Estimates of the primary productivity of different components of Galveston Bay are presented in Table A1.III.1 below. These data are combined from eight different sources, each of which were measured in different periods. These data are based on research done over 10 and 20 years ago, and for a variety of reasons productivity values today may be quite different (e.g., climate change and pollution loadings). Differences in both the timing of the experiments and measurement methods may contribute to errors in our calculations. Moreover, the productivity estimates presented in Table A1.III.1 are averages for the whole bay. Some of these values could vary significantly over subregions of the bay. Despite these limitations, we believe these data are the best available estimates of the primary productivity of Galveston Bay.

Table A1.III.1 Primary Productivity in Galveston Bay

Plant Production	Primary Productivity (g dry/m^2/yr.)
Open Water Area:	
Phytoplankton$_{1,2,3}$	350
Benthic microflora$_{1,3}$	500
Submerged vegetation$_{4,5,6}$	2600
Freshwater marsh$_{4,7}$	820
Salt-Brackish Marsh$_{7,8}$	1100
Woodlands/swamps$_{7,3}$	700

Sources: 1. Flint (1984); 2. Corliss (1971); 3. Gosselink et al. (1979); 4. Texas Department of Water Resources (1981); 5. White et al. (1985); 6. McRoy and McMillan (1977); 7. Fisher et al. (1972); 8. Ward and Armstrong (1980);

III.3.2 Energy Equivalent of Gross Primary Production

Since the gross primary production in Table A1.III.1 is given in the units of mass, it needs to be converted to energy units. Conversion factors of mass to energy vary for different living organisms. Table A1.III.2 lists some of the mass-to-energy conversion factors.

Table A1.III.2 Conversion Factors from Mass to Energy

Biomass	kcal/g dry weight	kcal/g ash-free dry weight
Terrestrial Plants	4.5	4.6
Algae	4.9	5.1
Invertebrates	3.0	5.5
Insects	5.4	5.7
Vertebrates	5.6	6.3

Source: Odum (1971).

Using an average conversion factor of 5 kcal/g dry weight, the gross primary production of Galveston Bay in energy units can be calculated. The results of these calculations are found in Table A1.III.3.

Table A1.III.3 Embodied Energy of Primary Production

Flora	Primary production (kcal/m^2/yr)
Phytoplankton	1,750
Benthic Microflora	2,500
Submerged Vegetation	13,000
Freshwater Marsh	4,100
Salt-Brackish Marsh	5,500
Woodlands/Swamps	3,500

III.3.3 Fossil Fuel Equivalents of Gross Primary Production

Before converting GPP to a measure of equivalent economic value, it must first be adjusted to reflect its quality as a fuel input to the economy. The most common unit used for this purpose is the fossil fuel equivalent (FFE). Different forms of energy have different levels of quality. Table A1.III.4 lists energy-quality conversion factors for various forms of energy in FFEs.

Table III.4 Energy Quality Conversion

Type of Energy	Fossil Fuel Equivalent (FFE cal/heat cal)
Heat from Sun's Rays, Uncollected	0.0001
Sunlight	0.0005
Gross Plant Production	0.05
Wood, Collected	0.5
Coal and Oil, Delivered for Use	1.0
Energy in Elevated Water	3.0
Electricity	4.0

Source: Odum and Odum (1976).

Table A1.III.4 shows that, when burned, gross primary (plant) production yields about one twentieth of the calories of fossil fuel. The fossil fuel equivalent of GPP in the Galveston Bay ecosystem is listed in Table A1.III.5. It is calculated by multiplying the primary production values in Table A1.III.4 by the fossil fuel conversion factor (0.05). The numbers in Table A1.III.5 represent the FFE energy production per unit area of different types of habitats.

Table A1.III.5 Fossil Fuel Equivalents of Gross Primary Production for Six Habitats in Galveston Bay

Flora	Primary Productivity (FFE kcal/m²/yr)
Phytoplankton	87.50
Benthic Microflora	125.00
Submerged Vegetation	650.00
Freshwater Marsh	205.00
Salt-Brackish Marsh	275.00
Woodlands/Swamps	175.00

III.3.4 Dollar Value Equivalent of Gross Primary Production

The embodied energy valuation technique assumes that the ecosystem's total direct and indirect energy consumption (embodied energy) is highly correlated with its dollar value in the U.S. economy (Costanza, 1980, 1984; Cleveland et al., 1984; Costanza and Herendeen, 1984). The dollar-value conversion factor is calculated either of two ways. One way is to use the ratio of the total annual U.S. energy consumption to the Gross National Product (GNP) for that year (Heichel, 1973). The other way is to regress the embodied energy used in each economic sector on the dollar value of its product to obtain a coefficient that measures the same ratio (Costanza, 1984). Since the efficiency of energy use in an economy changes over time, this conversion factor also changes over time. In 1970-1972, this factor was 20,000 kcal/dollar (Heichel, 1973; Costanza, 1984). In 1973, it rose to 25,000 kcal/dollar (Odum and Odum, 1976). But by 1983, it had fallen to 15,000 kcal/dollar (Costanza, 1989). We assume that the dollar-value conversion factor is lower today than it was in 1983 because industries and households have had time to adjust to the generally higher energy prices. Taking into account inflation and changes in the efficiency of energy use in the U.S. economy, we assumed that the conversion factor for 1993 is 10,000 kcal/dollar.

Table A1.III.6 presents estimates of the dollar value for each plant-type component in the Galveston Bay estuary ecosystem in terms of dollars per acre per year. As shown, submerged vegetation and salt-brackish marsh have the highest dollar value per acre.

Table A1.III.6 Dollar-Value Equivalent of Gross Primary Production

Flora	Primary Productivity (1993 cents/m^2/yr)	Primary Productivity (1993 dollars/acre/year)
Open Water Area:		
Phytoplankton	0.875	35.41
Benthic Microflora	1.250	50.59
Submerged Vegetation	6.500	263.06
Freshwater Marsh	2.050	82.96
Salt-Brackish Marsh	2.750	111.29
Woodlands/Swamps	1.750	70.82

III.3.5 Dollar Value of the Annual Energy Flow in Galveston Bay

Estimates of the acreage of each land/water use type in the Galveston Bay area and the dollar value of the energy flows in each component of the bay are listed in Table A1.III.7. It is assumed that the productivity of phytoplankton and benthic microflora within Galveston Bay is constant over the total bay surface of 352,000 acres.

Table A1.III.7 Dollar Value of the Annual Energy Flow

	Acreage (acres)	Annual Energy Value (Million dollars/year)
Open Water Area	352,000	30.27
Submerged Vegetation	247	0.065
Freshwater Marsh	58,900	4.89
Salt-Brackish Marsh	94,900	10.56
Woodlands/Swamps	123,500	8.75
Total	629,547	54.54

Sources of Acreage Information: NOAA (1988, 1991).

III.3.6 Unit Value of the Galveston Bay Ecosystem

For the purposes of comparison, the per-acre values of the flow- and stock-embodied energy are shown in Table A1.III.8. For the flow value, the net present value of the energy flows from each land/water use type are listed. For the stock value, the stored energy value of the bay can be estimated as the energy flow required to replace the bay ecosystem (H. T. Odum, 1978). These replacement factors *S* are shown for each land/water use type along with the per acre stock values derived from them.

Table A1.III.8 Unit Value of Each Component of the Bay System

	Present Value of Flow (1993 dollars/acre) r=0.04	Value of Stock (1993 dollars/acre) S=5, 7, 10	Maximum of Columns 1 and 2 (1993 dollars/acre)
Open Water Area	2200	430 (s= 5)	2200
Submerged Vegetation	6400	1,800 (s= 7)	6400
Freshwater Marsh	2200	830 (s=10)	2200
Salt-Brackish Marsh	2900	1,100 (s=10)	2900
Woodlands/Swamps	1800	710 (s=10)	1800

For each land/water use type in Table A1.III.8, the present value of the flow exceeds the value of the stock.

III.3.7. The Total Embodied Energy Value of Galveston Bay

By multiplying the per-acre unit values for each land/water use type by the estimated acreage they inhabit over the bay, we can calculate the total value of the bay ecosystem (Table A1.III.9). Thus, the total embodied energy value of the Galveston Bay ecosystem comes to about $55 million per year (in 1993 dollars). The present value of this infinite flow of energy is about $1.4 billion (assuming a 4 percent real [i.e., net of inflation] discount rate).

Table A1.III.9 The Total Present Value of Galveston Bay Using the Embodied Energy Approach to Valuation (in $ Million, r=0.04)

Open Water Area	$780
Submerged Vegetation	$2
Freshwater Marsh	$130
Salt-Brackish Marsh	$270
Woodlands/Swamps	$220
Total	$1,400 (approximate)

III.4 Concluding Remarks: Limitations of the Embodied Energy Approach

The embodied energy analysis presented here was performed as accurately as possible with the available data. There are, however, inherent limitations of the methodology. The embodied energy method of ecosystem valuation is predicated upon two assumptions. The first is that there is a limited amount of energy available within which the global environment can operate. The second is from an empirical observation that the ratio of annual GNP to annual energy consumption is stable over time. We will deal with these assertions one at a time.

The first assumption, that there is a fixed amount of energy available, is true in an absolute scientific sense. Energy is produced in the process of taking matter from an ordered state to a state of greater disorder, or higher entropy. But why should only energy be used as a benchmark by which to value other resources? The global carbon stock also ultimately limits the amount of biomass that can be produced on the planet. It is not even clear that energy is a uniquely constraining factor in the global economy. We currently use only a small part of the incoming solar radiation; there are vast untapped sources of energy in ocean thermal gradients and the earth's hot core; and there are still undiscovered reserves of fossil and nuclear fuels within the earth. Someday it may even be possible to capture solar winds or solar radiation from places other than earth to power the terrestrial economy.

The basic energy flows used here do not begin to capture the true social value of an ecosystem. Galveston Bay, for example, if eutrophied, could produce abundant algal primary productivity. Would this be considered to be of greater value than the present bay system? Of course not. Energy flows also do not distinguish between relatively abundant habitats and unique ones. A patch of wetland that was critical to the survival of an endangered species, such as the whooping crane, would be considered equivalent in value to any other patch of wet or dry land that could fire up one's stove to produce the same amount of heat. Some critical information is obviously lost in the translation into kilocalories.

Also, the kilocalories that the embodied energy approach employs are *average* kilocalories. For example, if one barrel of oil were removed from the U.S. economy, the embodied energy logic would conclude that something on the order of $139 would be lost from the economy. This is fundamentally incorrect.[38] If a barrel of oil were taken away, the economy would lose the price of that barrel of oil, something less than $20 at current prices. Market forces would, hopefully, ensure that the barrel would disappear from its least productive use in the economy as some substitutions were made, some conservation occurred, or some good of low value ceased to be produced. So, the embodied energy approach does not provide a useful value.

Second, the assertion that there is a stable ratio of GNP to economy-wide energy use has already been shown above to be untrue. The embodied energy technique was developed in earnest in the 1970s when the world was suffering from a significant increase in energy costs and an artificial reduction in energy availability. In the short run, energy demand appeared to be quite inelastic. However, with energy price increases, energy consumption relative to GNP has declined dramatically, particularly in the United States. It is clear that there is great long-term flexibility to respond to reductions in the availability of traditional fuels and still maintain a high standard of living. A number of economic historians have observed long patterns of increasing and decreasing real prices for basic resources, including energy (see Kuznets, 1967) and these are likely to happen again; indeed, real energy prices have been falling since the late 1970s.

Finally, EEA is claimed to be free of the alleged subjectivity of the economist's approach to resource valuation since the latter is based on arbitrary values assigned by uninformed consumers. Yet the embodied energy approach *is* using dollar values from the economy, specifically, the ratio of GNP to kilocalories of fuel consumed. These dollar values come from consumers making decisions every day based on their subjective valuation of all the goods that they consume. These dollar figures can also be biased by the failure of the market to properly price all aspects of marketed goods.

In summary, although we have presented these estimates of the embodied energy value of the Galveston Bay ecosystem as a point of reference, we do not believe they provide useful information for policy.

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[38] This is based on approximately 1.39 million kcal per barrel of oil, and converted into dollar value by using the factor of 10,000 kcal per dollar of GNP, as cited earlier in this section.