LAVACA BAY INJURY QUANTIFICATION AND RESTORATION DETERMINATION

1.0 INTRODUCTION

The federal and state trustees for natural resources (the Trustees) are conducting a Natural Resource Damage Assessment (NRDA) at the Aloca Point Comfort/ Lavaca Bay NPL Site (the Site). This assessment includes analyses of the injuries to natural resources and the resulting service losses. The injuries are the interim losses that occur from 1981 until recovery to baseline and the losses due to response actions. The Trustees seek restoration to compensate the public for the interim and response action losses. The restoration is referred to as compensatory restoration. The Trustees have evaluated a number of restoration alternatives and have determined that, if the Environmental Protection Agency (EPA) selects its currently anticipated remedy for the Site, salt marsh – at Powderhorn Lake and the Whitmire division of the Aransas National Wildlife Refuge – and oyster reef restoration – in the open waters of Lavaca Bay – are the appropriate restoration actions.

The focus of this document is the determination of the scale (i.e., size) of the restoration projects. The scale of the projects should be that which provides value to just offset the value of the losses. The process of determining the scale of restoration is called restoration scaling.

Restoration scaling requires a framework for quantifying the value of losses and for quantifying the benefits of restoration so the losses and benefits can be compared. The Trustees used habitat equivalency analysis (HEA) as the framework for quantifying losses and benefits.

2.0 DESCRIPTION OF HABITAT EQUIVALENCY ANALYSIS

Habitat equivalency analysis is an approach to restoration scaling. Losses are quantified as lost habitat resources and services. The scaling exercise is to determine size or quantity of the restoration projects that would provide the resources and services that were lost. Restoration habitat of the same type, quality, and of comparable value is preferred to compensate for the resource and service losses so

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that the per unit values of the lost and replacement habitat resources and services are equal and the value of the total losses equals the value of restoration benefits.

The HEA requires injury parameters to quantify lost habitat resources and services. The parameters needed to estimate losses include the area of habitat injury, the degree of injury within that habitat, and how that degree of injury changes over time. The degree of injury is determined by the condition of key or representative resources or services in the habitat (for example, primary production or macrofaunal density). The losses are quantified by year as lost service acre-years, where a service acre-year is the loss of one acre of habitat and its resources and services for a year.

Because the losses occur in different time periods, they are not comparable. People have a rate of time preference and prefer to use or consume goods and services in the present rather than postpone their use or consumption to some future time. To make the losses that occur in different time periods comparable, a discount factor is applied to the losses to determine discounted service acre-years.

Interest-bearing savings accounts are based on the same principle of discounting. In order to get people to save money (i.e., forgo present use or consumption), banks pay customers an additional amount of money in the form of interest. The interest rate, equivalent to the discount factor when considering goods and services, determines equivalency of dollars received (or services provided) over different time periods.

Other parameters are necessary to quantify the benefits of restoration projects. They include when the habitat restoration project begins, the time until the habitat provides full services, the level of services provided between the time when the project begins and when it provides full services, and the relative services of the created or enhanced habitat compared to the injured habitat before the incident. Given the size of a project and the discount rate, these parameters define the discounted service acre-year benefits that result from the project. The task is to determine the size of the projects such that the discounted service acre-years offset the losses.

3.0 HEA MODEL

The simplest form of the mathematical model states that the present value of habitat service losses is equal to the present value of the service gains. Thus,

$$L = G$$

where

L = the present value of services losses from the injured habitat, and

G = the present value of gains from created habitat of the same type.

L is defined as:

$$L = N * \sum_{t=d}^{R} W_t (1+i)^{(T-t)}$$

where

N = the economic value per acre of the services from the injured habitat,

W_t = the number of acres of habitat forgone in year t,

d = year in which habitat service losses begin,

R = year in which habitat services return to baseline levels,

T = current year, and

i = real interest rate (or discount rate).

G can be expressed with a similar formula:

$$G = N * \sum_{t=b}^{P} X_t (1+i)^{(T-t)}$$

where

N = the economic value per acre of the services from the newly created or improved habitat,

X_t = the number of acres of additional habitat provided by the replacement projects in year t,

b = year in which habitat service gains begin,

P = year in which habitat service gains terminate,

T = current year, and

i = real interest rate (or discount rate).

Note that N, the economic value of habitat services, appears in both sides of this equation. As originally proposed, the economic value per acre of the forgone habitat services must equal the economic value per acre of the newly created or improved habitat in an HEA. However, habitat equivalency can be applied when lost and replacement habitats are not of comparable value as long as there is a common resource or service metric at the injury and restoration areas that accounts for value differences. This approach is discussed more fully in Section 5.0.

4.0 QUANTIFICATION OF HABITAT LOSSES

Typically, the HEA framework is used to quan tify losses by habitat type. In the assessment for this Site, three types of habitats are impacted: [1]

Marsh

The marsh habitat includes bayshore intertidal zones dominated by smooth cordgrass (*Spartina alterniflora)* and marshhay cordgrass (*Spartina patens)*. This habitat type also includes adjacent or contiguous patches of sparsely vegetated mudflat. The emergent vegetation of interest is in narrow bands of marsh along the shoreline near the Alcoa facility and Dredge Island. The bands vary seasonally in size and configuration with biomass fluctuating from year to year. The critical characteristics of this habitat type include benefits to benthic infauna, epifauna, macrophytic vegetation, sediment attached flora, and other attached substrate as well as benefits for populations of shorebirds and finfish (especially juvenile and larval forms).

[1] Impacts to another type of habitat – terrestrial habitat – are addressed in a separate document (see RWC Analysis for Terrestrial Resources, 2000).

Oyster reef

Oyster reef habitat is composed exclusively of hard substrate. The habitat is composed of aggregated oyster shell that provides substrate for large populations of non-reef building encrusting organisms. The shells of live and dead oysters are encrusted with bryozoans, sponges, barnacles, mussels, anemones, slipper shells, and algae.

Soft-sediment bay bottom

Soft-sediment bay bottom includes soft sediments in areas of the bay where the bottom is between two and eight feet below mean sea level. Critical biological characteristics of this habitat include benthic infauana, epifauna, and attached flora (mainly algae). This habitat type also includes scattered clusters of oyster shell and mussels.

Injuries to these three types of habitats occur as injuries due to contamination and injuries due to response actions. The interim habitat service losses due to contamination are being quantified by the degree of injury to benthic invertebrates, fish, and birds in the reasonable worst case analyses for them. The response action habitat losses are being quantified by the amount of habitat that is lost in the course of response actions to clean up the contamination.

Figure 1 shows the process for estimating the habitat losses. The figure shows two tracks that represent interim losses and response losses. Some of the specific steps in this process merit further explanation. For example, the magnitude and extent of the injury may have changed over the assessment period. Incorporating a slope accounts for a change in conditions since the release of contaminants of concern. Similarly, some of the response actions can result in year-to-year differences in the level of service losses. For example, response dredging temporarily disturbs open bay bottom habitats. For habitat services that are only temporarily affected, the recovery path indicates how soon these services will recover. The two tracks come together when the interim and response losses are added together to get annual habitat losses

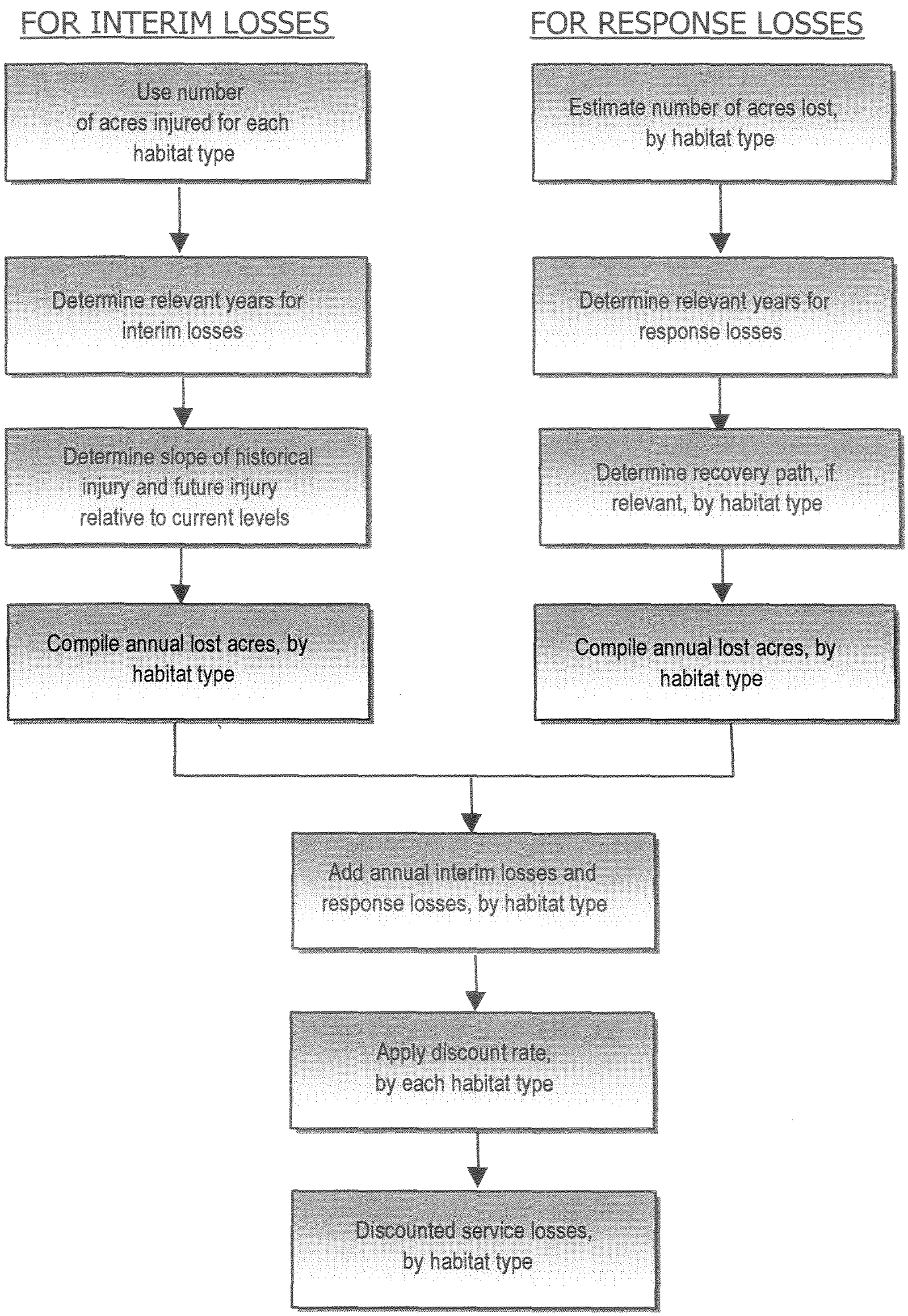

Figure 1.
Process for Estimating Habitat Losses

by type. The discounted service losses are determined after applying a 3 percent discount rate to the annual losses in accordance with accepted economic principles. [2]

Before describing the interim and response losses in more detail, it is first necessary to explain the framework used for injury assessment. The Trustees and Alcoa use a "reasonable worst case" (RWC) approach in identifying and quantifying natural resource injuries and service losses. Under this approach, before proceeding to plan and implement any specific studies to further investigate and/or quantify any resource injury or loss, the Trustees and Alcoa considered relevant existing data related to the affected area and information bearing on the risk of injury to each resource, including historical data, data collected as part of the remedial investigation (RI) process and the results of prior relevant scientific studies or literature reviews. In considering this information, the Trustees and Alcoa sought to err on the side of conservatism, i.e. in favor of predicting "resource injury" for an exposure level at which at least one data or information set indicated an adverse effect was reasonably likely. Then, consistent with circumstances for exposure at the Site, the same conservatism was applied to predict the extent of the potential injury or loss for each resource at that conservative exposure level. For each resource, the results of this analysis were then considered in determining the need for additional data to confirm and/or fully quantify these injuries. Where specific additional information was needed, the Trustees and Alcoa, with EPA's concurrence, were often able to influence the design of RI studies [3] so that the results of these studies would serve both RI and assessment data needs.

The Trustees and Alcoa sought to reach agreement on resource injury determination that could appropriately be based on the available data and scientific information, using conservative scientific assumptions under the RWC approach. Where agreements were reached, the resulting injury determination was then used to quantify injuries to that resource. If agreement could not be reached, then specific

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[2] See Freeman, 1993 and Lind, 1982. For further discussion of discounting and an explanation of the 3 percent discount rate, see NOAA (1999).

[3] No RI study was changed in ways that affected its use or otherwise reduced its value to the RI process.

damage assessment injury studies were jointly developed to address the data gaps critical to determining and/or quantifying that resource injury.

Table 1 contains the components for the interim losses that occur through 1999.[4] The RWC process for injury assessment evaluates the two pathways for exposure by which injury can occur: direct exposure (benthos) to mercury in sediments; and indirect exposure (fish and bird populations) through bioaccumulation. Service losses for a particular habitat are assessed by combining lost services from the RWC benthic analysis and from the RWC analysis for fish.[5] That is, for a particular habitat type, losses are assessed as the combined injury from benthic and the fish resource categories.[6]

The numbers in Table 1 are the number of acres injured per habitat type as calculated in the RWC analyses (RWC Technical Memorandum, 2000). The number of acres for each degree of injury (percent service loss) is separated for direct (benthic injury) and indirect (fish injury) exposure effects for pre-response interim losses. Combined, the benthic and fish injuries comprise the pre-response interim losses.

The injury categories (percent service loss) are based on contaminant

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[4] Interim losses occur in two time periods: there are interim losses on habitats before response actions and interim losses on habitats that remain after the response actions have been completed. The year 1999 separates pre and post-response interim losses because Alcoa began substantial response actions in that year. The pre-response interim losses in Table 1 include losses from 1981 – 1999. Post-response interim losses will be described in the last section of this document.

[5] The injury through indirect exposure is only quantified as injury to fish or birds since either category captures the effect of the "dirty food." Restoration done for one resource category also benefits the other category. The injury due to indirect exposure was quantified as a fish injury since that injury is more severe than the bird injury (see RWC Analysis for Finfish, 2000 and RWC Analysis for Birds, 2000) and restoration to compensate for the fish injury will provide enough benefit to offset the bird injury.

[6] Note that there are two types of marsh habitat incorporated into the analysis. The distinction is related to differences in the quality of services provided by these habitats. Because the quality of habitat services is different, different amounts of restoration will be required.

Table 1. Habitat Loss Components for Injured Habitats

Habitat Loss Component	Fringe Marsh/Mudflat (acres) Dredge Island	Other Marsh	Open-bay Bottom (acres)	Oyster Reef (acres)
Benthic Injury Number of acres injured, Pre-response:				
10 % Loss of Service	1.51	4.37	316.70	0.00
20 % Loss of Service	3.01	1.90	37.23	0.00
25 % Loss of Service	1.93	1.82	72.65	18.06
30 % Loss of Service	0.00	0.00	0.00	0.00
35 % Loss of Service	10.61	2.61	47.24	0.00
40 % Loss of Service	0.00	0.00	0.00	0.00
50 % Loss of Service	0.05	0.00	3.86	3.97
Slope of losses	Constant	Constant	Constant	Constant
Fish Injury Number of acres injured, Pre-response:				
10 % Loss of Service	11.92	3.48	0.00	3.13
20 % Loss of Service	2.10	1.18	9.58	1.09
25 % Loss of Service	0.00	0.00	0.00	0.00
30 % Loss of Service	0.00	0.00	2.50	0.00
35 % Loss of Service	0.00	0.00	0.00	0.00
40 % Loss of Service	0.00	0.00	0.00	0.00
50 % Loss of Service	0.00	0.00	0.00	0.00
Slope of losses	Linear, 81 loss two times 99 loss	Linear, 81 loss two times 99 loss	Linear, 81 loss two times 99 loss	Linear, 81 loss two times 99 loss

concentrations. Percent loss of services were derived for different concentration ranges using available scientific literature and were based on the type of endpoint affected and the degree of effect in the studies reviewed. Through habitat mapping, the Trustees determined the number of affected acres of habitat at each of the injury thresholds.

The slope of the pre-response losses refers to historical injury. For benthos, historical sediment data suggest that the extent of past contamination to be fairly constant for the period of interest. However, a review of historical finfish and shellfish data collected by Texas Department of Health suggests that mercury concentrations in fish were higher in the past. The Trustees analyzed the data and determined that in 1981 the percent service losses were roughly double their level in 1999. Between 1981 and 1999, the service losses declined linearly.

For habitats that are lost either temporarily or permanently due to response actions,[7] the losses to those habitats are quantified as response losses. Table 2 contains information for the losses associated with response actions taken through 1999.[8] These response actions include the Dredge Island stabilization effort and dredging associated with the treatability studies for Lavaca Bay. The removal of fringe marsh habitats on the northern end of Dredge Island is assumed to result in permanent removal of this habitat. Similarly, the portion of oyster reef removed as part of work mobilization is assumed to be permanently removed. Benthic habitat, however, is only temporarily affected by dredging. While some studies show that benthic recovery from dredging can occur within a few months to a year (Swartz et al., 1980; Kenny and Rees, 1994; and Van Dolah et al., 1984), recovery often takes longer and the Trustees chose three years as a conservative estimate.[9] The date that both permanent and temporary effects begin corresponds to the date of the response actions.

[7] This analysis assumes dredging of oyster reef habitat results in a permanent loss of oyster reef habitat and services. For other habitats, the service losses associated with response are temporary.

[8] The last section of this document will identify response losses for response actions that have been taken or are planned beyond 1999.

[9] The shape of the recovery path is estimated to be linear.

Table 2.
Habitat Loss Components for Response Losses
Associated with Dredge Island Stabilization

Habitat Loss Component	Bay Bottom	Oyster Reef	Dredge Island Marsh	Other Marsh
Number of acres permanently lost	N/A	1.79	17.0	0.13
Date that permanent losses begin	N/A	1998	1999	1999
Number of acres temporarily affected	17.86	NA	NA	NA
Dates of temporary effects	1998-2000	NA	NA	NA
Shape of Recovery Path	Linear	NA	NA	NA

Table 3 summarizes the total discounted acre-years of losses (both interim service losses and response losses) by habitat type. The interim service losses are calculated from 1981 through 1999. The response losses are calculated for response actions undertaken to date. Future interim and response losses (beyond 1999) are projected in the last section of this document.

Table 3. Discounted Habitat Losses

HABITAT	DISCOUNTED ACRE-YEARS
Open-bay bottom	2035.61
Other Marshes	81.93
Dredge Island Marshes	747.12
Oyster Reefs	244.72

5.0 HABITAT RESTORATION

The Trustees have identified two types of habitat restoration projects: oyster reef creation and marsh creation/enhancement. These projects directly offset the losses to oyster reefs and marshes. It is not practical to seek in-kind restoration for injuries to open-bay bottoms and their benthic communities; the creation of open-bay bottom benthic habitat is typically considered undesirable since it generally involves the destruction of existing terrestrial and/or wetland habitats. The Trustees have determined that marsh restoration is appropriate as alternative restoration for open-bay bottom losses since marsh restoration would support the same kinds of services that were lost.

The Trustees worked with experts familiar with Texas marshes and estuaries to develop a habitat exchange rate between marsh services and open-bay bottom services (for the Lavaca Bay area) in order to stay within the HEA framework, i.e., provide habitat services of the same kind that were lost. The exchange rate would account for differences in services and the quality of services of the open-bay bottom habitat relative to the marsh habitat. The experts were tasked with evaluating habitats, including open-bay bottom, relative to natural marsh based on five ecological functions. The five functions were primary production, secondary production, benefits to fish and decapods, organic detritus production, and decomposition and remineralization. From the experts' evaluations, the Trustees developed an open-bay bottom/marsh exchange rate of 5:1. Specifically, the services provided by five acres of bay-bottom are equal to the services provided by one acre of marsh.[10]

Table 4 contains the habitat loss results after applying the open bay- marsh exchange rate. The discounted losses associated with open-bay bottom habitat have been converted and added to the discounted marsh losses.

Having calculated the losses in habitats of the kind that are to be provided through restoration, the next steps are to estimate the benefits of the salt marsh and oyster reef restoration projects and to determine project scale to offset the losses.

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[10] See the memorandum "Relative Habitat Service Provision Exercise" for additional information about the development of the exchange rate; see also the memorandum "Expert Scores for Relative Habitat Service Provision" for the expert scores that were the basis for the exchange ratio.

Table 4. Discounted Habitat Losses After Exchange

Habitats	Discounted Acre-years	Discounted Acre-Years After Exchange
Open-bay bottom	2035.61	--
Other Marshes	81.93	489.05
Dredge Island Marshes	747.12	747.12
Oyster Reefs	244.72	244.72

Figure 2 shows the process for estimating habitat benefits. The process is similar to calculating habitat losses. The process starts with the number of quality-adjusted acres for each restoration project. The quality adjustment accounts for the fact that the restoration site in its initial state can vary in the services it provides and the project's services can differ in productivity from the lost services. The third and fourth steps determine how the restoration habitat services change over time and how long it takes the habitat to provide full services. These parameters determine the services per year by habitat type. Applying the discount rate results in the discounted service benefits.

There are specific parameters that characterize the salt marsh and oyster reef restoration projects. Two components are common across the projects. The discount rate for the restoration gains is three percent and both projects will begin providing services in the year 2001. The remaining inputs are specific to each project and are described more fully below.

It was the Trustees judgement, based on the development of other created oyster reefs and discussions with an oyster reef expert, that a created reef matures rapidly in the near term and then slowly provides services approaching those of natural reefs. To reflect this judgement, the Trustees used a maturity path with two different slopes. The first leg of the path applies to years 1 through 5, where the level of services increases linearly to reach 75 percent services (relative to the services of the

FOR RESTORATION GAINS

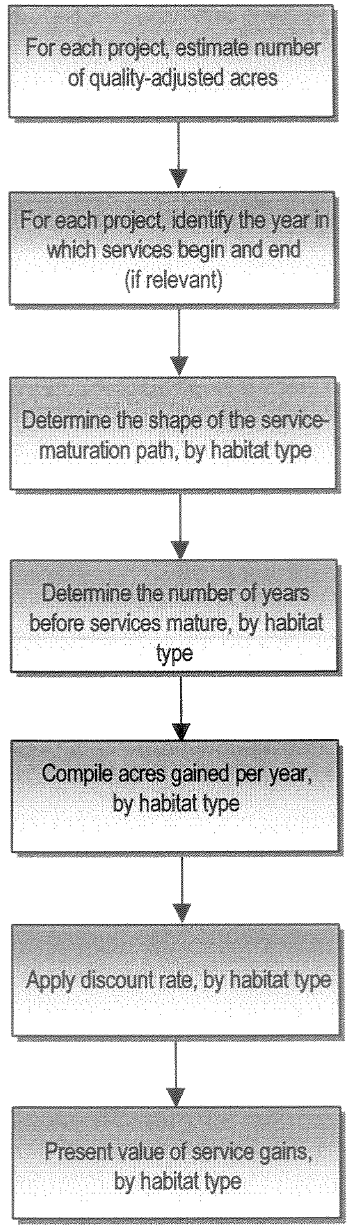

Figure 2.
Process for Estimating Habitat Gains.

injured oyster reef before the incident) at the end of five years. The second portion of the maturity path applies to years 6 through 15, where the increase in services is linear reaching 95 percent services at the end of fifteen years. Services are expected to remain at 95 percent for the life of these created oyster reefs, which is estimated to be 100 years.

Because the two types of injured marsh habitat provided different levels of services, the requirements for compensation differ. The Trustees accounted for the differences in service levels in the injured habitats by adjusting the maturity curve of the restored marshes. Table 5 below details the two maturity paths.

Table 5.
Maturity Path for Created Marshes.
(Percent of Services)

Year	Created Marshes to Replace Dredge Island Marshes (% of maximum services provided)	Created Marshes to Replace Other Marshes (% of maximum services provided)
1	31.7%	22.6%
2	56.2%	40.1%
3	73.9%	52.7%
4	85.3%	60.8%
5	94.8%	67.6%
6	95.5%	68.1%
7	96.2%	68.6%
8	96.9%	69.1%
9	97.6%	69.6%
10	98.2%	70.0%
11	98.6%	70.3%
12	99.0%	70.6%
13	99.4%	70.9%
14	99.7%	71.1%
15	100.0%	71.3%

The Trustees conducted a literature review to assess the function of created marshes and the time it takes created marshes to reach maximum function. Based on the review, the Trustees determined the average created marsh function for each year after creation. Marshes created to replace natural marshes (other marsh services) will provide, at maturity, approximately 70 percent of the services provided by other marshes that were lost. Maturity was determined to occur after 15 years.[11] The maturity path of marshes created to replace Dredge Island marshes is the same path as the maturity path previously described except the created marshes percent function in each year is relative to 100 percent. At maturity, marsh constructed to replace the Dredge Island marshes will provide the same level of services as the Dredge Island Marshes.[12] With an appropriately engineered design that includes some breakwater protection, the service life of the created marshes is estimated to be 50 years under normal coastal conditions.

Finally, using the described inputs, the HEA model was used to determine the scale of the oyster reef and marsh restoration projects. For created oyster reefs, the HEA model indicates that 9.34 acres of oyster reef are needed to offset the losses described above. As for marsh restoration, 29.32 acres of created marsh are required to offset the losses associated with injured open-water and other marsh habitat. The model indicates 31.94 acres of created marsh are necessary to offset the losses associated with Dredge Island marshes. The amount of marsh to be created totals 61.3 acres.

6.0 EXPECTED INTERIM AND RESPONSE LOSSES AND RESTORATION REQUIREMENTS

Interim losses at the Site are not eliminated with response actions. The response actions return resources and services to baseline more quickly, but interim losses continue after 1999. Not only are there interim losses beyond 1999, there are expected losses for a response action that is being planned. This section identifies

[11] See the memorandum Created Marsh Function and Maturity for the Trustees development of created marsh function and maturity.

[12] The original Dredge Island marshes were "man made" or were formed as a result of human activities. The restoration marshes are expected to provide the same level of services as the original Dredge Island marshes since they too will be the product of human creation.

expected interim and response losses, in addition to the extra restoration that would be necessary to offset the expected losses.

Table 6 addresses the post-1999 interim losses. The numbers in the table are the remaining acres injured by habitat type as calculated in the RWC analyses. The acres represent both the direct (benthic injury) and indirect (fish injury) exposure areas. The benthic and fish resources are expected to return to their baseline levels in 2014, fifteen years after the response actions that occurred in 1999. [13] Between 2000 and 2014, the resources and services are estimated to improve linearly.

Table 6. Post-1999 Habitat Loss Components

Habitat Loss Component	Fringe Marsh/Mudflat Dredge Island	Fringe Marsh/Mudflat Other Marsh	Open-bay Bottom	Oyster Reef
Benthic and Fish Injury Number of acres injured Post-response:				
10 % Loss of Service	0.60	7.77	315.32	2.86
20 % Loss of Service	0.51	3.08	45.11	0.84
25 % Loss of Service	0.06	1.77	68.94	17.69
30 % Loss of Service	0.00	0.00	1.53	0.00
35 % Loss of Service	0.56	2.61	40.32	0.00
40 % Loss of Service	0.00	0.00	0.00	0.00
50 % Loss of Service	0.00	0.00	2.11	3.62

Table 7 summarizes the expected interim losses from 2000 through 2014 by habitat type.

[13] Based on a study of mercury surficial sediment concentration half lifes (Alcoa, 1998), all concentrations in surficial sediments are estimated to be below injury threshold levels ten years after the 1999 response. To account for predicted hurricane events (Alcoa 1998b) and the mixing of sediments which may increase surficial mercury concentrations, another five years were added to the time until resource recovery to baseline.

Table 7. Post-1999 Interim Losses

Habitats	Discounted Acre-years	Discounted Acre-Years After Exchange
Open-bay bottom	441.13	--
Other Marshes	16.52	104.75
Dredge Island Marshes	2.24	2.24
Oyster Reefs	40.18	40.18

There are also expected losses from a planned response action. In 2001, approximately 0.86 acres of fringe marsh will be covered and permanently lost. The flow of losses associated with that action totals 27.02 discounted acre-years. Unless the Environmental Protection Agency's record of decision, which outlines the preferred response action, changes from what is currently planned, these losses and the losses identified in Table 7 are the Trustees' best estimates of future losses at the Site.

Based on the restoration parameters described in Section 5, the Trustees calculated the additional acreage for the preferred restoration projects that will be needed to offset the post-1999 losses. An additional 1.53 acres of oyster reef must be created to offset the oyster reef interim losses. Another 6.28 and 0.096 acres of salt marsh are needed to offset the other marsh (and open-bay bottom) and Dredge Island habitat interim losses, respectively. Finally, to compensate for the expected response action, an extra 1.62 acres of marsh is required. In total, to offset all the habitat losses, i.e., pre and post-1999, the created reef should be 10.9 acres and the created marsh should be 69.3 acres. Table 8 summarizes the restoration requirements for the different habitat injuries in the different time periods.

Table 8. Restoration Requirements for Past and Expected Habitat Losses

	Number of Restoration Acres			
Habitat Injury[a] to:	1981 - 1999	Post-1999 Interim Losses	Post-1999 Response Losses	Total
Open Bay-Bottom and Other Marsh[b]	29.32	.096	1.62	31.04
Dredge Island Marsh[b]	31.94	6.28	--	38.22
Oyster Reef[c]	9.34	1.53	--	10.9

[a]Includes consideration of injury to fish from contaminated prey in these habitats.
[b]All restoration acres are in marsh creation.
[c]All restoration acres are in oyster reef creation.

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