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TECHNICAL MEMORANDUM
REASONABLE WORSE CASE ASSESSMENT:
DIRECT INJURY TO BENTHOS

ALCOA, LAVACA BAY SUPERFUND SITE

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PHASE 1: Injury through December 31, 1999

1.0 INTRODUCTION

This technical memorandum summarizes an assessment of interim loss of benthos services due to exposure to chemicals released from the Alcoa site. Benthos is a broad term that describes the aquatic invertebrate organisms living on or in the sediments in an aquatic ecosystem. Benthic organisms are found in and on bottom and oyster reef habitats in Lavaca Bay. Benthic organisms often feed on organic detritus that is mixed with the top few centimeters of sediment or is trapped in the silty fines that cover the sediment surface. Most other trophic niches (herbivores, predators, scavengers, etc.) are also represented in the benthic community. Benthic communities utilize sediment-bound nutrients and organic substances that are not generally available to epiphytic or pelagic organisms and therefore provide an important part of the overall food web within an estuary. The types of services that are provided by benthos that can be affected include the following:

- **Food and Production:** Benthic populations include both meiofauna and macrofauna that are classified into groups based on their relationship with the sediments. These relationships include either burrowing (infaunal), deposit feeders or epibenthic species. Benthic organisms are generally fast growing, adaptable and serve as an important basal component of the baywide food web. Infaunal and epibenthic organisms utilize nutritional resources that are not available to larger organisms (i.e. bacteria, algae, and partially decomposed organic detritus). Benthic organisms serve as an important source of food for fish, crabs and shrimp that use the bays. By providing the nutritional base for the developing stages of many finfish and shellfish, benthos production affects all trophic levels in the bay system.

  Many species of small deposit feeding annelid worms, mollusks and amphipods live in surficial sediments without burrows. The worm populations feed on organic detritus that includes bacteria and other microscopic decomposers. Populations of polychaete worms grow rapidly when bay waters warm and serve as one of the primary sources of food for juvenile shrimp and crabs. Juvenile shrimp and crabs enter the estuary and feed on worms, dramatically reducing polychaete worm populations. The shrimp and crabs are prey items for spotted seatrout, sand trout, red drum, southern flounder, gafftopsail catfish, lizardfish, birds and other organisms.

  Burrowing benthos include lug worms, parchment worms, tube worms, bivalves, amphipods, shrimp eels, worm eels and mudshrimp. In permanently submerged habitats (open water) finfish predators like spot, pinfish, and Atlantic croaker feed on the burrowing benthos. These finfish are prey items for larger predators like spotted seatrout, red drum, black drum and southern flounder. In shallow water or on exposed mud flats, wading birds (i.e., willets, long-billed dowitchers, long-billed curlews, and black-necked stilts) feed on the burrowing worms and amphipods.

Epibenthic species include animals such as juvenile blue crabs, mud crabs, stone crabs, penaeid shrimp, mysids, copepods, and non-burrowing polychaete worms. Epibenthic species tend to be more mobile and feed on epiphytic algae and surficial detritus. The small crabs use their chelipeds to crush and eat oyster spat, barnacles, limpets, and mussels that are generally attached to hard substrate. The adult shrimp, mysids, and copepods feed primarily on algae and surficial detritus.

- **Conditioning & Improvement of Habitat:** The benthic ecosystem includes a variety of habitat types in and on sand, mud, and shell bay bottoms. Many infaunal species live in burrows and filter their food from water that is circulated through the burrow. Sediment excavated from the burrows is deposited on the sediment surface at the burrow opening. Water circulated through the burrows helps to oxygenate deeper sediments allowing other organisms and aerobic bacteria to inhabit deeper sediment layers. In addition, the excavation of sediment re-introduces nutrient-rich deep sediment to the surface where it can be utilized by grazers and deposit feeders.

- **Decomposition and Nutrient Cycling:** A complex community of bacteria, meiofauna and macrofauna exist within the sediments that contributes to the reduction and decomposition of organic matter and debris. The process of decomposition is important for the cycling of carbon and nutrients back through the aquatic food web.

To summarize, the benthic community provides important ecological services primarily related to food production, decomposition and energy cycling. These services are related to the productivity of the system and therefore affect nearly all organisms within an estuarine system. Potential adverse impact on benthic populations has the potential to impact biota in all trophic levels of the bay system by overall reducing the productivity of the system.

2.0 DATA

The potential for interim loss from exposure to Alcoa Point Comfort Operation (PCO) contaminants was determined both directly and indirectly through studies conducted to assess injury to benthic habitat within Lavaca Bay. Analytical chemistry has been collected during the remedial investigation on the nature and extent of polylchlorinated biphenyls (PCB) mercury (Hg), and polynuclear aromatic hydrocarbons (PAH) contamination in Lavaca Bay sediments. The scientific literature on the potential effects of the contaminants was examined and compared to site analytical chemistry data. Laboratory bioassays and benthic macroinvertebrate studies were conducted to determine whether any relationship exists between mercury concentrations in surficial sediments and observed effects on survival, growth and reproduction endpoints for benthic populations within Lavaca Bay. Benthic surveys /bioassays were not conducted in areas with PAH contamination in sediment, thus, any conclusion of potential injury for PAHs was based on a comparison of the Site data to results of studies conducted at other locations with similar contaminants. Low levels of PCB contamination were irregularly distributed in bay sediment. Sediment PCB concentrations were compared to ecological effects benchmarks to determine the potential for injury to benthos. The assessment process used supporting information from the remedial investigation of Lavaca Bay including the following information:

1. Analytical data collected in the remedial investigation that documents the nature and extent of contamination in sediments in or near existing benthic habitats.
2. Results from the sediment quality triad study (SQT) conducted to assess a relationship between the concentration of mercury in sediments, the toxicity as measured in standard laboratory bioassessment tests and observed changes in benthic macroinvertebrate populations in Lavaca Bay sediments.
3. Information from the scientific literature that documents the adverse effects on growth, survival and reproduction of PAH and PCB detected in sediments to benthic populations.

Specific information used to quantify potential injury in this analysis includes:

- Sediment samples for the Remedial Investigation results from the Phase 2A (B2b), 2B (B2a), Mercury Reconnaissance Study (B2c), and well as supplemental data collected under Workplan Refinement Notices B2b-RN06 through B2b-RN09 that present the nature and extent of contamination in Lavaca Bay;
- Supplemental PAH sampling conducted in the open water areas of Lavaca Bay to the southwest of Dredge Island;
- Sediment sampling results for oyster reefs, fringe marshes and open water areas from the Prey Item Study (B2e);
- Sediment, bioassay and benthic macroinvertebrate results from Sediment Quality Triad (SQT) study (B2g);
- Sediment sample results from the Radiochemistry program (B3a);
- Habitat Mapping that identifies the location of specific habitats important for benthos, including open water areas, fringe marsh/inter-tidal zones, and oyster reefs.
- A site specific delineation of oyster reefs in the area of potential injury (Hg > ER-M or hPAH > ER-L)
- Literature-derived benchmark concentrations on the toxicity of chemicals to sediment benthos.

3.0 ASSESSMENT PROCEDURES

Potential injuries from interim losses were assessed following a reasonable worst-case (RWC) approach using primarily existing data sources from the remedial investigation and information from the scientific literature. Interim loss estimates of injury to benthos were developed based on an evaluation of direct toxicity to benthic organisms from chemicals of concern, principally PAHs, mercury and PCBs.

Injury estimates for PCBs, PAHs and mercury were quantified using a reasonable worse-case approach based on the following procedures:

- For each chemical, contamination benchmarks were identified that are known or suspected injury thresholds for benthic resources. Benchmark concentrations were derived primarily from a number of different literature-based sources for PCBs, mercury and PAHs. The benchmarks were then used, in a weight of evidence fashion, to identify concentration ranges that provide an increasing severity of injury associated with the chemicals present in the sediment.

- Habitats where sediment concentrations exceeded benchmark concentration ranges were mapped. The areal extent of co-occurring contaminants (mercury and PAHs) was also mapped for each habitat type. The specific sediment data used was from analytical data collected in support of the Remedial Investigation as well as focused PAH sampling in support of NRDA. Separate estimates were prepared for oyster reef habitats, fringe marshes (with contiguous mudflats), and open water areas;
- Potential sediment effects from mercury were evaluated directly in an open water area using a Sediment Quality Triad (SQT) study. The RWC analysis relied primarily on literature-based criteria because it was recognized that the Sediment Quality Triad study did not evaluate all potential endpoints for benthos. The selection of the appropriate benchmarks used in the analysis, and the percent loss of services for the injury associated with these concentrations, was influenced by the findings of the Sediment Quality Triad study.
- For each concentration range, service losses were estimated that intended to approximate the reduction in ecological services provided by the benthic community in each habitat type. Percent loss of service estimates were derived based on weight-of-evidence using results of the mercury SQT, available scientific literature, and knowledge of Texas estuarine ecosystems.

3.1 SELECTION OF INJURY THRESHOLD CONCENTRATIONS

The Effects Range-Low (ER-L) is calculated as the lower 10th percentile concentration of the Biological Effects Database (available sediment toxicity data) that has been screened for only those samples which were identified as toxic by the original investigators; it is not an LC_{10}. The ER-L is at the low end of a range of levels at which effects were observed in the studies examined. It represents the value at which toxicity may begin to be observed in sensitive species. The Effects Range-Median (ER-M) is simply the median concentration of just samples labled as toxic by the original investigators; it is not an LC_{50}.

Apparent Effects Thresholds (AETs) were developed for use in Puget Sound to relate chemical concentrations in sediments to at least one of five biological indicators of injury (i.e., four sediment bioassays or diminished benthic infaunal abundance.) AETs are essentially equivalent to the concentration observed in the highest non-toxic sample. As such, AETs represent the concentration above which adverse biological impacts would always be expected in that biological indicator due to exposure to that contaminant alone.

3.1.1 Polychlorinated biphenyls (PCBs)

A qualitative risk evaluation was presented for PCBs detected in sediment in the Technical Memorandum: Bay System Phase 2B Data Assessment report. The purpose was to determine whether PCBs would contribute significantly to potential site risk and whether PCBs would be contaminants of concern for further evaluation. An overview of the results of that qualitative assessment is provided below.

The qualitative analysis of potential risks from PCBs concluded that there is a low risk associated with PCB contamination in sediments but this low risk did not warrant further evaluation or quantification. This conclusion was based on a comparison of analytical data to sediment benchmark concentrations the results of which include:

- 15 samples exceed the NOAA effects range low [ER-L].at 0.0227 mg/Kg.
- 3 samples exceeded the NOAA effects range medium [ER-M] at 0.18 mg/Kg;
- No samples exceeded apparent effects threshold (AETs) developed for PCBs in Puget Sound.

The analytical results and these comparisons are depicted in Figure 1.

The potential for PCBs to pose significant risk was considered “low” based on a weight-of-evidence using the following:

(1) No sediment samples had total PCB concentrations that exceeded an AET value developed for Puget Sound (1 ppm for benthos, 1.1 ppm for oyster larvae, and 3.1 ppm for amphipod).

(2) Only a limited number of samples, in localized areas exceeded the NOAA ER-M value. The areal extent of contamination exceeding the ER-M was restricted and co-located with elevated PAHs and mercury. and

(3) There are limitations and uncertainties in the data from studies used to derive the sediment benchmarks. These uncertainties are their effect on deriving sediment benchmarks is discussed below.

The reliability and accuracy of the PCB ER-L and ER-M values is considered low (Long et al. 1995; MacDonald 1994). This “low” rating is based on limitations in the studies used in the development these benchmarks that suggest the values are uncertain and may be conservative. The incidence of effects associated with PCB concentrations greater than the ER-M value of 180 ppb was only 51 percent, compared with a greater than 80 percent incidence of effects for other organic compounds when the ER-M value is exceeded (Long et al. 1995). This indicates that increasing concentrations of PCBs at these low concentrations were not necessarily correlated with an increased incidence of toxic effects. This low correlation may be related to bioavailability, the presence of different combinations of toxic PCB congeners, and/or for some studies, the presence of co-occurring chemicals may have resulted in PCBs actually contributing a relatively minor role in causing biological effects at these low concentrations. Often observed effects, such as mortality, may be more a function of co-occurring contaminants within a sample (Long and Morgan 1990). However, in deriving these values, the assumption is made that the chemicals, for which a benchmark is being quantified, is responsible for the measured effects. Thus, the presence of other chemicals not quantified or accounted for may be significantly influencing the biological outcome of the test endpoints for the studies in question.

To summarize, although PCBs were detected in sediment and may slightly contribute to benthos injury, the trustees decided not to explicitly quantify that potential injury. PCBs that were detected at low levels were co-located with areas with elevated concentrations of mercury and PAHs. Due to the reasonable worst case approach that was employed, the small potential injury associated with PCBs will be compensated by restoration provided for injuries related to mercury and PAHs. Thus, no further evaluation of potential injuries due to PCB contamination was conducted.

3.1.2 Mercury

Sediment benchmarks from the scientific literature reviewed and considered for mercury include:

- Effects Range-Low (ER-L) of 0.15 ppm from Long et al. (1995);
- Effects Range-Median (ER-M) of 0.71 ppm from Long et al. (1995);
- Puget Sound amphipod (and overall benthos) AET of 2.1 ppm (State of Washington, 1995);
- Puget Sound oyster larvae AET of 0.59 ppm (State of Washington, 1995);

Sediment Quality Triad study found no relationship along a sediment mercury gradient of concentrations (from 0.3 ppm to 4.6 ppm) from endpoints measured in bioassays such as reduction in growth and survival of *Neanthes spp.*, or survival in *Leptocheirus spp*. Also, no relationship was detected between sediment concentrations and indices related to benthic macroinvertebrate community abundance and richness. However, the benchmark concentrations used for the Reasonable Worse Case analysis were conservatively chosen from a review of the open literature to account for potential injury associated with endpoints not studied in SQT. Also, for purposes of RWC, a conservative benchmark was used because the focus for quantification of injury was based on existing (rather than historical) mercury and PAH distributions in sediment, determined from Phase 2A and 2B Remedial Investigation studies.

Significant reduction in activity behavior for *Pontoporeia affinis* at 2.15 to 3.35 ppm (no reduction in activity behavior at 0.65 to 1.15 ppm) (Long and Morgan, 1990).

SQT results suggest that the ER-L value of 0.15 ppm is significantly below potential levels where injury would expect to occur, and, therefore, it is not a reasonable benchmark value to represent potential injury to the benthic community within Lavaca Bay. Benchmark criteria and concentrations ranges selected for estimating injury from mercury include:

- For estimating injury to benthos in open water, deep channel open water and shallow channel open water; and intertidal mudflats/fringe marsh habitats, the concentration ranges for mercury are:
    - ♦ No injury = sediment concentrations < ER-M (0.71 ppm)
    - ♦ Possible injury = ER-M < sediment concentrations < benthic AET (2.1 ppm);
    - ♦ Probable injury = sediment concentrations > benthic AET.
- For oyster reefs, the proposed benchmark concentration is oyster larvae AET and the concentration ranges are:
    - ♦ No injury = sediment concentrations < oyster larvae AET (0.59 ppm);
    - ♦ Probable injury = sediment concentrations > oyster larvae AET.

Both the ER-M of 0.71 ppm and benthic AET of 2.1 ppm are well within the range of mercury concentrations studied in SQT where toxic effects were not detected. However, it is recognized that the SQT study may not have addressed all endpoints associated with potential service losses related to benthic exposure to mercury. Thus, following the RWC principle, injury thresholds were established at the ER-M and AET levels.

Figure 2 depicts the locations within Lavaca Bay where sediment concentrations exceed the ER-M (0.71 ppm) and benthic AET (2.1 ppm) values. Because few locations exceed the benthic AET for mercury, Figure 3 provides a close-up of the specific locations near the Alcoa facility where mercury concentrations in sediment exceed the benthic AET value. Figures 2 and 3 also present the total acres of intertidal mudflat, fringe marsh and open water habitats with sediment concentrations that exceed these benchmarks. Note, the "low marsh" habitat from the Habitat Mapping study was used to determine acres of fringe marsh habitat. Figure 4 depicts the locations of oyster reef habitat within Lavaca Bay with sediment concentrations exceeding the oyster larvae AET (0.59 ppm) for mercury. The acres of bay sediments exceeding mercury benchmark concentrations include:

- Open water habitats:
  - ♦ sediment > ER-M: 247.80 acres
  - ♦ sediment > Benthic AET: 18.93 acres
- Fringe marsh habitats (with contiguous mud flats):
  - ♦ sediment > ER-M: 13.75 acres
  - ♦ sediment > Benthic AET: 0.10 acres
- Oyster Reefs:
  - ♦ sediment > Oyster Larvae AET: 12.40 acres

3.1.3 PAHs

No site-specific benthic-effect studies were performed on sediments from locations with significant PAH contamination. Therefore, the RWC analysis for PAHs did not have the benefit of site-specific studies to quantify potential injury or to evaluate the appropriate literature-based benchmark criteria. The majority of PAH sediment toxicity tests summarized in the literature were based on contaminated sites with complex mixtures of PAHs, namely from coal-tar-based or creosote-based sources of PAHs. PAH contamination in the bay originating from the WITCO PSA is generally similar to that from coal tar type sources. The open literature was reviewed to identify benchmark criteria based on grouping PAH compounds. Groups considered for this analysis include total PAHs, total low-molecular weight (LPAHs), and total high-molecular weight PAHs (HPAHs), consistent with Long et al (1995). Relevant sediment benchmarks were reviewed and considered for evaluating potential Reasonable Worse Case injury to benthos from PAHs include:

- Effects Range-Low (ERL) of 4.022 ppm for total PAHs from Long et al. (1995);
- Effects Range-Median (ERM) of 44.792 ppm for total PAHs from Long et al. (1995);
- Effects Range-Median (ERM) of 9.6 ppm for HPAHs from Long et al. (1995);
- 1988 Puget Sound benthic community AET of:
  - ♦ 13 ppm for total LPAHs
  - ♦ 69 ppm for total HPAHs;
- 1988 Puget Sound amphipod AET of:
  - ♦ 24 ppm for total LPAHs;
  - ♦ 69 ppm for total HPAHs;
- 1988 Puget Sound oyster larvae AET of:
  - ♦ 5.2 ppm for total LPAHs;
  - ♦ 17 ppm for total HPAHs;

- San Francisco Bay:
  - 0.87 ppm based on bivalve larvae AET for total PAHs;
  - 15 ppm for amphipod bioassay AET for total PAHs;
- Mississippi Sound:
  - >205 ppm based on amphipod bioassay AET for total PAHs;
  - 99.4 ppm based on mysid bioassay AET for total PAHs;

Literature-based benchmark concentrations for PAHs suggest effect concentrations are highly variable, encompassing 2 or more orders-of-magnitude. This uncertainty relates to the variation of the source type of PAHs, sediment type, and the physical environmental conditions of the water bodies studied, and/or a range of different organisms tested. The majority of literature studies were either from sites having different sources types of PAHs, co-occurring contaminants (non-PAH), or different environmental settings which can effect the bioavailability of PAHs and their toxicity. Therefore, given the uncertainty relating to source type, toxicity and bioavailability, benchmark criteria and concentration ranges were conservatively chosen for PAHs that include:

- For open water, deep channel open water and shallow channel open water; and intertidal mudflats/fringe marsh areas:
  - No injury = sediment concentrations < ER-L (total PAHs > 4.022 ppm);
  - Possible injury = ER-L < sediment concentrations < ER-M HMW PAHs (total PAHs > 4.022 ppm & HPAH < 9.6 ppm) and
  - Probable injury = sediment concentrations > ER-M (HMW PAHs $\geq$ 9.6 ppm).
- For oyster reefs:
  - No injury = sediment concentrations < oyster larvae AET (LPAHs < 5.2 ppm, **and** HPAHs < 17 ppm).
  - Probable injury = sediment concentrations >oyster larvae AET (LPAHs > 5.2 ppm, **or** HPAHs > 17 ppm).

Figure 5 depicts the locations and acreage within Lavaca Bay where sediment concentrations of total PAHs exceed the ER-L (4.022 ppm) and HPAHs ER-M (9.6 ppm) values. Figure 6 depicts the locations of oyster reefs within Lavaca Bay exceeding the oyster larvae AET (LPAHs > 5.2 ppm and/or HPAHs > 17 ppm). The acres of bay sediments exceeding benchmark concentrations, by habitat type, include:

- Open water habitats:
  - total PAHs in sediment > ER-L: 171.84 acres
  - high PAHs in sediment > ER-M: 105.73 acres
- Fringe marsh habitats (with adjacent mudflats):
  - total PAHs in sediment > ER-L: 5.02 acres
  - high PAHs in sediment > ER-M: 14.73 acres
- Oyster Reefs:
  - PAHs in sediment > Oyster Larvae AET: 10.45 acres

3.1.4 Co-occurring Mercury and PAHs

For estimating potential injury, effects that may result from elevated concentrations of co-occurring mercury and PAH concentrations were considered. For RWC purposes, an assessment was made to determine the locations where both mercury and PAHs concurrently exceed their respective benchmark concentrations. Because a range of potential effects concentrations were considered for mercury and total PAHs, when considered simultaneously, there are a series of combinations within the various habitats that must be considered independently. For open water, intertidal mudflats and fringe marsh habitats, the possible combinations of co-occurring chemicals concentrations considered include:

Mercury[a]		PAHs[b]
• Mercury < ER-M	&	tPAH ER-L<PAHs<hPAH ER-M
• Mercury < ER-M	&	hPAHs > ER-M
• ER-M < Mercury <AET	&	tPAHs < ER-L
• ER-M < Mercury <AET	&	tPAH ER-L<PAHs<hPAH ER-M
• ER-M < Mercury <AET	&	PAHs > hPAH ER-M
• Mercury > AET	&	tPAHs < ER-L
• Mercury > AET	&	tPAH ER-L<PAHs<hPAH ER-M
• Mercury > AET	&	hPAHs > ER-M

[a]Mercury ER-M = 0.7 ppm, AET = 2.1 ppm.

[b]PAH ER-L =4.022 ppm; hPAH ER-M = 9.6 ppm.

and for oyster reefs:

Mercury[c]		PAHs[d]
• Mercury < AET	&	PAHs > AET
• Mercury > AET	&	PAHs < AET
• Mercury > AET	&	PAHs > AET

[c]mercury oyster larvae AET = 0.59 ppm

[d]PAH oyster larvae AET is LPAHs = 5.2 ppm and/or HPAHs = 17 ppm.

Figure 7 depicts locations and acres of bay sediments associated with co-occurring PAHs and mercury in open water and intertidal mudflats/fringe marsh habitats. Note, the locations where mercury and PAHs co-occur in oyster reefs was inferred from Figure 4 and 6. The estimated acres for open water, intertidal mudflats and fringe marshes that are effected include:

Co-occurring Chemicals		Open Water	Fringe Marshes
Hg < ER-M	& ERL<PAHs<ERM	100.64	3.90
Hg < ER-M	& hPAHs > ERM	38.62	12.64
ER-M < Hg <AET	& tPAHs < ERL	129.91	0
ER-M < Hg <AET	& ERL<PAHs<ERM	23.46	1.42
ER-M < Hg <AET	& hPAHs > ERM	38.47	2.74
Hg > AET	& tPAHs < ERL	6.35	0
Hg > AET	& ERL<PAHs<ERM	0.0	0
Hg > AET	& hPAHs > ERM	2.3	0

For oyster reefs, the estimated acres affected include:

Co-occurring Chemicals			Oyster reefs
Mercury < AET	&	PAHs > AET	3.70
Mercury > AET	&	PAHs < AET	12.08
Mercury > AET	&	PAHs > AET	6.75

3.2 INJURY ESTIMATES IN SUPPORT OF HABITAT EQUIVALENCY ANALYSIS

For each area of habitat that is potentially injured, an estimate is made of the extent of injury through an assessment of real and potential ecological service losses. Habitat Equivalency Analysis (HEA) is an accounting procedure used for scaling restoration options. However, a HEA requires some knowledge or estimates of the service losses in order to evaluate the adequacy and appropriateness of proposed restoration options. For each habitat type, the amount of benthic community injury or service losses will vary according to the nature and extent of sediment contamination and remedial options implemented. This objective is accomplished by knowing the area of each habitat potentially injured by remedial activities or chemical contamination (presented in Section 4.0) and, for each area, determining the severity of injury. The severity of injury is used to develop estimates percent loss of benthos services that results from elevated concentrations of site-related chemicals.

3.2.1 Percent Loss of Services

An estimate of the percent loss of services was made for areas where mercury or PAH concentrations exceeded selected benchmark concentrations. Additionally, for all areas that are covered or dredged during remedial/removal activities through December 1999, are assumed to have been 100% injured. The predicted benthos service losses in each habitat type resulting from mercury or PAH concentrations in sediment was determined based on the mercury SQT, available scientific literature, and professional knowledge of Texas estuarine ecosystems. This estimate will be used as an input to the Habitat Equivalency Analysis (HEA) model.

Assumptions made regarding assigning an estimate to the percent loss of services were:

1. 100% service losses relates only to locations where chemical concentrations or remedial activities are sufficient to eliminate benthic populations and where no ecological services (decomposition, food, energy flow and cycling) are provided by benthos;
2. Prey item sampling for Mercury Reconnaissance (B2c), Sediment Quality Triad (B2g) and the Prey Item Study (B2e) identified and collected benthic macroinvertebrates in nearly all habitats at all locations. This implies that, where contamination exists, injury to services provided by benthos is <100%.
3. The ecological service associated with benthos from direct toxicity relate principally to a reduction in services associated with decomposition, energy flow and cycling. The service flows from a particular habitat type are much broader than the specific services provided by benthos. Thus, for overall service flows from a particular habitat type, of which benthos provides only a portion, service losses from benthos are assumed to be <100%;
4. The ecological services provided by all resources within a habitat type at a particular location are assumed to have combined service flows totaling 100%.
5. Estimates of percent loss of services for mercury and PAHs were based on a weight-of-evidence approach using results of available studies reported in the scientific literature, results of SQT, and knowledge of Texas estuarine ecosystems. For mercury, the percent loss of services and weight-of-evidence used were as follows:
   - A 10 % loss of services was assumed for sediment concentrations >ER-M and < benthic AET, in open water, intertidal mudflats and fringe marsh habitats. The SQT found no observed decrease in survival for *Leptocheirus* spp*.,* no apparent reduced growth for *Neanthes* spp, and no observed change in the macroinvertebrate assemblages. The SQT was conducted over a mercury concentration range from 0.3 to 4.6 ppm, which encompasses the range of both the ER-M and AET. However, sub-lethal toxicological endpoints such as behavioral changes, loss of reproductive capacity, etc., were not endpoints studied in SQT.
   - No reduction in activity behavior of *P. affinis* was noted in spiked sediment bioassays at concentrations of 0.65 to 1.15 ppm, as reported by Magnuson et al. (1976), as cited by Long and Morgan (1990).
   - A 25% loss of services from was assumed for concentrations > benthic AET. Significant decrease in activity behavior of *P. affinis* was noted at concentrations exceeding 2.15 to 3.35 ppm from sediment bioassays, as reported by Magnuson et al. (1976), as cited by Long and Morgan (1990).
   - A 25% loss of services was assumed for mercury concentrations above the oyster larvae AET on oyster reefs based on best professional judgment.

For PAHs, the percent loss of services and weight-of-evidence used were as follows:

- In open water and intertidal mudflats/fringe marshes, a 10% percent loss of services was assumed for hPAH concentrations >ER-L and hPAH concentration < hPAH ER-M. This severity was assumed because:
  - ♦ The NOAA ER-L is based on sites with co-occurring chemicals. Additivity between mercury and PAHs was made separately in this analysis.
  - ♦ The NOAA ER-L is lower than reported apparent effects thresholds (AETs) for PAHs, including the benthic AET (Puget Sound: LPAHs > 13 ppm and HPAHs > 69 ppm), amphipod AETs (Puget Sound: LPAHs > 24 ppm and HPAHs > 69ppm; San Francisco Bay: total PAHs >15 ppm; Mississippi Sound total PAHs > 205 ppm) and mysid AETs (Mississippi Sound total PAHs > 99.4 ppm).
- A 25% percent loss of services was assumed for concentrations > hPAH ER-M. PAHs detected in Lavaca Bay sediments are predominately the higher molecular weight PAHs. The NOAA hPAH ER-M (9.6 ppm) is lower than reported apparent effects thresholds (AETs) for PAHs, including the benthic AET (Puget Sound: HPAHs > 69 ppm), amphipod AETs (HPAHs > 69ppm; Mississippi Sound total PAHs > 205 ppm) and mysid AETs (Mississippi Sound total PAHs > 99.4 ppm).
- A 25% loss of services was assumed for total LPAHs (AET: 5.2 ppm) or total HPAH (AET: 17 ppm) concentrations above the oyster larvae AETs for sediments on oyster reefs.

For co-occurring PAHs and mercury:

- Estimates of percent loss of services for the individual constituents were assumed to be additive.

Based on available site-specific data, a greater uncertainty exists for estimating direct injury from PAHs since no site-specific studies were conducted to assess PAH toxicity. The SQT study was performed for mercury that excluded co-located PAH contamination. Therefore, it was assumed that injury would begin where sediment concentrations exceed the lowest reported sediment benchmark criterion (i.e., the ER-L).

For locations where there are co-occurring elevated concentrations of mercury and PAHs, estimates for the percent loss of services were assigned to areas exceeding chemical benchmark criteria assuming additivity of effects for mercury and PAHs. Additivity was assumed since no data are available to suggest either the assumption of synergistic or antagonistic toxicity between these chemicals to benthic invertebrates. Therefore, where co-occurring chemicals were present, the ranges used to assess the percent loss of services were:

Mercury in Sediments		**PAHs in Sediments**	**% Service Losses**
For open water and fringe marsh habitats:			
• Mercury < ER-M	&	ERL<PAHs<ERM	10%
• Mercury < ER-M	&	PAHs > ERM	25%
• ER-M < Mercury <AET	&	PAHs < ERL	10%
• ER-M < Mercury <AET	&	ERL<PAHs<ERM	20%
• Mercury > AET	&	PAHs < ERL	25%
• ER-M < Mercury <AET	&	PAHs > ERM	35%
• Mercury > AET	&	ERL<PAHs<ERM	35%
• Mercury > AET	&	PAHs > ERM	50%
and for oyster reef habitats:			
• Mercury < AET	&	PAHs > AET	25%
• Mercury > AET	&	PAHs < AET	25%
• Mercury > AET	&	PAHs > AET	50%

3.3 RESTORATION SCALING

The process of “scaling” a compensatory restoration action involves adjusting the size of the restoration action to ensure that the value of resource and service gains equals the value of interim losses due to the incident. Compensatory restoration generally involves enhancing resources or providing replacement resources. In this case, estuarine open water habitat injuries will be compensated with estuarine marsh or oyster reef creation projects. Oyster reef habitat injuries will be compensated through creation of new oyster reef. Because the duration of the injury differs from the life span of the replacement action, equivalency should be calculated in terms of the present discounted value of service flows lost due to resource injuries and gained due to compensatory resource enhancement or creation.

The appropriate scaling approach depends on the type of available replacement resources and services relative to those injured. The two major approaches are the service-to-service or resource-to-resource approach and the valuation approach. The former approach (hereafter referred to as service-to-service) is a simplification of the valuation approach. The service-to-service approach requires that the lost and restored resources and services be the same type and quality, and of comparable value. In other words, the injured and compensatory resources must demonstrate similar capacity and opportunity to provide services, and provide comparable payoffs in human benefits.

The Trustees intend to useHabitat Equivalency Analysis (HEA), an accounting technique that provides a logical framework to determine the appropriate scale for restoration projects and/or to evaluate restoration alternatives. In general, HEA is balances "debits" (injuries to habitat and resources) that have occurred as a result of releases of hazardous substances against compensatory "credits" (habitat restoration projects). Scaling restoration for all injury categories, including those to benthic resources, are (will be?) documented in a separate technical memorandum.

4.0 SUMMARY AND CONCLUSIONS

A reasonable worse case analysis was conducted to determine interim loss of ecological services as a result of the effects of elevated concentrations of mercury and PAHs in surficial sediments. The RWC approach utilized a weight-of-evidence approach using data collected from the remedial investigation studies and quantifying potential injury based on sediment benchmark concentrations known or suspected to pose adverse effects on benthic populations.

The result of this RWC approach provided an estimate of the total acres of each benthic habitat type (open water, fringe marsh and oyster reef) that is potentially affected by elevated concentrations of mercury, PAHs or a combination of these hazardous substances. A subsequent technical memorandum will employ HEA to scale restoration necessary to offset public losses of habitat and benthos services, as well as losses in other injury categories, through December 31, 1999. Additional analyses for remaining periods of injury will be conducted after final decisions on the remedy for the Alcoa (Lavaca Bay) NPL site are complete..

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