Habitat Equivalency Analysis

Industri-plex Operable Unit (OU)-2

Superfund Site

Woburn, Massachusetts

Prepared For:
The Natural Resource Trustees of the Industri-plex Site
U. S. Department of Interior/U. S. Fish and Wildlife Service
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Analysis: Habitat equivalency analysis (HEA) is a method designed to 1) sum the injuries to natural resources resulting from contaminant releases and 2) calculate the amount of restoration needed to compensate for the releases (Cacela et al. 2005). For the purpose of this claim, an HEA was performed for the 23 different Injured Areas comprised of various habitat types (wetland, pond/lake, riverine and floodplain soil) (Fig. 1). The focus of the HEA is the impact of arsenic and chromium contamination on the ecological services provided by these areas to trust natural resources.

Software: Visual HEA software (Copyright © 2003-2004 National Coral Reef Institute) was used to calculate the amount of acreage necessary to compensate for past (since the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980), present, and future injuries to natural resources. Based upon parameter inputs, the software models the ecological services provided at the injured area ('injury site' model) and a projected compensatory area ('compensatory action' model), and then computes the size of area needed so that the total increase in services provided by the compensatory area equals the total loss of services at the injured area (Kohler and Dodge 2006).

Model Inputs:

Standard Inputs

1) 'Discount rate per time unit': This is a percentage and incorporates the assumption that having resources in the present is more valuable than those in the future. A rate of 3% was utilized for all calculations. This rate is commonly used in natural resource damage assessments (NOAA 1999).

2) Beginning Year: Enactment of CERCLA was in December 1980, and thus, natural resource injuries begin to accrue from this time onward. However, because the Visual HEA calculations are computed in year increments, all models were created such that natural resource injuries begin to accrue at the beginning of 1981 (the first full year after the enactment of CERCLA), although contamination and environmental harm likely existed prior to this year.

3) End Year: Models were carried out to year 2040 (33 years from the anticipated date of settlement (year 2007)), based on the economic theory of perpetuity associated with the 3% discount rate.

4) Year for Onset of Remedial Activities: In modeling the services provided at contaminated areas ('injury site models'), the approximate year for onset of remedial activities was 2009. This was based upon the time guidelines proposed in the draft Remedial Design/Remedial Action Statement of Work. It is estimated the Final Remedial Action Workplan will take approximately 2 years to be developed and approved by appropriate institutions, and that remedial construction will commence immediately thereafter.

5) ‘Value injured/value restored’ Ratio: This is the ratio of the value per unit area of the injured area to the value per unit of the restored area. The default value ‘1’ was used for all models (differences in value between injured and restored areas were accounted for in individual models by adjusting service level percentages).

Variable Inputs

Other input values differed with each individual HEA model according to the specifics pertaining to each area.

1) Location Acreage: data for these inputs were obtained from Massachusetts Geographic Information System files provided by the USFWS Gulf of Maine Program.

2) Service Level Percentages: The ‘pre-injury service level’ is the level of natural resource services that would be expected at “background” levels in the vicinity of the Injured Areas. Determination of these levels was based upon a general ecological assessment of the area (e.g. surrounding land usage, natural versus created/altered habitat) and level of contamination in nearby reference areas. Any decrease in service level percentages from 1981 until present were based upon injury caused by arsenic and chromium contamination. Service level percentages in the future were predicted based upon planned remedial activities as specified in the United States Environmental Protection Agency (USEPA) 2006 Record of Decision (see below for rationale used in modeling areas with a natural attenuation remedy) and the impact of the remediation on the arsenic and chromium contamination at the Injured Areas.

Criteria or Benchmarks Used in Comparing Against Site Specific Data

Sediment – Comparison criteria used were Probable Effect Concentrations (PEC) (MacDonald et al. 2000, Ingersoll et al. 2000) (arsenic – 33 mg/kg, chromium – 111 mg/kg). Data were collected between 1982-1991 (Ebasco Services Inc. 1988, Roux Associates 1991, Roux Associates 1992, Stauffer Chemical Company 1983) and between 1995-2004 (Breault et al. 2005, Tetra Tech NUS, Inc. 2005a). Field duplicates were averaged. Samples taken at the same location but on different days (within the two different dataset intervals stated above) were averaged.

Floodplain Soil – Comparison criteria were EPA Ecological Soil Screening Levels (arsenic – 43 mg/kg, chromium III – 34 mg/kg). Data were collected between 2000 and 2004 (Tetra Tech NUS, Inc. 2005a). Field duplicates and samples taken at the same location but on different days were averaged.

Plant Tissue Data – Contaminant concentrations in site samples were compared to concentrations from reference areas. Plant tissue data were collected from emergent and submergent vegetation (cattail, common reed, burreed, pondweed, pickerelweed, arrowhead, spike rush, coontail, water chestnut, and yellow water lily) in 1995 by Foster Wheeler and in 1999 by Menzie Cura. Samples were collected only in Reaches 0 and 1.

Surface Water – Criteria used were 2005 National Recommended Water Quality Criteria: Criteria Maximum Concentration (acute) (arsenic – 340 μg/L, chromium – 570 μg/L) and Criteria Continuous Concentration (chronic) (arsenic – 150 μg/L, chromium – 74 μg/L). "Snap-shot" or grab sample data were collected in 1995 by Foster Wheeler and in 1999 by Menzie-Cura; base flow and storm flow data were collected between 2001 and 2002 by Tetra Tech NUS (Tetra Tech NUS, Inc. 2005a).

Crayfish Tissue – For arsenic, contaminant concentrations in site samples were compared to concentrations from tissue samples collected from a reference river, Shawsheen River. For chromium, criterion was 4 mg/kg dry weight for tissues (Eisler 1986). Since the chromium benchmark was in dry wet, wet weight was converted to dry wet using the formula [wet wt conc./1-(% moisture/100) = dry wt conc.]. Tissue samples were collected in 1995 by Foster Wheeler (Tetra Tech NUS, Inc. 2005a).

Fish Tissue – Comparison criteria for arsenic was 0.52 mg/kg whole body (NOED for mortality, Environmental Residue Effects Database (ERED), database ref. – URS10); criteria for chromium was 4 mg/kg dry weight for tissues (Eisler 1986). Since the chromium benchmark was in dry wet, wet weight was converted to dry wet. Since no % moisture data was available from Reach 0, average % moisture data from Reaches 1-6 were used for the dry weight conversion for concentrations above the detection limit (see Figure 1 for Aberjona River Reaches). Only comparable data (from the same species and within a similar body size range) for each tissue sample were used to calculate the average % moisture. Arsenic concentrations are given as whole body concentrations (some whole body concentrations were reconstructed from carcass, fillet, and liver tissues). Tissue samples were collected in 1995 by Foster Wheeler and in 1999 by Menzie-Cura. Fish tissue data are representative of the entire Reach, with the exception of Reach 0, where samples were collected from only HBHA Pond and HBHA wetland (Tetra Tech NUS, Inc. 2005a). Fish species that were sampled included brown bullhead, largemouth bass, pumpkinseed, white sucker, American eel, redfin pickerel and yellow perch.

Benthic Invertebrate Tissue – Comparison criteria for arsenic was 6.2 mg/kg (average concentration for NOED for mortality for invertebrate species, ERED database); criteria for chromium was 1.84 mg/kg (Effective dose for 50% mortality of the population – ED50, ERED database reference – SEQ97-14). Tissue samples were collected in 1999 by Menzie-Cura and only in Reach 0. Benthic invertebrates that were sampled included amphipods, chironomid larvae, and odonate nymphs.

<u>Tests/Studies</u>

Benthic Invertebrate Toxicity Testing and Community Impairment Assessment – Acute or chronic toxicity to benthic invertebrate (*Chironomus tentans, Hyalella azteca*) growth, survival or life cycle (effects to a measurable life cycle parameter, e.g. days to emergence, % emergence, % hatch, reproduction) as indicated by a statistical difference from reference sites or laboratory controls; Community Impairment -Evaluation of benthic invertebrate community impairment by using the Community Index. The Community Index is the summation of all community characteristics (e.g. invertebrate abundance, # taxa) that indicate impairment as compared to reference sites (highest possible value = 9). All sites with Community Index values of 3 or more have a moderate to high likelihood of impaired benthic invertebrate communities. Benthic invertebrate toxicity tests for the Northern Study Area (Reach 0) were conducted in 1999; tests for the Southern Study Area (Reaches 1-6) were conducted in 1995, 1997, and 2001 (Tetra Tech NUS, Inc. 2005a).

Monitoring/Natural Attenuation Remedy

Pursuant to the USEPA 2006 Record of Decision, the majority of water bodies, river segments, floodplain soils, and wetlands along the Aberjona River will not be actively remediated. The remedy "involves no active treatment, but monitors the status of contamination that may or may not be attenuated by natural processes or other selected groundwater and sediment remedial alternatives". In areas where there is contamination by organics, such as the deeper zones of the Halls Brook Holding Area (HBHA) Pond, degradation of the contaminants is expected (USEPA 2005). For inorganic contaminants, such as arsenic, which are not expected to degrade from naturally occurring processes, natural recovery may occur if contaminants are buried by 'cleaner' sediments and there is a decrease in contaminant resuspension and transfer to other sites (Magar and Wenning 2006, USEPA 2005). Under this process, aquatic plants and animals that exist and interact at surficial sediment layers should experience a reduction in exposure to toxic sediments, although burrowing organisms will continue to be exposed (thereby presenting a continual source of contamination to higher organisms via dietary exposure) (USEPA 2005). Additionally, these burrowing organisms will continue to mix the sediments layers, bringing buried contaminated sediments to the surface through bioturbation (Magar and Wenning 2006, Matisoff 1995). While most benthic organisms reside within the top 10-15 cm of sediment (Thoms et al. 1995), some chironomids will burrow into deeper sediment layers (Matisoff 1995, Shull and Gallagher 1998). With each new layer of 'clean' sediment, however, the service level of an impacted area is expected to increase as fewer burrowing organisms are expected to be exposed. A subjective examination of sedimentation deposition along the Aberjona River indicates low to moderate deposition rates (Rodgers 1998) and estimated sedimentation rates (from sediment core analyses) for the Mystic Lakes and Upper Forebay range from 0.482-0.658 cm/yr (Knox 1991). Therefore, the value of 0.6 cm (middle range value) was used as an estimate of the amount of sediment that will be deposited on a yearly basis for all injured areas. Using this rate, an estimated twenty-five years would be required for the accumulation of 15 cm of sediment needed for the sufficient protection of benthic invertebrates.

HEA Analysis

Areas are listed in order according to geographic location (moving in a southern direction from the Industri-plex Site), with the exception of river segments and areas affected by the remedy which are listed at the end. See Figure 1 for map locations.

The detailed calculations for each Injured Area are shown in Appendix I, attached hereto.

1. Halls Brook Holding Area (HBHA) Pond, north end (map location 1, Reach 0, area of injury = 1.55 acres): Two separate injury assessments for the HBHA Pond were done – one for the north end of the Pond and one for the south end, due to the different remedial plans for each end. The total area for the HBHA Pond is 4.66 acres. A sediment treatment zone will be constructed in the northern third of the Pond. It is an estimated 1.55 acres in size.

In examining the data previously collected in this area, contaminant concentrations were found to exceed criteria established to protect aquatic life in the sediment. Although contaminated hide piles to the north of this site were capped by 1998, currently, there is still high contamination in all media sampled (sediment, floodplain soil, and surface water) (injury for floodplain soils is addressed separately, see section on areas affected by remedy). From recent data, five out of six sediment samples exceed the probable effect concentration (PEC) for arsenic and four out of six samples exceed the PEC for chromium as established by MacDonald et al. (2000). For arsenic, the average of all samples is approximately ten times greater than the PEC. At least one surface water sample was above the arsenic acute toxicity criterion. Additional investigation of the deep surface water concentrations at this end of the pond are extremely high (maximum arsenic concentration: 5,043 μg/L) (Ford 2004). The elevated contaminant concentrations in various media support the benthic invertebrate toxicity results – data indicate that the conditions are acutely toxic to benthic invertebrates and negatively affect benthic invertebrate communities (only one organism was collected at two sample locations). Arsenic concentrations in fish tissue for one-quarter of the fish sampled are at potentially toxic concentrations. The arsenic concentrations in several liver samples (5 out of 18) are within a range associated with reduced blood measures (hemoglobin, hematocrit, mean corpuscular hemoglobin concentration) (Oladimeji et al. 1984) and one concentration (16 mg/kg wet weight) is within a range that causes morphological changes in the liver (increased volumes for necrotic and fibrous bodies, increased volume occupied by abnormal lysosomes and autophagic vacuoles) (Sorensen et al. 1985).

For the 'injury site' model construction, the pre-injury service level was estimated to be 70%, given that this pond was man-made, created recently (early 1970s), and located in a highly industrialized area. Based upon the data described in the paragraph above, the site service level in 1981 was at 45%. The service level at 2009 (at the estimated start of remedial activities) is predicted to remain at 45%, considering the continual input of contaminated groundwater. The proposed remedial plan for this location is to create a sediment treatment area, at which sediments would be periodically dredged and disposed of off-site. Therefore, the majority of potential future service this area of the pond would have provided to natural resources will be lost in perpetuity. After initiation of remedial activities, the service level is expected to decrease to 20% by year 2010 and continue at this service level into the future because of the disruptions to the ecosystem caused by dredging.

The calculated 'total discounted effective acre-years lost' is **31.200** (see Appendix I for calculations).

HBHA Pond (N. end)	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	15 – 9,830 mg/kg	1,893 mg/kg	33 mg/kg	4 (6)	13 – 1,090 mg/kg	227 mg/kg	111 mg/kg	1 (6)
Current Sediment (1995-2004)	9.9– 1,103 mg/kg	320.4 mg/kg	33 mg/kg	5 (6)	10.2 – 422.5 mg/kg	172 mg/kg	111 mg/kg	4 (6)
Floodplain Soil	Addressed separately	Addressed separately	Addressed separately	Addressed separately	Addressed separately	Addressed separately	Addressed separately	Addressed separately
Surface water	Snap-shot 481 µg/L Base Flow 3 – 10 µg/L Storm Flow 21 – 82 µg/L	Snap-shot 481 µg/L Base Flow 5 µg/L Storm Flow 47.6 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 1 acute (1) Base Flow 0 (16) Storm Flow 0 (5)	Snap-shot 14 µg/L Base Flow 1 – 3 µg/L Storm Flow 2 – 5 µg/L	Snap-shot 14 µg/L Base Flow 1 µg/L Storm Flow 3.1 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1) Base Flow 0 (16) Storm Flow 0 (5)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA	NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	0.08 – 1.6 mg/kg wet wt.	0.42 mg/kg wet wt.	0.52 mg/kg wet wt.	6 (23)	1.0 mg/kg wet wt. (det. limit)	1.0 mg/kg wet wt. (det. limit)	4.0 mg/kg dry wt.	0 (59)
Benthic Invertebrates Toxicity Test Results	Acute Growth (*C. tentans* – diff. vs lab control), Acute Survival (*C. tentans* – diff. vs lab control, *H. azteca* – diff. vs lab control, 1999), Community Impairment (1999). Results for *H. azteca* acute survival are provisional as the lab control did not meet the performance criterion. Number of sediment sites tested = 1.							
1981 % Service Level	45 %							

NA – not available

2. HBHA Pond, south end (map location 3, Reach 0, area of injury = 3.11 acres): (The total area for the HBHA Pond is 4.66 acres and it is estimated that the south end is two-thirds of the pond and is therefore 3.11 acres.)

Data collected from this area indicate that elevated concentrations of contaminants are accumulating in various media and biota. Currently this end of the pond has high concentrations of contaminants in sediment (maximum arsenic and chromium concentrations are 2,390 and 790 mg/kg, respectively), and one out of four samples from the surrounding floodplain soils exceed selected criteria for arsenic and chromium. The average arsenic concentration in plant tissue is over eighteen times that as found in reference areas. Thus, avian and mammalian herbivores foraging in this region are likely exposed to elevated arsenic concentrations via their diet. Similar to the north end of the Pond, there are high arsenic concentrations in the deep surface water (maximum: 2,839 µg/L) (Ford 2004) and acute toxicity and negative impacts to benthic invertebrate communities has been demonstrated upon exposure to sediments from this location. Benthic invertebrate tissue concentrations at one location also exceed benchmarks for arsenic and chromium. Several fish collected from this pond have arsenic concentrations that exceed benchmark criteria.

The ‘injured site’ model inputs are the same as the HBHA Pond north end from years 1981 to 2009. The remedial plan for this location is to have dredging and off-site disposal of highly contaminated sediments with restoration of disturbed areas. Due to the disturbance created by the dredging process (removal of benthic invertebrate and fish habitat, potential resuspension of contaminants and movement into surface water), the service level at this site is expected to initially decrease to 20% by year 2010. But with the removal of a portion of the contaminated sediments and future deposition of uncontaminated sediments over time, the service level is expected to be at its baseline service level (70%) twenty-five years after start of the remedial activities (year 2034).

The calculated 'total discounted effective acre-years lost' is **47.219** (see Appendix I for calculations).

HBHA Pond (S. end)	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	1,750 mg/kg	1,750 mg/kg	33 mg/kg	1 (1)		529 mg/kg	529 mg/kg	111 mg/kg	1 (1)
Current Sediment (1995-2004)	7.4 – 2,390 mg/kg	544 mg/kg	33 mg/kg	6 (7)		14.9 – 790 mg/kg	322.1 mg/kg	111 mg/kg	4 (7)
Floodplain Soil	6.1 – 250 mg/kg	69.6 mg/kg	43 mg/kg	1 (4)		8 – 46.3 mg/kg	22.1 mg/kg	34 mg/kg	1 (4)
Plant Tissue	submergent 4 – 43 mg/kg	submergent 21.8 mg/kg	submergent 1.2 mg/kg	submergent 4 (4)		submergent 1– 3 mg/kg	submergent 1.9 mg/kg	submergent 1.3 mg/kg	submergent 2 (4)
Surface water	Snap-shot 28 – 106 μg/L Base Flow 3 – 10 μg/L Storm Flow 21 – 82 μg/L	Snap-shot 46 ug/L Base Flow 5 ug/L Storm Flow 47.6 ug/L	Chronic 150 μg/L Acute 340 μg/L	Snap-shot 0 (2) Base Flow 0 (16) Storm Flow 0 (5)		Snap-shot 9 – 18 μg/L Base Flow 1 – 3 μg/L Storm Flow 2 – 5 μg/L	Snap-shot 11 μg/L Base Flow 1 μg/L Storm Flow 3.1 μg/L	Chronic 74 μg/L Acute 570 μg/L	Snap-shot 0 (2) Base Flow 0 (16) Storm Flow 0 (5)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	0.08 – 1.6 mg/kg wet wt.	0.42 mg/kg wet wt.	0.52 mg/kg wet wt.	6 (23)		1.0 mg/kg wet wt. (det. limit)	1.0 mg/kg wet wt. (det. limit)	4.0 mg/kg dry wt.	0 (59)
Benthic Invertebrate Tissue	2.3 – 26 mg/kg	14.2 mg/kg	6.2 mg/kg	1 (2)		1.2 – 16 mg/kg	8.6 mg/kg	1.8 mg/kg	1 (2)
Benthic Invertebrates Toxicity Test Results	Acute Growth (*C. tentans* – diff. vs lab control), Acute Survival (*C. tentans* – diff. vs lab control, *H. azteca* – met project-specific criterion for severe toxicity (>50% mortality), 1999), Chronic Survival (*C. tentans* – diff. vs lab control, *H. azteca* – diff. vs lab control, 1999), Life Cycle (*C. tentans* – diff. vs lab control, *H. azteca* – diff. vs lab control, 1999), Community Impairment (1999). Results for *H. azteca* acute survival are provisional as the lab control did not meet the performance criterion. Number of sediment sites tested = 2.								
1981 % Service Level	45%								

NA – not available

3. HBHA Wetland (map location 5, Reach 0, area of injury = 13.95 acres):

The extent of contamination at this wetland is considerable, with the majority of sediment samples exceeding the PEC (average arsenic and chromium concentrations are over 15 and 2.5 times their respective PEC concentrations). Nearly one-quarter of the soil samples contain chromium concentrations that exceed the selected benchmark and at least one surface water sample collected during base flow conditions exceeded the chronic criteria for arsenic and chromium concentrations. Average arsenic concentrations in emergent and submergent plants are several times higher than reference areas. Benthic invertebrate toxicity tests indicate that the sediment is chronically and acutely toxic to the growth of benthic invertebrates and negatively affects community structure. Lastly, tissue data taken from benthic invertebrates and fish indicate that these organisms are accumulating arsenic and chromium at potentially toxic concentrations.

The livers from fish (4 out of 9 samples) contained arsenic concentrations that alter blood parameters (Oladimeji et al. 1984) and two samples (2.3 and 2.5 mg/kg) are within a concentration range that has been shown to alter morphology of hepatocyte organelles (Sorensen et al. 1985).

For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this wetland is located in a highly industrialized area. At year 1981, the service level was estimated to be 55% - the assessment being based upon past and recent data. The proposed remedial plan for this location is for institutional controls only, and thus will not improve the habitat for wildlife. Therefore, the service level at 2009 (before onset of remedial activities) is predicted to be 60%, since there is an indication that sediment concentrations have decreased over time. Although this location is not expected to undergo any remedial actions except monitoring, it is assumed that the groundwater intercept and sediment treatment upstream at the HBHA Pond will reduce future contaminant inputs to this area. Over a period of approximately twenty-five years, the conditions are expected to improve via natural attenuation to a 75% service level (i.e. the baseline level for this area).

The calculated 'total discounted effective acre-years lost' is **122.349** (see Appendix I for calculations).

HBHA Wetland	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	607 – 1,380 mg/kg	1027 mg/kg	33 mg/kg	4 (4)	382 – 2,180 mg/kg	1011 mg/kg	111 mg/kg	4 (4)
Current Sediment (1995-2004)	23 – 1,220 mg/kg	497.7 mg/kg	33 mg/kg	40 (41)	20 – 641 mg/kg	284.1 mg/kg	111 mg/kg	31 (41)
Floodplain Soil	5.9 – 38.4 mg/kg	21.4 mg/kg	43 mg/kg	0 (18)	8.9 – 54.4 mg/kg	25.8 mg/kg	34 mg/kg	4 (18)
Plant Tissue	emergent 0.28 – 240 mg/kg submergent 1.7 – 28 mg/kg	emergent 34.4 mg/kg submergent 11.6 mg/kg	emergent 2.2 mg/kg submergent 1.2 mg/kg	emergent 8 (12) submergent 12 (12)	emergent 1 – 29 mg/kg submergent 1 – 3.4 mg/kg	emergent 7.3 mg/kg submergent 1.5 mg/kg	emergent 1.5 mg/kg submergent 1.3 mg/kg	emergent 6 (12) submergent 5 (12)
Surface water	Snap-shot 23 – 45 µg/L Base Flow 9 – 171 µg/L Storm Flow 6 – 116 µg/L	Snap-shot 31 µg/L Base Flow 37 µg/L Storm Flow 33 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (4) Base Flow 1 chronic (16) Storm Flow 0 (134)	Snap-shot 9 – 10 µg/L Base Flow 2 – 85 µg/L Storm Flow 1 – 12 µg/L	Snap-shot 9 µg/L Base Flow 12 µg/L Storm Flow 4 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (4) Base Flow 1 chronic (16) Storm Flow 0 (134)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA	NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	0.05 – 1.6 mg/kg wet wt.	0.63 mg/kg wet wt.	0.52 mg/kg wet wt.	7 (14)	5.05 – 72.35 mg/kg dry wt. (det. samples)	19 mg/kg dry wt. (det. samples)	4.0 mg/kg dry wt	5 (35)
Benthic Invertebrate Tissue	4.3 – 8.3 mg/kg	6.1 mg/kg	6.2 mg/kg	1 (3)	1.4 – 2.2 mg/kg	1.8 mg/kg	1.8 mg/kg	1 (3)
Benthic Invertebrates Toxicity Test Results	Acute Growth (*C. tentans* – diff. vs lab control), Chronic Growth (*H. azteca* – diff. vs lab control, 1999), Community Impairment (1999). Number of sediment sites tested = 4.							
1981 % Service Level	55%							

NA – not available

4. Wetland east of mid-HBHA (map location 4, Reach 0, area of injury = 3.57 acres):

Data available for this wetland is limited to only recent sediment samples but a contaminated groundwater plume is known to affect this wetland (See Fig. J-3 in USEPA 2006 ROD and Fig. 2-4 in Tetra Tech, NUS 2005b). Although the majority of sediment samples exceed the PEC for arsenic, the concentrations are not as high as some of the other areas within this reach (average arsenic concentration is approximately 1.5 times greater than its PEC).

The remedial plans for this wetland are for institutional controls only. Additionally, remedial plans to intercept the groundwater plumes at the HBHA Pond will not minimize the impact to this wetland.

For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this wetland is located in a highly industrialized area. At year 1981, the service level was estimated to be 65% - the assessment being based upon recent sediment data. The planned remedial action (institutional controls) will not reduce future contamination via groundwater plumes. Additionally, this area is not expected to undergo heavy sedimentation since it is not directly connected to the Aberjona River. It is anticipated that this area will only minimally improve in the future (70% service level by year 2040).

The calculated 'total discounted effective acre-years lost' is **17.776** (see Appendix I for calculations).

Wetland E. of mid-HBHA	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	13 – 88 mg/kg	52.4 mg/kg	33 mg/kg	4 (6)		26 – 182 mg/kg	70.2 mg/kg	111 mg/kg	1 (6)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	NA	NA	Chronic 150 µg/L Acute 340 µg/L	NA		NA	NA	Chronic 74 µg/L Acute 570 µg/L	NA
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	NA	NA	0.52 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	65%								

NA – not available

5. Wetland north of Wells G&H wetland (map location 7, Reach 1, area of injury = 2.15 acres):

From previous and current data, this wetland has been shown to have relatively high sediment contaminant concentrations. From the recent data, the average arsenic and chromium concentrations in sediment are approximately 6 and 3.5 times their respective PECs. Although there was no evidence for benthic invertebrate toxicity, arsenic and chromium concentrations in benthic invertebrate tissues are above criteria (for chromium, the concentrations are over 8 times the benchmark). Metal concentrations in crayfish are well above those from reference tissues (approximately 10 times greater for arsenic). Fish tissue data for Reach 1 indicate that fish are accumulating arsenic at potentially hazardous concentrations.

For the ‘injury site’ model construction, the pre-injury service level was estimated to be 75%, given that this wetland is located in a highly industrialized area. At year 1981, the service level was estimated to be 55%. The service level at year 2009 is predicted to continue at 55%, since recent data reveals no evidence of decreased contaminant concentrations. The proposed remedial plan for this location is for monitoring and institutional controls only, and thus will not improve the habitat for wildlife. However, it is assumed that the groundwater intercept and sediment treatment at the HBHA Pond will reduce future contaminant inputs to this area. Therefore, in twenty-five years (year 2034), the service level will improve via natural attenuation to 75%. No improvement in service level is expected beyond that percentage because of the industrial setting of the area.

The calculated ‘total discounted effective acre-years lost’ is **21.855** (see Appendix I for calculations).

Wetland N. of Wells G&H wetland	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	40 – 196 mg/kg	118 mg/kg	33 mg/kg	2 (2)	51 – 143 mg/kg	97 mg/kg	111 mg/kg	1 (2)
Current Sediment (1995-2004)	131 – 339 mg/kg	209 mg/kg	33 mg/kg	3 (3)	104 – 956 mg/kg	406 mg/kg	111 mg/kg	2 (3)
Floodplain Soil	38.9 – 39.6 mg/kg	39.3 mg/kg	43 mg/kg	0 (2)	40 – 42.4 mg/kg	41.2 mg/kg	34 mg/kg	2 (2)
Surface water	Snap-shot 27 μg/L	Snap-shot 27 μg/L	Chronic 150 μg/L Acute 340 μg/L	Snap-shot 0 (1)	Snap-shot 11 μg/L	Snap-shot 11 μg/L	Chronic 74 μg/L Acute 570 μg/L	Snap-shot 0 (1)
Crayfish Tissue	3.1 – 4.4 mg/kg	3.75 mg/kg	0.39 mg/kg wet wt.	2 (2)	3.29 – 4.29 mg/kg dry wt.	3.79 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (2)
Fish Tissue	0.23 – 1.4 mg/kg wet wt.	0.82 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (5)	0.94 – 3.07 mg/kg dry wt.	1.98 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (5)
Benthic Invertebrate Tissue	9.8 mg/kg	9.8 mg/kg	6.2 mg/kg	1(1)	16 mg/kg	16 mg/kg	1.8 mg/kg	1 (1)
Benthic Invertebrates Toxicity Test Results	No significant difference from lab control for toxicity parameters examined (acute and chronic growth, acute and chronic survival, life cycle, and community impairment) to *C. tentans* or *H. azteca*, 1999. Number of sediment sites tested = 1.							
1981 % Service Level	55%							

6. Wells G&H wetland (map location 9, Reach 1, area of injury = 27.27 acres):

Several sediment samples have been collected from this wetland, with the majority of sample concentrations for arsenic and chromium exceeding the PEC (maximum arsenic and chromium sediment concentrations are 4,550 and 24,600 mg/kg, respectively). Benthic invertebrate toxicity testing of sediments has demonstrated acute and chronic toxicity, impairment of life cycle progression, and community impairment. At least one surface water sample exceeded the chronic criterion for chromium. All plant tissue concentrations for arsenic and chromium exceed those from reference areas (the average chromium concentration is over twenty times that of the reference concentration). Thus, the vegetation in this area is at toxic concentrations for avian and mammalian herbivores foraging in this area (estimated No Observable Adverse Effect Level (NOAEL) for trivalent chromium in black ducks is 1.0 mg/kg/day) (Sample et al. 1996). Lastly, crayfish and fish tissues have elevated tissue concentrations of arsenic - the majority of fish collected from Reach 1 have contaminant concentrations that exceed benchmark criterion for arsenic.

For the ‘injury site’ model construction, the pre-injury service level was estimated to be 75%, given that this wetland is located in a highly industrialized area. At year 1981, the service level was estimated to be 55% - the assessment being based upon the data provided above. The service level at year 2009 (before estimated start of remedial activities) is predicted to continue at 55%, since recent data reveals no evidence of decreased contaminant concentrations (comparison of metal concentrations in sediment collected at similar sampling locations for the two different time periods indicate no general decrease in concentrations). The proposed remedial plan for this location is for dredging of near-shore sediments. The potential future service of this wetland to natural resources will likely initially decrease due to the disturbance created by the dredging process. After initiation of remedial activities, the service level was estimated to be 50% in year 2010 because of the dredging process disturbance (accounting for the actual removal of a small acreage of sediments as well as the likely impact to the majority of remaining wetland acres due to the disruption of the surface sediment ecosystem and possible resuspension of contaminants into the water column) (Lewis et al. 2001, Mager 2001). However, by the removal of a portion of the contaminated sediments, the service level of the injured wetland is expected to be at 75% by year 2034 but is not expected to increase thereafter given the industrial setting.

The calculated ‘total discounted effective acre-years lost’ is **292.269** (see Appendix I for calculations).

Wells G&H wetland	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	11 – 4,650 mg/kg	1148 mg/kg	33 mg/kg	12 (13)	24 – 1,250 mg/kg	300	111 mg/kg	6 (13)
Current Sediment (1995-2004)	4 – 4,550 mg/kg	503 mg/kg	33 mg/kg	101 (116)	7 – 24,600 mg/kg	2,120 mg/kg	111 mg/kg	103 (116)
Floodplain Soil	NA	NA	43 mg/kg	NA	NA	NA	34 mg/kg	NA
Plant Tissue	emergent 2.9 – 15.9 mg/kg	emergent 10.2 mg/kg	emergent 2.2 mg/kg	emergent 6 (6)	emergent 15 – 71.2 mg/kg	emergent 31.4 mg/kg	emergent 1.5 mg/kg	emergent 6 (6)
Surface water	Snap-shot 12 – 77 µg/L Base Flow 9 – 28 µg/L Storm Flow 12 – 23 µg/L	Snap-shot 26 µg/L Base Flow 20 µg/L Storm Flow 15 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (6) Base Flow 0 (16) Storm Flow 0 (6)	Snap-shot 2 – 146 µg/L Base Flow 2 – 14 µg/L Storm Flow 4 – 12 µg/L	Snap-shot 30 µg/L Base Flow 7 µg/L Storm Flow 7 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 1 chronic (6) Base Flow 0 (16) Storm Flow 0 (6)
Crayfish Tissue	3.1 – 4.4 mg/kg	3.75 mg/kg	0.39 mg/kg wet wt.	2 (2)	3.29 – 4.29 mg/kg dry wt.	3.79 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (2)
Fish Tissue	0.23 – 1.4 mg/kg wet wt.	0.82 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (5)	0.94 – 3.07 mg/kg dry wt.	1.98 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (5)
Benthic Invertebrates	Acute Growth [*C. tentans* – diff. vs field ref. (1995, 1997, 2001), *C. tentans* – diff. vs lab control (1995, 2001), *H. azteca* – diff. vs field ref. (1995, 2001)], Acute Survival [*C. tentans* – diff. vs field ref. (2001), *H. azteca* - diff. vs field ref. (1995)], Chronic Growth							

Wells G&H wetland	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Toxicity Test Results	[*C. tentans* – diff. field ref. (2001) and *H. azteca* – diff. vs lab control (2001)], Life Cycle [*C. tentans* – diff. vs lab control (2001), *H. azteca* – diff. vs lab control (2001)]. Community Impairment (2001). Results for 1995 *H. azteca* survival and growth are provisional as the lab control did not meet the performance criterion. Number of sediment sites tested = 16.							
1981 % Service Level	55%							

NA – not available

7. Cranberry Bog Conservation Area (CBCA) (map location 10, Reach 2N, area of injury = 20.18 acres):

Similar to the Wells G&H wetland, this wetland contains high contaminant concentrations in sediment (maximum arsenic and chromium sediment concentrations are 1,410 and 5,310 mg/kg, respectively). Benthic invertebrate toxicity tests indicate that sediments from this area cause acute and chronic toxicity and impair benthic invertebrate life cycle progression and community structure. From crayfish tissue analysis, the samples from this reach contain elevated concentrations of arsenic (as compared to reference site) and contain the highest concentrations of chromium (nearly 2 and 3 times greater than the benchmark criterion) of the entire river. Of the five fish sampled, one tissue sample exceeded the benchmark criteria for arsenic.

As with the Wells G&H wetland, the proposed remedial plan includes removing a portion of the near-shore sediments in this area. For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this wetland is located in a highly industrialized area. At year 1981, the service level was estimated to be 55% - the assessment being based upon the past and recent data provided above. The service level at year 2009 (before estimated start of remedial activities) is predicted to continue at 55% (although the average arsenic and chromium concentrations of more recent data is lower than that from a previous sampling period, there were fewer samples from which to make this comparison; comparison of metal concentrations in sediment collected at similar sampling locations for the two different time periods indicate no general decrease in concentrations). After initiation of remedial activities, the service level was estimated to be 50% in year 2010 because of the dredging process disturbance. However, by the removal of a portion of the contaminated sediments, the service level of the injured wetland is expected to be at 75% by year 2034 but would not likely increase thereafter given the industrial setting.

The calculated 'total discounted effective acre-years lost' is **216.281** (see Appendix I for calculations).

Cranberry Bog Conservation Area	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	20 – 325 mg/kg	178 mg/kg	33 mg/kg	3 (4)	214 – 1,560 mg/kg	946 mg/kg	111 mg/kg	3 (4)
Current Sediment (1995-2004)	6 – 1,410 mg/kg	135 mg/kg	33 mg/kg	54 (86)	3 – 5,310 mg/kg	356 mg/kg	111 mg/kg	52 (86)
Floodplain Soil	16.8 – 86.3 mg/kg	30 mg/kg	43 mg/kg	2 (10)	13.4 – 211 mg/kg	56.3 mg/kg	34 mg/kg	4 (10)

Cranberry Bog Conservation Area	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Surface water	Snap-shot 20 µg/L	Snap-shot 20 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1)		Snap-shot 12 µg/L	Snap-shot 12 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1)
Crayfish Tissue	2.7 mg/kg	2.7 mg/kg	0.39 mg/kg wet wt.	2 (2)		7.88 – 11.57 mg/kg dry wt.	9.73 mg/kg dry wt.	4.0 mg/kg dry wt.	2 (2)
Fish Tissue	0.1 – 0.7 mg/kg wet wt.	0.37 mg/kg wet wt.	0.52 mg/kg wet wt.	1 (5)		1.09 – 3.61 mg/kg dry wt.	2.02 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (5)
Benthic Invertebrates Toxicity Test Results	Acute Growth [*C. tentans* – diff. vs field ref. (1995, 2001), *C. tentans* – diff. vs lab control (1995), *H. azteca* – diff. vs field ref. (2001)], Chronic Growth [*C. tentans* – diff. vs field ref. (2001)], Life Cycle [*C. tentans* – diff. vs lab control (2001)]. Community Impairment (2001). Number of sediment sites tested = 4.								
1981 % Service Level	55 %								

8. Davidson Park Pond (map location 12, Reach 3, area of injury = 2.09 acres):

The majority of contaminant concentrations in the sediments of this pond exceed their respective PECs (average arsenic and chromium concentrations are 62 and 184 mg/kg, respectively) and the majority of floodplain soil samples exceed the criterion concentration for chromium. Additionally, invertebrate toxicity testing indicates acute toxicity to growth upon exposure to sediments from this location. Crayfish tissue concentrations are elevated above reference concentrations and a portion of the fish sampled had arsenic and chromium concentrations in that exceed benchmark criteria.

For the ‘injury site’ model construction, the pre-injury service level was estimated to be 75%, given the location of this pond within an urban area. At year 1981, the service level was estimated to be 60% - the assessment being based on past and recent data. The service level at year 2009 is predicted to be 65%, since natural attenuation may have occurred over time. There are no remedial plans for this pond with the exception of monitoring. Therefore, it is assumed that in approximately twenty-five years, with lower contaminant input due to upstream remedial activities and natural attenuation, the service level will improve to a 75% service level.

The calculated ‘total discounted effective acre-years lost’ is **13.019** (see Appendix I for calculations).

Davidson Park Pond	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	10.3 – 129 mg/kg	61.5 mg/kg	33 mg/kg	8 (13)		31.9 – 442 mg/kg	183.7 mg/kg	111 mg/kg	9 (13)
Floodplain Soil	8.1 – 219 mg/kg	33.3 mg/kg	43 mg/kg	5 (26)		24.4 – 316 mg/kg	109.7 mg/kg	34 mg/kg	22 (26)
Surface water	Snap-shot 14 µg/L	Snap-shot 14 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1)		Snap-shot 3 µg/L	Snap-shot 3 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1)
Crayfish Tissue	1.1 – 2.1 mg/kg	1.53 mg/kg	0.39 mg/kg wet wt.	3 (3)		2.59 – 5.56 mg/kg dry wt.	3.72 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (3)

Davidson Park Pond	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Fish Tissue	0.09 – 1.9 mg/kg wet wt.	0.43 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (19)		0.36 – 10.20 mg/kg dry wt.	1.91 mg/kg dry wt.	4.0 mg/kg dry wt.	3 (28)
Benthic Invertebrates Toxicity Test Results	Acute Growth [*C. tentans* – diff. vs lab control (1995)]. Number of sediment sites tested = 1.								
1981 % Service Level	60 %								

NA – not available

9. Leonard Pool (map location 14, Reach 3, area of injury = 1.57 acres):

Unlike other water bodies along the Aberjona, the river does not bisect Leonard Pool. Based upon sediment concentrations (no data is available for floodplain soil or surface water), the contamination is considerably less than in other areas along the river and is generally localized to the inlet region which intersects the river. Fewer sediment samples contain contaminant concentrations that exceed the arsenic and chromium PECs.

For the 'injury site' model, the pre-injury service level was estimated to be 75%, given that this pond is located in a highly industrialized area. At year 1981, the service level was estimated to be 70% - the assessment being based on current data. There are no remedial plans for this pond with the exception of monitoring, but the service level is predicted to be at the original 75% service level by 2009 due to natural attenuation effects.

The calculated 'total discounted effective acre-years lost' is **1.800** (see Appendix I for calculations).

Leonard Pool	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	5.4 – 81.8 mg/kg	30.2 mg/kg	33 mg/kg	2 (8)		8.2 – 134 mg/kg	40.4 mg/kg	111 mg/kg	1 (8)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	NA	NA	Chronic 150 µg/L Acute 340 µg/L	NA		NA	NA	Chronic 74 µg/L Acute 570 µg/L	NA
Crayfish Tissue	1.1 – 2.1 mg/kg	1.53 mg/kg	0.39 mg/kg wet wt.	3 (3)		2.59 – 5.56 mg/kg dry wt.	3.72 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (3)
Fish Tissue	0.09 – 1.9 mg/kg wet wt.	0.43 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (19)		0.36 – 10.20 mg/kg dry wt.	1.91 mg/kg dry wt.	4.0 mg/kg dry wt.	3 (28)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	70%								

NA – not available

10. Water body south of Leonard Pool (map location 16, Reach 3, area of injury = 2.74 acres):

For this water body, very little data is available. Only two sediments samples were taken, but both exceed the PEC. Information from data collected from river segments and water bodies located in proximity to this water body, as well as crayfish and fish tissue data collected from Reach 3 suggest that this water body is at least moderately contaminated.

For the 'injury site' model construction, the variable inputs are the same as those for Davidson Park Pond.

The calculated 'total discounted effective acre-years lost' is **17.068** (see Appendix I for calculations).

Waterbody S. of Leonard Pool	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	111 – 121 mg/kg	116 mg/kg	33 mg/kg	2 (2)		576.5 – 918 mg/kg	747 mg/kg	111 mg/kg	2 (2)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	Base Flow 4 – 8 µg/L Storm Flow 5 – 18 µg/L	Base Flow 6 µg/L Storm Flow 10 µg/L	Chronic 150 µg/L Acute 340 µg/L	Base Flow 0 (16) Storm Flow 0 (6)		Base Flow 2 – 6 µg/L Storm Flow 3 – 13 µg/L	Base Flow 3 µg/L Storm Flow 6 µg/L	Chronic 74 µg/L Acute 570 µg/L	Base Flow 0 (16) Storm Flow 0 (6)
Crayfish Tissue	1.1 – 2.1 mg/kg	1.53 mg/kg	0.39 mg/kg wet wt.	3 (3)		2.59 – 5.56 mg/kg dry wt.	3.72 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (3)
Fish Tissue	0.09 – 1.9 mg/kg wet wt.	0.43 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (19)		0.36 – 10.20 mg/kg dry wt.	1.91 mg/kg dry wt.	4.0 mg/kg dry wt.	3 (28)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	60 %								

NA – not available

11. Judkins Pond (map location 17, Reach 4, area of injury = 4.81 acres):

Similar to the waterbody south of Leonard Pool, the arsenic and chromium contaminant concentrations in the majority of sediment samples exceed their respective PECs. Additional data from benthic invertebrate toxicity tests verify that the sediments from this pond can impede growth and chronic survival of invertebrates as well as affect life cycle stages.

For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this pond is located in a highly industrialized area. At year 1981, the service level was estimated to be 65% based upon recent data. The service level at year 2009 is predicted to be at 70%, given that natural attenuation effects may have occurred. With the exception of monitoring, there are no remedial plans for this pond.

Through natural attenuation, this pond is expected to increase to a 75% service level by year 2034.

The calculated 'total discounted effective acre-years lost' is **17.739** (see Appendix I for calculations).

Judkins Pond	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA	NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	21.8 – 135 mg/kg	68.8 mg/kg	33 mg/kg	6 (8)	142 – 442 mg/kg	266.4 mg/kg	111 mg/kg	8 (8)
Floodplain Soil	NA	NA	43 mg/kg	NA	NA	NA	34 mg/kg	NA
Surface water	Snap-shot 7 µg/L	Snap-shot 7 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1)	Snap-shot 4 µg/L	Snap-shot 4 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA	NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	0.07 – 0.18 mg/kg wet wt.	0.12 mg/kg wet wt.	0.52 mg/kg wet wt.	0 (13)	0.27 – 1.72 mg/kg dry wt.	0.94 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (19)
Benthic Invertebrates Toxicity Test Results	Acute Growth [*C. tentans* – diff. vs field ref. (1997, 2001)], Chronic Survival [*C. tentans* – diff. vs lab control (2001)], Life Cycle [*C. tentans* – diff. vs lab control (2001)]. Number of sediment sites tested = 2.							
1981 % Service Level	65 %							

NA – not available

12. Water body north of Upper Forebay (map location 19, Reach 5, area of injury = 3.38 acres):

The data from this water body show that nearly half to one-third of the sediment samples exceed the arsenic and chromium PECs, respectively, although the average concentrations for these contaminants are lower than found in other areas. The injury for the floodplain area is addressed separately (see below).

The variable inputs for the 'injury site' model construction are the same as those for Leonard Pool.

The calculated 'total discounted effective acre-years lost' is **3.876** (see Appendix I for calculations).

Waterbody N. of Upper Forebay	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA	NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	9.4 – 57.5 mg/kg	26.9 mg/kg	33 mg/kg	3 (14)	11 – 235 mg/kg	89.3 mg/kg	111 mg/kg	5 (15)
Floodplain Soil	19 – 98 mg/kg	49 mg/kg	43 mg/kg	4 (9)	19 – 90 mg/kg	40 mg/kg	34 mg/kg	5 (9)
Surface water	Snap-shot 7 µg/L	Snap-shot 7 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1)	Snap-shot 1 µg/L	Snap-shot 1 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1)

Waterbody N. of Upper Forebay	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Crayfish Tissue	0.48 mg/kg	0.48 mg/kg	0.39 mg/kg wet wt.	1 (1)		1.04 mg/kg dry wt.	1.04 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (1)
Fish Tissue	0.09 – 0.29 mg/kg wet wt.	0.15 mg/kg wet wt.	0.52 mg/kg wet wt.	0 (16)		0.30 – 2.88 mg/kg dry wt.	1.10 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (22)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	70 %								

NA – not available

13. Upper Forebay, Lower Forebay, Upper Mystic Lake (map location 20, Reach 6, area of injury = 176.45 acres reduced to 44.11 acres[1]):

The arsenic and chromium concentrations in the sediment of these water bodies are at a moderate level (the average arsenic and chromium concentrations are over three and two times their respective PECs). The benthic invertebrate toxicity tests support the toxicity of these sediments – concentrations are sufficiently high to impede benthic invertebrate growth and development during the life cycle.

For the 'injury site' model, the inputs are the same as for Judkins Pond.

The calculated 'total discounted effective acre-years lost' is **162.678** (see Appendix I for calculations).

Upper Forebay, Lower Forebay, Upper Mystic Lake	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	2.4 – 1,570 mg/kg	118.1 mg/kg	33 mg/kg	25 (41)		6.9 – 3,000 mg/kg	269.8 mg/kg	111 mg/kg	23 (41)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	Snap-shot 3 – 5 µg/L Base Flow 1.5 – 3.8 µg/L Storm Flow 2 – 4.2 µg/L	Snap-shot 4 µg/L Base Flow 1.8 µg/L Storm Flow 2.6 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (3) Base Flow 0 (16) Storm Flow 0 (6)		Snap-shot 1 – 4 µg/L Base Flow 0.5 – 1.1 µg/L Storm Flow 0.6 – 0.6 µg/L	Snap-shot 2 µg/L Base Flow 0.54 µg/L Storm Flow 0.6 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (3) Base Flow 0 (16) Storm Flow 0 (6)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	0.08 – 0.23 mg/kg wet wt.	0.13 mg/kg wet wt.	0.52 mg/kg wet wt.	0 (11)		0.24 – 1.36 mg/kg dry wt.	0.76 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (21)

[1] The acreage for the total area injured was reduced due to the fact that a significant portion of this location was not sampled, and therefore there is uncertainty as to the extent of injury.

Upper Forebay, Lower Forebay, Upper Mystic Lake	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Benthic Invertebrates Toxicity Test Results	Acute Growth [*C. tentans* – diff. vs field ref. (2001) and *C. tentans* – diff. vs lab control (2001)], Life Cycle [*C. tentans* – diff. vs lab control (2001)]. Number of sediment sites tested = 2.								
1981 % Service Level	65 %								

NA – not available

14. Lower Mystic Lake (map location 21, Reach 6, area of injury = 92.79 acres reduced to 30.93 acres[2]):

Of the sediment samples collected, the majority exceed the PEC for arsenic and all samples analyzed for chromium exceed the chromium PEC (the 8 samples collected in the USGS study were not analyzed for chromium). This indicates that organisms, particularly benthic invertebrates, are being exposure to heavy metals at concentrations known to cause injury.

For the 'injury site' model construction, the inputs are the same as for Judkins Pond.

The calculated 'total discounted effective acre-years lost' is **114.07** (see Appendix I for calculations).

Lower Mystic Lake	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	below min. reporting lim. – 144 mg/kg	70 mg/kg	33 mg/kg	9 (11)		170 – 428 mg/kg	306.7 mg/kg	111 mg/kg	3 (3)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	Base Flow 1 – 3 µg/L Storm Flow 1– 3 µg/L	Base Flow 1 µg/L Storm Flow 1 µg/L	Chronic 150 µg/L Acute 340 µg/L	Base Flow 0 (16) Storm Flow 0 (6)		Base Flow 1 – 2 µg/L Storm Flow 1 – 2 µg/L	Base Flow 1 µg/L Storm Flow 1 µg/L	Chronic 74 µg/L Acute 570 µg/L	Base Flow 0 (16) Storm Flow 0 (6)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	0.08 – 0.23 mg/kg wet wt.	0.13 mg/kg wet wt.	0.52 mg/kg wet wt.	0 (11)		0.24 – 1.36 mg/kg dry wt.	0.76 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (21)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	65 %								

NA – not available

[2] The acreage for the total area injured was reduced due to the fact that a significant portion of this location was not sampled, and therefore there is uncertainty as to the extent of injury.

15. Aberjona River Segment 1 (from Commerce Way crossing (south of Cabot Road) to HBHA wetland) (map location 1, Reach 0, area of injury = 1.06 acres):

This segment of the Aberjona has high sediment contamination (average arsenic and chromium concentrations are approximately 11 and 2 times their respective PECs), and relatively moderate floodplain contamination (approximately one to two-thirds of samples exceed arsenic and chromium benchmark criteria). Injury to benthic invertebrates and wildlife foraging in this area is expected to occur through exposure and uptake of these elevated heavy metal concentrations.

For the ‘injury site’ model construction, the pre-injury service level was estimated to be 70%, given that this river segment is located in a highly industrialized area and has been affected by recent construction in the Mishawum area of Woburn (early 1970s) such that it was diverted from its natural course. At year 1981, the service level was estimated to be 55% - the estimate being based on past as well as recent data. The service level at 2009 is predicted to continue at 55% since there is no evidence that contaminant concentrations have decreased over time. There are no remedial plans for this part of the river. Current remedial actions in areas adjacent to this river segment would theoretically only minimally affect this river segment (by reducing any potential sources of contamination from the HBHA Pond and wetlands during seasonal flooding events). Therefore, this river segment is not anticipated to significantly improve in the future years (service level at 60% by year 2040).

The calculated ‘total discounted effective acre-years lost’ is **9.261** (see Appendix I for calculations).

Aberjona River Segment 1	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	9.4 – 91.5 mg/kg	50.45 mg/kg	33 mg/kg	1(2)		18.6 – 1,160 mg/kg	589.3 mg/kg	111 mg/kg	1 (2)
Current Sediment (1995-2004)	16.1 – 889 mg/kg	363.5 mg/kg	33 mg/kg	5 (6)		18.1 – 1,120 mg/kg	294.8 mg/kg	111 mg/kg	4 (6)
Floodplain Soil	5.7 – 192 mg/kg	66.3 mg/kg	43 mg/kg	4 (10)		18.3 – 274 mg/kg	102.9 mg/kg	34 mg/kg	6 (10)
Surface water	Base Flow 3 – 24 µg/L Storm Flow 8 – 28 µg/L	Base Flow 17 µg/L Storm Flow 15.2 µg/L	Chronic 150 µg/L Acute 340 µg/L	Base Flow 0 (20) Storm Flow 0 (6)		Base Flow 1 – 2 µg/L Storm Flow 1 – 6 µg/L	Base Flow 2 µg/L Storm Flow 3 µg/L	Chronic 74 µg/L Acute 570 µg/L	Base Flow 0 (20) Storm Flow 0 (6)
Crayfish Tissue	NA	NA	0.39 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Fish Tissue	NA	NA	0.52 mg/kg wet wt.	NA		NA	NA	4.0 mg/kg dry wt.	NA
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	55 %								

NA – not available

16. Aberjona River Segment 2 (from HBHA wetland to wetland north of Wells G&H wetland) (map location 6, Reach 1, area of injury = 0.39 acres):

Little data is available for this river segment. Very few sediment samples were taken but all exceed the PECs for arsenic and chromium; floodplain data indicate at least moderate contamination. Metal concentrations in crayfish are several times greater than reference concentrations and tissue collected from fish at Reach 1 indicates that accumulation of arsenic is occurring at concentrations that could potentially cause injury.

For the 'injury site' model, the pre-injury service level was estimated to be 75%, given that this pond is located in a highly industrialized area. At year 1981, the service level was estimated to be 55% - the estimate being based on past and recent data. The service level at year 2009 is predicted to continue at 55% since there is no evidence that contaminant concentrations have decreased over time. With the exception of monitoring, there are no remedial plans for this river segment. Through natural attenuation, this segment is expected to increase to a 75% service level by year 2034.

The calculated 'total discounted effective acre-years lost' is **3.964** (see Appendix I for calculations).

Aberjona River Segment 2	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	11 – 24 mg/kg	18 mg/kg	33 mg/kg	0 (5)		12 – 19 mg/kg	15 mg/kg	111 mg/kg	0 (5)
Current Sediment (1995-2004)	106 – 221 mg/kg	180.7 mg/kg	33 mg/kg	3 (3)		156 – 258 mg/kg	223 mg/kg	111 mg/kg	3 (3)
Floodplain Soil	42.5 – 126 mg/kg	84.4 mg/kg	43 mg/kg	2 (3)		43.9 – 108 mg/kg	74 mg/kg	34 mg/kg	3 (3)
Surface water	NA	NA	Chronic 150 μg/L Acute 340 μg/L	NA		NA	NA	Chronic 74 μg/L Acute 570 μg/L	NA
Crayfish Tissue	3.1 – 4.4 mg/kg	3.75 mg/kg	0.39 mg/kg wet wt.	2 (2)		3.29 – 4.29 mg/kg dry wt.	3.79 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (2)
Fish Tissue	0.23 – 1.4 mg/kg wet wt.	0.82 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (5)		0.94 – 3.07 mg/kg dry wt.	1.98 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (5)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	55 %								

NA – not available

17. Aberjona River Segment 3 (from wetland north of Wells G&H wetland to Wells G&H wetland) (map location 8, Reach 1, area of injury = 0.23 acres):

As with Segment 2, very little data is available for this segment. However, all three sediment samples taken exceed the PEC for arsenic, and similar concentrations in sediment have demonstrated to be toxic to benthic invertebrates.

For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this pond is located in a highly industrialized area. At year 1981, the service level was estimated to be 65% - the estimate being based on past and recent data. The service level at year 2009 is predicted to continue at 65% since there is no evidence that contaminant concentrations have decreased over time. With the exception of monitoring, there are no remedial plans for this river segment. Through natural attenuation, this segment is expected to increase to a 75% service level by year 2034.

The calculated 'total discounted effective acre-years lost' is **1.169** (see Appendix I for calculations).

Aberjona River Segment 3	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	19 – 36 mg/kg	28 mg/kg	33 mg/kg	1 (2)		21 – 27.9 mg/kg	24 mg/kg	111 mg/kg	0 (2)
Current Sediment (1995-2004)	49.1 – 73.4 mg/kg	61.2 mg/kg	33 mg/kg	3 (3)		43 – 216 mg/kg	104 mg/kg	111 mg/kg	1 (3)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	Snap-shot 13.4 µg/L	Snap-shot 13.4 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1)		Snap-shot 2.4 µg/L	Snap-shot 2.4 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1)
Crayfish Tissue	3.1 – 4.4 mg/kg	3.75 mg/kg	0.39 mg/kg wet wt.	2 (2)		3.29 – 4.29 mg/kg dry wt.	3.79 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (2)
Fish Tissue	0.23 – 1.4 mg/kg wet wt.	0.82 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (5)		0.94 – 3.07 mg/kg dry wt.	1.98 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (5)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	65 %								

NA – not available

18. Aberjona River Segment 4 (from Cranberry Bog Conservation Area to Davidson Park Pond) (map location 11, Reach 2S, area of injury = 2.74 acres):

More than half of the sediment samples for this river segment exceed the PEC for arsenic, and the majority of floodplain samples exceed the set criteria for both arsenic and chromium. Injury resulting from exposure and uptake of existing heavy metals is expected for organisms foraging in this area, including benthic invertebrates, crayfish, fish and other wildlife.

For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this pond is located in a highly industrialized area. At year 1981, the service level was estimated to be 65% and by year 2009, it was estimated to be 70% since natural attenuation effects could have occurred over time. With the exception of monitoring, there are no remedial plans for this part of the river. Through further natural attenuation, this segment is expected to increase to a 75% service level by year 2034.

The calculated 'total discounted effective acre-years lost' is **10.105** (see Appendix I for calculations).

Aberjona River Segment 4	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	10.8 – 121 mg/kg	40.2 mg/kg	33 mg/kg	7 (14)		21 – 322 mg/kg	83.2 mg/kg	111 mg/kg	2 (14)
Floodplain Soil	19.9 – 272 mg/kg	59.3 mg/kg	43 mg/kg	7 (15)		32.6 – 550 mg/kg	133.8 mg/kg	34 mg/kg	14 (15)

Aberjona River Segment 4	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Surface water	Snap-shot 7 µg/L Base Flow 4 – 19 µg/L Storm Flow 15 – 26 µg/L	Snap-shot 7 µg/L Base Flow 11 µg/L Storm Flow 20 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1) Base Flow 0 (16) Storm Flow 0 (6)		Snap-shot 2 µg/L Base Flow 1 – 17 µg/L Storm Flow 8 – 24 µg/L	Snap-shot 2 µg/L Base Flow 4 µg/L Storm Flow 14 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1) Base Flow 0 (16) Storm Flow 0 (6)
Crayfish Tissue	2.7- 2.7 mg/kg	2.7 mg/kg	0.39 mg/kg wet wt.	2 (2)		7.88 – 11.57 mg/kg dry wt.	9.73 mg/kg dry wt.	4.0 mg/kg dry wt.	2 (2)
Fish Tissue	0.1 – 0.7 mg/kg wet wt.	0.37 mg/kg wet wt.	0.52 mg/kg wet wt.	1 (5)		1.09 – 3.61 mg/kg dry wt.	2.02 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (5)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	65 %								

NA – not available

19. Aberjona River Segment 5 (from Davidson Park Pond to Leonard Pool) (map location 13, Reach 3, area of injury = 0.45 acres):

Little data is available for this segment but the majority of sediment samples exceed the PEC for arsenic. For a subset of the crayfish and fish sampled from Reach 3, accumulation of metals is occurring at concentrations expected to result in injury.

For the ‘injury site’ model construction, the inputs are the same as for Aberjona River Segment 4.

The calculated ‘total discounted effective acre-years lost’ is **1.660** (see Appendix I for calculations).

Aberjona River Segment 5	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	20.7 – 505 mg/kg	132.8 mg/kg	33 mg/kg	3 (5)		22.6 – 124 mg/kg	69.9 mg/kg	111 mg/kg	2 (5)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	NA	NA	Chronic 150 µg/L Acute 340 µg/L	NA		NA	NA	Chronic 74 µg/L Acute 570 µg/L	NA
Crayfish Tissue	1.1 – 2.1 mg/kg	1.53 mg/kg	0.39 mg/kg wet wt.	3 (3)		2.59 – 5.56 mg/kg dry wt.	3.72 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (3)
Fish Tissue	0.09 – 1.9 mg/kg wet wt.	0.43 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (19)		0.36 – 10.20 mg/kg dry wt.	1.91 mg/kg dry wt.	4.0 mg/kg dry wt.	3 (28)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	65 %								

NA – not available

20. Aberjona River Segment 6 (from Leonard Pool to water body south of Leonard Pool) (map location 15, Reach 3, area of injury = 0.27 acres):

As with segment 5, little information is available for this segment but the two sediment samples taken exceed the PEC for arsenic. No data is available to indicate floodplain soil or surface water condition.

For the 'injury site' model, the inputs are the same as for Aberjona River Segment 4.

The calculated 'total discounted effective acre-years lost' is **0.996** (see Appendix I for calculations).

Aberjona River Segment 6	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA
Current Sediment (1995-2004)	73.4 – 74.9 mg/kg	74.2 mg/kg	33 mg/kg	2 (2)		45.2 – 69.2 mg/kg	57.2 mg/kg	111 mg/kg	0 (2)
Floodplain Soil	NA	NA	43 mg/kg	NA		NA	NA	34 mg/kg	NA
Surface water	NA	NA	Chronic 150 µg/L Acute 340 µg/L	NA		NA	NA	Chronic 74 µg/L Acute 570 µg/L	NA
Crayfish Tissue	1.1 – 2.1 mg/kg	1.53 mg/kg	0.39 mg/kg wet wt.	3 (3)		2.59 – 5.56 mg/kg dry wt.	3.72 mg/kg dry wt.	4.0 mg/kg dry wt.	1 (3)
Fish Tissue	0.09 – 1.9 mg/kg wet wt.	0.43 mg/kg wet wt.	0.52 mg/kg wet wt.	4 (19)		0.36 – 10.20 mg/kg dry wt.	1.91 mg/kg dry wt.	4.0 mg/kg dry wt.	3 (28)
Benthic Invertebrates Toxicity Test Results	NA								
1981 % Service Level	65 %								

NA – not available

21. Aberjona River Segment 7 (from Judkins Pond to water body north of Upper Forebay) (map location 18, Reach 5, area of injury = 0.63 acres):

Few data points are available from this segment of the river. Sediment samples are generally below the arsenic and chromium PECs, but at least two surface water samples (taken under storm flow conditions) exceeded the CMC.

For the 'injury site' model, the pre-injury service level was estimated to be 75%. At year 1981, the service level was estimated to be 70% - the estimate being based on contaminant concentrations in sediment. There are no remedial plans for this river segment with the exception of monitoring, but the service level is predicted to be at the original 75% service level by 2009 due to natural attenuation effects.

The calculated 'total discounted effective acre-years lost' is **0.722** (see Appendix I for calculations).

Aberjona River Segment 7	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	NA	NA	33 mg/kg	NA		NA	NA	111 mg/kg	NA

Aberjona River Segment 7	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Current Sediment (1995-2004)	5.1 – 24.8 mg/kg	12.4 mg/kg	33 mg/kg	0 (4)	15 – 149 mg/kg	62.4 mg/kg	111 mg/kg	1 (4)
Floodplain Soil	NA	NA	43 mg/kg	NA	NA	NA	34 mg/kg	NA
Surface water	Snap-shot 3 µg/L Base Flow 3 – 7 µg/L Storm Flow 3 – 427 µg/L	Snap-shot 3 µg/L Base Flow 4 µg/L Storm Flow 16 µg/L	Chronic 150 µg/L Acute 340 µg/L	Snap-shot 0 (1) Base Flow 0 (16) Storm Flow 2 acute (88)	Snap-shot 1 µg/L Base Flow 1 – 5 µg/L Storm Flow 2 – 1070 µg/L	Snap-shot 1 µg/L Base Flow 2 µg/L Storm Flow 27 µg/L	Chronic 74 µg/L Acute 570 µg/L	Snap-shot 0 (1) Base Flow 0 (16) Storm Flow 2 acute (88)
Crayfish Tissue	0.48 mg/kg	0.48 mg/kg	0.39 mg/kg wet wt.	1 (1)	1.04 mg/kg dry wt.	1.04 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (1)
Fish Tissue	0.09 – 0.29 mg/kg wet wt.	0.15 mg/kg wet wt.	0.52 mg/kg wet wt.	0 (16)	0.30 – 2.88 mg/kg dry wt.	1.10 mg/kg dry wt.	4.0 mg/kg dry wt.	0 (22)
Benthic Invertebrates Toxicity Test Results	NA							
1981 % Service Level	70 %							

NA – not available

Areas to be Affected by the Selected Remedy

22. New Boston Street Drainway (map location 22, Reach 0, area of injury = 0.275 acres[3]):

The arsenic and chromium contaminant concentrations in all or the majority of sediment samples for this stream exceed their respective PECs (the average arsenic and chromium concentrations are approximately 5 and 2 times their respective PECs).

For the ‘injury site’ model construction, the pre-injury service level was estimated to be 75%, given that this water drainway is located in a highly industrialized area. At year 1981, the service level was estimated to be 65% - the estimate being based on past and recent data. The planned remedial activity for this area is to line the stream channel with an impermeable cap (USEPA 2006). This action will destroy currently existing riparian habitat and eliminate any future ecological services provided by this area. Therefore, the service level at year 2009 is predicted to remain at 65% but decrease to 0% at year 2010 with the onset of remedial activities. The loss continues into the future.

The calculated ‘total discounted effective acre-years lost’ is **5.151** (see Appendix I for calculations).

New Boston Street Drainway	Arsenic				Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Previous Sediment (1982-1991)	511	511	33 mg/kg	1 (1)	118	118	111 mg/kg	1 (1)
Current Sediment (1995-2004)	112 – 384 mg/kg	181.3 mg/kg	33 mg/kg	5 (5)	53.1 – 406 mg/kg	220.9 mg/kg	111 mg/kg	4 (5)

[3] Acreage was estimated from Figure J-6 of the USEPA 2006 ROD.

New Boston Street Drainway	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Floodplain Soil	3.4 – 7.5 mg/kg	5.5 mg/kg	43 mg/kg	0 (7)		10.2 – 33.3 mg/kg	25 mg/kg	34 mg/kg	0 (7)
1981 % Service Level	65 %								

23. Upland soils at HBHA Pond (map location 2, Reach 0, area of injury = 0.4 acres[4]):

The upland soils just north of HBHA Pond have high concentrations of contaminants – the arsenic and chromium concentrations are approximately 10 and 19 times their respective benchmark concentrations. Thus, any small mammals or avian species foraging for soil invertebrates would likely intake toxic concentrations of heavy metals through dermal and oral exposure routes (estimated NOAELs for arsenite in small mammals is between 0.11 to 0.15 mg/kg/day) (Sample et al. 1996).

For the 'injury site' model construction, the pre-injury service level was estimated to be 75%, given that this scrub-shrub upland area is located in a highly industrialized area. At year 1981, the service level was estimated to be 55% - the estimate being based on recent data. The planned remedial activity for this area is to cover it with a permeable cap (USEPA 2006). The cap will have 4 inches of topsoil which will allow for growth of certain types of herbaceous and grassy vegetation; however, in order to maintain the structure of the cap, the size and type of vegetation must be restricted. The service level at year 2009 is predicted to remain at 55% but decline to 20% at year 2010. This predicted estimate is based on the fact that this area will be limited to an early successional stage of vegetation growth, and therefore reestablishment of the original habitat with fully-mature trees and shrubs will not be possible. The lost continues into the future.

The calculated 'total discounted effective acre-years lost' is **7.606** (see Appendix I for calculations).

HBHA Upland Soils	Arsenic					Chromium			
	Conc. range	Mean	Criteria	# Exceed Criteria (# samples)		Conc. range	Mean	Criteria	# Exceed Criteria (# samples)
Floodplain Soil	142 – 719 mg/kg	440.6 mg/kg	43 mg/kg	8 (8)		62.7 – 2680 mg/kg	655 mg/kg	34 mg/kg	8 (8)
1981 % Service Level	55 %								

[4] Acreage was estimated from Figure J-6 of the USEPA 2006 ROD.

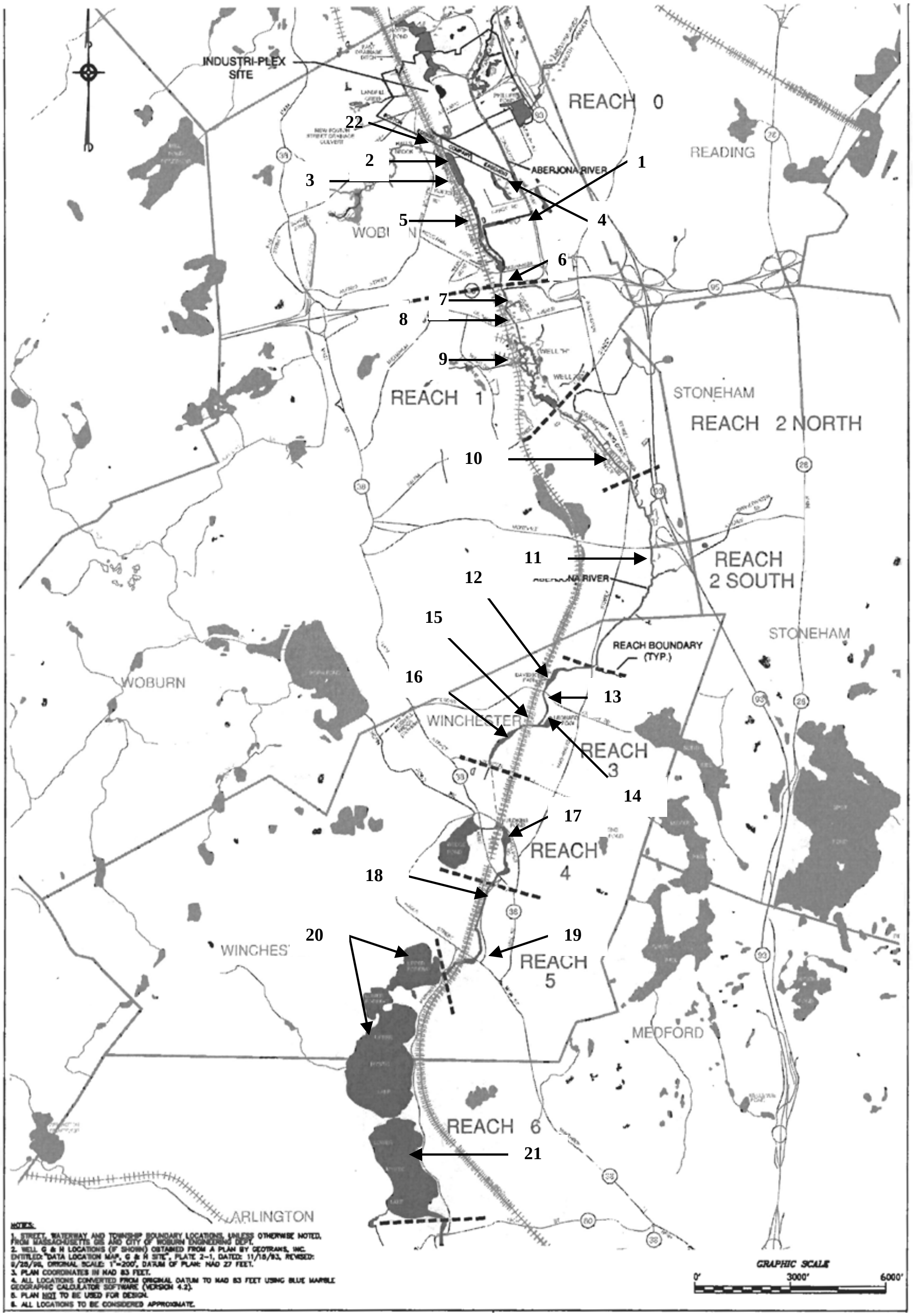


Fig. 1. Location of Injured Areas.

HEA Inputs and Calculated Total Discounted Effective Acre-Years Lost for Injured Wetland Habitat

Number Ref. in Text	Map Ref. #	Location	Injured Acreage	Initial Service Level (%)	1981 Service Level (%)	Service Level % Before Start of Remedial Activity	Service Level % One Year After Remedial Onset	Final Year Service Level (%)	Total Discounted Effective Acre-Years Lost
3	5	HBHA wetland	13.95	75	55	60	60.60	75	122.349
4	4	Wetland E. of mid-HBHA	3.57	75	65	67.46	67.54	70	17.776
5	7	Wetland N. of Wells G&H wetland	2.15	75	55	55	55.80	75	21.855
6	9	Wells G&H wetland	27.27	75	55	55	50	75	292.269
7	10	Cranberry Bog Consv. Area	20.18	75	55	55	50	75	216.281
								Total	**670.530**

HEA Inputs and Calculated Total Discounted Effective Acre-Years Lost for Injured Pond/Lake and Riverine Habitat

Number Ref. in Text	Map Ref. #	Location	Injured Acreage	Initial Service Level (%)	1981 Service Level (%)	Service Level % Before Start of Remedial Activity	Service Level % One Year After Remedial Onset	Final Year Service Level (%)	Total Discounted Effective Acre-Years Lost
1	2	HBHA Pond (N. end)	1.55	70	45	45	20	20	31.200
2	3	HBHA Pond (S. end)	3.11	70	45	45	20	70	47.219
8	12	Davidson Park Pond	2.09	75	60	65	65.40	75	13.019
9	14	Leonard Pool	1.57	75	70	75	75	75	1.800
10	16	Water body S. of Leonard Pool	2.74	75	60	65	65.40	75	17.068
11	17	Judkins Pond	4.81	75	65	70	70.20	75	17.739
12	19	Water body N. of Upper Forebay	3.38	75	70	75	75	75	3.876
13	20	Upper Forebay, Lower Forebay, Upper Mystic	44.11	75	65	70	70.20	75	162.678

Number Ref. in Text	Map Ref. #	Location	Injured Acreage	Initial Service Level (%)	1981 Service Level (%)	Service Level % Before Start of Remedial Activity	Service Level % One Year After Remedial Onset	Final Year Service Level (%)	Total Discounted Effective Acre-Years Lost
14	21	Lower Mystic Lake	30.93	75	65	70	70.20	75	114.070
15	1	Abj. River Seg. 1	1.06	70	55	55	55.16	60	9.261
16	6	Abj. River Seg. 2	0.39	75	55	55	55.80	75	3.964
17	8	Abj. River Seg. 3	0.23	75	65	65	65.40	75	1.169
18	11	Abj. River Seg. 4	2.74	75	65	70	70.20	75	10.105
19	13	Abj. River Seg. 5	0.45	75	65	70	70.20	75	1.660
20	15	Abj. River Seg. 6	0.27	75	65	70	70.20	75	0.996
21	18	Abj. River Seg. 7	0.63	75	70	75	75	75	0.722
22	22	New Boston Street Drainway	0.275	75	65	65	0	0	5.151
								Total	**441.697**

HEA Inputs and Calculated Total Discounted Effective Acre-Years Lost for Injured Upland Habitat

Number Ref. in Text	Map Ref. #	Location	Injured Acreage	Initial Service Level (%)	1981 Service Level (%)	Service Level % Before Start of Remedial Activity	Service Level % One Year After Remedial Onset	Final Year Service Level (%)	Total Discounted Effective Acre-Years Lost
23	2	HBHA Upland Soils	0.40	75	55	55	20	20	7.606
								Total	**7.606**

Estimating Amount of Restoration Needed to Compensate for Injured Areas:
HEA is a tool to calculate the amount of restoration necessary to compensate for past, present, and future injuries to natural resources. This is done through three steps: 1) modeling the services provided at the injured area ('injury site' model), 2) modeling the services projected for a compensatory area ('compensatory action' model), and 3) computing the size of compensatory restoration needed so that the total increase in services provided by the compensatory area equals the total loss of services at the injured area (dividing the acre-years lost at the injured area by the acre-years/acres benefit at the compensatory area = # acres needed).

In order to project the size of restoration project needed, there are at least 3 key factors: 1) the amount of acre-years lost due to the injury, 2) the expected acre-years/acre benefit expected from a compensatory action, and 3) differences in ecological value according to habitat type.

1. <u>Injured Areas</u>

As shown above, the total acre-years lost for wetland, pond/lake and riverine, and upland habitat are 670.530, 441.697 and 7.606, respectively.

2. <u>Compensatory Actions</u>

There are several possible options for compensatory actions. Appropriate compensatory actions would be projects that benefit wetland, pond/lake, riverine and upland habitat. Wetland projects could involve creation, restoration or enhancement of a wetland – or a combination of those three. As defined in the literature (Interagency Workgroup on Wetland Restoration 2003, Spiels 2005), wetland *creation* is establishing a wetland in an area where no wetland formerly existed. Wetland *restoration* is returning a degraded wetland or former wetland to a pre-existing condition or close to that condition as possible. Wetland *enhancement* is increasing one or more of the functions performed by an existing wetland beyond what currently or previously existed in the wetland. An example of a wetland restoration project would be to take a filled wetland and convert it back to a full-functioning wetland. Examples of wetland enhancement would be invasive species removal with additional replanting of native species, removal of debris, and implementing changes to hydrology to increase flooding frequency and duration. Options for compensatory actions at lake/pond or river areas could include plans for bank stabilization, creating or enhancing fish spawning habitat, or incorporating Best Management Practices (BMP) such as Low-Impact Development (LID) to improve water quality. Options for upland habitat restoration could be land protection or creating buffer areas around wetlands.

3. <u>Habitat-to-Habitat Scaling</u>

In recognition that different habitat types provide different ecological services, a site-wide assessment of biological injury should take into account these differences in ecological services across habitat types. In this HEA, four different habitat types were examined: wetlands, pond/lake, riverine, and upland habitat.

Comparing ecological services necessitates using some sort of a habitat-to-habitat scaling ratio. Secondary productivity, defined as the rate at which plant material is synthesized into animal tissue, could be considered an appropriate scaling measure; however, no local or regional rates of secondary productivity could be determined from a recent search of published literature. Therefore, the animal production rates from Table 5.3 in Robert Whittaker's *Communities and Ecosystems* (1975) were used. The animal production rate for swamp and marsh ecosystem types was 32,000,000 tons dry organic matter/year whereas that for lake and stream ecosystem types was 10,000,000 tons dry organic matter/year. Thus, the pond/lake/stream-to-wetland scaling ratio would be 1:3.2, meaning that a unit of wetlands is 3.2 times more productive than a unit of pond/lake/stream.

<u>Projected Project Benefits</u>

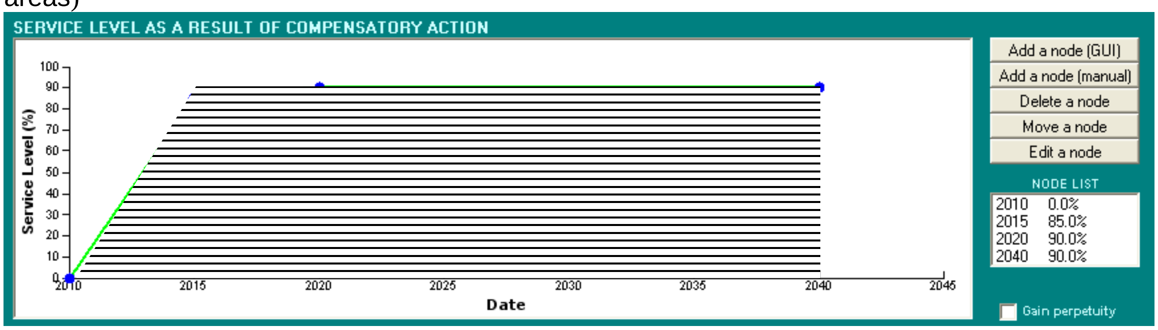
The projected amount of benefit from one or several of the projects mentioned above would depend upon a number of factors, including the original condition of the restoration site. Since no restoration projects have been identified at this point in time, hypothetical scenarios have been modeled below. The estimated start for restoration activities is year 2010.

To give a clearer indication of the loss or gain of ecological services, shaded areas have been drawn onto the original Visual HEA models. The shaded areas, however, have not been precisely drawn and may display a slight under estimate or over estimate of the area as outlined by the original Visual HEA model.

loss in ecological services

gain in ecological services

Created Palustrine Emergent Wetland (the predominant wetland type within injured wetland areas)[5]



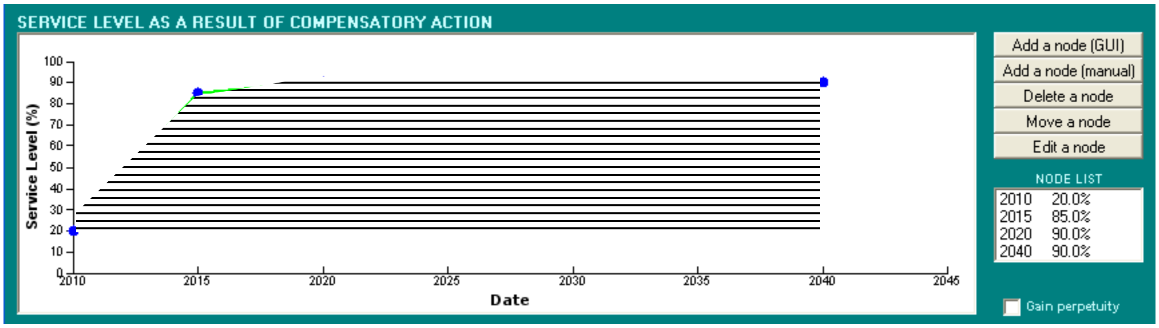
Initial Service Level: 0%

Functional Trajectory: 85% increase in the first 5 years, 5% increase in the second 5 years

Calculated benefit: 14.824 acre-years/acre

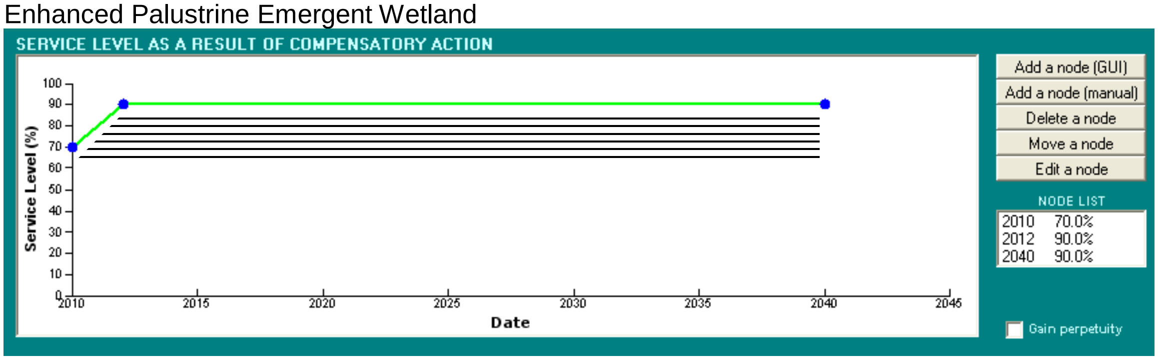
Restored Palustrine Emergent Wetland

[5] Although the space/area prior to wetland creation most likely provided some level of service as appropriately assessed for that particular habitat type (although, perhaps not in the case of a converted parking lot), the Trustees assumed that for *wetland* value, the initial service level is 0%.



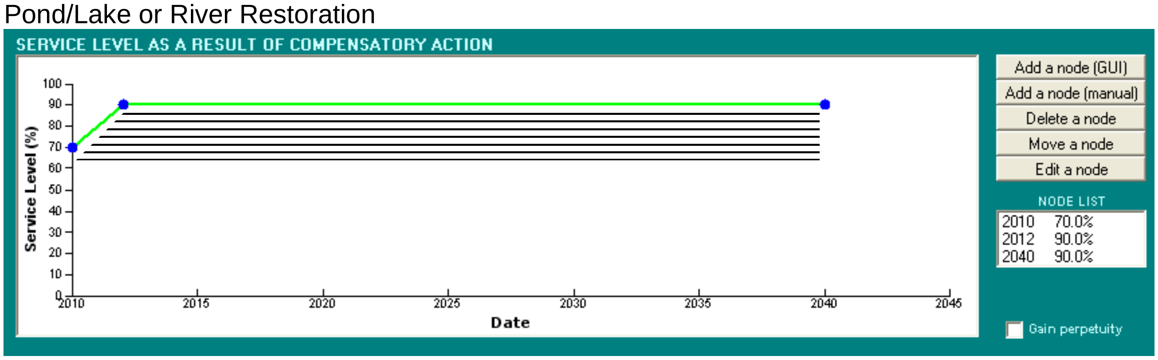
Initial Service Level: 20%
Functional Trajectory: 65% increase in the first 5 years, 5% increase in the second 5 years
Calculated Benefit: 11.485 acres-years/acre

Enhanced Palustrine Emergent Wetland



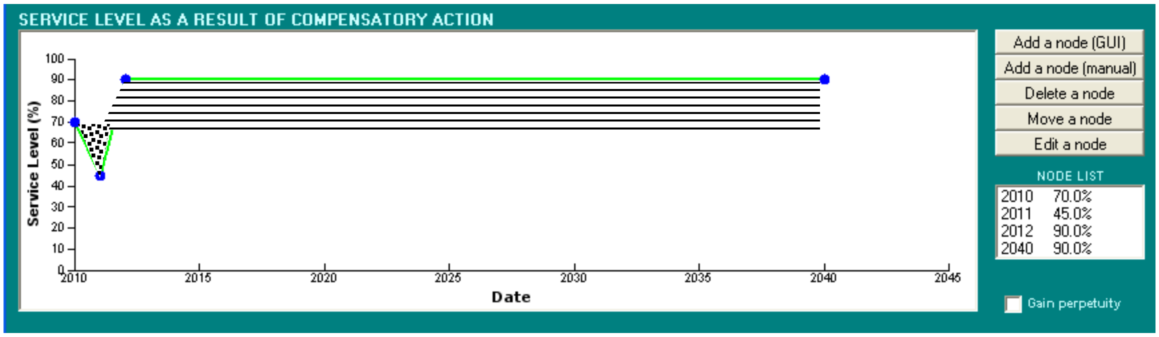
Initial Service Level: 70%
Functional Trajectory: 20% increase in 2 years
Calculated Benefit: 3.604 acres-years/acre

Pond/Lake or River Restoration



Initial Service Level: 70%
Functional Trajectory: 20% increase in 2 years
Calculated Benefit: 3.604 acres-years/acre

Upland Buffer Creation



Initial Service Level: 70%
Functional Trajectory: 25% decrease during first year (due to excavation and disturbance), 45% increase during second year
Calculated Benefit: 3.283 acres-years/acre

Estimated Number of Compensatory Acres Required for Various Restoration Projects to Address Wetland, Pond/Lake, Riverine, and Upland Injury (assuming that projects will achieve the acre-years/acre benefits as projected above):

1) Option A - Wetland Creation:

All pond/lake and river acre-years lost are converted to wetland acres-years:
441.697 divided by 3.2 (the productivity ratio of wetlands to pond/lakes/river) = 138.030 acre-yrs.

The total acre-years lost becomes:
670.530 + 138.030 = 808.560 acre-yrs.

If the compensatory action is creating a palustrine emergent wetland, the # acres of created wetland needed is:
808.560 acre-yrs. lost divided by 14.824 acre-yrs./acre of wetland benefit = **54.544 acres of wetland created**

For upland injury, one restoration project option is to provide a wetland buffer area. Using the model above, the projected restoration benefit from this is 7.606 acre-years/acre. Therefore, the number of upland buffer acres provided is:

7.606 acre-years lost divided by 3.283 acre-years/acre = **2.317 acres of buffer area**

2) Option B: Wetland Restoration with Pond/Lake or River Restoration:

The estimated amount of wetland restoration needed is:
670.530 wetland acre-years lost divided by 11.485 restoration acre-years/acre benefit = **58.383 acres of restored wetland**

The amount of acres needed to compensate for the pond/lake and river injured areas is:
441.697 pond/lake/river acre-years lost divided by 3.604 generic restoration acre-years/acre benefits = **122.557 acres of restored pond/lake or river**

For upland injury, the number of acres of created buffer area is the same as calculated above (**2.317 acres of buffer area**).

3) Option C: Wetland Creation with Pond/Lake or River Restoration

For the wetland creation, the number of acres needed is:
670.530 wetland acre-years lost divided by 14.824 acre-yrs./acre of wetland benefit = **45.233 acres of created wetland**

The number of acres needed for pond/lake or river restoration is the same as calculated in Option B (**122.557 acres of restored pond/lake or river**).

For upland injury, the number of acres of created buffer area is the same as calculated in Option A (**2.317 acres of buffer area**).

4) Option D: Wetland Restoration

For this option, the injured pond/lake and river acre-years are again converted to acre-years of wetland as calculated in Option A, to get an acre-years lost total of 808.560 acre-years of wetland habitat.

If the compensatory action is wetland restoration, the # acres needed is:
808.560 acre-years lost divided by 11.485 acre-years/acre benefit = **70.401 acres of restored wetland**

For upland injury, the number of acres of created buffer area is the same as above (**2.317 acres of buffer area**).

5) Option E: Wetland Restoration and Enhancement with Pond/Lake or River Restoration

For wetland restoration and enhancement, there could be an equal split of resources toward restoration and enhancement:
670.53 wetland acre-years lost divided by 2 = 335.265 acre-years

For wetland restoration:
335.265 wetland acre-years divided by 11.485 acre-years/acre benefit = **29.192 acres of restored wetland**

For wetland enhancement:
335.265 wetland acre-years divided by 3.604 acre-years/acre benefit = **93.026 acres of wetland enhancement**

The number of acres needed for pond/lake or river restoration is the same as calculated in Option B (**122.557 acres of restored pond/lake or river**).

For upland injury, the number of acres of created buffer area is the same as above (**2.317 acres of buffer area**).

Compensatory Action Option	**Projected Number of Acres Needed for Injury Compensation**
Option A: Wetland Creation with Buffer Area	54.5 acres of created wetland 2.3 acres of buffer area
Option B: Wetland Restoration with Buffer Area and Pond/Lake or River Restoration	58.4 acres of restored wetland 122.6 acres of restored pond/lake or river 2.3 acres of buffer area
Option C: Wetland Creation with Buffer Area and Pond/Lake or River Restoration	45.2 acres of created wetland 122.6 acres of restored pond/lake or river 2.3 acres of buffer area
Option D: Wetland Restoration with Buffer Area	70.401 acres of restored wetland 2.3 acres of buffer area
Option E: Split Wetland Enhancement and Restoration with Buffer Area and Pond/Lake or River Restoration	29.2 acres of restored wetland 93.0 acres of wetland enhancement 122.6 acres of restored pond/lake or river 2.3 acres of buffer area

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