Malden River Ecosystem Restoration
Detailed Project Report

APPENDIX E

ECOLOGICAL BENEFITS REPORT

US Army Corps
of Engineers®
New England District

MALDEN RIVER FEASIBILITY STUDY

MALDEN, EVERETT, AND MEDFORD, MASSACHUSETTS

APPENDIX E

ECOLOGICAL BENEFITS REPORT

US Army Corps of Engineers
New England District
696 Virginia Road
Concord, MA 01742-2751

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ACRONYMNS AND ABBREVIATIONS

AVS/SEM	Acid volatile sulfide/simultaneously extractable metals
COPEC	chemicals of potential ecological concern
DO	dissolved oxygen
DOQ	digital orth-quad
EPH	extractable petroleum hydrocarbons
Ft	Feet
GIS	Geographic Information Systems
GPS	Global Positioning System
HEP	habitat evaluation procedure
HIS	habitat suitability index
HU	habitat units
NEPA	National Environmental Policy Act
OW	open water
PAHs	polynuclear aromatic hydrocarbons
PAMHEP	Pennsylvania Modified Habitat Evaluation Procedure
PCBs	polychlorinated biphenyls
PEC-Q	probable effects concentration quotient
PGC	Pennsylvania Game Commission
SI	suitability index
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USACE/NED	United States Army Corps of Engineers, New England District
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VPH	volatile petroleum hydrocarbons

1.0 INTRODUCTION

The United States Army Corps of Engineers, New England District (USACE/NED), is in the process of preparing a feasibility-level study that identifies habitat restoration opportunities in the Malden River, a small urban waterway located in Malden, Medford, and Everett, Massachusetts. The principle goals of USACE/NED's study are to identify environmental restoration needs and opportunities in the River, develop plans and cost estimates for restoration alternatives, assess benefits and costs of alternative restoration plans, select a recommended restoration plan, and prepare appropriate NEPA documentation.

The USACE and the Mystic Valley Development Commission (MVDC) have determined habitat benefits (measured in habitat units) for three restoration components (wetland, benthic, and fish habitat restoration). The restoration components were analyzed in various combinations along with a No-Action alternative. This Ecological Benefits Report is designed to evaluate the relative habitat benefits for each of the various combinations of wetland, benthic and fish restoration components. This report provides a summary of the habitat evaluations and other analyses conducted for the Malden River Study. It includes a brief introduction to the Habitat Evaluation Procedures (HEP) study conducted, including existing conditions, the HEP process, and the goals and objectives of this evaluation (Section 1.0); a presentation of the methods used throughout the data collection, analysis, and documentation (Section 2.0); and the results of the HEP study (Section 3.0).

1.1 Site Description

The Malden River is a tributary of the Mystic River located within the cities of Malden, Medford, and Everett, Massachusetts. It is a highly engineered waterway, originating at Spot Pond and flowing through a series of interconnected natural and man-made channels and culverts for approximately 3.5 miles before its confluence with the Mystic River. The study area includes about 40 acres of aquatic and wetland habitat.

The Malden River watershed is a sub-basin of the much larger Mystic River watershed. The Malden River watershed is approximately 11 square miles, located in the towns of Wakefield, Stoneham, Melrose, Malden, Medford and Everett (see Figure E-1). The Malden River originates from the outflow from Spot Pond in the Fells Reservation and passes beneath or through the cities of Melrose and Malden in underground culverts or channelized conveyances through much of the upper watershed. It daylights from two sets of stormwater culverts south of Malden Center and flows for approximately 2 miles as open surface water through the densely populated cities of Malden, Everett and Medford prior to its confluence with the Mystic River, just upstream of the Amelia Earhart Dam. Four small tributaries flow into the Malden River below Malden center; Little Creek on the western side, two unnamed tributaries that both enter from the east and are referred to hereafter as North Creek and South Creek and a small drainage (Mall Creek) flows between the Revere Beach Parkway and the Gateway Mall.

The Malden River Federal channel is on average 6 feet deep by 100 to 150 feet wide from the Medford Street Bridge in Malden to its confluence with the Mystic River, approximately 2 miles (Fort Point Associates, 2003). In locations outside of the channel, water depths have been observed to be as shallow as 2 feet (D. Klinch, pers. observation). Spot depth elevations compiled during river assessment studies and corresponding bathymetric profiles for the river system may be referenced in Appendix F (Figures F-1 and F-2). The Malden River has an estimated surface area of 54 acres (from the stormwater culvert to the confluence with the Mystic River) and an approximated volume of 14,700,000 ft3 (110 million gallons), based on preliminary provisional USGS bathymetric data.

Figure E-1 Malden River Watershed

The Malden River watershed has been subject to the effects of gradual urbanization for several centuries. The results of development on river and aquatic resources have been significant. The majority of tributary streams and associated wetlands have been filled or culverted. Construction of the Earhart Dam in the mid 1900's converted part of the waterway from a tidally influenced salt-water estuary to a freshwater system. Water quality has deteriorated as an array of natural and man-made contaminants are carried off the land surface during rainstorms and deposited into the river. Poor water quality and sediment quality and degraded fish and benthic invertebrate communities have been documented. Non-native invasive species of flora such as *Phragmites* and knotweed have proliferated, crowding out native species, and limiting the diversity of riparian and wetland plant communities. Sediment testing conducted by Nangle Associates indicates that Malden River sediments and the surrounding riverbank soils contain elevated levels of contaminants, including metals, petroleum hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), and pesticides (Nangle 2000, 2003, 2005).

To assist in the evaluation of ecosystem characteristics, in particular the development of incremental building blocks for an alternatives analysis, the entire study area was divided into six (6) smaller sub-areas. Each of the six distinct sub-areas of the Malden River (see Environmental Assessment, Section 10, Figure EA 5-4) was evaluated independently. The following sections describe the general characteristics of each of these smaller study areas.

1.1.1 Sub-Area 1

Sub-area 1 represents the input or northerly limits of the Malden River study area immediately adjacent to and downstream of the Medford Street Bridge crossing. This portion of the Malden River was straighten and deepen under the U.S. Rivers and Harbors Act (June 14, 1880). Sub-area 1 consists of approximately 60,000 square feet of surface area, with an average depth of 6.2 feet ± along the river centerline. Sub-area 1 contains approximately 900 linear feet of bordering banks. Elevated concentrations of coal gasification residuals were identified within the sediment deposits along the easterly and westerly banks of the Medford Street Bridge.

1.1.2 Sub-Area 2

Sub-area 2 extends southerly from Sub-area 1 to TeleCom City Rivers Edge Parcel 5-2 and encompasses a majority of the early 1970's dredging project. Sub-area 2 consists of approximately 221,000 square feet of surface area, with an average depth of 7.0 feet ±. Sub-area 2 contains approximately 2,200 linear feet of bordering banks. The advancement of test borings within Sub-area 2 revealed a high degree of river competency reflective of the historic dredging activities that have been conducted in this portion of the project study area.

1.1.3 Sub-Area 3

Sub-area 3 represents the Little Creek portion of the project study area. Sub-area 3 consists of approximately 208,500 square feet of surface area, with an average depth of 4.6 feet ±. Sub-area 3 contains approximately 1,400 linear feet of bordering banks. The greatest degree of sediment variations and contaminant accumulation within the Malden River exists at its confluence with Little Creek. Sediment accumulation is highest along the easterly banks of the Malden River, reflective of once tidal dispersion and settling patterns. During Nangle Consultant Associates, Inc initial assessment of baseline characteristics, Sub-area 3 was identified as a target area for further evaluation due to the nature of sediment deposition and corresponding magnitude of coal tar constituents. The evaluation of contaminant distribution in Sub-areas 1 and 3 suggests that separate and discrete source conditions are responsible for contaminant distribution identified during site characterization. Figure 4-2 illustrates surface water depths decline in both easterly and westerly directions away from the centerline of the Malden River within Sub-Area 3.

1.1.4 Sub-Area 4

Sub-area 4 is an oxbow of the original Malden River that appears to have not been disturbed during the historic dredging activities. This oxbow receives surface water recharge from an unnamed creek (Report referenced as North Creek) situated along the northerly boundary of TeleCom City Rivers Edge Parcel 2-5. Sub-area 4 consists of approximately 250,400 square feet of surface area, with an average depth of 2.4 feet ±. Sub-area 4 contains approximately 4,100 linear feet of bordering banks.

1.1.5 Sub-Area 5

Sub-area 5 extends southerly from Sub-area 3 to Route 16 Revere Parkway Bridge. Sub-area 5 consists of approximately 682,000 square feet of surface area, with an average depth of 8.4 feet ±. Sub-area 5 contains approximately 6,400 linear feet of bordering banks. Sub-area 5 receives surface water recharge from unnamed creek (Report referenced as South Creek) situated along the southerly boundary of Parcel 2-5.

1.1.6 Sub-Area 6

Sub-area 6 extends southerly from Route 16 Revere Parkway Bridge to the Amelia Earhart Dam. Sub-area 6 consists of approximately 1,995,000 square feet of surface area, with an average depth of 9.5 feet ±. Sub-area 5 contains approximately 8,500 linear feet of bordering banks. Sub-area 6 receives surface water recharge from unnamed creek (Report referenced as Mall Creek) situated along the northerly boundary of the Gateway Mall.

1.2 Habitat Evaluation Procedures

Several restoration alternatives have been proposed for the Malden River Study. These alternatives have the potential to directly and indirectly impact the existing natural resources in the Study Area. USACE/NED has used the HEP methodology (USFWS 1980) in previous studies (i.e., Muddy River Flood Control Project, Stewart's Creek Salt Marsh Restoration Project) and determined that HEP is adequate to quantify effects (beneficial and adverse) in terms of wildlife habitat units and can be used to assist in the development and identification of the most ecologically beneficial restoration alternative. Also, HEP enables a comparison of future wildlife habitat units of the No-Action alternative to the future wildlife habitat units of the various restoration alternatives.

HEP provides information for two general types of wildlife habitat comparisons, the relative value of different areas at the same point in time, and the relative value of the same area at different points in time. This information is useful in baseline and impact assessments to evaluate proposed actions that potentially result in a change in either habitat quantity or quality. Through the use of HEP, the relative value of wildlife habitats can be quantitatively assessed through a final numerical output (McCrain 1992) that is technically defensible, replicable, and consistently applicable in a variety of different habitat types. HEP and Pennsylvania Modified HEP (PAMHEP) (a modified HEP version also used in this study) is based on combining a measure of habitat quantity with an index of habitat quality to determine habitat values (USFWS 1980, Pennsylvania Game Commission [PGC] 1980). The underlying assumption of HEP is that the habitat for a given wildlife species can be described by a Habitat Suitability Index (HSI) model.

HSI models typically denote habitat suitability of a species as the relationship between two or more environmental variables that are deemed to affect the species' presence, distribution, and/or abundance. The HSI is defined as a value between 0.0 and 1.0, with 1.0 representing optimum habitat, and is assumed to be positively correlated to carrying capacity (USFWS 1980, PGC 1980). The HSI value is multiplied by the area of available habitat to obtain Habitat Units (HUs). The HU values provide a quantitative estimate of overall habitat benefits.

The HEP models were used to evaluate the wetland restoration alternatives for the Malden River. However, no existing HEP models were available to adequately evaluate the benthic restoration and fish habitat restoration components of this study. In order to quantify habitat units for the benthic restoration component of this study, a predictive model was used to assess the toxicity of the sediments. The model (described in detail in section 2.5.1) calculates HSIs based on predicted survivability of benthic organisms. Habitat units for fish passage and fish habitat restoration were also developed. Habitat units for fish passage were defined as 60% of the total open water available in the project area (in acres), while the habitat units for improved fish habitat were defined as acres of suitable substrate restored for spawning.

1.3 Goals and Objectives

The specific goal of this appendix is to calculate the habitat benefits (*i.e.*, HUs) associated with the restoration alternatives proposed for the Malden River system. The following objectives were established:

1. Assess wetland/terrestrial habitat quality and quantity through the use of HSI models of selected evaluation species.
2. Analyze bulk sediment chemistry to assess benthic invertebrate habitat quality.
3. Analyze current fish passage procedures to assess the availability of fish habitat.

The overall goal of the Malden River Restoration Project is to improve habitat conditions in the River for fish and wildlife species. Habitat improvement will be accomplished through the removal of invasive species, the re-establishment of native wetland species, the creation of additional wetland habitat, the remediation of contaminated sediments, the diversification of substrate type, and the adjustment of fish passage procedures through the Amelia Earhart dam.

2.0 METHODS

This section presents the methodology used during the Malden River ecological benefits study. Established HEP and PAMHEP models were used to evaluate wetland restoration alternatives, while a predictive toxicity model and acreages of accessible areas were used to evaluate benthic habitat restoration and fish passage restoration, respectively.

In this section, the species selection process is discussed in Section 2.1, cover type mapping is outlined in Section 2.2, field survey methods are presented in Section 2.3, the laboratory analysis and procedures are briefly discussed in Section 2.4, and the habitat assessment for each of the targeted species is presented in Section 2.5. In addition, Section 2.6 describes the process used to develop the various restoration alternatives.

2.1 Species Selection

Four ecological guilds were selected for the purpose of evaluating habitat benefits. They include a benthic invertebrate guild, a fish guild, a piscivorous (fish-eating) wildlife guild, and a wetland/riparian dependant wildlife guild. Two of these guilds, benthic invertebrates and fish, are typically evaluated at the community level. However, specific species are required to evaluate the piscivorous and wetland/riparian guilds. Therefore, species accounts, life history information, site conditions, and plant communities were evaluated to identify species likely to occur in the study area. At least 175 species were identified as likely to occur in the greater study area (Burt and Grossenheider 1976, Godin 1977, Peterson 1980, DeGraaf and Rudis 1983, Ehrlich *et al* 1988, Whitaker 1988, Conant and Collins 1991, Behler 1995, Stokes and Stokes 1996, Terres 1996). To focus the HEP study, species that did not have

existing USFWS and/or Pennsylvania Modified HEP (PAMHEP) HSI models were eliminated from further consideration, narrowing the list to 25 species. Species that were not closely associated with the potential effects (*i.e.*, upland species) or study goals (*i.e.*, not included in one of the four target guilds) were also eliminated. As a result, 8 species remained for further consideration as evaluation species in the HEP study: belted kingfisher (*Cerlye alcyon*), catbird (*Dumetella carolinensis)*, slider turtle (*Pseudemys scripta*), raccoon (*Procyon lotor*), yellow warbler (*Dendroica petechia*), marsh wren (*Cistothorus palustris)*, common yellowthroat (*Geothlypis trichas)*, and green heron (*Butorides virescens*).

In order to further reduce the list of candidate species and determine which species would best fulfill the goals and objectives of the HEP study, the variables within each species' HSI model were reviewed with regard to their applicability to the Malden River and the proposed restoration alternatives. Specifically, each species model was evaluated to determine its sensitivity to potential project effects, site contaminants, its association with the targeted guilds, and the availability of toxicity and food ingestion data needed to establish links between the site contaminants and their diet. Table 1 summarizes the justifications for eliminating species from the HEP study. Based on these evaluations, three species were selected for the Malden HEP study: marsh wren, common yellowthroat, and green heron. The marsh wren and common yellowthroat represent the wetland/riparian dependant wildlife guild, and the green heron represents the piscivorous wildlife guild.

2.2 Cover Types

To evaluate the Malden River Study area in terms of wetland and aquatic habitat quality and quantity, a cover type map of the wetland areas was prepared. Specifically, a 2000 color, 1:5,000 scale digital ortho-quad (DOQ), printed at a scale of 1:3,600 (1 inch = 300 feet), was used to outline the cover types present within the study area. Standard photo-interpretation methods were used to distinguish different/unique cover type signatures on the DOQ. Unique cover type signatures were delineated and designated by polygons and digitized and geo-referenced in GIS software ARCView®, then transferred into ARC/INFO® GIS for additional editing (ESRI 1992-1998, 2000-2007). Wetland classification systems of Cowardin *et al*. (1979) and Tiner (1985) provided the foundation for cover type identification.

2.3 Field Surveys

Site-specific information was required to define certain habitat quality parameters. Field surveys were conducted by Nangle Associates (2000, 2003, 2005) to collect the sediment samples necessary for defining the habitat quality of the bottom sediments. In addition, the field procedures used by USACE to measure the habitat variables of the selected HEP evaluation species are presented.

2.3.1 Sediment Sampling

The sediments and soils in and adjacent to the Malden River have been sampled and tested to varying degrees. The river sediments have been extensively sampled in the upper reaches of the river while the lower reaches have had limited sampling (Nangle, 2000, 2003, 2005). A detailed description of the sediment chemistry in the Malden River can be found in the Environmental Assessment for this project while the data used in the predictive model can be found in section 2.4 of this appendix. Wetland soils in some of the wetlands adjacent to the river have been tested for contaminants. Additionally, many adjacent upland areas have been extensively studied as part of various remediation efforts (Jordan Co. 1985; GEI Consultants 1986; Haley and Aldrich, 1988, 1997; Camp Dresser & McKee 1991).

For planning purposes of this study, wetland soils were assumed to contain elevated levels of contaminants. Actual sampling and testing of the wetland soils will occur during the plans and specifications phase of this project. The sediment chemistry of the river sediments reported by Nangle

(2000, 2003, 2005) was used for input into the predictive models used to evaluate benthic habitat restoration.

2.3.2 HEP Data

In accordance with PAMHEP guidelines (PGC 1980), field measurements were collected within compartments representative of each of the vegetated wetland cover types identified within each study area. Compartments of cover types were sampled as needed to accurately assess the quality of the cover type in a given study area.

The habitat suitability of each compartment was determined by visually assessing the overall habitat conditions within the entire compartment. For the green heron, the compartment included the vegetated cover type being assessed as well as any waterbodies adjacent to the compartment. Each field team member independently assigned a value to the habitat variables presented below for each of the evaluation species:

- Marsh Wren (USFWS, Gutzwiller and Anderson, 1987)
  - Variable 1 (V1): Growth form of emergent hydrophytes
  - Variable 2 (V2): Percent canopy cover of emergent herbaceous vegetation
  - Variable 3 (V3): Mean water depth
  - Variable 4 (V4): Percent canopy cover of woody vegetation

- Common Yellowthroat (PAMHEP, Palmer and Hartman, 1994a)
  - Variable 1 (V1): Percent area in shrub crown cover
  - Variable 2 (V2): Average height of shrubs
  - Variable 3 (V3): Percent of grass or grass-like plants in ground cover
  - Variable 4 (V4): Proximity to wetlands

- Green Heron (PAMHEP, Palmer and Lange, 1994b)
  - Variable 1 (V1): Distance to clumps of deciduous shrubs and trees
  - Variable 2 (V2): Littoral substrate composition (of compartment and/or adjacent waterbody)
  - Variable 3 (V3): Percent of water less than 10 inches deep (of compartment and/or adjacent waterbody)
  - Variable 4 (V4): Percent of water surface covered by emergent vegetation, woody vegetation, logs, and/or trees (of compartment and/or adjacent waterbody).

Specifically, in increments of 0.10, the field team members selected a number between zero and one, with a rating of zero representing unsuitable habitat conditions and a rating of one representing optimal habitat conditions. The suitability index curves for each evaluation species, the field data forms, and a printout of the raw field data are provided in Appendix E-1 and E-2.

2.4 Sediment Chemistry Analysis

Sediment chemistry used for the predictive toxicity model, which was used to calculate habitat benefits for the benthic restoration component of this study, was taken from Nangle (2000, 2003,2005). Bulk sediment chemistry sampling and testing procedures used are described in Nangle (2004).

2.4.1 Bulk Sediment Chemistry

Sediment samples from various locations in the Malden River were analyzed for SVOCs, VOCs, EPHs, TOC, PCBs, and metals (Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Tl, and Zn) by Nangle Associates (2000, 2003, 2005). This sediment chemistry data set (detailed in Table 21) was used to evaluate both current conditions and predicted future conditions associated with various benthic habitat restoration alternatives for the Malden River. A detailed description of the various restoration alternatives and the associated dredging activities is provided in Section 2.6. For the purpose of this evaluation, the sediment data collected by Nangle (2000,2003, 2005) from 0 to 4 feet in depth were assumed to reflect current conditions. Future sediment concentrations were estimated as concentrations present below 4 feet of the existing sediments (the project dredging depth) for each of the sub-areas of the river.

For the modeling described in section 2.5.1, the following information/assumptions were applied according to the restoration plans:

- For no action scenarios, it was assumed that current sediments would mix with newly deposited sediments over time. Specifically, it was assumed that over the course of 25 years, approximately six inches of new sediment would be deposited, and that this material would mix evenly (*i.e.*, 1:1 ratio) with the underlying sediments. To reflect likely reductions in sediment concentrations due to future source controls, newly deposited sediments were assumed to contain 50 percent of contaminants present in current surface sediments with the exception PCBs (non-detect at 0.05 mg/kg).
- Total organic carbon concentrations (TOC) at the surface and at depth were assumed to remain constant over time. TOC concentrations of newly deposited sediments were assumed to be the same as those in current sediments. TOC concentrations were assumed to mix evenly over time as described for sediments.
- Nangle (2000, 2003, 2005) collected sediment cores from the Malden River system and evaluated bulk sediment concentrations at varying depths. These data were used to represent concentrations of chemicals in sediment exposed following proposed dredging activities. Specifically, chemical concentrations reported at depths approximately equivalent to the depth of proposed dredging. The data evaluated are summarized in Table 21.
- For capping scenarios, probable effects concentrations (PECs) (see Appendix F) were used as the concentrations of contaminants in the sediments following capping activities.

2.5 Habitat Assessment

This section presents the methods used to quantify the habitat suitability of the Malden River study area and determine the effect of site contaminants and invasive species on the area's habitat value for benthic invertebrates, fish, piscivorous wildlife, and wetland/riparian dependent songbirds.

2.5.1 Benthic Invertebrates

The benthic invertebrate community includes a wide array of organisms living in close association with the sediments. Many of these organisms burrow into sediments, while others live at the sediment water interface. Due to their direct exposure to surface sediments, benthic invertebrates are a key indicator species when evaluating the potential effects of sediment-associated contaminants. Numerous laboratory-based toxicity tests have been developed for the purpose of evaluating the potential toxicity of field-collected sediments.

One of the primary goals of this evaluation was to consider the potential habitat benefits associated with reducing sediment contamination (see Appendix F for existing sediment quality conditions in the Malden River). However, although there are diversity indices with which to evaluate the relative health of an ecological community, there are currently no available HSI models for evaluating benthic habitat quality. In addition, sediment quality is typically not considered as a habitat parameter. Therefore, it was necessary to develop an approach for calculating HSIs for this component. For the purpose of this evaluation, it was assumed that sediment chemistry would be the key measure of sediment quality associated with any observed response of benthic invertebrates. This assumption is supported by the research of MacDonald *et al*. (2000) and Ingersoll *et al*. (2000) who found that sediment toxicity could be predicted in freshwater systems through the use of a sediment effects ratio described as a Probable Effects Concentration Quotient (PEC-Q).

As described by MacDonald *et al*. (2000) and Ingersoll *et al*. (2000), the PEC-Q is derived by a three-step process developed by Long *et al*. (1998). In the first step, the concentration of each chemical in a given sample is divided by its respective sediment quality criteria, in this case defined as a Probable Effects Concentration (PEC) as derived by MacDonald *et al*. (2000). The resulting ratio is defined as a PEC quotient or PEC-Q. The PEC-Qs for each chemical are then summed and divided by the number of individual chemicals evaluated to derive a mean PEC-Q for each sample. Derivation of the mean PEC-Q facilitates comparisons between stations, particularly in situations where differing numbers of chemicals have been evaluated. Based on a sample size of 175, MacDonald *et al*. (2000) found that the incidence of toxicity in freshwater sediments could be predicted in up to 94.4 percent of sediments considered through use of the mean PEC-Q.

Ingersoll *et al*. (2000) further evaluated this relationship, exploring different methods of deriving the mean PEC-Q. They found that the best predictive relationship was associated with mean PEC-Qs calculated by equally weighting the contribution of metals, PAHs and PCBs in the evaluation of sediment chemistry and toxicity. Specifically, they calculated the geometric mean of the average PEC-Q associated with the metals, the PEC-Q with total PCBs and the PEC-Q associated with total PAHs. The geometric mean of the three PEC-Qs were used in place of the arithmetic mean based on the assumption that it provides a better measure of central tendency.

To calculate HSI values for benthic invertebrates in the Malden River Study Area under future conditions, mean PEC-Qs were generated for various alternatives in each sub-area according to the method described by Ingersoll *et al*. (2000). Percent survival was then predicted for each alternative using the regression relationship reported (Ingersoll *et a*l., 2000). The predicted results based on the regression equation were used for both the current (no action) and future HSI calculations.

Using this method, HSI values were calculated for the benthic restoration scenario (Table 21) using sediment concentrations for the Malden River and reference area estimated as described in Section 2.4.1. A capping and a non-capping scenario were run. Baseline HSI values are equivalent to the values predicted for the no action plan. The specific HSI values and a summary of the calculations used to derive them are provided in Table 22.

2.5.2 Fish

A resident, pollution-tolerant, warmwater fishery currently dominates the Malden River. Selected fishes from this assemblage include: carp (*Cyprinus carpio*), yellow perch (*Perca flavescens*), brown bullhead (*Ictalurus nebulosus*), and the catadromous American eel (*Anguilla rostrata*) (MADMF, 2003). The adjoining Mystic River and Lower Mystic Lake system is currently known to support an anadromous fish run, which includes blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*). Mystic River Watershed Association (MRWA) volunteers have presented anecdotal evidence of blueback herring

in the Malden River. Based upon the observations of MRWA, herring and potentially other anadromous fish are present annually near outfalls and creek mouths along the Malden River in readily observable numbers. However, state and federal regulatory agencies have not documented any significant fishery in the Malden River (MADMF/NMFS, 2003).

The anadromous fish run into the Malden River, Mystic River, and Lower Mystic Lake system is restricted by the Amelia Earhart dam, a lock and dam structure that spans the mouth of the Mystic River. The dam was constructed in 1966 for flood control purposes. Currently, the sole means of passing anadromous fish through the dam is via lock operation by the Department of Conservation and Recreation (DCR). While the frequency and duration of lock operations and the number of fish passed is not known, it is known that blueback herring numbering over one million arrive at the Lower Mystic Lake to spawn each year (MADMF, 2003). Amelia Earhart dam operations occur in the daytime hours only, inhibiting night-migrating anadromous fish such as smelt from moving upstream. Based upon discussions with the MADMF, numbers of smelt and shad that were known to migrate upstream prior to dam construction became nonexistent within several years of installation. Therefore, the fish passage impairment through the dam is assumed to be a significant factor in the absence of a good quality anadromous fishery in the Malden River. Other factors such as lack of water flow and suitable habitat conditions (as exists in the Mystic River) may be of equal importance. However, based on the long-term restoration goals for the Malden River, the lower reach of the Malden River (from confluence with the Mystic River to the culverted upstream sections of the River) has the potential to attract and support a significant population of anadromous fish. Improvements to the Malden River system needed to improve the anadromous fish run would include: 1) improved water quality, 2) increased flow volume in the River, 3) an increase in the availability of good quality spawning habitat, and 4) improved passing procedures through the dam. While improving water quality and increasing flows in the system are outside the scope of this project, many entities such as local, state and federal government agencies, private interest groups, and non-governmental organizations are currently addressing these issues to aid in the overall improvement of the Malden and Mystic River systems. Therefore, this study concentrated only on improving the availability of spawning habitat and improving the passing procedures of anadromous fish through the dam and assumes that these programs will generate sufficient improvement in water quality to sustain the anadromous fishery.

The availability of spawning habitat will be improved by placing appropriate substrate in selected areas throughout the River. Habitat units for this component were defined as acres of suitable substrate placed in each sub-area. The improvement of passing procedures for anadromous fish will be accomplished by developing and implementing an operations manual that will optimize locking procedures by extending the seasonal duration of passing, the frequency of openings for passing, and the temporal duration. Habitat units for the passing of anadromous fish were defined (in acres).

2.5.3 Piscivorous and Wetland Dependant Wildlife

As presented in the following sections, the habitat assessment for piscivorous wildlife and wetland dependant wildlife includes the calculation of HSI values using PAMHEP models.

2.5.3.1 Habitat Suitability Index Values

The relationship between a given habitat variable and an estimate of that habitat's suitability for a particular species are expressed by mathematical equations and described graphically using suitability index curves and histograms presented in each species' HSI model (Appendix F-2). Therefore, in order to determine the HSI values for the various cover types in the Malden River Study area, the field team visually assessed each variable according to the HSI model and assigned it a Suitability Index (SI) based on the suitability curves and histograms. In accordance with the PAMHEP models, the habitat suitability of an area is directly related to the most limiting life requisite; therefore, the common yellowthroat's and

green heron's HSI values are equal to the lowest average SI value for all the habitat variables within a specific cover type. The marsh wren's HSI value for each cover type was calculated based on the following equation: $(V1 \times V2 \times V3)^{1/3} \times V4$ (Gutzwiller and Anderson 1987). Table 15 presents the SI data and HSI values for all the cover types for each of the species.

2.6 Development of the Restoration Plans

Based on environmental, economic, and engineering constraints, several restoration plans (Plans) were developed by the Malden River project delivery team. The following provides a brief description of the actions associated with USACE/NED's proposed No-Action and restoration activities at all six of the study sub-areas.

Sub-Area 1

- No-Action:
  - Contaminated sediments exposed.
- Benthic Restoration:
  - Dredge selected areas to remove contaminated sediments.
- Fishery Restoration:
  - Improve spawning habitat.
  - Improve fish passage.

Sub-Area 2

- No Action
  - Herbaceous vegetation and *Phragmites* will encroach at a constant rate into the waterways.
  - Contaminated sediments exposed.
- Benthic Restoration:
  - Dredge selected areas to remove contaminated sediments.
- Wetland Restoration:
  - Eradicate all wetland *Phragmites*.
  - Plant riverbanks with native wetland species
- Fishery Restoration:
  - Improve fish passage.

Sub-Area 3

- No Action
  - Herbaceous vegetation and *Phragmites* will encroach at a constant rate into the waterways.
  - Contaminated sediments exposed.
- Restoration Dredge:
  - Dredge selected areas to remove contaminated sediments.
- Wetland Restoration:.
  - Eradicate all wetland *Phragmites*.

Sub-Area 3 (cont.)

- Plant riverbanks with native wetland species.
- Fishery Restoration:
  - Improve spawning habitat.
  - Improve fish passage.

Sub-Area 4

- No Action
  - Herbaceous vegetation will encroach at a constant rate into the waterways.
  - Contaminated sediments exposed.
- Restoration Dredge:
  - Dredge selected areas to remove contaminated sediments.
- Wetland Restoration:
  - Eradicate all wetland *Phragmites*.
  - Plant riverbanks with native wetland species.
- Wetland Creation:
  - Create wetlands in existing open water habitat
- Fishery Restoration:
  - Improve spawning habitat.
  - Improve fish passage.

Sub-Area 5

- No Action
  - Herbaceous vegetation will encroach at a constant rate into the waterways.
  - Contaminated sediments exposed.
- Restoration Dredge:
  - Dredge selected areas to remove contaminated sediments.
- Wetland Restoration:
  - Eradicate all wetland *Phragmites*.
  - Plant riverbanks with native wetland species
- Fishery Restoration:
  - Improve spawning habitat.
  - Improve fish passage.

Sub-Area 6

- No Action
  - Herbaceous vegetation will encroach at a constant rate into the waterways.
  - Contaminated sediments exposed.
- Restoration Dredge:
  - Dredge selected areas to remove contaminated sediments.

Sub-Area 6 (cont.)

- Wetland Restoration:
  - Eradicate all wetland *Phragmites*.
  - Plant riverbanks with native wetland species.
- Fishery Restoration:
  - Improve spawning habitat.
  - Improve fish passage.

2.7 Habitat Unit (HU) Calculations

This section presents the methods used to calculate the value of the habitat in the Malden River Study area and express it in terms of HUs for benthic invertebrates, fish, piscivorous wildlife, and wetland dependent wildlife. HUs are equal to the quantity of the habitat (*i.e*., acres) multiplied by the quality of the habitat (*i.e*., HSI value).

2.7.1 Piscivorous Wildlife and Wetland Dependant Wildlife

As described in Section 2.5.3, the HSI values for piscivorous and wetland/riparian species for each cover type were calculated by incorporating 2004 field data into suitability indices for each variable in each species' HSI model equations. To calculate the number of HUs for each sub-area, acreages of predicted cover type within all sub-areas were multiplied by each species' corresponding HSI value for that particular cover type in a given study area. Table 20 presents the HU values calculated for the piscivorous and wetland dependant species. Tables 2-19 present all the HEP data tables and calculations for the green heron, marsh wren, and common yellowthroat.

2.7.2 Benthic Invertebrates

To calculate HUs for the benthic invertebrate community, the HSIs (as described in Section 2.5.1) were multiplied by the total open water acreage to be dredged. Table 22 presents a summary of the HUs calculated.

2.7.3 Fish

For the purpose of calculating HUs for the fish community, the total open water acreage of the project area (81 acres) was calculated (i.e., the HSI was assumed to be 1) and 60% of that value (49) was used for the HU. In addition, acreages were determined for the areas that were defined as suitable for the placement of material to provide spawning habitat. Table 23 presents a summary of the HUs calculated.

3.0 RESULTS

This section presents a summary of the HUs generated for the Malden River HEP study. In particular, baseline HU results are discussed in Section 3.1, future HU and weighted HU results are presented in Section 3.2.

3.1 Baseline Conditions

3.1.1 Piscivorous and Wetland Dependant Species

Baseline HSI and HU values for the piscivorous and wetland dependant species were generated from HEP field data collection activities conducted in the project area in 2004. Baseline HUs are based on acreages of habitat available in the given study area at the time of field sampling (*i.e.*, year 2004). The overall

suitability of wetland habitat in the Malden River area is relatively low, with most HSI values for individual species below 0.60. Table 20 provides the overall HSI values for each wetland restoration alternative throughout the sub-areas as well as the HUs.

3.1.2 Benthic Invertebrates

The predictive toxicity model was used to develop the baseline conditions (HSI values) for the No Action alternative. The HUs for no action for sub-areas 1, 2, 3, 4, and 5 were 0.79, 0.79, 2.33, 0.96, and 1.29 respectively.

3.1.3 Fish

The baseline conditions for the fish passage component, based on professional judgment, were assumed to be approximately 40% of existing open water habitat in the project area. The HU used for the baseline for the project area was 32.4. Appropriate fish spawning habitat was assumed to be non-existent, so a HU of 0 was used.

3.2 Future HUs

3.2.1 Piscivorous and Wetland Dependant Species

Future HU values for the piscivorous and wetland dependant species were based on acreage changes resulting from the removal of *Phragmites* and other non-native species cover and the restoration or creation of functional wetlands. Table 20 provides a summary of HUs for each species and sub-area. In general, all the action alternatives improved habitat quality for targeted species.

3.2.2 Benthic Invertebrates

Future HUs for benthic invertebrates were based on predictive toxicity modeling results of selected areas within sub-areas. A dredge and non-capping scenario as well as a dredge and cap scenario was run with the model. The HUs for the non-capping action alternatives for sub-areas 1, 2, 3, 4, and 5 were 1.10, 0.78, 2.44, 1.95, and 1.46 respectively. These values tended to increase in relation to the no action HUs. Although the overall changes in HUs appear to be slight, marked improvements in benthic invertebrate survivability are predicted. The HUs for the capping action alternatives for sub-areas 1, 2, 3, 4, and 5 were 1.13, 0.91, 3.86, 3.00, and 1.63 respectively. The dredge and cap alternatives provided more HUS than the no action and the non-cap alternatives.

3.2.3 Fish

Future HUs for fish passage were based on 60% of the total open water in the project area. The future HU was assumed to be 49. In addition, HUs were calculated for the areas that will be enhanced by the placement of substrate for spawning. The future HUs for sub-areas 1, 3, 4, 5, and 6 were 0.07, 0.69, 0.84, 0.42, and 0.79 respectively.

3.3 Summary

The use of various models and professional judgement decisions were used to create habitat units for six sub-areas of the Malden River. The HUs were developed to allow a comparison of various proposed action alternatives to the existing conditions. The HUs developed in this report will be incorporated into an Incremental Analysis that will evaluate the ecological benefits realized by various actions and the estimated costs of each action.

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5.0 TABLES

Table 1. Habitat Evaluation Procedure (HEP) models reviewed for the piscivorous and wetland dependant species guilds for the Malden River Restoration Feasibility Study.

Model	Status	Reasons for Selecting or Not Selecting
Green-backed Heron	Selected	Applies to the piscivourous feeding guild in wetland areas and contains variables that will be affected by the alternatives.
Belted Kingfisher	Not Selected	Suitable nesting habitat must be located within 1.9 miles of the study area or the overall HSI will equal zero. Based on the surrounding land use, it is unlikely that suitable nesting habitat will be present.
Slider Turtle	Not Selected	The USFWS HEP model available for the slider is only pertinent to populations in the southern United States.
Marsh Wren	Selected	Applies to species nesting in herbaceous vegetation (i.e, *Typha* and *Phragmites*) and contains variables that will be affected by the alternatives.
Common Yellowthroat	Selected	Applies species inhabiting shrub communities near open water and wetland areas and contains variables that will be affected by the alternatives.
Yellow warbler	Not Selected	Applies only to cover types dominated by shrubs.
Catbird	Not selected	Does not apply to alternatives being considered.
Raccoon	Not Selected	The variables for the raccoon are not sensitive enough to distinguish improvements in habitat based on the alternatives being considered.

MARSH WREN HEP MODELS

Table 2. Marsh Wren HEP Model Results in Subarea 1

Alternative	Growth form of Emergent Hydrophytes	SI (V_1)	% Canopy Cover of Emergent Herbaceous Vegetation	SI (V_2)	Mean Water Depth (cm)	SI (V_3)	% Canopy Cover of Woody Vegetation	SI (V_4)	Overall Marsh Wren HSI
1	4	0.0	0	1.0	>40	1.0	0	1.0	0.0
2	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 3. Marsh Wren HEP Model Results in Subarea 2

Alternative	Growth form of Emergent Hydrophytes	SI (V_1)	% Canopy Cover of Emergent Herbaceous Vegetation	SI (V_2)	Mean Water Depth (cm)	SI (V_3)	% Canopy Cover of Woody Vegetation	SI (V_4)	Overall Marsh Wren HSI
1	2	0.5	90	1.0	>40	1.0	10	0.9	0.71
2	2	0.5	100	1.0	>40	1.0	0	1.0	0.79
3	1	1.0	100	1.0	>40	1.0	0	1.0	1.0
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4. Marsh Wren HEP Model Results in Subarea 3

Alternative	Growth form of Emergent Hydrophytes	SI (V_1)	% Canopy Cover of Emergent Herbaceous Vegetation	SI (V_2)	Mean Water Depth (cm)	SI (V_3)	% Canopy Cover of Woody Vegetation	SI (V_4)	Overall Marsh Wren HSI
1	2	0.5	65	0.7	>40	1.0	35	0.70	0.49
2	2	0.5	75	1.0	>40	1.0	25	0.75	0.59
3	1	1.0	90	1.0	>40	1.0	10	0.90	0.90
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 5. Marsh Wren HEP Model Results in Subarea 4

Alternative	Growth form of Emergent Hydrophytes	SI (V_1)	% Canopy Cover of Emergent Herbaceous Vegetation	SI (V_2)	Mean Water Depth (cm)	SI (V_3)	% Canopy Cover of Woody Vegetation	SI (V_4)	Overall Marsh Wren HSI
1	2	0.5	65	0.7	>40	1.0	35	0.70	0.49
2	2	0.5	75	1.0	>40	1.0	25	0.75	0.59
3	1	1.0	90	1.0	>40	1.0	10	0.90	0.90
4	1	1.0	95	1.0	>40	1.0	5	0.95	0.95

Table 6. Marsh Wren HEP Model Results in Subarea 5

Alternative	Growth form of Emergent Hydrophytes	SI (V_1)	% Canopy Cover of Emergent Herbaceous Vegetation	SI (V_2)	Mean Water Depth (cm)	SI (V_3)	% Canopy Cover of Woody Vegetation	SI (V_4)	Overall Marsh Wren HSI
1	2	0.5	70	0.9	>40	1.0	30	0.7	0.53
2	2	0.5	90	1.0	>40	1.0	10	0.9	0.71
3	1	1.0	100	1.0	>40	1.0	0	1.0	1.00
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 7. Marsh Wren HEP Model Results in Subarea 6

Alternative	Growth form of Emergent Hydrophytes	SI (V_1)	% Canopy Cover of Emergent Herbaceous Vegetation	SI (V_2)	Mean Water Depth (cm)	SI (V_3)	% Canopy Cover of Woody Vegetation	SI (V_4)	Overall Marsh Wren HSI
1	2	0.5	65	0.5	>40	1.0	35	0.65	0.41
2	2	0.5	75	1.0	>40	1.0	25	0.75	0.59
3	1	1.0	95	1.0	>40	1.0	5	0.95	0.95
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Common Yellowthroat HEP Models

Table 8. Common Yellowthroat HEP Model Results in Subarea 1

Alternative	% shrub canopy cover	SI (V_1)	Average Shrub Height	SI (V_2)	% grass-like ground cover	SI (V_3)	Proximity to wetlands	SI (V_4)	Overall Common Y-throat HSI
1	0	0.1	0	0.0	0	0.0	Yes	1.0	0.0
2	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 9. Common Yellowthroat HEP Model Results in Subarea 2

Alternative	% shrub canopy cover	SI (V_1)	Average Shrub Height (m)	SI (V_2)	% grass-like ground cover	SI (V_3)	Proximity to wetlands	SI (V_4)	Overall Common Y-throat HSI
1	20	0.1	2-4	0.5	10	0.10	Yes	1.0	0.16
2	30	0.5	1-2	1.0	20	0.20	Yes	1.0	0.50
3	75	1.0	1-2	1.0	25	0.25	Yes	1.0	0.75
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 10. Common Yellowthroat HEP Model Results in Subarea 3

Alternative	% shrub canopy cover	SI (V_1)	Average Shrub Height	SI (V_2)	% grass-like ground cover	SI (V_3)	Proximity to wetlands	SI (V_4)	Overall Common Y-throat HSI
1	40	0.5	2-4	0.5	10	0.1	Yes	1.0	0.36
2	30	0.5	1-2	1.0	10	0.1	Yes	1.0	0.46
3	80	0.7	1-2	1.0	20	0.2	Yes	1.0	0.60
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 11. Common Yellowthroat HEP Model Results in Subarea 4

Alternative	% shrub canopy cover	SI (V_1)	Average Shrub Height	SI (V_2)	% grass-like ground cover	SI (V_3)	Proximity to wetlands	SI (V_4)	Overall Common Y-throat HSI
1	40	0.5	2-4	0.5	10	0.1	Yes	1.0	0.36
2	30	0.5	1-2	1.0	10	0.1	Yes	1.0	0.46
3	80	0.7	1-2	1.0	20	0.2	Yes	1.0	0.60
4	60	1.0	1-2	1.0	40	0.4	Yes	1.0	0.81

Table 12. Common Yellowthroat HEP Model Results in Subarea 5

Alternative	% shrub canopy cover	SI (V_1)	Average Shrub Height	SI (V_2)	% grass-like ground cover	SI (V_3)	Proximity to wetlands	SI (V_4)	Overall Common Y-throat HSI
1	20	0.1	2-4	0.5	10	0.10	Yes	1.0	0.16
2	30	0.5	1-2	1.0	20	0.20	Yes	1.0	0.50
3	75	1.0	1-2	1.0	25	0.25	Yes	1.0	0.75
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 13. Common Yellowthroat HEP Model Results in Subarea 6

Alternative	% shrub canopy cover	SI (V_1)	Average Shrub Height	SI (V_2)	% grass-like ground cover	SI (V_3)	Proximity to wetlands	SI (V_4)	Overall Common Y-throat HSI
1	40	0.5	2-4	0.5	20	0.20	Yes	1.0	0.40
2	40	0.5	1-2	1.0	20	0.20	Yes	1.0	0.51
3	70	1.0	1-2	1.0	30	0.30	Yes	1.0	0.77
4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Green Heron HEP Models

Table 14. Green Heron HEP Model Results Subarea 1

Alternative	Presence of Shrub Habitat	SI (V_1)	% of waterbody covered w/ emergent vegetation, woody vegetation, logs, or trees	SI (V_2)	Permanency of water	SI (V_3)	Overall Green Heron HSI
1	None	0.1	0	0.0	Perm. > 25 cm	0.8	0.30
2	NA	NA	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA	NA	NA

Table 15. Green Heron HEP Model Results Subarea 2

Alternative	Presence of Shrub Habitat	SI (V_1)	% of waterbody covered w/ emergent vegetation, woody vegetation, logs, or trees	SI (V_2)	Permanency of water	SI (V_3)	Overall Green Heron HIS
1	Shrubs – not overhanging	0.5	0	0.0	Perm. > 25 cm	0.8	0.43
2	Shrubs – not overhanging	0.5	0	0.0	Perm. > 25 cm	0.8	0.43
3	Shrubs – overhanging	1.0	10	0.2	Perm. > 25 cm	0.8	0.66
4	NA	NA	NA	NA	NA	NA	NA

Table 16. Green Heron HEP Model Results Subarea 3

Alternative	Presence of Shrub Habitat	SI (V_1)	% of waterbody covered w/ emergent vegetation, woody vegetation, logs, or trees	SI (V_2)	Permanency of water	SI (V_3)	Overall Green Heron HSI
1	Shrubs – overhanging	1.0	20	0.5	Perm. > 25 cm	0.8	0.76
2	Shrubs – overhanging	1.0	20	0.5	Perm. > 25 cm	0.8	0.76
3	Shrubs – overhanging	1.0	35	0.7	Perm. > 25 cm	0.8	0.83
4	NA	NA	NA	NA	NA	NA	NA

Table 17. Green Heron HEP Model Results Subarea 4

Alternative	Presence of Shrub Habitat	SI (V_1)	% of waterbody covered w/ emergent vegetation, woody vegetation, logs, or trees	SI (V_2)	Permanency of water	SI (V_3)	Overall Green Heron HSI
1	Shrubs – overhanging	1.0	30	0.5	Perm. > 25 cm	0.8	0.76
2	Shrubs – overhanging	1.0	35	0.7	Perm. > 25 cm	0.8	0.83
3	Shrubs – overhanging	1.0	45	1.0	Perm. > 25 cm	0.8	0.93
4	Shrubs – overhanging	1.0	60	1.0	Perm. > 25 cm	0.8	0.93

Table 18. Green Heron HEP Model Results Subarea 5

Alternative	Presence of Shrub Habitat	SI (V_1)	% of waterbody covered w/ emergent & woody vegetation, logs, or trees	SI (V_2)	Permanency of water	SI (V_3)	Overall Green Heron HSI
1	Shrubs – not overhanging	0.5	10	0.2	Perm. > 25 cm	0.8	0.50
2	Shrubs – overhanging	1.0	10	0.2	Perm. > 25 cm	0.8	0.66
3	Shrubs – overhanging	1.0	25	0.5	Perm. > 25 cm	0.8	0.76
4	NA	NA	NA	NA	NA	NA	NA

Table 19. Green Heron HEP Model Results Subarea 6

Alternative	Presence of Shrub Habitat	SI (V_1)	% of waterbody covered w/ emergent & woody vegetation, logs, or trees	SI (V_2)	Permanency of water	SI (V_3)	Overall Green Heron HSI
1	Shrubs – not overhanging	0.5	15	0.2	Perm. > 25 cm	0.8	0.50
2	Shrubs – not overhanging	0.5	15	0.2	Perm. > 25 cm	0.8	0.50
3	Shrubs – overhanging	1.0	25	0.5	Perm. > 25 cm	0.8	0.76
4	NA	NA	NA	NA	NA	NA	NA

Table 20. Overall Habitat Suitability Indices (HSIs) for the piscivorous and wetland dependant species guilds and their associated Habitat Units (HUs).

	Marsh Wren	Common Yellowthroat	Green Heron	Overall HSI	Area (acres)	Habitat Units
sub-area 1						
No Action	0.0	0.0	0.30	0.30	0	0
Invasive Removal	NA	NA	NA	NA	NA	NA
Wetland Restoration	NA	NA	NA	NA	NA	NA
Wetland Creation	NA	NA	NA	NA	NA	NA
sub-area 2						
No Action	0.71	0.16	0.43	1.30	1.29	1.68
Invasive Removal	0.79	0.50	0.43	1.72	1.29	2.22
Wetland Restoration	1.0	0.75	0.66	2.41	1.29	3.11
Wetland Creation	NA	NA	NA	NA	NA	NA
sub-area 3						
No Action	0.49	0.36	0.76	1.61	3.37	5.43
Invasive Removal	0.59	0.46	0.76	1.81	3.37	6.10
Wetland Restoration	0.90	0.60	0.83	2.33	3.37	7.85
Wetland Creation	NA	NA	NA	NA	NA	NA
sub-area 4						
No Action	0.49	0.36	0.76	1.61	3.39	6.05
Invasive Removal	0.59	0.46	0.83	1.88	3.39	7.07
Wetland Restoration	0.90	0.60	0.93	2.43	3.39	8.24
Wetland Creation	0.95	0.81	0.93	2.69	8.09	21.76
sub-area 5						
No Action	0.53	0.16	0.50	1.19	3.78	4.50
Invasive Removal	0.71	0.50	0.66	1.87	3.78	7.07
Wetland Restoration	1.00	0.75	0.76	2.51	3.78	9.48
Wetland Creation	NA	NA	NA	NA	NA	NA
sub-area 6						
No Action	0.41	0.40	0.50	1.31	14.23	18.64
Invasive Removal	0.59	0.51	0.50	1.60	14.23	22.76
Wetland Restoration	0.95	0.77	0.76	2.48	14.23	35.29
Wetland Creation	NA	NA	NA	NA	NA	NA

NA = Not Applicable

Table 21. Sediment chemistry values used in predictive toxicity model. Initial concentrations represent composite data from 0-4 feet in each sub-area. Concentration after dredging values represent composite data below 4 feet.

Area	Chemical	Initial Concentration (mg/kg)	Concentration After Dredging (mg/kg)
Sub-area 1	Total PAHs	3610.00	1193.00
	Total PCBs	0.050	0.050
	Arsenic	35.0	17.0
	Cadmium	12.00	1.10
	Chromium	78.00	45.00
	Copper	310.00	63.00
	Lead	1100.00	170.00
	Nickel	43.00	27.00
	Zinc	1100	190
Sub-area 2	Total PAHs	1446	1192
	Total PCBs	0.050	0.050
	Arsenic	27.500	15.700
	Cadmium	11.000	7.000
	Chromium	116.000	88.000
	Copper	343.000	320.000
	Lead	1970	780
	Nickel	56.00	44.00
	Zinc	2838.00	1038.00
Sub-area 3	Total PAHs	4604.00	7197.00
	Total PCBs	0.050	0.050
	Arsenic	234.20	40.00
	Cadmium	7.00	7.00
	Chromium	242.00	152.00
	Copper	467.00	286.00
	Lead	1120.00	780.00
	Nickel	47.00	48.00
	Zinc	2300.00	863.00
Sub-area 4	Total PAHs	3103.0	813.0
	Total PCBs	0.532	0.532
	Arsenic	250.00	50.00
	Cadmium	7.30	3.20
	Chromium	140.00	120.00
	Copper	220.00	220.00
	Lead	850.00	360.00
	Nickel	46.00	46.00
	Zinc	1100.00	1100.00
Sub-area 5	Total PAHs	917.00	892.00
	Total PCBs	0.050	0.050
	Arsenic	43.20	41.00
	Cadmium	14.00	7.00
	Chromium	536.00	166.00
	Copper	275.00	206.00
	Lead	1100.00	590.00
	Nickel	295.00	38.00
	Zinc	3610.00	813.00

Table 22. Habitat Suitability Indices (HSI) and Habitat Units (HU) generated from the predictive toxicity model for the Malden River sub-areas.

Plan	Location	Total Acreage	Predicted Survival-*Hyallela*	HSIs-*Hyallela*	HUs - *Hyallela*
No action	Sub-area 1	1.240	50.42	0.64	0.79
	Sub-area 2	1.000	62.50	0.79	0.79
	Sub-area 3	4.230	43.48	0.55	2.33
	Sub-area 4	3.290	23.08	0.29	0.96
	Sub-area 5	1.790	57.13	0.72	1.29
Dredging	Sub-area 1	1.240	70.41	0.89	1.10
	Sub-area 2	1.000	61.83	0.78	0.78
	Sub-area 3	4.230	45.61	0.58	2.44
	Sub-area 4	3.290	46.91	0.59	1.95
	Sub-area 5	1.790	64.66	0.82	1.46
Dredging and Capping	Sub-area 1	1.240	75.19	0.91	1.13
	Sub-area 2	1.000	75.19	0.91	0.91
	Sub-area 3	4.230	75.19	0.91	3.86
	Sub-area 4	3.290	75.19	0.91	3.00
	Sub-area 5	1.790	75.19	0.91	1.63

Table 23. Fish Passage and Fish Spawning Habitat Units (HU)

Plan	Location	Total Acreage	Baseline HU	Future HU	
Fish Passage	Open Water in Project Area	81.0	32.4	49	
Fish Spawning Enhancement	Sub-area 1	0.07	0	0.07	
	Sub-area 2	0	0	0	
	Sub-area 3	0.69	0	0.69	
	Sub-area 4	0.84	0	0.84	
	Sub-area 5	0.42	0	0.42	
	Sub-area 6	0.79	0	0.79	