APPENDIX F

User's Guide: Beneficial Use of Dredged Material for Marsh Restoration or Creation

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1 Evaluation of Dredging and Disposal Needs

Two different types of projects require an assessment of the potential beneficial use of dredged material. In one, a dredging project necessitates the disposal of dredged material and thus a site which is suitable for disposal of the material is sought. In the other, creation or restoration of a habitat is desired and dredged material is considered as a possible sediment source (Hayes et al. 2000). In either project type, the choice of alternatives may be limited and less than optimum. The feasibility of beneficial use of dredged material is dependent on a variety of factors including: the distance between the dredging and proposed restoration sites, sediment composition, sediment transport and rehandling requirements, and the volume and timing of dredging in relation to restoration (USACE 2004). Most projects are associated with a specific dredging or marsh site; seldom is there the luxury to locate the most compatible site for already established project requirements (Hayes et al. 2000).

This User's Guide assumes that a need for dredging has been identified, a requirement for the deposition of the dredged material exists, and the dredging project has been approved.

2 Evaluation of Dredging Project Requirements

The U.S. Environmental Protection Agency (USEPA) and the U.S. Army Corps of Engineers (USACE) developed a Technical Framework to provide a consistent approach to identifying environmentally acceptable alternatives for the disposal of dredged material that meet the requirements of the National Environmental Policy Act (NEPA), the Clean Water Act (CWA) and the Marine Protection, Research, and Sanctuaries Act (MPRSA) (USEPA/USACE 2004). The NEPA relates to the need for the proposed dredging project while the CWA and MPRSA are concerned with the justification of the need for dredged material disposal in U.S. waters (CWA) or ocean waters (MPRSA) (USEPA/USACE 2004). Further information on the NEPA, CWA and MPRSA can be found on U.S. EPA website (USEPA 2017c), (USEPA 2017a) and (USEPA 2017b), respectively.

The USEPA and USACE developed the Technical Framework (USEPA/USACE 2004) to provide a national approach to evaluating typical, critical issues to environmentally acceptable disposal of dredged material. The USEPA/USACE outlined a general approach to identifying and assessing alternatives for disposal of dredged material:

- Evaluation of dredging project requirements
- Identification of dredged material disposal alternatives
- Initial screening of alternatives
- Detailed assessment of alternatives
- Alternative selection

In this User's Guide the Technical Framework has been modified to identify the process necessary to assess the feasibility of beneficial use alternatives starting with the evaluation of the dredging project requirements (*Figure 1*).

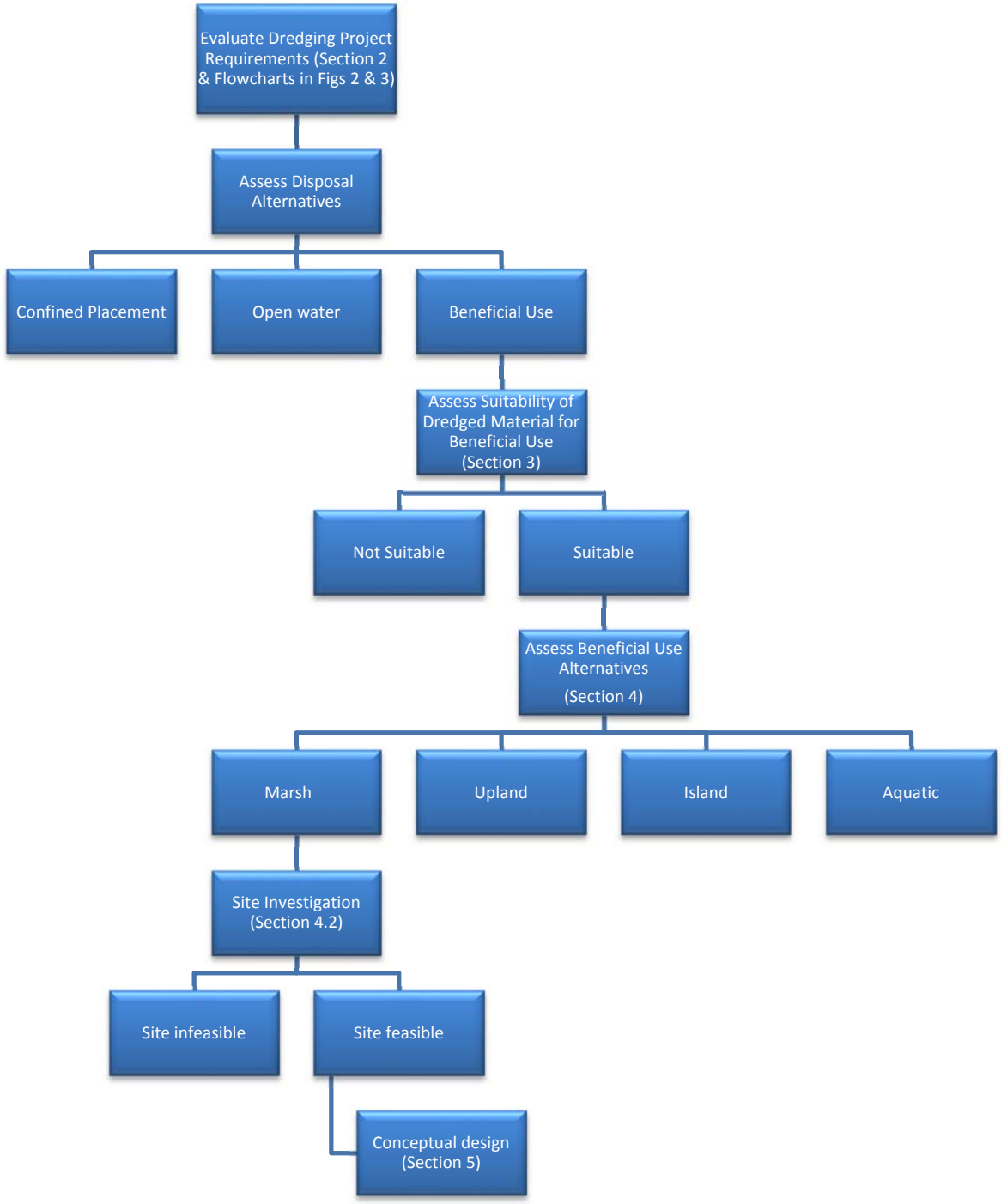

Figure 1. Technical framework for assessing the environmental suitability of dredged material disposal alternatives based on USEPA/USACE (2004). Information on each step can be found in the referenced section.

It is beyond the scope of this document to discuss all the steps in the Technical Framework preceding the assessment of the feasibility of beneficial use alternatives; however, it should be noted that prior to

determination of the suitability of the dredged material and selection of a disposal alternative (i.e., confined, open water or beneficial use) information on the dredging location and the volume of material to be dredged must be determined, and the assessments required by the NEPA and the CWA or the MPRSA must be documented.

Additionally, if a large number of potential disposal alternatives are identified, examples of the alternatives must be assessed in the NEPA document (40 CFR 1502.9[c]). Feasible alternatives that exceed the capability of the applicant or the jurisdiction of the lead agency must also be considered in the NEPA document. Council of Environmental Quality (CEQ) regulations require that the no-action alternative (i.e., no dredging or continuation of the historical effort) must also be analyzed in the NEPA document for comparison of the impact of the proposed project (USEPA/USACE 2004; USACE 2015a). USEPA/USACE (2004) and USACE (2015a) provide additional information on the evaluation of dredging project requirements and the identification of disposal alternatives.

The Technical Framework outlines the process necessary to identify the dredging material disposal alternatives (Figure 2).

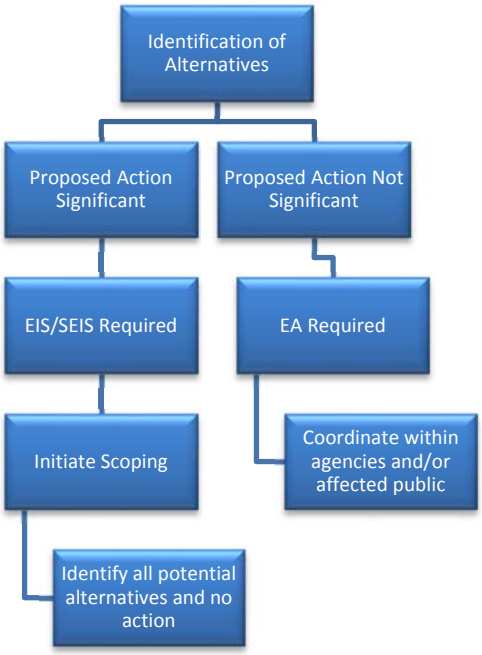

Figure 2. Technical Framework for identifying all dredged material disposal alternatives (USEPA/USACE 2004). These steps must be completed before the initial screening of all potential alternatives.

More information about the process for identifying all potential dredged material disposal alternatives can be found in USEPA/USACE (2004).

2.1 Screening of Disposal Alternatives

The screening of all potential disposal alternatives is performed in two phases. The initial screening relies on available information to eliminate all unreasonable alternatives from further consideration. A

detailed assessment of the remaining alternatives is then performed. The flowchart shown in Figure 3 is based on the USEPA/USACE (2004) Technical Framework in which only beneficial use alternatives are retained.

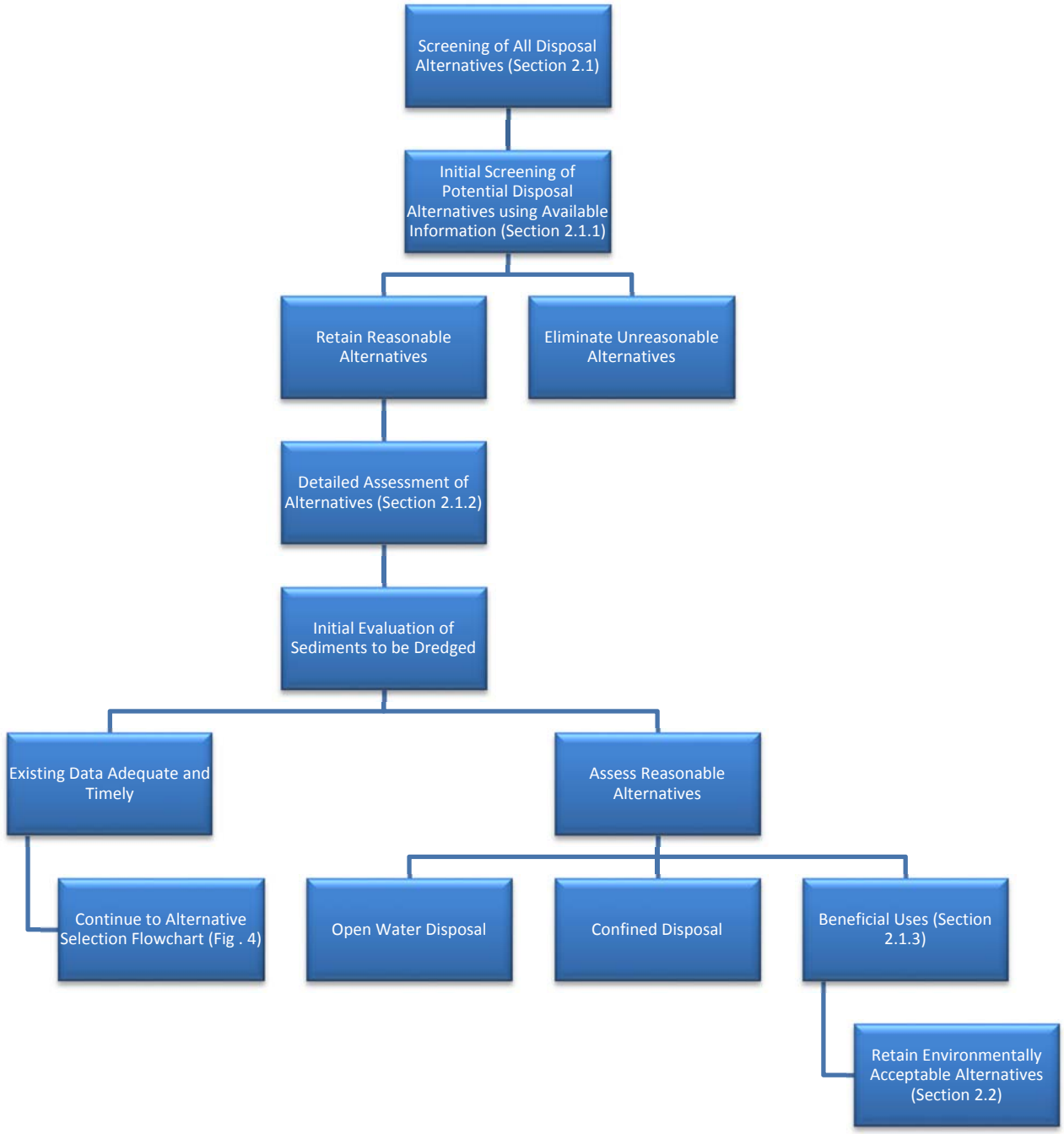

Figure 3. Technical framework for screening of potential alternatives for dredged material disposal (USEPQ/USACE 2004).

2.1.1 Initial Screening of Alternatives

In addition to using dredged materials for marsh and island restoration and creation, other beneficial uses include upland disposal, beach nourishment, land reclamation, and aquatic habitats, such as offshore berms (USACE 2015a). The initial screening removes alternatives from further consideration that are clearly not feasible due to environmental concerns (such as the presence of endangered species), technical feasibility (such as site availability and site characteristics that may be incompatible with the volume or characteristics of the dredged material), economic issues, and legal considerations (USEPA/USACE 2004; USACE 2015a). Consideration must also be given to design limitations of the project, climatic conditions, dredging equipment availability, and public concerns (USACE 2015a).

2.1.2 Detailed Assessment of Alternatives

If beneficial use of the dredged material is still a consideration once the unacceptable alternatives have been eliminated, detailed assessment of the remaining alternatives must be performed. To determine the environmental acceptability of the alternatives, detailed information about the dredged material and the dredge management plan are needed, including:

- Adequacy and timeliness of existing data: determine if existing data are sufficient to assess compliance with the CWA or the MPRSA. If data are insufficient, additional assessment is required (USACE 2015a).
- Physical characteristics of the dredged sediment: evaluate the physical characteristics of the dredged material to determine potential environmental impacts of placement, need for additional chemical or biological testing, and potential beneficial uses of the dredged material (USACE 2015a).
- Potential sediment contamination: determine if dredged sediments contain any contaminants in forms or concentrations that could cause unacceptable environmental impacts (USACE 2015a).
- Sampling, testing and evaluations (including required CWA or MPRSA testing).

2.1.3 Assessment of Beneficial Use Alternatives

For projects in which the goal is to restore or create a specific site, the challenge is to modify the site to ensure the conditions are suitable for wetlands habitat. Alternatively, for projects seeking a suitable site for disposal of dredged material, the challenge is identifying and assessing potential sites. Preliminary assessment will identify the sites that require the least modification to existing conditions, which are usually the most cost-effective and likely to succeed (Hayes et al. 2000).

In either project type, specific project goals well-defined early in the process are necessary to evaluate proposed alternatives. As some wetlands functions are mutually exclusive, primary and secondary goals need to be identified to enable concessions among project objectives (Hayes et al. 2000).

2.1.3.1 Habitat Development

Beneficial use options include habitat development of wetlands, uplands, islands, beaches and aquatic environments, as well as recreational, agricultural and construction uses. Habitat development is a viable disposal alternative when one or more of the following conditions are present:

a) Public/agency opinion strongly opposes other alternatives;
b) Recognized habitat needs exist;
c) Enhancement measures on existing placement sites are identified;
d) Feasibility has been demonstrated locally;
e) Stability of dredged material deposits is desired;
f) Habitat development is economically feasible;
g) Extensive quantities of dredged material are available

(USACE 2015).

The USACE (2015a) provides a general procedural guide to assess habitat development alternatives (see Figure 4). Not all categories will necessarily be relevant to a particular project and may be neglected while other issues may need to be added (USACE 2015a). Additionally, although the level of detail in the assessment may vary from project to project, the steps involved – alternative analysis, hydraulic/hydrologic evaluation and design evaluation – can be useful even for projects in which they are not required by regulations (Mohan et al. 2007).

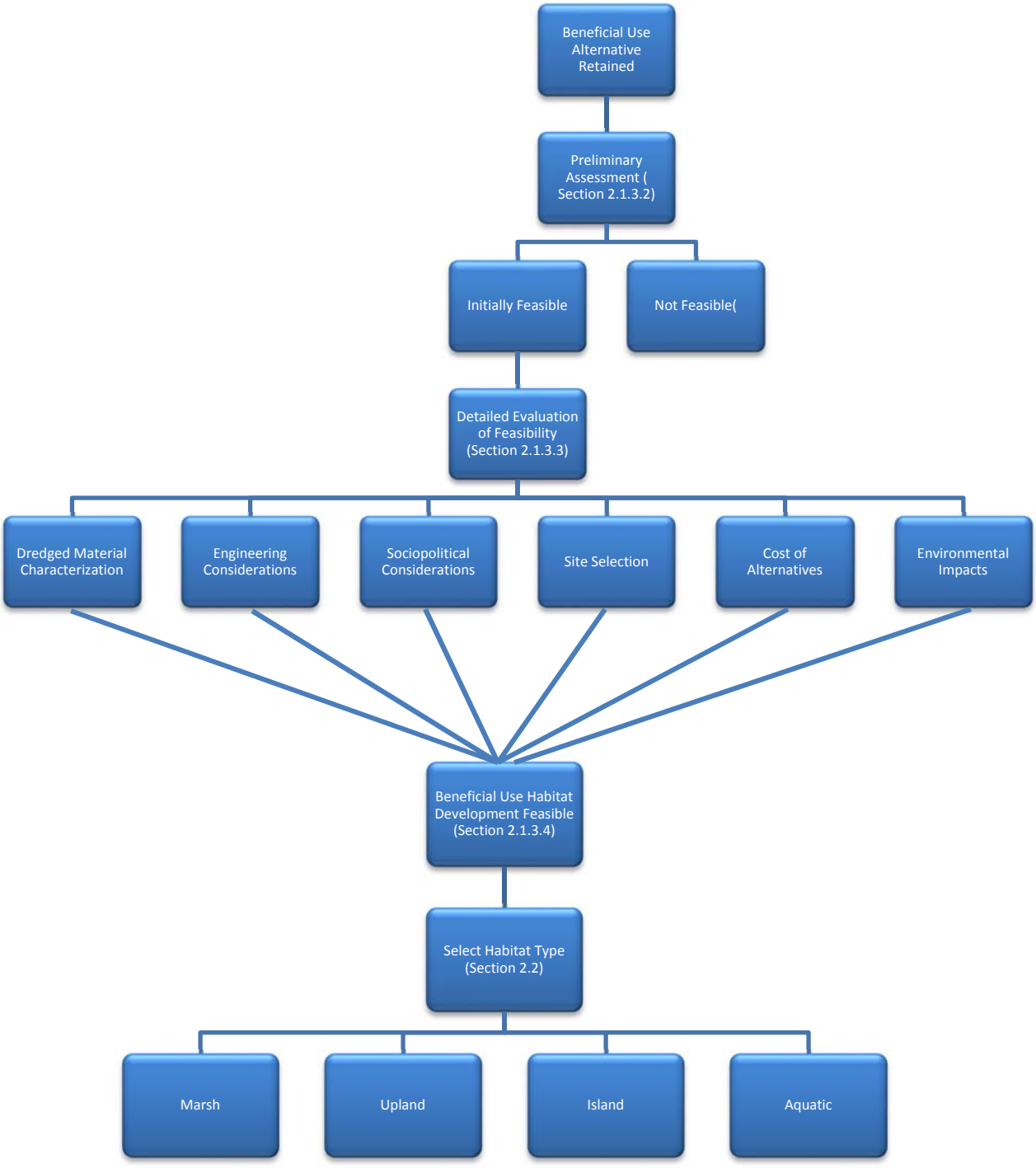

Figure 4. Procedural guidelines for the selection of various habitat development alternatives using dredged material (from USACE 2015a).

2.1.3.2 Preliminary Assessment.

The preliminary assessment of feasibility involves judgment based on local biological and engineering expertise, public opinion, and available data on the following:

a) Dredged material characterization,
b) Site selection,
c) Engineering considerations,
d) Costs of alternatives,
e) Sociopolitical considerations,
f) Environmental Impacts.

In the absence of sufficient information to reject habitat development as a placement option, the USACE (2015) recommends performing a detailed evaluation of the feasibility.

2.1.3.3 Detailed Evaluation of Feasibility.

Detailed evaluation of feasibility provides further analysis of the factors outlined above.

Dredged material characterization: Physical, chemical, and engineering characteristics of the dredged material determine the suitability of the site for dredged material disposal and environmental acceptability of the dredged material for habitat development (USACE 2015a).

Site selection*:* Site selection is based on the wave conditions, existing soil characteristics, salinity, tidal effects, and bottom topography at the site. Wave conditions determine the feasibility of establishing a stable substrate or the necessity of protection structures. Existing soil conditions will determine if the site can support construction equipment or protective structures. Salinity and tidal effects determine suitable plant species. A more detailed analysis of these factors will be required for detailed design purposes, but some field sampling may be necessary during this phase if available information is insufficient for alternative selection (USACE 2015a).

Engineering considerations*:* Engineering considerations in the detailed feasibility phase are based primarily on initial designs and an assessment of equipment needs and availability. Additional information on scheduling to account for critical environmental dates (such as planting, and nesting and spawning seasons) and dredged material transport considerations may provide useful information when comparing and assessing alternatives. Of particular concern is the number and analysis of core samples from the dredge site. Insufficient analysis can lead to inaccurate assessment of the final percentages of fine sediment or sands at the placement site resulting in incorrect determination of the consolidation ratio and therefore, the final wetlands elevation (USACE 1987a; USACE 2015a).

Costs of alternatives*:* Detailed economic analyses are not feasible until development of the design criteria; however, a general cost comparison should be undertaken to eliminate any potential alternatives that are cost-prohibitive (USACE 1987a; USACE 2015).

Sociopolitical considerations: Sociopolitical considerations of greatest concern when considering beneficial use of dredged material include public attitudes, legal and institutional constraints, and costs. Negative public attitudes generally occur when the community views the proposed habitat as a threat to the existing environment or property values. Legal and institutional constraints are frequently caused by questions of ownership and access or when local interests have identified the proposed site for an alternative use. Economic impacts could occur if the proposed habitat affected shell fishing, recreational areas or a water view. Beneficial use projects may not be feasible due to lack of funds from the USACE or required cost-sharing sponsors (USACE 1987a; USACE 2015).

Environmental Impacts: Environmental impacts include the loss of open-water habitat or wetland systems and changes in hydraulic and energy regimes. The relevance of these impacts must be weighed against the benefits of habitat development, particularly in areas that have lost or risk losing habitat of the type to be developed. In addition, contaminant uptake by vegetation might be of concern, and its potential should be determined prior to habitat development (USACE 1987a; USACE 2015).

2.1.3.4 Selection of Beneficial Use Alternative

At this stage, it is feasible to determine whether the dredged material and the proposed placement sites are compatible with a beneficial use. This document focuses on the beneficial use of dredged material for creation and restoration of coastal and island marshes. Other references (for example, USACE 1987a; USEPA/USACE 2004; USACE 2015) provide information on alternative beneficial uses.

Should several potential alternatives for marsh restoration or creation be feasible, the next step is to identify local needs and opportunities and specify criteria for evaluating each alternative. The evaluation criteria can be developed using a generic criteria or USEPA/USACE (2007) describes a five-step process in which the project partners and other stakeholders collectively develop custom criteria. Although more time-consuming, this approach helps integrate the identification and evaluation of beneficial use projects with existing plans. Additionally, stakeholder involvement (including regulatory authorities) in developing criteria is likely to improve the probability that the selected alternative will be implementable (USEPA/USACE 2007).

Two levels of criteria may prove useful: threshold criteria which any project must meet to be acceptable, and balancing criteria which can be useful in evaluating alternatives if there is more than one potential project. Table 1 lists suggested threshold criteria as identifiable human or ecological benefits, compatibility with estuary- or watershed-wide plans and goals, legal authority, and public acceptance (USEPA/USACE 2007).

Table 1. Criteria for evaluating beneficial use alternatives (USEPA/USACE 2007).

Criterion	Examples
Human Benefits	Recreation Flood protection Economic development
Ecological Benefits	Improved hydrologic functions Habitat enhancement Improved water quality
Compatibility with Estuary- or Watershed-Wide Plans/Goals	Habitat restoration Enhanced public access to water resources
Feasibility	Technical Logistical Institutional (decision process/infrastructure)
Cost	Dredging Transportation and placement Maintenance Monitoring
Availability of Funding Mechanisms (see Chapter 5)	USACE EPA Other federal agencies State agencies Local governments Public/private partnerships Private lenders/partners
Environmental Impacts	Of construction Of project, after construction
Legal Authority	Authority to take action Regulatory requirements/compliance
Public Support	Decision leaders (e.g., elected officials) Regulators Neighbors Advocacy groups Other interested parties General public
Risk	Ecological Human health Financial Schedule of project

Not all the criteria may be applicable to the proposed project while other site specific conditions may need to be considered (USEPA/USACE 2007).

2.2 Alternative Selection

Subjective comparison of all environmental, technical, and economic factors affecting the environmentally acceptable alternatives is likely to result in one alternative that is clearly preferable from environmental considerations based on fewer or less significant adverse impacts or greater environmental benefits. Necessary coordination and environmental documentation is shown in *Figure **2*** (USEPA/USACE 2004).

3 Suitability of Dredged Material for Beneficial Use

Once beneficial use has been identified as a disposal alternative, the physical characteristics of the dredged material must be evaluated to determine the suitability of the material for the selected alternative and the potential environmental impacts of placement, and the need for additional chemical or biological testing (USEPA/USACE 2007; USACE 2015a). Initial screening of the physical characteristics of the dredged material can help determine if additional testing is warranted (USEPA/USACE 2004).

Dredged material texture must be conducive to the proposed vegetation habitat, soil drainage and stability, and the long-term success of the restored or created wetland (Barone et al. 2014). The physical characteristics of the dredged material must be tested and evaluated to determine grain size, specific gravity, bulk density, water content or percent solids, permeability, plasticity and volatile solids (Burt 1996; USEPA/USACE 2004). The sediment physical characteristics should also be evaluated for compatibility with different kinds of biological communities likely to develop (USEPA/USACE 2004; USACE 2015a). Clean, coarse grained sediments (sands) are suitable for a wide range of beneficial uses while fine-grained sediments (consolidated clay and silt/soft clay) are suitable for more limited uses such as wetlands habitat development (USEPA/USACE 2007).

Consolidated clay, silt/soft clay and a mixture of material are suitable for wetland creation/restoration projects, and because it is usually found in undisturbed sediment, consolidated clay is likely to be uncontaminated. Consolidated clay is typically dredged as lumps of clay or in a homogeneous mixture of water and clay, which could require dewatering before use (USEPA/USACE 2007).

The most commonly excavated sediments from rivers and ports are silt and soft clay which are more likely to be contaminated, especially from areas of heavy industrial activity or agricultural runoff, because fine grained soils tend to accumulate pollutants more rapidly than coarser soils. Therefore, fine grained soils should be tested for toxicity to plants and animals before placement for wetlands enhancement. Depending on the application, fine grain soils may require dewatering and desalination before placement. In addition to increasing costs due to rehandling, stockpiled material that becomes oxidized will lose organic matter and nutrients, while dry clay is extremely hard and unsuitable for use in restoration (Callaway 2001). However, if the dredge site is previously undisturbed, the material may be a mixture of sediments layers that can be dredged and managed separately (USEPA/USACE 2007).

In addition to the physical characteristics of the dredged material, the chemical and engineering characteristics of the material must be assessed to help determine suitability of the potential placement sites (USACE 1987a). The amount of sediment sampling required depends on the project. Data from

previous sediment sampling may reduce the testing required for routine maintenance projects, while large maintenance projects or dredging in new areas will require more detailed sampling. Grab samples are typically sufficient for most habitat development; however, for new dredging work, samples of sediments from borings are required (Hunt et al. 1978). USEPA/USACE (1998) and the Maryland Department of the Environment (2017) provide detailed guidance for determining type, locations, depths, and quantities of samples, preservation of samples, and the use of sediment sampling equipment to properly characterize the dredged material. Burt (1966), USEPA/USACE (2007), and USACE (2015a) present additional information on the initial screening of contaminants and biological properties.

Winfield and Lee (1999) provides guidance on testing the physical, engineering, chemical, and biological characteristics of dredged material to determine the potential for beneficial uses. Dredged material that is contaminated may still have beneficial uses if some treatment is applied to reduce contamination (USEPA/USACE 2004). Low-cost treatment of contaminants includes bioremediation and phytoremediation. Price and Lee (1999) describe an approach for assessing the phytoreclamation alternative while Fredrickson et al. (1999) provide guidance on determining the suitability of bioreclamation for dredged material treatment.

4 Assessment of Beneficial Use Alternatives

By far the most difficult aspect of beneficial use of dredged material for marsh restoration/creation is the identification of suitable sites (USACE 1987a). Wetland restoration/creation is a long-term process which requires the establishment or reestablishment of conditions suitable for the development and natural sustainability of a viable wetland ecosystem (Hayes et al. 2000). Beneficial use of dredged material further contributes to the challenge due to cost and material suitability considerations.

The selection of a suitable wetland restoration/creation site depends upon existing site characteristics and the potential to modify these characteristics to produce a functioning wetland system (Shisler 1989). Low energy, shallow-water sites are the most suitable; however, cost may become a deciding factor if the distances between dredged and placement sites are significant or protective structures are required to mitigate wave energy (USACE 1987a). Projects adjacent to established and functioning wetland systems which can be used as design models offer the greatest likelihood of long-term success. The lack of wetlands at a site indicates conditions that must be identified and addressed in the design process if the wetland creation is to succeed (Shisler 1989).

Analyzing existing site conditions for marsh restoration is different from that for a creation project. Since wetlands were present in the past, the investigation must determine what caused the degradation of the wetlands and whether the present conditions, including substrate, circulation and sedimentation, can be modified to reestablish and maintain the restored habitat (Shisler 1989; USEPA/USACE 2004). Due to the importance of site conditions on the long-term success of the habitat, restoration of a wetland site is likely to be more successful than creation of a wetland where one had never existed previously (Kusler and Kentula 1989).

Evaluation of a potential wetland creation site requires assessment of existing conditions that may preclude wetlands development, and determination of the economic and environmental feasibility of modifying these conditions to create a suitable environment (Shisler 1989). Marsh development frequently results in the destruction of an existing habitat to create questionably functional habitat. Evaluating the relative benefits of the existing and proposed habitats is likely to be subjective and based on the knowledge and opinions of local authorities (USACE 1987a).

4.1 Site Selection Criteria

Wetland development requires comparison of the environmental conditions at the proposed site(s) with those essential for the development of the biological, chemical, and physical functions that enable the restored or created wetlands to develop into a natural, sustainable ecosystem (Shisler 1989; Hayes et al. 2000).

Critical aspects that should be considered in site selection are listed in *Table **2***.

Table 2. Critical Aspects of Site Selection

Logistical Considerations	• Availability for marsh restoration/creation (USACE 1978) • Dredging volume versus beneficial use requirements (USEPA/USACE 2004). • Jurisdiction concerns (Mohan et al. 2007) • Proximity to dredging area (USACE 1978, USEPA/USACE 2004; USEPA/USACE 2007) • Site accessibility (USEPA/USACE 2004) • Equipment compatibility (USEPA/USACE 2004)	• Scheduling of dredging operations with marsh construction (Broome 1989) • Public acceptability (Broome 1989; USEPA/USACE 2004; USEPA/USACE 2007) • Costs (Broome 1989) • Presence of cultural or archeological resources (Mohan et al. 2007) • Material rehandling requirements (USEPA/USACE 2004)
Physical Considerations	• Topography: tide elevation determines suitable plant species (Broome 1989). • Shape and orientation of shoreline (Broome 1989) • Wave climate, currents, boat wakes and storm surge: susceptibility to erosion and potential necessity of protective structures (USACE 1987a; Broome 1989) • Hydrology (i.e., circulation and sedimentation)	• Salinity: influences plant species composition (USACE 1987a; Broome 1989) • Slope, tidal range and water depth: affect size of intertidal zone, suitable plant species, drainage and susceptibility to erosion (Broome 1989)
Environmental Impact on Existing Habitat	• Potential impacts on water quality • Presence of contaminants at the site • Relative value of existing and proposed habitats (USACE 1978)	• Presence of domestic or wildlife animals, and foot or vehicular traffic (Broome 1989)
Geotechnical Considerations	• Existing soil chemical properties (Broome 1989). • Soil physical properties: sediment type and characteristics, and potential for consolidation and instability (Broome 1989).	• Sediment supply and littoral drift (Broome 1989) • Foundation characteristics: site's ability to support construction activities or structures. (USACE 1987a)
Habitat Development Potential	• Feasibility and level of effort to create or restore sustainable marsh (Hunt et al. 1978)	

4.2 Site Investigation Stages

Site investigation for obtaining the information necessary to evaluate a potential marsh restoration site is most effective when conducted in a series of stages. Site investigation begins with a reconnaissance survey of the potential site and continues through baseline and detailed site investigations (see Figure 5). Information is obtained on an as-needed basis with the sources and amounts of information varying as the site investigation process proceeds from the screening of candidate sites, through site studies, to the design and implementation stages. Decisions on site compatibility with project objectives can often be made during the literature search and on-site reconnaissance stage. The design process, however, may require additional information that can only be obtained during a construction monitoring program (Hayes et al. 2000).

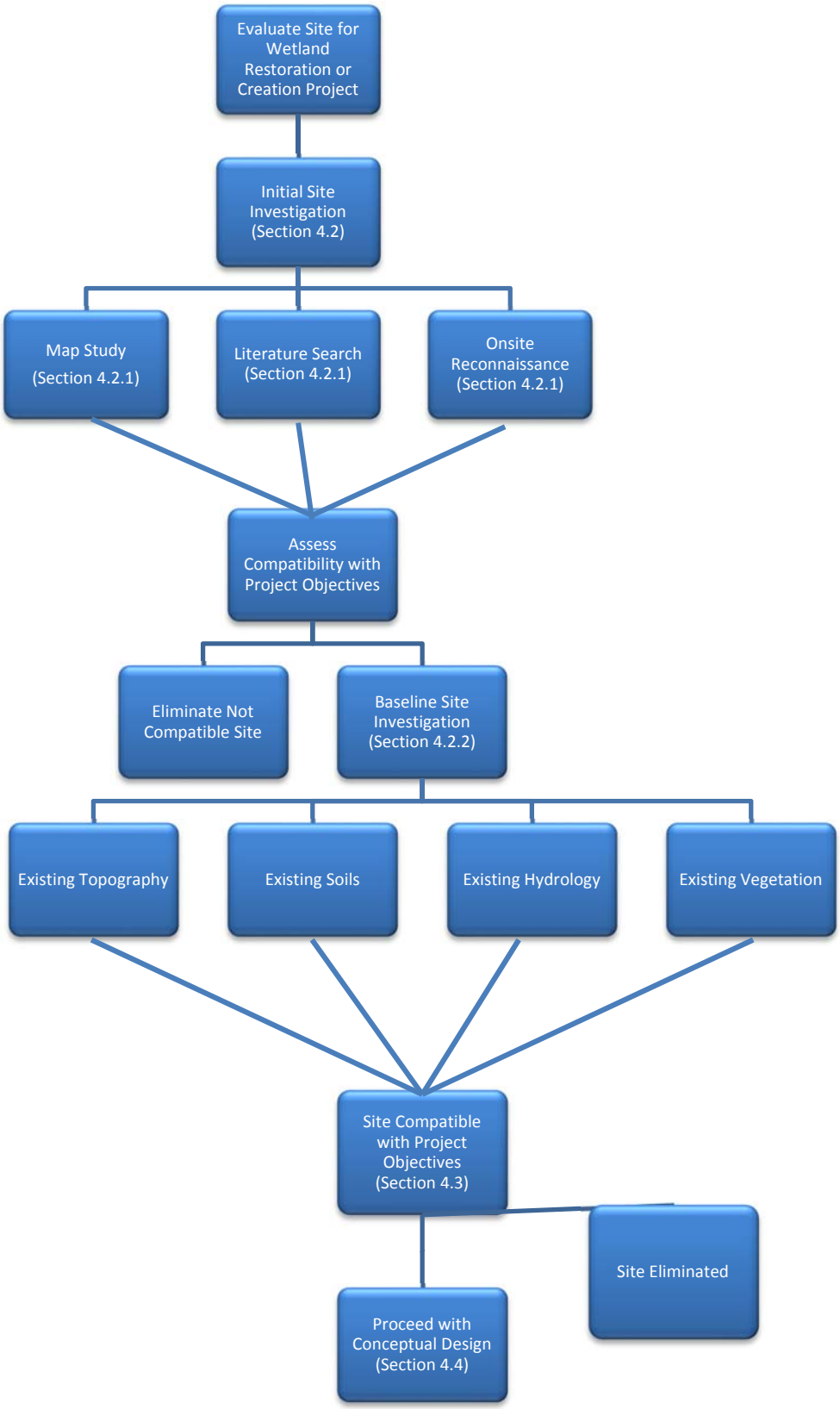

Figure 5. Flow chart of general site investigation process (Hayes et al. 2000).

4.2.1 Map Study, Literature Search and Onsite Reconnaissance

Projects in which the objective is beneficial use of dredged material typically do not have a specified site for placement, so candidate sites must be identified and evaluated. Criteria for suitable sites include the composition of the dredged sediments, site conditions as well as the distance between the dredge and placements sites, costs and other logistic considerations. If possible, several potential sites should be identified for consideration in the screening process (Hayes et al. 2000).

The screening process starts by using available mapping data to evaluate the topography, existing soils, geology, land use and ownership of potential wetland restoration or creation sites. Additional information may be available from local, state and federal environmental agencies or local environmental conservation organizations (Hayes et al. 2000). Sites selected based on the mapping survey should be further evaluated using available literature and on-site surveys of the site surface, drainage patterns and existing vegetation (Hayes et al. 2000). Aerial surveys of potential sites may provide additional information.

The screening process is also necessary to evaluate the potential success of a marsh restoration/creation project. Site topography, soil conditions, geology and land use, and current drainage and vegetation must be assessed to consider site suitability for marsh restoration/creation and to determine the feasibility of meeting project objectives.

4.2.2 Baseline Site Investigation

A baseline site investigation of proposed sites should be undertaken to determine the existing conditions at the proposed wetland site in order to design the wetlands restoration/creation and to establish the baseline conditions against which the site modifications and project success can be measured. Baseline site investigations usually include field observations and measurements, and testing of soil, water, and vegetation samples (Hayes et al. 2000). The baseline site investigation should include:

a) ***Existing Topography***. Topographic maps should include elevation contour intervals so slope angles, slope aspects, and water flow lines can be determined with reasonable precision. Topography can be determined using topographic maps, LiDAR surveys or on small sites, spot topo surveys. Further information on appropriate map scales and survey techniques can be found in Hayes et al. (2000).

b) ***Existing Soil Properties***. The physical, chemical and biological properties of the existing soil are necessary input to the design of the wetlands restoration/creation process. The near-surface soils should be tested for permeability, organic content, salinity, pH, texture, structure, density, moisture content, and compaction. A detailed subsurface investigation is undertaken to test the texture, consistency limits, permeability, and in situ strength, if information about the existing or potential subsurface soil is required for major structural or excavation efforts. Unlike a baseline soil investigation which is primarily undertaken to assess the existing vegetative wetland characteristics, a detailed subsurface investigation is designed to obtain information about modifying the existing soils (Hayes et al. 2000). Hayes et al. (2000) provides information about field and laboratory tests for undisturbed and disturbed soil testing.

***Existing Hydrologic Conditions*.** Existing hydrologic conditions must be evaluated to determine if a functional wetlands is feasible at the site, and if so, to provide hydrologic data necessary for the wetland restoration/creation design (Hayes et al. 2000). The hydrologic investigation should include tidal range, depth and duration of inundation events, salinity, stormwater runoff, and wave (wind wave and boat wake) and wind forces. Tidal range and inundation potential are factors that regulate elevation of sites. Water salinity is an important consideration in the selection of species for planting. Critical wave data includes height, fetch, period, direction, and probability of occurrence. Wetland restoration/creation projects in low wave energy sites are much more likely to be successful. Protective structures are likely to be necessary to sustain marsh vegetation at high energy wave sites (USACE 1987b). The USACE (1981) developed a site evaluation form for marsh planting based on the site shoreline characteristics which may be used to evaluate the potential success of marsh creation/restoration (

c) *Figure 6*). Other evaluation forms for rating the potential success of marsh vegetation based on site characteristics can be found in Knutson et al. (1981) and Hardaway et al. (1984).

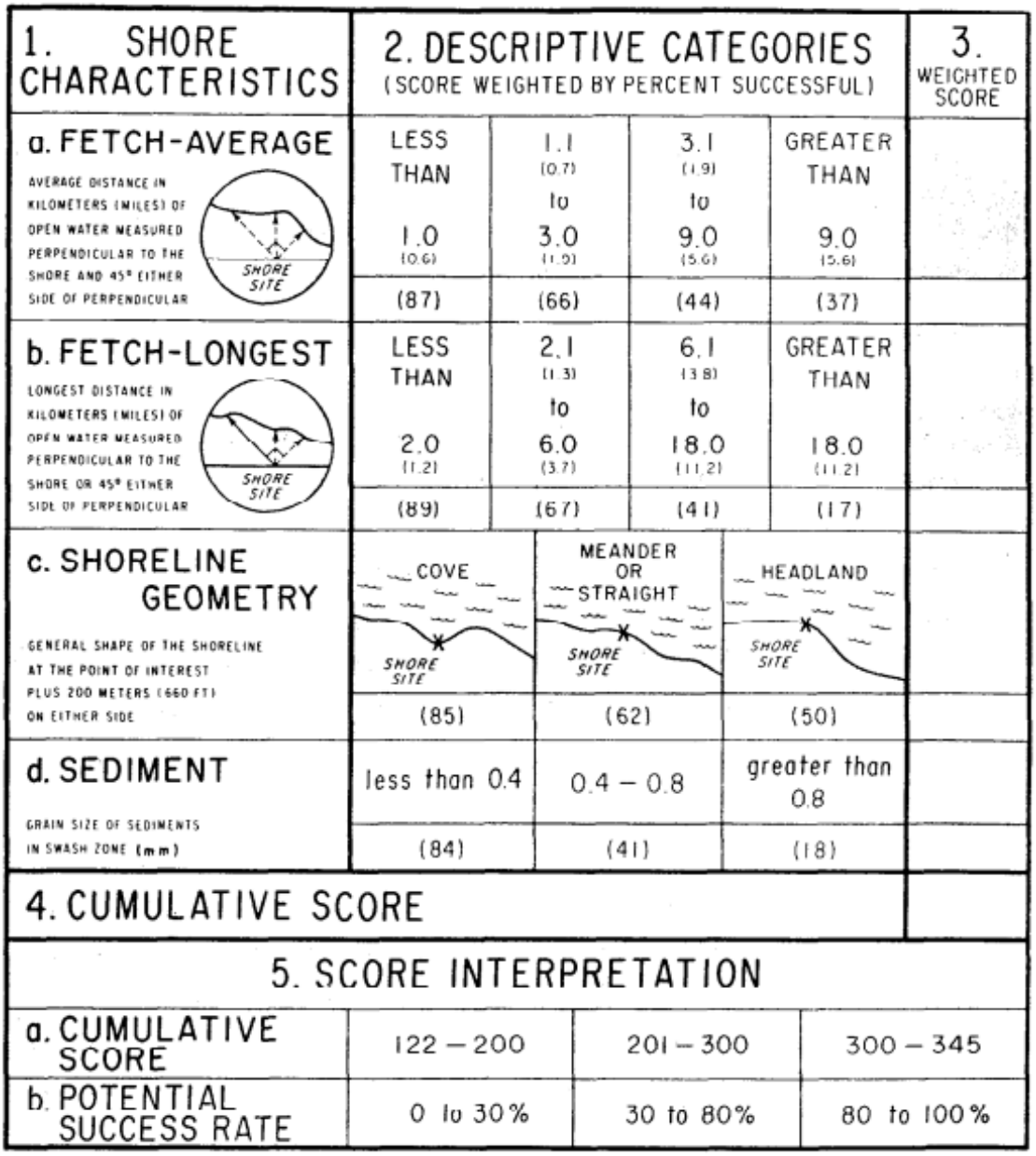

Figure 6. Site evaluation form for marsh restoration/creation (USACE, 1981).

d) ***Existing vegetation*****.** The types and densities of the various plants existing at the wetland site and their distribution over the landscape must be established to determine if natural colonization of marsh vegetation is likely to occur or if site modification will be necessary. Hayes et al. (2000) provides a checklist for evaluating potential wetland project sites based on wetland vegetation (Table 3). A discussion of sampling distributions and sampling size necessary to provide statistically relevant information is provided in Hayes et al. (2000).

Table 3. Summary of Potential Site-Specific Conditions Limiting Wetland Vegetation (from p. 2-66-67, Hayes et al. 2000).

1) Determine the physical limitations for dispersal of propagules onto the site and the establishment of plants on the site.
   a) What are the slope and soil characteristics of the site?
   b) Does the site have the potential for poor drainage characteristics, i.e., for being either well drained or permanently flooded or inundated?
   c) What is the orientation of the slope with respect to the wind and the sun?
   d) Will this orientation have an effect on the potential success of establishment of natural vegetation?
   e) Are there any physical barriers to the natural dispersal of propagules to the site and if so what are these barriers?
   f) Can these barriers be removed easily and still meet the planned project goals?
   g) Are the soil conditions and characteristics adequate for the revegetation by local species?
   h) What is the soil condition including fertility and potential for productivity?
2) Evaluate the climatic limitations of the site. In which season will the site be ready for vegetation to be established?
3) Determine the biological limitations to natural revegetation.
   a) Is there an abundance of nuisance animals in the surrounding communities that often feed on seeds and young seedlings?
   b) What are the dispersal mechanisms of the native vegetation in the area?
   c) Is there a natural wetland complex near the site to provide a source of propagules?
   d) Are there sufficient numbers of desirable species at the site or adjacent to the site?
   e) How far away are the nearest sources of natural propagules and are the propagules likely to be dispersed to the site?
   f) What is the composition of the seed rain will reach in the interior of the site?
   g) Is the seed bank a reliable source of a sufficient number of species?
   h) Are the sources of propagules in good, healthy condition, stress-free, free of deleterious insect damage and signs of disease?
   i) Are there any undesirable species at the site or near the site?
   j) Are there any desirable species remaining on the site or adjacent to the site and what is the areal extent of the species?
4) Evaluate the site history and compare with current site conditions.
   a) Hydrology - Has the natural hydrology of the site been significantly altered so that local species or species indigenous to the area would be precluded from the normal course of revegetation because the species and the site conditions are no longer compatible?
   b) Soils - Have the soil characteristics of the site been significantly altered so that natural revegetation will be difficult without some site preparation or manipulation?
5) Identify any of the above problems that cannot be overcome.
6) Finally, determine if the site condition is compatible with the planned project goal if the site is not planted with transplants.

4.3 Determination of Environmental Suitability

Contaminated dredged material is usually not acceptable for wetlands restoration/creation unless the material is exempt from testing through 40 CFR 230.60 (General Evaluation of Dredged or Fill Material)

or testing indicates the material is suitable for open-water disposal. State and local jurisdiction regulations determine if the dredged material is suitable for beneficial use (USEPA/USACE 2004). The Great Lakes Commission (2004) provides guidance on testing and evaluation of dredged sediments for beneficial use.

4.4 Retention of Environmentally Acceptable Beneficial Use Alternatives

Once the appropriate assessments have been completed, determination of the project to meet all standards and criteria can be made, and other factors such as technical feasibility and costs can be weighed in the selection of an alternative (USEPA/USACE 2004). In instances where the project is identification of potential disposal alternatives, this would include options in addition to tidal wetlands restoration or creation. In this document, only beneficial use of marsh restoration or creation is considered. A detailed discussion of all evaluation criteria is beyond the scope of this document; however, more information, including a description of the procedures to be followed with respect to NEPA, CWA, and MPRSA, can be found in USEPA/UASCE (2004). The Great Lake Commission (2004) offers an example of one possible method of evaluating beneficial use alternatives (Table 4). The weights of each category need to be determined by the stakeholders based on their priorities. Each criterion can be scaled from negative to positive values to account for adverse and beneficial impacts. The score can be then multiplied by the weighting factor and summed to determine the total score for each alternative.

Table 4. Sample evaluation criteria table for beneficial use selection (Great Lakes Commission 2004).

	Criterion	Weight	Option 1	Option 2	Option 3	Option 4	Non-beneficial use
Economic	Immediate cost to agency						
	Long-term cost to agency						
	Immediate external costs						
	Long-term external costs						
	Immediate economic benefits						
	Long-term economic benefits						
Social	Human health impacts						
	Human health benefits						
	Aesthetics						
	Social perceptions						
	Public support / opposition						
	Other social impacts / benefits						
Environmental	Toxicity to terrestrial species						
	Toxicity to aquatic species						
	Impact on water quality						
	Impact on terrestrial habitat						
	Impact on aquatic habitat						
	Impact on wetlands						
Other							
	Sum						

4.5 Long Island Sound Site Identification

Multi-Criteria Decision Analysis (MCDA) is a tool that enables stakeholders to work collaboratively to create a decision model that allows different points of view to be represented. Increased stakeholder involvement improves the likelihood that the selected alternative will be approved and implemented. Stakeholder values on evaluation criteria and weighting factors for potential dredged material disposal alternatives as part of the Long Island Sound (LIS) Dredged Material Management Plan (DMMP) were identified by the USACE New England District in cooperation with the Engineer Research and Development Center (ERDC) Risk and Decision Science Team (USACE 2015b). The LIS stakeholders identified navigation and environmental protection as the highest priorities but there was agreement that that all identified criteria were at least somewhat important (USACE 2015b). The final report on the MCDA conducted for the LIS DMMP, "Stakeholder Elicitation for Long Island Sound Dredged Material Management Plan, December 2013," provides additional information on the MCDA process followed in this study (USACE 2015b). The study identified sites that were too small to be suitable for Federal dredging disposal needs, but could be appropriate for smaller dredging projects. Forty-four sites were

identified in Connecticut, most of which are beaches with a total of 37 municipal, county, or state beaches, and Federal Shore Protection projects (USACE 2015b).

All four habitat restoration sites identified in the DMMP (USACE 2015b) are located in New York; two of which have already reached capacity; however, in Connecticut, beneficial use of dredged material has not been pursued other than for shoreline protection (USACE 2015). Therefore, the DMMP has identified three sites where dredged material could be used for marsh creation: Norwalk Outer Harbor Islands [enlargement of a confined disposal facilities (CDF) site proposed for that location]; Sandy Point in Little Narragansett Bay, and Sandy Point in New Haven Harbor at West Haven, both of which would involve filling in the lee of an existing barrier spit or island to create. The Sandy Point sites were identified too late and so were not included in the screening process. The capacities of these sites are shown in in Table 5. Any of these sites could be a demonstration project for habitat restoration in LIS (USACE 2015b).

Table 5. Salt marsh creation sites considered in DMMP (USACE 2015b, Table 4-13).

Site Name	State	Municipality	Area (Acres)	Fill Capacity (CY)
Norwalk Outer Harbor Islands	CT	Norwalk	78	930,000
Sandy Point at Little Narragansett Bay	RI	Westerly	65	500,000
Sandy Point at New Haven Harbor	CT	West Haven	70	1,100,000

Participation in local beneficial uses planning should be encouraged as it facilitates coordination in the scheduling, location, and scale of dredging and beneficial use. Private parties interested in funding or promoting a beneficial use project should contact the appropriate USACE District office (USEPA/USACE 2007).

5 Design

Designing wetland restoration/creation projects is very challenging. Project success frequently depends on disparate fields of expertise coming together to create a coherent, functional design which achieves the project objectives, provides the necessary ecosystem services and fits seamlessly into the existing landscape. Additionally, the project must achieve these objectives in a very short period of time compared with the length of time needed for a natural marsh to develop, and it must be sustainable over the expected lifetime of the project (Hayes et al. 2000). Typically, stakeholders and designers must consider the consequences of destroying an existing habitat with the potential of creating the desired wetlands habitat since our limited understanding of wetlands systems precludes guarantees of functional and sustainable success (Burt 1996; Hayes et al. 2000; Zimmerman and Rozas 2000).

The most efficient and successful approach for marsh restoration/creation relies upon natural processes rather than hard engineering to achieve natural marsh functions. Nature based engineering from project inception, through design, construction and monitoring results in a project that works with rather than against nature. This reduces costs while increasing the potential for success (Mohan et al. 2007).

Two general approaches can be undertaken in wetland design. The first is a cookbook approach where the design is based on generalized concepts, plans, specifications and plant species. The second is a site-specific approach where the design is based on the specific objectives of the project and the site (Mohan et al. 2007). Regardless of which approach is followed, well-conceived projects all include:

- Site assessment
- Development of detailed plans and specifications with appropriate review and stakeholder participation
- Construction, and operations and maintenance procedures developed and implemented
- Monitoring and evaluation

(Shisler 1989; Mohan et al. 2007).

5.1 Developing Site Designs

There are several techniques that can be used to beneficially dispose of dredged material in coastal environments:

- Thin layer disposal in which dredged material is applied in thin layers to increase the elevation of a degraded wetland;
- Placement on the seaward edge of a marsh to restore the width of the intertidal zone and stabilize eroding marsh edges;
- Subtidal placement to reduce erosion in intertidal regions;
- Intertidal deposition to reduce wave energy and thus erosion of marsh edges; and
- Creation of berms and dikes for erosion protection

(Colenutt 2001).

Regardless of the technique, design of wetland projects is based on the project goals and the specific environmental conditions at the site; thus, a rigid set of designs or a cookbook approach to the design process is unlikely to result in a successful wetlands project. The health of adjacent wetlands can provide useful information on design parameters by identifying the aspects of the wetlands that are performing well and those that may need to be modified in the current project. The objective of most wetland projects is to enhance the physical, chemical, and biological processes that support the wetland ecosystem. Therefore, it is essential that the project goals be correlated with wetland functions (i.e., hydrologic, water quality and life support). As some wetland functions may be mutually exclusive, it is worthwhile to identify the goals as primary and secondary objectives for evaluating the conceptual designs (Hayes et al. 2000).

The most successful conceptual design alternative will be one in which the site conditions and constraints most closely match the goals of the marsh restoration or creation project. The procedure for developing and selecting the most viable alternative is:

1) establishment of design criteria;
2) brainstorming among stakeholders;
3) development of conceptual designs;
4) design phase analysis;
5) refinement of best designs;
6) development of the detailed design for project site

(Hayes et al. 2000).

Mohan (2001) provides a detailed discussion of the steps in the design process.

5.1.1 Design Criteria

Design criteria are related to wetland characteristics necessary to provide wetland functions. These can be divided up into four categories: biologic, hydrologic, geotechnical and engineering design; however, there is considerable overlap between the categories and the related wetland functions (Hayes et al. 2000). The primary focus of biologic design criteria is the establishment of suitable wetlands vegetation with the assumption that once planted vegetation is successful, wildlife usage will develop naturally (Hayes et al. 2000). Wetland hydrology is critical to the wetland system; if the hydrology is incorrect, the wetlands will not exist (Shisler 1989; Hayes et al. 2000). Previously existing wetlands can be degraded or destroyed by changes in the wetland hydrology. Thus, an accurate understanding of the hydrologic conditions, such as rainfall, runoff and surface and groundwater infiltration, is critical to the successful establishment of wetlands vegetation (Mohan et al. 2007). Adjacent wetlands can provide valuable information in the determination of hydrologic design conditions (Shisler 1989). Geotechnical criteria, such as the geologic setting, soil characteristics and geomorphic processes, affect the biological and hydrological conditions at the site (Hayes et al. 2000).

These design criteria categories are addressed in the conceptual design by four primary components: location, elevation and slope, orientation, and shape and size (Burt 1996). For instance, important hydrologic design criteria include hydrologic setting (location), flood duration, timing, and depth (elevation and slope), wave and current conditions (location, orientation and shape), flow velocities (location, elevation and shape), storage capacity and surface area (shape and size) (Hayes et al. 2000). Design decisions cannot be made independently. Decisions of project location will influence elevation, slope, orientation and size which in turn will affect vegetation selection, types and diversity of habitats, susceptibility to erosion, and the hydrologic regime (McBride and Pfannkuch 1975; Hayes et al. 2000).

5.1.1.1 Location

The project location may be the most critical decision in determining the success of the created or restored marsh (USACE 1987a; Burt 1996). Wave and current energy acting on the site is one of the most important site components during the decision process and subsequent project development (Hayes et al. 2000). Low energy sites with sandy dredged material are the most suitable for wetlands projects (USACE 1987a; Burt 1996). Although high energy sites should be avoided if possible (Hayes et al. 2000), the goals of the wetland project may be achievable with the structural protection or containment. Additionally, high energy sites are likely to require periodic maintenance for the life of the project (Hayes et al. 2000).

The tidal range at the project location along with elevation and slope determines the intertidal zone, the areal extent, timing and duration of daily inundation, zonation of vegetation and the transport of sediments.

The grain-size distribution of the site may necessitate temporary or permanent containment. While containment is usually needed for hydraulically placed clay regardless of the site's wave and current conditions, silt place in low energy conditions may not require confinement but will in moderate energy conditions (USACE 1987a; Burt 1996).

Ice can be an extremely destructive force in New England marshes. Ewanchuk and Bertness (2003) suggest that after wrack disturbance, ice is the most important natural disturbance in New England marshes. Southern and Northern New England are affected somewhat differently from ice forces. In Southern New England, ice damage primarily affects low marsh. Ice adhesion can remove large portions (1 - 3 m^2) and transport the vegetation on the ebb tide (Bertness and Ellison 1987; Brewer et al. 1998; Ewanchuk and Bertness 2003). Further north, ice damage destroys low marsh vegetation every winter (Ewanchuk and Bertness 2003). In northern New England, ice disturbances also affect the middle and high marsh when ice sheets melt and deposit sediment that had been transported within the ice sheet from other locations (Ewanchuk and Bertness 2003). Ice damage consists of the formation of ice ridges, and scouring and gouging of the marsh substrate (Majka 2015). Despite its importance, there is very little in the literature on design guidelines for living shorelines in ice impacted climates; most of what exists is anecdotal (Majka 2015). Therefore, if possible, wetland restoration/creation projects should not be constructed where ice floes are possible due to wind and currents. Ice accumulation and transport is likely to destroy recently constructed wetlands (Reimold and Cobler 1986; Shisler 1989).

5.1.1.2 Elevations and Slopes

The areal extent of the intertidal zone is determined by elevation, slope and tidal range which determine the degree of submergence, and thus are critical to wetland design and construction since the hydrologic regime is vitally important to wetland vegetation and animal species (Broome et al. 1981). The intertidal zone can be divided into the area which is regularly flooded by the tides, known as the low marsh, and the high marsh which is flooded less frequently during periods of storm surge or spring tides (Shisler 1989). Project elevations and slopes must meet vegetation criteria for inundation frequency and depth (Hayes et al. 2000). Dredged material must be placed within the elevation limits of the desired habitat, while allowing for settlement of the soil due to consolidation of the dredged material and compaction of the foundation soils (USACE 1987b; Shisler 1989). Determination of the final elevation is the most critical of the operational considerations as it controls the amount of material required and the biological productivity of the restored or created habitat (USACE 1987a; Burt 1996). As long as project goals can be met, variation in elevation across the wetlands is desirable as it increases biological diversity. The desired final elevation can be achieved with successive placement of dredged material (USACE 1987a; Burt 1996).

The final elevation of fine substrate is much more difficult to predict than substrates formed of sandy material since these dry more quickly than substrates composed of fine clays and silts. Fine substrate will remain in a slurry state for a significant period of time following placement and may require a

retaining structure for containment (USACE 1986b). Guidance on estimation of consolidation is provided in the HR Estuarine Muds Manual (Delos and Ockenden 1992).

The slope of the created or restored wetland is also a critical design consideration. If the slope is too steep, the vegetation will not be able to maintain cover and stabilize the slope to mitigate erosion (Shisler 1989). However, slopes that are too gradual can result in poor drainage and high salinities (Broome et al. 1981). Reimold and Cobler (1986) in their evaluation of four New England wetland projects determined three of them had problems due to excessively steep slopes. Shisler (1989) recommends slops of 1:5 to 1:15 for increasing wetland species diversity and decreasing erosion potential, while Broome (1989) suggests slopes in the range of 1 to 3 percent are preferable.

5.1.1.3 Orientation and shape

The orientation and shape of the wetlands influence the capacity to provide wetlands functions (Hayes et al. 2000). Therefore, the orientation and shape of the wetland project should be designed to mitigate drainage and runoff issues and to blend in with the existing environment (USACE 1987a; Burt 1996). If the site is subjected to high energy waves or currents, the project should be oriented and shaped to minimize exposure. This will not only increase the potential sustainability of the site, but will also reduce structural protection costs (USACE 1987a; Burt 1996).

5.1.1.4 Size

The size of the restored or created wetland affects the type, diversity and success of wetlands species (Adamus et al. 1991; Hayes et al. 2000). While wetlands constructed adjacent or in close proximity to existing wetlands will more easily develop wetland functions, small, isolated wetlands may have limited productivity, and therefore limited value as wetlands habitat, due to the size requirements of various species. Additionally, a wetland system consisting of open water, a transition zone and uplands is likely to be more viable and productive than a system constructed only of emergent wetland vegetation. Therefore, it is important to determine the size criteria of the wetland species which are likely to use the restored or created wetland (Shisler 1989).

The challenge is to match the size of the marsh with the volume of the dredged material. The wetlands project can be based on a single dredging operation or deposition over multiple years of maintenance dredging. Containment cells can be constructed and filled, with new cells created as fill material becomes available. The USACE (1987a) and Burt (1996) recommend this gradual method of marsh development whenever possible.

Maintenance and economics also should be considered when evaluating the size of the wetland (Shisler 1989).

5.1.1.5 Sediment design

The sediment characteristics will determine if temporary or permanent containment substrate is necessary. Fine-grained dredged material must be confined to allow retention of the solids by gravity sedimentation during the placement. Discussions of containment structures is beyond the scope of the document; however, the design must account for the size of the containment area, the inflow rate,

operational conditions, physical property of the sediment and the salinity of the water which influences flocculation and settlement rates (USACE 1987a; Burt 1996).

5.1.2 Initial Site Assessment

Once the design criteria are established, an initial site assessment should be performed. Wetlands designs should align with existing site conditions as much as possible (Hayes et al. 2000). The site assessment should be conducted to attain the necessary data to address the design criteria:

- Biological: species sampling and mapping to determine populations, diversity, productivity;
- Hydraulic and hydrologic: water depth, tidal range, wave and current conditions;
- Geotechnical: sediment characteristics, borings, site permeability, etc.; and
- Environmental: tests for water and sediment contamination

(Mohan et al. 2007).

It is important to assess the conditions not only at the dredge site but also at the wetlands placement site. Much of the data will likely be available from assessments conducted during the site selection process. Previous dredging records can also be a good source of information.

5.2 Creating Island Habitats

Since the 1890's over two thousand man-made islands have been created by the deposition of dredged material throughout U.S. coastal, Great Lakes, and riverine waterways (USACE 2015a). Most of these were created during the construction of the Intracoastal Waterway System in the 1930's and 1940's (Guilfoyle et al. 2006). Many of these islands were created simply as a convenient place to dump dredged material. Over time they developed naturally into wildlife habitats. In other cases, islands were created to provide habitat for birds and other wildlife (Landin 1997).

Dredged material islands range in size from less than one acre to over 200 acres. The islands may be constructed individually or as aggregated cells created over a period of time. Islands can also be created by increasing existing or eroding islands. The islands are typically created using sand or silt-sand dredged material. The placed sediment may be confined using with a man-made structure, stabilized with wetlands vegetation or with a combination of structures and vegetation (Cox et al. 2011).

The bird and wildlife islands that are part of USACE Dredged Material Research Program (DMRP) habitat sites are generally well-document with respect to construction techniques, vegetation establishment, and design for bird and wildlife habitation. Moreover, recreational activities such as camping, fishing and bird watching have been created on some islands (Yozzo et al. 2004). Studies conducted by the USACE on created islands have revealed the components of successful wildlife islands. These included creation of varied topography to include dunes, swales and mudflats as well as allowing trees and shrubs to colonize (Yozzo et al. 2004). Buckley and McCaffrey (1978), Chaney et al. (1978), Soots and Landin (1978) and Yozzo et al. (2004) provide additional information about components of dredged material island creation. However, information on island habitat development, whether new or existing islands, is primarily focused on the needs for bird habitats. Very little information is provided for other motivations for island development using dredged material (USACE 1987a).

As with wetlands restoration and creation, construction of artificial islands requires a trade off in existing habitat. Shallow water marine habitats can be very productive, so existing resources and potential benefits of the proposed project must be balanced (Oceanic Society 1982).

While not an island, the Tommy Park Cell One Project (TRCA 2017) provides information and justification on why and how a marsh island can be created. The Cell One capping project was undertaken to create a wetland to support aquatic and terrestrial species habitats and to increase the ecological integrity and biodiversity of Tommy Thompson Park in Toronto. The project incorporated varied slopes and shoreline conditions as well as different substrates and structures to create habitat features for the desired species (TRCA 2017).

5.3 Conceptual Designs Evaluation

Formal conceptual designs should be developed for all initial designs likely to fulfill the design criteria. Preliminary drawings and design calculations, including all engineered structures such as flow control and containment structures, culverts and gates, must be sufficiently detailed to estimate costs, constructability and comparison with project objectives to enable assessment of the design alternatives with the design criteria. This step, in addition to identifying the most suitable design and potential suggestions for improvements, provides a quantitative estimate of construction, maintenance and operational costs of the proposed designs (Hayes et al. 2000).

5.4 Final Design

The selection of the final design should be based on the most cost-effect plan that will achieve the project objectives (Hayes et al. 2000). A critical component of the final design is the volume and type of material to be dredged and the rate at which it will be available for marsh construction from which site capacity and operating life can be estimated. Capacity is determined by the amount of material the site can handle accounting for bulking (expansion of the dredged material due to the addition of water and handling of the material) and long-term shrinkage due to consolidation (from gradual release of excess pore-water pressure) and desiccation (drying and formation of a crust). The operating life is the number of years it will take for the site to be completely filled with dredged material (Mohan et al. 2007).

The gradual shrinkage due to consolidation and desiccation is a major determinant of the volume of material for fine-grained dredged material (Mohan et al. 2007). The U.S. Army Engineer Research and Development Center (ERDC) has developed a computer model, Primary Consolidation Secondary Compression and Desiccation of Dredge Fill (PSDDF) (Stark 2014) which can be used to estimate the total settlement of dredged material based on the consolidation characteristics of the layers above and below the fill material, the consolidation characteristics of the dredged fill material, local environmental conditions and the surface water management practices within the containment facility (Mohan et al. 2007).

5.5 Subgrade and Substrate Design

Subgrade and substrate soils are vital components of a wetlands restoration or creation project and the functions provided by the wetland system (Hayes et al. 2000). Subgrade soils provide the structural

support for the marsh. Substrate soils provide the physical support for vegetation, a biological interface for macro and micro-invertebrates and a medium for nutrients for plant growth (Hayes et al. 2000). The physical characteristics of the soil are critical for geotechnical engineering, while the chemical and biological characteristics influence the types of plants and organisms that will colonize the restored or created wetlands. Depending on the source of the wetlands hydrology, subgrade soils may need to be able to contain the water or allow groundwater exchange and therefore may not be suitable for wetland substrate. Additionally, soils which provide sufficient structural support for wetland construction may be too dense or impervious for vegetation establishment (Hayes et al. 2000).

Substrate materials for constructed wetlands must be able to physically support vegetation establishment, thus the substrate should be dense enough to remain consolidated when wet but not so dense that rooting is impacted. The substrate also must be deep enough to allow for a root system (Hayes et al. 2000). Case studies have shown that a separate substrate layer of 15-30 cm over a constructed subgrade layer is sufficient for most wetland systems (Gilbert 1995).

The dredged sediment must be evaluated to assess its suitability for marsh substrate. An adjacent or nearby natural wetlands can function as a reference source, providing valuable insight on suitable soil parameters such as texture, permeability, bulk density, and organic and nutrient content, as well as effective substrate depth (Hayes et al. 2000). In addition, the dredged materials should be evaluated for consolidation, potential contaminant release, and sediment stabilization (Callaway 2001). Because soils are very slow to develop, substrate is frequently the limiting step for marsh restoration. In San Francisco Bay, the preferred approach is to use dredge spoils below the final desired marsh elevation, allowing the upper 20-30 cm of substrate to accumulate naturally (Callaway 2001).

5.6 Containment Structures

Marsh restoration/creation sites may require protection from erosion and potential structural failure caused by waves (wind or ship wake) and currents. Typically, this protection is provided by existing landforms or dikes. Structures may also be used to constrain the dredged material until it consolidates and to control the migration of fines (Burt 1996). Marsh creation projects may also be developed as Confined Aquatic Disposal (CAD) cells to segregate dredged materials with less suitable physical or chemical characteristics into more protected areas of the marsh fill (USACE 2015b).

Locating the restoration/creation project in a low wave energy environment is the ideal solution, yet this is not always possible. In higher energy conditions, dikes protected with filter cloth, revetment or anti-scour blankets may be required (USACE 1987a). Design of a wetland dike must consider the environmental conditions (waves, tidal range, foundation) as well as the proposed construction materials and construction approach (Hayes et al. 2000). Hayes et al. (2000) provides information on dike design, foundation stability and geometry including information on the recommended freeboard as a function of fetch, minimum allowance for dike internal settlement (based in part on Soil Conservation Service 1992) and side slopes for dikes on strong foundation (based on USBR 1973). Additional sources of dike design and construction guidance can be found in the USDA-SCS Engineering Field Manual (Soil

Conservation Service 1984) and USACE publications such as Hammer and Blackburn (1977) and USACE (1987b).

6 Construction Considerations

Unlike most construction projects, the outcome of a marsh restoration/creation project is not entirely predictable. Therefore, the planning and construction of a wetlands project require flexibility. The goals of the project should be defined in terms of wetlands functions, with quantifiable and qualifiable metrics to evaluate the success of the project. However, achievement of precise values may not be feasible so the stated objectives should be conservative and flexible. Otherwise, failure to attain the stated objectives may result in excessive maintenance costs and potentially, legal liability. Attempts to over design and landscape the wetlands into performing functions that do not occur naturally or are unsuited to the project location are likely to result in partial or complete failure of the project (Mitsch and Gosselink 1993). While the contract should contain detailed specifications, such as final elevations as they are critical to specific habitat species and therefore the success of the project, it should refrain from stating the final qualities of the wetlands (Hayes et al. 2000). A cost-effective, low maintenance approach allows time for nature to respond within the constraints of the project goals (Mohan et al. 2007).

After the design and construction specifications have been finalized, the actual construction of the wetlands is usually left to the independent contraction. Therefore, the unique requirements and intricacies of marsh restoration/creation appropriate equipment and construction approaches should be emphasized in the request for bids documents (Hayes et al. 2000). Potential contractors must be aware of specialized planting techniques, appropriate equipment and construction approaches for marsh restoration/creation projects and the critical importance of final elevations to ensure the elevations are appropriate for the design vegetation and animal species. Contractors need to be aware to not maximize dredged material disposal as it could jeopardize the entire project (Hayes et al. 2000). Hammer (1992) recommended that the proposed restoration/creation site be staked and that potential contractors be invited to a pre-bid site investigation to help ensure that they appreciate the complexities of the project and therefore, the bids received will be realistic (Hayes et al. 2000). Federal, state and local governments usually require selection of the lowest cost qualified bidder. Additional quantifiable considerations can be included in the bid evaluations if they can be used to equitably compare among bidders and the evaluation metrics are explained fully in the bid documents; however, this usually complicates the evaluation process and is often opposed by the contracting officials (Hayes et al. 2000).

Scheduling is particularly important since certain times of the year are more favorable to construction in wetlands due to the effect of construction activities on existing species, and the need to have the dredged material in place and a stable surface elevation at the start of the growing season (Shisler 1989; Burt 1996).

Collaboration between the contractor and engineers and the biologists should continue through the construction phase. Seemingly insignificant changes in one aspect of the project could have major impacts on another aspect beyond the knowledge or experience of another discipline (Hayes et al. 2000). The design specifications must integrate the concerns and priorities of all specialties into a constructible document. Even the final grade of the marsh is frequently a problem in restoration projects (FTN 1993). Site conditions should be monitored throughout the construction phase to ensure that the project is built as designed (Shisler 1989). Small changes in project elevation could result in a dramatic change in the establishment of vegetation. Although flexibility may be necessary, corrections or modifications to the specifications during the construction phase could significantly increase costs (Hayes et al. 2000).

7 Lessons Learned

Cammen (1976) determined marsh restoration/creation success depended on five factors:

1) Similar elevations for the restored/created marsh using dredged material to natural marsh in vicinity;
2) Similarity of the dredged material with natural marsh sediment particle size;
3) The natural sedimentation rate in the vicinity of the restored/created marsh;
4) The proximity of the dredge site to natural marsh;
5) The relative maturity of the natural marsh faunal community.

Since Cammen's paper was published, dredged material has been used successfully for marsh restoration/creation projects with a resulting increase in the lessons learned for the beneficial use of dredged materials.

7.1 Planning Observations

Beneficial use of dredged material for marsh restoration/creation projects have demonstrated that development of successful, implementable projects have been led by local interests responding to a need (Collins et al. 2015). A team should be formed consisting of technical, social and economic experts as well as local and community groups capable of identifying and understanding local concerns. Regulators and landowners should be involved early in the project to bring all interested parties to a common cause (Mohan et al. 2007). The team should be engaged often to identify and address issues as they occur (Chaffee and Frisell 2017; Yepsen et al. 2017); Collins et al. (2015) recommends monthly meetings as an overall team with sub-committees meeting weekly. The project team should establish the project goals, objectives and performance criteria as discussed in sections on site selection criteria and design criteria. If dredging will be an ongoing concern or the volume of dredged material is likely to exceed the requirements of a particular marsh restoration/creation, a regional beneficial use plan should be developed to provide detailed habitat restoration/creation alternatives and goals, and to support engineering and material placement options (Collins et al. 2015). As-built and post-construction project goals should be clearly documented to evaluate the project's success (Yepsen et al. 2017).

7.2 Assessment of Suitability for Marsh Restoration and Creation

When evaluating the dredging project requirements and assessing the suitability of the dredged material for beneficial use, and the suitability of the marsh restoration/creation site alternatives, it is essential to conduct site visits (Chaffee and Frisell 2017), not only in the planning and design stages but also during the construction phase to ensure that design and construction issues are addressed promptly and accurately. Site surveys, sediment characteristics analysis and consolidation estimates are essential for successful design and implementation of a marsh restoration/creation project (Collins et al. 2015). The impacts of the project on the proposed site should be documented and if possible, future impacts should be anticipated (Chaffee and Frisell 2017).

7.3 Design

A successful marsh restoration/creation project must have physical and biological attributes that mimic a natural marsh. The physical attributes include:

- Hydrology (Collins et al. 2015);
- Elevation using bio-benchmarks and reference marsh surface elevation (Collins et al. 2015; Pecchioli 2015);
- Undulating marsh surface condition (Collins et al. 2015);
- Mixture of vegetated edge and open water areas to allow free tidal exchange and full circulation through tidal channels and tributaries (Collins et al. 2015);
- Sufficient habitat that meet the proposed vegetation and wildlife species criteria (Collins et al. 2015).

The required biological attributes include:

- Intertidal marsh habitat for birds, fish and other aquatic and wildlife species typically found in natural marshes;
- Biological function similar to existing natural marshes;
- Enhance habitat heterogeneity to increase biodiversity

(Collins et al. 2015).

Of these, arguably the most important is the final marsh elevation since errors in the design or constructed marsh elevation will lead to failure to meet the project objectives (Mohan et al. 2007; Yepsen 2017). Not only will the design vegetation fail to become established and appropriate wildlife species habitat not develop when the constructed marsh elevation exceeds the design or reference elevation, failure to develop a system of tidal channels can extend the time it takes for the constructed marsh to achieve functional equivalency to the reference natural marsh and could prevent the development of the desired marsh functions (Winfield et al. 1997). Therefore, implementing a system that allows the marsh to evolve naturally, maintaining tidal flushing and reducing the need for containment, is the preferred option (Mitsch and Wilson 1996; Yepsen 2017).

Additional lessons learned in the design phase include:

- Plan for extensive data collection including detailed site surveys to support project design (Pecchioli 2015; Chaffee and Frisell 2017);
- Plan and budget for adaptive management changes to avoid adverse impacts (Chaffee and Frisell 2017);
- Manage stakeholder expectations for design and outcomes (Chaffee and Frisell 2017).

Coordinating a marsh restoration/creation project with maintenance dredging schedules and locations is challenging. To reduce design and construction obstacles and increase the likelihood of project success:

- Be responsive to bidder feedback and open to issuing addenda to ensure proposed project is constructible (Chaffee and Frisell 2017);
- Consider the distance that sediments can be pumped from the dredge site and the distance from the marsh edge that sediment can be pumped onto the marsh (Yepsen et al. 2017);
- Chaffee and Frisell (2017) recommend a single contractor for dredging and in-marsh work, although others have suggested that may result in a project elevation more likely to meet dredging disposal needs than marsh restoration/creation requirements;
- For larger marsh projects, constructed as a series of wetland cells, the cell should be optimized for the volume of dredge material. Larger cells decrease construction costs and reduce the volume of material need to construct containment dikes; however, larger wetland cells are more difficult to manage in terms of consolidation of the dredged material and the complexity of the hydraulics (Mohan et al. 2007).

Finally,

- The planting schedule should ensure that the dredged material has undergone most of its consolidation and settlement prior to the time of planting;
- Pilot demonstration projects are useful in obtaining site specific conditions, increasing public support and field testing new techniques and assumptions

(Mohan et al. 2007).

7.4 Construction Considerations

- Criteria and objectives should be followed as closely as possible through construction, initial development, and some period of follow-up (long-term) monitoring by data collection and site evaluation (Landin et al. 1989); however, immediate and long-term adaptive management measures are critical (Pecchioli 2015, Chaffee and Frisell 2017).
- Need to be prepared to make decisions in the field about project design and target elevations so frequent construction oversight is necessary (Collins et al. 2015; Chaffee and Frisell 2017).
- Site variables must be taken into account and allowance made for margin of errors since correct elevation of the site after consolidation and settling is absolutely critical (Landin et al. 1989). If a site is allowed to evolve naturally over time, it may develop into an alternative but functional habitat. Development of a contingency plan recognizes that this should not necessarily be considered a project failure without assessment of the habitat attribute (Landin et al. 1989).

7.5 Monitoring

- Monitoring is critical to evaluate project success or failure (Landin et al. 1989; Collins et al. 2015; Pecchioli 2015). Allowing a marsh to develop naturally is a long-term process, and natural disturbances should be anticipated in monitoring and evaluation of project success.
- Regular, periodic site visits should include repeatable, qualitative observations, such as fixed photographic locations, condition of containment, marsh elevation, vegetation and animal species assessments) (Yepsen et al. 2017).
- Individual species are vital to ecosystem function. These critical species should be identified and monitored and their function in the habitat incorporated into the site management (Collins et al. 2015).
- Because marsh development takes time, it is important to find funding to monitor for more than three years after construction; five to ten years of monitoring is preferable to allow for corrective actions and provide lessons learned for future marsh development projects (Pecchioli 2015; Yepsen et al. 2017).
- Marsh elevations should be measured during construction, after consolidation and settling, and for at least three to five years post construction (Pecchioli 2015).
- Continued local communication and financial support is critical to the success of beneficial use of dredged material for marsh restoration and creation (Collins et al. 2015).

8 Conclusions

The question of whether using dredged material for marsh restoration/creation is a win-win situation is undetermined. Many questions remain unanswered (Winfield et al. 1997; Yepsen et al. 2017):

- Are there long-term negative impacts of such projects?
- Are there really cost savings by combining projects?
- Is this a once and done solution or will we need to place sediment on the marsh repeatedly over time?

But the question of greatest interest to researchers and project planners seems to be how long does it take for the marsh to be enhanced and can functional equivalency even be attained?

Although marshes constructed from dredged material develop some of the same physical and biological attributes as nearby natural marshes, data does not show that the constructed marshes provide all the functions of natural marshes. Limited data has even shown that dredged material marshes provide habitat for a different community of birds than natural marshes (Steever 2000).

Only by continued efforts in designing, creating and monitoring beneficial use of dredged material will the answers to these questions be resolved.

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