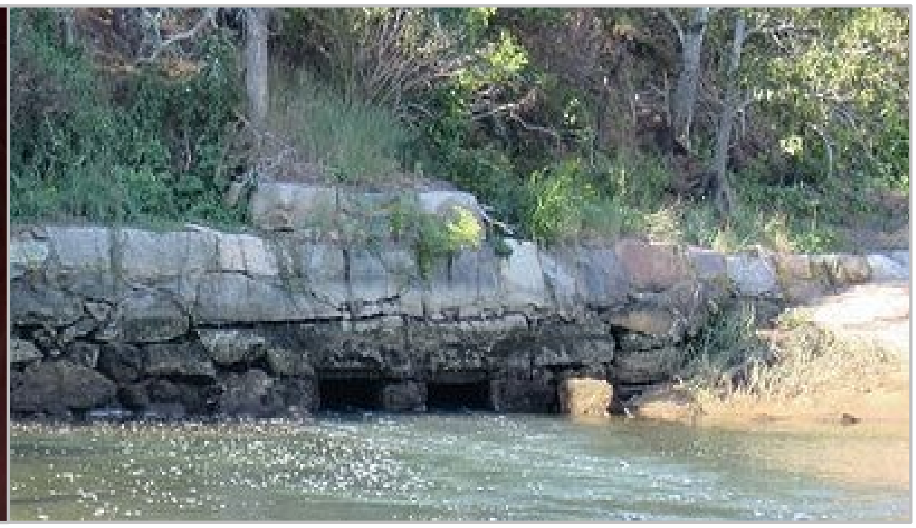

TIDAL RESTRICTIONS SYNTHESIS REVIEW

An Analysis of U.S. Tidal Restrictions and Opportunities for their Avoidance and Removal

United States Environmental Protection Agency

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Executive Summary

ES.1 Introduction

The coastal ecosystem is comprised of a wide array of tidally influenced habitats such as mud flats, barrier beaches, and wetlands, including salt-, brackish-, and freshwater marshes as well as mangroves and other types of shrub or forested swamps. Tidal wetlands are important transitional habitats located between uplands and the larger estuary environment. In that role, they provide numerous ecosystem services, which include: providing nursery and spawning habitat for different life stages of fish and shellfish; providing nesting and foraging habitat for salt marsh specialist birds and migratory waterfowl; acting as carbon sinks and, in the instance of high-salinity salt marsh, keeping methane gas emissions low; providing uptake, processing and/or flushing of nutrients; and providing protection against coastal storms. Loss of functioning tidal wetlands is a critical and ongoing issue, especially as sea levels are predicted to rise. One potentially significant and addressable contributor to tidal wetland degradation and loss in the United States is tidal restriction.

A tidal restriction occurs when a structure or built landform limits or prevents tidal exchange between upstream and downstream habitats. These structures can reduce or eliminate tidal exchange, which can lead to direct loss of tidal wetlands through alteration of their hydrologic regime and/or to their function through lower salinities that “freshen” salty and brackish tidal wetland types. Common examples of tidal restrictions include dikes, berms, dams or levees, undersized bridges and culverts, road causeways, ditches, and water control structures (e.g., tide gates or weirs). Many of these tidal restrictions were put in place specifically to alter site hydrology for agriculture, flood control, mosquito control, or to protect infrastructure, among other purposes. However, some of the most common tidal restrictions are those related to transportation, where altered hydrology is an unintended effect of installed bridges, culverts, and causeways.

This document summarizes the state of knowledge of tidal restriction extent and their potential effects on the coastal environment. Furthermore, this document identifies needs and provides recommendations for tidal restriction avoidance and removal when practicable. These recommendations are intended to help state and local transportation departments, state and federal resource agencies, municipal governments (including planning and flood control entities), their partners, and other stakeholders, take actions to remove tidal restrictions from the landscape. It is important to note that some tidal restrictions provide a vital role in protecting infrastructure, and many factors should be considered in prioritizing which to address.

This document was developed under an Interagency Agreement between the U.S. Environmental Protection Agency (EPA) and the Federal Highway Administration (FHWA) and was conducted through literature review, as well as through interviews with subject matter experts. The document is organized into the following topics: 1) Type and Abundance; 2) Potential Adverse Effects; 3) Existing Tools to Facilitate Avoidance or Removal; and 4) Recommendations.

ES.2 Type and Abundance

Tidal restriction can result from structures in three general categories: 1) structures built to impede the movement of water, such as dikes, dams, and levees; 2) structures built to move or drain water, including ditches, weirs, and tide gates; and 3) transportation structures, such as bridges, culverts, and causeways. In order to determine the extent of existing tidally restrictive structures in the U.S., three main types of sources were consulted: 1) direct surveys of tidal restrictions conducted by others; 2) estimates derived from available modeling; and 3) related sources or those which can act as a proxy for tidal restriction, such as salt marsh quality or aquatic organism passage (AOP). For each state where information was available, the sources are described in detail in this synthesis. In general, there is a lack of information on the abundance of tidally restricting structures, especially along the southeast Atlantic and Pacific coasts. Direct surveys are scarce and of those completed, the degree of restriction is not often documented, as the primary goal of such studies is often salt marsh restoration potential. Many of the direct surveys of restrictions have focused on the northeastern U.S. (NH, MA, ME), as well as the Gulf Coast (FL, AL, MS, LA, TX).

Modeling efforts estimate that 1,764 severe transportation-related tidal restrictions and 70,450 acres of affected salt marsh are found along the northeast and mid-Atlantic coasts (Maine to Virginia). While modeling efforts necessarily include assumptions and are not always field verified, these can provide insight into locations with opportunities for reducing potential restrictions. In addition to direct inventories and modelling efforts, there are also a few related data sources that may function as proxies for estimating type and abundance of tidal restrictions. These include data on salt marsh quality and AOP available in some states.

In general, transportation infrastructure is a common cause of tidal restriction where restrictions have been evaluated or modeled, especially in the northeast and mid-Atlantic. Other sources of restriction, however, such as dikes, mosquito ditching, and water control structures may be more important in certain regions of the U.S., but knowledge of their extent is limited.

ES.3 Potential Adverse Effects

Tidal wetland function is greatly influenced by the frequency and duration of tidal inundation, which in turn affects salinity levels. Tidally restricted wetlands experience lower frequency of tidal inundation and can also be drained or impounded, depending on the type of restriction. The main effect of tidal restriction on tidal wetlands is reduced salinity and a change in inundation time, whether it be of shorter or longer duration. These restriction effects can reduce the extent of tidal wetlands and/or impact their function, which can result in:

- An increase in invasive species such as *Phragmites australis*;
- A decrease in the ability of tidal wetlands to remove pollutants;
- Loss of habitat and/or barriers to movement for marsh dependent species;
- A decrease in carbon storage potential and greater methane emissions; and
- A reduction in marsh elevations that can impact the wave attenuation and shoreline stabilization properties of tidal marsh.

In addition to effects on the natural environment, restrictions formed by transportation infrastructure may also create maintenance issues for the structures themselves due to a restriction's effect on flooding, erosion, and scour forces. In general, tidal restoration can reverse the impacts of a restriction, though the speed and degree of recovery will often depend on the type of restriction removed and its severity.

ES.4 Existing Tools to Facilitate Avoidance and Removal

There are a number of existing tools, resources, policies, and practices that can be applied towards avoiding and/or removing tidal restrictions. Some have been developed specifically for that purpose, and others can be appropriated from other disciplines, such as AOP, conservation planning, and regulatory actions. There are five general categories of tools, with various sub-categories for which a summary is listed in Table ES1. For more information on specific tools mentioned, refer to Section 4.

TABLE ES1: Available tools to facilitate tidal restriction avoidance and removal.

Sub-Category	Summary of Available Tools / Resources / Policies / Practices
Restriction ID and Prioritization for Removal Tools	
Existing Atlases and Inventories	Direct tidal restriction surveys.
Tidal Crossing Assessment Methods	Qualitative and quantitative field methods to determine presence and degree of restriction.
Remote Sensing	Models that rely on remotely gathered information to identify tidally restricted areas or simulate proposed tidal restoration actions.
Conservation & Ecological Restoration Planning	Models and estuary assessment methods primarily developed for prioritizing conservation and/or restoration efforts that can be used to determine tidal restriction extent.
Tidal Restoration Project Planning and Implementation Tools	
N/A	NOAA "Returning the Tide" guidance manual developed using tidal hydrology restoration projects in the southeast U.S.
Structure Design and Operation Tools	
Roadway and Structure Design	Existing transportation engineering manuals and guidelines.
Tide Gates	Tide gate designs that promote greater upstream tidal inundation, and a literature review and synthesis of tide gate retrofit and removal projects in the Pacific Northwest.
Regulatory Tools	
Clean Water Act (CWA) Compensatory Mitigation	Mitigation programs or actions that use the re-establishment of tidal wetlands from the removal or retrofit of a tidal restriction for mitigation credit under the CWA, with a focus on dam removal and transportation improvement projects.

Sub-Category	Summary of Available Tools / Resources / Policies / Practices
Regulatory Tools	
Infrastructure Maintenance and Regulatory Compliance	CWA and National Flood Insurance Program regulations that govern structure maintenance and/or changes to structures that affect upstream base flood elevations.
Aquatic Organism Passage (AOP) Compliance	Programs or actions that mitigate for impacts to AOP under state laws that may also result in removal or avoidance of tidal restrictions.
Endangered Species Act (ESA) & Magnuson-Stevens Fishery Act (MSA) Compliance	USFWS*and NOAA* decisions on actions that affect species regulated under the ESA or the MSA that may also result in removal or avoidance of tidal restrictions.
Funding Tools	
National Oceanic and Atmospheric Administration	The Coastal Resilience Grant Program and Community Based Restoration Grant Program fund resilience and restoration projects, which may include tidal restriction removal.
U.S. Fish and Wildlife Service	The National Coastal Wetlands Conservation Grant Program may be applicable to tidal restriction removal projects. The Coastal Program and the National Fish Passage Program provide financial and technical assistance to projects that restore coastal habitats or remove fish barriers.
U.S. Army Corps of Engineers	The Estuary Restoration Act and Water Resources Development Act provide funds to estuary restoration projects and fish and wildlife habitat restoration projects that could be used to remove tidal restrictions.
Federal Emergency Management Agency	The Public Assistance and Hazard Mitigation Grant Programs fund facility damage and hazard mitigation projects. The National Flood Insurance Program Community Rating System provides incentives to municipalities to lower flood insurance premiums.
Federal Highway Administration	The Emergency Relief and Emergency Relief for Federally Owned Roads programs offer funds to repair or replace damaged infrastructure.
U.S. Department of Agriculture, Natural Resources Conservation Service	The Watershed Protection and Flood Prevention Program funds projects for watershed protection, including ecosystem restoration type activities. This program has funded coastal habitat restoration and fish barrier removal projects.
U.S. Environmental Protection Agency	CWA section 319 grants fund activities that address nonpoint source pollution (including hydrologic modifications). Wetland Program Development Grants target building capacity of state and tribal water agencies to increase the quantity and quality of wetlands in the U.S. The National Estuary Program Coastal Watersheds Grant Program may fund projects that address loss of habitats, including tidal wetlands, within certain geographies.
Multiple Agencies	Funds disbursed under the Natural Resource Damage Assessment process required for actions regulated under CERCLA*and the Oil Pollution Act. To mitigate environmental damages caused by these actions, projects where tidal restrictions were removed have been completed. The Five Star and Urban Waters Restoration Grant Program funds local partnerships to improve water quality, watersheds, species and habitats.

**NOAA=National Oceanographic and Atmospheric Administration, USFWS= United States Fish and Wildlife Service CERCLA= Comprehensive Environmental Response, Compensation, and Liability Act ("Superfund")*

ES.5 Recommendations

The non-binding recommendations build from information gaps and needs identified from a discussion of the existing tools, resources, policies, and practices to address tidal restriction, as well as wider use of promising tools that are currently being used at a state or regional level. The eleven recommendations are arranged into four categories and are followed in the report by a discussion of potential actions and challenges to implementation, where applicable.

Category 1: Reduce Data Gaps

1. Use and adapt existing tidal crossing field evaluation methods to confirm the existence of restrictions, determine their severity, and prioritize them for removal where practicable.
2. Support and utilize remote-based methods to identify and target restrictive structures, as well as datasets that further these efforts.
3. Incorporate potentially restrictive structures of all types into existing locational databases (GIS) or produce new ones where none currently exist.
4. Determine effectiveness of alternative tide gate designs for increasing tidal flow upstream and standardize operational parameters that balance ecological and societal needs.
5. Increase use of modeling to predict restorative effects of removing tidal restrictions to inform compensatory mitigation efforts.

Category 2: Coordinate with Aquatic Organism Passage Practitioners to Leverage Resources in Support of Shared Goals

6. Collaborate with and/or supplement efforts of AOP practitioners to evaluate tidal restrictions.
7. Encourage greater cooperation between AOP and tidal restriction communities and better alignment of practices and goals.

Category 3: Better Integrate Tidal Restriction Considerations into Transportation Planning Processes

8. Incorporate awareness of the role of transportation structures as potential tidal restrictions early in the transportation project planning process.
9. Balance ecological needs with structural and budgetary constraints in transportation structure design.

Category 4: Explore Regulatory Processes and Policy Goals that Support Tidal Restriction Removal

10. Explore regulatory processes that can be used to more efficiently authorize removal of transportation-related tidal restrictions during maintenance or emergency situations and clarify USACE and other Federal Agencies permit authorities to allow for broader use for projects that result in net increases to aquatic function.
11. Build support for the use of tidal restriction removal and restoration of upstream habitats as compensatory mitigation under the Clean Water Act, Rivers and Harbors Act, and other regulatory programs.

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Section 1: Introduction to Tidal Restrictions

Tidal Marsh at Low Tide, Billy Frank Jr. Nisqually National Wildlife Refuge, WA (David Patte/USFWS)

The coastal ecosystem is comprised of a wide array of tidally influenced habitats such as mud flats, barrier beaches, and wetlands of varying vegetative compositions. Tidally influenced wetlands can take a number of forms, including salt-, brackish-, and freshwater marshes as well as mangroves and other types of shrub or forest swamps. Tidal wetlands are an important component of the coastal ecosystem, providing nursery and spawning habitat for commercially and recreationally important fish and shellfish species; breeding and foraging habitat for migratory waterbird species; water quality benefits including filtration of water and uptake of nutrients and pollutants; and critical buffer from coastal flooding associated with storm surges and other adverse weather events. Tidal wetland habitats have been, and continue to be, impaired or lost due to a variety of human activities, including conversion to agriculture and urban land uses, introduction of non-native species, metal and nutrient pollution, and alteration of coastal hydrology (Gedan et al., 2009). Sea level rise is also an important contributor to the loss of tidal wetlands. For example, between 2004 and 2009 in the conterminous U.S., over 124,000 acres of salt marsh were lost, mainly due to sea level rise and associated erosional effects (Dahl and Stedman, 2013).

This synthesis review document focuses on one contributor to tidal wetland degradation and loss: anthropogenic tidal restrictions. A tidal restriction occurs when a structure or built landform limits or prevents tidal exchange between upstream and downstream habitats. Tidally restrictive structures impact upstream wetland habitats largely by reducing or eliminating natural tidal flow above the restriction. Reducing or eliminating natural tidal flow causes lower salinities above the restriction and leads to the "freshening" of salt or brackish tidal wetlands. In cases where water is impounded behind a restriction, a tidal wetland may be lost through permanent flooding. By influencing flood durations and salinities or blocking flow entirely, tidal restrictions can impact the composition of plant and animal communities found in upstream tidal wetlands as well as their extent, resulting in habitat alteration. Degradation and loss of tidal wetlands through tidal restriction greatly influences their ability to perform those functions, outlined above, that are vital to maintaining healthy coastal ecosystems and the human and biological communities that depend on them.

This document was developed under an Interagency Agreement between the U.S. Environmental Protection Agency (EPA) and the Federal Highway Administration (FHWA) and is intended to serve as a synthesis of the current state of knowledge regarding tidal restrictions in the U.S. In addition, this document identifies needs and provides recommendations for avoidance and removal of tidal restrictions that are intended to help state and local transportation departments, state and federal resource agencies, municipal governments (including planning and flood control entities), their partners, and other stakeholders to implement actions that will work to remove tidal restrictions from the landscape.

This synthesis was conducted through literature review, as well as through interviews with subject matter experts, and is organized into sections as follows:

- Section 2: Type and Abundance of Tidal Restrictions
- Section 3: Potential Adverse Effects of Tidal Restrictions
- Section 4: Existing Tools to Facilitate Avoidance or Removal of Tidal Restrictions
- Section 5: Recommendations

Case studies presented in the document were chosen based on the best information currently available and are not exhaustive.

Section 2: Type and Abundance of Tidal Restrictions

The first step to address the tidal restriction issue in the U.S. is to determine the scope of the problem. To that end, this section compiles information on the most common types of tidal restrictions as well as their abundance and geographic distribution. As documented below, tidal restrictions can be classified into three general structure categories:

1. Structures to protect lands by purposefully impeding movement of water
    - Dikes, berms, dams, or levees
2. Structures to move or drain water on and off tidal lands
    - Ditches
    - Water control structures such as weirs and tide gates
3. Transportation structures over or through tidal streams, rivers, and wetlands
    - Bridges and culverts
    - Road and railroad causeways

TIDAL RESTRICTION EXAMPLES

Top Left*: Series of levees in south San Francisco Bay (Andrei Stanescu/iStock);* **Top Right***: Mosquito Ditches at Assateague Island National Seashore (National Park Service);* **Bottom Left***: Round Hill culvert in Dartmouth, MA (Lia McLaughlin/USFWS);* **Bottom Right***: Undersized bridge on Parkers River in Barnstable, MA (Lia McLaughlin/USFWS)*

Tidal restrictions can also arise from sediment, debris, or vegetation blockages caused by these structures or surrounding land uses. However, most tidal restrictions were put in place specifically to alter site hydrology for agriculture, development, mosquito control, flood control, and other human uses. Numerous transportation structures (culverts and bridges) can also restrict tidal exchange because they are not sized to support full hydrologic function. These structures can inhibit tidal exchange through their size (span length and rise) and/or their elevation. Many times, a structure exhibits both problems, though they can occur separately. For example, a culvert may be properly sized, but is set too high so that flow in (filling) and out (drainage) are still restricted. Given the prevalence of tidal restrictions related to transportation infrastructure, it will be a primary focus in this discussion, though other types of tidal restrictions will also be addressed as appropriate.

Information resources used to explore the type and extent of tidal restrictions in the U.S. fell into three categories: 1) direct survey; 2) model-based methods; and 3) related sources, usually those related to AOP. Table 1 summarizes information and resources found for coastal states,[1] where available.

TABLE 1: Tidal restriction type and abundance resources by state.[2]

State	Method / Resource
Maine	Direct survey; related source (state-wide AOP database)
New Hampshire	Direct survey (2 separate inventories)
Massachusetts	Direct survey (4 separate inventories); related source (AOP database)
Rhode Island	Model (transportation crossings only)
Connecticut	Model (transportation crossings only)
New York	Model (transportation crossings only)
New Jersey	Model (transportation crossings only)
Delaware	Model (transportation crossings only)
Maryland	Model (transportation crossings only)
Virginia	Model (transportation crossings only); related source (dam inventory/AOP database)
North Carolina	Related source (dam inventory/AOP database)
South Carolina	Related source (dam inventory/AOP database)
Georgia	Related source (dam inventory/AOP database)
Florida (Atlantic coast)	Related source (dam inventory/AOP database)
Florida (Gulf coast)	Direct survey (2 separate inventories); related source (dam inventory/AOP database)
Alabama	Direct survey
Mississippi	Direct survey
Louisiana	Direct survey
Texas	Direct survey
California	Related source (synthesis of coastal wetland condition)
Oregon	Related source (AOP database; tide gate and levee inventory)
Washington	Related source (AOP database)
Alaska	Related source (AOP database)

[1] The 23 states with coastline along the Atlantic Ocean, Pacific Ocean, or Gulf of Mexico.
[2] This table is based on information readily available at the time of collection and may not be exhaustive. The North Atlantic Aquatic Connectivity Collaborative houses AOP data for northeastern states, but is only referenced where data is denoted as tidal as part of a "Tidal Connectivity Assessment" (MA).

2.1 Type and Abundance of Tidal Restrictions: Direct Survey

Starting in the mid-1990s, there was an interest in cataloging tidal restrictions to guide planning and restoration efforts by some state and municipal governments. These early efforts were focused in the northeastern U.S. (New Hampshire, Massachusetts, and Maine) and emphasized the restoration or remediation potential of upstream salt marshes. In one instance (New Hampshire) there was also an effort to measure the degree of tidal restriction. Outside of the northeastern U.S., states on the Gulf Coast have undertaken surveys of hydrologic restoration opportunities that are focused on barriers to tidal exchange. In addition, a focused survey of Tampa Bay, Florida, for tidal restrictions (termed “salinity barriers”), was also completed. Direct surveys are generally limited in availability and were not found for other geographic areas.

2.1.a. Northeast Atlantic States

Maine

The Casco Bay Estuary Partnership (Bohlen et al., 2012) has generated a list of potential tidal restrictions affecting salt marsh and other intertidal habitats bordering Casco Bay, Maine. Casco Bay is bounded by Cape Elizabeth and Cape Small, south and north of Portland, Maine, respectively. As part of a prioritization effort, 128 potential restriction sites were evaluated using longitudinal profiles derived from LIDAR (Light Detection and Ranging) to determine: 1) whether the potential restriction had intertidal elevations both up- and downstream, indicating potential for affected tidal wetlands; 2) whether water was impounded by the potential restriction; and 3) whether the site would become a tidal restriction with 3 feet of sea level rise. Out of 128 sites, only 76 were at appropriate elevations to avoid tidal restriction. Road crossings comprised most of the potential restrictions (52; includes railroads and roads with impoundments), followed by dams (16). Field measurements at a subset of 11 sites correlated well with those derived from LIDAR.

The locations of these potential restrictions and other barriers are captured in the Maine Stream Habitat Viewer, a database maintained and updated by the Maine Stream Connectivity Work Group (2018), a partnership of state, federal, industry, and non-government organizations convened by the State of Maine Coastal Program to improve stream restoration efforts. This database is focused primarily on fish passage but can inform tidal restoration planning efforts in coastal areas. Many of the culverted crossings have pictures of the structure as well as up- and downstream habitats. The estimated number of miles “blocked” upstream is also included for both dams and culverts. A tidal marsh layer derived from wetlands categorized as Estuarine and Riverine Emergent Wetlands (includes saline and fresh) by the National Wetlands Inventory (NWI) is also included, which can aid in targeting tidal systems, though this layer is indicated as incomplete per the Maine Stream Connectivity Work Group.

New Hampshire

The USDA Natural Resources Conservation Service (NRCS) completed the first survey of non-natural tidal restrictions in the “Evaluation of Restorable Salt Marshes in New Hampshire” (1994; reissued 2001). This survey involved the identification of sites that appeared to be restricting tidal flows as well as an engineering field survey of the structural openings and their relationship to tidal elevation. The engineering analysis was based on a simplistic hydraulic model that evaluated an opening’s ability to pass a tide rising to a National Geodetic Vertical Datum (NGVD) elevation of 5.0, which was expected to occur or be exceeded at least 10 days every month.

One hundred (100) potential marsh restrictions were initially field visited, and included sites located upstream of a road, railroad, dam, or other obstruction that were accessible by land. Initial evaluations of restriction were qualitative and generally based on present and predicted plant community structure, presence of invasive species (i.e., *Phragmites*, purple loosestrife), and dominant surrounding land uses. Of the 100 crossings evaluated, 84 were selected for further engineering analysis. The engineering analysis concluded that 50 crossings were restrictive to the passage of the tide.

The 50 restrictive crossings accounted for approximately 1,300 acres of affected upstream salt marsh, about 20% of the remaining salt marsh in New Hampshire at the time of the study (1994). Municipal road crossings were responsible for the greatest numbers of restrictions (22), though the marsh acreage affected (366 acres) was less than that affected by state highways, which accounted for 15 restrictions, or 583 acres of affected marsh.

In 2019, the New Hampshire Department of Environmental Services (NHDES) Coastal Program, completed a state-wide assessment of 118 tidal crossings in the “Resilient Tidal Crossings” project (NHDES, 2019). The project applied the NH Tidal Crossing Assessment Protocol referenced in Section 4, with the goal of informing community officials of management considerations and replacement opportunities specific to each tidal crossing that affect both human and ecological systems. This endeavor included collection of both field and geospatial data for tidal crossings in the state and prioritized each based on management objectives. Scoring components in the prioritization included infrastructure condition, inundation risk, degree of tidal restriction, opportunity for fish passage and salt marsh migration potential.

The results of the project showed that 89% of tidal crossings exhibited moderate to high levels of tidal restriction and that seven crossings created permanent barriers to aquatic organism passage. Additionally, 33 tidal crossings were identified that required immediate maintenance or replacement, and 58% of crossings were potentially at risk when inundation data were factored in. The final prioritization of sites for management action indicated that 23 tidal crossings were identified as the highest priority and 32 as high priority.

The locations of restrictions along with scores of structure condition, flood risk and effect on adjacent tidal habitats are captured in the NH Coastal Viewer, a database maintained by the University of New Hampshire and the NHDES Coastal Program (NHDES, 2015).

Massachusetts

The entire coastline of Massachusetts has been evaluated for tidal restrictions in four separate documents: Atlas of Tidally Restricted Marshes—North Shore of Massachusetts (Massachusetts Wetlands Restoration & Banking Program et al., 1996), Atlas of Tidal Restrictions on the South Shore of Massachusetts (Massachusetts Wetlands Restoration Program, 2001), Cape Cod Atlas of Tidally Restricted Salt Marshes (Cape Cod Commission, 2001), and Atlas of Tidally Restricted Salt Marshes in the Buzzards Bay Watershed Massachusetts (Buzzards Bay Project National Estuary Program, 2002). All atlases considered only those potential restrictions that were publicly accessible.

North Shore

The first Massachusetts atlas published is the North Shore Atlas, which covers the north shore of Boston Harbor to the New Hampshire border. Potential sites were identified using color infrared aerial photographs used to update NWI maps. These photos were examined to identify markers of tidal restrictions, such as *Phragmites* upstream of a road or railroad embankment, the presence of typical salt marsh downstream or evidence of scouring attributable to the potential restriction. Ninety-four (94) sites were field checked, though only 48 were categorized as having "potentially restricting upland features." Each restricting "feature" is not identified, and no further details are given. The atlas estimates the number of potentially restricted tidal wetlands, which total to just over 1,400 acres.

South Shore

The South Shore Atlas covers the area from Cape Cod to the southern shore of Boston Harbor. Potential tidal restriction sites were identified using aerial imagery, U.S. Geological Survey (USGS) topographic maps, GIS data, and input from local conservation commissions. Each site was visited to document information on the restricting structure (condition, dimensions, material) and collect observational evidence of restriction (structure broken or clogged, vegetation die back, marsh slumping, scouring basins, etc.). The researchers then assigned a qualitative restoration priority ranking (high, medium, or low) to each site based on the evaluation of eight prioritization "factors," the most important of which was the size of affected wetland areas upstream. Other factors included presence of an anadromous fish run or shellfish resource area, feasibility, and contiguous open space.

A total of 119 sites were ranked, though it is not apparent from the data provided whether these were only a subset of sites where evidence of restriction was present. Approximately 90 of the ranked sites were transportation-related (culvert, bridge, roadway, railroad); others include tide or flapper gates, and dikes. Twenty-eight (28) sites were identified as having a “high” restoration priority. About half of the high-ranked sites were directly related to transportation—though some of the remaining half were those where tide-gates associated with a transportation structure were causing the restriction.

Cape Cod

This atlas documents tidal restrictions on Cape Cod, including marshes along Vineyard Sound, Nantucket Sound, and Cape Cod Sound, as well as the Atlantic Ocean (Cape Cod Commission, 2001). The stated focus was on sites where salt marshes have been impacted by transportation facilities (i.e., dirt and paved roads, causeways, railroads, footpaths), as well as berms, dikes, and past cranberry farming operations. The analysis did not rank each tidal restriction based on restoration potential, but instead included information that can assist in project planning and design efforts.

Publicly accessible potential restriction sites were identified using USGS topographic maps, aerial photography and input from local officials. Sites were further defined for inclusion using the presence of certain wetland types up and/or downstream of a structure using a wetlands data layer produced by the MA Department of Environmental Protection. Presence and severity of restriction were determined through field reconnaissance and based on three factors: 1) the ratio of channel width to the diameter or width of the crossing structure; 2) evidence of flow restriction compared with the severity of erosion; and 3) visual indicators associated with the structure (e.g., culvert or pipe), marsh vegetative composition, and marsh/channel condition.

Out of 204 potential sites identified through the Atlas inclusion methodology, 114 sites were determined to be causing a tidal restriction using the three factors described above. Only six were associated with old cranberry bog berms or earthen dikes not related to transportation facilities. Approximately 1,400 acres of upstream salt marsh were found to be affected by these restrictions, as estimated from a GIS coverage based on Wetland Conservancy Program (WCP; MA Department of Environmental Protection) orthophotograph maps.

Buzzards Bay Watershed

The Buzzards Bay watershed atlas covers the geographic area between the Rhode Island border and Woods Hole, Massachusetts. Potential restriction sites were located using aerial photography, with restrictions verified during field reconnaissance using visual indicators only. The study identified 257 tidally restrictive sites; however, as with the South Shore atlas, it is not apparent from the data provided whether these were only a subset of sites where evidence of tidal restriction was present (Buzzards Bay Project National Estuary Program, 2002). Out of the 257 sites, 170 were transportation-related (bridge, causeway, culvert, road, or railroad). Roads were the greatest contributor of any category at 139. In comparison, the next most common restrictive structures were dikes, at 34. The approximate total of tidal wetland acres upstream of all structures was 3,600 acres, as estimated from the WCP GIS layer mentioned above.

Sites were given a "remediation score" ranging from 0 to 29, with higher scores indicating increased potential benefit from removing the restriction. The score was determined using points awarded based on: 1) size of the affected upstream wetlands; 2) cost-effectiveness based on a simplified cost estimate and affected wetland area; 3) wetland impairment, as determined by the degree of cover of *Phragmites*; 4) tidal restriction size, which evaluates the cross-sectional area of the restriction in relation to the upstream wetland acreage; and 5) other criteria, including whether the restriction was on public property, whether it would benefit anadromous fish or designated rare/endangered species habitat, or whether its removal would lead to adverse impacts to special resources, which awarded negative points.

Remediation scores ranged from -2 (1 site; due to "adverse impacts") to 20 (2 sites). There were 8 sites with remediation scores of 4 or less. Because the sites were ranked based on their restoration potential, it is difficult to determine the degree of tidal restriction from these scores, or whether sites with lower scores are less impacted by the restriction or even functionally non-restrictive. For instance, the Interstate 195 bridge crossing of the Weweantic River has a remediation score of 7, which is distributed thusly: 2 points for upstream wetland acreage, 3 points for public property, and 2 points for rare/endangered species habitat. Based on the information given, it is difficult to infer from this score distribution whether the crossing is restricting tidal exchange.

2.1.b. Gulf States

For the Gulf Coast states, the National Oceanic and Atmospheric Administration (NOAA) Restoration Center and the four Gulf of Mexico Sea Grant College Programs (Texas, Louisiana, Mississippi/Alabama, and Florida) partnered to inventory potential hydrologic restoration opportunities (Bishop and Dunlap, 2013). These projects had to satisfy the following definition of "hydrologic restoration" from the NOAA Restoration Center: "To remove or modify anthropogenic barriers to restore historic tidal estuarine and freshwater exchange to benefit coastal and marine fisheries habitat." To be eligible for consideration, projects also needed to include the restoration of at least 5 acres of upstream habitats, have a budget of $5 million or less, and a lifespan of 20 years or more (Bishop and Dunlap, 2013). These criteria limit the number of projects inventoried through this effort yet still provide an idea of their types and abundance in Gulf States. A report was written for the Texas portion, but the remaining states have their projects cataloged only in an online map and database (Gulf Sea Grant, 2014). A summary of this effort by state is provided below. A separate inventory for Tampa Bay completed by a different entity is also included under the Florida heading.

Texas

Texas has 19 projects identified, with 7 being directly related to transportation infrastructure such as roadside drainage ditches, road causeways, and railroad bridges (Bishop and Dunlap, 2013). The remaining projects result from a variety of issues, including dams to create waterfowl impoundments, construction of the Gulf Intracoastal Waterway, dredging for ship channels, water diversion, and siltation from upstream sources.

Louisiana

Louisiana has 8 projects identified, with 3 being directly related to transportation (Gulf Sea Grant, 2014). The remaining projects result mainly from the construction of canals and waterfowl impoundments.

Mississippi/Alabama

Mississippi and Alabama have 14 total projects identified (8 in MS and 6 in AL), 7 of which are directly tied to transportation (4 in MS and 3 in AL; Gulf Sea Grant, 2014). The remaining projects result from mosquito ditching and other channelization issues.

Florida

The Gulf Coast of Florida has 43 projects identified, 11 of which are related to transportation, or a combination of transportation and silviculture (logging roads; Gulf Sea Grant, 2014). The majority of the remaining projects result from mosquito ditching, created berms, mangrove removal, and water control structures. Three of the water control structures identified in this inventory are also included in the Tampa Bay inventory.

Tampa Bay

The Tampa Bay Estuary Program and the Southwest Florida Water Management District commissioned the Tampa Bay Salinity Barrier Inventory and Restoration Feasibility Matrix, which was completed by a private consultant (Deitche, 2012). In this analysis, 344 potential tidal restrictions (termed "salinity barriers") were identified on tidal tributaries flowing into Tampa Bay. Barriers were identified using aerial image interpretation, anecdotal information, data reports, survey data and field reconnaissance. Of the potential barriers, the vast majority were road crossings (243), followed by footpaths (29) and railroad crossings (27). Other barriers included weirs and other water control structures. Maps show the locations of the potential barriers, but additional information on type or severity of restriction (if present) is only available for the 30 sites evaluated for the restoration feasibility matrix.

Of the 30 structures presented in more detail, 12 were road or railroad crossings. The evaluation of tidal exchange at these sites was observational only. Evidence of potential tidal restriction included: 1) build-up of sediment or rock ballast (railroad crossings) under the structure; 2) build-up of vegetation at the structure's inlet or outlet; and 3) presence of mangrove vegetation downstream of the structure, but an absence of mangrove vegetation upstream. In some cases, it was not possible to definitively determine if, or the degree to which, a structure was acting as a salinity barrier. In fact, three of the twelve road or railroad crossings evaluated did not show evidence of limiting tidal exchange.

2.2 Abundance of Tidal Restrictions: Model-based Methods

Modeling a structure's severity as a tidal restriction is another avenue to estimate tidal restriction abundance on the landscape. One example of a model that also provides an estimate of tidal restriction extent is that of the Designing Sustainable Landscapes (DSL) initiative (McGarigal et al., 2017a). DSL has developed a GIS-based model proposed to be used as a tool to identify and prioritize lands and waters for habitat and biodiversity conservation based on an Index of Ecological Integrity (IEI) for states from Maine to Virginia. A tidal restriction severity metric was developed as an element of the IEI and is covered in greater detail in Section 4. This metric predicts the restriction severity of road and railroad crossings (including tide gates associated with transportation infrastructure) by estimating the salt marsh "loss" ratio above each crossing. The ratio represents the proportion of the upstream area that is modeled as potential salt marsh based on tide range and elevation but is not mapped as existing salt marsh by the NWI (McGarigal et al., 2017b).

GIS shapefiles and raster files (McGarigal et al., 2017c) are available that map the locations of potential restrictions and show areal coverages of potentially affected salt marsh. From these products, an estimate of the number of "severe" transportation-related tidal restrictions and the acreage of affected salt marsh predicted by the model can be determined for each state considered (Table 2). Crossings and affected salt marsh areas are given a score ranging from 0 (no effect) to 1 (severe effect). For this exercise, only crossings and affected salt marsh areas that scored 0.75 or greater were considered to create a restriction severe enough for inclusion. Salt marsh with higher scores are likely to have been lost or degraded or are former estuarine systems that have been converted to freshwater by tidal restrictions.

This modeling effort, while not field verified, provides an estimate of potentially severe restrictions and corresponding areas of wetlands affected among the states considered. For instance, while New Jersey and Delaware are small states, the scope of their restriction problem may be greater than would be expected based on their size or length of coastline.

TABLE 2: DSL modeled restrictions and estimated affected salt marsh derived from McGarigal et al. (2017c).

State	Number of Severe Transportation-Related Tidal Restrictions (predicted)	Affected Salt Marsh Acreage (predicted)
Maine	50	735
New Hampshire	11	58
Massachusetts	200	4,952
Rhode Island	46	704
Connecticut	75	319
New York	149	875
New Jersey	389	14,539
Delaware	150	2,725
Maryland	298	34,483
Virginia	396	11,060
Total	**1,764**	**70,450**

2.3 Abundance of Tidal Restrictions: Related Information Sources

Direct inventories of tidal restrictions themselves are scarce; therefore, indirect but related sources were consulted when identified. There are data sources available for the southeast U.S., California, Alaska, and the Pacific Northwest (Oregon, Washington) that center on salt marsh quality or AOP (generally, fish in these examples) concerns but which can also potentially be used as proxies for estimating general types and/or abundance of tidal restrictions in those states. Limited data from AOP assessment protocols are also available in the Northeast (see Section 4.1.b, Northeast Atlantic Aquatic Connectivity Collaborative).

2.3.a. Southeast U.S.

The Southeast Aquatic Resource Partnership (SARP) is a regional, collaborative organization involved in aquatic connectivity and organism passage issues. To that end, one of the datasets it maintains is a dam inventory spanning Texas to Virginia, which is available to the public through a data-use agreement. This inventory synthesizes many distinct datasets into a single standardized database. Information accessible for each documented dam structure in the inventory includes the stream name, the structure name, and its purpose, though other available information varies based on the specific underlying data. This inventory includes all documented dams including those in coastal areas; however, whether the dam is located in a tidally influenced area is not specified as an attribute. Based on aerial photo interpretation conducted for this synthesis, the incidence of tidally restrictive dams appears to be relatively low in the southeastern states. Florida and South Carolina had the largest number of potentially restrictive dams (approximately 20 each), followed by Texas (approximately 10). The remaining states either had none (MS, AL, LA) or less than 10 (GA, NC, VA). The most common documented purposes of these dams were water supply/control, recreation, or agriculture. Through a partnership with Conservation Biology Institute, SARP has expanded this effort and created the Southeast Aquatic Barrier Inventory and Prioritization Tool (SARP, 2020). This interactive tool includes the location of both dams and road-stream crossings and includes an assessment of prioritization for AOP considerations.

2.3.b. California

Solek et al. (2012) completed a probability-based survey of the condition of tidal saline estuarine wetlands (salt marshes) statewide using the California Rapid Assessment Method (CRAM). One-hundred and fifty (150) field sites were evaluated along the north coast (n=30), San Francisco estuary (n=30), central coast (n=30), and southern coast (n=60). For reference, the San Francisco estuary contains approximately 75% of the state's salt marsh.

Of the four attributes scored in CRAM (i.e., buffer and landscape context, hydrology, physical structure, and biological structure), the physical structure attribute produced the lowest scores, with 62% of salt marsh acreage scoring in the bottom 50% of possible scores. Since CRAM documents specific wetland stressors, the presence of dikes and levees as severe stressors appears to be the reason for low physical structure scores.

For instance, salt marsh along the southern coast and the San Francisco estuary had the highest frequencies of dikes and levees (70% and 50% of sites, respectively), and had the most sites where these were the most prevalent severe stressor (63% and 37%, respectively). In addition, flow obstructions (culverts and paved stream crossings) were found in 8% of sites statewide, and, when present, were considered severe stressors most often along the central and southern coasts (17% and 10% of sites, respectively).

While this study is not an inventory or evaluation of tidally restrictive structures, it does give some insight into the main types of tidal restrictions in California and the general areas where many of them are located.

2.3.c. Alaska

The Alaska Department of Fish and Game maintains an interactive map (2017) that monitors more than 2,500 stream crossings (mainly culverts) throughout the state for anadromous fish passage. Concerns for fish passage potentially overlap with tidal restrictions, as a blocked or perched culvert can both impede fish passage and tidal exchange. Each crossing in the database is rated based on its potential to impede fish passage; for each, a detailed report can be accessed that gives culvert measurements, elevations along the crossing, photos, and the main reasons for fish passage impairment, as appropriate. Whether the crossing is tidal or not is also indicated on the detailed report, though how this designation is determined is not defined. The database suggests that most of the monitored coastal creek crossings are not tidally influenced. Therefore, while many culverts along the Alaskan coast may impede fish passage, most do not appear to also act as tidal restrictions. It is important to note that this database is not exhaustive of potentially tidally restricting structures in Alaska.

2.3.d. Pacific Northwest

Washington

Like Alaska, the Washington Department of Fish and Wildlife maintains an interactive map (2017) that monitors stream crossings for anadromous fish passage; however, much less information is available for each crossing compared to the Alaska data, and the data do not include information regarding whether the crossing is tidally influenced. Based on aerial image interpretation, the upstream extent of tidal influence appears limited along most of Washington's Pacific Coast likely due to steep topography. Tidally influenced areas appear to be primarily associated with the major river deltas along the Puget Sound, Strait of Georgia, the Strait of Juan de Fuca, as well as the Columbia and Chehalis River estuaries. The database also shows a greater coincidence of low gradient tidal areas and potentially fish-passage limiting structures in estuaries, though their incidence is low based on the data provided.

As with Alaska, it is important to note that this database is not exhaustive of potentially tidally restricting structures in Washington.

Oregon

The Oregon Department of Fish and Wildlife (ODFW) provides a downloadable GIS shape file that contains crossings and other structures evaluated for fish passage. Like Washington, the database does not include whether a crossing is tidally influenced. Based on aerial image interpretation, the upstream extent of tidal influence appears limited along most of Oregon's Pacific Coast likely due to steep topography. There is a greater coincidence of low gradient tidal areas and potentially fish-passage limiting structures (largely tide gates) in the large coastal estuaries on the central and north coast (e.g., lower Columbia River, Tillamook Bay, Coos Bay). However, the overall coincidence of tidal areas and fish-passage limiting culverts or tide gates is low. As with Alaska and Washington, it is important to note that this database is not exhaustive of potential tidally restricting structures in Oregon.

In 2011, the Oregon Department of Land Conservation and Development's Coastal Management Program (OCMP) combined available local and state level tide gate inventories into one GIS database (Mattison, 2011a), including those maintained by ODFW in its fish passage shape file referenced above. These inventories comprised tide gates owned by the Oregon Department of Transportation (ODOT), local governments, diking and drainage districts, as well as private landowners, though ownership is categorized as unknown or left blank for many. Based on this dataset, there are over 450 tide gates in those areas of Oregon where inventories were available (confined to major estuaries and their tributaries). Information on tide gate location came from mapping exercises, conversations with local experts, as well as field verification. Some of the entries include notes on whether the gate is working as intended, or has been replaced or retrofitted for fish passage, but this information is not consistently given for every tide gate. Therefore, while some of these structures may be acting as tidal restrictions, they were not specifically assessed for this purpose, nor does the dataset claim to be an exhaustive inventory.

There are ongoing efforts to improve this tide gate inventory. ODOT has identified 54 tide gates that they own or maintain. However, private landowners have placed additional tide gate structures on roadway culverts. The Oregon Watershed Enhancement Board (OWEB) is working with private landowners on a multi-year effort to create a comprehensive inventory of tide gates. The long-term goal is to facilitate fish passage improvements at these locations through permitting assistance and cost-saving design options (Cindy Callahan, personal communication, August 15, 2018).

The OCMP also produced an estuarine levee inventory (Mattison, 2011b), available as a shapefile or as a layer in the Estuary Data Viewer maintained by the Oregon Coastal Atlas (2018). The inventory includes man-made dikes and “sidecast” (from dredge spoils), natural and “enhanced” levees, as well as dikes that have been breached or removed. Locations of levee features were digitized from LIDAR derived products; field work and participatory mapping techniques were then used to verify the existence of dikes and levees as well as to clarify areas where LIDAR use was limited. There are more than 2,300 features in the dataset, though only a subset potentially acts as tidal restrictions.

2.4 Discussion

There is a general lack of information on the abundance of tidally restricting structures, especially along the southeast Atlantic and Pacific coasts. Of those inventories completed, salt marsh restoration potential is often the primary goal, and degree of restriction is not often assessed.

When determining potential type and abundance of tidal restrictions, transportation infrastructure is a common cause where restrictions have been evaluated, especially in the northeast. However, other sources of restriction, such as dikes, mosquito ditching, and water control structures may be more important in certain regions of the U.S., though knowledge of their extent is somewhat limited. Even then, transportation infrastructure is still a large part of the tidal restriction equation, and solutions for removing and/or avoiding tidal restrictions in transportation could potentially be applied to other restriction sources.

The engineering analysis of tidal crossings in the New Hampshire study makes it particularly useful in determining the magnitude of the tidal restriction, as it evaluates functionally restrictive and non-restrictive crossings; however, this level of analysis may be cost prohibitive in other states and regions. New Hampshire has the shortest tidal coastline of any coastal state, at 131 miles (NOAA Office for Coastal Management, 2017a). New Hampshire’s short coastline reduced the study scope appreciably compared to other states.

Massachusetts has also produced an analysis of tidal restrictions state-wide. However, this effort is broken into four different atlases that differ in goals, methodology and ultimate output, making it difficult to compare each and estimate the abundance of tidal restrictions state-wide. In the case of the Buzzards Bay Atlas, it appears that the prevalence of tidal restrictions may be somewhat overestimated as the focus was on remediation potential and not degree of restriction. In some cases, the evidence for restriction is weak enough to suggest that the crossing is functionally non-restrictive.

Similar to the Massachusetts efforts, the Tampa Bay, Florida inventory appears to also count functionally non-restrictive crossings in its totals. For instance, about a third of the structures evaluated in detail showed no evidence of tidal restriction, including 3 of the 12 transportation-related crossings (roads and railroads). Unlike Massachusetts, the inventories produced by Gulf of Mexico Sea Grant College Programs all have the same focus: hydrologic restoration opportunities that meet certain acreage, monetary, and life span requirements. However, these criteria are less concerned with surveying for all restrictions and therefore likely underestimate their abundance along the Gulf coast. For instance, 39 projects were initially identified for the Texas inventory (Bishop and Dunlap, 2013), but only 19 projects met the inclusion criteria.

Model-based methods such as those produced by the Designing Sustainable Landscape initiative for the northeast and mid-Atlantic states have great potential for identifying tidally restrictive transportation structures and affected areas on a large scale. However, these methods would also have to be underpinned by field efforts to confirm the model's findings, which have largely been lacking in the past. The intersection of wetland quality assessments and fish passage data also shows promise for determining the general scope of tidal restrictions and as a source of information to help focus where to find potential restrictions. However, since the goals of these investigations do not focus on tidal exchange per se, these data sources, where available, may underestimate the abundance of tidal restrictions.

Section 3: Potential Adverse Effects of Tidal Restrictions

Tidal wetlands are important transitional habitats located between uplands and the larger estuary environment. In that role, they provide numerous ecosystem services, which include: providing nursery and spawning habitat for different life stages of fish, crabs, and shrimp; providing nesting and foraging habitat for salt marsh specialist birds and migratory waterfowl; acting as carbon sinks and, in the instance of high-salinity salt marsh, keeping methane gas emissions low; providing uptake, processing and/or flushing of nutrients; and providing protection against coastal storms.

Tidal wetland function is greatly influenced by the frequency and duration of tidal inundation, which in turn affects salinity levels. As discussed in Section 2, tidal restrictions can take many forms that affect upstream habitats, particularly tidal wetlands. Tidally restricted wetlands experience lower frequency of tidal inundation and can also be drained or impounded, depending on the type of restriction. However, no matter the restriction, the main effect to tidal wetlands is reduced salinity and a change in inundation time, whether it be of shorter or longer duration. These restriction effects can combine to reduce the benefits of tidal wetlands through their potential adverse effects on:

- Vegetation
- Water quality
- Salt marsh specialist bird communities
- Fish and shellfish community composition and movement
- Greenhouse gas (GHG) emissions and carbon sequestration
- Resiliency of coastal areas to storm and flood events
- Sedimentation and subsidence

The upstream effects of tidal restrictions on each of these areas is summarized in Table 3 and are covered in more detail below. While the following discussion focuses on the natural environment, it is also important to note that tidal restrictions may have adverse effects on the built environment as well, especially as it concerns transportation structures. Restrictive infrastructure can create structure maintenance issues or even failure due to greater erosional and scour forces as well as increased chances of road flooding where flows are made to go through or around an undersized conveyance.

The literature review conducted for this report focuses on research conducted in the U.S. regarding the response of tidal wetlands, and particularly salt marsh, to tidal restriction. Much of the available research has been conducted in the New England area; therefore, this review focuses primarily on that region of the U.S. In cases where literature on restriction response was lacking, supporting studies were used. This section is not intended as a comprehensive review but instead attempts to provide examples of common effects of tidal restriction and how the restoration of tidal flow can reverse these effects.

TABLE 3: Potential effects of tidal restrictions on upstream wetlands and associated resources.

Resource / Function Affected	Proximate Cause	Potential Upstream Effects
Vegetation	Reduced salinity	Invasion of salt intolerant non-native invasives like *Phragmites australis* that drastically alter vegetative community structure.
Water Quality	Reduced tidal flushing	Decrease ability of tidal wetlands to remove pollutants such as metals and excess nutrients; promote conditions that favor the accumulation of harmful bacteria.
Salt Marsh Specialist Bird Species	Vegetation change; loss of tidal wetlands	Loss of breeding habitat for species like the saltmarsh sparrow (*Ammodramus caudacutus*), that are highly dependent on intact salt marsh.
Fish and Shellfish	Reduced tidal inundation; increased water velocity	Limited habitat availability and restriction of movements between upstream habitats and the estuary.
Greenhouse Gas Emissions and Carbon Sequestration	Reduced tidal inundation, salinity	Reduced or negative organic carbon accumulation rates, greater methane emissions.
Resiliency to Storm and Flood Events	Loss of tidal wetlands	Loss of wave attenuating and shoreline stabilizing effects of coastal wetlands.
Sedimentation and Subsidence	Reduced tidal inundation	Reduced vertical sediment accretion rate and marsh elevations.

3.1 Vegetation

The vegetation in a functioning salt marsh is generally arrayed along a salinity gradient, where salt tolerant species (e.g., *Spartina alterniflora*) are found in the "low marsh" and less salt tolerant species (e.g., *Spartina patens*, *Distichlis spicata*) are found in the "high marsh", with more transitional species occupying areas upslope of the high marsh (e.g., *Iva frutescens*, *Phragmites australis*, *Juncus* spp.). However, lower salinities caused by tidal restrictions can lead to the alteration of this vegetative community structure by favoring less salt tolerant species throughout the marsh. These can include native species such as *Typha angustifolia* (narrow-leaf cattail), and *Solidago sempervirens* (seaside goldenrod), but in many cases also promotes the spread of non-native invasive species such as *Lythrum salicaria* (purple loosestrife) and a variety of *Phragmites australis* (common reed) from Europe.

Phragmites forms dense, tall monocultures that limit plant diversity, degrade marsh habitat for juvenile fish (Buchsbaum et al., 2006), birds, and other animals, and limit the marsh's value for recreational uses such as boating, hunting, and birdwatching. Due to its fast-growing nature and persistence of large amounts of dead material, *Phragmites* also pose a fire risk to surrounding communities (Kowalski et al., 2015; Marks et al., 1994). The restoration of tidal flow, and the higher salinities associated with it, may provide a means to reduce or remove less salt tolerant species established due to tidal restriction, particularly in low marsh areas.

Monocultural stand of Phragmites australis along the Duck River in Old Lyme, CT (Ken Weidemann/iStock)

In a study on six tidally restricted marshes in Connecticut, Roman et al. (1984) found that *Phragmites* became the dominant species over most of the high and low marsh, except in thin bands along creeks and in cases where restriction was non-continuous (two sites had seasonally managed tide gates). When a tidal restoration project at one of the marshes replaced an old tide gate with a new self-regulating one, allowing for tidal exchange on incoming (flood) tides and free flow of water away from the marsh during outgoing (ebb) tides, a significant reduction in *Phragmites* height was observed within one growing season. Another restoration effort removed dikes and tide gates completely, allowing full tidal flushing. After one year of reintroduced flow, *Phragmites* vigor decreased with a reduction in heights from 2-3m to 1m or less, and its density declined by at least 50%.

Warren et al. (2002) found a similar response of *Phragmites* to tidal restoration at nine marshes in Connecticut where *Phragmites* cover was significantly negatively correlated with salinity. However, rates of vegetation recovery ranged from just 0.5% per year to 8.6% per year; this large range appeared to be attributable to different rates of tidal inundation among sites. More rapid recovery was characterized by greater hydroperiods and higher soil water tables. In Massachusetts, Buchsbaum et al. (2006) monitored the vegetation response of a salt marsh to a tidal restoration project where an undersized culvert was replaced with a larger one. Eighty-five percent of the dissimilarity in plant species composition between pre- and post-restoration conditions was accounted for by four species: *Phragmites*, *T. angustifolia*, *S. sempervirens*, and *S. alterniflora*. The first three have low salt tolerances and decreased in the restored marsh; *Phragmites* decreased in abundance by 18% one year after restoration, and *T. angustifolia* decreased 20% by three years after restoration. *S. alterniflora* increased exponentially into areas formerly occupied by these species. While *Phragmites* and *T. angustifolia* both showed steep, initial declines, their abundances eventually leveled off after 2-3 years.

3.2 Water Quality

Healthy tidal wetland systems provide a variety of benefits that are important for maintaining clean water. For example, they remove pollutants such as metals, harmful bacteria, and excess nutrients that come from urban areas, agricultural runoff, and other sources (Etheridge et al., 2015; Koop-Jackobsen and Giblin, 2010; Anisfeld, 2012). Many of these pollutant removal capabilities are specifically tied to regular tidal flushing. Tidal restrictions can inhibit these processes mainly by altering inundation times, which can lead to loss or degradation of upstream tidal wetlands that play an important role in regulating water quality.

For example, tidal wetlands act as a buffer between excess nutrient (e.g., nitrate) loads coming from upstream sources and estuarine waters. In a study of a 5-year old constructed tidal marsh located between row-crop agriculture and the New River in Carteret County NC, Etheridge et al. (2015) quantified its nutrient retention capacity and overall nutrient dynamics after a large rain event (10 days; 19 complete tidal cycles). This event carried fertilizer applied to agricultural fields immediately upstream and deposited these nutrients into the marsh system. It was found that 25% of nitrate flushed into the system after the rain event was retained by the marsh, much of which appeared to be physically trapped by the marsh before it was biogeochemically processed. Similarly, Anisfeld et al. (1999) found that restored marshes in Long Island Sound had slightly higher nitrogen accumulation rates compared to restricted marshes and reference sites (Anisfeld et al., 1999; Anisfeld, 2012). While nutrient cycling and biogeochemistry of wetlands is complex, changes in biogeochemistry caused by tidal restrictions may alter marsh ability to retain and remove nitrates.

Salt marshes also act to trap metals such as arsenic, lead, and copper, by binding them up in marsh soils and vegetation as organic complexes or sulfides. However, tidal restrictions that reduce regular marsh inundation can lead to the oxidation of organics and sulfides, which frees up the formerly bound metals and releases them back into the water, where they can negatively affect aquatic organisms, and in turn, human populations through consumption (Anisfeld, 2012).

Tidal restrictions can also lead to conditions that favor the accumulation of harmful bacteria that can impair water quality, harm shellfish and other organisms, and cause serious illness in humans. Portnoy and Allen (2006) undertook a study to determine if removing a tidal restriction (dike) on the Herring River in Cape Cod, MA, would affect natural oyster and cultured hard clam beds seaward of an area with increased fecal coliform bacteria (an indicator of fecal contamination). Natural oyster beds located near the seaward side of the dike are routinely closed for harvest due to high fecal coliform levels, while the clam beds are further downstream and receive marginal protection from the high salinity waters of Cape Cod Bay. The highest fecal coliform concentrations (measured using *E. coli*) in sediment samples were found 200 to 1,400 meters upstream of the dike, while concentrations of fecal coliform in surface water was found to be greatest 1,000 meters above and below the dike, at low tide (and lowest salinity). The results found that fecal coliform concentrations in surface waters were dependent on tidal stage and quantity of freshwater contributions. When compiled with data from two other nearby restricted sites and one restored site, fecal coliform was found to be directly related to the degree of tidal restriction, and all sites created conditions that favored fecal coliform accumulation and survival except for the restored site. These conditions include depressed tidal flushing, low salinity, lower pH levels, and fine sediment deposition in the river channel where fecal coliform bacteria is less exposed to desiccation and solar ultraviolet radiation. Using modeling, it was determined that by restoring tidal flushing along the Herring River, fecal coliform bacteria in the oyster beds could be reduced to levels where the oysters are safe for harvest and human consumption.

3.3 Salt Marsh Specialist Bird Communities

Coastal wetlands serve as important habitat and breeding grounds for birds. Migratory birds rely on salt marshes, in particular, as important stop-over points on their migration routes. Other birds have evolved to live in the marsh environment and nowhere else. Tidal restrictions can cause habitat changes that negatively impact the bird species that depend on these areas.

Saltmarsh Sparrow (Aaron Maizlish)

Certain bird species, especially in the Eastern U.S., are highly dependent on *Spartina* dominated salt marsh for breeding, including *Ammodramus maritimus* (seaside sparrow), *Ammodramus caudacutus* (saltmarsh sparrow), *Ammodramus nelsonii subvirgatus* (nelson's sharp-tailed sparrow), *Tringa semipalmata* (eastern willet) and *Rallus crepitans* (clapper rail). Warren et al. (2002) showed that with the recovery of salt marsh vegetation after the restoration of tidal flow, formerly restricted sites dominated by *Phragmites* were eventually recolonized by species associated with healthy salt marsh. They found that during the early stages of restoration (4-5 years), the habitat was still unsuitable for marsh specialists, but by 15 years post-restoration, the use of the marsh by *A. maritimus* and *A. caudacutus* was equivalent with the reference wetland. In the case of *A. caudacutus*, it is important to note that tidal restoration alone is not necessarily enough to provide breeding habitat. Elphick et al. (2015) found that this species was less common where tidal flow had been restored than at reference sites and nested in only one of 14 flow restoration plots. *A. caudacutus* is dependent specifically on high marsh habitats for breeding, and many tidal restoration projects are at an elevation where low marsh is most affected by restoration practices.

Correll et al. (2017) used a large dataset of bird surveys in coastal marshes from Maine to Virginia spanning 18 years to generate population trends for salt marsh specialist species (*A. maritimus, A. caudacutus, A. nelsonii subvirgatus, R. crepitans,* and *T. semipalmata semipalmata*). The trends were then related to four potential stressors including transportation-related tidal restrictions, marsh ditching, local rates of sea-level rise, and potential for extreme flooding events. The analysis showed that population declines for all species examined were best explained by the presence of transportation-related tidal restrictions. In other words, salt marsh specialists maintained their populations in marshes with no road crossings but declined in marshes restricted by downstream road crossings. The authors posit that this outcome stems from these tidal restrictions limiting sediment accretion because they reduce marine sediment supply to the marsh, which can lead to changes in marsh elevation and potential marsh loss (see also *Sedimentation and Subsidence*, Section 3.7).

3.4 Fish and Shellfish

Estuaries and their associated salt marshes provide spawning, foraging and nursery habitat to fish and shellfish, including those significant to commercial and recreational fisheries. In fact, more than half of the fish caught for sport or sale in the United States depend on estuaries and their coastal wetlands at some point in their life cycles (Lellis-Dibble et al., 2008). By altering tidal regimes, tidal restrictions can affect the availability of fish and shellfish habitat, limit fish and shellfish movements, and ultimately jeopardize their ability to survive.

Raposa and Talley (2012) performed a meta-analysis of tidal restriction impacts on nekton (free-swimming fish, shrimp, and crabs) as well as their response to tidal restoration efforts using datasets primarily from Rhode Island and Massachusetts. Of sixty-nine total datasets, thirty-three were from reference marshes, twenty-five from tidally restricted marshes, and eleven from marshes undergoing tidal restoration. In this study, nekton community composition was found to be significantly different between reference marshes and tidally restricted marshes. The species mainly responsible for the composition difference were *Palaemonetes* spp. (grass shrimp), *Fundulus heteroclitis* (mummichog), and *Fundulus majalis* (striped killifish), all of which were present in greater numbers in the reference marsh. However, among the three marsh groups, the total number of nekton species did not differ significantly, and the densities of only 7 species (out of 42) differed significantly among the groups. Across eight sites that had both pre- and post-tidal restoration nekton data, both total nekton density and richness increased on a percentage basis during the first year after restoration. But, the degree of percent change varied greatly among sites, such that four of the sites actually experienced a loss of nekton density and richness post-restoration. The authors cite differences in degree and type of tidal restrictions for this variation. A diked/drained marsh holds less water over a tidal cycle and has considerably dampened conditions during high tides, which would be expected to limit nekton densities and their access to habitat on the vegetated marsh surface. However, a diked and impounded marsh can provide nekton with a stable body of water, which may have increased their numbers pre-restoration and led to declines post-restoration.

Buchsbaum et al. (2006) reached a similar conclusion in their study on the effects of increased tidal exchange on nekton. Two years of pre-restoration surveys showed that the abundance of nekton (individuals) in the tidally restricted marsh was greater than that of the downstream reference marsh. Post-restoration, nekton abundance in the recovering marsh more closely matched that of the reference marsh, which itself saw an uptick in abundance of certain species post-restoration (i.e., *F. heteroclitis* and *Crangon septimspinosa*, sand shrimp). Changes to the nekton community in the restored marsh were species specific. Some species remained at the same relative abundances, but others declined (*Palaemonetes* spp.), disappeared (*Apeltes quadracus*, four-spined stickleback), or declined in the restored marsh but increased in the downstream reference marsh (*C. septimspinosa*). The authors postulate that the impoundment created by the tidal restriction likely provided equal or greater habitat value to nekton as a refugia than the unrestricted marsh. Since certain nekton species increased in abundance downstream of the restriction once it was removed, it may be that the effect of its removal was to restore or enhance the link between the restricted marsh and the downstream ecosystem. In addition, as *Spartina* replaced *Phragmites* in the restored marsh, use of the flooded marsh surface by the lower size classes of *F. heteroclitis* increased, which suggests *Spartina* marshes provide better habitat for juvenile fish than marshes composed mostly of *Phragmites*.

In a study comparing nekton communities (particularly fish) in New Hampshire and Maine marshes restricted by undersized road culverts to restored and reference marshes, Eberhardt et al. (2011) found no significant difference in density or species present among the three marsh groups. The researchers also performed a *F. heteroclitis* mark-recapture effort of eight culverts of varying dimensions to evaluate the impacts of crossing size, water velocity, and light intensity on fish passage rates. Both crossing size and mean water velocity had a significant effect on *F. heteroclitis* movement. That is, fish passage from the upstream marsh to the downstream marsh decreased as culvert size decreased and water velocity rates increased. The study found that the presence of an undersized culvert that experiences greater water velocities can act as a physical barrier to *F. heteroclitis*, while favorable impounded conditions upstream can act as a behavioral barrier. As *F. heteroclitis* is a large and important component of the New England nekton community, this decreased population connectivity may inhibit a sizeable transfer of marsh production to the estuary. Deegan (1993) showed that species that use estuarine habitats for at least part of their life cycle comprise a large part of the biological production exchange between the marsh and the larger coastal ecosystem.

In the Pacific Northwest, migratory juvenile salmonids (*Oncorhynchus* spp.) use off-channel tidal wetlands seasonally as rearing habitat. However, many of these historical estuarine and riverine tidal wetlands have been converted to agricultural land through the use of hydrologic barriers (e.g., dikes and levees) and flood control structures (e.g., tide gates). These structures can present physical barriers to tidal flow and subsequent fish passage, channel water out of the system, lead to a decrease in wetlands and fish habitat, and/or create temperature and dissolved oxygen conditions upstream that inhibit use by salmon species. Roegner et al. (2010) explored the fish community structure pre- and post-tidal restoration for two restoration projects in the Grays River, a tributary to the Columbia River in Washington. Treatments involved the removal of tide gate structures or dike breaching, both of which resulted in the complete re-establishment of tidal pattern. Pre-restoration sampling above the restricting structures resulted in the capture of only one fish species, three-spine stickleback (*Gasterosteus aculeatus*). Post-restoration sampling showed the use of areas formerly upstream of those structures of larger numbers of species (7 to 10), including the juvenile stages of coho (*O. kisutch*), chum (*O. keta*), and Chinook (*O. tshawytscha*) salmon.

3.5 Greenhouse Gas Emissions and Carbon Sequestration

Tidal wetlands have the ability to store carbon in plants and sediments thereby offsetting greenhouse gas emissions of carbon dioxide. Tidal wetlands (particularly salt marshes and mangroves) provide long-term carbon sequestration through the accumulation and retention of large amounts of organic material. However, tidal restriction can limit this process, by disconnecting the wetland from coastal waters and reducing its ability to accumulate organic material. In instances were tidal restriction causes wetland drainage, this beneficial process is actually reversed by exposing the accumulated organic layer to oxygen, promoting its breakdown to carbon dioxide by aerobic microbial respiration, and ultimately its return to the atmosphere. Tidal restriction also lowers salinity, which can lead to greater emissions of methane, another greenhouse gas, since fresher water does not have the abundant sulfate ions found in more saline environments that limit methane production and release to the atmosphere.

Historic rice impoundment, Beaufort County, SC (Henry De Saussure Copeland)

Drexler et al. (2013) assessed differences in carbon sequestration rates between naturally tidal freshwater marshes and “moist soil” managed impoundments over a 40-year time period. These marshes occur on the Waccamaw National Wildlife Refuge (NWR) in South Carolina, in an area where rice cultivation was prevalent in the late eighteenth to late nineteenth centuries. NWRs throughout the country use moist soil management, with 14,000 hectares alone managed as such in the southeast region, where roughly half the NWRs are found along the coast.

Moist soil treatments drain marshes during the growing season, while maintaining adequate moisture to provide seeds, forage, and invertebrates for waterfowl and other wildlife. Using soil cores, it was found that the natural tidal wetlands had rates of carbon sequestration two times higher than the moist soil managed impoundments, and a vertical accretion rate that was four times higher (Drexler et al., 2013). Conversely, the inorganic sedimentation rates in the moist soil sites were significantly greater than at the naturally tidal sites, though the total mass accumulation rates in the two treatments were similar. Because the vertical accretion of the tidal marshes was so much higher, it indicates that the tidal sites accumulated and stored organic matter, which typically occupies a greater volume than inorganic matter, at a much greater rate. In addition, drainage of the impoundments initiates the microbial decomposition of the organic carbon in the top layers of the soil, especially during late spring and summer, contributing to lower carbon accumulation rates than natural/unrestricted tidal flow regimes. This same effect might be expected in areas where tidal restrictions prevent or reduce the upstream reach of the tide, especially during times of the year where water entering the system from upland runoff is lower.

The organic carbon stored by marine environments, including tidal wetlands, has been termed “blue carbon” by natural resource managers. Blue carbon is starting to be used as a tool to determine the climate mitigation benefits of coastal habitat restoration and conservation efforts and to prioritize these efforts using their effects on blue carbon stocks (Restore America's Estuaries, 2016). Kroeger et al. (2017) used modeling to determine how restoring tidal flow to currently restricted habitats could affect greenhouse gas emission reductions, with a focus on reducing sustained methane emissions which are naturally low in salt marsh systems. The results showed that, over a 20-year period following restriction, the climactic warming from an impounded and freshened salt marsh due to methane emissions was greater, per unit area, than the magnitude of climactic cooling provided by carbon sequestration in continental U.S. forests and unaltered salt marsh and mangroves.

The authors also compared the climactic cooling potential of tidal restoration projects to other carbon management scenarios, including biological carbon sequestration projects (creation of salt marsh or sea grass beds), and rewetting of terrestrial (freshwater) peatlands to reduce the rate of carbon dioxide emissions from drained peatland soils. Tidal restoration, especially to impounded and freshened wetlands, proved to be the more efficient way to achieve climactic cooling than the other scenarios, reducing sustained methane emissions up to 98% from pre-restoration levels. To get an idea of the scale of potential methane emission reductions, the authors used existing mapped and areal data of managed impoundments (Carolinas, Georgia, Florida) and incidental impoundments created by transportation infrastructure (New England) to estimate the amount of tidally restricted salt marsh along the U.S. Atlantic Coast. The analysis estimated that approximately 27% of tidal wetlands along the Atlantic Coast are experiencing lower salinities and increased methane emissions due to restrictions, equivalent to 20 years of continuous emissions from 0.6 to 3.1 million automobiles.

3.6 Resiliency of Coastal Areas to Storm and Flood Events

Another key ecosystem function provided by coastal wetlands is their role as buffers in protecting coastlines during storms, hurricanes, and other coastal hazards. As development in coastal areas of the U.S. continues to increase, so does the amount and value of coastal infrastructure that could potentially be impacted by storms.

Shepard et al. (2011) conducted a global meta-analysis of published studies to review the evidence that salt marsh offers coastal protection services such as wave attenuation, shoreline stabilization, and floodwater attenuation. All studies fitting the inclusion criteria found that wave energy/height attenuation was greater across marsh vegetation than intertidal mudflat (n=10, where "n" is the number of studies). Seven of the studies had enough data to include in a meta-analysis, which showed a significant positive effect of vegetation on wave attenuation. Factors given as important determinants for wave attenuation in salt marsh included vegetation density, stiffness, height, and marsh width. To determine the effects of marsh on shoreline stabilization, studies evaluating accretion, marsh elevation changes, or marsh erosion were included. Thirty-three of those studies meeting the inclusion criteria (n=57) reported a positive effect of marsh vegetation on shoreline stabilization (increased accretion/elevation, reduced erosion). Across all studies explicitly comparing vegetated and unvegetated areas (n=33), there were 18 studies and 38 independent measures of accretion, erosion, or elevation change that had sufficient quantitative data for a meta-analysis. This analysis (n=38), showed an overall positive effect of vegetation on shoreline stabilization, which was significantly positive for each response variable when controlling for tidal elevation (n=30). Factors most correlated with shoreline stabilization included vegetation type density, height, and biomass production, as well as inundation time and distance to a creek or river supplying sediment.

Coastal wetlands are also assumed to help attenuate coastal flooding, though Shepard et al. (2011) did not find enough quantitative data to include in a meta-analysis. However, the studies that were identified showed a clear pattern of the effects of marsh alteration on floodwater regulation. That is, natural marsh areas drained more efficiently than those that had been altered, and that wetland alteration (of which tidal restriction is one) can increase flooding events on a regional scale.

The potential value of coastal wetlands to reduce flood damage was explored by Narayan et al. (2017) using regional losses from Hurricane Sandy, which impacted 12 states from North Carolina to Maine, and local annual losses in Ocean County, New Jersey. This study attempted to quantify the value of coastal wetlands for flood risk and property damage reduction using models and databases used to quantify risk in the insurance sector. For Hurricane Sandy, the authors quantified avoided property damages by comparing flood heights and damages for two scenarios: wetlands present and wetlands lost. This analysis estimated that coastal wetlands avoided more than $625 million in flood damages across the 12 states impacted, and reduced flood damages by an average of 11% across the 707 affected zip codes.

Wetland extents were heavily correlated with avoided damages in all states except North Carolina. Wetlands had even greater value in urbanized and upstream environments. For example, in New Jersey, coastal wetlands only cover 10% of the land area, but are estimated to have reduced damages by an average of 27% ($430 million or 3% of the state's total losses). In addition, zip codes at the upper end of estuaries, with few wetlands themselves, appear to have received cumulative benefits from downstream wetlands reducing flooding throughout the estuary. For example, Hamilton Township in Atlantic County, New Jersey has few coastal wetlands but would still have had a 138% increase in property damages if downstream wetlands along the Great Egg Harbor River estuary were not present. The local study in Barnegat Bay in Ocean County, New Jersey revealed similar results to the regional findings from Hurricane Sandy. Properties behind a marsh saved 16% on average in flood losses every year compared to properties where marsh had been lost. While salt marsh presence reduced maximum annual flood losses across all elevations, the effect was more pronounced at elevations ranging from -0.5 to +1.5m relative to sea level.

3.7 Sedimentation and Subsidence

The preceding section illustrates that coastal wetlands can potentially provide flood protection for coastal communities. In addition, coastal wetlands trap and accrete sediment and organic material, which can make coastal communities more resilient to future sea level rise. Tidal restrictions can impact the natural buffering effects of coastal wetlands in two main ways: 1) impounding fresh water upstream and drowning tidal wetlands directly; or 2) altering tidal inundation times such that upstream marsh elevations are reduced due to loss of stored organic carbon and/or lower rates of sediment accretion.

As mentioned in the carbon sequestration example above, draining marsh sediments can lead to the oxidation of surface organic matter and a decrease in marsh elevation. Turner (2004) found increased subsidence of marshes hydrologically altered by weirs, culverts, tide gates, and other restrictions, a result attributed to the loss of water and organic material, not mineral matter. While this subsidence generally decreased after the initial alteration, the findings suggested it could be difficult for the restricted marsh to ultimately keep pace with relative sea level rise. Roman et al. (1984) also found that marsh surface elevations in tidally restricted marshes were significantly lower relative to unrestricted marshes. The authors posited that the lowered water table in the restricted marsh allowed the marsh peat to dry out, which increased its oxidation and decomposition by soil microbes adapted to less saline environments, leading to decreased soil porosity and compaction.

Marsh sedimentation has been shown to be positively correlated with increasing tidal inundation time, which suggests that a larger tidal exchange, helps to “build” marsh along the coast (Temmerman et al., 2003). Anisfeld et al. (1999) found that sedimentation rates in salt marsh restricted by tide gates along the Long Island Sound, while still lower, were not significantly different from rates in reference marshes. However, even though the overall sedimentation rates were not different, the organic matter accumulation rate in the restricted marshes was found to be significantly lower than that in the reference marshes. Organic matter greatly affects sediment structure through greater porosity and lower bulk soil densities, which allow for greater rates of vertical accretion in the marsh. Reflecting the lower rate of organic matter accumulation, pore space accretion was also significantly lower in the restricted marshes, which also showed higher bulk soil densities at depth. Therefore, even if the sedimentation rate may be positive and only slightly lower in the restricted marshes, their vertical accretion rate may be slowed due to lower rates of organic matter accumulation. It is important to note that a nearby marsh where a greater tidal prism was restored accreted sediment much more quickly than even reference marshes, suggesting that restoration may reverse the effects of marsh subsidence caused by tidal restriction.

3.8 Discussion

Tidal restrictions can have a range of effects on tidal wetland habitats and functions as a result of changes in salinity and inundation times. These changes can adversely impact tidal wetland ecosystem services, including water quality maintenance and improvement, carbon and methane gas sequestration, coastal storm protection through wave attenuation and shoreline stabilization, and sediment accretion that can buffer the effects of sea level rise. In addition, restrictions can adversely affect tidal wetland habitats we rely on for recreational and commercial purposes.

While most of a restriction's ecological effects are adverse in nature, some impacts may benefit certain species. For example, restricted marshes not subject to draining provide more open water and greater pooling on the marsh surface, which can serve as refugia for nekton. Restoring a fuller tidal cycle may reduce the availability of these habitats, which can lead to lower nekton densities; however, restoration can also promote greater nekton exchange between upstream and downstream habitats, connecting formerly distinct communities.

In general, it appears tidal restoration can help to reverse the impacts of a restriction on vegetation, water quality, and greenhouse gas emissions, among others, though the speed and degree of recovery will often depend on the type of restriction removed and its severity. Also, as noted by Anisfeld (1999), it is important to consider the new equilibrium of the restricted marsh when undertaking a restoration project. For instance, if the marsh elevation has dropped appreciably from pre-restriction conditions, restoring full tidal flow could, in some cases, lead to drowning of the remnant marsh and conversion to open water.

Section 4: Tools for Tidal Restriction Avoidance and Removal

Previous sections have established that tidal restrictions can take varied forms, are relatively common and abundant where inventoried, and can have adverse effects on the natural and human environments. This section presents available tools, resources, policies, and practices that can be applied towards avoiding and/or removing tidal restrictions, as well as their potential limitations and general effectiveness, if known. Because transportation infrastructure is a large contributor to tidal restriction abundance (see Section 2), this discussion will concentrate on existing tools that focus on these structures and their use by state and local transportation departments. However, it is not exclusive of other types of tidal restriction or organizations involved in their avoidance and/or removal.

Existing tools to address the removal or avoidance of tidal restrictions fall into five general categories; whether the category addresses avoidance, removal, or both is shown in brackets:

1. Restriction Identification and Prioritization for Removal Tools [removal];
2. Tidal Restoration Project Planning and Implementation Tools [removal];
3. Structure Design and Operation Tools [avoidance and removal];
4. Regulatory Tools [avoidance and removal]; and
5. Funding Tools [removal]

4.1 Restriction Identification and Prioritization for Removal Tools

The suite of tools covered here can be used to identify tidal restrictions, and prioritize their retrofit or removal, depending on the structure and type of restriction. They are designed to be used by a wide array of stakeholders, including state and municipal governments, non-governmental organizations (NGOs), and citizens, and include existing restriction atlases, tidal crossing assessment protocols, remote sensing techniques, and conservation and ecological restoration planning tools.

4.1.a. Existing Atlases and Inventories

The tidal restriction atlases and inventories and fish passage datasets identified in Section 2 can serve as initial planning tools for determining where to look for potential restrictions. For instance, the Massachusetts Department of Transportation (MassDOT) uses the four tidal restriction atlases developed for Massachusetts (MA) to determine potential "red flags" during transportation project planning (Tim Dexter, personal communication, December 18, 2017). If a potential restriction is identified, MassDOT will send an information request to the MA Department of Fish and Game, Division of Ecological Restoration (DER). DER has worked extensively with municipalities to identify potential salt marsh restoration projects and often conducts detailed tidal hydrology analyses to better determine a site's tidal prism and degree of restriction. In that way, the MA inventories have been effective in aiding removal of tidal restrictions associated with transportation infrastructure.

Using existing inventories to identify restrictions is constrained by their limited geographic range, broad definitions of what constitutes a "restriction," and in some cases, a lack of enough detailed information to accurately determine location. The use of datasets that evaluate structures for fish passage can expand the available geographic range, but these datasets tend to be focused on inland structures and/or fail to evaluate all potential structures within the tidal area. For example, fish passage criteria developed for inland crossings may not adequately consider how tidal flow affects water velocity and depth at crossings in the coastal area; therefore, tidal restrictions may not always be identified by criteria used to evaluate whether structures are acting as fish barriers.

4.1.b. Direct Tidal Crossing Assessment Methods

As seen in previous sections, some areas have existing atlases where much of the work (office and field) associated with identifying potential restrictions has already been done. However, even in cases where an atlas is available, the actual presence and/or degree of restriction was often not assessed. The following assessment methods aim to both identify tidal restrictions and determine their degree of restrictiveness to tidal flows or fish passage.

There are two existing methods that explicitly assess tidal crossings (specifically roads and railroads) for restriction. Both were developed in New England but, with some adjustment, should have application outside this region. The first is a relatively simple method contained in the ***Tidal Crossing Handbook, A Volunteer Guide to Assessing Tidal Restrictions*** developed by the Massachusetts-based Parker River Clean Water Association (PRCWA; Purinton and Mountain, 1998). There are three phases associated with PRCWA's method: 1) identify potentially restrictive crossings; 2) assess the crossing's effect on tidal range; and 3) take the results from Phase 2 and provide them to local officials, particularly local highway or public works departments.

Transportation-related tidal crossings are initially identified using topographic maps to determine where roads and railroads cross streams and rivers at an elevation lower than the topographic contour corresponding to the local high tide level. Potentially restrictive crossings chosen for further analysis are then identified using a combination of crossing ratio (ratio of stream channel width at culvert or bridge to diameter of the culvert or width of the bridge opening) and evidence/degree of erosion/scour at the crossing (Phase 1). In Phase 2, the crossing's effect on tidal range is determined by measuring the difference in water level between the low and high tide on each side of the crossing. If the tidal ranges differ, the crossing is altering tidal flow (significant restriction is defined as >5 inches difference).

While this method is basic enough for volunteers with little technical knowledge, it is labor intensive. Tidal measurements are taken approximately every two hours over an entire tidal cycle (12 hrs. in this region), and the site should be visited beforehand at high and low tides to establish a well-placed reference point for measurement. It is also unclear if any surveys (volunteer or otherwise) were organized using this method, or if survey results were used by local governments and/or stakeholders.

The second method, ***New Hampshire's Tidal Crossing Assessment Protocol*** (Steckler et al., 2017), is a more technical assessment methodology used to evaluate tidal crossings and prioritize their replacements based on a set of management objectives. These objectives include both infrastructure replacement and ecological restoration priorities, such as the structure's physical condition, restrictiveness to tidal flows, ability to allow aquatic organism passage, effect on upstream and downstream vegetation, and vulnerability to sea level rise. The protocol gives instructions on how to complete field assessments, including those for crossing type and condition (bridge/culvert, dimensions, materials, perching, and scour severity), cross sections and longitudinal profiles, and classification and condition of existing salt marsh vegetation. It also includes the collection of desktop and GIS-based information including structure ownership and any existing replacement plans, the number of upstream and downstream tidal crossings/restrictions, watershed area and land use, upstream salt marsh area, and representative upstream/downstream channel and pool widths.

Measurements collected and derived from field and desktop assessments are then used to develop scores based on evaluation criteria associated with each management objective —such as crossing condition, inundation risk, restrictiveness to tidal flows, and salt marsh migration—all of which can be rolled up to produce an overall crossing score, depending on the specific objective. For instance, an overall infrastructure or ecological score can be calculated that prioritizes crossing replacements based on either structure or ecological condition. Alternatively, all management objective scores can be integrated into one overall score.

This assessment protocol requires more technical knowledge than the Tidal Crossing Handbook method, though clear instructions, pictures, and diagrams are included in the manual to assist practitioners. The management objectives included in the protocol appear to be generally relevant to other regions of the country even though it was developed specifically for New Hampshire. Most of the measurements and categories are broadly applicable, though some of the plant communities and species are specific to the northeast. For instance, the salt marsh vegetation field assessment portion includes selecting the natural communities and invasive species present. Species cited as indicative of communities such as high and low salt marsh will differ in other regions, as will potential community types and invasive species.

Aside from crossing assessment methods specifically targeting the identification of tidal restrictions, others are being developed for tidal systems from the perspective of aquatic organism passage that may also have applicability as restriction screening tools. Most of the currently available stream crossing assessment methods that target fish passage are focused on non-tidal waters, mainly because these environments are easier to evaluate and have less inherent variability. However, the ***Northeast Atlantic Aquatic Connectivity Collaborative's (NAACC) Tidal Stream Crossing Survey Data Form*** (2019a) and ***Tidal Stream Crossing Instruction Manual for Aquatic Passability Assessments*** (2019b) provides a rapid assessment methodology designed to evaluate potential barriers to fish and other aquatic organisms in tidal areas. The assessment includes the evaluation of: 1) road, stream, and crossing type; 2) inlet and outlet type, shape, dimensions and whether either is perched at low or high tide; 3) structure length, substrate, slope, and alignment; 4) up- and downstream channel and pool width, tidal range, and comparability of vegetation type; and 5) whether a tide gate is present and its severity as a barrier.

Although this method is focused on aquatic organism passage, its creators believe it also has potential as a screening tool for identifying tidal restrictions and closely communicated with the authors of the NH Tidal Crossing Assessment Protocol during its development (Scott Jackson, personal communication, April 30, 2018). Though the NAACC only encompasses the area from Maine to Virginia, this assessment method has been adapted to have a broader geographic applicability and is currently used by practitioners in the southeast U.S. (Kat Hoenke and Jessica Graham, personal communication; see Section 5). However, data collection using this protocol is still in its infancy, and only a portion of potential sites have been assessed on the ground. AOP Data are publicly available, but whether each structure is located in a tidally influenced area is not specified as an attribute for datasets outside of the “Tidal Connectivity Assessments”.

4.1.c. Remote Sensing

Identifying tidal wetlands affected by restrictions through remote sensing techniques could allow the detection of tidal restrictions over large areas. Artigas and Yang (2004) used hyperspectral imagery collected from an aircraft flying at low altitude to delineate marsh community types (e.g., different types of high marsh depending on species present, tall and stunted *Phragmites* monocultures) and their spatial patchiness in the New Jersey Meadowlands. This tidally influenced area on the Hackensack River is a mixture of relatively unaltered wetlands, wetlands degraded by ditching and diking, and former wetlands filled by commercial and industrial development. Each marsh community type had its own spectral signature, which was field-determined beforehand to allow for classification of the hyperspectral aerial imagery. Tide-restricted sites were found to have a distinct landscape-level signature from tide-open sites, based on the number and distribution of marsh community patches.

The authors envisioned that a computer-learning algorithm could be developed to identify tidally restricted areas using landscape metrics derived from remote sensing images. However, with this technique, the spectral signature of targeted community types would need to be determined beforehand for the algorithm to work. Some of the community types in this study are applicable to other regions (i.e., *Phragmites* monoculture), but it does not capture all of those that might be found. This technique may require too much specialized knowledge and training to be broadly applicable to entities attempting to identify restrictions, at least in this form.

Remote sensing methods can also be used to prioritize tidal restriction removal or retrofit projects. The ***Salt Marsh Assessment and Restoration Tool*** (SMART) is a GIS-based simulation model that uses remote-sensing technology (LIDAR, hyperspectral imagery) and field data to predict how a proposed action to restore tidal flow (e.g., replace a culvert with a bridge; complete removal) will affect salt marsh vegetative communities upstream (Konisky, 2012). The model uses a site’s hydrology, elevation, vegetation, and salinity levels to predict the location and extent of native salt marsh vegetation resulting from a proposed restoration action. Therefore, the potential expansion of native salt marsh species under different tidal restoration scenarios can then be used to prioritize projects with a greater capacity to increase salt marsh habitat or the use of certain actions/structures over others. A wide variety of restoration project proponents (federal, state, local, NGO) in the Gulf of Maine have used the model to determine a project's potential for results as well as the specific actions to be taken (Konisky, 2012). The model was developed using salt marsh species typical of the northeast and mid-Atlantic, which limits its use; however, the model lends itself to adaptation with species assemblages typical of other regions of the country.

4.1.d. Conservation and Ecological Restoration Planning

There are a number of tools that can help in locating tidal restrictions and prioritizing their removal that are part of resources used in conservation or ecological restoration planning. The ***Conservation Assessment and Prioritization System*** (CAPS), developed for Massachusetts (McGarigal et al., 2011), was designed primarily to identify and prioritize lands and waters for habitat and biodiversity conservation based on an Index of Ecological Integrity (IEI; see Section 2.2). The IEI is a measure of the relative intactness and resiliency of ecological systems to environmental change determined by a set of stressor and resiliency metrics, one of which is the presence and severity of tidal restrictions. In CAPS, potential restrictions are first located using the intersection of stream centerlines in the coastal area with roads and railroads. It then models the restriction severity of each crossing using a regression developed by the MA Department of Environmental Protection (MA DEP) and Office of Coastal Zone Management of the ratio of expected salt marsh above each restriction (areas where the tidal regime suggest salt marshes) to the area of salt marsh actually mapped by MA DEP above each restriction. Areas of salt marsh affected by tidal restrictions, shown by severity, are available as a georeferenced coverage that can be displayed in GIS (McGarigal et al., 2015) and can aid in determining the general location of restrictive transportation crossings and areas of affected habitat for field verification.

Using the CAPS framework, the ***Designing Sustainable Landscapes*** (DSL) initiative (McGarigal et al., 2017a) is developing an IEI for the northeast U.S., from Maine to Virginia. As in CAPS, tidal restriction severity is one of the metrics used to determine the IEI and is calculated similarly. In DSL, the amount of existing salt marsh mapped by the National Wetlands Inventory (NWI) upstream of a road or railroad crossing is compared to the amount that would be expected based on tide range and elevation (McGarigal et al., 2017b). The resulting ratio indicates the severity of the restriction. GIS data files are available that show the crossings evaluated, their restrictive severity, and the potential amount of salt marsh habitat affected. These files were used in Section 2 to estimate the number of severe tidal restrictions associated with transportation infrastructure and the potential amount of affected salt marsh habitat in the northeast and mid-Atlantic. This method of modeling tidal restriction effects uses data that are widely available (i.e., NWI) or could be acquired or developed in other regions. There are two main constraints to this metric in both CAPS and DSL—the model does not evaluate the effect of stand-alone tide gates (i.e., those not associated with transportation infrastructure), mainly due to lack of comprehensive mapping, nor does it consider potential effects on tidal freshwater systems.

Brophy (2007) developed an ***Estuary Assessment Component XII of the Oregon Watershed Assessment Manual*** that identifies and prioritizes tidal wetland sites for conservation or restoration, depending on their level of alteration. The first step in this process is to identify the historic extent of tidal wetlands in an estuary using historic aerial photo interpretation and a variety of different map sources. Some of these sources are produced on a national level, including the NWI and topographic and soils mapping. However, some are Oregon-specific and include: 1) a data layer of tidal wetlands in Oregon classified using the Hydrogeomorphic Approach (HGM), which includes diked and other altered areas that may no longer be wetlands; 2) the Oregon Estuary Plan Book, which includes historic diking information of low and high tidal marsh; and 3) historic vegetation mapping from the Oregon Natural Heritage Information Center.

Once the historical extent of tidal wetlands is estimated, the next step is to assess the number and type of tidal wetland alterations estuary-wide, including tidal restrictions such as culverts and tide gates, dikes and embankments, and ditching. Alterations are located using some of the mapping identified above, as well as aerial photos and field investigations. Instructions on how to use and interpret all sources employed in the assessment are included in the manual. While this process does not focus on tidal restrictions or restoring tidal flow, it can be used to identify where restrictions are occurring and prioritize heavily restricted areas for tidal flow restoration. The Coos Watershed Association completed a tidal wetlands assessment for four sub-basins of the Coos Bay Estuary watershed (2010) using the Estuary Assessment process. It identified 1,789 acres (46% of total) of high priority areas for tidal wetland restoration in the assessment area due primarily to flow restrictions from tide gates, roads serving as dikes, culverts, and ditching for agriculture. The Estuary Assessment has limited applicability outside Oregon, but could be adapted for use outside the state if similar types of data are available elsewhere.

4.2 Tidal Restoration Project Planning and Implementation Tools

Once a tidal restriction has been identified, tidal restoration projects can be implemented if practicable. These projects can be initiated by a variety of entities, including federal and state natural resource agencies, state and local transportation departments (DOTs), county and municipal governments, and NGOs. Resources for completing tidal restoration projects range from those focused on restoring salt marsh to more comprehensive tools that consider a range of effects when introducing or increasing tidal exchange. For instance, the New York Department of Environmental Conservation has a set of salt marsh restoration and monitoring guidelines that specifically address the manipulation of tidal regime as a path towards salt marsh restoration (Niedowski, 2000).

A particularly useful resource for tidal restoration projects is *Returning the Tide* (NOAA Restoration and Coastal Service Centers, 2010), a guidance manual that was developed for tidal hydrology restoration projects, with a primary focus on those in the southeastern U.S. The manual is designed to walk restoration practitioners and coastal resource managers through the restoration process from project planning and design, to permitting and construction, to post-construction monitoring, and building community support for tidal restoration projects. The manual is underpinned by knowledge gathered from completed tidal restoration projects in California (1), Texas (1), Louisiana (1), Florida (7), South and North Carolina (2), and New Hampshire (1). Comprehensive project portfolios are presented that include information, supporting documentation, and lessons learned in:

- Project identification, feasibility, and planning;
- Goals and objectives;
- Project design;
- Permitting;
- Construction and maintenance;
- Scientific evaluation and monitoring; and
- Community involvement.

The projects comprise a variety of structures or practices, or a combination, that lead to a reduction or elimination in tidal exchange, the most common being the placement of dredge material road fill or causeways, and restrictive culverts. Project leads were mainly from state and federal resource agencies, with some involvement from local governments, and NGOs, though all projects had a number of partner organizations. By and large, these projects were not completed as part of compensatory mitigation or permitting requirements, but rather as voluntary restoration. Mitigation projects are addressed in the Regulatory Tools section (Section 4.4) of this document. In addition, a tide gate resource for tidal restoration practitioners is found in the Structure Design and Operation Tools section (Section 4.3 below).

4.3 Structure Design and Operation Tools

Roads, and the culverts and bridges associated with them, are often cited as the most common type of tidal restriction. This section presents current tools used by those in the transportation field to design and locate bridges and culverts in the coastal environment, as well as current research on tide gates and their use in conjunction with transportation infrastructure.

The foundation for bridge and culvert structure design in the U.S. is the ***Hydraulic Engineering Circular (HEC) or Design (HDS) Series*** produced by the U.S. Department of Transportation, Federal Highway Administration (FHWA). ***HDS 5 Hydraulic Design of Highway Culverts*** addresses the hydraulic design of highway culverts (FHWA, 2012a). Although this document is not intended to be specific to culvert design in tidal areas, there is some applicability to tidal systems as well. Culvert design for AOP is addressed in HDS 5 and in more detail in ***HEC-26 Culvert Design for Aquatic Organism Passage*** (2010). Barriers for fish can also coincide with conditions found at restrictive culverts, such as outlet drops and excessive velocities in the culvert barrel. Limiting these conditions when designing for AOP in coastal areas has the potential to reduce tidal restriction in certain cases.

HEC-25 (2008), ***Highways in the Coastal Environment***, is the only HEC that has a primary focus on structural design in tidal areas. The content is focused on the effects of coastal processes including tides, longshore sediment transport, wave action, and storm surge on bridge design and structural integrity (scour). Because this document was intended for structural design, tidal exchange is generally discussed in terms of how it can affect structures and is not focused on the impacts the structures themselves may have on ecological systems. For instance, the effects of tidal prism on inlet crossings and storm surge on bridge causeways are discussed, but the effects on tidal exchange and estuarine function from inlet crossings and causeways may warrant additional consideration. A supplement to this document, HEC-25 Volume 2, Highways in the Coastal Environment: Assessing Extreme Events, was added in 2014 to provide considerations for coastal transportation infrastructure under changing climate conditions and extreme events.

The Washington State Department of Transportation attempts to further refine material in HEC-25 in its ***Water Crossing Design Guidelines for Tidally Influenced Crossings*** (Barnard et al., 2013; Appendix D). These guidelines attempt to consider both the basic hydraulic conveyance and fish passage needs of tidal crossings as well as their impacts to ecological function. It introduces a hierarchy of benefits approach to determine what crossing width and/or location will have the maximum benefit for the lowest incremental cost. Different levels of tidal connectivity represented by different crossing sizes, types, and/or locations are given quantitative scores based on their impacts to hydraulic/hydrodynamic, sedimentary, and geomorphic ecosystem processes as well as water quality. Because the ecosystem processes underlying barrier estuaries and river deltas are distinct, these crossings are scored using different parameters. Crossing alternatives can then be given an ecological benefit score (sum and relative, expressed as a percent) and a “benefit cost” by dividing the relative benefit by the infrastructure cost of each alternative. The “incremental costs and benefits” is the given change in benefits for a given change in costs between alternatives, which can determine what alternative has the largest ecological benefit for the lowest monetary cost. These guidelines appear to be quite adaptable to situations outside Washington State, and could be used by DOTs elsewhere to build on and supplement the HEC series.

The HEC-18, ***Evaluating Scour at Bridges: Fifth Edition***, provides structural guidance for reducing scour in transportation infrastructure (FHWA, 2012b). Chapter 9 of this document discusses additional scour concerns for coastal waterways and evaluating long-term trends in inlet stability. Another foundational document on highway stream crossings is the HDS-6, River Engineering for Highway Encroachments: Highways in the River Environment (FHWA, 2001). This document reviews the important hydrogeomorphic considerations for any classification of transportation infrastructure in the floodplain.

In addition to the structural guidance in the HEC and HDS series, FHWA has published several documents on implementation of natural infrastructure to improve resilience, that may be applicable to situations involving tidal restrictions. The FHWA White Paper: ***Nature-based Solutions for Coastal Highway Resilience***, provides background on the existing state of the science of nature-based solutions in highway resilience (FHWA, 2018a). Examples of state DOT projects involving natural infrastructure are outlined in pilot reports from Maine and New Hampshire (MaineDOT and NHDOT, 2018), New Jersey (USACE, 2018c), Delaware (DelDOT, 2018), Oregon (ODOT, 2018) and Mississippi (MDOT, 2018).

4.3.a. Tide Gates

Traditional tide gates allow for the draining of upstream areas during outgoing (ebb) tides but prohibit the movement of water upstream during incoming (flood) tides. Such tide gates have been most commonly used in conjunction with dikes or transportation infrastructure to drain wetlands and protect upstream agriculture and development from flooding. They are typically top- or side-hinged lids fitted to the downstream end of a culvert, and open only when the water pressure upstream exceeds both that found downstream and the gate's effective weight or "restorative force" (Giannico and Souder, 2005). In preventing the upstream flow of brackish estuarine water, traditional tide gates can be considered tidal restrictions and can have the same sorts of adverse effects on upstream habitats and natural communities documented in Section 3.

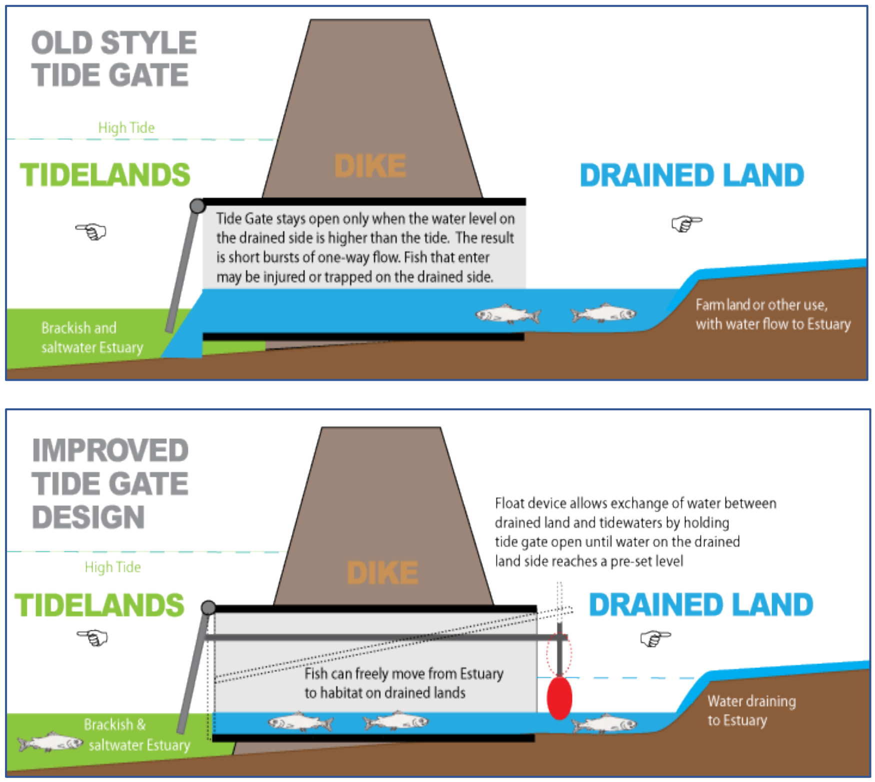

FIGURE 1: Traditional or "old style" tide gate vs. self-regulating or "improved" tide gate (SRT) operation (NOAA Fisheries)

Due primarily to fish passage concerns, different types of tide gates and associated modifications have been developed in recent years to permit greater bi-directional fish movement between up- and downstream environments in the tidal zone (Giannico and Souder, 2005). In some cases, these designs can also alleviate the tidally restrictive effects of traditional tide gates. One example that has gained interest in recent years is the self-regulating tide gate, or SRT. Unlike traditional tide gates where closed is the default position, the SRT can remain open except during periods of flood tides high enough to cause upstream flooding. SRTs are generally comprised of a top-hinged buoyant lid with counterbalancing arms fitted with floats, the height of which can be adjusted to modify the water elevation at which the gate will close. This flexibility allows site-specific management but can also nullify the increased tidal exchange expected from an SRT if the closure elevation is set too low. In addition, the floats can collect debris and hamper the SRT's performance without regular maintenance.

The use and performance of SRTs in Massachusetts has been documented by Reiner (2012). To restore/enhance salt marsh ecology, and provide greater flood protection, 11 SRTs were installed to provide controlled tidal flow to 32 hectares of wetlands in Rumney Marsh. This system is the largest remaining salt marsh in the Boston metropolitan area. Construction of roads and railroads in the nineteenth century as well as more recent road projects segmented the marsh and altered tidal hydrology. The SRTs replaced existing traditional tide gates on culverts that were missing, broken, leaking, or non-functional. The SRTs were installed by MassDOT, though their overall effectiveness was limited by problems stemming from improper installation and repair, irregular maintenance, and vandalism. In addition, MassDOT and participating local governments either did not correctly calibrate SRT settings or chose a setting that did not allow for natural marsh flooding due to the potential for residential property damage upstream. As mentioned above, SRTs require regular maintenance and repair to keep them functioning properly, which was largely not performed in this case. This need for periodic SRT inspection and maintenance requires a clear assignment of maintenance responsibility and adequate commitment of resources to follow through.

Recognizing the need to balance ecological concerns with agriculture and development requirements, the California Department of Transportation (Caltrans) conducted a preliminary investigation on the use of tide gates, with a focus on those that allowed greater tidal exchange (Caltrans Division of Research, Innovation and System Information [DRISI], 2016). The discussion concentrated on the use of SRTs, and stressed that to operate as intended, the SRT open and close settings should allow for greater tidal exchange. However, no western state had a comprehensive set of criteria and/or hydrologic standards for SRTs or other tide gate projects. The discussion concluded that more information needs to be gathered through hydraulic modeling of the tidal environment, with specific routines for tide gates, to develop better hydrologic guidelines for these structures.

Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis, recently completed by Souder et al. (2018) for the Oregon Watershed Enhancement Board (OWEB) is a resource for entities planning tide gate retrofit or removal projects. This document outlines the state of knowledge of the effects to aquatic organisms (largely salmonids) and estuarine environments of removing or replacing traditional tide gates with

West River SRTs in New Haven, CT (Tom Sturm/USFWS) alternative designs (like SRTs), alone or in combination with other restorative actions (e.g., dike removal or set-back), in the Pacific Northwest (PNW; OR, WA, and northern CA). It also includes summaries of tidal restoration projects that included tide gate upgrade or removal in the PNW, their implementation history, associated monitoring and validation efforts, and funding sources. Finally, the document presents lessons learned by tidal restoration practitioners, as well as findings and recommendations for future use.

4.4 Regulatory Tools

There are many different federal and state laws that regulate coastal aquatic habitats and associated wildlife. At the federal level, laws that might have a direct bearing on tidal restriction avoidance and removal include the Clean Water Act (CWA), the Rivers and Harbors Act of 1899 (RHA), the Endangered Species Act (ESA), the Magnuson-Stevens Fishery Conservation and Management Act (MSA), and the National Flood Insurance Act, which established the National Flood Insurance Program (NFIP). There are also state level delegated authorities and laws that serve to protect the coastal environment, including AOP. Regulatory mechanisms exist at both the federal and state level that may promote the avoidance or removal of tidal restrictions.

Section 404 of the CWA requires activities that result in the discharge of dredge or fill material into the "waters of the United States" (WOTUS), including jurisdictional wetlands, to obtain authorization from the U.S. Army Corps of Engineers (USACE) or a Section 404-assumed state (e.g., New Jersey, Michigan), and may require appropriate and practicable compensatory mitigation to offset those impacts.[3] *See* 33 U.S.C § 1344; 40 C.F.R. § 230, Subpart J; 33 C.F.R. § 322, 323, and 332. Certain activities are statutorily exempt from CWA Section 404 permit requirements under CWA Section 404(f).[4] Section 10 of the RHA requires projects that will affect the course, location, condition, or capacity of navigable waters to obtain authorization from the USACE, and may also require compensatory mitigation to offset impacts. *See* 33 U.S.C. § 403; 33 C.F.R. § 322, 323, and 332. Transportation projects often contribute to tidal restriction and may impact WOTUS. Therefore, retrofitting or removing restrictive structures, including those associated with transportation infrastructure, could potentially require a permit under CWA Section 404 and/or RHA Section 10 (and possibly require compensatory mitigation), but may also be used as mitigation to offset other permitted impacts.

In addition to the CWA and RHA, requirements to satisfy the ESA, MSA, or state-level permits that regulate fish passage can also be drivers for addressing tidal restrictions in transportation infrastructure. *See*, *e.g.*, 16 U.S.C. §§ 1531 through 1544; 16 U.S.C. §§ 1801 through 1891d. Conversely, certain regulatory requirements or conditions (see Section 4.4.b) may

[3] The CWA Section 404(b)(1) guidelines, the substantive environmental criteria which 404 permit decisions are to be evaluated under, require that the permit applicant evaluate avoidance and minimization measures in identifying the least environmentally damaging practicable alternative (40 C.F.R. § 230.10(a)) and identifying appropriate compensatory mitigation to address significant degradation of WOTUS (40 C.F.R. § 230.10(c)) and take appropriate and practicable steps which will minimize potential adverse impacts of the discharge on the aquatic ecosystem (40 C.F.R. § 230.10(d)) prior to a final CWA Section 404 permit decision.

[4] See part (f) of 33 U.S.C § 1344 for list of exempt activities.

unintentionally lead a project proponent to retain tidally restrictive structures during maintenance or emergency repair situations, when it might otherwise make more sense to remove or replace them with structures that do not cause restrictions.

4.4.a. CWA/RHA Compensatory Mitigation

Compensatory mitigation to comply with environmental regulations presents a possible means to reduce the environmental effects of tidal restrictions. Removal of tidal restrictions has the ability to restore aquatic resource functions and habitats dependent on tidal flow, which can offset environmental impacts either on- or off-site. However, there are several different reasons why mitigation crediting for tidal restriction removal may not be pursued or chosen over other mitigation options by project sponsors. They include: 1) regulatory and resource agency preference for in-kind mitigation (i.e., replace like with like); 2) limited data on tidal restriction project outcomes that might inform a potential crediting framework; and 3) the number of credits granted by the regulatory agency is too small to be cost-effective. Still, there has been some recent regulatory guidance to help facilitate mitigation crediting for the removal of certain types of tidal restrictions, including dams and other structures such as culverts.

Top*: Exeter River during removal of the Great Dam in Exeter, NH;* Bottom*: The Exeter River joins the tidal Squamscott River just downstream of the Great Dam removal project (NOAA, Greater Atlantic Regional Fisheries Office)*

In 2018, the USACE released ***Regulatory Guidance Letter No. 18-01*** (RGL 18-01; USACE, 2018b), which provides general guidance to USACE District Engineers nationwide in how to credit compensatory mitigation projects that remove dams (obsolete and otherwise) and other structures, including the removal or replacement of undersized or perched culverts. RGL 18-01 allows for the use of existing assessments in USACE Districts where appropriate functional or condition assessments are available to inform crediting determinations for these types of projects. For USACE Districts where an appropriate assessment is not available, RGL 18-01 provides guidance on areas to be considered for credit production, including the affected waterbody and its associated riparian areas (including wetlands), as well as additional factors that may influence credit generation, including a project's contribution to the recovery of an endangered or threatened species, benefits to diadromous fish, improvements to water quality, and distance to the next in-stream obstruction. RGL 18-01 can direct or enhance the development of credit determination methodologies that would potentially facilitate the use of tidal restriction removal as compensatory mitigation since both dams and undersized or perched culverts can act as restrictions.

In addition, even before release of RGL 18-01, the removal of dams has been used for CWA Section 404 mitigation credit. As documented in Wilkinson et al. (2017), 38 dam or other barrier (largely culverts) removal projects in ten states and District of Columbia have generated compensatory mitigation credit. These include four projects in Maine and Massachusetts that involved tidal waterways, as well as others like the Great Dam in Exeter, NH, that are adjacent to tidal waterways and provide a vital upstream link for alewife and other sea-run fish.

As covered in Section 2, transportation structures are a significant source of tidal restriction. Transportation projects can also be a significant source of impacts to CWA and RHA regulated waters that require compensatory mitigation. Therefore, tidal restriction removal presents an opportunity to meet compensatory mitigation requirements associated with new transportation projects. Following are examples of transportation projects or programs that successfully used the removal of a tidal restriction as compensatory mitigation, along with information on the mitigation credits generated, if available.

The North Coast Corridor (NCC) project in northern San Diego County, California, is a good example of comprehensive transportation planning that both addresses existing tidal restrictions and their role in providing compensatory mitigation. The NCC proposes a 40-year program of critical transportation improvements (rail, highway, transit, etc.) along a 30-mile long corridor that includes Interstate 5, Highway 101, and the Los Angeles – San Diego – San Luis Obispo Rail Corridor (LOSSAN) and is a partnership between Caltrans and the San Diego Association of Governments (SANDAG). The project is outlined in the NCC Public Works Plan/Transportation and Resource Enhancement Program (Caltrans and SANDAG, 2016) that strives to integrate long range transportation planning with environmental preservation, enhancement, and restoration priorities. A central piece of the PWP/TREP is the ***Resource Enhancement and Mitigation Program*** (REMP). The REMP was developed to enhance and restore habitat functions and services of important ecological coastal resources within the NCC as compensatory mitigation in advance of permitted impacts associated with PWP/TREP projects. As such, these efforts focus on six tidally influenced, regionally significant lagoon systems in the NCC corridor that are each affected, to some extent, by restrictive transportation crossings and/or ocean inlets that fill with sediment.

In service of the REMP, each of the lagoon systems was studied to document their historical and existing conditions and determine the availability of restoration opportunities (Caltrans and SANDAG, 2009), both conventional and hydrodynamic. Hydrodynamic restoration relates to actions that increase the tidal prism. Based on bridge optimization studies completed for each lagoon (e.g., Caltrans, 2012), the I-5 bridges at three lagoons (Batiquitos, San Elijo, and Buena Vista) and one LOSSAN bridge at one lagoon (San Elijo) will be widened to varying degrees as part of NCC improvements. The bridge widenings alone are considered avoidance and minimization measures and will not result in mitigation credit (Susan Scatolini, personal communication, April 12, 2018). However, because widening these bridges will complement and facilitate adjoining salt marsh restoration projects by increasing the tidal prism in their respective lagoons (e.g., the San Elijo Lagoon Restoration Project), they are considered "enhancement elements" for all PWP/TREP project impacts. That is, the act of increasing the width of the replacement structure will be used to offset their impacts to water quality, shading, and eel grass as well as potential impacts associated with temporary construction activities.

Caltrans is receiving mitigation credit for endowing two funds that will provide maintenance monies to keep the ocean inlets at two lagoons (Batiquitos and Los Peñasquitos) open through periodic dredging, known as the regional lagoon maintenance program (RLMP). Both lagoons experience increased sedimentation due to an altered tidal prism and surrounding urbanization, to the point that the Los Peñasquitos inlet closes completely on a seasonal basis without management. In this area of California, there is precedent for this type of arrangement associated with the development permit issued by the California Coastal Commission for the San Onofre Nuclear Generating Station (SONGS; Susan Scatolini, personal communication, April 12, 2018). In that instance, SONGS was able to use maintaining the inlet at San Dieguito lagoon in perpetuity as mitigation credit to offset losses to marine fish stocks due to its operation (Southern California Edison Company, 2005). The 35-acre credit from this action was combined with 115 acres of additional tidal wetland restoration to satisfy the 150-acre total required by SONG's coastal development permit. For the RLMP, available mitigation credit was calculated by multiplying the percentage increase in tidal range expected through inlet management by the existing wetland acreage in each lagoon. In the case of Batiquitos, the total percentage change is equal to 47.2 additional wetland acres immediately following a dredging event. Because dredging will only occur every three years, the increase in tidal range will gradually decrease; therefore, the additional wetland acreage was reduced by a third for a total of 15.7 mitigation credits.

In the northeastern U.S., tidal restoration projects have been proposed and/or implemented as compensatory mitigation for transportation-related CWA Section 404 permits as well. In 1991, the Rhode Island Department of Transportation (RI DOT) received approval from regulatory agencies to enhance tidal flow at Galilee Bird Sanctuary (74 acres) as mitigation for the filling of a 0.7-acre *Phragmites* marsh nearby (Golet et al., 2012). Tidal flow into the Sanctuary was restricted by a 4-lane road constructed in 1956, where only one culvert, 75-cm in diameter, was placed along a 2,100-foot long causeway. The restoration effort involved a large suite of partners, including RI DOT, the USACE, the RI Division of Fish and Wildlife (RIDFW), USFWS, EPA, National Fish and Wildlife Foundation, Ducks Unlimited, University of Rhode Island (URI), and the Town of Narragansett. The USACE and RIDFW assumed major responsibility for the project including regulatory compliance, hydraulic modeling, culvert and tide gate design, construction management, and adaptive management efforts. RI DOT provided elevation surveys and shared culvert construction costs while USFWS funded URI ecological monitoring efforts. The close collaboration and clearly defined roles among partner organizations was essential for project success. The restoration project ultimately led to the installation of two pairs of box culverts fitted with SRTs, and the excavation of a network of channels to enhance tidal flushing and reduce mosquitoes. The SRTs were calibrated to close at a tide level determined to avoid flooding of nearby residential areas but that would still fulfill the purpose of increased tidal flushing.

In New Jersey, the restoration of tidal flow to a tidal freshwater canal was used as partial CWA Section 404 mitigation for 3 acres of wetland fill associated with a light rail corridor, along with *Phragmites* removal (3.25 acres) and tidal wetland creation (2 acres; Masters et al., 2001). Before restoration, a service road blocked the canal entirely; the project added a culvert to allow upstream tidal flushing and fish passage to a ponded 3.26-acre area. There was also an identified restriction further downstream that was slated for removal in the future. Therefore, the new culvert was designed to accommodate the maximum tidal flows that would result from future removal of the downstream restriction.

4.4.b. Infrastructure Maintenance and Regulatory Compliance

Routine and/or emergency maintenance of culverts and bridges presents opportunities to address restrictions associated with those structures. Regulatory programs that may be triggered by these maintenance activities include CWA Section 404 (see CWA Section 404(f) for activities exempt from Section 404 permitting requirements), RHA Section 10, and the NFIP. Efficient pathways for obtaining authorizations under these programs serve as incentives for project proponents to address restrictions during maintenance activities rather than leaving restrictive structures in place (and retaining as-built design).

Although CWA Section 404(f) provides an exemption for certain maintenance activities,[5] there are limits to the exemption that are established in CWA Section 404(f)(2).[6] In addition, the exemption also does not allow any modifications that “change the character, scope or size of the original fill design” (see 40 C.F.R. § 232.3(c)(2)). Since no similar exemption exists under RHA Section 10, maintenance activities on structures in tidal waters may require authorization under the RHA.

USACE Nationwide Permits 3 (Maintenance), 14 (Linear Transportation Projects), and 53 (Removal of Low-Head Dams) are relevant to this topic and can be used in both waters regulated by RHA Section 10 and CWA Section 404. 82 Fed. Reg. 1860 (January 6, 2017). These three Nationwide Permits offer pathways for authorizing maintenance-related tidal restriction removal. In addition, targeted maintenance can be tied to a larger project. For example, MassDOT is completing a 23-acre wetland restoration by coupling the replacement of a crushed

[5] For example, for maintenance, including emergency reconstruction of recently damaged parts, of currently serviceable structures such as dikes, dams, levees, groins, riprap, breakwaters, causeways, and bridge abutments or approaches, and transportation structures.

[6] Any discharge of dredge or fill material into WOTUS incidental to any activity having as its purpose bringing an area of WOTUS into a use to which it was not previously subject, where the flow or circulation of WOTUS may be impaired or the reach of such waters be reduced, is required to obtain a Section 404 permit.

culvert restricting tidal flow with a larger bridge replacement project that already requires CWA permits (Tim Dexter, personal communication, December 18, 2017).

The Maine Department of Transportation (MaineDOT) proposed to address tidal flow at a storm-damaged bridge crossing by viewing the site as a potential mitigation opportunity (MaineDOT, 2013). An earthen dam and bridge span across the southern branch of the tidal Marsh River was constructed along US Rt. 1 in 1934, resulting in a large, impounded freshwater pond. A new bridge was constructed in the 1960's, but the dam was left in place. The dam was breached in 2005 due to a heavy rain event, which reintroduced tidal flushing but also exposed the bridge piers, creating a safety concern. In initial discussions with permitting agencies, it was decided to simply re-build the old dam; however, further discussion led to a proposal that would allow for near-term stabilization measures for the bridge piers without replacing the tidally restrictive dam. This work gave MaineDOT and the agencies time to work out a new bridge and channel design that would allow for active salt marsh restoration. The Sherman Marsh site was eventually proposed as a deposit in the state-wide MaineDOT aquatic resource umbrella mitigation bank but was eventually rescinded from consideration by MaineDOT due to local landowner opposition to easement boundaries (Zewert, 2017).

Floodplain management requirements for communities that participate in the National Flood Insurance Program (NFIP), which is administered by FEMA, can also make retrofits to tidally restrictive infrastructure more complex and expensive (Tim Dexter, personal communication, December 18, 2017). *See* 44 C.F.R. § 59 through 80. In order to participate in the NFIP, communities must adopt and enforce floodplain regulations that meet or exceed NFIP criteria. *See*, *e.g.*, 44 C.F.R. § 60.3. These regulations require, in part, that projects are evaluated in advance of their construction for potential flood risk impacts to the surrounding area. More specifically, the community or a project proponent must request FEMA comments on any project that will affect the hydrologic or hydraulic characteristics of a flooding source and thus result in the modification of the existing FEMA-designated regulatory floodway, the effective Base Flood Elevations (BFEs), or the Special Flood Hazard Area (SFHA; FEMA 2018b). *See* 44 C.F.R. § 65.8. FEMA's comments take the form of a Conditional Letter of Map Revision (CLOMR) and typically require that the community or project proponent submit hydrologic modeling of proposed project conditions and analysis of flood hazards, as prepared by a qualified, registered Professional Engineer. After project construction is complete, FEMA follows up with a Letter of Map Revision (LOMR) that is a binding, regulatory submission that will officially update the Flood Insurance Rate Map (FIRM), the regulatory tool of the NFIP. *See* 44 C.F.R. § 65.9.

Since enlarging tidally restrictive infrastructure would likely increase the BFE upstream (i.e., landward of a restriction), a CLOMR analysis would be required. In urgent maintenance or emergency repair situations, the additional time and cost required to prepare a CLOMR may be enough to dissuade project proponents from upsizing restrictive structures since that would require a CLOMR whereas retaining the same-sized structure would not. Further, if the project results in increased flood risk to nearby developed areas, landowners may oppose the project. *See* 44 C.F.R. § 61.

4.4.c. Aquatic Organism Passage (AOP) Compliance

Aquatic connectivity is important in both tidal and non-tidal areas to facilitate aquatic organism movement, especially of migratory species that move between freshwater and saline habitats as part of their life cycle. For these species, culverts, dams, and other structures in the tidal zone can also act as barriers to aquatic organism movement in the same way as those found inland. In that way, entities concerned with the documentation and removal of tidal restrictions can find common cause with entities concerned with the documentation and removal of barriers to AOP.

For example, avoidance and removal of tidally restrictive transportation infrastructure can also be accomplished through compliance with fish passage requirements established under state statute. The Oregon Fish Passage Statutes (established through House Bill 3002 in 2001) require that for a given project, fish passage must be addressed wherever native, migratory fish are currently or were historically present. In addition, an applicant may provide compensatory mitigation that results in a net benefit to migratory fish to offset impacts, as determined by the Oregon Department of Fish and Wildlife (ODFW) who is responsible for administering the statutes. To account for prioritization and cost considerations, the Oregon Department of Transportation (ODOT) and the ODFW implemented a 3-year pilot ***Culvert Repair Programmatic Agreement*** that allows ODOT to make specific short-term repairs to culverts without having to meet full fish passage criteria, though fish passage would be improved to some degree at each site repaired (Warnke and Martin, 2016).

This program gives ODOT the flexibility to stagger the costs of meeting Oregon's full fish passage criteria while still improving existing conditions. In exchange, ODOT will fund five of the highest priority fish passage projects as mitigation for delaying full passage at culvert repair locations. One of these projects is part of the larger "Sturgeon Lake Restoration Project," which aims to restore tidal and fluvial processes in Sturgeon Lake, a shallow, tidally influenced lake along the lower Columbia River used by salmonids, lamprey, and sturgeon. The compensation project will remove two undersized, failing culverts on a creek that feeds the lake and replace them with an appropriately sized bridge.

In a separate but related initiative, ODFW, with support from ODOT and two NGOs, has commenced a ***Fish Passage Mitigation Banking Pilot Program*** along Oregon's north coast (ODOT and ODFW, 2014). ODFW issues waivers for actions that will impact fish passage; this program will allow ODFW to consolidate mitigation from multiple waivers toward a fish passage bank, where high priority barriers are removed and significant benefits for fish are created. While this program is not specific to tidal areas, it could generate mitigation projects that address fish passage while increasing tidal exchange.

4.4.d. ESA and MSA Compliance

Mechanisms to avoid or remove tidal restrictions can also originate from ESA compliance where it involves migratory fish species. *See* 16 U.S.C. §§ 1531 through 1544. For instance, MaineDOT developed a ***Programmatic Biological Assessment (PBA) for Atlantic Salmon*** to satisfy ESA

Section 7 requirements (MaineDOT et al., 2016). This PBA addressed routine transportation activities (e.g., bridge and culvert replacements and some extensions) over a five-year period. The USFWS issued their ESA Biological Opinion which requires MaineDOT to implement the Atlantic salmon avoidance, minimization, and conservation measures proposed in the PBA in order to receive ESA Section 9 liability protections for activities that may "take" ESA-listed species. For instance, the first conservation measure specifies the width of culvert and bridge replacements depending on priority level tier (1-3), where Tier 1 indicates the highest priority recovery watersheds. Many of the Tier 1 priority areas are along the coast, where bridge and culvert widths must be at least 1.2 times the bankfull channel width. In general, this width should allow for fish passage as well as restoring tidal exchange. The second conservation measure is the development and implementation of an in-lieu fee (ILF) mitigation program specific to Atlantic salmon for certain activities detailed in the PBA. The ILF program was chosen as an option to provide an alternative to permittee-responsible mitigation, which could potentially increase the extent and quality of mitigation projects and present more opportunities to integrate ILF projects with other conservation activities. As with the ODFW pilot program described in the previous section, this program could also produce projects that remove or retrofit tidal restrictions.

The USACE Portland District breaches the Steamboat Slough levee along the Columbia River to restore tidal wetlands that will provide habitat for young salmon (USACE Portland)

NOAA's National Marine Fisheries Service (NMFS) also has the authority under the ESA to regulate certain migratory fish species in coastal waters. *See* 16 U.S.C. § 1536; *see also* 16 U.S.C. §§ 1361 through 1423h. In Oregon, a ***Programmatic Biological Opinion (PBO) issued by NMFS (2018a) for endangered species populations of Chinook and coho salmon***, among others, will assist in the authorization, funding, and implementation of tidal area restoration projects (referred to collectively as the Tidal Area Restoration Program, or TARP). This PBO permits activities in twelve categories that are proposed to be authorized, funded, or implemented by the USACE, FEMA, and FHWA. These activities include tide gate removal, replacement, or retrofit, set-back or removal of dikes and levees, and dam and legacy structure removal. The PBO includes conservation measures and other action requirements that must be met for an action to qualify for inclusion.

The MSA is the primary law governing marine fisheries management in federal coastal waters. *See* 16 U.S.C. §§ 1801 through 1891d. An important component of the MSA mandates NMFS to regulate "Essential Fish Habitat" (EFH), defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity," including tidal wetlands. 16 U.S.C. § 1802(10). If a federal action may adversely affect EFH, the subject agency must consult with NMFS as part of MSA compliance. 16 U.S.C. § 1855(b)(2). In the Greater Atlantic region (defined here as coastal and riverine areas within and offshore of states from Maine to Virginia), FHWA and NMFS coordinated on a ***Programmatic EFH Consultation*** (FHWA, 2018b) that applies to certain routine transportation actions, including bridge and culvert repair, demolition, and replacement. To qualify, activities covered by this programmatic consultation must meet certain requirements and satisfy NMFS conservation recommendations and provide the liability protections offered by the MSA. One of the recommendations applies to fish passage/migration habitat and requires that replacement culvert or bridge crossings: 1) provide sufficient water depth and maintain suitable water velocities during migration periods; and 2) maintain or replicate natural stream channel and flow conditions. As with the MaineDOT/USFWS PBA/PBO, these design requirements should assist in avoiding and/or removing tidal restrictions.

4.5 Funding Tools

Grant monies are available to local, state, and tribal governments, NGOs, private (for-profit) entities, regional organizations, and universities to restore coastal habitats for plants and wildlife and to strengthen coastal communities. Projects funded with these monies can include those that restore tidal flow, as there is no dedicated funding source just for these types of projects. In some cases, funding to enhance AOP can also be used for projects where tidal restrictions are removed, though these tend to be at the state or local level and are beyond the scope of this document. Federal funding will be the focus of this section and is discussed by agency or department below. Due to the nature of federal funding, the foremost constraint is that these grants may not be consistently available into the future and/or are tied to distinct events that are not predictable.

4.5.a. The National Oceanic and Atmospheric Administration (NOAA)

NOAA manages two sources of applicable grant funds, the ***Coastal Resilience Grant Program*** (NOAA Office for Coastal Management, 2017b) and the ***Community-Based Restoration Grant Program*** (NOAA Fisheries, 2018). In 2017, the Coastal Resilience Grant Program recommended funding for nineteen projects totaling $13.8 million. Of these 19, four were projects that would remove tidal restrictions—specifically, causeways, undersized culverts, and dikes. The recommended federal funding total for these four projects is approximately $4.5 million; all were in western states (CA, OR, and WA).

Over the course of 2016 and 2017, the ***Community-Based Restoration Grant Program*** awarded funding to twenty-seven projects totaling $30.6 million. Of these 27, two were projects that would remove tidal restrictions—specifically, dikes, undersized culverts, and tide gates. The recommended federal funding total for these two projects is approximately $4.0 million over three years, with one project in CA and one in MA. This grant program was also used extensively for projects associated with *Returning the Tide* in past years (see Tidal Restoration Planning and Implementation section).

4.5.b. U.S. Fish and Wildlife Service (USFWS)

The ***National Coastal Wetlands Conservation Grant Program*** (USFWS, 2018a), administered by the USFWS, aims to protect, restore, or enhance coastal wetlands and associated uplands through competitive grants to state agencies or their delegated representatives. In 2017, the program awarded funding to twenty projects totaling $17 million. Of these, four, two in WA and two in CA, were awarded funding to remove tidal restrictions—specifically, dikes and causeways. The federal funding total for these four projects is approximately $3.0 million.

The ***USFWS Coastal Program*** itself also provides financial and technical assistance to partner organizations (e.g., federal, state, and local governments, universities, NGOs, and private landowners) every year for restoration and protection of coastal wildlife habitats. For example, in 2014, the program provided almost $2.3 million in funding (not including the Great Lakes region) to project partners, including funds to aid in restoring McDaniel Slough in California, which had been degraded by tidally restrictive levees and other fish passage barriers (USFWS, 2014).

The ***National Fish Passage Program***, administered by USFWS, provides financial and technical assistance to partner organizations for projects that improve the movement of fish or other aquatic organisms by reconnecting habitat that has been fragmented by barriers, including dams and perched culverts. On average, the fish passage program contributes $70,000 to projects that have at least 50% matching funds (USFWS, 2018b).

4.5.c. U.S. Army Corps of Engineers (USACE)

The ***Estuary Restoration Act (ERA) of 2000***, as amended, authorizes the USACE to grant funds and provide technical assistance to non-federal partners to implement estuary restoration projects consistent with the ERA's goals (USACE, 2018). The USACE may also provide ERA funds to other federal agencies on the "Estuary Habitat Restoration Council," comprised of representatives from NOAA, EPA, USFWS, and USDA. Funds from this program have been used or are being used to plan the removal of various kinds of tidal restrictions (levees/dikes, mosquito ditches, and undersized culverts) in California, Florida, Massachusetts, and Washington (USACE, 2013).

Section 206 of the Water Resources Development Act of 1996 authorizes the USACE to cost-share with non-federal entities in the planning, design, and construction of projects to restore aquatic ecosystems for fish and wildlife, which can include removal and/or retrofit of tidal restrictions that hinder AOP. Projects should be cost effective, improve the environment, and be in the public interest. Non-federal sponsors can solicit the USACE at any time for assistance, which begins with a feasibility study and then, if warranted, project implementation (USACE, 2015).

4.5.d. Federal Emergency Management Agency (FEMA)

FEMA Public Assistance Program Grants or the ***FEMA Hazard Mitigation Grant Program*** could potentially be used for tidal restriction removal projects that would restore tidal wetland habitat and/or alleviate flooding issues. These grants are available for projects within officially designated disaster areas; eligible work includes: 1) functional improvements to disaster-damaged facilities (e.g., road and bridge systems, public buildings, parks and recreation areas) that might prevent damage in the future; 2) mitigation measures in the surrounding area that will directly reduce the potential for similar disasters to damage a facility; 3) long-term hazard reduction measures that will reduce or prevent loss of life or property from future disasters. For example, the Port of Tillamook Bay in Oregon was then able to obtain funds from the public assistance grant program for a habitat restoration project that removed or set back levees and retrofitted tide gates to create more tidal wetlands to better buffer surrounding uplands from flooding (Oregon Solutions, 2017). The FEMA Public Assistance Policy Digest provides guidance on the public assistance program (FEMA, 2008).

FEMA's NFIP Community Rating System (CRS) is another potential source of economic credit (though not direct funding) for tidal restriction removal projects. The CRS is a voluntary program that allows municipalities to earn "credit points" towards reducing flood insurance premiums for the community's property owners. One of the activities that can be used to earn credit is to "prepare, adopt, implement, and update a plan to protect natural functions within the community's floodplain" (FEMA, 2018a). Given that removing tidal restrictions can potentially restore functionality to tidal wetlands and eliminate flow constrictions from the floodplain, these types of projects could play an important part in plan development.

4.5.e. Federal Highway Administration (FHWA)

FHWA established the **Emergency Relief (ER) program** to help fund the repair or reconstruction of Federal-aid highways which have suffered severe damage as a result of natural disasters or catastrophic failures from an external cause. FHWA's associated Emergency Relief Manual is a guide for FHWA and state and local transportation agency personnel for requesting, obtaining, and administering ER funds (FHWA, 2013). ER funds may be used to bring damaged assets (including tidally restrictive structures) up to current design standards based on existing conditions and model forecasts. ER projects are typically restricted to the existing structure's footprint, however additional opportunities exist to expand beyond the footprint with appropriate resource and regulatory agency coordination.

A similar FHWA program, the **Emergency Relief for Federally Owned Roads** (ERFO) **program,** assists federal land management agencies (such as US Forest Service and National Park Service), which are not part of the Federal-aid highways program, with funding the repair or reconstruction of federally owned roads that have suffered severe damage as a result of natural disasters or catastrophic failures. The Disaster Assistance Manual provides guidance for this program (FHWA, 2015).

4.5.f. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS)

The ***Watershed Protection and Flood Prevention Program*** (USDA NRCS, 2019) helps federal, state, local and tribal governments protect and restore watersheds up to 250,000 acres. This program provides for cooperation between the Federal government and the states and their political subdivisions to work together to prevent erosion; floodwater and sediment damage; to further the conservation development, use and disposal of water; and to further the conservation and proper use of land in authorized watersheds. This program has funded coastal habitat restoration and fish barriers removal projects.

4.5.g. U.S. Environmental Protection Agency (EPA)

Nonpoint Source Management (CWA Section 319) Grants support states, territories, and tribes with a wide variety of activities related to addressing nonpoint source pollution. EPA guidance (US EPA, 2013) includes hydrologic modification as a type of nonpoint source pollution and therefore tidal restriction removal projects are potentially eligible for funding. Potential 319 funding applicants should note that projects need to be consistent with a state's written Nonpoint Source Management Program Plan. These documents are five-year strategic plans that describe the state's priorities for its nonpoint source program. However, even in states that do not explicitly discuss hydrologic modification as a priority in their Nonpoint Source Management Plan documents, tidal restriction removal projects could be eligible for 319 funding through the implementation of watershed-based plans. EPA requires states to use at least half of their annual 319 grant funds to implement watershed projects guided by watershed-based plans. Tidal restriction removal projects included in local watershed-based plans that are consistent with EPA guidelines would be eligible for 319 funds.

Wetland Program Development Grants (WPDGs; US EPA, 2019) provide eligible applicants an opportunity to conduct projects that promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution. These grants, provided to state, tribal, and local governments, as well as interstate/intertribal entities, could fund studies to identify how tidal restriction removal can improve wetland restoration and include those options in wetland protection plans developed by the states. Therefore, WPDGs may be a potential source of funding for states and tribes that want to develop their in-house technical expertise (e.g., obtain training) and/or conduct scientific studies about the effects of tidal restriction removal. For instance, states have used WPDGs to conduct studies to monitor and assess the impacts of small impoundments in tailwaters below dams as well as studies necessary to develop restoration plans. However, use of WPDGs for construction activities (including restoration projects) is specifically prohibited, unless those efforts are being undertaken as part of a scientific demonstration or “study.” In general, WPDGs are not intended to financially support individual, on-the-ground projects, even if they restore wetlands or waterbodies. Instead, WPDGs are targeted towards building technical and programmatic capacity of state and tribal water agencies (primarily) and local government agencies (secondarily). It should be noted that there is a distinction between wetland program "development" and program "implementation" activities, and EPA refrains from funding the latter category of activities.

National Estuary Program (NEP) Coastal Watersheds Grant Program (RAE, 2020) is a grant program that aims to address coastal and estuarine issues within the 28 National Estuary Program study area boundaries along with some additional upstream and/or downstream areas. This grant program is funded by EPA and administered by Restore America's Estuaries (RAE). The program focuses on meaningful, on-the-ground change and addresses urgent and challenging issues such as loss of key habitats including tidal wetlands, freshwater wetlands, and forested wetlands among others. Therefore, the NEP Coastal Watersheds Grant Program may be a potential source of funding for coastal wetland restoration and may specifically be able to help address certain tidal restriction removal or restoration projects.

4.5.h. Multiple Agencies

Ni-lestun Tidal Marsh Restoration along the Coquille River in Bandon National Wildlife Refuge (OR). This project was partially funded by the New Carissa oil spill settlement mandated under the Oil Protection Act (Roy Lowe/USFWS)

Damages to natural resources in the public trust are regulated under the ***Comprehensive Environmental Response, Compensation and Liability Act*** (CERCLA, also known as Superfund) and the ***Oil Pollution Act*** (OPA). These laws require both clean-up and restorative actions that bring damaged resources back to the condition they were in before exposure to the environmental contaminant. As part of this process, a Natural Resource Damage Assessment (NRDA) is conducted to assess the extent of injury and determine appropriate ways of restoring and compensating for that injury. Depending on the contaminant, the NRDA follows guidelines set out by the DOI (for CERCLA) or NOAA (for OPA). The removal of tidal restrictions could be funded as a way of restoring habitat lost or degraded through environmental contamination. For example, in Massachusetts, the Buzzard's Bay Tidal Restriction Atlas (2002) was used during the NRDA process for both the Buzzards Bay oil spill (2003) and the New Bedford Harbor cleanup to identify potential salt marsh restoration sites and award settlement funding (Joe Costa, personal communication, February 15, 2018). Under the oil spill NRDA, the removal of two tidal restrictions were identified for funding: a non-functioning culvert and an old dam (Buzzards Bay Trustees, 2017). Under the New Bedford NRDA, at least one tidal restriction has been removed as part of a salt marsh restoration project

(New Bedford Harbor Trustee Council, 2004), with other restriction removal projects identified (New Bedford Harbor Trustee Council, 1998 and 2001).

The ***Five Star and Urban Waters Restoration Grant Program*** (National Fish and Wildlife Foundation [NFWF], 2019) seeks to develop community capacity to sustain local natural resources for future generations by providing modest financial assistance to diverse local partnerships focused on improving water quality, watersheds, and the species and habitats they support. This program is currently managed by the NFWF through a cooperative agreement with EPA. The program is funded by EPA, USFS, USFWS, and several private-sector companies. Geographic focus depends on funding available from the funding partners. Grants for this program are available nationwide, but additional funding is available for priority watersheds identified in the solicitation. Key elements for a tidal restriction removal restoration project to be eligible, include:

- On-the-ground wetland, riparian, in-stream and/or coastal habitat restoration
- Meaningful education and training activities, either through community outreach, participation and/or integration with K-12 environmental curriculum
- Measurable ecological, educational and community benefits
- An appropriate and diverse partnership of five or more organizations (public and private, including the applicant) that exists to implement the project, leverages additional contributions, and sustains the project after the life of the grant.

4.6 Discussion

The preceding discussion makes clear that a range of tools, resources, policies, and practices are available to address tidal restriction in the U.S. Some of these were developed specifically for this purpose, though the majority were not. Most of the indirectly related tools can be applied to tidal restriction avoidance and removal without a lot of modification; however, greater coordination with a different set of policy and practice stakeholders may be necessary to fully integrate tidal restriction concerns into these existing tools. The next section provides non-binding recommendations for better utilizing existing tidal restriction resources and developing new ones based on observed data gaps and needs in what is currently available to practitioners.

Section 5: Recommendations

The preceding sections introduced the issue of tidal restrictions, including types and extent, effects on upstream habitats, and current tools, practices, and policies that can be used to identify tidal restrictions and aid in their avoidance or removal. This section builds on the previous discussion and lays out recommendations to further address tidal restriction issues in coastal areas of the U.S. These suggested actions are largely built from identified gaps and needs listed at the end of Section 4 as well as existing tools that are successfully being used at a state or regional level but could be used more widely. Following are eleven non-binding recommendations to better address tidal restrictions in the U.S., arranged into four categories. These recommendations are aimed at state and local transportation departments, state and federal resource agencies, municipal governments, their partners, and other interested stakeholders to better implement the avoidance and removal of tidal restrictions from the landscape.

Reduce Data Gaps

1. Use and adapt existing tidal crossing field evaluation methods to confirm the existence of restrictions, determine their severity, and prioritize them for removal where practicable.
2. Support and utilize remote-based methods to identify and target restrictive structures, as well as datasets that further these efforts.
3. Incorporate potentially restrictive structures of all types into existing locational databases (GIS) or produce new ones where none currently exist.
4. Determine effectiveness of alternative tide gate designs for increasing tidal flow upstream and standardize operational parameters that balance ecological and societal needs.
5. Increase use of modeling to predict restorative effects of removing tidal restrictions to inform compensatory mitigation efforts.

Coordinate with Aquatic Organism Passage Practitioners to Leverage Resources in Support of Shared Goals

6. Collaborate with and/or supplement efforts of AOP practitioners to evaluate tidal restrictions.
7. Encourage greater cooperation between AOP and tidal restriction communities and better alignment of practices and goals.

Better Integrate Tidal Restriction Considerations into Transportation Planning Processes

8. Incorporate awareness of the role of transportation structures as potential tidal restrictions early in the transportation project planning process.
9. Balance ecological needs with structural and budgetary constraints in transportation structure design.

Explore Regulatory Processes and Policy Goals that Support Tidal Restriction Removal

10. Explore regulatory processes that can be used to more efficiently authorize removal of transportation-related tidal restrictions during maintenance or emergency situations and clarify USACE and other Federal Agencies permit authorities to allow for broader use for projects that result in net increases to aquatic function.
11. Build support for the use of tidal restriction removal and restoration of upstream habitats as compensatory mitigation under the Clean Water Act, Rivers and Harbors Act, and other regulatory programs.

5.1 Detailed Recommendations

5.1.a. Reduce Data Gaps

1. Use and adapt existing tidal crossing field evaluation methods to confirm the existence of restrictions, determine their severity, and prioritize them for removal where practicable.

Description of Need

Once potential tidal restrictions are identified a field effort is necessary to confirm the existence of a restriction and its severity. Since the 1990s and early 2000s, when the first atlases of tidal restrictions were produced for Massachusetts and New Hampshire, more standardized, comprehensive tidal crossing evaluation methods have been developed that can greatly aid in field verification efforts. One such method, released in 2017, is New Hampshire's Tidal Crossing Assessment Protocol, introduced in Section 4. The protocol both assesses tidal crossing condition and its effects on the surrounding ecosystem and acts as a decision support tool for crossing replacement and/or improvement. This method collects information (both qualitative and quantitative) to support different but related structure or ecological management objectives, including tidal restriction. For instance, crossing condition can be used solely to address a structure management objective, but a failing structure may also indicate that a crossing is restrictive to the tide, fish passage, and/or salt marsh migration, all of which are considered ecological management objectives in the protocol. Therefore, the objectives can be used singularly or in combination to prioritize the use of limited funds to address infrastructure needs based on structural condition, ecological condition, or both.

Considerations for Implementation

This protocol was developed for use in New Hampshire and does have some aspects that are specific to the northeast; however, the main parameters are broadly applicable and/or could be adapted for other regions. This method involves the collection of data for assessing the presence of a tidal restriction as well as its severity, and data that addresses related issues valuable to both transportation and natural resource managers. Therefore, it is recommended that this method be considered for use and/or adaptation more widely in tidal restriction field verification efforts, and potentially used as a basis for developing a more standardized crossing evaluation method.

2. **Support and utilize remote-based methods to identify and target restrictive structures, as well as datasets that further these efforts.**

Description of Need

Published data on the occurrence of tidal restrictions is limited in certain regions of the U.S., particularly the west coast and parts of the southeast (e.g., the Carolinas and Georgia), which suggests that a basic accounting of tidally restrictive infrastructure is lacking in these areas. Building datasets of restrictions and where they occur is important to understanding the scope of the tidal restriction problem at a regional level, which includes both number of restrictive structures as well as the amount of upstream wetland acreage potentially affected. Limitations to compiling this information include lack of staff resources and dedicated funding, or a combination of the two.

Considerations for Implementation

Data to aid in identifying structures, particularly those used for transportation, potentially acting as restrictions are widely available as GIS data or base layers maintained by national, state, and local organizations (e.g., road and railroad centerlines, culvert and bridge locations). For example, this sort of basic data was used to develop Designing Sustainable Landscape's (DSL) tidal restriction severity metric (McGarigal, 2017b), as discussed in Sections 2 and 4. This metric uses existing data and modelling to identify road and railroad crossings potentially acting as tidal restrictions in coastal states from Maine to Virginia.

Spatial and informational datasets used in modeling efforts like DSL are publicly available and could be found or used for other regions of the country; however, models of tide range/elevation, as developed for the DSL initiative, do not appear to exist and/or be publicly available for other regions of the country except Oregon. The Oregon Coastal Atlas (2018) maintains a "head of tide" data layer in its Estuary Data Viewer for most of its main coastal drainages. A GIS coverage at a national or regional scale that models the inland tidal limit, based on tide range and local elevation, would be invaluable for determining: a) whether structures are within a tidal area; and b) the potential for tidal wetlands upstream of such structures.

3. **Incorporate potentially restrictive structures of all types into existing locational databases (GIS) or produce new ones where none currently exist.**

Description of Need

In addition to the lack of data on transportation related tidal restrictions, comprehensive mapping of non-transportation related restrictions (e.g., tide gates, dikes/levees, mosquito-control ditches, weirs, dams) does not appear to be widely available, either as hard copy maps or in electronic form. Some resources are available in Oregon and Massachusetts; however, there does not appear to be comprehensive databases of these structures for other states or regions. This limits the utility of geospatial models. For example, the DSL tidal restriction metric did not evaluate tide gates, aside from those attached to transportation infrastructure, because they have not been comprehensively mapped in the mid-Atlantic and northeast. This problem likely extends beyond the northeast given that many tide gates are on private property and not associated with public roadways.

Considerations for Implementation

As discussed in Section 2, there are other types of restrictions aside from culverts, bridges, and tide gates, and more mapping of these structures is necessary. Mapping efforts might best be completed at a local level, as local knowledge is an invaluable resource in locating structures, especially on private land. Aggregation of mapping can then be coordinated with state or regional entities to provide a more complete geographic picture of tidal restriction type and extent. Results of these mapping efforts could then inform models, like the DSL tidal restriction metric, to estimate severity of tidal restriction and the acreage of upstream wetlands potentially affected.

4. **Determine effectiveness of alternative tide gate designs for increasing tidal flow upstream and standardize operational parameters that balance ecological and societal needs.**

Description of Need

Traditional tide gates are used by both private and public entities to protect upstream development from flooding. Alternatives to traditional tide gates, such as those that are “self-regulating” (SRTs), are available to increase tidal flow upstream while still providing some degree of flood protection. In addition, there are tide gates that were designed specifically to promote greater bi-directional AOP that may also serve to increase tidal range upstream. More research is needed to assess the effectiveness of alternative tide gate designs and their operation to increase bi-directional tidal flow, AOP, or both. Some research has been conducted comparing SRTs and traditional tide gates to reference sites (without tide gates) and their effects on anadromous fish passage (mainly salmon) and certain physical factors in the Pacific Northwest (Greene et al., 2012), but in general there is a lack of studies that systematically determine how effective SRTs are at increasing tidal and/or aquatic organism connectivity.

Considerations for Implementation

A promising avenue for encouraging more of this type of research lies in leveraging funding for AOP, estuary restoration, and flood protection. For example, the Greene et al. study (2012) was funded by the Estuary and Salmon Restoration Program, administered by the Washington State Department of Fish and Wildlife. As documented in Souder et al. (2018) in Section 4, the

Oregon Watershed Enhancement Board has also funded estuary restoration projects and effectiveness monitoring efforts for projects including tide gate “upgrades,” such as replacing traditional tide gates with SRTs.
Flood protection efforts may spur new research as municipalities strive to become more resilient to flooding from sea level rise, changing climate patterns, and coastal storms. For instance, in New Hampshire, state funding was approved to replace aging, non-functional traditional tide gates with SRTs in the Cove River to both restore the upstream ecosystem and mitigate against high-tide and storm-surge flooding (Zaretsky, 2018). FEMA funding was used by the Port of Tillamook Bay in Oregon to complete a large restoration project that involved upgrading traditional tide gates to SRTs, which would provide both flood level reductions and tidal habitat restoration (Oregon Solutions, 2017). While neither of these projects specifically studied the effectiveness of different tide gate designs to increase tidal flushing or AOP, opportunities for funding the underlying research may become available as interest in flood mitigation and resiliency increases in coastal communities.

As discussed in Section 4, the effectiveness of SRTs for increasing tidal flow appears to be influenced by the water elevation at which the gate is set to close. Set at too low an elevation, SRTs will not be effective in increasing tidal range upstream; set too high and upstream development may be adversely affected. Therefore, determining the elevation that strikes the balance between ecological and societal needs is critical. While this closure elevation will largely be site-specific, the upstream tidal range allowed by an SRT that provides ecological benefits while avoiding societal costs may be a measurement that could be modeled and standardized. It is recommended that this optimal elevation range be determined on a state or regional level to better address site specific ecological and societal considerations.

5. **Increase use of modeling to predict restorative effects of removing tidal restrictions to inform compensatory mitigation efforts.**

Description of Need

One of the recommendations in this document (#11) is to build additional support among regulatory agencies to use the removal of tidal restrictions as compensatory mitigation. While existing wetland crediting methods could be used for tidal marsh re-establishment or enhancement, there may be uncertainty regarding how much wetland acreage and other aquatic resource functions and values would be re-established/restored and/or how much ecological uplift would occur through increased tidal range. In addition, the added acreage and function of these wetlands may differ based on the degree of increased tidal flow; that is, some tidal restoration projects may increase tidal range without restoring the full range completely. Data may be gleaned from the monitoring of non-mitigation tidal restoration projects, though such data are limited and may be difficult to obtain.

Considerations for Implementation

Modeling can help predict outcomes of restoration actions performed as part of compensatory mitigation projects. The Salt Marsh Assessment and Restoration Tool (SMART), as discussed in Section 4, is a GIS-based simulation model that uses remote-sensing technology (LIDAR, hyperspectral imagery) and field data to predict the location and extent of native salt marsh vegetation resulting from a proposed restoration action. In that way, SMART could be used to inform mitigation planning efforts and credit amounts. SMART has been used successfully by restoration practitioners in the Gulf of Maine, though to be used outside the northeast or mid-Atlantic states it would need to be adapted for salt marsh species typical of other regions of the country.

5.1.b. Coordinate with Aquatic Organism Passage Practitioners to Leverage Resources in Support of Shared Goals

6. **Collaborate with and/or supplement efforts of AOP practitioners to evaluate tidal restrictions.**

Description of Need

A related method for evaluating tidal crossings was developed by the Northeast Atlantic Aquatic Connectivity Collaborative (NAACC), as introduced in Section 4. While this protocol was developed specifically for assessing tidal crossings for fish passage, the NAACC coordinated with the authors of the New Hampshire protocol in its development and feel that it could also be used as a tidal restriction screening tool (Scott Jackson, personal communication, April 30, 2018). Tidal restriction practitioners could use the method directly to assess crossings in the field and/or they could leverage data collected by fish passage practitioners using the tool to identify crossings for further evaluation.

Considerations for Implementation

Once the protocol is officially rolled out, the NAACC will train its state partners (Maine to Virginia) in the method, so that they can collect and add data using the protocol to NAACC's existing fish passage database. In addition, out of region partners such as SARP also plan on training partners (Virginia to Texas) to complete fish passage surveys using the NAACC tidal crossing assessment method (Kat Hoenke and Jessica Graham, personal communication, April 5, 2018). It is recommended that tidal restriction practitioners investigate using data collected with this method and/or collaborate with fish passage practitioners in its collection. The more general collaboration among these fields is addressed in the following section.

7. Encourage greater cooperation between AOP and tidal restriction communities and better alignment of practices and goals.

Description of Need

AOP and tidal restriction issues have a natural intersection given that increasing tidal flow through restrictive structures should also aid in increasing AOP. In addition, removing tidally restrictive structures promotes the restoration of salt marsh that is important as habitat for numerous aquatic organisms at all life stages. However, to date, the entities studying and advocating for these issues largely appear to be working separately from one another, with little coordination. One reason this may be the case is that, until very recently, most stream crossing assessments for AOP (largely fish) only evaluated potential barriers that were non-tidal. The effect has been that the resulting policy regarding stream crossing guidelines for AOP appear to largely focus on inland crossings. While non-tidal and tidal crossings can have the same issues (e.g., perching, under-sizing), tidal action adds a layer of complexity that has not been adequately addressed or understood in how it relates to AOP in the past.

Considerations for Implementation

The NAACC tidal crossing assessment protocol highlighted above will likely go a long way towards promoting greater understanding of AOP in the tidal environment, however gaps still remain. Increased understanding should better allow practitioners in both fields to leverage the other's knowledge to increase overall aquatic connectivity in the tidal ecosystem. Therefore, it is recommended that these two communities work together to achieve practices and goals that further both AOP and tidal restoration efforts.

There are numerous regional, state, and local agencies and organizations that deal with AOP issues, though there are not as many that are solely dedicated to tidal restrictions or have tidal restoration experience. One way to jump start a cooperative effort would be to convene meetings at the federal level to share tools and protocols and develop high-level joint practices and goals, to avoid duplication of work and provide consistency. The most relevant agencies could include EPA, NOAA, USFWS, FHWA, and USACE. The resulting points of intersection could be further discussed with regional aquatic connectivity organizations like NAACC and SARP that have state-level partners, state DOTs, as well as state agencies and NGOs that deal with tidal restoration issues and/or aquatic connectivity (e.g., MA Division of Ecological Restoration, The Nature Conservancy) for further refinement. Cooperation can advance both issues simultaneously and can allow for collaborative field, policy, and funding efforts.

5.1.c. Better Integrate Tidal Restriction Considerations into Transportation Planning Processes

8. Incorporate awareness of the role of transportation structures as potential tidal restrictions early in the transportation project planning process.

Description of Need

Many tidal restrictions arise from undersized or failing transportation infrastructure; however, the systemic consideration of tidally restrictive structures in transportation decision-making, including planning, structure design, repair, and maintenance appears to be limited. This shortcoming may largely stem from both a lack of awareness and accompanying data, as well as how projects are traditionally addressed from a DOT perspective. DOTs usually address tidal restriction issues on a project-by-project basis, either because a problem is anticipated or at the request of regulators. Therefore, DOTs generally do not systematically inventory their assets for restrictive structures or use modeling to predict where they occur before the project planning stage. In some instances, this information is provided from outside sources. For example, in Massachusetts, where tidal restriction atlases were completed for most of the state in the early late 1990s and early 2000s, MassDOT uses these documents during its planning process to flag transportation projects that may facilitate removal of tidal restrictions. Caltrans has also sought to address existing tidal restrictions in its planning for the North Coast Corridor project in San Diego County, by tying their removal to compensatory mitigation efforts. However, there is no comprehensive policy to address tidal restrictions on an agency-wide basis (Susan Scatolini, personal communication, April 12, 2018).

Considerations for Implementation

Given the prominent role of transportation infrastructure in tidal restrictions, it is important to better integrate awareness of this role into long range project planning and programmatic mitigation plans to facilitate removal of existing tidal restrictions. Identifying potential restrictions early in the environmental planning process (either through the National Environmental Policy Act [NEPA] or state equivalents) can inform design and permitting decisions as well as potential mitigation opportunities, including programmatic opportunities (i.e., mitigation banks or in-lieu fee sites) or on- or off-site project-specific permittee responsible mitigation opportunities. For transportation projects proposed in the tidal environment (e.g., bridge replacements, linear projects involving improvements to bridges and culverts), identification of potentially restrictive infrastructure could be incorporated into the data gathering phase of the project and included in the NEPA environmental document. Data collected early in the process can then guide design efforts and regulatory coordination.

9. Balance ecological needs with structural and budgetary constraints in transportation structure design.

Description of Need

Standard hydraulic design in the transportation sector primarily focuses on structural requirements, but in many instances more information is needed on the existing ecological characteristics. A good example of incorporating both structural and ecological considerations is HEC-26, which deals specifically with AOP and addresses hydraulic conveyance from both a structural and ecological approach. However, as with the majority of AOP hydraulic models, HEC-26 is best applied to non-tidal environments.

Considerations for Implementation

As discussed in Section 4, the Washington State Department of Transportation (WSDOT) has developed a set of design guidelines that evaluates different crossing types in the tidal environment from an ecological perspective. Structure location and width are assessed based on their effects on tidal zone ecosystem processes, which differs from the usual design standard where the effects of natural processes are analyzed for how they impact a given structure. The WSDOT guidelines also incorporate infrastructure costs into decision-making by assessing what structure width and location have the greatest ecological benefit for the lowest monetary cost. This type of cost-benefit analysis is recommended for broader use as a way to account for both hydraulic and ecological requirements in tidal areas and facilitate transportation decision-making when retrofitting tidal restrictions or avoiding new ones.

5.1.d. Explore Regulatory Process and Policy Goals that Support Tidal Restriction Removal

10. Explore regulatory processes that can be used to more efficiently authorize removal of transportation-related tidal restrictions during maintenance or emergency situations and clarify USACE and other Federal Agencies permit authorities to allow for broader use for projects that result in net increases to aquatic function.

Description of Need

Coupling the removal or retrofit of tidally restrictive transportation infrastructure with maintenance or emergency repair is another potential avenue for addressing the tidal restriction issue, as noted in Section 4. There may be opportunity to improve regulatory or related processes to incentivize addressing restrictions during maintenance and emergency situations rather than replacing with similarly restrictive structures.

Considerations for Implementation

The opportunity exists to identify provisions in existing programs across the Federal Agencies to address tidal restrictions in the course of normal maintenance of relevant structures or in the context of carrying out emergency actions. Among multiple Federal programs related to tidal restrictions, DOT road specifications and CWA Section 404 authorizations are some of the more common, and may also intersect with the National Flood Insurance Act.

Permitting flexibility during emergency repair or maintenance conditions may help to avoid replacing an existing tidally restrictive structure with another restriction. However, for projects that will require the preparation of a CLOMR analysis (see Section 4.4.b), the additional time and cost needed to analyze upstream flooding effects may present a barrier to enlarging restrictive structures during emergency repair or maintenance actions, which are generally time-sensitive. These analyses are necessary to determine possible flood risk impacts and facilitate design solutions that minimize unintended impacts to development and flood insurance rates. Therefore, determining a replacement dimension that both prevents upstream flooding and is not tidally restrictive should be done well before structures are scheduled for replacement in a traditional transportation improvement program. Having this information up-front can help in determining the viability of enlarging a structure and increase opportunities to remove tidal restrictions when replacing or repairing these structures during emergency or maintenance situations.

Nationwide Permits 3, 14, and 53 all offer current, potential pathways for tidal restriction removal authorization under CWA Section 404 and RHA Section 10. FHWA, USACE, and other agencies could evaluate options that allow for greater design modifications, in instances where the proposed tidal restriction removal results in a net increase of aquatic function, consistent with updated road safety and resilience design standards.

Another potential avenue for consideration is to use CWA Section 404 Regional General Permits (RGP) to provide greater regulatory flexibility in maintenance and emergency situations where tidally restrictive infrastructure could be removed. RGPs are developed by USACE districts to authorize categories of activities in a specific geographic area that cause only minimal individual and cumulative environmental impacts. For instance, the USACE Seattle District has developed RGP-8 to authorize activities initiated through the U.S. Forest Service Region 6 Aquatic Restoration Program in the state of Washington. Activities include fish passage restoration, dam, tide gate, and legacy structure removal, and set-back or removal of existing berms, dikes, and levees. The RGP sets out conditions under which work must occur and defines what constitutes a covered activity. Developing an RGP that explicitly addresses the removal and/or retrofit of tidal restrictions as part of transportation infrastructure maintenance or emergency repair actions would likely occur on a district by district basis and would require support from both USACE and state agencies that have regulatory authority over coastal waters. It would also involve more data collection on potentially restrictive structures by project sponsors (e.g., DOTs), which could be complemented by field evaluation methods and efforts documented in this report.

11. Build support for the use of tidal restriction removal and restoration of upstream habitats as compensatory mitigation under the Clean Water Act, Rivers and Harbors Act, and other regulatory programs.

<u>Description of Need</u>

The removal of tidal restrictions generally leads to conditions upstream that favor the re-establishment of salt marsh and/or the conversion of salt marsh vegetation from *Phragmites*-dominant to more typical native species assemblages (see Section 3). In that way, both wetland acreage and function may be increased when a more natural tidal range is restored upstream of a removed restriction. Removing tidal restrictions can be an environmentally beneficial means of fulfilling compensatory mitigation requirements under CWA Section 404 and RHA Section 10. However, potential obstacles include those specific to regulatory and resource agencies outlined in Section 4.4.a, as well as those related to flooding concerns or an unwillingness to give up land for easements from upstream landowners, and the historic, cultural, or recreational value of existing restrictions and/or the types of habitat they create.

<u>Considerations for Implementation</u>

Building mechanisms to enable the use of tidal restriction removal for compensatory mitigation when appropriate is highly recommended. It is important to create support among the many federal, state, and local regulatory and resource agencies that are responsible for ensuring that environmental standards are met when mitigating for project impacts.

Finally, when tidal restriction removal acts to restore a more natural tidal range to affected aquatic resources, tidal restriction removal should not require compensatory mitigation if those actions result in net increases in aquatic resource functions.

5.2 Conclusion

Tidal restrictions take many forms and are found throughout coastal regions of the United States. Changes to salinity and water levels caused by a decrease or elimination of tidal flow can have numerous effects on natural and human communities. These effects range from the displacement of native salt marsh plant species, to the disconnection of fish populations from estuarine nursery habitat, to the loss of the marsh buffer that helps to protect development from coastal storms. There are a number of tools already available to aid in tidal restriction avoidance or removal covered in this synthesis, but overall, there is a lack of a comprehensive framework to address this issue in an integrated manner. The recommendations presented in this section are a first step towards better addressing wetland degradation and loss due to tidal restrictions. Developing and implementing actionable next steps from these recommendations will benefit from involvement of state and local transportation departments, state and federal resource agencies, municipal governments (including planning and flood control entities), their partners and other interested stakeholders.

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