Greater Atlantic Region Policy Series [23-01]

The Effects of Tide Gates on New England Wetlands and Other Tidal Resources

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Abstract

Tide gates are structures used to protect personal property, agricultural land, and public infrastructure from flooding due to extreme tides and storm surges by restricting tidal flow to intertidal, shallow subtidal, and brackish estuarine environments. However, these structures can result in impacts to marine, estuarine, and tidal riverine resources, including but not limited to resident fish and shellfish, diadromous fish, coastal marshes, seagrass, macroalgal and shellfish beds, mudflats, and tidal creeks. Tide gates can restrict access to fish and invertebrates to and from habitats important for feeding, spawning, predator avoidance, and migration, and can alter environmental conditions that can impact individual fitness. Tide gates can also interfere with physical and chemical dynamics such as nutrient and sediment flux, which are critical factors in marsh building processes. In addition, the increasing effects of climate change, including sea level rise and more extreme precipitation patterns, will amplify many of the adverse effects of tide gates. There are likely several hundred individual tide gates in use throughout New England, although a comprehensive, regional inventory and assessment of tide gates has not been conducted. Many of the known tide gates are in various states of disrepair, and lack appropriate operations and management plans. It is likely many unreported tide gates exist in the region and a subset of those are similarly inoperable and restrict tidal exchange. This paper describes the types of tide gates commonly found in New England coastal areas and the various physical, chemical, and biological impacts associated with them. We have included a series of recommendations that regulatory and policy makers should implement to reduce the long-term and chronic impacts of tide gates in New England coastal areas.

Keywords

Tide gates; coastal wetlands; fish passage; tidal restriction; climate change; sea level rise; flood control

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Introduction

Tide gates are structures used to protect personal property, agricultural land, and public infrastructure from flooding from extreme tides and storm surges by restricting tidal flow to intertidal, shallow subtidal, and brackish estuarine environments. The construction of dikes and tide gates has enabled farmers and coastal communities to convert coastal wetlands into agricultural and grazing fields, and flood-prone lands into urban zones (Giannico and Souder 2005). However, these structures can result in impacts to a number of NOAA Fisheries trust resources, including but not limited to, marine, estuarine, and tidal riverine fish and shellfish, diadromous fish species, coastal marshes, seagrass, macroalgal and shellfish beds, mudflats, and tidal creeks. Tide gates can restrict access to fish and invertebrates to and from habitats important for feeding, spawning, predator avoidance, and migration, and can alter environmental conditions such as temperature and salinity that can impact individual fitness (Alcott et al. 2021; Castro-Santos and Haro 2010; Rillahan et al. 2021; Wright et al. 2016). Tide gates can also interfere with physical and chemical dynamics such as nutrient and sediment flux, which are critical factors in marsh building processes (Giannico and Souder 2005).

There are likely several hundred individual tide gates in use throughout New England, although a comprehensive, regional inventory and assessment of existing tide gates does not exist. An inventory of tide gates in the Massachusetts Bay Region, from Cape Cod to the North Shore of Massachusetts, identified 137 sites with at least one tide gate (MassBays 2017). Many of the tide gates identified in this inventory were in various states of disrepair, and lack up-to-date operations and management plans. It is likely many unreported tide gates exist in the region and a subset of those are similarly inoperable and restrict tidal exchange.

Some salt marsh wetlands upstream of tide gates are able to survive and persist due to leakage around older-style tide gates or tide gates that are in various states of disrepair and do not seal completely. Repair or replacement of old tide gate structures typically eliminates leakage of tidal waters, thereby further degrading salt marsh wetlands upstream due to lack of necessary tidal exchange, unless bi-directional type tide gates are used.

New tide gate proposals are expected to increase in ever-expanding developed land in the coastal floodplain, and in response to greater flooding from rising sea levels, increased precipitation, and storm intensity. This document is intended to be an overview of known existing and future impacts of tide gate operations on coastal aquatic species and ecosystems in New England, and to provide a series of recommendations that regulatory and policy makers should implement to reduce the long-term and chronic impacts of tide gates in New England coastal areas.

Background

Tide gates are defined here as "any conveyance of tidal flow with the ability to passively or actively manipulate water flow" (MassBays 2017). This definition does not include structures installed for the sole purpose of conveying storm water drainage. Once permitted and installed, tide gates tend to remain as permanent structures that will alter tidal flow to salt marsh wetlands and other tidal resources, and impact the ability for fish to pass unimpeded for as long as the structures are in place.

The growing interest in the use of tide gates by communities is driven primarily by a combination of increasing development in the coastal floodplain (Crossett et al. 2004; Dahl and Stedman 2013), sea level rise (Kunkel et al. 2013; Sallenger et al. 2012; Sweet et al. 2022), and increasing intensity of precipitation and coastal storms due to climate change (Armstrong et al. 2012; 2014; Easterling et al. 2017).

Types of Tide Gates

There are many different tide gate designs, but common types in New England include self-regulating tide gates, manually-controlled structures, traditional passive flapper and sluice style tide gates, and automated tide gates. Tide gates are typically installed within concrete vaults, or box-type structures, located on the downstream side of a drainage pipe or culvert.

Self-Regulating Tide Gates

Self-regulating tide gates (SRTs) use a top-hinged buoyant valve that opens with an incoming tide to allow saltwater to flow into the up-gradient, tidally-restricted areas and to tidal wetlands (Figure 1). The buoyant valve is counterpoised with adjustable back floats whose greater buoyancy counteracts the buoyant valve so as to close the gate at predetermined, adjustable water levels for flood protection of interior areas. Similar to conventional top-hinged tide gates, on the ebb tide the hydraulic force of the water pushes the gate open when the head pressure is higher on the interior, allowing for upstream drainage. The SRTs can also be deployed in a cantilevered, normally-open position using weights installed in the back-arm assembly. This installation method is particularly useful to avoid premature closure of the gate valve from hydraulic forces in the confined vault.

Figure 1. Self-regulating tide gates with floats at Route 1, Town Line Brook, Revere, Massachusetts. Photo credit: Edward Reiner, US EPA.

Manually-Controlled Structures

Manually-controlled structures are not a type of tide gate, but rather a type of tide gate management that allows for active management to control bi-directional flows. The tide gate is propped open, and it is closed only during the winter months or when high tides that are capable of causing flooding are predicted to occur. A combination gate combines a top-hinged flap gate with a vertical sluice gate to provide adjustable flows depending on the opening of the sluice gate. Manually-controlled devices can be operated with an electrical motor and activated remotely.

Traditional/Passive Tide Gates

Traditional tide gates or passive control structures typically use flapper gates with either a heavy lid (made of treated wood) attached at the top of the culvert by either a bar with hinges or chains, or a metal lid (usually of cast iron or steel) and double hinged from above (Figure 2). Alternative flapper designs include side-hinged gates and top-hinged gates with small "pet doors" that are located within the larger and heavy hinged flapper gate that opens with very low hydraulic head differential to improve water flow and fish passage (Giannico and Souder 2005).

Figure 2. Traditional, top-hinged flapper gates with metal lids, Machias, Maine. Photo credit: Matt Bernier, NOAA Fisheries.

Automated Tide Gates

Automated tide gates are opened and closed with the use of hydraulic pumps or electrical motors. These tide gates can be opened automatically with the use of adjacent or remote water level sensors. In most situations the tide gate sensors are set to trigger tide gate closures when the incoming tide reaches a specified elevation, and opens back up when the sensor detects the downstream water elevation has receded.

Other Tide Gate Designs

Lastly, there are tide gates that are designed to prevent all tidal flow by use of tightly fitting rubber check valves, which can be installed inside of the culvert, or rubber "duckbill" tide gates installed on the outlet culvert, which only allows for downstream flow (Figure 3).

Figure 3. A rubber duckbill-type tide gate, Swampscott, Massachusetts. Photo credit: Edward Reiner, US EPA.

New England Tide Gate Inventory

Although a comprehensive inventory of tide gates for New England states does not exist, some information on the number of tide gates in the region is known (Table 1). For example, in a 2016 inventory of tide gates in the Massachusetts Bay Region from Cape Cod to the North Shore, 137 sites with at least one tide gate were identified (MassBays 2017). Except for Massachusetts, the state estimates of tide gates shown in Table 1 are based on communication with state and federal agencies, researchers, non-governmental organizations, and NOAA Fisheries file records, and likely underrepresent the actual numbers of tide gates in the region. Many tide gates are in locations that are difficult to identify and access, as they are often located underground within drainage or vault structures, under rail lines and highways, and are otherwise hidden from public view.

State	Tide Gate Identified	Sites Identified	Source
Maine	~16	~6	Various pers. comm.
New Hampshire	~5	~5	Various pers. comm.
Massachusetts	137	100	MassBays (2017)
Rhode Island	~5	~2	Various pers. comm.
Connecticut	~82	~53	Various pers. comm.

Table 1. Estimates of tide gates in New England coastal states. Note: some sites contained more than one tide gate device.

Operational Plans

All tide gates should have an operations and management (O&M) plan. These plans should include criteria for determining when tide gates should be opened and closed, maintenance and repair schedules, along with other relevant considerations such as the responsible party for implementing the O&M plan. However, prior to about 20 years ago, most tide gates were authorized without O&M plans or enforceable operational requirements. The monitoring and enforcement needed to ensure O&M implementation can be a difficult process to track, even when provided as a permit condition. Unless tide gates are equipped with internet accessible, real-time and continuous monitoring of surface water elevations, it is difficult for department of public works and/or permitting agencies to know when tide gates are not functioning correctly.

The type of tide gate to deploy, and the operation of the gate to allow for bi-directional tidal flow, depends on a combination of predicted weather and tidal conditions, as well as the elevations and the extent of developed land upstream of a tide gate that may be susceptible to flooding. Some tide gate closures occur with daily high tides, while others may be operated once every few years in response to predicted storm events. For example, a tide gate may be closed when the predicted tide elevation exceeds the mean or maximum high water elevation and/or when specific events, such as very high winds speeds, storm surges associated with coastal storms, or heavy rainfall events, are forecasted. However, the O&M plans for some tide gates have no specific closure criteria, other than general assessments by the town or responsible party of predicted precipitation events and storm/tidal surges.

There are many documented examples of gate closures occurring despite the criteria in operational plans not being met. These may occur when urban flooding occurs, or is perceived as a threat –often related to complaints from property owners to city officials that prompt town action to close the gate. In other cases, the gate closure criteria may be met, but the gate is not reopened after the flooding event as is normally required in an O&M plan.

There is often no mechanism to alert city officials or property owners when tide gates remain closed after a flooding event. Often tide gates are reopened only after complaints from citizens or natural resource agencies and, in many cases, they remain closed for days or weeks after a flooding event. This can effectively eliminate diurnal tidal inundation of coastal wetlands and result in a wide variety of impacts to living marine resources during the period of gate closure.

Other issues that affect tide gate operation compliance include inoperable gates (e.g., sealed shut, missing required float, etc.), gates that do not form seals (i.e., leaking observed), deformation, waterlogged and rotten wood, excessive corrosion, and parts not secured in place (e.g., missing bolts) (MassBays 2017). Gates can also inadvertently remain in the open or closed position due to lack of maintenance, vandalism, or debris preventing proper gate valve operation.

Failure to maintain tide gates can increase the threat of flooding to low-lying development that was intended to receive protection from the structures. For example, prior to restoration actions in Rumney Marsh in Revere, Saugus, and Lynn, Massachusetts, 21 missing, poorly functional, or nonfunctional tide gates were identified as adversely affecting more than 45 hectares of up-gradient wetlands (Reiner 2012). Between 1997 and 2001, 11 SRTs were constructed with the intention of providing controlled tidal flow and flood protection to approximately 32 hectares of wetlands, and restoring or enhancing salt marsh ecology. However, a lack of maintenance of the SRTs, and other issues such as obstructed culverts have been reported, such that the objectives of the projects have not been fully met (Reiner 2012).

In many cases, limited or no monitoring of up-stream and down-stream water level elevation is undertaken, which reduces the ability of tide gate owners and regulatory agencies to know if a tide gate is operating as planned. Very few tide gates have remote sensing capabilities, thus preventing the operator from knowing flooding or tide gate status without physically visiting the site. Inoperable tide gates can remain unreported for long periods of time when they are located in remote areas, installed in culverts under streets and are not visible from the surface, or lack tide gauge monitoring equipment.

Natural Resource Impacts

When tide gates function properly, and are operated according to approved O&M plans, they can balance the need to reduce flood risk while maintaining the regular tidal exchange necessary for maintaining the health of marsh ecosystems or to restore previously degraded marsh systems. However, when tide gates are not installed or operated properly, they can alter tidal exchange between the upstream- and ocean-side of a structure, and can cause deleterious physical, chemical, and biological effects to the estuarine system.

Physical Effects

Physical effects can include elimination of the natural tidal regime, and changes in the velocity, turbulence, and pattern of freshwater discharge that can result in fluctuations between water stagnation and flushing flows that can scour and erode streambeds and banks. These changes in the circulation of water between both sides of a tide gate cause alterations in water temperatures, salinity, soil moisture content, sediment transport, and channel morphology (Giannico and Souder 2005). Tide gates restrict the flow of saltwater and, as a result, can cause a dramatic difference in salinity between one side of the gate and the other. When the gate opens, pooled freshwater moves into the estuarine channel, creating a lens of fresher water that can adversely affect brackish animals and plants. Soil salinity is also reduced because tide gates can prevent salt or brackish water from reaching past tide gates, and the freshwater that is allowed to drain toward the estuary removes salts from soils over time (Giannico and Souder 2005). In almost all cases, tide gates periodically or commonly reduce sediment transport due to decreased tidal flux and hydraulic conditions. These conditions can result in an accumulation of both fine and coarse sediments upstream of a tide gate.

Chemical Effects

Chemical effects of tide gates include upstream increases in water nutrient concentration, heavy metal suspension, and reductions in dissolved oxygen and pH (Portnoy 1991; Portnoy and Giblin 1997). Soils in estuarine marshes are naturally anaerobic (i.e., lack oxygen), and as the operation of tide gates lowers the salinity of soils on the upland side of tide gates and periodically desiccate them, these soils become exposed to air, and a variety of aerobic (oxygen-driven) processes begin. Immobilized, reduced sulfides combined with the soil iron are oxidized and converted into sulfates and sulfuric acid (Portnoy and Giblin 1997). These compounds make the soil acidic and can cause heavy metals in the soil (e.g., lead, copper, silver, and cadmium) and bound nutrients (e.g., phosphorous) to be released into the water (Giannico and Souder 2005). Some preliminary research has provided evidence that along with accumulated sediments, the water chemistry upstream of a tide gate can have elevated nutrients and conditions prone to eutrophication (M. Patterson, pers. comm. 2022). Portnoy and Allen (2006) reported a diked tidal river (i.e., Herring River, Wellfleet, Massachusetts) contributed to shellfish-water closures because of water-column fecal-coliform contamination.

Biological Effects

Tide gates can alter the hydrology of coastal wetlands, particularly for high salt marsh communities, and negatively affect the species that depend upon them. Tide gates can reduce the tidal amplitude and duration of inundation in salt marsh wetlands, alter the salinity of soils and increase the prevalence of invasive plant species such as *Phragmites* (Burdick et al. 2001; Chambers et al. 1999) (Figure 4).

Figure 4. *Phragmites*-dominated marsh upstream of the Gloucester Mills tide gate, Gloucester, Massachusetts. Photo credit: Eric Hutchins, NOAA Fisheries.

The MassBays (2017) tide gate inventory in Massachusetts reported *Phragmites* and other invasive plant species present at a majority of sites that were inspected (75% of sites). An expansion of *Phragmites* can lead to a loss of the native salt marsh (Silliman and Bertness 2004) and increase the threat of fire (Fusco et al. 2019). *Phragmites*-dominated marshes have been reported to be more vulnerable to bulk erosion of the marsh platform during coastal storms due to weaker soil strengths and reduced rooting depths compared to higher-salinity marshes dominated by native *Spartina alterniflora* (Howes et al. 2010). Additionally, tide gates associated with culverts that have an inappropriately high invert elevation can limit the low-water elevation in the impounded area, leading to an overall reduction in tidal prism further exacerbating the degradation of the marsh system.

Long-term effects of tide gates, and flood control structures in general, on tidal marshes can include land subsidence or submergence, conversion to terrestrial vegetation, ponding, reduced invertebrate populations and general loss of productive wetland characteristics (Hanson et al. 2003). Alteration of salt marsh hydrology can reduce estuarine productivity, restrict suitable habitat for aquatic species, and result in salinity and temperature extremes during droughts and floods (Johnson et al. 2008). For example, recent monitoring of water temperature behind a tide gate in Revere, Massachusetts, indicated tide gates elevated water temperatures due to decreased tidal water flushing (M. Patterson, pers. com. 2022).

In addition, tide gates cause habitat fragmentation and decrease ecological continuity, which can have significant implications to fish passage. Any type of tidal restriction, including tide gates, can negatively affect migratory phenology, access to vital habitat, and incur energetic costs, among other factors, for migratory fish (Castro-Santos and Letcher 2010; Hall et al. 2011; Limburg and Waldman 2009). However, tide gates differ from other restrictions because flow is either completely obstructed during part of the tide or else periodically reverses direction (Alcott et al. 2021). Fish can become trapped behind the tide gates, preventing them from accessing deeper water and potentially stranding them during periods of low water (Williams and Thom 2001). As documented by Rillahan et al. (2021) and Alcott et al. (2021), tide gates installed on the Herring River in Massachusetts have had a deleterious effect on fish behavior including unsuccessful passage and delay, injury and mortality, and increased exposure to predators like striped bass. Any tide gate, whether fully open or partially open, is likely to provide an attraction flow that fish may try to use for passage. Additionally, partially open or fully open tide gates can create high velocities that sweep fish through narrow openings. When velocities exceed the burst speeds of fish, their ability to make evasive maneuvers away from predators and obstacles is reduced. Debris in the water column near a tide gate increases the risk of injury, mortality, and exhaustion. In particular, high velocity flow through the narrow openings of flap gates increase collisions with the gate structure itself, including the gate and frame (Alcott et al. 2021; Rillahan et al. 2021). Therefore, because tide gates can restrict fish passage for some, or all of a tidal cycle, few if any tide gates provide full tidal transparency for migrating and resident fish.

Climate Effects

Even when adherence to O&M plans are met, sea level rise (SLR) will generally trigger more frequent closures as high water elevations and storm surge from coastal storms increase. Higher mean sea levels will also result in higher low tide elevations, and tide gates can affect the time needed for impounded systems to drain on ebb tides. Research has shown that SLR rise has been and will be higher on the northeast Atlantic coast (Virginia to Maine) than the global average, due largely to vertical land movement, varying atmospheric shifts and ocean dynamics, and ice mass loss from the polar regions (Dupigny-Giroux et al. 2018). For example, under the 1.0 m (Intermediate) global mean SLR scenario, the projected increase in mean sea level for Boston, Massachusetts will be 1.13 m higher in 2100 compared to today (Sweet et al. 2022).

Annual average air temperatures in recent decades have increased in New England to about 1.7°C or more in New England since 1901 (Dupigny-Giroux et al. 2018). The Fourth National Climate Assessment projects air temperatures in the northeast region to increase 5.1ºC higher than today by late-century (2071-2100) under the high emissions scenario [Representative Concentration Pathway (RCP) 8.5[1]] (Vose et al. 2017). Kaushal et al. (2010) found significant increases in annual mean water temperatures over the 20th century in 20 of the 40 assessed U.S. rivers and streams. The authors reported increased river and stream water temperatures were typically correlated with increases in air temperatures and urbanization. Climate change induced increases in tidal stream temperatures can exacerbate the effect of elevated water temperatures due to decreased tidal water flushing upstream of tide gates.

Most tide gate O&M plans include gate closure criteria associated with heavy precipitation events that can trigger storm-induced flooding upstream of tide gates. These events are occurring more frequently and in greater intensity than long-term averages would predict. Between 1958 and 2012, the northeast region saw more than a 70% increase in the amount of precipitation falling as very heavy events (defined as the heaviest 1% of all daily events) (Horton et al. 2014). In addition, nor'easters in the northeast region have increased in

[1] RCP climate scenarios used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). These scenarios were modified for the IPCC Sixth Assessment Report as Shared Socioeconomic Pathways (SSPs), which consider a broader range of greenhouse gas and air pollutant futures, and describe the socio-economic trends underlying the scenarios. However, modelling studies relying on the RCPs used in the AR5 complement the assessment based on SSP scenarios, for example at the regional scale (IPCC 2021).

intensity and their tracks have shifted northward (Vose et al. 2014; Wang et al. 2012). The change in precipitation patterns have reportedly affected stream flows in New England rivers and streams. Collins (2009) reported 25 of the 28 examined New England stream gages with minimal human influence had upward trends in the highest annual instantaneous discharges. This study also demonstrated evidence of a step increase in flood magnitudes around 1970. The result of a similar study of New England streams (Armstrong et al. 2012), identified widespread hydroclimatic increases in flood magnitude and frequency, as well as evidence of a step increase around 1970, as reported by McCabe and Wolock (2002) and Collins (2009). It should also be noted that increased development and subsequent expansion of impervious surfaces upstream of tide gates can compound the impact of flooding from increased precipitation, particularly heavy rain events.

These extreme weather events are projected to occur more frequently in the future. The Fourth National Climate Assessment projects more extreme precipitation events in the northeast U.S. and parts of New England with corresponding higher air temperature (Easterling et al. 2017). For example, under the RCP 8.5, the number of extreme precipitation events (defined as events exceeding a 5-year return period) increases by 200–300% compared to the historical average in every region by the end of the 21st century, with the largest increases in the northeast U.S. Under the intermediate emissions scenario (RCP 4.5), increases in extreme precipitation events are 50–100% compared to the historical average (U.S. Global Change Research Program 2017). In an assessment of four unregulated rivers in Maine, Hodgkins and Dudley (2013) reported increases in maximum peak river flows based on projected higher temperature and precipitation rates by the end of the century. More extreme precipitation and river flows will affect the operation of tide gates, flow rates within structures, and the ability of fish to pass through them.

To stem increasing rates of flooding exacerbated by climate change, tide gate closures will need to occur more frequently and potentially for longer duration on average to allow for increased volume of runoff to drain. Gate closures triggered by SLR and coastal storm surges may exacerbate inland flooding due to extreme precipitation and runoff, which typically occurs during coastal storms.

One notable example of a large coastal storm barrier installed with tide gates is the New Bedford Hurricane Protection Barrier located across the New Bedford and Fairhaven Harbor. The structure was constructed in 1966 after hurricanes in 1938, 1944 and 1954 caused severe flooding damage to the communities in New Bedford, Fairhaven, and Acushnet (Trustees of Reservations 2022). The New Bedford Hurricane Protection Barrier consists of two main harbor barrier gates, spanning across a 150-foot wide by 30-foot deep (at low water) navigation barrier, and three smaller street gates that can be closed during storm events (Sullivan 2020). The U.S. Army Corps of Engineers operates the gates, designed to protect the port from flooding associated with large storms (i.e., maintaining water levels in the harbor below 1.6 m above mean lower low water). More recently, however, the water level has been reaching this threshold at extreme high tides (e.g., the barrier gates closed 26 times in 2019) (Trustees of Reservations 2022). Using a 0.8 m SLR projection for 2050, the 2022 State of the South Coast Report estimated that maintaining this water level threshold behind the barrier could mean one to two closures a day as soon as 2050 (Trustees of Reservations 2022). New Bedford Port Authority stated it would not be possible to operate the port with this many closures and that a new management strategy would need to be developed, which likely would require more flooding to occur in low lying areas along the Fairhaven waterfront while also adapting high priority infrastructure and implementing strategic retreat (Trustees of Reservations 2022).

When O&M plans are provided as part of new permit applications for tide gates, criteria for closing gates are typically based on exceedances of high tide elevations, wind speed, storm surge elevation, 24-hour rainfall amount, or some combination of these factors. However, few if any O&M plans include closure adjustments for projected SLR or increased intensity of precipitation events. In general, projected increases in sea levels will trigger more frequent tide gate closures because the high tide elevation will be exceeded more frequently, although gate closure frequency will be dependent upon the magnitude of future SLR at each tide gate location. In addition, other closure criteria for tide gates often include exceeding storm surge elevations or 24-hour high rainfall events, both of which are projected to increase in the northeast U.S. region (Dupigny-Giroux et al. 2018; Easterling et al. 2017; U.S. Global Change Research Program 2017). This suggests additive effects of climate change will result in tide gate closures increasing in the New England region, resulting in significant adverse effects to salt marsh wetland functions and other tidal resources on the upstream side of tide gates. In particular, fish and invertebrates depending upon access to tidal creeks and salt marsh wetlands for feeding, spawning, and early life history growth and development will be restricted more frequently by tide gates.

Tide Gate Operability Issues

NOAA Fisheries staff have been involved with review, implementation, and monitoring of a large number of proposed and existing tide gates throughout New England over the past 20 years. Lessons learned over this time period highlight the reality of what can go wrong with tide gates under field operations over the life of a project. Below is a partial list of tide gate issues that have occurred in coastal areas of New England.

Broken Hardware: Tide gates undergo continuous wear and tear under normal operating conditions. Parts such as hinges, screws, floatation, gaskets and other hardware and mechanical parts deteriorate over time and become prone to breakage. For example, in the summer of 2021, the Oak Island tide gate in Revere, Massachusetts malfunctioned due to some mechanical parts breaking. Over the course of several months, the Revere Department of Public Works (RDPW) attempted without success to find a contractor to fix the problem or to find the unique replacement parts. It was not until the fall of 2022 that this tide had been repaired (E. Hutchins, pers. comm. 2022). In two other examples within Rumney Marsh in Revere, Massachusetts, the Massachusetts Department of Transportation (MADOT) replaced a series of top-hinged, cast iron tide gates with SRTs that had become inoperable between 1997 and 1999 (i.e., Route 1A improvements and Town Line Brook). The U.S. Environmental Protection Agency (EPA) issued non-compliance reports for these projects to inform the U.S. Army Corps of Engineers and the MADOT of needed repairs to these flood control structures (EPA 2018a; 2018b). As of the date of this publication, repairs to these structures have not been completed (Figure 5).

Figure 5. SRT gate on Route 1A in Revere, Massachusetts, showing missing top floats broken at the hinge joint of the top float assembly. Photo credit: Edward Reiner, US EPA.

In the spring of 2022, the tide gate at the Jacobs Meadow Marsh in Cohasset, Massachusetts was inoperable for several months due to issues with an automated actuator and operating gear. During this period, the tide gate was in a closed position with no accommodation for bi-directional tidal flow, restricting migration of fish to Jacobs Meadow Marsh. Fresh water flow from James Brook, which flows through the marsh before entering Cohasset Harbor, was discharged via a flapper valve that had been retrofitted to the tide gate vault chamber (J. Burtner, pers. comm. 2022).

Electrical Malfunctions: Many tide gates function with the use of electrical motors and sensors, which are prone to electrical shortages, power outages, and overall degradation in a marine setting. Unfortunately, power outages are most likely to occur during storm events when the tide gate is needed to prevent or reduce flooding of upstream areas. Storm events can create flooding situations near tide gates that can prevent technicians from reaching the site to attempt repairs. This can leave a tide gate inoperable for many days after a storm has passed. For example, tide gates at Straits Pond in the Towns of Hull, Cohasset, and Hingham, Massachusetts were inoperable for an extended period due to issues with the automated control system. In order to provide for tidal exchange, in 2020 the operator maintained the gates in a partially open configuration and would adjust them manually in response to spring/neap tide cycles and storms in order to maximize tidal exchange and address flooding considerations (J. Burtner, pers. comm. 2022). Manual adjustments of tide gates like this can greatly increase local municipal staff time and cost.

Debris Blockages: Both natural (e.g., fallen trees) and man-made debris (e.g., tires) can lodge themselves in the opening of a tide gate or obstruct hinges or other moveable parts and shut down normal operations until the obstruction is manually cleared away. Many tide gates are installed with trash racks, which can also be impacted by the accumulation of debris and cause backwater flooding of upstream areas. Remote locations of tide gates often make them difficult for local public works staff to reach and clear debris. In addition to field staff, debris clearing often requires heavy machinery and access is often difficult. As noted above, several of the SRTs installed in Rumney Marsh by MADOT are not operating properly due to sediment and debris accumulation (EPA 2018a; 2018b) (Figure 6).

Figure 6. Debris in front of clogged trash rack on upstream side of Route 1, Town Line Brook tide gate, Revere, Massachusetts. Photo credit: Edward Reiner, US EPA.

In the Town of Hingham, Massachusetts, a 60-inch reinforced concrete pipe provides tidal flow from Hingham Harbor to the Broad Cove estuary and salt marsh system. During an evaluation of the culvert as part of a potential wetland restoration project, it was discovered that the hydraulic conduit also contained a tide gate vault located under the Broad Cove Roadway. The vault contained a sluice type gate structure and a by-pass diversion channel designed with a flapper gate to allow for water to discharge from Broad Cove to the Harbor in the event the sluice gate was closed. Inspection of the vault revealed that the sluice gate was stuck in a partially open position from a large granite stone lodged within the sluice gate frame, significantly blocking the primary hydraulic flow, and the by-pass diversion channel flapper gate had fallen away from its frame. Had the diversion channel flapper gate not failed, allowing for bi-directional flow, the partially closed sluice gate and granite block obstruction would have significantly impaired tidal flow to the Cove. These tide gate failures were identified as part of the investigation of the system for a potential ecological restoration initiative, otherwise this situation would not have been discovered (J. Burtner, pers. comm. 2022).

Ice Blockages: New England in particular is prone to periodic heavy ice formation that can form directly on a tide gate or large chunks of ice that float to the site with the ability to disable the function of a tide gate. Ice blockages often continue until weather conditions have improved and the heavy ice has melted.

Vandalism: Acts of vandalism have been reported at a number of tide gates impairing the intended operation. In recent times, it is possible that high values of scrap steel and aluminum have led people to dismantle tide gates in order to sell the metal for scrap. For example, several incidents of vandalism of tide gates in Rumney Marsh, Massachusetts were reported to the MADOT and U.S. Army Corps of Engineers (Reiner 2012) (Figure 7).

Figure 7. SRT gate on Route 1A in Revere showing missing top floats broken at the hinge joint, likely the result of vandalism. Photo credit: Edward Reiner, US EPA.

Replacement Parts and Services: As noted above, many factors can result in tide gates breaking and becoming disabled. However, most tide gates, even the most simplistic ones, are custom made and owners typically do not store replacement parts, and in many cases, they do not have the technical equipment or skill to undertake repairs. Replacement parts are not always readily available by the manufacturer and have to be custom built. In some circumstances, the owner may be aware of broken parts on a tide gate and attempts to acquire replacement parts. In those cases, it is often difficult for regulatory agencies to enforce permit conditions while the permit holder is making good faith efforts to rectify the situation. However, under these circumstances the tidal flow through the gate may be eliminated or reduced, which eliminates or greatly reduces the function and value of the upstream marsh and creek system. Efforts to arrange for contractors and the necessary parts can sometimes lead to tide gates being inoperable for weeks and months at a time. As noted above, the Oak Island tide gate in Revere, Massachusetts malfunctioned in 2021, and it was not until the fall of 2022 that the RDPW was able to secure the parts and a contractor to make the repairs (E. Hutchins, pers. comm. 2022).

Short Notice Storm Events: During the summer months, in particular, sudden localized high intensity rain events can coincide with high tide and overwhelm the flood storage capacity before tide gate owners have time to close them. Significant stormwater runoff from these types of rain events is particularly threatening to urban areas with high levels of impervious surfaces in the upstream watershed. Impacts are often exacerbated from these types of rain events when they occur on weekends, holidays and evenings, when fewer staff are available to address the situation.

Access Issues: Tide gates are often located in areas that are difficult to access, monitor, and repair. Tide gates can be located underground within drainage or vault structures, or under rail lines and highways, which require special permission and/or access agreements and are otherwise hidden from public view. As noted above, a previously unknown tide gate vault located under the Broad Cove Road in the Town of Hingham, Massachusetts was discovered as part of an evaluation of a potential wetland restoration site. For known tide gates, winter weather and summer storm events compound the difficulty of accessing tide gates when repairs and maintenance are necessary.

Responsible Parties: In many situations, local public works departments are responsible for the operation and maintenance of tide gates within a community. With staff turnover, institutional knowledge regarding the presence of tide gates in the community and their associated operation is lost over time. Incoming directors and staff are frequently unaware of the existence of tide gates until they fail or are notified by the public or resource agencies. Similarly, municipal staff may not be aware of formal O&M plans, and may alter gate operations in response to concerns from abutters or personal preferences rather than criteria established in permit authorizations.

Floodplain Storage Issues

In the closed position, tide gates can limit and temporarily reduce flooding in the up-gradient area, providing a false sense of security for existing and new infrastructure that flood storage has increased in the area. In many cases, proposed development in the floodplain does not trigger FEMA requirements for compensation of flood storage losses. Flooding of properties upstream of tide gates is a kind of regulatory loophole that has not been fully addressed by wetland regulators. For example, new development in upland areas can be encouraged following the installation of a tide gate because perceptions of flood risks are reduced. Municipalities may be encouraged to make further adjustments to tide gate operations that restrict tidal flow as additional development further reduces flood storage capacity and to account for flooding from climate-induced changes (e.g., SLR, increased in coastal storm intensity and frequency).

Enforcement and Compliance Issues

Non-compliance with O&M Plans: In many cases in the past, regulatory permits have been issued for the construction phase of a tide gate installation, but lacked O&M plans that defined their use. In addition, when O&M plans were included in permits, such as a special condition of the authorization, the language has proven difficult to enforce. Even when resource agencies or the public provided evidence that permit conditions for O&M plans have been violated, enforcement and compliance measures were seldom taken. As discussed above, tide gate non-compliance issues have been reported for the tide gate at Oak Island in Revere, as well as the tide gates on Route 1A, and three tide gates at Town Line Brook in Revere, Massachusetts (EPA 2018a; 2018b). In addition, there are cases of modifications to the operation of a tide gate that are not entirely in compliance with its O&M plan. This situation can occur due to local complaints about mosquitoes or flooding. Tide gate operators may respond by adjusting the tide gate to reduce tidal inundation, regardless of whether or not it complies with the O&M plan.

Lack of Staff and Training at Local Levels: Many towns that own tide gates have limited number of staff with the access and knowledge to properly adjust a tide gate when necessary. It is often challenging for towns to have a qualified and trained staff person available 24 hours a day over 365 days a year. This situation results in tide gates preemptively adjusted prior to an expected weather or extreme tide event, and then failure to readjust gates after an event. Due to their typical location near tidal creeks and high velocity water passing through a pipe opening, which can be dangerous conditions for municipal staff to work, adjustments to tide gates may require more than one staff person to be on site for safety measures. Tide gates can therefore present staffing challenges to municipalities, and often lead to deficiencies in permit compliance.

Recommendations

As described above, numerous issues associated with existing tide gates have been documented in New England and have resulted in chronic and acute impacts to NOAA Fisheries trust resources. New tide gate proposals are expected to increase as development in the coastal floodplain increases and the effects of climate change exacerbate flooding in vulnerable areas. A comprehensive, regional inventory and assessment of tide gates is needed to evaluate the full scope of tide gate issues. Furthermore, tide gates can exacerbate flooding impacts to infrastructure and property when structures are not maintained and repaired as designed. To address these issues, we offer the following technical and policy recommendations for all new and existing tide gate projects and proposals.

1. Regional Inventory: Currently, only the Massachusetts Bay portion of Massachusetts has a comprehensive inventory of tide gates, which is now five years old and would benefit from a reassessment of the numbers and condition of tide gates across the state. Although we have attempted to provide estimates of the number of operable and inoperable tide gates in the New England region in this assessment, our confidence in the thoroughness and accuracy of these estimates is not high. For example, as discussed above, tide gates can often be located underground within drainage or vault structures, or under rail lines and highways, and otherwise hidden from public view. A New England region-wide inventory of tide gates is needed to assess the scope of tide gate issues and to prioritize areas for action. For example, tide gates identified in or adjacent to particularly environmentally sensitive areas (e.g., Massachusetts Area of Critical Environmental Concern, National Wildlife

Refuges), where flooding of developed properties are less of a concern, could be prioritized over tide gates in highly urbanized areas. The data should be located in an accessible, public database that is shared with state and local governments, who may want to take action themselves or use the information for climate resiliency and restoration funding. A federal agency, such as the U.S. Army Corps of Engineers, U.S. EPA, or NOAA, works across multiple state jurisdictions and is best positioned to carry out such a regional inventory.

2. Design and Engineering: The design and engineering of tide gates should balance the benefit of reducing flood risks and allow regular tidal exchange that maintain the health of marsh ecosystems and restore previously degraded marsh systems. In addition, tide gate designs should allow for safe and effective passage for resident and migrating fish. Compared to the most restrictive gates, tide gate installations should have a gate that opens wider and for longer periods of time, creates less water velocity and turbulence, and provides a gradual transition between fresh and saltwater for fish species to acclimate to changes in salinity (Giannico and Souder 2005). The design and type of tide gate needed should be dependent on the predicted weather and tidal conditions of the site, the elevations of areas upstream being protected, the presence or absence of adjacent developed areas that may be susceptible to flooding, and the frequency of gate operation. The design and engineering plan should be informed by a default condition under which the tide gate will typically operate, and a "storm condition" that can be used for a limited time in response to a predicted or unanticipated storm condition (see recommendation 3 below). A climate change assessment that considers future sea levels, the frequency and intensity of rainfall and storms, and water temperatures in the project area should be conducted to inform the design and engineering plan to project future operations over the life of the structure (i.e., 50-75 years) for proposed tide gates (see recommendation 4 below).

3. O&M Plans: Long-term O&M plans should be developed and written to be enforceable by federal, state, and local regulatory agencies. Regulatory agencies should commit to monitoring the compliance of O&M plans, and applying enforcement when necessary to avoid short- and sometimes long-term impacts to the upstream marsh system. Because tide gate parts often have operational lives of just a few years, ongoing maintenance and/or replacement is necessary for all tide gate equipment and should be anticipated in the O&M plans. In order to avoid and minimize equipment malfunction, planned maintenance schedules should be included in O&M plans, and compliance with the maintenance and replacement schedules should be a priority for permit holders and regulatory agencies.

In order to ensure tidal resources are protected and permit conditions are enforceable by regulatory agencies, tide gate O&M plans should include specific criteria for determining when gates will be opened and closed. Tide gate O&M plans typically include a default condition under which the tide gate will typically operate and a "storm condition" that can be used for a limited time in response to a predicted or unanticipated storm condition. The default operation is generally determined during the engineering and design phase of the project and will seek to maximize potential tidal elevation up-gradient of the tide gate without exacerbating flooding of adjacent properties or development. The "storm condition" operational setting is typically triggered by a predicted storm surge, high tide elevation exceedances, and heavy precipitation events as criteria for gate closure. The "storm condition" operation should be implemented only when the threat of storm-related flooding is imminent, and should return to the default operation as soon as practicable after the storm. O&M plans should also have a mechanism for logging operational settings, implementation of storm condition operation and return to default operation, maintenance, and repair. Therefore, O&M plans should include all criteria used for typical operation and gate closures and gate opening, and the tide gate operational criteria should be clear and enforceable by regulatory authorities. There should be an annual reporting requirement where the responsible party is required to provide the O&M log sheet to the relevant permitting authorities to ensure that the gate is being operated in conformance with the O&M plan.

4. Climate Change: New or modified tide gate project proposals should include climate change assessments that consider projected sea levels, storm surge, water temperature, and changes in precipitation (average and extreme events), and how these changes may affect the operation of the tide gates and associated impacts to natural resources, over the life of the structure (i.e., 50-75 years). Climate assessments of tide gates should be based on pre-construction tide gauge data and projected changes in tidal amplitude and frequency as a result of tide gate closures. Although the contents of climate change assessments may vary somewhat from one site to another, these climate factors will likely be relevant to all tide gate projects. In particular, the factors considered in climate change assessments should be applicable to the criteria applied for determining gate opening and closing for each project. For example, if predicted rainfall events or tidal water elevations are triggers for gate closure, projected changes in extreme rainfall and SLR should be evaluated in the climate change assessment. The selection of emission scenarios used in assessments should include, at a minimum, a “high” (e.g., RCP/SSP 8.5) and an “intermediate” (e.g., RCP/SSP 4.5 or RCP 6.0) scenario (IPCC 2021). For SLR projections, at a minimum the 1.0 m mean global scenario should be used with the relevant downscaled projections for the closest tide gauge location identified in Sweet et al. (2022).

5. Compensatory Mitigation: Assessments for compensatory mitigation to offset tidal resource impacts and losses due to the operation of proposed tide gate projects should be conducted during permit review by state and federal regulatory agencies and funding program applications (e.g., FEMA flood protection, NOAA coastal resiliency programs). This should include both initial tidal resource impacts from construction related activities, as well as compensatory mitigation for future tide gate operational adjustments due to climate change. Climate-related impacts may include, but are not limited to, sea level rise, water temperature, storm intensity and frequency, and changes in precipitation volume, intensity, and seasonality (see recommendation 4 above). Mitigation plans should be developed to offset the projected losses to tidal resources from reduced tidal flow, amplitude, and seasonality. Periodic monitoring of tide gate operations and tide elevations in affected marsh habitat should be conducted to verify the accuracy of modeled tidal resource losses. To account for increased stormwater runoff associated with upland development and changes in climate, modifications to tide gate operations should be anticipated to protect private and public infrastructure. Most if not all of these future adjustments will result in additional impacts to upstream tidal marsh systems and should be offset through compensatory mitigation.

6. Long-term Maintenance, Training, and Management: As discussed above in recommendation #3, the operational lives of some tide gate parts are limited to a few years and should be regularly replaced. Ongoing maintenance and/or replacement is necessary for all tide gate equipment and should be reflected in O&M plans. Compliance with the maintenance and replacement schedules should be a priority for permit holders and regulatory agencies. Tide gate-permit holders (e.g., departments of public works and other responsible parties) should ensure staff are available and properly trained. This should include staff trained in repairs of broken tide gate parts and for debris removal. Because tide gates are typically located near tidal creeks, and often experience high velocity water passing through a pipe opening, repairs, adjustments, and debris clearing generally require more than one staff person to be on site for safety measures. Departments responsible for tide gate compliance should maintain and communicate institutional knowledge regarding the tide gates under their purview to new directors and staff. It should be the responsibility of the tide gate owner to ensure appropriate staff are aware of formal O&M plans and compliance with permit conditions are followed.

7. Flood Storage Evaluations: We recommend new tide gate proposals be required to assess upstream watershed changes that may require tide gates be closed more frequently and for longer durations in the future as increased development in the flood plain and climate-induced flooding (from SLR and increased coastal storm intensity and frequency) reduces flood storage capacity. Since runoff is not possible when tides exceed interior water levels, compensatory flood storage mitigation on an incremental basis should be required for any fill within the floodplain behind tide gates.

8. Tidal Monitoring: All permitted tide gates should be required to install and maintain internet accessible, real-time continuous monitoring of both up and downstream water surface elevations. Such monitoring will assist local authorities in their ability to more effectively reduce upstream flooding and avoid impacts to aquatic resources. Tide gauge monitoring devices can be equipped with alarms that are immediately directed to local authorities (e.g., department of public works and/or permitting agencies) when tide gates are not functioning correctly and flooding is imminent or underway at a tide gate site. Tidal monitoring is also critical in evaluating short- and long-term tide gate operations and tidal resource impacts upstream of the tide gate.

When a new tide gate installation is coming on-line, the initial tide gate “high water” closure setting can be adjusted to be lower than the predicted high tide to allow for a risk-averse ramping up process. Under this scenario, the initial “high water” setting can be raised incrementally until a targeted high water elevation is achieved without risk of flooding to properties. Having an internet accessible, real-time monitoring system, as described above, will facilitate adaptive operational and management protocols.

9. Future Enforceable Permit Conditions: Most regulatory permits are associated with a short-term construction/impact phase that have expiration dates. However, tide gate impacts likely will increase over time due to a wide variety of issues cited above. Therefore, regulatory agencies should identify and utilize their authority to enforce permit conditions after the initial construction phase is completed. This will necessitate the use of clear, concise, and enforceable permit conditions included in state and federal authorizations and O&M plans (see recommendation 3 above).

10. Review of Policies and Regulations: Because many of these recommendations will have implications for state and federal agencies that regulate and manage structures in the coastal floodplain, we recommend conducting a review of existing agency policies and regulations related to tide gates. This would include state and federal wetland regulators, as well as emergency management and natural resource agencies that provide funding and technical assistance for coastal flood and climate resiliency programs. Modifications and adjustments to wetland policies and regulations may be necessary to address existing issues related to tide gates, and to provide effective protection of property, infrastructure, and coastal wetlands and other tidal resources from changes in climate.

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