Ecological Effects of Tide Gate Upgrade or Removal: Considerations for Restoration Practitioners

Oregon Watershed Enhancement Board, May 2021

Introduction

Tide gate restoration includes projects that remove tide gates completely or replace them with fish-friendly designs. Many projects also include other restoration actions such as dike removal, breaching, or setback; tidal channel reconfiguration; off-channel habitat construction or reconnections; large wood placements; and vegetation plantings. Such projects can be costly and complex to design and implement; this report reveals best practices to optimize a project's ecological benefits.

In July 2016, the Oregon Watershed Enhancement Board (OWEB) awarded funding to the Institute for Natural Resources (INR) at Oregon State University (OSU) to investigate the collective lessons learned from tide gate restoration and monitoring projects by performing a literature review and compilation effort. The *Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis*[1] report, completed in 2018, includes:

- A literature review pertaining to tide gate removals and upgrades;
- A summary and review of completed, primarily OWEB-funded tide gate removal and or/upgrade projects and associated effectiveness monitoring;
- A summary and review of completed tide gate removal and/or upgrade projects and associated effectiveness monitoring not funded primarily by OWEB; and
- Summary and synthesis, including findings and recommendations.

The 2018 literature review report provides information useful to a variety of audiences including policymakers, local officials, agency staff, engineers and restoration practitioners. In addition, there is ongoing tide gate restoration and monitoring that has and will continue to yield valuable information from practitioners since the literature review was completed. In order to capture this valuable information from practitioners we invited their review of this bulletin and made every effort to incorporate their feedback into the relevant sections.

[1]**Literature Review Report Citation:** Souder, J.A., L.M. Tomaro, G.R. Giannico and J.R. Behan. 2018. Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis. Report to Oregon Watershed Enhancement Board. Institute for Natural Resources, Oregon State University. Corvallis, OR. 136 pp. Submitted to Oregon Watershed Enhancement Board in fulfillment of grant #217-8500-17090.

Cover Photo: McDonald Slough tide gate. Ken Fetcho, OWEB.

Purpose

This bulletin summarizes both the content from the 2018 Literature Review Report and key information from practitioners. These findings may be of particular interest to those designing and implementing tide gate restoration projects. This bulletin lists the pages of the literature review report that contain more detail and source information. The referenced pages are indicated in parentheses at the end of themes and sections. For example, (7-1) indicates that the entire Findings and Recommendations begin on page 7-1.

While this bulletin provides key findings and recommendations, please access the full report on OWEB's website https://www.oregon.gov/oweb/Documents/Tide-Gate-Ecological-Effects.pdf or visit Oregon Sea Grant's website for a copy of the report https://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/t-18-001_tide_gates.pdf as well as a separate summary document aimed at policy makers https://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/t20001_tide_gates_2020_accessible.pdf that was completed by Jon Souder and Guillermo Giannico.

Background

Tide Gates Impact Fish Passage & Water Quality

Fish Passage

Tide gates affect fish passage, presence, and abundance. The gate (a physical barrier), how long it is open, and outflow velocities all affect fish passage. The fish not only have to pass through the tide gate but also traverse the associated structure, often a culvert. Fish can only pass a tide gate when 1) it is opened sufficiently wide, 2) there are limited to no water surface elevation discontinuities between the waterway and the tide gate structure, 3) water turbulence is low, and 4) the velocity is slow enough to allow for fish sustained swimming. Species presence and abundance may be lower as a direct result of passage impediments. At some locations, gates may be perched during some lower tide cycles or closed for long periods by extremely high storm surge tide periods or seasonal flows. Gates can also remain closed during the summer/fall when there is insufficient fresh water inflows to the reservoir pool to rebuild the head after low-low tides so that the gates can open during the high-low tides. Fish passage obstruction due to perching can be resolved through proper installation of the culvert height. To help address other fish passage issues, a number of technological advancements have resulted in modifications and new tide gate designs; these include vertical slide-gate style tide gates, side-hinged aluminum tide gates with multi-arm hinged doors, passage orifices, levers, floats, mitigators, self-regulating tide gates, and muted tidal regulators. (3-8)

Water Quality

It is imperative that practitioners understand the salinity and associated water quality regimes within in the system they are working, as well as how those regimes fluctuate seasonally. Some systems have brackish waters and others have tidally influenced water levels, but are completely freshwater. Water quality characteristics such as dissolved oxygen (DO) and salinity are generally lower above (upstream) the tide gate structure, which may limit fish use of reservoir pools above tide gates in certain seasons, and the abrupt change from freshwater to brackish water can have deleterious effects on juvenile salmonids.

PRACTITIONER DISCUSSION

Low dissolved oxygen levels associated with tide gate structures have not been a factor in over-wintering Coho salmon abundance in the Coquille system when cold temperatures exist.

Coho Salmon Exhibit Diverse Life Histories

Coho salmon early life history diversity and movement patterns are more complex than historically recognized. Representation of the four early life histories of coho salmon recognized on the Oregon coast are described in Figure 1a through 1d from Souder, Giannico. 2020. Juvenile coho salmon move within and between stream and estuarine environments in different seasons. Moving freely between fresh and brackish waters during their first

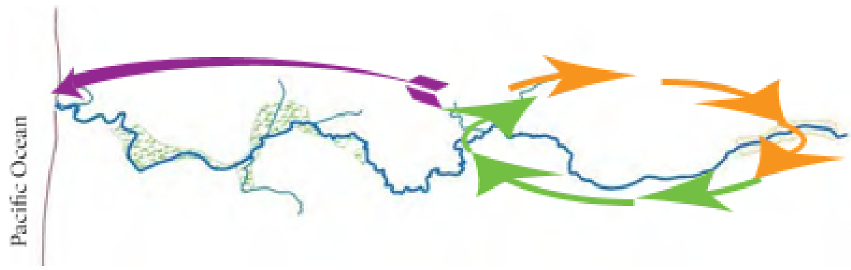


Figure 1a: **Smolt migrants**—Spend first year in freshwater stream, then migrate to estuary and ocean the next spring.

Figure 1b: **Fry migrants**—Within a few weeks of emerging from gravel in spring, they move to estuary where they stay until they swim to ocean the next spring.

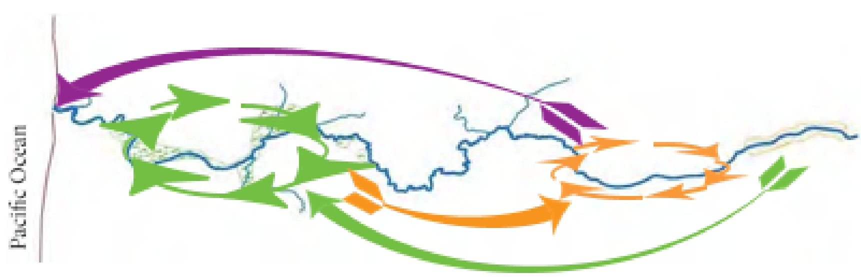
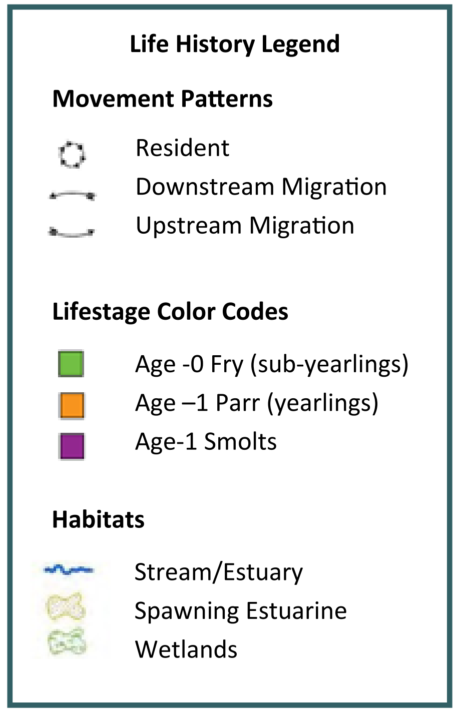


Figure 1c: **Fry migrant nomads**—Enter estuary in spring and summer. Return to freshwater in fall and winter. Re-enter estuary and ocean in spring.

Figure 1d: **Parr migrants**—Spend spring and summer in freshwater stream. Migrate to estuary in fall and winter. Move to ocean the next spring.



Fry. Emerge from spawning gravel from March through May after their egg yolk sacs are completely consumed. Stay in this state for about three months, depending on water temperatures and food availability, until 1” to $1^{1/2}$” long.

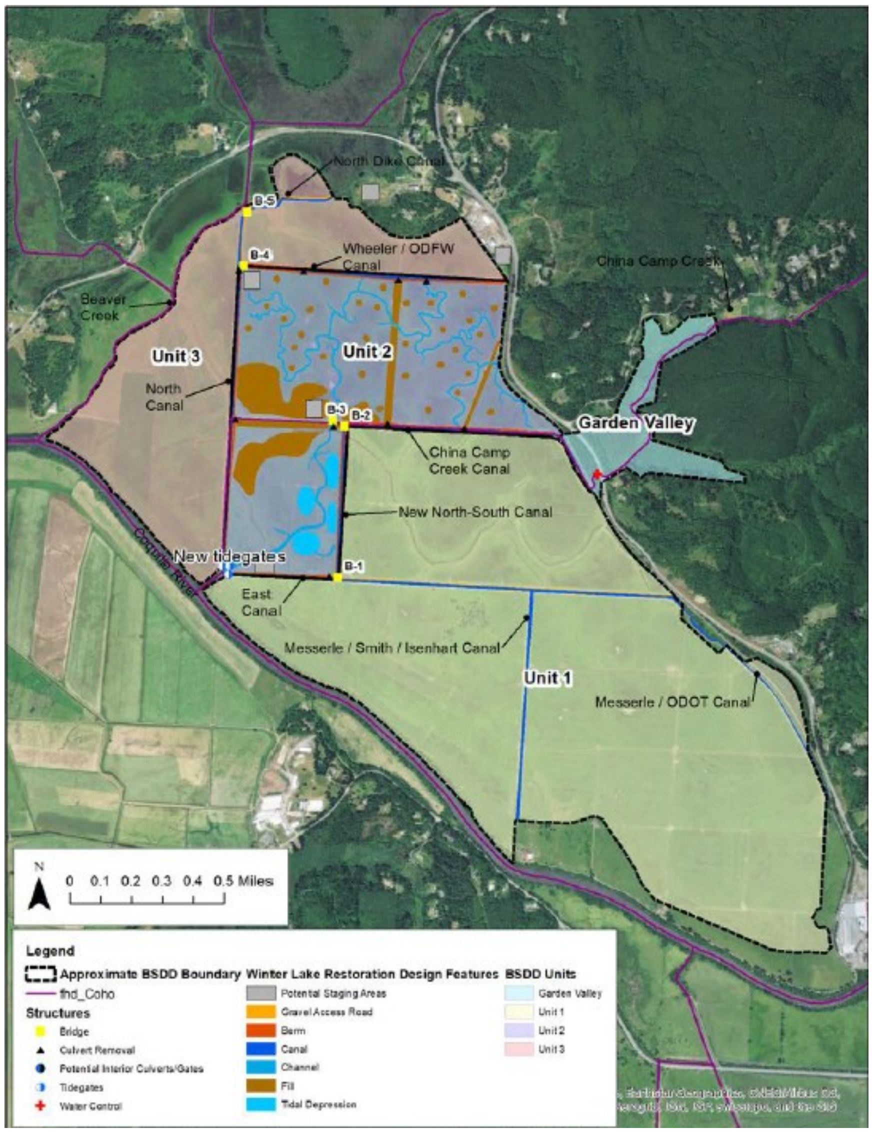
Parr. Recognized by vertical gray bars. Begin to defend territories. Stay in this stage for about 1 year.

Smolts. Undergo physiological and morphological changes to adapt to salinity, taking about two months. Parr marks fade. Migrate to ocean from late March to June.

year of life and not having anything that interferes with that movement greatly improves their odds for survival. They enter the estuary in distinct pulses as sub-yearlings in their first spring of life, in the fall, or as smolts during their second spring. Some individuals remain in the estuary until they migrate into the ocean, while others move back upstream to overwinter. In general, survival seems to be lower in the estuary, but growth rates are higher, which likely compensates for the higher risks. It is estimated that estuary-rearing life history variants may contribute between 20% and 40% of coho salmon spawners. The higher percentages are likely associated with years of drier and warmer stream rearing conditions. Tide gates constrain the expression of these diverse early life histories in coho salmon, which are adapted to utilize multiple habitats and exhibit varied movement patterns to take advantage of seasonal resources that change in availability and quality from year to year (3-4 and 3-8).

Categorization of Tide Gate Related Estuarine Restoration Projects

While there is often a primary goal that provides the original impetus for a project, many—if not most—projects encompass more than this main goal to build support and acquire needed funding. Multi-goal projects also often respond to and leverage the needs of multiple funders and landowners so that each one gains some benefit. For example, a levee setback project that removes a tide gate to improve estuarine rearing habitat may need to install an upgraded gate at an interior location to protect adjacent infrastructure. Multi-goal complex projects may also take longer to plan, fund, permit and implement. When fish passage is the primary goal, it is important to consider the entire system, including the amount and quality of habitat upstream of the tide gates. Replacing the tide gate(s) with a fish-friendly design might only provide access to a minimal amount of quality habitat due to other constraints (i.e., interior tide gates, perched culverts, dikes or levees, and/or incompatible land uses (6-1, 7-5 and 7-6). More information is available in Table 1, below, based on Table 6.1 of the Literature Review Report and includes additional information from tide gate practitioners.



The goals at the Winter Lake project in the Coquille River Valley on the southern Oregon coast include flood control and restoring estuarine rearing habitat. *Source: Coquille Watershed Association*

Table 1. Categorization of tide gate (TG) related estuarine projects (Table 6.1, pg 6-2)

Project Goals	Action Descriptions	TG Removal	TG Upgrade
a) Estuarine Rearing Habitat	Occurs primarily in areas that have tide gates in dikes or levees to allow water behind them to drain into the estuary. Actions may include: • Tide gate removal • Dike or levee breaching • Dike or levee removal • Dike or levee setback • Tide gate upgrade • Development of Water Management Plan • Channel reconstruction above and below the tide gate	Potential benefits and limitations include: • Improved or restored tidal influence and connectivity • Discreet dike or levee breaches may still have high velocities and limited inundation • Improved sediment scour (channels) and deposition (marsh surface) • Increase in quality and diversity of tidal wetlands dependent on restoring marsh surface elevation and natural hydrology	Potential benefits include: • Balanced protection and restoration • Improved tidal influence and connectivity • Improved water quality upstream from the gate
b) Fish Passage Between Freshwater and the Estuary	Focus is on the stream channel. Actions may include: • Remove tide gate • Tide gate upgrade • Addressing other barriers (culverts) or constriction points near the tide gate • Development of Water Management Plan	Potential benefits include: • Improved or restored tidal influence and connectivity • Improved passage for all life stages • Improved sediment scour (channels) and deposition (marsh surface) • Thorough mixing of fresh and brackish water	Potential benefits include: • Improved passage for at least some periods • Reduction in delays of fish movements up and downstream of tide gate • Reservoir pool may provide suitable habitat and velocity refuge • Improved tidal influence and connectivity
c) Flood Control (major events)	Tide-gated lowlands prevent flows from spreading onto floodplains, raising water levels during floods and storm surges. Actions may include: • Dike or levee removal • Dike or levee setback • Tide gate upgrade • Development of Water Management Plan	Potential benefits include: • Provides flood storage area • Fish access to off-channel velocity refuge • Improved food web productivity • Sediment deposition	Potential benefits include: • Seasonal management, for flood storage (open) or protection (closed) • Provide velocity refugia in areas behind the gate
d) Infrastructure Protection (tides)	This need is likely to expand with sea level rise. Action may include: • Tide gate upgrade • Raise road and building elevations.	Tide gate removal is an unlikely action for infrastructure protection	Potential benefits include: • Support working landscapes and provide incentives to cooperate in restoration. • Better drainage due to greater outflow capacity.

Tide Gate Geography

Benefits and effects of tide gates are related to their geographic location: stream/river mouth and tributaries allow tide gate upgrades to meet multiple goals. When considering tide gate projects, ensure that suitable rearing or off-channel refuge habitats are available, restored or created as a project component. The location of tide gates in relationship to the estuary influences their effects as shown in Figure 2 (Figure 6.1, 6-2 and 7-9, 7-10). To maximize benefits for salmonids (among other benefits such as flood mitigation) prioritize projects where tide gates are located at stream/ river mouths or on tributary creeks.

- **Stream/river mouth tide gates** (also called "tidal barrages") potentially have the largest impact on aquatic life because of their location at the mouth of mainstem streams where they enter the estuary. This critical location controls fish passage between freshwater and estuarine waters, while diminishing the transitional salinity gradient between those two environments.
- **Tributary stream tide gates** drain smaller areas, and control shorter distances of stream. These tributary streams will extend beyond the floodplain, and may have limited spawning areas for salmonids in their upper reaches. In contrast to stream/river mouth tide gates, tributary stream tide gates have few subsidiary tide or floodgates above their installation. The ecological gains to the stream channel and adjacent floodplains (pastures) will be dependent upon whether the tributary empties directly into an estuary, whether another tide gates exists between the site and the estuary, and whether the floodplain is diked and drains are tide-gated.

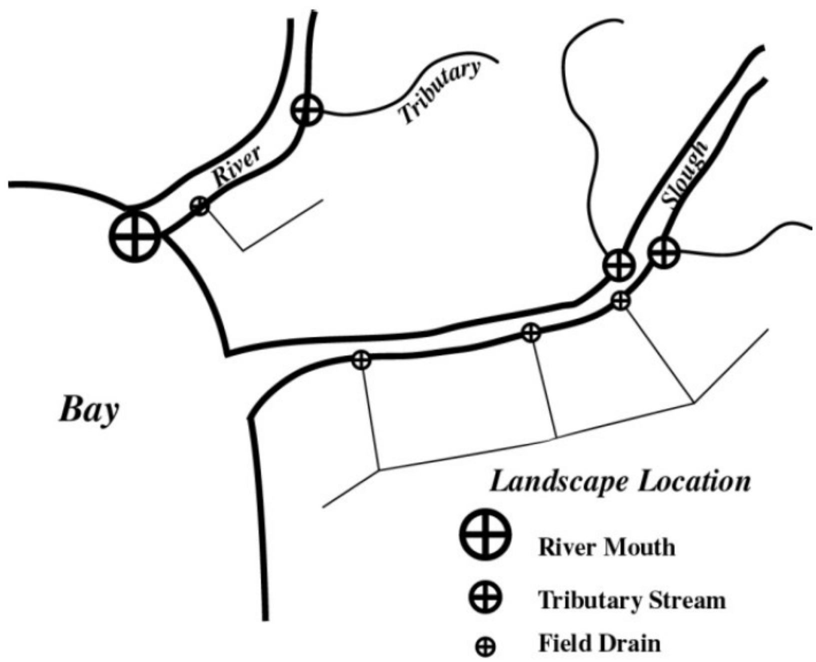


Figure 2. Geography of tide gate locations (Giannico and Souder, 2005).

- **Tide gates that drain fields** or areas converted to commercial or residential use (Figure 6-1) is the third geographic category. These tide gates may empty into the estuary, but also commonly into either streams controlled by tributary or stream/river mouth tide gates. Drain tide gates are usually located in dikes, which may also serve as roads and driveways. Often, there is additional infrastructure (e.g., houses, garages, barns) that these gates protect.

  More information is available in Table 2, below. This table is based on Table 6.2 of the Literature Review Report and includes additional information from tide gate practitioners.

Table 2. A systems perspective on tide gates in their watersheds (Table 6.2, 6-5)

Tide Gate Location	Description	TG Removal	TG Upgrade
a) River/Stream Mouth	Typically located at the mouth of mainstem streams where they enter the estuary. In many cases, these tide gates are located at road or highway crossings, and often have multiple gates within a larger structure. The salient feature of these tide gates are: 1) They drain 6th or 7th HUC watersheds that have named tributaries up stream. 2) There are secondary tide (or flood) gates upstream that control tributary streams and field drains.	Effects of removal depends upon whether the attachment structure remains or is removed: • Velocities likely to be reduced, especially if the opening is enlarged. • Volitional fish movement up to the extent of the tidal influence or the next barrier. • Restoration of sediment transport processes in main channel. • Expansion of salt marsh habitat	Potential effects include: • Amount of habitat accessed dependent on next upstream barriers (lateral and longitudinal). • Reservoir behind TG may provide (seasonally) freshwater habitat if water quality is suitable
b) Tributary Creek	These streams have comparatively small drainages, often into remnant sloughs that have tide gates downstream. Tide gates on these streams protect upstream areas from tidal inundation, commonly to create pastureland, but may also contain areas filled for development. These upstream areas historically provided tidal wetlands suitable for estuarine rearing habitat. There are no (or few) subsidiary gates upstream.	Effects of removal depends upon whether the attachment structure remains or is removed: • Velocities likely to be reduced, especially if the opening is enlarged. • Volitional fish movement up to the extent of the tidal influence or the next barrier. • Restoration of sediment transport processes in main channel. • Potential expansion of salt marsh habitat	In addition to effects of River/Stream Mouth location, potential effects include: • Improved passage window while protecting areas behind TG. • Improved water quality due to increased tidal influence and connectivity
c) Drain	These tide gates can be located in agricultural fields or in urbanized areas. While some drain directly into tidal waters, others are placed above River/Stream Mouth and Tributary Creek tide gates to protect adjacent fields. The salient feature is that there may be limited habitat upstream of the gate (i.e., ditch channel), except during flood events, and no salmonid spawning areas.	Dependent upon whether there are intervening TGs between site and estuary: • Tidal reconnection if no downstream barriers; typical in former estuarine fringe wetlands. • Potential expansion of habitat	Potential effects include: • Outbound passage after floods to prevent stranding if habitat is poor. • Additional habitat, especially refugia during flooding, if good habitat is available. • Bi-directional passage for all life stages.

Tide Gate Monitoring and Evaluation

Types of Monitoring (pg 5-31 of the Literature Review Report)

While there are many categories and types of monitoring (Roni et al. 2013), the three most commonly used in evaluating tide gate projects are:

a) **Implementation, Construction, or Compliance Monitoring.** Considers whether the project was implemented according to designs and met all regulatory conditions. This is the most fundamental monitoring, and is usually required by grantors. OWEB Restoration Grants require compliance and implementation monitoring. In addition, many regulatory agencies require the development and implementation of a monitoring plan for many years post-restoration as a condition of permitting.

b) **Effectiveness or Performance Monitoring.** Considers whether the project had the anticipated, desired effects and benefits. Effectiveness monitoring can be used by practitioners as a learning tool, especially if there is a focus on adaptive management whereby individual projects are considered experiments (Walters and Holling 1990). This type of monitoring is also critical for adapting Water Management plans in order to maximize seasonal benefits.

c) **Validation Monitoring.** Goes further than effectiveness to evaluate whether the hypothesized causal relationships (e.g., between habitat quality and smolt production) are correct. While this is often characterized as "research," monitoring of this type has been successful in expanding knowledge about variations of coho salmon life histories as well as quantifying interactive tidal environmental and biological relationships.

Effectiveness and validation monitoring are eligible activities under the OWEB Monitoring Grant Program. Both of these usually require a good set of baseline data from which comparisons of project-related effects can be made. In most cases, there will need to be a comparison between the project effects and some reference. More information is available in Table 3, below, and lists important considerations for developing a monitoring plan (pg 5-31). This table is based on Table 5.4 of the Literature Review Report and includes additional information from tide gate practitioners.

Field sampling for fish movement at Nolan Slough post-restoration at Southern Flow Corridor project, Tillamook Bay, Oregon. *Source: Janousek C, Bailey S, van de Wetering S, Brophy L, Bridgham S, Schultz M, Tice-Lewis M. 2021.*

Table 3. Typical Monitoring Activities by Different Category and Project Goal (Table 5-4, pg 5-32).

Monitoring activities are ordered from simple to complex, considering factors such as the estimate of the time needed after project completion to see change, the level of effort, and cost estimates. Effectiveness/Performance monitoring builds upon activities listed under Compliance/Implementation monitoring. Validation monitoring builds upon both Compliance/Implementation and Effectiveness/Performance monitoring activities.

Monitoring Type	Estuarine Rearing Habitat	Fish Passage	Flood Control	Infrastructure Protection
a) Compliance/ Implementation **Has the project been constructed according to specifications and permit requirements? Is the tide gate being managed in accordance with the Water Management Plan?**	Quantity and quality of resulting habitat. • Area of resulting habitat at Mean Higher High Water (MHHW)* • Drainage network characteristics • Channel geometry • Marsh surface elevation • Water surface elevation at spring tides	Passage conditions: • Miles of accessible habitat • Tide gate culvert invert and Mean Lower Low Water (MLLW)** elevation • Duration of gate opening (and opening angle) • Velocity measurement and distribution through opening	Purpose of these projects is to lower flood levels. Were they implemented as designed? • Flood elevation (spatial and temporal) • As-built volume for flood storage • Tide gate culvert invert elevation	Purpose of these projects is to protect infrastructure. Were they implemented as designed? • As-built elevations and locations for features • Water surface elevation of reservoir pool during king tides and freshets • Tide gate culvert invert elevation
b) Effectiveness/ Performance **Has the project met its goals and objectives?**	Were wetland functions improved, especially as they relate to rearing habitat quantity and quality? • Amount of newly accessible habitat • Water quality conditions • Uplift in HGM wetland function • Fish relative abundance and distribution • Fish survival and growth	Was the project effective in improving fish passage? • Water quality conditions • Physical habitat quality conditions in newly opened or improved stream areas • Hydraulic analysis of water velocities; seasonality, and timing of open periods (tide gate upgrades) • Fish relative abundance and distribution in relationship to upstream intrinsic potential	Was the project effective in reducing flooding? • Flood damages avoided • Flood elevation and duration (modeled versus actual)	Is the project, with or without tide gates, effective to protect infrastructure? • Storm damages avoided • Duration and timing of water level height during high tide events
c) Validation **Are assumptions, models, and methods valid?**	Does restoring natural hydrologic regimes (or improved ones with TG upgrades) lead to desired reference conditions? • Shorebird/waterfowl/wildlife relative abundance and distribution • Uplift in hydrogeomorphic (HGM) wetland functions • Fish survival and growth • Food web dynamics, i.e. vegetation, plankton, macroinvertebrates, fish	Are tide gates the limiting factor for improvements in fish production? • PIT tagging to assess movement within streams and through tide gates • Survival, growth, and recruitment of salmon in the stream-estuary system • Fish production capacity	Are these projects a valid advancement over traditional structural approaches? • Cost: benefit of any mitigation needed for potential flood risk • Adequacy and appropriateness of hydrodynamic models used for the design	Are there different approaches to flood protection that are equally beneficial? • Damages from various storm scenarios (modeled versus actual) • Cost effectiveness of project designs • Do hydrodynamic models represent actual, post-construction conditions?

*Mean Higher High Water means the average height of the highest tide recorded at a tide station each day during the recording period.

** Mean Lower Low Water means the average height of the lowest low tide recorded at a tide station each day during the recording period.

Key Findings and Recommendations

A. PHYSICAL & ECOLOGICAL EFFECTS OF TIDEGATES

The following are key research findings that provide background information and develop ecological context for tide gate related restoration projects along with practitioner input. The full report page numbers are referenced after each finding.

1) Finding: Limited or nonexistent connectivity significantly affects fish community composition and water quality. (7-1)

- Fish community composition is influenced by the presence of tide gates and seasonal conditions; nonnative species may be more abundant at gated sites, and juvenile salmon abundance is higher at ungated sites (Scott et al. 2016). Differences in above and below gate fish communities were greater when the gates opened less frequently (Seifert and Moore 2017).
- Water quality in gated and ungated streams differs; especially for salinity gradients and water temperature. The effects may limit the reservoir pool's habitat quality and rearing capacity, especially during smolt migration and summer (Bass 2010; Gordon et al. 2015; Weybright and Giannico 2017).

Recommendation: The science is clear that for salmonid fish habitat and passage, the absence of tide gates is preferred, if possible. However, this does not take into consideration current land uses and other factors associated with the use of tide gates. Improved tide gate designs and their capacity for adaptive and active management have the potential to ameliorate some adverse impacts to fish passage and water quality. This is especially true when seasonal passage needs and habitat utilization are considered and direct manipulation of tide gate open time and water inflow/outflow is incorporated into management plans.

PRACTITIONER DISCUSSION A.1

The benefits to be realized by tide gates depends upon continued maintenance and management of the gate throughout the seasons. Roles and commitments for long-term operations should be clear among project partners.

2) Finding: Life-history diversity of juvenile coho salmon is greater than previously realized. (7-2)

- Conventional wisdom held that coho salmon reared in their natal reaches for their first year, then migrated rapidly as smolts through the estuary on their way to the ocean; any pre-smolts that moved downstream were considered to be competitively displaced and less successful (Sandercock 1991).
- Although Tschaplinski (1988) was the first one to report estuarine rearing coho salmon fry, the view that these fish could represent an alternative life history began to develop in the early 2000s with the work of Miller and Sadro (2003) in Winchester Creek, Coos estuary. Koski's (2009) study in Duck Creek, Mendenhall estuary, Alaska, added to this knowledge by identifying a nomadic life-history type, which showed seasonal movements between brackish and fresh waters. Juvenile coho salmon nomadic migration expands the available rearing area, food resources, and growth potential and increases overall productivity (Koski 2009).
- More recent studies in Oregon by Jones et al. (2014) in the Salmon River estuary and Nordholm (2014) in Palouse Creek, Coos Bay estuary, identified as many as four distinct coho salmon rearing life histories, including

Winter Lake Unit 2 restoration channels following completion of tide gate installation, October 2018.
Source: Coquille Watershed Association

fry migrants, nomads and parr migrants, as well as spring migrant smolts, which remain in freshwater during their first year of life. Both of these studies documented that all life-history types contribute to the spawner population as adults. Four distinct coho juvenile life histories were found in the Grays River estuary, WA (Craig et al. 2014). There may be additional endemic coho salmon juvenile life history diversity yet to be identified: Tryon (2011) found multiple coho salmon age classes rearing for variable amounts of time in the Courtney River estuary, BC and Wallace et al. (2015) found the same in the Humboldt Bay, CA estuary.

- Diverse life histories, including estuary rearing, provide long-term resiliency to salmon populations under changing ocean and climatic conditions (Craig et al. 2014).

Recommendations: The clear implication of this body of literature is that, besides Chinook salmon, coastal populations of anadromous species, including, but not limited to coho salmon, will benefit significantly from increased connectivity and fish passage opportunities in the freshwater and estuarine ecotones of rivers and this should be incorporated into tide gate design, installation, upgrades or removal projects. Additional research into juvenile salmonid rearing life histories and their habitat utilization would benefit practitioners, if targeted to potential restoration prioritization strategies and project site selection and implementation.

3) Finding: Estuary rearing provides increased growth and survival opportunities for juvenile coho salmon. (7-3)

- After tide gate removal and dike breaching in the Salmon River estuary, juvenile salmon use of estuarine habitats, especially by sub-yearlings, began earlier and lasted longer than prior to the restoration work (Bottom et al. 2005).
- Condition factor of sub-yearling coho salmon did not differ between those collected above the tide gate and those collected below in Courtenay River estuary (Guimond and Bio 2010). Growth rates were similar between sedentary and mobile juveniles in Palouse Creek, but in the low, tidally influenced reaches, summer to smolt survival was higher for mobile than for sedentary individuals (Weybright and Giannico 2017). Coho salmon rearing in the stream/estuary ecotone of a Humboldt Bay tributary were larger than those rearing upstream; likewise, those rearing in lower sloughs were larger than those in the upper sloughs (Wallace et al. 2015).

- Chinook and coho salmon sub-yearlings utilized different habitats in the Courtenay River estuary, B.C., Canada. Chinook salmon preferred upper ecotone habitats near freshwater input, while coho salmon were collected in areas with good refuge and freshwater inflow. Estuary rearing coho salmon grew faster than those in stream habitats did, and even faster than estuary rearing Chinook salmon (Tryon 2011). However, during early restoration, foraging opportunities for juvenile salmonids may be modulated by lower quality habitat and prey resources, which can also be affected by connection to upland habitats (Gray et al. 2002).

Water levels controlled by a muted tidal regulator at the Seestrom Tide Gate project in the Coquille River Valley. *Source: Coquille Watershed Association*

Recommendation: Plan restoration actions with the expectation that not all beneficial ecological effects, such as increased prey productivity creating improved foraging opportunities for juvenile salmon, will occur immediately. They may take several years to develop after project completion.

4) Finding: No tide gate is entirely fish friendly; they all have some impact on aquatic organism passage. (7-3)

- Some tide gates, particularly self-regulating tide gates (SRT), may open for longer periods of time than other tide gate types, but they still restrict tidal flow and interfere with normal up and downstream movements of sub-yearling salmonids and with the timing of smolt downstream migration (Bass 2010). Even those gates that are upgraded to facilitate fish passage still delay the movements of both juvenile and adult fish significantly (Wright et al. 2014 and 2016).

Recommendation: Have realistic expectations on the fish passage effects of tide gate upgrades or complete replacement projects. Take into account that they may have some negative impact on fisheries resources, at least initially. Variable annual conditions and the way in which the tide gate is operated seasonally can also confound the assessment of tide gate upgrade effects. Tide gate removal provides the best fish passage benefit.

PRACTITIONER DISCUSSION A.4

In order to evaluate passage effectiveness, the water management plan for a specific tide gate must be reviewed. In some systems, the tide gates can be tethered open to facilitate passage during peak use for fish.

5) Finding: Although the negative impacts of tide gates on water quality and aquatic habitats have been well documented, the upgrade of tide gates or their replacement with newer designs have produced mixed outcomes. This may be influenced by the monitoring not being sufficiently intensive or designed in a manner that allows understanding of the effects and their magnitude after restoration has been completed. (7-4)

- Some studies (Franklin and Hodges 2015) reported DO increases and water temperature reductions above gates only in some of their study locations, while others (Boys et al. 2012) were able to detect only pH improvements above tide gates.

Recommendation: Do not expect the simple upgrade of an old tide gate for a new one that remains open longer to solve an entire series of water quality factors. Consider that not all estuarine channels (i.e., streams, marsh channels, ditches, sloughs, etc.) have similar characteristics (e.g., salinity gradient, discharge, tidal flushing level, sediment deposition rates, water chemistry, etc.). Therefore, the simple replacement of a tide gate is not going to yield the same results every time. Keep in mind that adjacent and upstream historic or current land uses, including remaining undersized and failing tide gates and culverts can still cause water quality impacts after upgrades occur. Restoration and improved land management upstream of the tide gate is critical to realizing the desired habitat improvements.

A side-hinged tide gate near the Southern Flow Corridor project reconnects a channel to the Tillamook River. The tide gate is installed in a setback-levee to protect the pasture from high tides, while allowing it to drain at low tides. *Source: OWEB*

B. PROJECT SCOPING, PRIORITIZATION & PLANNING

The following are key research findings to inform project design and expectations for conservation outcomes. There are additional useful findings and recommendations in the report, OWEB is highlighting a sub-set of those that are key to this topic. (7-4 to 7-10). The full report page numbers are referenced after each finding.

1) Finding: Tide gate upgrade or removal projects produce highly variable results. The design, operation, and maintenance of these structures are important factors, but their location in the channel network and installation are equally important. (7-3)

- The gates that remain open the longest and widest improve fish passage conditions and opportunities (Boys 2012, Bocker 2015).
- Many tide gate upgrades (i.e., drilling of small orifices, addition of pet doors, SRTs) by themselves do not improve fish passage (Johnson et al. 2008, Wright et al. 2014 and 2016, Greene et al. 2012, Henderson et al. 2016). Upgrades that improve tidal exchange and water quality, but not fish passage may still benefit fish communities by restoring prey productivity, particularly in relation to salinity gradients. (Boys et al. 2012, Johnson et al. 2013).

  Recommendation: Consider that a replacement tide gate, in some cases, might produce better results if installed elsewhere along a dike or in a different location in a channel. When determining tide gate location, consider the sill elevation of the culvert, its length, width and gradient to maximize fish passage. A benefit/cost analysis should be considered where the existing superstructure remains functional to ensure that any added benefits from replacing some of its components are commensurate with additional costs.

PRACTITIONER DISCUSSION B.1

Inundation area and upstream flows into the tide-gated system are also significant factors that influence design and installation. A thorough hydraulic analysis and monitoring of a site is critical to inform the elevation of the culvert, type of gate, and other design factors.

It is also critical to evaluate the channel elevation below and above the tide gate to determine if there are natural or manmade grade control points that will affect tidal influence and hydrology.

2) Finding. Hydrodynamic modeling is critical to project prioritization, planning and monitoring. There is a lack of bathymetric and other types of data to support construction of hydrodynamic models.

- As estuary restoration projects have become more complex, agencies and planners are increasingly using hydrodynamic modeling to help inform decisions regarding which projects to prioritize and the potential hydrological outcomes of restoration alternatives.
- Evidence suggests that these models are very useful because they address the key information need of forecasting hydrologic outcomes of restoration actions (e.g., how susceptible my property will be to flooding if dike is set back or agricultural land converted back to wetland). Evidence also suggests that such models are becoming more sophisticated.

- Hydrodynamic modeling that is being conducted in a number of Oregon's estuaries by scientists from the University of Oregon (David Sutherland) and Oregon State University (David Hill) can form a foundation for the modeling needed for project prioritization and implementation.

Recommendations: Identify the kinds of raw data [GIS, Lidar] needed to develop hydrodynamic models for estuary restoration, and prioritize location and acquisition of such data. Integrate this into protocols for pre- and post- project monitoring. Work with the Oregon research community to develop strategies for acquiring bathymetric and other types of data needed to develop hydrodynamic models for estuary restoration project prioritization and planning.

3) Finding: Several categories of tide gate restoration goals emerged from the 45 projects evaluated. (7-5 and pgs. 5-1 to 5-41)

a) **Estuarine rearing habitat expansion**, including increasing the area of suitable habitat for salmonids (and other species), and providing unique conditions (such as improving water quality and access to high flow refuges).

b) **Fish passage improvements** to increase connectivity and facilitate movement between the estuary and freshwater streams for salmonids, both out-migrating smolts and returning spawners.

c) **Flood damage reduction** by increasing the area available for high flow storage and gradual release downstream.

d) **Infrastructure protection** through upgrading tide gates and associated structures to meet current engineering and regulatory standards. This project type is commonly requested by local agencies and landowners to protect land upstream of the tide gate including but not limited to agricultural lands.

Recommendation: These restoration categories provide a basis for identifying a continuum of project types and their relative benefits in the interactive tidal zone. Some projects might focus solely on one goal, and have neutral or adverse effects on other goals. Other projects may provide joint benefits for multiple goals, with or without adversely affecting other goals.

PRACTITIONER DISCUSSION B.3

Protecting agricultural land from long-lasting effects of salinity is a common goal related to flooding.

Project proponents should be able to fully describe the quantity of ecological benefits and the benefit to infrastructure, where it applies, to funding agencies.

Wood installed in the channel at the Cochrane tide gate project, Coos County. *Photo: Coquille Watershed Association*

C. PROJECT IMPLEMENTATION & EFFECTIVENESS

The following are key research findings to inform project design, post-restoration management/maintenance of the tide gate, and expectations for conservation outcomes. The full report page numbers are referenced after each finding.

1) Finding: The best restoration results have been reported for tide gate upgrade projects that included other restoration actions and were done on a large scale. (7-10)

- Fish and habitat responses were consistently stronger and more positive from restoration projects that combined a spectrum of actions (i.e., tide gate upgrade or removal, dike setback or breaching, tidal channel creation, upstream riparian plantings and in-stream complexity enhancements) than those of simple and localized enhancement work (Hering 2010, Roegner et al. 2010, Silver et al. 2015, Diefenderfer et al. 2016, Henderson et al. 2016).

Recommendation: Whenever possible, favor comprehensive restoration projects that aim at reestablishing connectivity and ecosystem level processes over those that focus on changing one single factor (e.g., number of fish that pass, water quality above tide gates).

2) Finding: Upgrading a tide gate is only the first step in the process of improving ecological conditions and fish migration corridors. (7-11)

- Monitoring indicates that active and informed management of the tide gate is critical to realizing the full potential benefits of the upgrade.
- Also, some landowners may be reluctant to actively manage tide gates, even after cooperating on upgrading. Therefore tide gate improvements often underperform.

Recommendations: To fully realize the potential benefits of restoration involving tide gates, post restoration water management and monitoring plans should explicitly provide for active and adaptive management of the gates in order to incorporate knowledge gained from research and monitoring, and to account for unforeseen effects or outcomes.

Recognize that to optimize tide gate design and management for fish requires a balancing of: 1) gate opening time and width, 2) culvert width, 3) invert elevation, and 4) upstream pool depth at high tide (Lyons and Ramsey 2013).

PRACTITIONER DISCUSSION C.2

Water Management Plans and landowner agreements are key documents that are effective tools during the planning process when working with landowners to ensure clarity on commitments. Both documents should explicitly describe roles and responsibilities of all stakeholders, especially as it pertains to seasonal and real-time management, long-term maintenance, and potential tide gate failure. Water Management Plans will ensure that water quality conditions are suitable for fish and that fish passage permitting requirements are met.

Wherever possible, establish a Water Management Team to collaborate on long term tide gate management in accordance with the Water Management Plan. Having Councils or ODFW staff participate on the Team can help with reminders and making the actual adjustments.

Tide gate optimization must also consider watershed hydrology, including river influences and upstream catchment size. The goals of upstream landowners must also be balanced with other considerations for managing for fish.

Where and when appropriate and available, tide gates should be more actively managed, in real time, in order to maximize the benefits of seasonal conditions.

Newly planted trees along channels at Winter Lake, Coos County.

Photo: Coquille Watershed Association

Tide gates should be managed seasonally to ensure that fish passage requirements, water temperatures, and dissolved oxygen are suitable for juvenile salmonids when they are present in the system. Additionally, any maintenance that requires a tide gate to be closed should be conducted when salmonids are least present. (Beamer et al. 2017.)

3) Finding: Some unforeseen outcomes should be expected after implementation of large restoration projects. (7-11)

- Appropriate attention to the quality and extent of pre-project planning, combined with considerations of the scale of hydrological processes and the possible final outcomes of the cumulative effects of multiple restoration actions will reduce the likelihood of unforeseen outcomes.
- Regular monitoring of upgraded tide gates is critical to help identify and mitigate unforeseen impacts before they accumulate or worsen.
- Each project should have an operations and maintenance plan in a Water Management Plan, with provisions for funding seen and unforeseen needs in place prior to project completion.

Recommendations: Sites should be operated to ensure that any adverse effects arising from implementation of the restoration actions are identified and rectified in a timely fashion. Post-implementation monitoring will provide information on the project's long-term outcomes, facilitating an adaptive management approach to subsequent estuarine restoration projects.

PRACTITIONER DISCUSSION C.3

Long-term maintenance is often something that many districts do not realize they are responsible for. It is often outside of what watershed councils can do, and a lack of maintenance can seriously hinder the function of conservation-funded projects.

Maintenance plans are required under the *Tidal Area Restoration Program (TARP)* permitting.

Identifying provisions for funding future operation and maintenance needs can be challenging, particularly under typical state and federal funding sources. It is important for funders to understand that post-project adjustments are common and not a result of poor design.

The adaptive management plan should identify the team of technical advisors and how frequently they should meet to troubleshoot issues as they arise.

D. MONITORING AND EVALUATION OF TIDE GATE REMOVALS AND UPGRADES

1) Finding: Monitoring can be a learning tool for practitioners, and can aid in identifying and improving effectiveness over time, especially when it is part of a feedback loop in an adaptive management approach (Walters and Holling 1990). (7-12)

- Monitoring is challenging, however, given the complexity of tide gate related restoration projects, the difficulty of prizing out effects of different project components, and the long period often required to detect effects.

2) Finding: Long-term monitoring is critical, but this is resource and time-intensive and support for it is usually limited. There is no comprehensive estuary restoration project monitoring strategy (7-12).

- It is preferable to apply monitoring resources on fewer projects, but with more robust protocols (e.g., multiple sites, number of days sampled, sampling for several years). If monitoring resources are spread too thinly, or monitoring is truncated after only a couple of years, the resulting data may not be useful.
- Many monitoring projects that OWEB has supported are well-grounded and executed, but there has not been an integrated and consistent approach among different monitoring entities.

Recommendations: Develop a more integrated and cohesive monitoring strategy for estuary restoration projects, starting with rigorous analysis of what questions the monitoring should be designed to inform or answer. Explicitly consider how monitoring results would be used to inform adaptive management of tide gates. To the extent possible, institutionalize and standardize existing monitoring protocols, so existing data can be compared to new data.

Review monitoring protocols used by other programs in the PNW (e.g., the Columbia Estuary Ecosystem Restoration Program) to inform development of a more standardized and cohesive approach for monitoring OWEB-funded estuary projects.

Carefully consider which projects to monitor, who will be using the resulting knowledge, and how it will be used. Focus tightly on a carefully selected subset of potential sites or projects to track through time, i.e., 10-20 years.

PRACTITIONER DISCUSSION D

Monitoring goes hand-in-hand with the ability to adaptively manage a project site in real time, year after year. It is challenging, if not impossible, to implement adaptive management of tide gate projects if real time or recent data is not available to inform operations. In addition, as-built surveys are critical for timely verification and adaptation or adjustment.

Pre-project monitoring is extremely important. Project implementation and Water Management Plan development cannot proceed without it. The intensity of pre-project monitoring should be relative to the size and scope of the project, including potential risks and benefits of all stakeholder aspects. Minimally, water level and species presence are required by the National Marine Fisheries Service (NMFS) under their *Tidal Area Restoration Program (TARP)* permit.

Lessons Learned in Fish Ecology, Project Planning, Implementation, and Monitoring

This section shares lessons learned from implementation of past tide gate restoration projects, including examples of past OWEB-funded projects. Additional lessons learned are in the full report , this is a sub-set of those. (6-9)

FISH ECOLOGY CONSIDERATIONS

Lesson: A specific habitat quality level or threshold may need to be achieved before fish and invertebrate communities respond as desired. (6-9)

Observation: Incrementally staged tide gate management resulted in faunal assemblages becoming more similar to reference sites assemblages only after the final implementation stage was completed. (Boys 2015).

Lesson: Tide gate upgrades can be especially important for passage of weak swimming species. (6-9)

Observation: The PNW representatives of this group include sculpin species (Scott et al. 2016, Brophy et al. 2014). (6-9)

PRACTITIONER LESSONS LEARNED - FISH ECOLOGY CONSIDERATIONS

- Juvenile coho tend to move in pulses based on environmental signals.
- When stream flow sharply increases, fish often look to find refuge in floodplain habitats, and the timing of gate operations should align with those periods of hypothesized fish movement, when possible.
- Work with fish passage staff at ODFW and NMFS to hone in on the relative importance of velocity versus gate door openness. Each site should model the tide gate function in order to identify optimal operations that balance velocity and time of door open to maximize fish passage.

Coho found at Winter Lake, Coos County.

Photo: Coquille Watershed Association

PROJECT PLANNING AND PERMITTING

Reporting documents identified a number of challenges that practitioners faced during the project planning and permitting stage.

Lesson: Being up to date on fish passage design and permitting requirements is critical. (6-10)

Advice: Project partners should establish a clear protocol for communicating with permitting agencies and outline expectations (modeling approach, metrics, and conditions) at the outset of a project. This should decrease delays associated with requirement clarity and staff turn-over (OWEB grant 215-1017-11365).

Tip: Check for permitting changes prior to application submission. Designs that fit outdated requirements will have to be reworked, causing delays (OWEB 212-2022-8872).

PRACTITIONER LESSONS LEARNED - PROJECT PLANNING AND PERMITTING

- Overall, consult early and often with all permitting agencies from the onset of the project.
- Seek feedback from permitting agencies at multiple points during project design to ensure alignment with all federal and state regulations. Communicate via email to have record of all permitting discussions and considerations.
- Pre-project monitoring/data gathering provides vital information for design and is often required by permitting agencies. Consider the amount of time needed to complete pre-project monitoring in regard to developing the timeline for tide gate replacement.
- Inform the landowner of potential for Oregon Department of State Lands (DLS) to require an easement on tide gates over tidally influenced waters of the state. The easement application fee is $750 and will need to be renewed in future years.
- Cultural resource concerns and requirements are highly site-specific. Consult with tribes and SHPO and identify the lead federal agency early in the planning phase in order to facilitate Section 106 National Historic Preservation Act (NHPA) review, including the potential need for secondary impacts surveys to cultural resources from changing tidal regimes and erosion.
- Consult with ACOE about the possibility that ACOE constructed dikes or levees on the site. This could trigger additional reviews.

Lesson: Project implementation will be smoother, monitoring more successful, and goals more readily attainable with careful and detailed planning. This will lessen the likelihood of scheduling difficulties, project delays, and cost overruns. (6-10)

Advice: Cost contingencies should be developed to respond to unexpected issues. A strategy should be developed with project funders to fund these contingencies since most grants do not allow for a fixed percentage.

Advice: A high priority should be placed on effective distribution and design of channels to provide adequate drainage for all areas of the site, limiting potential areas for stranding and mosquito breeding (OWEB grant 210-2032-7450).

Advice: Consider additional costs when planning and budgeting, particularly for organizing, storing, delivering, and distributing plants. Bare root timing is critical because they should not dry out or be exposed to harsh weather (OWEB grant 214-3032-10845).

Tip: Site tours with regulatory agencies and potential contractors prior to creating construction bid packages will help make the work and equipment estimates more accurate (OWEB grant 208-1061-7658).

PRACTITIONER LESSONS LEARNED - PROJECT PLANNING AND PERMITTING

- For projects seeking multiple benefits (restoration and working lands) set goals early with landowners to ensure that inundation area and timing is identified, which drives pipe sizing and tide gate door type.
- Consider the potential for water quality impacts to occur in tidal channels from land management practices (i.e., grazing) after the project is completed.
- Integrate NRCS tools for pasture assessment and management with restoration plans and habitat conservation easements. Relatively user-friendly Pasture Inventory and Forage Balance tools are available that provide condition scores and decision support tools for future pasture management.
- Consult with tide gate manufacturers and engineer early and often to hone in on the feasibility of designs and water management plan – current tide gate technology has its limit, which can constrain project objectives and outcomes.
- Have tide gate manufacturers sign a contract that details the intended performance of the gate and includes an outline of adaptive management expectations from the manufacturer.
- Clearly understand what is under warranty and what is not when it comes to tide gate installation and function.
- Consider additional costs when planning and budgeting for post-project updates to facilitate adaptive management (e.g. an extra gate for fencing, additional ballast weight for MTR, etc.)
- The success of the project will be greatly influenced by the competency of the hired engineering firm that will perform hydraulic analysis, field data collection, alternatives analysis, designs, etc. Widely publicize bids for engineering to ensure a competitive selection process. Vet not only the firms experience and expertise on modeling and designing projects, but also their communications abilities as tide gate projects often require extensive collaboration among landowners, local organizations, and agencies.
- The engineer should make sure hydraulic modeling includes any new channel network proposed and evaluates a range of inundation levels. The engineer should also assess grade control structures above and below tide gate to inform hydraulic function (e.g. artificial fill in channel or natural (beaver dams)).

CONT. PRACTITIONER LESSONS LEARNED - PROJECT PLANNING AND PERMITTING

- There is additional complexity in modeling, designs, and operations in systems with significant and unpredictable freshwater inputs (e.g., floods on the Coquille River). Thorough planning when developing the water management and adaptive management plans are key to realizing success in objectives in these scenarios (during winter storm events when river is at or near flood stage for prolonged periods of time during known juvenile coho migration season).
- When feasible and cost-effective, consider addressing upstream constrictions such as undersized livestock crossings or silted in drainage ditches at the time of tide gate replacement.
- Stakeholder engagement is an invaluable first step in project development that allows landowners the opportunity to learn more about what options they have for their property. Intentional and well-crafted messaging can be critical to building a collaborative team with landowners, local organizations and other partners.
- Consider impacts to all neighbors from changing drainage and tidal inflow/outflow. Larger projects may provide more habitat, but often include multiple landowners, which requires significantly more time for coordination and communication. This can be streamlined if there is a functioning drainage district.

ON-THE-GROUND PROJECT IMPLEMENTATION

All the best strategies and plans can be for naught if projects can't be implemented successfully.

Lesson: Specialized expertise may be required from construction contractors and technical advice from agency, watershed council, or engineering staff. There are few contractors experienced in tidal area construction, but these people and groups are very valuable for restoration projects. (6-10)

Observation: A lack of qualified contractors may limit the number of projects that can be included in large-scale time-sensitive projects (Bringing Back the Fish NSW, Australia).

Advice: Providing flexibility for a good contractor can achieve design goals while saving money and improving production and product (OWEB grant 207-261).

Advice: If possible give preference to competent local contractors. Their intimate knowledge of the project area can result in benefits such as cost savings and positive grass roots public relations (OWEB grant 212-8004-9544).

Tip: When undertaking unfamiliar restoration goals, full time contract inspection by staff that are knowledgeable of the tide gate technical aspects during the work will assist in successful completion and limit delays or costly reworking (OWEB grant 207-261).

Tip: All utilities should be moved prior to restoration activity (OWEB grant 207-261).

PRACTITIONER LESSONS LEARNED - ON-THE-GROUND PROJECT IMPLEMENTATION

- Hiring local contractors is often a priority, but it is still important to carefully consider the expertise and track records of contractors from out of town who may be more familiar with the technical aspects of tide gate replacement such as the invert elevation for tide gate installation and dewatering strategies.
- Work closely with the engineer to develop a comprehensive construction bid package, attend initial site visits with hired construction firm, and also coordinate with engineer for onsite evaluation of work (e.g., checking elevations, dimensions, etc.) to ensure a thorough as-built report. Be prepared for fire season and coordinate early with fire protection district to initiate exemptions for closure if working in pastures away from forestland.
- Have a plan in place for possible discovery of cultural resources prior to ground disturbing activities and ensure that contractors are aware of the plan to mitigate any potential damage.
- Liability should be considered during maintenance: if a Council or District was responsible for the management or maintenance of a tide gate, liability could be passed onto them if something happened.

Lesson: The success of restoration plantings can be increased by considering contingencies and implementing additional steps prior to placing the roots in the ground. (6-11)

Advice: Consider plant species sensitivities and strengths in relation to expected post-restoration conditions to optimize success of plantings. (OWEB grant 214-3032- 10845).

Advice: Marshes that have subsided drastically may need to be restored slowly so as to avoid flooding the area and creating open water habitat instead of marsh habitat.

Tip: Adding a layer of topsoil in newly excavated or graded areas may benefit plantings (OWEB grant 214-3032-11263).

Tip: Apply herbicide to weeds prior to planting, when it can be done with large equipment. Once plantings are done all herbicide must be applied by hand (OWEB grant 214-3032- 10845). Some herbicides have long soil residence times and may impair or even kill newly planted vegetation. Check the label and talk to licensed herbicide applicators first, depending on the targeted species and herbicides/surfactant used.

Lesson: Timber companies that are willing to partner to make wood placements upstream may not have experience with such placements in the estuary. (6-11)

Advice: Timber companies may be primarily concerned with liability and damage in the event that wood breaks free, which can increase the difficulty of getting ecologically successful placements (OWEB grant 210-2024-7458).

Tip: Organizing a site tour with local timber placement experts and the partnering timber company may be necessary to achieve placements that will create the intended habitat benefit (OWEB grant 210-2024-7458).

PRACTITIONER LESSONS LEARNED - ON-THE-GROUND-PROJECT IMPLEMENTATION

- To prevent unintended movement of log structures upstream of the tide gate, consider alternative methodologies for adding instream complexity. In the Coquille watershed, this has been successfully accomplished at multiple sites by pushing logs into the streambank, leaving rootwads exposed in the channel to provide cover and increase roughness (OWEB grant 219-2077.

MONITORING

Implementing a tide gate monitoring program is often challenging.

Lesson: Tidal reaches of lowland streams are seasonally dynamic and difficult to sample during the critical overwinter period. (6-11)

Advice: A variety of sampling approaches may need to be deployed to sample throughout the year. Sampling techniques such as PIT tag arrays can track multiple individual fish movements and migrations (OWEB grant 214-2031).

Tip: All equipment should be securely anchored to withstand high water conditions and deter theft (OWEB grant 212-2044).

Lesson: Monitoring data is most useful if measurements are taken at appropriate time scales. (6-12)

Advice: For tide gate effectiveness or ecological monitoring, sites should be sampled more than once per year and in subsequent years to be able to draw strong conclusions (OWEB grant 210-2032). Longer duration is better for tidal hydrology monitoring. Even year to year differences can obscure long term conditions (Ennis 2009).

Advice: Temporally sensitive metrics should be monitored continuously or at a high frequency (especially for metrics expected to vary with time, such as water temperature and fish density) over relatively long periods to capture important patterns. The use of data loggers can be extremely helpful. (Greene et al. 2012).

Lesson: Sampling needs to be adjusted to current site conditions at the restoration site. (6-12)

Advice: Gather elevation data for the site to be restored and design sampling so that these elevations are sampled at the reference and control sites. Pre-restoration reference data will be unusable if it does not correspond properly to the newly restored marsh (Brophy et al. 2014, Brown et al. 2016).

PRACTITIONER LESSONS LEARNED - MONITORING

- It is important to time sampling to be consistent with tides. E.g., conduct nutrient sampling on an outgoing tide to avoid inadvertently sampling downstream conditions rather than upstream conditions.
- When sampling year round, ensure the location is adequate for both low and high tide during winter and summer.
- It is often the late winter/spring period when species, like coho, are present and able to be detected, captured, measured, etc. Visual surveys of coho feeding can allow the identification of patterns with fish use of pastures at varying water depths.
- Communicate the potential for data gaps to occur due to storm events, high tides, and other impediments to safely accessing the site. It is important for stakeholders, funders, regulators, and policymakers to be aware of these constraints or limits on information collected. Adapting as monitoring work is implemented is the rule not the exception.
- Consider applying for a grant to monitor post restoration for 1-3 years and then go back to monitor with the same methods 10 years later. Often initial results the year after implementation may not reflect conditions as intended as the site recovers from restoration actions or as the water management plan is implemented and adaptively managed.

Pulling nets at Winter Lake, Coos County.

Photo: Coquille Watershed Association

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Additional Recommended Reading

- Brophy, L.S., and M.J., Ewald. 2018. Modeling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future.

  This project modeled and prioritized "landward migration zones" ("LMZs") for 23 estuaries on Oregon's coast south of the Columbia River. These LMZs that are potential future tidal wetlands under sea level rise (SLR). Tidal wetlands currently exist just at and above sea level, and healthy tidal wetlands are able to adapt to slow sea level changes. If sea level rises too fast, tidal wetland plant communities may not be able to persist at their current locations. To survive, these plants may have to move to areas of higher elevation in these LMZs. https://ir.library.oregonstate.edu/concern/technical_reports/tt44ps38k

- Brophy, L.S., E.K. Peck, S.J. Bailey, C.E. Cornu, R.A. Wheatcroft, L.A. Brown, and M.J. Ewald. 2018. Southern Flow Corridor effectiveness monitoring, 2015-2017: Sediment accretion and blue carbon. Prepared for Tillamook County and the Tillamook Estuaries Partnership, Tillamook, Oregon, USA. Corvallis, Oregon, USA: Institute for Applied Ecology.

  This report describes two main monitoring activities: 1) measurements of sediment accretion using feldspar marker horizon plots and sediment stakes, and 2) collection of deep soil cores to determine "blue carbon" sequestration rates. These activities spanned the period of restoration construction at the Southern Flow Corridor (SFC) site. The SFC site is located in the Tillamook Bay estuary on the northern Oregon coast, USA.

- Hodgson EE, Wilson SM, Moore JW. Changing estuaries and impacts on juvenile salmon: A systematic review. Glob Change Biol. 2020; 00:1–16. https://doi.org/10.1111/gcb.14997

  This journal article reports results from a systematic English-language literature review on the responses of juvenile salmon to anthropogenic activities in estuaries and nearshore areas asking: what has been studied, where are the major knowledge gaps and how do stressors affect salmon?

- Diefenderfer, H.L., et al. 2018. Designing topographic heterogeneity for tidal wetland restoration. Ecological Engineering 123: 212-225. https://www.journals.elsevier.com/ecological-engineering

  This journal article reports results from a from a synoptic survey of soil temperature and moisture on mounds at tidal wetland restoration sites in the Pacific Northwest (including several in Oregon), together with the results of a literature review, and the insights of regional restoration practitioners regarding ecological and practical considerations for mound construction. These findings will support design of wetland restoration sites where topographic heterogeneity is an objective.