



# **Tide Gates: Operation, Fish Passage and Recommendations for Their Upgrade or Removal**

*By Jon Souder and Guillermo Giannico*



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Cover image: Winter Lakes tide gate project. (photo by Brady Holden)







*Kilchis estuary restoration project. (photo by Zach Putnam)*

This document is intended for policymakers so they can make informed decisions about upgrading or removing tide gates in an effort to improve conditions for Oregon's native migratory fish and other animals and plants that inhabit estuaries.

It has two main sections: The first includes an overview of the technical aspects of tide gates, including non-traditional ones. The second contains findings from a review of scientific literature about upgrading or removing tide gates as well as conclusions from a review of estuary restoration projects involving tide gates. Based on those findings, we're also including recommendations to guide future investments in, and monitoring of, restoration projects associated with tide gates.

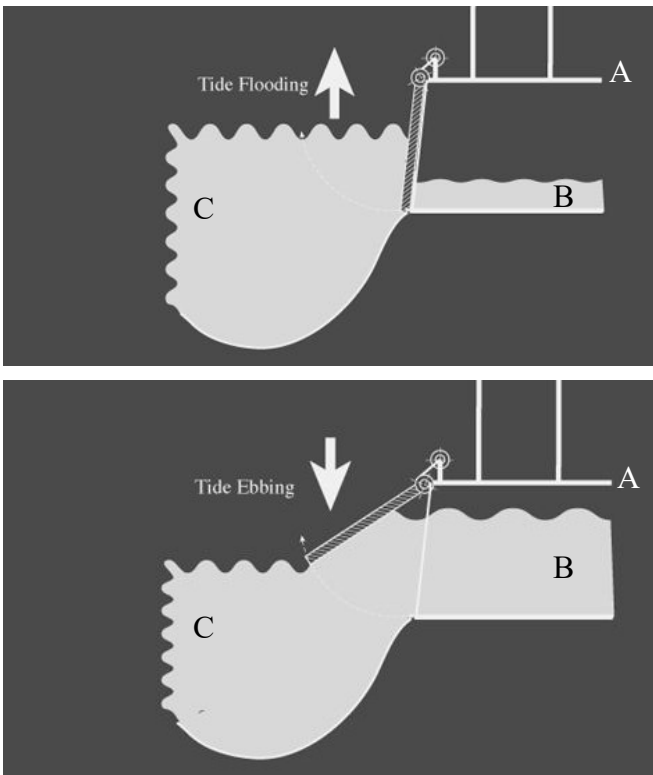
This document summarizes parts of a 140-page publication, [Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis](#), that the Oregon Watershed Enhancement Board (OWEB) funded through a 2016 grant to a team at Oregon State University. That report aimed to help readers understand how tide gates affect water quality and fish. It also sought to help OWEB understand the effectiveness of its investments in estuary habitat restoration projects involving tide gates so it can target future investments. For more information on types of tide gates and their environmental effects, see Oregon Sea Grant's publications [Tide Gates in the Pacific Northwest](#) and [The Effects of Tide Gates on Estuarine Habitats and Migratory Fish](#).



## How tide gates work

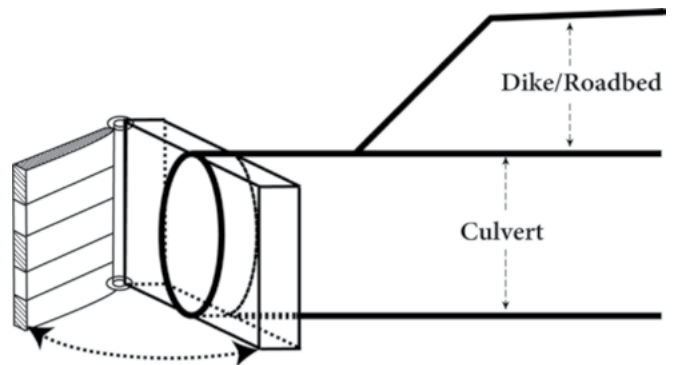
First, a note on terminology: When a tide gate is modified or removed and a new gate (or updated component of the gate) is installed in its place, it is usually referred to as a tide gate replacement. We refer to either instance as a tide gate upgrade.

Tide gates are doors or flaps mounted on the downstream ends of culverts or concrete boxes in dikes and levees or under roads that allow upstream waters to drain while preventing inflows from tidal surges or flooding (Figure 1).



*Figure 1: Top-hinge tide gate in the default closed position at top; the water elevation is higher downstream, forcing the gate closed. Bottom, the water elevation is higher upstream, forcing the gate open. A = culvert; B = freshwater side; C = bay or estuary side.*

These gates open when there is a positive hydraulic head between the freshwater reservoir pool compared to the estuary (i.e., when the water elevation on the upstream side is higher than on the downstream side). When this occurs, the gates open, resulting in outflows that drain the pool until the water elevations are equal again. Tide gates are generally closed by default, with some exceptions that will be discussed. Historically, most tide gates were top-hinged and constructed of steel or wood (Figure 1), but others can be side-hinged (Figure 2).



*Figure 2: Side-hinge tide gate on culvert in a dike. The tide gate remains open for a portion of the tidal influx when the water elevation downstream is below the water elevation in the culvert.*

Some systems have multiple gate types in a single structure. While tide gates refer to the mechanism that controls water flows, tide gates exist within an arrangement that consists of the superstructure that holds the gates, a culvert or concrete box that provides for the passage of water through the structure (usually installed in a dike or roadway), and potentially a number of accessory structures to protect the tide gate and/or prevent debris from lodging in the opening (Figure 3).



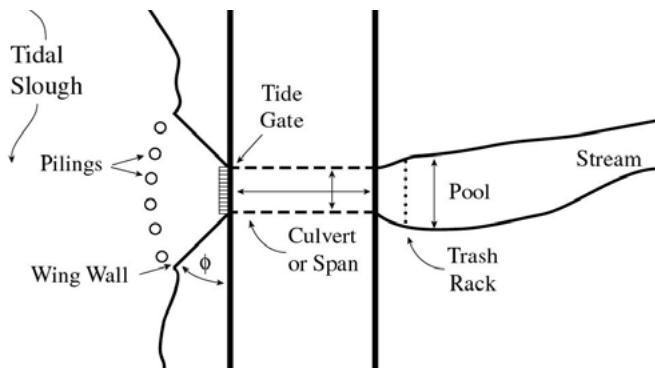


Figure 3: Typical configuration of a tide gate installation showing pilings protecting the gates, wingwalls to the sides, and a trash rack at the upstream (reservoir pool) side.

## Locations for tide gates

Based on earlier work (Giannico and Souder 2005), we categorized three different types of locations for tide gates (Figure 4):

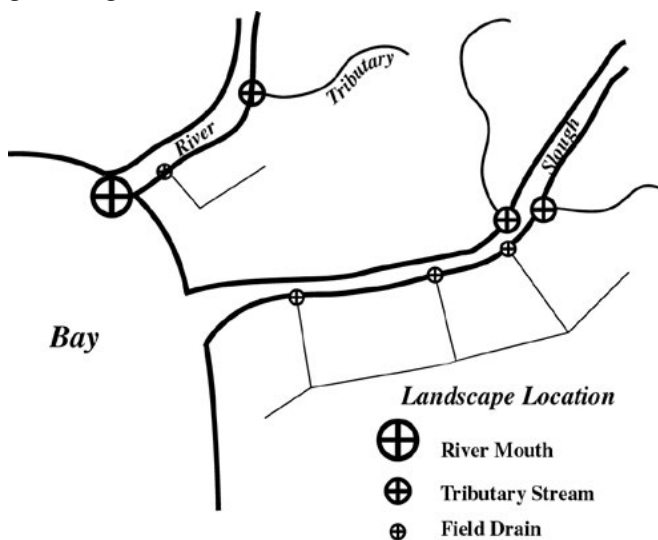


Figure 4: Representation of tide gates in estuarine and freshwater channel networks.

- Stream/river mouth tide gates are located where drainage from larger watersheds enters an estuary. These are larger structures, often containing multiple gates, and may be integrated into a road bridge or larger dike system.
- Tributary creek tide gates are at the mouths of smaller streams, but have spawning and nursery habitat outside the floodplain. These tide gates may be where the tributary enters the estuary, or may drain into a stream reach controlled by a stream/river mouth tide gate.

- Drains, whether they control tidal flows into fields or other protected areas, empty water only within the floodplain itself, and not into uplands beyond. Drains may empty directly into the estuary or into streams.

Stream/river mouth and tributary locations may have suitable lowland fish nursery habitat in the pool created behind the gate when it is closed (reservoir pool) or other nearby wetlands, and also suitable spawning habitat in the upper reaches of streams. In contrast, tide gates located on drains only have the potential to provide access to fish nursery habitat. The amount and quality of this potential habitat determine the relative value of the restoration project.

## Common goals for tide gate projects

Estuarine restoration projects often include upgrading existing tide gates with fish-friendlier gates, setting back the levees and gates, or removing the gates to restore more natural conditions. An increasing proportion also include other actions such as dike removal, tidal channel reconstruction, off-channel habitat construction or reconnection, large wood placements and vegetation plantings. In our review of 45 tide gate projects in the Pacific Northwest, we identified four common goals (Table 1):

- **Improve estuarine fish nursery habitat.** This includes increasing the area of suitable habitat for salmonids and other species, and providing unique conditions such as high-flow refugia.
- **Enable fish passage.** Tide gates prevent passage by anadromous fish when closed and may impede passage when open. Fish passage improvements increase connectivity and facilitate movement between the estuary and freshwater streams for out-migrating smolts and spawning adult salmonids.
- **Control floods.** Diked and tide-gated lowlands prevent flows from spreading onto floodplains, thereby raising water levels during floods and storm surges. Damage from floods can be reduced by increasing the area available for high-flow storage and gradual release downstream. This is usually

accomplished by removing or setting back levees. If tide gates are present, they can be managed seasonally, with longer opening periods during the winter and reduced open times in the summer to protect pastures.

- **Protect infrastructure from tidal flooding.** This involves upgrading tide gates and pertinent structures to meet current engineering and regulatory standards. Assistance for this type of project is frequently requested by local agencies and landowners due to high costs.

Table 1. Categorization of tide gate-related estuarine restoration projects	
Goals	Actions
Improve estuarine fish nursery habitat. Restoration occurs primarily in diked areas.	<ul style="list-style-type: none"> <li>• Breach or remove dikes.</li> <li>• Set back levees.</li> <li>• Remove tide gates.</li> </ul>
Enable fish passage. The stream channel is the focus of these projects.	<ul style="list-style-type: none"> <li>• Remove or upgrade tide gates.</li> </ul>
Control floods. The floodplain is the focus.	<ul style="list-style-type: none"> <li>• Manage tide gates seasonally.</li> <li>• Remove or set back levees.</li> </ul>
Protect infrastructure that is safeguarded by tide gates.	<ul style="list-style-type: none"> <li>• Upgrade tide gates.</li> <li>• Raise elevation of roads and buildings.</li> </ul>

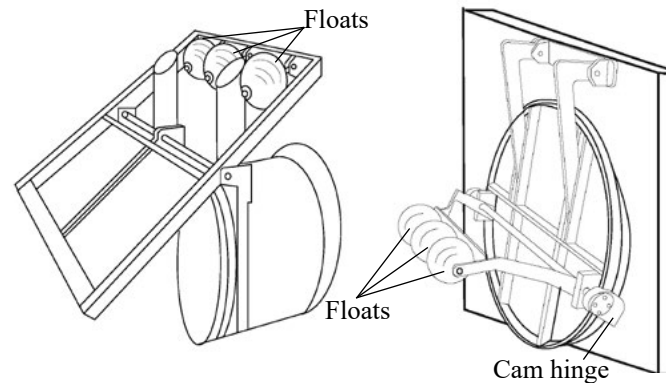
## Modern tide gate designs

One example of a newer design is the self-regulating tide gate, which has elevated door buoyancy and a set of counterbalancing arms with floats atop the gate (Figure 5a). The buoyant door floats on the incoming tide and remains open until the water elevation reaches the floats, which closes the door. These upgrades cause the door to be open most of the time.

Another contemporary design has a mitigator device attached to the tide gate door with a cam hinge that holds the tide gate open during the end of the outgoing tide and the beginning of the incoming tide (Figure 5b).

The door closes when the water level reaches the floats, causing the hinge to rotate and release the cam.

A more recent design, called a muted tidal regulator (Figure 6), holds the gate open, allowing flood tides to enter until the water level in the pool behind the gate reaches a preset surface elevation. This is the only gate control that is dependent on the water level upstream of the tide gate.



Figures 5a (left) and 5b (right): Self-regulating tide gate (left), which is default open. Top-hinge tide gate with mitigator device (right), which is open for a portion of the incoming tide.

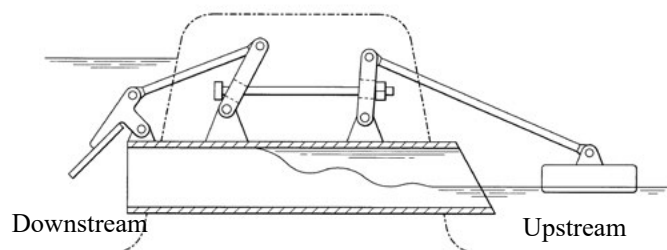


Figure 6: Muted tidal regulator. The tide gate on the estuary side (left) is controlled by the float in the upstream reservoir pool (right). Source: U.S. Patent and Trademark Office, Patent #US6988853 B1.

A fourth design uses a hybrid hydraulic-electronic control system. Such a system has been installed at the Winter Lakes restoration project along the Coquille River. This project replaced failing tide gates with seven new gates that control three units of pasture and restored wetlands that are managed differently. Of the seven gates, three are traditional side-hinged gates that operate on hydraulic principles.

The other four are vertical sluice gates similar to those used to control water in irrigation channels that are raised and lowered based on electronic controls (see photo at right). A supervisory control and data acquisition system controls gate operations, allowing for water levels in all three units to be managed independently.

A unique feature is that all gates, including the side-hinged ones, can be raised and lowered on rails. This allows the structure to be completely open during the winter when the area is flooded. This design allows for more flexibility in operations compared to traditional designs.



*Winter Lakes tide gate project. (photo courtesy of Beaver Slough Drainage District)*



*A road crosses over a tide gate at Willanch Creek. (photo courtesy of Oregon ShoreZone, CC-BY-SA)*

## Example of tide gates on Willanch Creek

The complexity of tide gates becomes apparent when evaluating tidal cycles, freshwater inflows and gate performance. To illustrate this complexity, we will describe the operation of one such system, on Willanch Creek, that has two tide gates at its mouth: one top-hinged, and one side-hinged with a muted tidal regulator that holds the gate open during flood tides until a trigger elevation of about 3 feet is reached in the reservoir pool.

Figure 7 shows the performance of the Willanch tide gates through four tide cycles. Figure 7a denotes water

surface elevation; the horizontal axis represents time, with grid lines every six hours. Labels are placed as space is available, but the patterns are consistent across the tide cycles. Tidal cycles, driven by the moon, have a twice-daily, 13-hour period. Within a daily tidal cycle there is a high-higher (HH) and a high-lower (HL), as well as a low-lower (LL) and low-higher (LH). The reservoir pool (dark line) drains when the tide gate is open, and refills with fresh water from upstream (and estuarine water when the muted tidal regulator holds the gate open). Note that the bottom of the Willanch structure is at an elevation of approximately 0.5 feet, so the

reservoir pool cannot drain below this level even when the estuary tide level is lower.

Figure 7b shows how the two gates operate during the tidal cycles displayed in Figure 7a. The orange line shows the opening angle for the side-hinged gate with a muted tidal regulator. The pink line represents the opening angle for the top-hinged gate. The tide gate doors open (Do) when the receding tidal elevation matches the reservoir's water surface elevation. The doors stay open until the rising tide matches the reservoir elevation (Dc on the top-hinged gate). A muted tidal regulator holds the side-hinged gate open (Mo) during flood tides for additional time until the reservoir's water surface elevation matches a predetermined trigger elevation (Mc) that's set to avoid unintended flooding. In this case, the muted tidal regulator gate is open approximately four hours more than the top-hinged gate; the reservoir pool refills quickly while the side-hinged gate with the muted tidal regulator is held open during the flood tide.

The green line in Figure 7c denotes the average water velocity through the side-hinged gate. Positive values represent outflows into the estuary during ebb tides. Negative values represent estuarine water entering the reservoir pool when the side-hinged gate is held open by the muted tidal regulator. As the tide gates open when the tidal level is equal to or less than the reservoir level (Figure 7a), outflow velocities increase to about 2 feet per second (fps) at their greatest, but most of the period they are around 1 fps. Tidal inflows when the muted tidal regulator holds the side-hinged gate open can rise to 3 fps, but during most of the open period they are less than 2 fps. Inflow velocities are higher than outflow velocities because the effective opening area (opening areas x opening angle) is smaller during inflows since the top-hinged gate is completely closed when estuarine water level is higher than the level of the reservoir pool.

Figure 7a

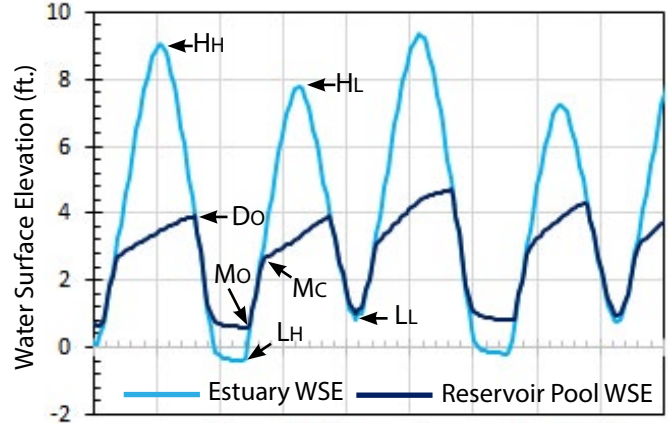


Figure 7b

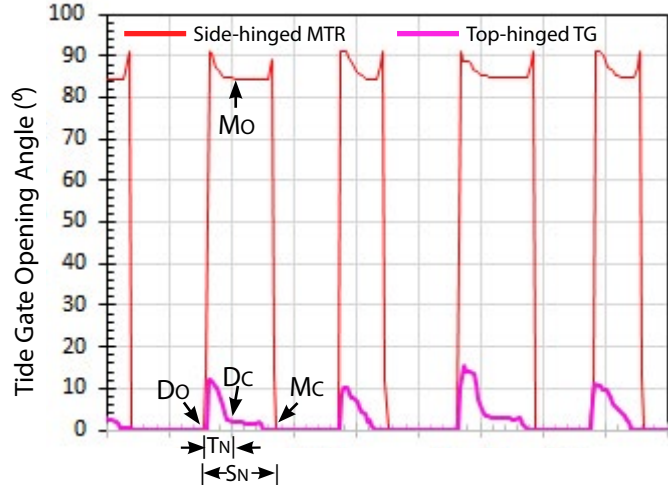
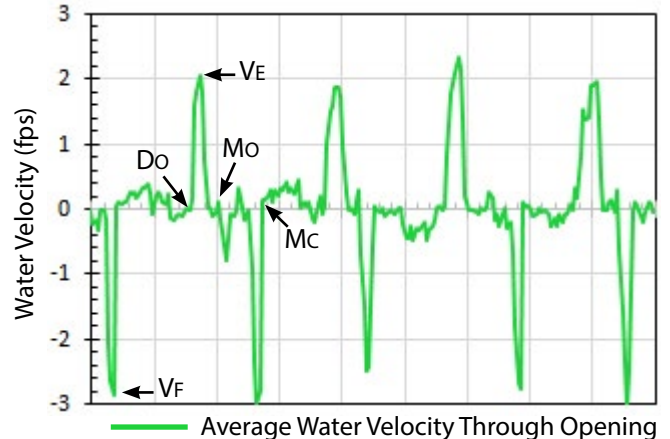


Figure 7c



Performance of the Willanch Creek tide gates in Coos Bay, Oregon, over four tide cycles. Note: Gray vertical lines represent six hours. Fig. 7a) Water surface elevations on the estuary side (light blue) and reservoir pool side (dark blue). Fig. 7b) Gate opening angles for the side-hinged gate with a muted tidal regulator (orange) and the top-hinged gate (pink). Fig. 7c) Average water velocities (green) through the side-hinged gate. Positive velocities are outflows and negative velocities are inflows. Source: Coos Watershed Association





## Fish passage at tide gates

Fish passage is affected by three interrelated factors:

- The area of the gate that is open (indicated by door angle).
- The water velocity distributions within the opening.
- The amount of time that the gate is open.

The force that is driving all three factors is the volume of water in the reservoir pool. Door opening periods are a function of how much water can pass through the effective opening and how fast the water exits. Rainfall affects how much water flows into the reservoir pool and thus can change the elevation of the reservoir.

There is a trade-off among the size of the openings, water velocities and opening periods, given the volume of water in the reservoir pool. The balancing act is to adjust the opening size to keep water velocities within the range that aquatic organisms can handle. Too large an opening will drain the upstream reservoir quickly, while too small an opening takes longer to drain and will result in higher water velocities through the opening.

In general, the gate angle should be open as close as possible to 80 degrees to reduce vortices, which are a passage impediment for some fish. The muted tidal regulator and other devices that allow estuarine water to enter the reservoir during flood tides refill the reservoir pool faster. They simultaneously provide additional fish passage into the reservoir pool during tidal flows until the muted tidal regulator's water elevation trigger is activated. During periods of summer low flows, these devices may allow the gates to open during the higher of the low tides.

Using Willanch Creek as an example (Figure 7b), it's obvious that the side-hinged tide gate has a longer opening period (SN) compared to the shorter period for the top-hinged door (TN). The side-hinged gate opens wider

(between 80 and 90 degrees) compared to the top-hinged gate (a maximum of about 15 degrees) and stays open approximately 1.5 hours longer per tide cycle due to the muted tidal regulator. The side-hinged gate is also open longer (SN) during low-lower tides (LL) compared to low-higher tides (LH) because of the longer period before the tide begins rising again. In the LL tides, the reservoir pool elevation may be controlled by where the bottom of the opening is, which is at about 0.5 feet. This doesn't affect the opening period because the rising tide still has to catch up to the bottom before the door closes, but this drop can create a passage barrier for fish moving upstream.

Velocities during the opening cycle show a distinctive pattern of a maximum outflow velocity ( $V_E$ ) of about 2 fps early in the opening sequence, when the top-hinged and side-hinged doors are near to their maximum opening angle and the reservoir pool is completely filled. As the reservoir volume lowers, the top-hinged gate almost closes, and velocities recede to about 0.5 fps during the majority of the opening period due to the lower hydraulic head. When the tide changes, the inflow flood velocities ( $V_F$ ) through the side-hinged gate are higher because the effective opening area is less since the top-hinged gate is completely closed. Maximum inflow velocities ( $V_F$ ) through the opening are about 3 fps.

Some velocities through the Willanch tide gates are considered outside the optimal for juvenile coho salmon passage velocity of 2 fps. These periods, however, represent less than one-quarter of an hour during any given tide cycle and happen just as the muted tidal regulator is closing (Mc). The daily period of opening in the Willanch side-hinged muted tidal regulator gate is approximately 50% during a tidal cycle in the winter. This meets the Oregon Department of Fish and Wildlife's criteria for fish passage. However, it is important to recognize that these patterns change by tidal cycle and seasonal inflows.

## Importance of coho life histories in understanding the effects of tide gates

To understand how tide gates can affect fish, it's important to understand movement patterns of the fish – called “life histories” – in the time leading up to their migration to the ocean. Coho salmon are the focus of most concern on the Oregon coast because they are listed as threatened under the federal Endangered Species Act.

Conventional wisdom held that coho stayed in their freshwater birthplace for their first year of life, then migrated rapidly as smolts (Figure 8a) 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). But now it's known that there are multiple coho life histories and these diverse life histories, including use of the estuary as nursery habitat, help salmon better cope with changing ocean and climatic conditions (Craig et al. 2014).

Studies in Oregon by Jones et al. (2014) in the Salmon River estuary and Nordholm (2014) in Palouse Creek, which enters the Coos Bay estuary, identified four early life histories for coho. They are:

- **Stream resident smolts** – They head to the ocean after residing in freshwater for one year. (Figure 8a)
- **Fry migrants** – Within a few weeks of emerging from gravel in the spring, they move to the estuary where they stay until they swim to the ocean the next spring. (Figure 8b)
- **Fry migrant nomads** – They follow the same pattern as fry migrants, but then return to freshwater in the fall and winter, and subsequently act like smolt migrants by moving rapidly to the ocean in the spring of their second year. (Figure 8c)
- **Parr migrants** – They spend spring and summer in a freshwater stream then migrate to the estuary in fall and winter. They swim to the ocean the next spring. (Figure 8d)

The Jones et al. (2014) and Nordholm (2014) studies documented that these life histories contribute to the spawner population as adults. These life histories also provide resiliency if conditions in streams are not suitable for rearing.



*Coho spawn on the Salmon River. (photo courtesy of Bureau of Land Management)*



Representation of the four early life histories of coho salmon recognized on the Oregon coast

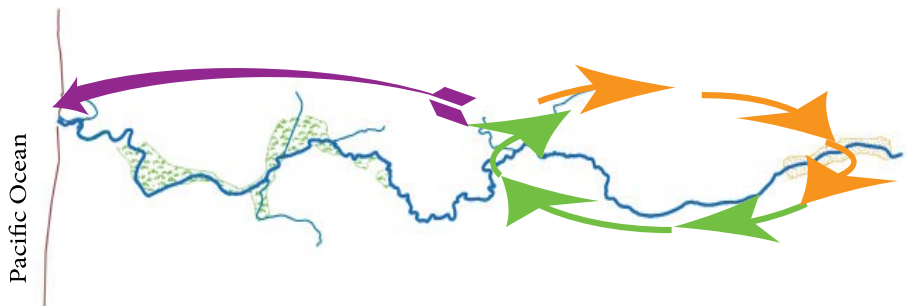


Figure 8a: **Smolt migrants** – Spend first year in freshwater stream, then migrate to estuary and ocean the next spring.

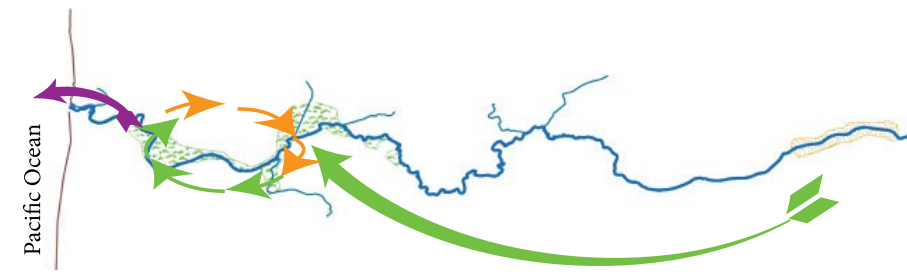


Figure 8b: **Fry migrants** – Within a few weeks of emerging from gravel in spring, they move to estuary where they stay until they swim to ocean the next spring.

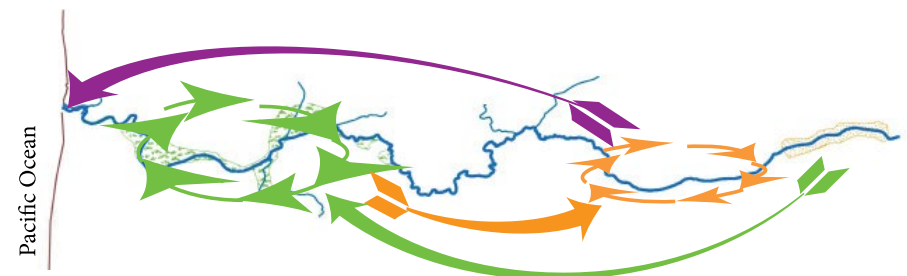


Figure 8c: **Fry migrant nomads** – Enter estuary in spring and summer. Return to freshwater in fall and winter. Re-enter estuary and ocean in spring.



Figure 8d: **Parr migrants** – Spend spring and summer in freshwater stream. Migrate to estuary in fall and winter. Move to ocean the next spring.

**Life History Legend**

**Movement Patterns**

- Resident
- Downstream Migration
- Upstream Migration

**Lifestage Color Codes**

- Age-0 Fry (Sub-yearlings)
- Age-1 Parr (Yearlings)
- Age-1 Smolts

**Habitats**

- Stream/Estuary
- Spawning
- Estuarine Wetlands

**Fry.** Emerge from spawning gravel from March through May after their egg yolk sacs are completely consumed. Stay in this stage for about three months, depending on water temperatures and food availability, until 1" to 1½" 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 of their second year.



Salmon River estuary. (photo by Pat Kight)

## Findings and recommendations

Here we present findings from our review of literature on upgrading or removing tide gates and our review of estuary restoration projects that involved tide gates in Washington, Oregon and California. We also submit recommendations for making cost-effective investments in restoring and monitoring estuaries and infrastructure that protects against floods.

This section is organized into four subsections:

1. Physical and ecological effects of tide gates.
2. Project scoping, prioritization and planning.
3. Project implementation and effectiveness.
4. Future monitoring.

The subsections are not necessarily independent of one another; several findings and recommendations apply across more than one.

### Physical and ecological effects of tide gates

**Finding:** Tide gates affect water quality and the composition of fish communities.

**Recommendation:** For fish habitat and passage, the science is clear that it's best not to use tide gates. However, this does not take into consideration land

usage and other factors. Improving tide gates and their management can ameliorate many of the adverse impacts to fish passage and water quality.

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**Finding:** The ways juvenile coho salmon move between freshwater and brackish water are more diverse than previously thought.

**Recommendation:** Incorporate opportunities for increased connectivity and fish passage into the design, installation, upgrade or removal of tide gates. Also, additional research into juvenile salmonid life histories and how they use their habitat is needed.

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**Finding:** Estuaries provide increased opportunities for juvenile coho salmon to grow.

**Recommendation:** Plan restoration actions with the expectation that all beneficial ecological effects, such as increased prey productivity for juvenile salmon, may not occur until several years after a project is completed.

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**Finding:** No tide gate is entirely fish friendly; they all have some impact on the passage of aquatic organisms.

**Recommendation:** Have realistic expectations on how upgrading or replacing tide gates may affect the passage of fish. Take into account that they may have



some negative impact on fisheries resources, at least initially. The best option for eliminating all interference with fish passage is to remove tide gates.

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**Finding:** The upgrading or removal of tide gates produces highly variable results. The design and operation of these structures are important factors, but their location in the channel network and installation are equally important.

**Recommendation:** Consider that a replacement gate, in some cases, might produce better results if installed elsewhere along a dike or in a different location in a channel. Equally important is the sill elevation of the culvert and the culvert's length, width and gradient, which may negatively impact the passage of fish through some of the best-designed gates. If the existing superstructure remains functional, an analysis should be considered to ensure that added benefits from replacing some of its components are commensurate with additional costs.

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**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 has produced mixed outcomes.

**Recommendation:** Don't expect that simply upgrading an old tide gate so that it remains open longer will solve all water quality issues. Consider that not all estuarine channels (e.g., streams, marsh channels, ditches and sloughs) have similar characteristics (e.g., discharge, tidal flushing level and sediment deposition rates). The simple replacement of a door is not going to yield the same results every time.

## Project scoping, prioritization and planning

**Finding:** Oregon's statewide land use planning framework includes requirements for the planning and management of Oregon's estuaries that need to be recognized in the scoping, design and implementation of projects.

**Recommendation:** Local conservation organizations should work with county planners in developing strategies. The collaborative process leading to the ongoing revision of the Coos Bay estuary management plan by Coos County and the Partnership for Coastal Watersheds can serve as a model and pilot for the revision of other coastal estuary management plans. Additionally, as estuary management plans are revised, OWEB should work with the Oregon Department of Land Conservation and Development to identify processes that facilitate incorporation of considerations associated with the upgrade or removal of tide gates.

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**Finding:** An overall strategy for upgrading tide gates and restoring estuaries needs to be consistent with state and federal regulations and plans.

**Recommendation:** The [Oregon Conservation Strategy](#) provides the best model on how to incorporate restoration and land-use planning processes.

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**Finding:** We identified four categories of goals for estuary restoration among the 45 projects we evaluated (Table 1).

**Recommendation:** Use these categories to provide a basis for identifying a continuum of project types and their benefits. Some projects might focus solely on one goal and have neutral or adverse effects on other goals. Other projects may provide benefits for multiple goals, with or without adverse effects on other goals. It would be possible to flesh out this continuum using the restoration projects identified in the OWEB report as well as information such as permits and watershed assessments.

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**Finding:** Projects to restore estuaries increasingly have multiple goals providing joint benefits.

**Recommendation:** Recognize that projects that can demonstrate some combination of water quality improvement, fish recovery, agricultural conservation, flood protection, climate change resilience or recreational benefits are more likely to be locally acceptable and fundable, but are also more complex and require coordinated management.

**Finding:** Oregon could benefit from a comprehensive framework for restoring estuaries.

**Recommendation:** Develop a comprehensive approach to estuary restoration in Oregon that acknowledges diverse goals and benefits for stakeholders while articulating a common vision for human uses of estuaries, floodplains and coastal wetlands. Oregon's business plan for coast coho has the potential to accomplish this.

**Recommendation:** Explore the potential for a coast-wide plan for restoring estuaries and renovating flood-control structures in Oregon that establishes a framework for prioritizing projects and coordinating implementation of them. Regional frameworks in Washington (e.g., the Skagit Delta tide gate and fish initiative; the Skagit farms, fish and flood initiative; and [Floodplains by Design](#)) are available as models.

**Finding:** Projects to restore estuaries increasingly include the sometimes controversial acquisition of the lands to be restored, a trend that is likely to continue.

**Recommendation:** Work with stakeholders to develop an integrated approach for identifying lands that are suitable for acquisition and those that are best retained and managed as working landscapes. The Skagit Delta in Washington provides an excellent example of this approach.

**Finding:** Funds for mitigation and environmental damage are underused for estuary restoration in Oregon.

**Recommendation:** Explore options for using mitigation funds to restore estuaries. This may involve making new rules or changing statutes.

**Finding:** Hydrodynamic modeling is critical to the prioritization, planning and monitoring of projects, but there's insufficient bathymetric and other data to support construction of such models.

**Recommendation:** Increase support for modeling the hydrodynamics of options for estuary restoration and their potential outcomes. Explore the potential to apply techniques and lessons learned from the Skagit Delta hydrodynamic modeling project to the restoration of

estuaries in Oregon. OWEB should work with partners to acquire bathymetric data and hydrodynamic modeling for high-priority estuarine restoration areas.

**Finding:** The benefits and effects of tide gates are related to their location.

**Recommendation:** To maximize benefits for salmonids and potentially mitigate flooding, prioritize projects where the gates are at tributary creeks or the mouths of streams or rivers. Ensure that suitable nursery or off-channel refugia habitat is available or that such habitat can be created if it's not available.

**Finding:** There's a dearth of reports on the likely costs and benefits of various types of tide gate and estuary restoration projects. However, we found sufficient data on the projects we reviewed that would allow estimates to be developed.

**Recommendation:** We encourage funders to invest in this area.

## Project implementation and effectiveness

**Finding:** The best restoration results have been reported for large-scale and comprehensive restoration projects and not solely upgrades to tide gates.

**Recommendation:** Favor comprehensive restoration projects that aim to reestablish connectivity and ecosystem-level processes over those that focus on changing one single factor such as the number of fish that pass through a tide gate or the quality of the water above a gate.

**Finding:** Upgrading a tide gate is only the first step in the process of improving ecological conditions and fish migration corridors.

**Recommendation:** Take into account the 1.) gate opening time and width, 2.) culvert width, 3.) invert elevation and 4.) upstream pool depth at high tide (Lyons and Ramsey 2013).



**Recommendation:** Tide gates should be managed seasonally to ensure that fish passage requirements, water temperatures, and dissolved oxygen are suitable for juvenile salmonids.

**Recommendation:** Post-restoration management plans should be based on knowledge gained from research and monitoring and should be flexible enough to address unforeseen effects or outcomes.

## Future monitoring

**Finding:** Information on the effects of upgraded tide gates is limited, making it difficult to build support for these renovations. One reason for this lack of information is that practitioners have insufficient support to prepare the results of their monitoring for peer-reviewed journals.

**Recommendation:** Encourage people who are monitoring estuary restoration projects to submit their findings to peer-reviewed journals and disseminate their findings using a variety of outreach tools.

**Recommendation:** Provide funding, incentives and technical assistance to enable people who are monitoring OWEB estuary restoration projects to submit their findings to peer-reviewed journals.

**Finding:** Long-term monitoring is critical, but it requires sufficient resources and time, and support is usually limited. Also, there is no comprehensive strategy in Oregon for monitoring projects that aim to restore estuaries.

**Recommendation:** Develop an integrated and cohesive strategy for monitoring estuary restoration projects. Start with a rigorous analysis of what questions the monitoring should answer. Monitoring should be conducted on the diversity of expected project types, but within those types only a few carefully selected sites should be monitored over time (e.g., 10-20 years).

**Recommendation:** Institutionalize and standardize existing monitoring protocols so existing data can be compared to new data. Review monitoring protocols used by other programs in the Pacific Northwest (e.g., the Columbia estuary ecosystem restoration program) to inform development of a more standardized and cohesive approach for monitoring OWEB-funded estuary projects.

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## Resources

Video: Oregon's Working Waterfront Tour: Tide Gates (produced by Oregon Sea Grant and featuring Jon Souder): <https://youtu.be/oROqhrXYFfs>.