Oregon’s Tide Gate Optimization Tool

SUPPORTING DECISIONS TO BENEFIT NATURE AND PEOPLE

The Nature Conservancy

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Cover photo: Stakeholders discuss a newly constructed tide gate. (Photo by Gail Oberst, purchased from Capital Press.)

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Executive Summary

Estuaries are exceedingly valuable for the biodiversity they harbor and the ecosystem services they provide to resident and migratory species. Despite their enormous importance and value to both biodiversity and humans, estuaries represent some of the most degraded habitats and continue to be stressed by threats from human activities on the ocean, on land, and in freshwater.

Over time thousands of acres on the Oregon Coast have been drained, and infrastructure—such as tide gates, levees, and channels—has been built to control the tide, reduce flooding, and drain the land. This infrastructure supports the use of roads, buildings, and productive working lands. But it can also prevent salmon, lamprey, and other aquatic species from accessing the historical streams and floodplains that are vital for their foraging, spawning, refuge, and rest, as well as transition zones between freshwater and marine ecosystems.

Much of the tide gate infrastructure along the West Coast is reaching its maximum life expectancy. A challenge facing landowners interested in replacing their tide gates is that new devices are expensive. Modern construction materials, coupled with the sophisticated designs necessary to meet current fish passage regulations, are not affordable to many landowners. At the same time, government agencies and private organizations interested in conservation and wildlife, such as salmon, are eager to help upgrade and modernize tide gate infrastructure.

The Nature Conservancy (TNC) is interested in solutions that allow for the productive use of coastal lands while providing access to habitats needed for wildlife to thrive. Over the past few years, TNC has taken a widely used fish passage optimization model (O'Hanley 2014) and applied it in a new and innovative way to assist tide gate removal and replacement decisions.

After the initial test runs in the Coquille and Coos estuaries, TNC sought to further develop the tool to add functionality beyond fish habitat gains and provide more information to a larger set of stakeholders in support of tide gate decision-making. In this white paper, TNC describes the information-gathering step to learn about stakeholder interests, the investigation to identify relevant spatial datasets to support additions to the tool, and the enhancements added to provide a useful decision-planning tool to a range of stakeholders.

TNC appreciates the opportunity to create and share the tide gate optimization tool with members of the Oregon Tide Gate Partnership. TNC plans to continue to work with tide gate stakeholders to disseminate the tool and provide resources for using the tool and understanding its products.

Preface

The Nature Conservancy (TNC) is a science-based, nonpartisan organization committed to conserving the lands and waters on which all life depends. In Oregon, TNC has over 80,000 supporters and members in every county. Based in communities around the state, we manage lands and waters in varied ecosystems and partner with ranchers, farmers, fishers, and timber and environmental interests on some of the most challenging conservation issues facing people and nature.

Around the world, TNC addresses the most pressing conservation threats at the largest scale and has built a record of success since our founding in 1951, which includes the following achievements:

- Protecting more than 125 million acres of land and thousands of miles of rivers worldwide and operating more than 100 marine conservation projects globally
- Advancing conservation in 72 countries spanning six continents and protecting habitats from grasslands to coral reefs, from Australia to Alaska to Zambia
- Conducting fisheries projects from the West Coast to Chile to Indonesia and bringing a collaborative, science-based approach to bear on the most critical fisheries issues facing our globe

For their expertise and contributions in preparing this white paper, TNC extends special thanks and appreciation to the many members of the Oregon Tide Gate Partnership, staff from all the coastal watershed associations, the Oregon Department of Fish and Wildlife, U.S. Natural Resources Conservation Service, Nehalem Marine Manufacturing and Porior Engineering, Oregon Farm Bureau, Oregon Cattlemen's Association, Oregon Dairy Farmers Association, Oregon Department of Land Conservation and Development, TerrainWorks, Wild Salmon Center, Institute for Applied Ecology, and Jesse O'Hanley. TNC also recognizes Tracey Westfield from Horizon26 for editing this paper, as well as the Wild Rivers Coast Alliance, Oregon Watershed Enhancement Board, and many private donors for generously supporting this project.

Introduction

Estuaries

Estuaries are exceedingly valuable for the biodiversity they harbor and for the ecosystem services they provide to resident and migratory species. The essential services of estuaries include provision of food, buffering from extreme natural forces, and refuge from predation. Estuaries act as a filter for the nutrients flowing through a watershed down to the ocean. The primary productivity in estuary habitats is among the highest of any on Earth. Both visible and microscopic plants produce a tremendous amount of carbon material from photosynthesis, resulting in fertile soils, abundant invertebrates, and robust plant life that serves as the base of an incredibly productive food web for fish and wildlife.

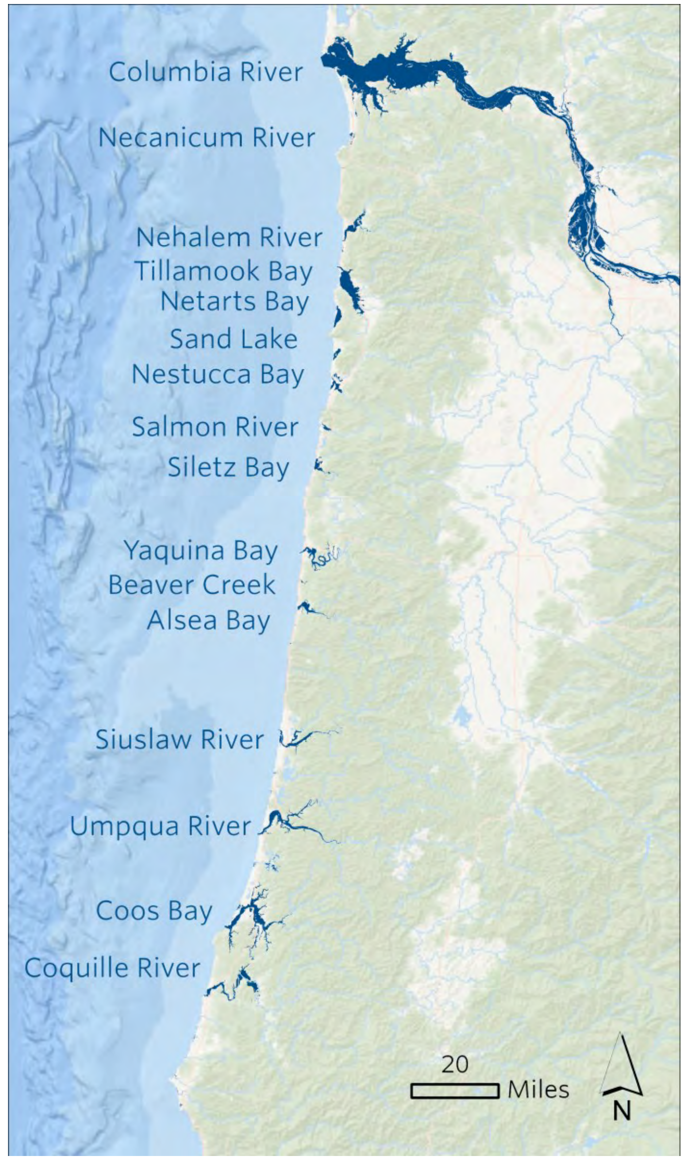
Estuaries also offer habitat complexity and diversity—open channels, tide flats, eelgrass beds, salt marshes, tidal swamps, freshwater marshes, mudflats. They allow wildlife, fish, and invertebrates, such as crab and shrimp, an opportunity to move between habitat types to hide, rest, and forage.

Oregon's most popular and lucrative commercial and recreational species depend on estuaries as nursery habitats, including coho salmon, Chinook, Dungeness crab, black rockfish, copper rockfish, and kelp greenling.

Estuaries in Oregon

Along the Oregon Coast, there are 22 large estuaries (Figure 1) and over 40 smaller ones. Each of Oregon's estuaries is truly unique and influenced by dynamic forces, including tides, precipitation, freshwater runoff, evaporation, and wind. Some of Oregon's estuaries extend inland a short distance, while others stretch inland for up to 30 miles. Certain estuaries are open to the ocean year-round, others seasonally. Some estuaries are large bays, such as Tillamook Bay or Coos Bay, and some have rivers with wide meandering valleys of habitat. Others appear to simply drain into the sea. The wide range of features and structures within and among estuaries plays a critical role in the life cycle of many species.

Figure 1. Oregon's 22 large estuaries represented by the 15 water bodies they are associated with. (Base map by CHS, Esri, GEBCO, DeLorme, NatureVure.)



Conversion of Oregon's Estuaries

Despite their enormous importance and value to both biodiversity and humans, estuaries represent some of the most degraded habitats and continue to be stressed by threats from human activities on the ocean, on land, and in freshwater. A major threat to fish and shellfish is loss of habitat, particularly the seagrasses and tidal wetlands that form prime nursery habitats for juvenile species.

Other threats to estuaries are land conversion, altered and blocked tidal flow, loss of habitat complexity, altered freshwater inputs, water quality degradation, increasing land development, invasive species, oil spills, and climate change. Climate change includes factors such as the loss of wetlands due to sea level rise, alteration of hydrology, increases in erosion and salinity, changes in storm patterns, and ocean acidification.

Historically, Oregon had over 228,000 acres of estuarine habitats (Scranton 2004), within which tidal wetlands covered 38,052 acres. With approximately 54% loss, today, tidal wetlands cover just 17,525 acres (Brophy 2019). Loss of estuarine and tidal wetland ecosystems is considered a key limiting factor for the survival of salmon, juvenile marine fishes, and migratory shorebirds and waterfowl. Oregon Coast coho salmon, for example, once numbered up to 2 million adult salmon but declined by 92% to just 20,000 adult salmon by the 1990s—a decline that coincided with habitat loss. The U.S. National Oceanic and Atmospheric Administration's (NOAA's) 2016 Endangered Species Act recovery plan for Oregon Coast coho salmon cites degraded habitat, particularly access to estuary rearing habitat, as the primary factor limiting recovery (NMFS 2016).

Tide Gates: Fish Passage Barriers

Over 100 years ago, Oregon Coast landowners sought to drain water from the lands and control the rivers and tides to convert estuarine lands into productive farms, coastal cities, and other businesses. The most frequently used infrastructures were levees, culverts, and tide gates. Many of the tide gates are still in use (Figure 2) and are simple structures, consisting of a chain holding a wood or

Figure 2. An older style of tide gate found in Oregon. (Photo by Coquille Watershed Association.)

metal door over a culvert. The devices rely on gravity and water pressure differences that keep the tide gate closed most of the time.

Much of the tide gate infrastructure along the West Coast is reaching its maximum life expectancy. In Oregon, inventories have identified over 1,000 tide gates, and recent surveys are finding more. Much of this infrastructure needs repairs or upgrades to meet modern fish passage standards. Poor-performing tide gates inhibit fish passage to significant amounts of stream miles and tidal wetlands. To lessen impacts on salmon and other species, these aging tide gates and ones utilizing old technology must be retrofitted to be fish passage compliant or completely replaced at considerable expense to the landowner. Removing, repairing, and replacing tide gates can allow regular water exchange, increased connectivity for fish, and improved water quality while remaining compatible with current land uses.

Optimizing Among Tide Gates

Over the past few years, TNC has taken a widely used optimization modeling approach for fish passage barriers (O'Hanley 2014) and applied it in a new and innovative way to assist in tide gate replacement decisions. Originally tested in the Coquille and Coos estuaries, the tide gate optimization tool focused on habitat gains for salmonids balanced with the costs of tide gate and culvert replacements and other factors.

The optimization tool is run across a range of dollar amounts to identify the optimal set of barriers that, if removed, replaced, or repaired, will achieve the largest habitat gains for the least cost. The optimization tool is designed to be easy to use, transparent, and repeatable as tide gates are replaced or additional information is gathered. The optimization tool can be applied consistently across any estuary along the Oregon Coast. The goal is to have a decision support tool that can inform decision-makers when evaluating potential net gain, estimating return on investment (ROI), fundraising, budgeting, and exploring spatial patterns.

After the initial test runs in the Coquille and Coos estuaries, TNC sought to further develop the tool to add functionality beyond fish habitat gains and to identify solutions that allow for the productive use of coastal agricultural lands and other community goals while providing access to habitats needed for wildlife to thrive. Through the generous support of the Oregon Watershed Enhancement Board, this project has expanded the tool's options to provide more information to a larger set of stakeholders in support of better tide gate replacement decision-making. In this white paper, TNC describes the information-gathering step to learn about stakeholder interests, the investigation to identify relevant spatial datasets to support additions to the tool, and the enhancements added to provide a useful planning tool to a range of stakeholders.

Stakeholder Outreach

Stakeholder outreach was conducted in two phases to understand the needs of the different stakeholders involved in tide gate decision-making and planning. In the first phase, the Oregon Watershed Enhancement Board facilitated one-on-one and group discussions with the relevant agencies and organizations involved in tide gate decision-making (e.g., permitting, funding, restoration, agriculture, infrastructure, compliance). These conversations sought to gather feedback and guidance on features that could be added to the optimization tool.

> TNC conducted a systematic and rigorous process that involved research, vetting and outreach to partners, interviews, and consultations with experts.

Next, a stakeholder outreach survey was distributed in February 2020 to 248 people, including everyone on the Oregon Tide Gate Partnership's communications list, numerous U.S. Natural Resource Conservation Service (NRCS) employees in Oregon, members of the three West Coast Fish Habitat Partnerships, and other tide gate stakeholders as recommended by survey respondents. Sixty-one people (25%) responded to the survey. Of the respondents, 90% said they work with tide gates, 77% said a tide gate optimization tool would be helpful, and 82% said they would be interested in learning how to use the tool.

Respondents also expressed a strong interest in how tide gates can protect infrastructure. This included the protection of private infrastructures, such as agricultural land, farm structures, and houses, as well as the protection of public infrastructures, such as roads and municipal buildings. Other interests that emerged from the feedback included the role of tide gates in flood risk reduction, tide gates' effects on fish and wildlife (Figure 3), water and habitat quality, and future climate change and sea level rise impacts.

When the survey closed, TNC analyzed the responses for content and followed up with staff from the NRCS, U.S. Department of Agriculture (USDA), Oregon Department of Fish and Wildlife (ODFW), Tillamook County, Oregon Farm Bureau, Oregon Department of Land Conservation and Development (DLCD), TerrainWorks, Wild Salmon Center, and Institute of Applied Ecology to better understand the details of the responses.

Following the stakeholder outreach process, the next step in the enhancement process was to identify and evaluate available spatial datasets capable of representing the stakeholder's interests.

Dataset Investigation

TNC's tide gate optimization tool relies on various environmental and social datasets that describe the complexities of the Oregon Coast and lower Columbia River. TNC conducted a systematic and rigorous process that involved research, vetting and outreach to partners,

Figure 3. Fish monitoring. (Photo by Chris Crisman.)

interviews, and consultations with experts in these topic areas. The datasets ultimately selected for the optimization tool were chosen based on public availability, coverage, spatial scale, and quality. An effort was made to select datasets that align with those already used by partner agencies and stakeholder groups when appropriate.

In the end, datasets for the following categories were used:

- Fish Habitat
- Agricultural Land
- Private Infrastructure
- Public Infrastructure
- Climate and Sea Level Rise

A detailed description of the investigation and datasets that were considered can be found in Appendix A.

Construction of the Optimization Tool

This section of the white paper focuses on the methodology that TNC used to construct the tide gate optimization tool. In simple terms, the tide gate optimization tool balances the potential gain in benefits against the costs necessary to achieve those benefits. The tool is designed to answer the following question:

> What is the set of tide gates and culverts in the watershed(s) that, if removed or replaced, would maximize net gains for the *benefit targets* of interest, subject to a limited financial budget?

> The tide gate optimization tool balances the potential gain in benefits against the costs necessary to achieve those benefits.

Throughout this paper, any attribute that can benefit from tide gate removal, repair, or replacement is referred to as a benefit target.

For the optimization tool, TNC selected OptiPass (O'Hanley 2014), a software package explicitly designed for optimizing the modification of artificial barriers in a stream network that block or otherwise reduce the dispersal of anadromous fish. The software integrates information on barrier passibility, replacement cost, and potential upstream habitat gain for one or more fish species to identify cost-efficient passage improvement strategies. OptiPass is explicitly designed to consider the spatial structure of barriers and interactive effects of passage improvement on longitudinal connectivity (O'Hanley 2014). Others who have used the OptiPass optimization algorithm (e.g., FISH*Pass* 2021; Maitland 2015; Moody et al. 2017; Pilson and Maser 2012) have focused exclusively on instream barriers. TNC extended the application of the approach to include tide gate barriers and associated off-channel flooded habitats in the optimization decision framework. This is the first-time estuaries and their associated infrastructure have been part of any optimization approach.

Three primary inputs are required to construct a tide gate optimization tool in OptiPass: (1) the location of barriers, including tide gates and culverts; (2) the estimated cost to replace each barrier; and (3) quantified measures of the potential benefit for each benefit target at each barrier.

Barrier Locations

The first input required for the optimization tool is an inventory of the location of barriers. Numerous efforts have documented and assessed Oregon's stream barriers to fish passage, including the *Assessment of Road Culverts for Fish Passage Problems on State- and County-Owned Roads* (ODFW 1999), *Oregon Fish Passage Barrier Data Standard* (ODFW 2010), and statewide *Fish Screening and Passage Program: Fish Passage Priority List* (ODFW 2013). In 2019, the Oregon Tide Gate Partnership compiled disparate datasets held by various partners into the first-ever coastwide tide gate inventory. This publicly available dataset includes point data for known tide gates as well as possible tide gate locations documented in earlier sources. In addition, the Institute of Natural Resources refined the location of tide gates based on high-resolution imagery to remove duplicate records, map tide gates that had been removed or were no longer present, and create the geodatabase with consistent information for all of Oregon's known tide gates. TNC is using the most up-to-date datasets available to construct the tide gate optimization tool. Efforts are underway in various watersheds to continue to update and validate tide gate locations.

Barrier Replacement Costs

The second essential input to the optimization tool is the cost for barrier replacement. TNC included in the optimization tool estimates of barrier replacement costs for each individual tide gate and upstream culvert. To generate estimates for tide gate replacement costs, TNC consulted with experts Leo Kuntz of Nehalem Marine Manufacturing and Don Porior of Porior Engineering. Together, the two experts provided actual project cost histories and recommended a costing approach reliant on 100-year peak flows to suggest the number, size, and configuration of replacement tide gates, thereby enabling the costing of the replacement and installation of the entire structure. Peak flow and cost associations were placed into categorical bins to account for design uncertainty. The replacement solutions ranged from a single 4-foot tide gate to multiple tide gates measuring 8 feet by 10 feet. And associated modification costs ranged from \$60,000 to \$1,500,000. Tide gate costs include all costs associated with installing appropriately sized, new Muted Tidal Regulator gates.

Similarly, the cost to replace an upstream culvert is based on the estimated diameter of a properly sized culvert for the drainage area. Replacement culvert size and cost associations were also binned to account for uncertainty.

These cost estimates are based on real projects and are relative to one another; however, they are not meant to be the total cost for a project. After projects are identified and move forward into a design phase, actual engineering costs still need to be calculated. Additionally, the cost estimates have omitted other costs associated with replacement, such as site planning, channel construction, and habitat restoration activities.

Further details regarding costs and methods for generating costs can be shared upon request.

Benefit Targets

The third key input to the optimization tool is benefit targets, selected by the user based on factors influencing their tide gate replacement decisions (see the Decision Context section below). A description of each benefit target and the datasets selected to represent each one in the optimization tool are described here. For detailed information on each of the benefit targets and associated datasets, see Appendix A.

The structure of the optimization tool requires that the amount of each benefit target be measured for each barrier. To quantify the area of influence for a tide gate, TNC first used the watershed above the tide gate to delineate the full area associated with that tide gate, including any upstream tributaries. That method allowed the area for one tide gate to be separated from the area of a neighboring tide gate. Once the upstream watershed is delineated, the potential area of tidal inundation within the watershed is used to define the potential area of influence behind the tide gate. This inundation area represents (a) the amount of potential off-channel habitat that is important as rearing and overwintering refugia for juvenile salmonids and (b) the area at risk to land and infrastructure inundation should a tide gate fail.

Potential tidal inundation is defined with the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) estuary extent boundary (Brophy et al. 2019, PMEP 2017). The PMEP estuary boundary is a conservative estimate of the maximum extent of tidal influence since it does not include the additive influence of river flow or storm surges. The included freshwater tidal zones combined with the documented accuracy and spatial coverage made the PMEP estuary boundary the best choice for estimating the expected inundation area for all the benefit targets.

Figure 4. Farm on the Youngs River. (Photo by Columbia River Estuary Study Taskforce.)

Fish Habitat

Fish habitat quantity is described with two forms of habitat important to five fish species (coho, chum and Chinook salmon, steelhead, and coastal cutthroat trout): (1) the area of tidal inundation and (2) the length of fish habitat in the stream network above the tide gate. Freshwater streams above the estuary increase the ecological value of an area for both adult and juvenile salmonids, allowing fish to escape high-water events and potentially providing spawning and rearing areas. The length of upstream fish habitat available following tide gate or culvert replacement is based on species distribution (ODFW 2014) and fish presence (ODF 2010) data, chosen as surrogates for stream habitat since the state of Oregon lacks a comprehensive database of stream habitat by fish species.

The two components for fish habitat quantity are attributed to barriers differently. The area of tidal inundation is measured for each tide gate but not relevant to stream barriers. Conversely, the length of stream habitat above a barrier to the next barrier or headwater is measured for each culvert but not relevant to tide gates.

Although there is stakeholder interest in fish habitat quality, no suitable spatial data are currently available at both the coastwide extent and the appropriate scale to integrate into the optimization tool. This situation will hopefully change in the coming months as ODFW works to develop a habitat quality metric. TNC has been in regular contact with the ODFW staff developing its product to ensure that the information can be readily incorporated into the optimization tool once available.

Agricultural Land

If tide gates fail, roads, businesses, homes, and agricultural lands (Figure 4) become more vulnerable to flooding and intense winter storms. Agricultural land area is defined for use in the optimization tool with the NRCS Farmland Classification (Soil Survey Staff, NRCS 2019). The classification describes 10 classes (Table A1), many of which are sparsely distributed across the coastal estuaries. Due to this sparse distribution, the datasets were aggregated into two classes: farmland and not farmland. The approach considers all coastal farmland as equal and does not assign a value to farmland.

Private Infrastructure

The location of buildings is represented by the Microsoft Building Footprints (Microsoft 2018) dataset. Microsoft Building Footprints provides location and general footprint shape but no distinction for private or public ownership, building type, or other attributes. When the optimization tool is run to include both agricultural land and buildings as benefit targets, it is assumed that the buildings occurring within the area influenced by a tide gate are part of the agriculture operation, such as homes, barns, and outbuildings.

It is important to note that the optimization tool's analysis identifies all the buildings located within the area of influence of each tide gate. It does not differentiate between various land heights within the influence of each tide gate. As a result, some structures may be located on higher ground relative to water levels. This analysis also does not differentiate among the degrees of flooding risk to structures.

Public Infrastructure

A subset of the Oregon Incidence Response Information System (OR-IRIS geodatabase) is used to represent the location and type of public-use infrastructure. The OR-IRIS geodatabase was prepared by the Preparedness Framework Implementation Team (Prep-FIT) to "aid the emergency response community in developing data systems to support their work in planning and responding to incidents in a safe, effective, and efficient manner" (Prep-Fit 2015). The full dataset was reduced to those elements potentially impacted by tidal flooding, representing elements across three themes: emergency response resources, transportation and infrastructure, and potential toxic sources (Table A2). Other than linear roads and railways, all other elements are point locations.

As with the buildings benefit target, the optimization tool's analysis does not distinguish between structures elevated above water level or assess flood risk. In addition, the tool does not measure the degree of risk to public safety, human health, or the local community. Instead, it is an enumeration of infrastructure that may be impacted by tidal flooding if an existing tide gate and other water control structures are not functioning properly.

Climate and Sea Level Rise

One of the primary themes to emerge from the survey was an interest in considering future climate predictions. Climate change is expected to impact coastal communities in a variety of complex and interacting ways. Sea level rise and the increased frequency and magnitude of tidal flooding are of particular concern since these impacts will most directly influence tide gates and each benefit target. However, estimating future sea level rise is challenging because predictions vary by location, the time frame of interest, and the climate modeling scenario being considered. In addition, coastal ecosystems and communities will experience the effects of sea level rise differently. After consideration, two sea level rise elevations were chosen from a variety of sources to differentiate the anticipated changes in fish habitat from changes to agriculture, buildings, and public-use structures that could be expected to occur over the coming decades.

In terms of salmonids, sea level rise is expected to change estuarine habitat availability and complexity, alter sedimentation rates, influence water circulation patterns, and shift the salinity gradient. Of these mechanisms, datasets describing predicted changes in habitat availability are the most readily available and most appropriate for modeling in this context. Recent research along portions of the Oregon Coast suggests that a sea level rise scenario of 4.7 feet by 2100 would lead to distinct changes in tidal wetlands as these ecosystems migrate upslope (i.e., landward migration zones, LMZs; Brophy and Ewald 2017). These areas serve as ecosystem gradients between tidal wetlands, nontidal wetlands, and upland habitats and thus indicate an approximate boundary for understanding future connectivity for fish habitat. To most closely capture the projected 4.7-foot increase by 2100, NOAA's 5-foot sea level rise extent (NOAA 2017) was chosen for the optimization tool to represent this shift. This dataset has consistent coverage throughout the state.

The Oregon Coastal Management Program (OCMP) completed *Sea Level Rise Exposure Inventory for Oregon's Estuaries* in 2017 to establish a dataset for conducting vulnerability and risk assessments for future flooding along the coast. Their dataset extends projected sea level rise landward by adding probability estimates for extreme water levels (NOAA 2013) in 21 of Oregon's estuaries. The water surface elevation for a 50% chance flood (two-year recurrence interval) in 2100 (7.2 feet on average) was chosen as the sea level rise inundation extent for the benefit targets of agricultural land and infrastructure. This elevation reflects an increase in water level due to sea level rise (4.7 feet) with an additional 2.3 to 2.7 feet flood event height (flood elevations vary by estuary). The OCMP dataset for the scenario of a 50% chance flood in 2100 does not include the Columbia River and some smaller estuaries, so the NOAA 7-foot sea level rise layer (NOAA 2017) is used as a supplement for the Columbia.

Interpretation of Optimization Results

With earlier versions of the optimization tool, TNC staff prepared and ran the tool in-house and prepared the results with watershed council staff for a given basin. The optimization tool has been expanded and enhanced per stakeholder interests, so TNC is building in flexibility for users to choose what factors to include, ensuring results reflect their interests in tide gate replacement decision-making.

> The tool and underlying data allow decision-makers to better understand the ROIs for different budget scenarios.

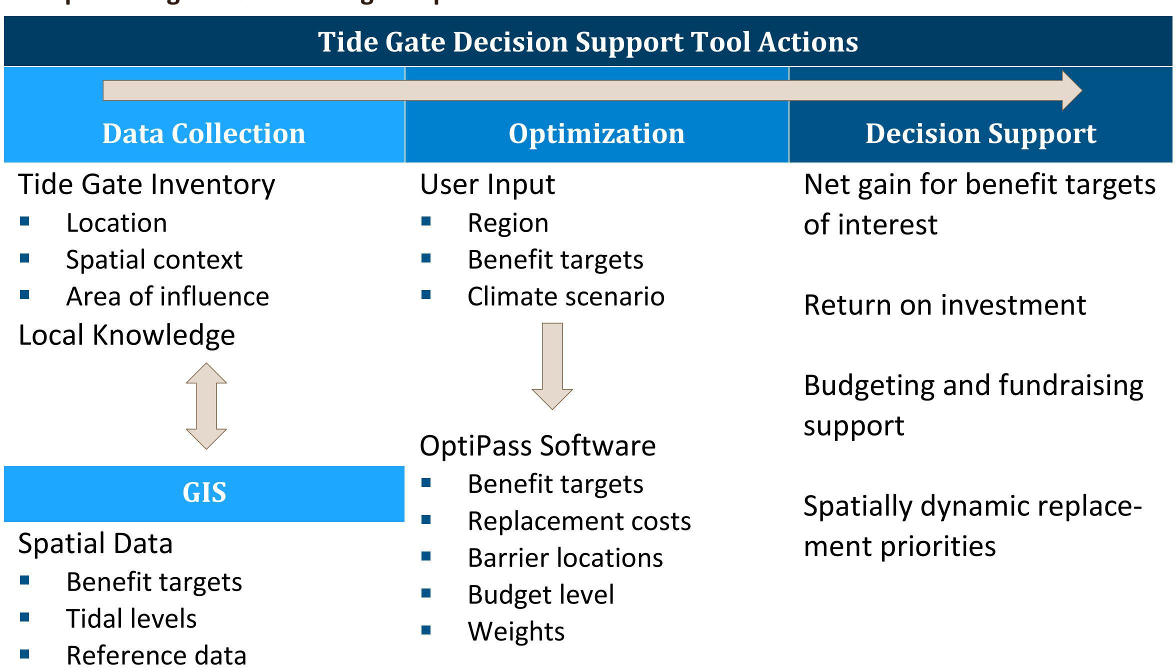
TNC intends to run the optimization tool for all of Oregon's major estuaries between now and 2023 and provide the resulting resource to the local watershed councils and other interested parties. In addition, TNC will create a user guide and training sessions for individuals and organizations interested in learning how to run and use the outputs of the optimization tool themselves.

Decision Context

The tide gate optimization tool is intended to assist user groups, including private landowners, watershed councils, funding agencies, and resource planners, by providing information useful for launching dialogues and for developing and implementing tide gate replacement strategies. The optimization tool also allows users to consider a range of benefit targets under current and future climate scenarios across various spatial scales. The results of optimization tool runs can be especially useful to project planners and decision-makers when evaluating potential net gains in benefit targets, estimating ROI, fundraising, budgeting, and investigating spatial patterns.

The optimization tool involves a flow of data between three actions: (1) preparing input data from field inventories, local knowledge, and a geographic information system (GIS); (2) constructing and executing optimizations; and (3) interpreting and integrating results in decision processes. A conceptual diagram of the tide gate optimization tool (Figure 5) helps illustrate the components of the tool and how they interact.

Figure 5. Conceptual diagram of the tide gate optimization tool actions.



To assist in removal or replacement decisions driven by different desired outcomes, the tool is designed for users to specify one or more benefits as targets of interest in the decision context. Flexibility is built into the tool to allow for the mixing of multiple benefit targets to achieve outcomes for both people and nature.

For added refinement, the user can emphasize the importance of one benefit target over another by specifying weights—that is, numerical multipliers added to the algorithm to express relative importance. The user can also focus replacement decisions on the current time period and tidewater levels or on longer-term planning, looking to the future with projected sea level and inundation changes.

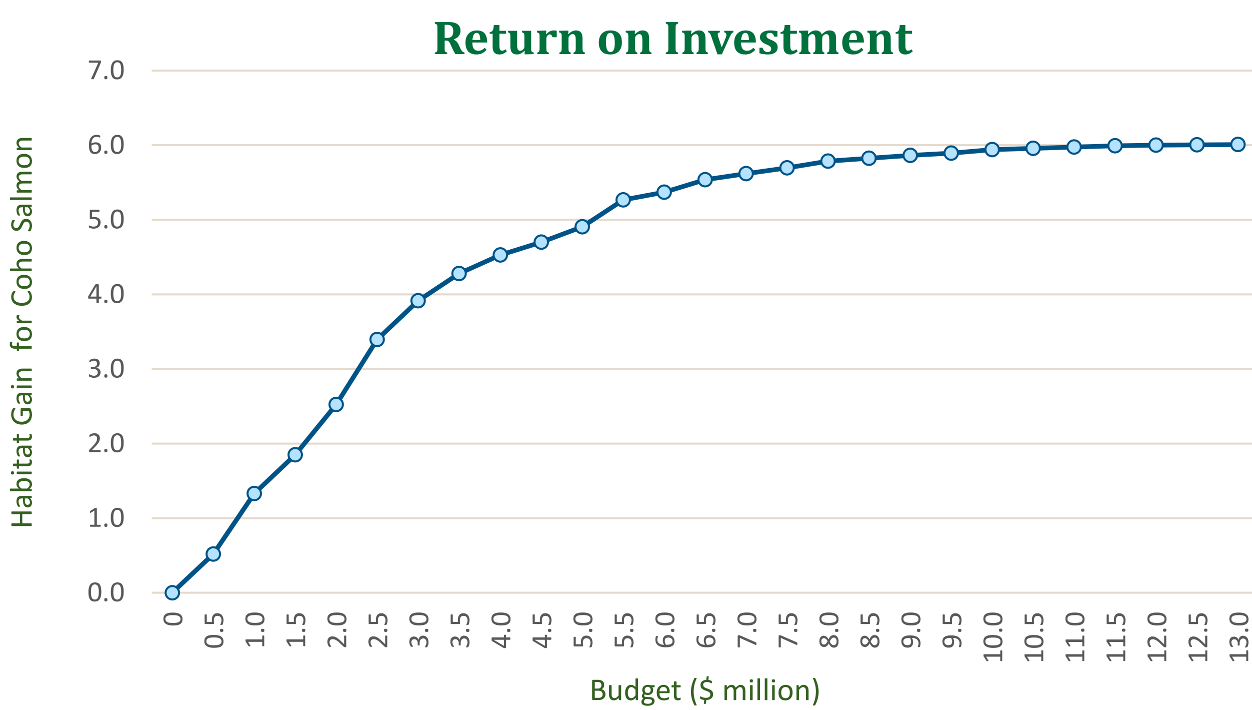
Furthermore, the user is given two additional options for defining the decision space. The geographic scope of interest is definable as a single basin, a broader coastal region of multiple basins, or eventually, the entire coast (coastwide optimization will be available once each of the estuaries has been individually modeled). And the financial budget is definable as a single dollar amount or a range of budget levels, each of which is iteratively executed.

For a detailed example of the expanded flexibility and how different desired outcomes can be accommodated in the tide gate optimization tool, see Appendix B.

Return on Investment

The results generated by the optimization tool and the underlying datasets on tide gate and benefit targets provide important information for decision-makers to better understand the ROIs for different budget scenarios. The tool's results indicate the barriers selected in the optimal set that would maximize the gain in benefit targets if all were replaced. The solution set differs by budget levels, depending on the potential gains and costs (Figure 6). Some barriers selected at lower budget levels are not selected at higher levels. It is recommended that a user execute the optimization tool several times, using multiple scenarios over a range of budget levels, to compare ROIs and identify the point at which additional financial investment would provide diminishing gains in the benefit targets of interest. For example, in Figure 6, results showed a substantial gain in accessible fish habitat at budget levels up to approximately $7 million, followed by a diminishing amount at higher budget levels.

Figure 6. Return on investment for tide gate replacements for coho salmon.



Note. Results are from a tide gate optimization example with two benefit targets: inundation habitat area (acres) and stream habitat length (miles). Quantities were standardized to range from 0 to 1 prior to input.

Fundraising and Budgeting

While ROI analyses are associated with project planning, the tide gate optimization tool can also be used to inform budget development and acquisition funding while exploring project feasibility. Research by Neeson et al. (2015) has shown that a single investment or repeated investments of a smaller funding amount(s) may not achieve as great a gain in aquatic connectivity as a one-time large-budget investment or large regional focus. However, if large investments are not feasible, the information provided by the tide gate optimization tool can still guide decisions made within smaller budget ranges and can be used to help acquire contracts and grants.

Evaluating Spatial Patterns

Tide gate optimization is designed to be used dynamically. Rather than producing a single static list of ranked priority barriers to work through over time, the model can be rerun to support new replacement and outreach goals. Specifically, the optimization tool can be rerun after some barriers have been addressed and projects completed or to incorporate new information about passage status at barriers. In addition, the base datasets and optimization tool results can be used in conjunction with supplemental information to aid in local and regional planning (see Appendix A and the descriptive information in the next section). Combining the optimization results with spatial datasets in GIS allows for information like tax lot boundaries, levees, public roads, and other features to be considered to create a data-driven and detailed understanding of how tide gates impact the people and ecosystems of the Oregon Coast and lower Columbia River.

Descriptive Information

A suite of additional descriptive data is provided for each tide gate to be used as a companion to the optimization results. The eventual decision of whether a tide gate is removed or replaced is influenced by other factors beyond maximizing benefit gain, including landowner willingness. Moreover, adjacent infrastructure can impose limitations on tide gate projects (CTC & Associates LLC 2016). The additional information provided is drawn from ideas and requests received during outreach conversations and can be used to sort potential removal or replacement projects by different criteria to gain initial information for outreach and planning. Descriptive information available for each basin and tide gate includes:

- The tide gate's association with a road, bridge, or levee
- The land use zone at the location of the tide gate (DLCD 2017)
- The number of owners in the estuary extent
- Land management at the tide gate—categories include Federal, Tribal, State, and Local (ODF 2016)
- The salinity zone (Nelson 2015)—a three-zone average annual salinity is used based on long-term salinity datasets

Stakeholder Briefings and Trainings

An important objective of this project is to disseminate the tool equitably to as many stakeholders as are interested in its application and results. Over the course of the project, we presented the tool and described its basic functions and capabilities to the following groups and gatherings:

- Coos Coho Strategic Acton Planning Team, consisting of staff from the Coos Watershed Association, NOAA, ODFW, NRCS, Coos Soil and Water Conservation District, Wild Rivers Land Trust, and Wild Salmon Center. In addition, we worked with the Coos Coho Strategic Action Planning Team to create customized optimization outputs for the action planning process. The results were incorporated into the planning exercises of 2019 to 2020.
- Inter Fish Habitat Partnership Working Group, consisting of representatives from the PMEP, California Fish Passage Forum, and the Pacific Lamprey Conservation Initiative. Presentation in 2019.
- Barriers to Tidal Connectivity Symposium, a two-day workshop held in 2020 and attended by approximately 300 people and hosted by the PMEP, California Fish Passage Forum, and Pacific Lamprey Conservation Initiative.
- 2020 Restore America's Estuaries Conference.

- NOAA Fisheries Restoration Center's West Coast Meeting, 2020.
- American Fisheries Society, Western Division, Symposia, 2020.
- TNC's Virtual Global Science Gathering, attended by TNC scientists and staff worldwide and held in 2020.

Training and support will be available for those stakeholders wishing to learn how to use the tool adaptively in one or more estuaries along the coast (e.g., Figure 7). Due to the global pandemic and associated restrictions on travel and face-to-face meetings, in-person trainings have not been held. This decision will be reevaluated as conditions improve, and in-person trainings could be available as early as Fall 2021. If they are not possible, TNC will provide recorded webinar trainings to interested stakeholders. A supplemental user manual will be provided to help educate user groups on the tool's capabilities and initiate best practices for how to use the tool for project planning.

Trainings will include a user tool customized to each of Oregon's major estuaries. The user tool will allow stakeholders to specify one or more benefits and weight them to align with their interests. These customizations can be achieved for current conditions using current tide levels or projected sea level in the year 2100.

Recommendations for Future Consideration

TNC appreciates the opportunity to create and share the tide gate optimization tool with members of the Oregon Tide Gate Partnership. TNC plans to continue to work with tide gate stakeholders to disseminate the tool and provide resources for using it and understanding its products. We also anticipate future opportunities to further expand the tool to meet ongoing stakeholder interests and incorporate data as it is created. Possible future additions to the tool include incorporating:

- ODFW's ecological uplift metric, either as input into the optimization tool or as additional descriptive data provided for each tide gate.
- Pacific lamprey as a target benefit. Currently, comprehensive Pacific lamprey species distribution data are lacking for most basins on the Oregon Coast.
- Freshwater river flooding and future precipitation changes with sea level rise scenarios.

Figure 7. Bandon Marsh National Wildlife Refuge in the Coquille River estuary. (Photo by ODFW.)

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Appendix A – Dataset Investigation

The following sections describe the datasets considered for use in the tide gate optimization tool to enhance functionality and increase the tool's utility for a broader set of stakeholders.

Fish Habitat Quantity

For the tide gate optimization tool, fish habitat quantity is defined by two parameters:

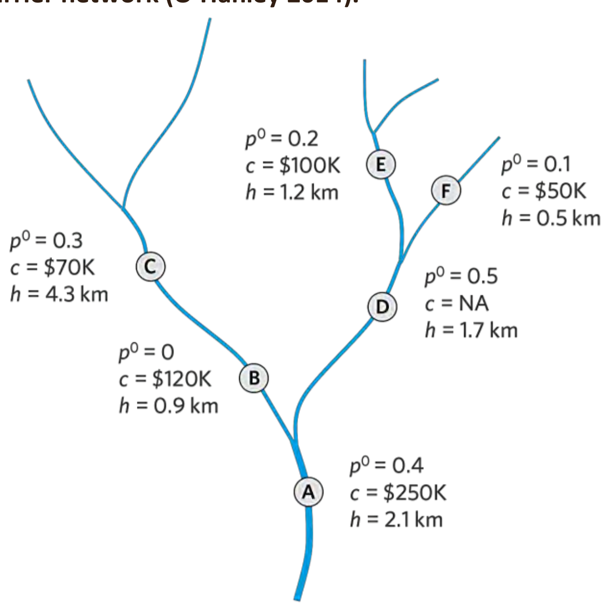
1. the area of potential tidal inundation, which is used as an index for the amount of potential off-channel habitat and is critical as rearing and overwintering refugia for juvenile salmonids, and
2. the length of fish habitat in the stream network above the tide gate.

Freshwater streams above the estuary increase the ecological value of an area for both adult and juvenile salmonids, allowing fish to escape high-water events and potentially providing spawning and rearing areas.

Modern tide gates are designed to allow the gates to be open for longer periods of time for better water exchange. With this flexibility in mind, TNC selected the area of potential tidal inundation as a surrogate for potential off-channel flooded habitat, assuming increases in the extent of regular tidal inundation behind the tide gates after replacement while still maintaining agricultural operations. Inundation area was estimated using the PMEP estuary extent boundary (Brophy et al. 2019; PMEP 2017).

The length of upstream fish habitat available following tide gate or culvert replacement is based on species distribution (ODFW 2014) and fish presence (ODF 2010) datasets, which were chosen as surrogates for stream habitat since the state of Oregon lacks a comprehensive database of stream habitat by fish species. To model the stream habitat's potential increases, the tool also requires the location of culverts in the stream network and the degree to which fish are able to pass each culvert (i.e., passage status). A key advantage to the OptiPass optimization algorithm is that it explicitly considers the spatial structure of barriers and interactive effects of passage improvement on longitudinal connectivity (O'Hanley 2014; Figure A1). For example, in Figure A1, the habitat (h) above Culvert C is not available for fish use until the downstream Culvert B that blocks fish passage is addressed.

Figure A1. Example of a stream barrier network (O'Hanley 2014).



Note. Barriers to fish passage are represented by lettered nodes (A–F), cost of barrier replacement (c), length of upstream habitat (h), and degree of fish passage at the barrier (p^0, where 0 indicates fully blocked). The OptiPass optimization algorithm considers the linear relationship of barriers in the stream network as well as passage status at each barrier. In this example, stream habitat above Barrier C (h = 4.3 km) is not accessible to fish until passage at Barrier B is addressed.

The tide gate optimization tool for fish habitat benefits differs from the tool's earlier versions in two ways. First, the two measures of fish habitat (inundation and stream length) were previously combined into a single, equally weighted metric for input into the optimization tool. Now, each habitat metric is available separately for independent selection as inputs into the tool. Users can then add a weight to any metric to emphasize the importance of one benefit over another. This flexibility resolves a key request among stakeholders: placing higher importance on increasing the availability to off-channel habitats critical for juvenile salmon, rather than basing tide gate replacement decisions on gains in upstream habitats.

Second, earlier versions of the optimization tool targeted only coho or four species together (coho, Chinook, steelhead, and cutthroat). Now, users can select one or more of the five salmonid species (those above plus chum) individually for inclusion in the optimization tool. Additionally, the tool is designed with the ability to include other fish species, such as lamprey, as spatial datasets become available.

Estuary Habitat Quality

Habitat quality is a key interest among stakeholders and could be particularly informative when combined with habitat quantity. To identify potential sources to describe habitat quality for salmonids in the estuaries and streams along the Oregon Coast, TNC and its partners conducted a data search using online and paper sources and had conversations with resource management partners. We identified no data capable of describing salmonid habitat quality in either the estuary or the coastal streams at a suitable scale for the entire coast.

Our investigation assessed the feasibility of constructing a quality habitat model specifically for coastal Oregon using climatic, geomorphic, and anthropogenic landscape characteristics factors from the literature (e.g., Esselman et al. 2013). However, the necessary habitat and environmental measurements for such a model were not available.

The most promising opportunity is a project under development by ODFW. The agency is in the process of developing a Bayesian Belief Network (BBN) model to calculate a probability of ecological uplift (i.e., fish uplift) after the removal of each tide gate and to use those probabilities to build a ranked list of tide gate removals across the Oregon Coast. The model is for ODFW's internal use to focus decisions about barrier replacements. As designed, the BBN model incorporates variables describing the habitat quantity and quality for the lowland area behind the tide gate, as well as broader watershed characteristics (ODFW 2020a, ODFW personal communications).

TNC and ODFW teams met regularly in 2020 and 2021 to build an understanding of the similarities and differences between the model approaches, agree on common data inputs, and propose how users of either tool can consider results from the other. When available, the ODFW data—i.e., the probability of uplift achieved if a tide gate were removed—will likely be the best available spatial dataset to indicate potential habitat quality and quantity combined. As of August 2021, the ODFW ecological uplift probability model was not yet available to incorporate into the optimization tool.

The following are data sources that were considered but rejected during this investigation as potential indices to habitat quality:

- *Priority estuary landward migration zones and associated vegetation classes* (Brophy and Ewald 2017) as an indicator of future habitat availability and quality: It was determined that the general estuary vegetation class was not a good indicator of fish habitat or habitat quality since fish take advantage of access to watered areas regardless of class
- *The intrinsic potential to provide high-quality habitat (Burnett et al. 2007) for salmon has been modeled* by NetMap (Benda et al. 2007; TerrainWorks n.d.) for river channel and floodplain characteristics within the watershed. Still, there is currently no model for lowland estuary habitats. A lowland intrinsic potential could include variables such as water quality, grazing pressure effects on water quality above tide gates, shading, temperature, and others. (personal communication with Dan Miller of TerrainWorks, April 2020). The basic assumption of such a model is that geomorphological characteristics could describe fish habitat quality in an estuary.
- *National Fish Habitat Partnership fish habitats* (Crawford et al. 2015): These datasets are built on the coarse-scale national hydrography data, which is of insufficient resolution for this project.
- *Stream classification system by McManamay et al. (2018)*: One disadvantage identified was that the

data source is tied to the coarse-scale national hydrography stream network rather than the higher-resolution network. Also, available metrics describe static geomorphic and physical characteristics, so additional data products would need to be created and vetted to describe habitat quality.

- *The Index of Watershed Integrity and the Index of Catchment Integrity* (Thornbrugh et al. 2018) both integrate a variety of stressors known to impact habitat quality. Stressors include sediment regime, temperature regime, network connectivity, water quality, and biotic measures at local and watershed scales. However, both indices are relative to a large geographic region that lacks the resolution necessary to distinguish between higher- and lower-integrity areas along the Oregon Coast.
- *Tidal Restoration Prioritization Tools* (Kauffman and Steinberg 2010): The GIS approach outlined in the publication was not helpful for the project.
- *Construction of a simple predictive model based on combinations of land use characteristics*: Datasets could include the land use (agriculture or other); zoning; land use type (natural, residential, commercial); presence of infrastructure; degree of land modification and therefore loss of aquatic connectivity (diked vs. non-diked, ditches vs. natural channels); and availability of upstream habitats. This approach was initially attractive as a possible method to map potential habitats for wildlife other than fish. However, it was abandoned given that it would require broad assumptions and generalizations.

Agricultural Land

Survey respondents expressed interest in prioritizing agricultural land for tide gate replacement.

For the optimization tool, it was decided to use the legally defined *high-value farmland* designation as well as the NRCS Farmland Classification (Soil Survey Staff, NRCS 2019). High-value farmland includes land in exclusive farm use or mixed farm and forest zones (Oregon Revised Statute [ORS] 215.710) with soils predominantly classified as prime, unique, and Capability Class 1 or 2. The NRCS Farmland Classification (Soil Survey Staff, NRCS 2019) "identifies map units … as prime farmland, farmland of statewide importance, farmland of local importance, or unique farmland. It identifies the location and extent of the soils that are best suited to food, feed, fiber, forage, and oilseed crops. NRCS policy and procedures on prime and unique farmlands are published in the 'Federal Register,' Vol. 43, No. 21, January 31, 1978" and "prime farmland is designated independently of current land use."

The NRCS farmland classification defines 11 classes (Table A1). Since many of the classes are sparsely distributed across the estuaries, the top 10 classes were aggregated to represent a single class of high-value farmland. The remaining binary dataset represents areas of high-value farmland and areas that are not.

Table A1. High-value farm soil classes in the NRCS farmland class datasets.

Class
Farmland classification Prime, nonirrigated
Farmland classification Prime, irrigated
Farmland of unique importance
Land Capability Class 1, nonirrigated
Land Capability Class 2, nonirrigated
Land Capability Class 1, irrigated
Land Capability Class 2, irrigated
Meets the definition of high-value farmland and in the Willamette Valley
Meets the definition of high-value farmland and west of the summit of the Coast Range (Oregon Administrative Rule [OAR] 660-033-0020(8)(d))
Meets the definition of high-value farmland and includes tracts located west of U.S. Highway 101
Not Prime Farmland – Areas not in one of the above classes

The following are dataset sources that were considered but rejected during this investigation as potential indices for agricultural land:

- *Measure 49 High-Value Farmland and Forestland Map Viewer* (ODA 2007), which provides data for high-value farm soils as defined by the relevant Oregon rule (equivalent to the dataset described above): It also provides data for high-value farmland dairy soils, which were defined with soils from tracts used for dairy operations in January 1998 (OAR 660-033-0020). This dataset underrepresented dairy agricultural land.

- *Zoning class (DLCD 2017), specifically the Exclusive Farm Use (EFU) classes* designated as required in Statewide Planning Goal 3 to protect farmland and place restrictions on development unrelated to agriculture: It was determined that EFU zones alone underrepresent agricultural lands along the coast.
- *DLCD Agricultural Land*, which is comprised of predominantly Capability Class I to IV soils in Western Oregon: These data overestimate farmland area compared to the NRCS farmland classification since they include Capability Classes III and IV. By legal definition, “high-value farmland” means tracts comprised of “predominantly soils that are prime, unique, and class I or II” (OAR 660-033-0020).
- *NRCS Nonirrigated Capability Class*: “Land capability classification shows the suitability of soils for most kinds of field crops” (Soil Survey Staff, NRCS 2019). Capability classes are designated by the numerals 1 through 8, where the numbers indicate “progressively greater limitations and narrower choices for practical use” (Soil Survey Staff, NRCS 2019). It was determined that these data do not accurately identify the agricultural land in production along the entire coast.
- *USDA National Agriculture Statistics Service (NASS) crop data layer*: Based on satellite imagery, the data layer is produced annually to provide acreage estimates for the state’s major commodities. The provided raster data layer is at a 30-m resolution and is aggregated to a possible 85 standardized categories, emphasizing agricultural land cover types (USDA 2019). It was determined that these data are not useful for this optimization tool since most of the area with the estuary extent is classified by the data as “herbaceous wetlands” or “open water.”
- *NRCS National Commodity Crop Productivity Index (NCCPI)*: The index provides a relative ranking of soils based on their potential for the production of commodity crops. It was determined that these data do not accurately represent the agricultural land in production along the entire coast.
- *NOAA Coastal Change Analysis Program (C-CAP) Regional Land Cover Database* (NOAA 2016), specifically three of the 26 land cover classes: cultivated land, pasture/hay, and grassland. These data are an update to the National Land Cover Database (NLCD) of the U.S. Geological Survey (USGS), which also provides general landcover types. While the three classes of interest are associated with the farm and dairy lands in use in tidal areas, the data was less accurate than the NRCS farmland classification chosen for the optimization tool.
- *Land use zoning (DLCD 2017) to define potential agriculture area*: These zones were too coarse to indicate agricultural land use.
- *County tax records* (e.g., Tillamook County Real Property Assessment/Tax Report), which indicate land area by zoned and property class: Using tax lot records would add value to the analysis; however, they would require purchasing tax lot data from many counties and a substantial effort to integrate such data across county datasets. Tax lot data will likely be useful, though, during landowner outreach and project development phases of tide gate projects.

Private and Public Infrastructure

Survey respondents expressed interest in the value of tide gates to protect public and private infrastructure. Private infrastructure near tide gates may include homes, barns, private roads, and other structures involved in agricultural or dairy operations. It may also include roads, bridges, railroads, power facilities, telecommunication structures, drinking water, wastewater treatment plants, potential contaminant sources, and essential facilities (DLCD 2015; OCMP 2017).

Available spatial data that would describe the location and types of the listed infrastructure were researched. Two datasets were selected for integration into the tool.

The first dataset was the OR-IRIS geodatabase from the *Emergency Preparedness Data Collection* prepared by Prep-FIT to “aid the emergency response community in developing data systems to support their work in planning and responding to incidents in a safe, effective, and efficient manner” (Prep-Fit 2015). The geodatabase consists of over 250 datasets arranged into themes: Transportation and Infrastructure, People at Risk, Water Resources Protection, Potential Toxic Sources, Incident Notification Groups, Emergency Response Resources, Wildlife & Habitat, and Natural Resources & Hazards. Each theme contains many sub-elements (Pettit n.d.). After reviewing the large dataset, three themes were selected, along with a subset of elements that represent infrastructure or potential toxic sources that may be influenced by tide gate function (Table A2). Other than roads and railways, which are provided as polylines, all other elements are points.

This OR-IRIS data is used to represent public-use infrastructure within the tide gate optimization tool. The location of potential toxic sources is included to call out areas that may be impacted by tidal inundation in the event of a tide gate failure.

Table A2. The themes and elements selected from the OR-IRIS geodatabase for use in the optimization tool.

Emergency Response Resources	Transportation and Infrastructure	Potential Toxic Sources
Emergency Shelters	Airports	Confined Animal Feeding Operations
Fire Stations	Campgrounds	DEQ DHS Potential DW Contaminant
Flood Gage	Cemeteries	ECSI
Hospital_Satellites_OHA	City_County_Parks_GNIS_2014	HazWaste
Hospitals_OHA	Fairgrounds	HSIS_Facilities
Licensed_Medical_Facilities_OHA	Libraries	LUST
ODFW_Facilities	Marine_Port_Offices	NPDES_Outfalls
Rain Gage	Museums_GNIS_2014	SewageWWTPs_2009
Veterinarians	Oregon_Dams	SWIFT
	Post_Offices	TRAACS
	TRANS_CommTowers_DOGAMI	WQSIS
	TRANS_railBridgeTunnel_ODOT	WQSIS
	TRANS_roadBridge_ODOT	
	TRANS_Towers_GNIS_2014	
	USFS_Facilities_GNIS_2014	
	TRANS_railInsideOR_USGS	
	TRANS_roadAll_TIGER_2014	

The second dataset selected to represent the remaining infrastructure not included in the OR-IRIS geodatabase was the Microsoft Building Footprints (Microsoft 2018) dataset, which consists of all building footprint polygons. Other than location, no other attributes are provided with the Microsoft Building Footprints data, and as a result, there is no method to distinguish between privately owned and used buildings or public buildings.

When used in the optimization tool, OR-IRIS data represent public-use structures and public safety, and data from Microsoft Building Footprints represent private structures.

It is important to note that the tide gate optimization tool does not measure the degree of risk to public safety, human health, or the local community. Instead, it is an enumeration of infrastructure that may be impacted by tidal flooding if an existing tide gate and other water control structures are not functioning properly.

The following data sources were considered but rejected during this investigation as potential indices for infrastructure:

- *The National Structure Inventory* (NSI; U.S. Army Corps of Engineers [USACE] 2019): This nationwide dataset includes some types of public buildings; however, compared to OR-IRIS, the data are at too coarse a scale and not sufficiently comprehensive for use along the Oregon Coast.
- *Homeland Infrastructure Foundation-Level Data* (HIFLD; U.S. Department of Homeland Security 2017): This nationwide dataset includes "essential facilities," such as care facilities, emergency operations, police stations, and others. When compared to OR-

IRIS, it is not sufficiently comprehensive for use along the Oregon Coast.

- *NLCD's 2011 impervious surface dataset*: These data are not useful in separating the location of buildings from other impervious surfaces, such as parking lots. The nationwide raster data is at a fairly coarse scale.
- *NOAA Critical Facilities in Coastal Geographies*: The data is based on USGS National Structures, then aggregated to law enforcement facilities, fire stations and EMS facilities, hospitals and other medical facilities, and schools within several area footprints of the coastal study. As with the NSI, when compared to the data collected for the state of Oregon (IRIS), it was determined that these data are incomplete and miss many structures of interest in the analysis.
- *Transportation "lifelines" and social vulnerability* (Johnson et al. 2018): It was determined that the scale of decision-making for tide gate replacement is different than the scale used in community social vulnerability modeling.
- *U.S. Federal Emergency Management Administration (FEMA) HAZUS loss and valuation modeling tools* (and Oregon DOGAMI Python script), which assist in determining the relative risk to building structures of natural events, such as earthquakes and floods: These tools could be used for this project. Generally, the risk to a residential structure differs based on type (single-family, multi-family, mobile home), building standards (such as floodplain management standards before or after 1970), number of floors, elevation position, and other criteria. It was determined that it was out of the project scope to predict how each structure may be impacted in the event of a tide gate failure.
- *FEMA special hazard areas (SFHAs)*: The data overestimates flooding potential for the purposes of this project, and it does not apply to future climate change analyses since it considers previous flood events rather than a projection for future events.

Tidal Inundation and Sea Level Rise

The PMEP estuary extent data (Brophy et al. 2019; PMEP 2017) was used to estimate the current extent of regular inundation for the tide gate optimization tool. The PMEP estuary extent data combine NOAA extreme-water-level models, high-resolution digital elevation models, ancillary land-cover data, and other ground-truthed information to estimate the boundary of regularly inundated tidal areas, including freshwater zones. These data are publicly available, span the contiguous United States West Coast, and have proven to accurately represent local estuary extent that can be applied accurately at large (i.e., coastwide) scales (Brophy et al. 2019). They are also directly relevant for all benefit targets included in the tide gate optimization tool. By explicitly incorporating the 50% exceedance intervals from NOAA's extreme-water-level data in the estuary extent data product, the PMEP estuary extent boundary encompasses areas that experience tidal inundation at least every two years.

Sea level rise poses a serious risk when it comes to the hydrology in Oregon's estuaries and the working lands found within them. Future sea level rise changes are attributed to global processes (warming oceans and melting ice) as well as regional factors, such as prevailing climate patterns, proximity to glaciers and ice sheets, land subsidence, and plate tectonics. Human activities, such as pumping groundwater, can contribute to lower surface elevations and a rise in the relative sea level at a local scale. There is an extensive body of literature exploring mechanisms responsible for sea level rise and projections for changes in sea level rise at both local and global scales. To date, no single model can accurately represent all the major processes that contribute to global mean sea level (GMSL) or regional sea level (RSL; Sweet, Horton, et al. 2017). We examined sea level projections from a variety of published projections to understand the best way to estimate the potential extent of sea level rise on tidal inundation levels in the estuary and how that change might impact tide gates and benefit targets over the coming decades.

It is important to understand the difference between GMSL rise predictions and RSL rise predictions to estimate the magnitude of change appropriately, especially since changes in RSL will impact communities and ecosystems differently by location. Regional sea level rise (the difference between sea-surface height and the solid-Earth surface) is measured with tide gauges and is included in estimates of GMSL. Estimates of the RSL changes often differ from GMSL estimates for various reasons, including differences in training datasets and other methodological considerations (Kopp et al. 2015). There are also national efforts underway to update GMSL rise estimates and regionalize those efforts to understand local differences, which are intended to address coastal risk management and vulnerability assessments

(Sweet, VanderVeer, et al. 2017). The aim of these efforts is not only to identify the likelihood of given sea level rise scenarios but to understand the most likely worst-case scenarios considering today's sea level and climate science. In Oregon, multiple sea level rise estimates are used among state and federal agencies, conservation organizations, and engineering partners. The discrepancies in these data sources and sea level rise estimates are understandable given the interest in understanding and preparing for sea level rise and the rapid advances in sea level and climate science. For example, the Oregon Climate Service, the state's climatology office, reports ranges in sea level rise for Astoria, Newport, and Charleston for 2050 and 2100 under six climate scenarios (low to extreme) from seven different sources (riskfinder.climatecentral.org).

Several different products describing the spatial extent of predicted sea level rise inundation scenarios have been developed for the Oregon Coast and Columbia River. TNC compared the following three datasets to the region's most recent sea level rise predictions and evaluated them for their spatial extent and coverage to determine whether they were appropriate to include in the tide gate optimization tool.

- *The Estuarine Sea Level Rise Exposure Inventory* (OCMP, 2017) was developed for use in vulnerability and risk assessments and therefore reflects possible sea level rise and flooding scenarios that assume the status quo regarding sea level rise preparedness. They estimate future flooding due to the combination of sea level rise and extreme water levels data. They use sea level rise estimates of 4.6 feet by 2100 (NRC 2012) and estuary-specific values for extreme water levels. This data does not include the Columbia River.
- *The LMZ data* (Brophy and Ewald 2017) was developed to predict the areas where tidal wetland plant communities are most likely to survive under future sea level rise conditions. The modeling uses a modified bathtub approach to estimate the upper and lower levels of the current and future inundation extents based on sea level rise projections (NRC 2012). This dataset does not include the lower Columbia River. In addition, given the researchers' specific goal to represent areas available for wetland communities, fully submerged areas (i.e., open water and mudflats) were excluded.
- *The NOAA dataset* (2017) forms a comprehensive suite of spatial data, describing the expected inundation area of sea level rise heights, ranging from 1 to 10 feet relative to the Mean Higher High Water (MHHW). These data do not consider landscape dynamics, such as subsidence or erosion, and are intended to be used as a screening tool.

A pilot analysis was performed to compare the differences in these datasets and determine which was appropriate for the optimization tool. Each sea level rise dataset was compared with the others and with the PMEP estuary extent boundary. Ultimately, the gaps included in LMZ data made it difficult to use it as a companion dataset with the PMEP boundary when understanding changes to fish habitat. Therefore, TNC built from the evidence laid out by Brophy and Ewald (2017) and used the NOAA 5-foot sea level rise extent to estimate expected impacts to fish habitat by 2100.

The four inundation scenarios included in the OCMP estuary exposure inventory performed well against the PMEP inundation extent layer. They demonstrated a consistent increase in the area relative to the "current" PMEP boundary condition. Since these data were developed specifically for conducting vulnerability and risk assessments on the coast, choosing one of these options is desirable. However, the OCMP data does not include the Columbia River. For the Columbia, there is good alignment between (a) the scenario of a 50% flood in 2100 and (b) the 7-foot NOAA sea level rise extent. Given this alignment, the NOAA 7-foot sea level rise layer is used in the tide gate optimization tool when working in the Columbia estuary.

Climate change and its potential impacts on future peak flow calculations, and thus tide gate cost analyses, were considered but rejected during this investigation. These costs are currently categorized according to estimates of 100-year peak flows calculated for each watershed.

Current reliability ensemble averaging values were used in the equation for calculating peak flows taken from the Cooper (2005) data. However, the values did not align well with the equation. Consequently, more rigorous hydrologic modeling is required and outside the scope of this work.

References for Appendix A

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Appendix B – Example Optimization Scenario

The simplified example described in this appendix illustrates how the tide gate optimization tool allows users flexibility in choosing their benefit target. It also demonstrates how their choices determine the optimal set of barriers to replace to achieve the largest gains for the benefit target(s) of interest (Figure B1). Each of the five tide gates is associated with differing amounts of benefit targets, and two of the tide gates have culverts upstream (Figure B1-A). The estimated cost to replace the tide gates and culverts ranges from $75,000 to $800,000. In this example, the proposed budget level is an important determinant for the number of tide gates identified in each solution (Figure B1-B). Changes to the proposed budget will result in different combinations of tide gates included in the solution for each scenario.

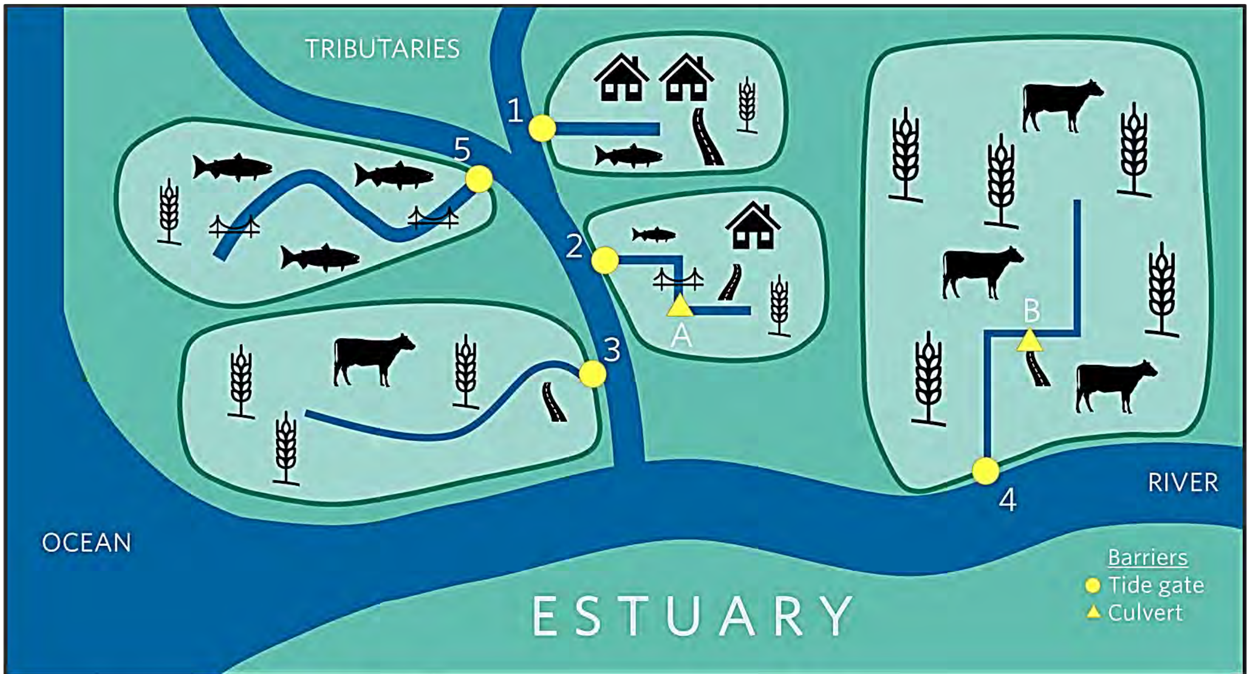
In Scenario 1, the desired outcome is to replace the barriers that will lead to the largest gain in coho habitat. Since coho use both stream and off-channel areas that are tidally inundated, the optimization model is run with both of these benefit targets. In this case, Tide Gate 5 is identified as the optimal candidate for replacement because it has a relatively large inundation area and the largest potential gain in stream habitat, even though it is the most expensive barrier.

Suppose the desired outcome is to only maximize the off-channel tidal inundation area (Scenario 2). In this case, Tide Gates 3 and 4 are identified for replacement since they have the largest inundation areas and the length of stream habitats is no longer a consideration. The model chooses Tide Gate 3 over Tide Gate 5 because it has a slightly larger area and a significantly lower replacement cost.

The optimal set of barriers also differs if the model considers the gain in agricultural land and buildings (Scenario 3) rather than focusing only on protecting agricultural land (Scenario 4). In Scenario 3, the large number of buildings present behind Tide Gates 1 and 2 (25 and 10, respectively) influence the solution. In Scenario 4, the large amount of agricultural land present behind Tide Gates 3 and 4 drives the solution.

In Scenario 5, the desired outcome is to replace the barriers that are protecting the most roads and bridges. Tide Gates 1 and 2 are identified for replacement in this scenario since they are associated with the largest road segment and both a bridge and smaller road, respectively. Even though Tide Gate 5 has two bridges, its estimated replacement cost prevents it from being included in the solution.

Figure B1. Example optimization for five tide gates in one estuary.



A. Optimization parameters	Barriers				
Benefit targets	**1**	**2, A**	**3**	**4, B**	**5**
Tidal inundation (ac)	200	250	550	825	510
Stream habitat (mi)	3	< 1	0	0	10
Agricultural Land (ac)	200	225	500	800	150
Buildings (#)	25	10	0	0	0
Bridges (#)	0	1	0	0	2
Roads (mi)	1	< 1	< 1	< 1	0
Cost ($1,000s)	300	600 & 100	400	525 & 75	800

B. Optimization Scenarios		$1 mil budget				
Scenario	**Benefit targets**	**1**	**2, A**	**3**	**4, B**	**5**
1	Coho habitat (tidal & stream habitat)					✓
2	Inundation habitat			✓	✓	
3	Agricultural land & buildings	✓	✓			
4	Agricultural land only			✓	✓	
5	Roads & bridges	✓	✓			

Note. Figure not drawn to scale. Each tide gate is associated with a variety of benefit targets and has a different estimated replacement cost (A). Depending on the budget and benefit targets included in the optimization run, different scenarios will result in different sets of optimal barriers chosen for replacement (B).