



Tide Gates: Technical and Ecological Considerations

Requested by
Melinda Molnar, Division of Environmental Analysis

March 4, 2016

The Caltrans Division of Research, Innovation and System Information (DRISI) receives and evaluates numerous research problem statements for funding every year. DRISI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field. The contents of this document reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the California Department of Transportation, the State of California, or the Federal Highway Administration. This document does not constitute a standard, specification, or regulation. No part of this publication should be construed as an endorsement for a commercial product, manufacturer, contractor, or consultant. Any trade names or photos of commercial products appearing in this publication are for clarity only.

Table of Contents

Executive Summary	2
Background	2
Summary of Findings	2
Gaps in Findings	5
Next Steps.....	5
Detailed Findings.....	6
Consultation with Practitioners and Experts	6
<i>Consultant</i>	6
<i>National Oceanic and Atmospheric Administration</i>	7
<i>California Department of Fish and Wildlife</i>	10
Related Research and Resources	12
<i>Fish Passage and Ecology</i>	12
<i>Hydrologic Modeling</i>	19
Contacts	23
Appendix A: Sidehinge Tide Gates & Muted Tidal Regulators Presentation.....	24

Executive Summary

Background

Tide gates control water flow between a tidewater area and a diked-off, drained upland area. A tide gate involves a hinged door at the end of a culvert that connects these areas and a mechanism that controls when and how the door is opened to allow water flow in either direction. Traditional tide gates are actuated by tidewater levels; a recent innovation, a muted tide regulator, is intended to improve connectivity for fish species by keeping the gate open or closed based on upland water levels.

Caltrans has limited experience with tide gates and is interested in building its knowledge base to improve its planning and decision-making efforts related to tide gate selection and deployment. This Preliminary Investigation addresses ecological topics and technical topics related to tide gates.

Summary of Findings

Consultation with Practitioners and Experts

CTC & Associates spoke and corresponded with practitioners and experts who provided detailed comments about a wide range of considerations, including the following:

Decision-Making

- Correigh Greene of National Oceanic and Atmospheric Administration (NOAA) discussed the need to balance development and agriculture requirements with the preservation of estuarine habitats when deciding whether and how to install a tide gate.
- Greene listed installation considerations related to overall need, likelihood of fish passage improvement, anticipated opening time, established recovery targets for fish, and site-specific constraints.

Design

- Consultant Michael Love discussed the modes of use for tide gates on tidal flows (with typical twice-daily drain cycles) and river flood flows (which might remain closed for lengthy time periods).
- Love discussed operational differences between top- and side-hinged tide gates. He also discussed retrofits and the “pet door” configuration.
- Several interviewees noted the need to design for juvenile fish, for which velocity barriers are a prime concern.
- NOAA’s Aaron Beavers said that the lack of knowledge about fish biology in estuaries, and the tendency to use knowledge of river biology, leads to less effective tide gate design.
- Project limitations, according to Beavers, can be imposed by adjacent infrastructure (roads, septic tanks, agricultural land).

Operational

- Greene discussed monitoring requirements after installation.
- Beavers discussed how making seasonal adjustments to tide gates can maximize their effectiveness.

Ecological Assessment

- Mike Wallace of the California Department of Fish & Wildlife discussed several restoration projects involving tide gates and criteria to assess their effectiveness on fish habitat: utilization of passage before-and-after removal or replacement; species composition; distribution, timing and length of residency; and specimen sizes.

Setting Tide Gate Criteria

- Beavers said that passage and habitat quality drive the design for NOAA, but West Coast state agencies focus primarily on passage (i.e., pipe hydraulics). He said that comprehensive criteria are difficult to set because design and site variables need to be well-known and consistent between projects, and this is usually not the case.

Modeling

Several people commented on the limitations of current hydrologic modeling efforts:

- Love said the U.S. Army Corps of Engineers' Hydrologic Engineering Centers River Analysis System (HEC-RAS) software is the most common modeling tool, but there is not sufficient data from the field or from numerical modeling to put in reliable energy loss coefficients or rates of closure.
- Greene suggested that the biggest uncertainties involved the modeling of the tidal environment and the tidal pulses and ebbs influencing the system.
- Beavers commented on the lack of research funding. He said that the expertise is well-established and a study to establish discharge/head relationships should be straightforward.
- Ehab Meselhe of The Water Institute of the Gulf corresponded about a modeling project conducted while he was with the University of Louisiana, Lafayette.

Hydrologic Standards

- Beavers noted that hydrologic standards for tide gate projects are not well-established and are needed.

Related Research and Resources

To supplement the findings from these discussions, we examined online resources related to fish passage and ecology, and hydrologic modeling.

Fish Passage and Ecology

National

- NOAA guidance includes a fact sheet on best practices for protecting estuaries that addresses tide gates. NOAA also presents information on the operation of traditional and modified tide gates.
- The Federal Geographic Data Committee's standard catalog of terms may help agencies and practitioners use consistent language for describing estuary projects.

State

- A research study in Louisiana provides a detailed methodology for studying fish passage through openings of different geometries.
- Research in Massachusetts addresses some of the problems associated with traditional tide gates and describes how self-regulating tide gates can alleviate such problems.
- Oregon resources include the state's fish passage criteria, which specifically note tide gates; two publications by Oregon State University that address tide gate operation, type and environmental impacts; and information on tide gate modifications.
- Washington State resources include water crossing design guidelines and a study on fish-friendly tide gates featuring a companion synthesis and practitioner Q-and-A.

International

- Research in Belgium analyzed the "pet door" style tide gate.
- Research in the United Kingdom described efforts in the design and operation of a self-regulating tide gate.

Hydrologic Modeling

National

- Modeling resources from the U.S. Army Corps of Engineers include the HEC-RAS and the Coastal Modeling System (CMS). Tide gate-specific guidance is presented for the CMS.
- Two NOAA research efforts also address modeling needs.

State

- New Jersey research sought to model the impact of sea level rise on tide gates.

- Two research projects in Oregon addressed improved modeling of tide gates within HEC-RAS.

Gaps in Findings

- There was relatively little information available specifically related to muted tide gate regulators beyond manufacturer information, which is not included in the scope of this Preliminary Investigation. When we asked experts about these, we learned that tide gate regulators are being used increasingly on the West Coast and that they can be beneficial under the right circumstances, but the focus of our discussions returned to considerations for tide gates in general.
- Despite multiple attempts and email exchanges, we were unable to connect with two Oregon experts, Guillermo Giannico and Jon Souder with Oregon State University, whose published works appear to be highly relevant to this topic.

Next Steps

- Every expert we spoke with shared one or more additional contact who would be able to provide more information and perspective on this topic. While it was beyond the scope of this Preliminary Investigation for us to speak with all of these people, there are opportunities for Caltrans or a research team to reach out to selected individuals based on specific questions. These names are listed in the **Consultation with Practitioners and Experts** section of this investigation.
- The practitioners and experts who were interviewed for this investigation agreed that there is a need for research on hydraulic modeling for tide gates. Expertise is available, they said, and the methodology would be straightforward if such research were to be pursued.

Detailed Findings

Consultation with Practitioners and Experts

Below we summarize our conversations and correspondence with experts and practitioners regarding tide gates.

Consultant

Contact: Michael Love, Principal Engineer, Michael Love & Associates, Inc., 707-822-2411, extension 1, mlove@h2odesigns.com.

We interviewed Michael Love, whose firm designs tide gates along the West Coast. Love stated that while there is not a great deal of research on this topic, a number of tide gates are being installed. He recommended we speak with NOAA and Oregon Fish and Wildlife, noting that Oregon codified fish passage criteria. In Oregon, the state department of transportation commonly replaces old tide gates, typically top-hinged flap gates that are believed not to allow sufficient fish passage, and is responsible for deciding what type of replacement will meet the fish passage criteria. In many cases, roads cross rivers or creeks with gates connecting to tidal lagoons or tidally influenced streams and rivers.

Uses

Love discussed the use of tide gates on tidal flows and flood flows.

Tidal Flows. In Humboldt Bay, north of San Francisco Bay, there are a number of tide gates all around the bay, and the tides follow a predictable twice-daily drain cycle. A good deal of land is diked and drained below high tide. The gates protect tidal flooding, but have to drain creeks and allow fish in and out. When tide waters are low, water behind the dike can drain out.

Flood Flows. Tide gates on rivers prevent flooding into creeks and back channels. As a result, a high river can keep tide gates shut for days. Currently a lot of fish passages focus on juveniles and the need to allow them to move into backwater habitats. These backwaters are very productive for fish, providing food and resulting in faster growth and larger sizes than fish grown in the creek. Therefore, a gate shut for an extended period can be counterproductive to the needs of the fish.

Configurations

Muted tide gates are commonly used all over the Northwest where fish are present and typically where an old-style gate is being replaced. These are nearly all designed by Leo Kuntz of Nehalem Marine Manufacturing.

Love said that the muted tide gates can be hinged on the top or side. A small force—as little as one pound—can fully open a side-hinged door. In theory, that configuration would allow more drainage and fish passage than a top hinge, but Love cautions that this hasn't been documented.

Love noted other possible configurations, including a muted tide gate retrofitted inside a traditional gate, or a “pet door” with a small door present on a larger door. Some other water control configurations, such as those that involve rubber tubes, would not typically be used when fish passage is required.

Images of various designs and configurations are shown in the presentation that Love provided:

Sidehinge Tide Gates and Muted Tidal Regulators, Leo Kuntz, Nehalem Marine Manufacturing, 2014.

[Appendix A](#)

Modeling

Love said that computer modeling is where the biggest gaps are, largely because the correct hydraulic coefficients are unknown. The U.S. Army Corps of Engineers’ HEC-RAS software is the most common modeling tool, and a script was added for tide gates. However, there is not sufficient data from the field or from numerical modeling to put in reliable energy loss coefficients or rates of closure.

International

Love commented on European interest in tide gates. In the Netherlands, for example, the primary concern is prohibiting saltwater into the diked areas, so there is no interest in muted tide gates. Belgium, however, has expressed an interest in implementing them on tidal rivers, allowing water to flow in and out behind the dikes.

National Oceanic and Atmospheric Administration

Contacts: Correigh Greene, Research Biologist, NOAA Fisheries, 206-860-5611, correigh.greene@noaa.gov.

Aaron Beavers, Hydraulic Engineer, NOAA Fisheries West Coast Region, 503-231-2177, aaron.beavers@noaa.gov.

We spoke in separate interviews with Greene and Beavers.

Correigh Greene

Balancing Needs

Greene explained that in the Pacific Northwest there is a need to balance development and agriculture requirements with the preservation of estuarine habitats. The decision to install a self-regulating tide gate—most commonly in replacement of a traditional flap gate—is commonly based on the dual need.

Selection Considerations

Greene spoke at length about the fundamental questions to ask in deciding whether to install a self-regulating tide gate (and if so, what kind). These include:

- Is a gate required at all?

- Will a self-regulating tide gate improve fish passage? The optimal environment of complete inundation for rearing juvenile fish must be considered.
- How long will the gate be open for fish passage?
- What are the recovery targets, if any, for the present fish? For example, for a particular site, will there be small or large benefits from the installation of a flap gate? Habitat size behind a gate can be a significant factor.
- Are there site-specific constraints that limit the installation or operation of the self-regulating tide gate? The geomorphology of the system may impose design requirements on the gate.

Design and Operation Considerations

Self-regulating tide gates have the very specific task of draining most of the time from the inside out while providing some tidal inundation upstream of the gate. Achieving this requires both proper design as well as operation.

- The system's settings for when to open and when to close will make a big difference in terms of inundation. It may be necessary to monitor the operation in the field and adjust the settings to achieve the desired results.
- Operational factors can significantly impact juvenile fish, where velocity barriers are a prime concern. (The gate open during an incoming tide is when such fish generally make use of it; water velocities during outflow limit the ability of juveniles to swim upstream).
- Other factors include opening width, duration of opening time, and the presence or absence of a vertical perch that juvenile fish would need to overcome.
- Gates are subject to environmental interference and deterioration (such as beaver activity and debris) that can limit function and cause failures in either open or closed mode, which lead either to complete inundation or complete disconnection upstream.

Hydraulic Modeling

Though this isn't Greene's specialty area, he believed that among the different models, the biggest uncertainties involved the modeling of the tidal environment and the tidal pulses and ebbs influencing the system. Other modeling challenges include modeling both day-to-day action as well as extreme events, and planning for long-term expectations (for example, whether a gate will meet standards in 50 years given possible sea level rise).

Extended Report

Caltrans was already aware of the report that Greene coauthored (see the citation **Biological and Physical Effects of "Fish-Friendly" Tide Gates** on page 16 of this Preliminary Investigation). He noted that a follow-up summary and synthesis, also cited, includes a lengthy question-and-answer section on a host of implementation issues.

Follow-Up

Greene suggested we speak with NOAA's Aaron Beavers, whose regional office provides consultations on list species impacts when a tide gate is proposed. A summary of our interview with Beavers follows.

Aaron Beavers

Beavers discussed some of the same design fundamentals that Greene mentioned. Additional comments from our interview are provided below.

Fish Biology in Estuaries Versus Streams

Beavers stated that passage and habitat quality drive the design for NOAA, but West Coast state agencies focus primarily on passage (i.e., pipe hydraulics). One of the challenges is that fish behavior (i.e., fish migration cues and modes) is not as well-known for estuarine environments as it is for in-stream passage. People often apply what they know about stream environments to estuarine environments because it is the best information they have, even though it is known that fish behavior is different in estuaries, and engineering design methods for streams and estuaries are significantly different. This often leads to less effective tide gate designs.

Tide Gate Project Limitations

Adjacent infrastructure must be evaluated for tide gate projects. If there is a road nearby, that sets a limit on how high water can rise relative to the grade. This is likewise true for houses, septic tanks and agricultural land, especially with respect to salinity killing grazing vegetation.

Setting Tide Gate Criteria

Beavers is very familiar with the status of tide gate criteria in Washington state, Oregon and, to a lesser degree, California, and he said that none of these states has a comprehensive set of criteria for tide gates. Comprehensive criteria are difficult to set because design and site variables need to be well-known and consistent between projects to effectively set criteria, and there is high variability of these factors in tide gate projects. Criteria related to consistent or established hydrology standards are also lacking. Hydrology is a critical component of analyzing fish passage and habitat conditions and designs.

As a result of project variables and limitations and the lack of research, the initial guidance on tide gate design from most agencies lacks established “thou shalts.” Instead they typically require a site-specific analysis and agency reviews and comments on the analysis before criteria are established for the project. States don’t generally have laws or statutes that provide a direct regulatory mechanism requiring analysis of habitat effects beyond a purely passage context, such as for rearing or spawning. For states, this means that fish passage can be enforced, but enforcement of habitat requirements is less clear. NOAA becomes involved when a listed species is involved (nearly every estuary in California will involve a listed species because it is assumed that all tributary species are in an estuary). Beavers noted that when NOAA writes a biological opinion on a project, fish passage is just one of many biological components analyzed. NOAA must also look at direct harm of fish and potential adverse effects of habitat quality.

Beavers said that the Federal Geographic Data Committee’s **Coastal and Marine Ecological Classification Standard** (see page 12 of this Preliminary Investigation) was proposed as a standard for describing estuary projects in order to get a consistent language among agencies and practitioners, and he believes this will be an important tool.

Seasonal Operation

In addition to the operational considerations discussed above by Love and Greene, Beavers also discussed seasonal adjustments to maximize their effectiveness. He suggested, for example, that it might be appropriate in some circumstances to lock tide gates open during certain times of the year, allowing inundation when tidal salinity is known to be lower and cattle have been moved off. Beavers gave an example where a muted tidal regular that allows upland inundation to 3 feet year-round may not be as beneficial as a side-hinged gate locked closed for the part of the year when no fish are present and locked open when it is important for juveniles to have access. The lesson is that “how you operate a tide gate may have a bigger effect on habitat and passage than the design of the tide gate itself.”

Modeling, Standards and Research Need

Like the others we interviewed, Beavers mentioned the need to make assumptions when using the HEC-RAS software for modeling tide gates. He noted a lack of research on establishing discharge/head relationships for the different types of tide gates available. There has been a lot of discussion about this, but there hasn't been money available (much more funding has been done on river passage; this may be tied to tide gates being more commonly located on private land). Given the expertise at the state and federal level on modeling fish passages, such a study should be straightforward if funding were made available.

Beavers noted that hydrologic standards for tide gate projects are not well-established. Future research identifying guidelines for developing project hydrology (this includes tidal cycle data, not just freshwater inputs) is needed to ensure modeled conditions of fish passage and habitat are appropriate and practical.

Follow-Up

Possible future partners for Caltrans for tide gate studies might include the NOAA Habitat Conservation Restoration Center, the nonprofit organization American Rivers, and the U.S. Department of Agriculture's Natural Resources Conservation Service. In addition, Beavers suggested that the following individuals would be able to speak to this topic further:

- Marcin Whitman, Senior Hydraulic Engineer, California Department of Fish & Game.
- Richard Wantuck, NOAA Fisheries, North-Central Coast Office, Santa Rosa.

California Department of Fish & Wildlife

Contact: Mike Wallace, Environmental Scientist, California Department of Fish & Wildlife (CDFW), 707-822-3702, mike.wallace@wildlife.ca.gov.

We interviewed Mike Wallace with CDFW.

Restoration Projects

At the start of this Preliminary Investigation, the Caltrans customer team provided CDFW's reports on fish habitat rehabilitation efforts on Wood Creek and Martin Slough in Humboldt County; these are not included here. Wallace noted that Wood Creek involved removal of an old flap gate, and Martin Slough involved the replacement of the entire old tide gate structure with a muted tide gate. Data collection is still ongoing for both of these projects.

Similar improvement projects in northern California include Salmon Creek, Rocky Gulch and Gannon Slough. Such projects are generally driven by restoration proposals that follow NOAA's and CDFW's recovery plans for specific fish species.

Wallace discussed the fish habitat criteria in CDFW's studies, noting that the agency asked "the basics": utilization of passage before-and-after removal or replacement; species composition; distribution, timing and length of residency; and specimen sizes. CDFW did not conduct species population estimates but did compare general abundance. Existing conditions (such as the presence or absence of species at different times of year) is the starting point in determining what you're trying to improve and how tide gates might play a role in that.

Follow-Up

Wallace said that the Pacific Northwest is ahead of California in terms of studying tide gates and the effect on fish populations. In addition to the people we spoke with already, Wallace noted four other individuals:

- Leo Kuntz, tide gate designer and manufacturer, would be able to speak in detail about a range of designs. Wallace said that the designs can be adjusted and fine-tuned for specific requirements on timing or water levels.
- Conor Shea, fluvial geomorphologist and engineer with the U.S. Fish & Wildlife Service in Arcata, could provide additional background on the engineering aspect of tide gates.
- Ross Taylor, with consulting firm Ross Taylor and Associates, is an expert in fish passage and could also speak to tide gates.
- Michelle Gilroy, CDFW District Fisheries biologist, and Allan Renger, CDFW supervising environmental scientist, could speak about additional tide gate modifications and replacements in Del Norte, Humboldt and Mendocino counties.

The Water Institute of the Gulf

Contact: Ehab Meselhe, Director of Natural Systems Modeling and Monitoring, The Water Institute of the Gulf, 225-227-2717, emeselhe@thewaterinstitute.org.

We corresponded with Meselhe, who was formerly with the University of Louisiana, Lafayette. Meselhe discussed a prior research effort on flap gates. The "experimental study, funded by the Louisiana Department of Natural Resources, investigates and quantifies the losses through circular double-hinged light- and medium-duty flap gates caused by the gate's own weight, the friction of the gate bearing and the flow turbulence downstream of the gate, for a wide range of flow rates and submergence levels.

The final report, draft title "Laboratory Study to Investigate Energy Losses Through Flap Gates," is still in progress and has not yet been published.

Related Research and Resources

Fish Passage and Ecology

National Resources

National Oceanic and Atmospheric Administration

Estuary Habitat: How Levees and Tide Gates in Estuarine Wetlands Affect Pacific Salmon and Steelhead, NOAA National Marine Fisheries Service, Spring 2012.

http://www.westcoast.fisheries.noaa.gov/publications/habitat/estuary_fact_sheet.pdf

This fact sheets includes “tide gate retrofits” among best practices for protecting estuaries:

Tide gates that limit free passage of juvenile salmon into and out of tidal channels can be modified to become less of a barrier. Replacing traditional tide gates with gates that close more gradually and stay open longer provide greater fish passage opportunity. When sized appropriately, they can also slow drawdown rates, which can reduce fish strandings. Modifying tide gate operations is also a simple practice that provides benefits. During seasons with no flooding, gates can be left open to provide free tidal exchange and fish passage.

Fish Passage: Tide Gates, NOAA, undated.

http://www.westcoast.fisheries.noaa.gov/fish_passage/solutions/tide_gates.html

This website discusses the operation of traditional and modified tide gates.

With traditional tide gates, passage of fish and water between the tidewater and the drained area is limited. This leads to stagnant water and fish being excluded from the habitat or trapped on the drained side when they wish to leave.

Modified tide gates use floats or other devices that hold the gate open until the water on the drained side reaches a particular level, and then it closes. This allows a longer period when the gate is open so water can be exchanged and fish may enter or leave the habitat in the drained area.

Federal Geographic Data Committee

Coastal and Marine Ecological Classification Standard, Marine and Coastal Spatial Data Subcommittee of the Federal Geographic Data Committee, June 2012.

https://coast.noaa.gov/digitalcoast/sites/default/files/files/publications/14052013/CMECS_Version%204_Final_for_FGDC.pdf

NOAA’s Aaron Beavers mentioned this publication in our interview with him. This national standard is a “catalog of terms that provides a means for classifying ecological units using a simple, standard format and common terminology” in coastal and marine ecologies.

State Resources

Louisiana

“Evaluating the Effect of Slot Size and Environmental Variables on the Passage of Estuarine Nekton Through a Water Control Structure,” Matthew E. Kimball, Lawrence P. Rozas, Kevin M. Boswell and James H. Cowan Jr., *Journal of Experimental Marine Biology and Ecology*, Vol. 395, Issues 1-2, pages 181-190, November 15, 2010.

Citation at <http://www.sciencedirect.com/science/article/pii/S0022098110003655>

This research is not focused on tide gates but provides a detailed methodology for studying fish passage through openings of different geometries. From the abstract:

Water control structures (WCSs) installed to regulate water levels can alter both the hydrology and ecology of salt marshes. WCSs are thought to limit nekton ingress into, and egress from, managed marshes. Slots (vertical openings that span most of the water column) incorporated into WCSs are thought to facilitate nekton passage through structures, but little research has directly examined how slot size affects passage rates. We used dual-frequency identification sonar (DIDSON) acoustic imaging to examine the effect of slot width (10, 15, 30, or 60 cm), tidal cycle, diel period, and season on nekton passage at a WCS located in a tidal salt marsh canal. Few individuals (total numbers and relative percentages) used the slots for passage through the structure during any stage of the tidal cycle, day or night, or seasonally. The number and size of migrants were similar for all four slot sizes examined. Nekton used the slots most often on flood tides to access the managed marsh (i.e., swim inside), primarily at night. Individuals entering the managed marsh were larger than those observed leaving the managed marsh. Whereas the majority of migrants were observed during winter months, season did not affect nekton passage in our study. Acoustic imaging allowed a unique and comprehensive evaluation of nekton passage by permitting an examination of factors such as swimming direction and proportion of migrants that are unobservable with other sampling techniques.

Massachusetts

“Restoration of Tidally Restricted Salt Marshes at Rumney Marsh, Massachusetts: Balancing Flood Protection with Restoration by Use of Self-Regulating Tide Gates,”

Edward L. Reiner, chapter in *Tidal Marsh Restoration: A Synthesis of Science and Management*, Charles T. Roman and David M. Burdick, editors, Island Press, 2012.

http://link.springer.com/chapter/10.5822%2F978-1-61091-229-7_21

This chapter addresses some of the problems associated with traditional tide gates (such as invasive plants and impaired drainage) and describes how self-regulating tide gates can alleviate such problems.

Oregon

Fish Passage, Oregon Department of Fish and Wildlife (ODFW), Fish Division
<http://www.dfw.state.or.us/fish/passage/>, 2016.

This web page is ODFW's clearinghouse for information on requirements, policy and practice to assure fish passage in Oregon. The overview outlines the processes of determining when fish passage needs to be addressed, approving passage plans, and granting of waivers and exemptions. The page links to the state's administrative rules (citation follows).

Related Resource:

Fish Passage Criteria, Division 412, Oregon Administrative Rules, Oregon Department of Fish and Wildlife, January 2015.

<http://www.dfw.state.or.us/OARs/412.pdf>

Oregon's state rules for fish passage discussed tide gates in section 635-412-0035: Fish Passage Criteria on page 10:

(4) Requirements for fish passage at artificial obstructions in estuaries, and above which a stream is present, are:

...

(c) Tide gates and associated fish passage structures shall be a minimum of 4 feet wide and shall meet the requirements of OAR 635-412-0035(2) within the design streamflow range and for an average of at least 51% of tidal cycles, excluding periods when the channel is not passable under natural conditions.

Paragraph (2) of this section as mentioned in (4c) spells out the "requirements for fish passage at dams and other artificial obstructions which create a discontinuity between upstream and downstream water surface or streambed elevations." Starting on page 8, this paragraph details such factors as fishway entrance locations (2b); fishway water velocities (2c); surface elevation differentials (2d); fishway widths (2f); and temperature, lighting and other factors (2j). Additional guidance in these paragraphs addresses specific fishway configurations and considerations for specific types of fish.

Tide Gates in the Pacific Northwest: Operation, Types, and Environmental Impacts,

Guillermo R. Giannico and Jon A. Souder, Oregon State University, 2005.

http://www.cooswatershed.org/Publications/tidegates_PACNW.pdf

From the introduction:

This report is an attempt to address some critical information gaps regarding the effects of dikes and tide gates on coastal ecosystems and fisheries resources. The authors have identified the information needs during their work with landowners, community organizations, and resource management agencies and through a compilation and summary of information on dikes and tide gates derived from an extensive literature review. They illustrate the characteristics of traditional tide gate designs and their operation, explain the environmental effects of dikes and tide gates, describe new tide gate designs—including those that are considered fish friendlier—and identify current knowledge gaps that may guide future research directions. Included at the end of the report are a brief directory of manufacturers (Appendix 1) and a summary of relevant U.S. and Canadian laws and regulations (Appendix 2).

Flood gates discussed include the following:

- Traditional designs:
 - Top-hinged, round and cast iron.
 - Top-hinged, rectangular and wood.
- New designs:
 - Aluminum and other lightweight materials.

- Radial.
- Side-hinged.
- Bottom-hinged.
- Rubber duckbill.
- Pet doors.
- Permanent hole.
- Self-regulating or buoyant.
- Mitigator fish-passage device.
- Muted tide regulator.
- Manually operated.
- Reversed fishway.

The Effects of Tide Gates on Estuarine Habitats and Migratory Fish, Guillermo R. Giannico and Jon A. Souder, Oregon State University, 2004.

http://www.oregon.gov/oweb/monitor/docs/mr_effectsoftidegates.pdf

This resource provides an overview of tide gates and describes the physical, chemical and biological effects of tide gates.

Tide Gate Modifications for Fish Passage and Water Quality Enhancement, Jay Charland, Tillamook Bay National Estuary Project, 1998.

http://www.oregon.gov/oweb/monitor/docs/mr_tiptidegatereport.pdf

Although this is an older publication, it presents a helpful comparison table (on page 8 of the report and reproduced below) for tide gate designs for critical performance considerations.

	Tidal flushing	Fish passage	Better Drainage?	Durability	Installation ease
Pet door, top	None	High	Yes	Good-Fair	Good
Pet door, bottom	Moderate	Moderate	No change	Fair	Fair
Side hinge, large	None	High	Yes	Good	Poor
Side hinge, small	None	High	Yes	Good	Fair
Radial (Gator)	None	Low-Mod	Yes	Poor	Good
Nekton design	Very high	Very high	N/A	Poor	Good
Aluminum	None	Low	Yes	Good	Good
Sluice/Flap gate	Very high	Very high	Yes	Fair	Fair
Conventional-Cast Iron	None	Low-None	N/A	Good	Fair
Conventional-Wood	None	Low-None	N/A	Good	Fair

Table 1. Comparison of tide gate designs for critical performance considerations.

Washington State

Water Crossing Design Guidelines, R.J. Barnard, J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith and P.D. Powers, Washington Department of Fish and Wildlife, 2013.

<http://wdfw.wa.gov/publications/01501/wdfw01501.pdf>

Discussion of tide gates begins on page 176 of these guidelines. It focuses on the effectiveness of tide gates for fish passage and the passability criteria (gate geometry, water velocity and head loss).

Biological and Physical Effects of “Fish-Friendly” Tide Gates, Correigh Greene, Jason Hall, Eric Beamer, Rich Henderson and Bruce Crown, Washington State Recreation and Conservation Office, January 2012.

http://skagitcoop.org/wp-content/uploads/EB2673_Greene-et-al_2012.pdf

From the report summary:

A number of restoration techniques exist to counter widespread estuary habitat and connectivity loss across the Pacific Northwest, ranging from dike breaching and removal to installation of “fish-friendly” or self-regulating tide gates (SRTs). However, the physical and biological effects of these techniques have not been rigorously examined. In this report, we focus on the effects of SRTs, and examine their effectiveness in two different ways. First, we used a spatially extensive design to compare three site types: SRTs, flap gates, and unimpeded reference sites. The study compared ten SRT sites located from the Columbia River estuary north to Samish Bay in northern Puget Sound, five traditional flap gate sites (designed to drain freshwater but prevent tidal inundation and saltwater intrusion), and five unimpeded reference sites. Second, we used a temporally extensive design at three SRT sites to determine changes in upstream cumulative densities of Chinook salmon across the rearing season, relative to downstream values, before and after SRTs were installed.

... [The] findings indicate that SRTs vary substantially based on design and operation and consequently vary in performance, depending upon the metric of interest. For estuarine-dependent species in general and juvenile Chinook salmon in particular, SRTs support habitat use above gates much less than natural channels and a little better than traditional flap gates. For other anadromous salmon species that may spawn in creeks above tide gates, SRTs do not appear to strongly inhibit passage or juvenile rearing density. These findings suggest that estuary restoration with SRTs will have limited benefits for juvenile Chinook salmon and other estuarine-dependent species, but can result in some improvement in connectivity and rearing habitat quality compared to traditional flap gate designs. SRT designs and operation standards that maximize connectivity, and site selection criteria that focus on reconnection of large amounts of habitat may overcome some of the limitations of reduced habitat use associated with SRT installation. These potential reductions can successfully be evaluated by comparing the benefits of SRT installation with those of other estuary restoration techniques (e.g., dike breaching or setback).

Table 1 (on page 25 of the report and reproduced below) presents temporal and spatial metrics that are used in connectivity studies:

Connectivity metric	Definition	Dimension
Spatially extensive study		
Connectedness	% of time that the channel or tide gate door is open, and water level downstream is not more than 10 cm below the downstream invert	Temporal
Leakiness	% of total tidal flux that is opposite the direction of tidal flow when SRTs gates are closed	Horizontal
Water level	Difference of tidal height (maximum or minimum) and downstream invert	Vertical
Maximum velocity	Maximum velocity (m/s) measured at site during ebb (out) and flood (in)	Horizontal
Temporally extensive study		
Tidal muting (m)	Downstream - upstream difference in maximum higher high water (MHHW)	Vertical
Effective MHHW (m)		Vertical
Tidal muting (%)	% of downstream MHHW that is muted (downstream-upstream MHHW)	Vertical
% channel width open	% of channel width that can pass water	Horizontal
% time channel is open	% of time that the channel or tide gate door is open	Temporal
% time fish can swim upstream	% of time channel or tide gate door is open and tide is flooding	Temporal

Table 7 (on page 31 of the report and reproduced below) shows the calculated correlations between these physical variables. A value of 1 indicates perfect direct relationship; -1 indicated perfect inverse relationship.

	Tidal muting (m)	Tidal muting (%)	Effective MHHW (m)	Channel wid. open (%)	Time doors open (%)	Cum. density ratio
Tidal muting (%)	0.96					-0.79
Effective MHHW (m)	-0.95	-0.93				0.75
% channel width open	-0.87	-0.88	0.93			0.87
% Time doors open	-0.98	-0.92	0.93	0.84		0.65
% Time fish can swim upstream	-0.95	-0.85	0.86	0.75	0.96	0.56

Related Resource:

Summary and Synthesis of Comments on a Study of the “Biological and Physical Effects of ‘Fish Friendly’ Tide Gates,” Betsy Lyons and Mike Ramsey, Washington Department of Fish & Wildlife, March 2013.

http://www.pugetsoundnearshore.org/esrp/files/tide_gate_synthesis_mar2013.pdf

This document “summarizes and translates” the report in the previous citation “into less technical language.” The authors provide a helpful, plain-language summary that begins on page 4 of the report:

- **Tide gates limit fish passage and provide less ecological benefits than natural systems.**
- **The effectiveness of self-regulating tide gates varies by species and life history groups.**
 - For estuarine-dependent species including juvenile Chinook salmon, natural sites in this study supported densities an order of magnitude greater than the systems with tide gates.

- Non-estuarine dependent species and adult salmonids were less negatively affected by tide gates.
- **Self-regulating tide gates (SRTs) can provide greater ecological benefits than traditional flap gates.**
- **Tide gates, including SRTs, vary considerably in type and amount of benefits provided.**
 - The driving factors related to the effectiveness of tide gates in providing ecological benefits are not well documented.
 - Although a good first step, the study was not able to evaluate variability in tide gate operations or design variability among SRTs. More information is needed to understand the potential for significantly improving the benefits of SRTs through informed design and operation.
- **Continued studies are needed** to better understand how tide gate design and operation affect physical process and how these changes affect habitat use by estuarine species, especially in the case of SRTs. Until these issues are better understood it will be difficult to evaluate whether SRTs provide significant enough benefits over traditional flap gates to be considered a useful restoration element. We also need to understand the type and amount of habitat potentially made available upstream of any replacement tide gate in order to gauge the value of the installation.

Appendix A, Technical Questions and Answers (Q&A), which starts on page 9, may also be of particular interest to Caltrans. It presents questions about the study posed by local, state and federal agencies, and answers provided by the report authors. These practical, implementation-oriented questions may be similar to the types of questions that Caltrans may have. These include the following (in abbreviated form):

- Question 7 (page 15): How do different gate designs and operating conditions affect gate function?
- Question 8 (page 15): What additional guidance can you provide for monitoring tide gate performance?
- Question 9 (page 16): [Could] future investigation focus on establishing design criteria for maximizing fish benefit that could be applied to site-specific SRT installations?
- Question 14 (page 18): What future supplemental studies do you suggest to demonstrate whether there can be adequate benefits from well-managed SRTs?

International Resources

Belgium

“On-Site Evaluation of a Fish-Friendlier Tide Gate Design,” Peeters Patrik, Leonid Verzhbitskiy, Tom Maris, Maarten Stevens and Peter Viaene, *33rd IAHR Congress: Water Engineering for a Sustainable Environment*, 2009.

<http://homepages.abdn.ac.uk/geo319/Document%20Library/Tide%20Gates.pdf>

This study conducted an analysis of the “pet door” style tide gate, providing head discharge calculations, calculated and measured flows, an examination of leakage and robustness, and a qualitative examination regarding fish migration.

United Kingdom

Self-Regulating Tide Gate: A New Design for Habitat Creation, Glen Ridgway and Mike Williams, Environment Agency, Bristol, United Kingdom, September 2011.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291577/scho0811_buay-e-e.pdf

From the executive summary:

The objective of the project was to develop a generic design for a structure to permit and control tidal flows through defenses and allow controlled inundation of currently defended land. The design should allow the creation of inter-tidal habitats behind existing defenses while maintaining a specified level of protection.

... The project has resulted in an innovative float-operated rotary valve that is adaptable to a wide range of situations and adjustable to refine its operation once installed. Two prototypes have been installed at Seaton in Devon and Lymington in Hampshire to demonstrate the successful use of the self-regulating tide gates in different applications. This report elaborates on the design and operation of the new tide gate and draws attention to the benefits of its adoption.

Hydrologic Modeling

National Resources

U.S. Army Corps of Engineers

Hydrologic Engineering Centers River Analysis System (HEC-RAS), U.S. Army Corps of Engineers, undated.

<http://www.hec.usace.army.mil/software/hecras/>

This is the official website of the HEC-RAS modeling software referenced as a primary modeling tool by individuals interviewed for this Preliminary Investigation. The site includes links to the HEC-RAS software, documentation and demonstrations.

Coastal Modeling System (CMS), U.S. Army Corps of Engineers, undated.

<http://www.erdc.usace.army.mil/Media/FactSheets/FactSheetArticleView/tabid/9254/Article/484188/coastal-modeling-system.aspx>

From the website:

The Coastal Modeling System (CMS) is a suite of coupled two-dimensional (2D) numerical models for simulating waves, hydrodynamics, salinity and sediment transport, and morphology change. Developed by the Coastal Inlets Research Program (CIRP) of the ERDC Coastal & Hydraulics Laboratory (CHL), the CMS provides coastal engineers and scientists an efficient tool for understanding coastal processes and for designing and managing of coastal inlets, navigation channels, ports, harbors, coastal structures and

adjacent beaches. The CMS was identified by the USACE Community of Practice (CoP) as a preferred model for Coastal Engineering and Coastal Navigation investigations.

Related Resource:

Implementation of Structures in the CMS: Part IV, Tide Gate, Honghai Li, Alejandro Sanchez and Weiming Wu, U.S. Army Corps of Engineers, 2013.

<http://acwc.sdp.sirsi.net/client/search/asset/1029160>

From the report purpose:

This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the mathematical formulation, numerical implementation, and input specifications of tide gates in the Coastal Modeling System (CMS) operated through the Surface-water Modeling System (SMS). A coastal application at an idealized inlet is provided to illustrate the implementation procedure and demonstrate the model capability.

The document details the mathematical formulation and numerical implementation of the tide gate model.

Hydraulic Design of Tidegates and Other Water Control Structures for Ecosystem Restoration Projects on the Columbia River Estuary, Patrick S. O'Brien, Hydrologic, Coastal, & River Engineering Section, U.S. Army Corps of Engineers, Portland District, 2005.

<http://www.dtic.mil/ndia/2005triservice/track2/obrien.pdf>

On page 28 of this presentation is a discussion of tide gate hydraulics for top- and side-opening gates. An overview of muted tide gates begins on page 46.

National Oceanic and Atmospheric Administration

Tide Gate Hydraulic Model, Christopher Gifford-Miears and Aaron Beavers, NOAA Fisheries Brown Bag Session, August 1, 2012.

<https://prezi.com/bas0szriwd3o/tide-gate-hydraulic-model-odfw-presentation/>

NOAA is developing a new tide gate hydraulic model to improve current techniques to more easily evaluate tide gate design options and assess fish passability. This presentation covers:

- A brief introduction to tide gates.
- Tide gate hydraulics.
- Previous tide gate modeling work.
- NOAA's motivation for an improved tide gate model.
- Progress toward the new model.
- Future work and anticipated results.

The presentation notes that "work in progress includes incorporating new tide gate technologies such as muted tidal regulators (MTR) and self-regulated tide gates."

One-Dimensional Tide Gate Hydraulics Model, Arturo Leon, School of Civil and Construction Engineering, Oregon State University, research in progress.

http://web.engr.oregonstate.edu/~leona/Projects_CGM.html

From the project description:

The goal of this project is to develop a one-dimensional model accounting for hydraulic and hydrologic effects at tide-gate installation and retrofit sites. The specific objectives of the project are:

1. To develop a simulation model with an intuitive interface assisting engineers to perform sensitivity analyses on tide-gate site components.
2. Utilize this simulation to assist in developing a set of guidelines and standards for Tide-Gate retrofits.

State Resources

New Jersey

“Impact of Sea Level Rise on Tide Gate Function,” S. Walsh and R. Miskewitz, *Journal of Environmental Science & Health*, Vol. 48, No. 4, pages 453-463, 2013.
<http://www.ncbi.nlm.nih.gov/pubmed/23379951>

From the abstract:

Higher downstream mean sea level elevations reduce the effectiveness of tide gates by impacting the hydraulics of the system. This project developed a HEC-RAS and HEC-HMS model of an existing tide gate structure and its upland drainage area in the New Jersey Meadowlands to simulate the impact of rising mean sea level elevations on the tide gate’s ability to prevent upstream flooding. Model predictions indicate that sea level rise will reduce the tide gate effectiveness resulting in longer lasting and deeper flood events.

While sea level rise is not the focus of this Preliminary Investigation, the hydraulic modeling of tide gates in this study may be of interest to Caltrans.

Oregon

“Using HEC-RAS 3.1.3 to Model and Design Tide Gate Systems,” Susan J. Novak and Christopher R. Goodell, *Proceedings of the West Coast Symposium on the Effects of Tide Gates on Estuarine Habitats and Fishes*, 2006.
<http://fw.oregonstate.edu/system/files/u3034/proceedings%20of%202006.pdf>

From the abstract (page 55 of the PDF):

As estuary restoration progresses, it is impossible to overlook the importance of proper tide gate design. Most tide gates in use today are broken, ill-fitting, or do not function to meet current design criteria for fish passage. Habitat and marine life standards and issues must be taken into account when designing these in-stream structures. Pursuant to this task, NOAA engineers and biologists have developed a set of design criteria for fish passage at tide gates, modeled on NOAA’s draft culvert criteria. These criteria are still in the writing process and have not been rigorously used or tested yet. Numerical modeling programs such as HEC-RAS 3.1.3 can be used to accurately model tide gates in estuarine systems. A representative test set of tide gate scenarios and tidal data was run in HEC-RAS to examine differences in hydraulic characteristics. The results showed that for the scenarios tested, NOAA criteria could be simultaneously satisfied only about ten to fifty percent of the time the

gate was open. This was demonstrated by a case study performed by WEST Consultants on Kentuck Slough near Coos Bay, Oregon. The modeling also indicates that the percent time passable may be increased by improving the hydraulic efficiencies in the culvert inlet, exit, and in the tide gate opening.

Kentuck Slough Tide Gate Replacement Project (Oregon), Water Environmental Sedimentation Technology (WEST) Consultants, Inc., 2016.

<http://www.westconsultants.com/services/hydraulics/kentuck-slough-tide-gate-replacement-project--or->

From the project summary:

WEST developed an HEC-RAS unsteady flow hydraulic model of the tide gate designs to accommodate and improve upon conditions that encourage the estuarine habitat, while at the same time, will not increase the volume of salt-water influx to the slough over the existing conditions.

Contacts

CTC contacted the individuals below to gather information for this investigation.

Consultant

Michael Love
Principal Engineer
Michael Love & Associates, Inc.
707-822-2411, extension 1, mlove@h2odesigns.com

National Oceanic and Atmospheric Administration

Correigh Greene
Research Biologist
NOAA Fisheries
206-860-5611, correigh.greene@noaa.gov

Aaron Beavers
Hydraulic Engineer
NOAA Fisheries West Coast Region
503-231-2177, aaron.beavers@noaa.gov

California Department of Fish & Wildlife

Mike Wallace
Environmental Scientist
California Department of Fish & Wildlife
707-822-3702, mike.wallace@wildlife.ca.gov

The Water Institute of the Gulf

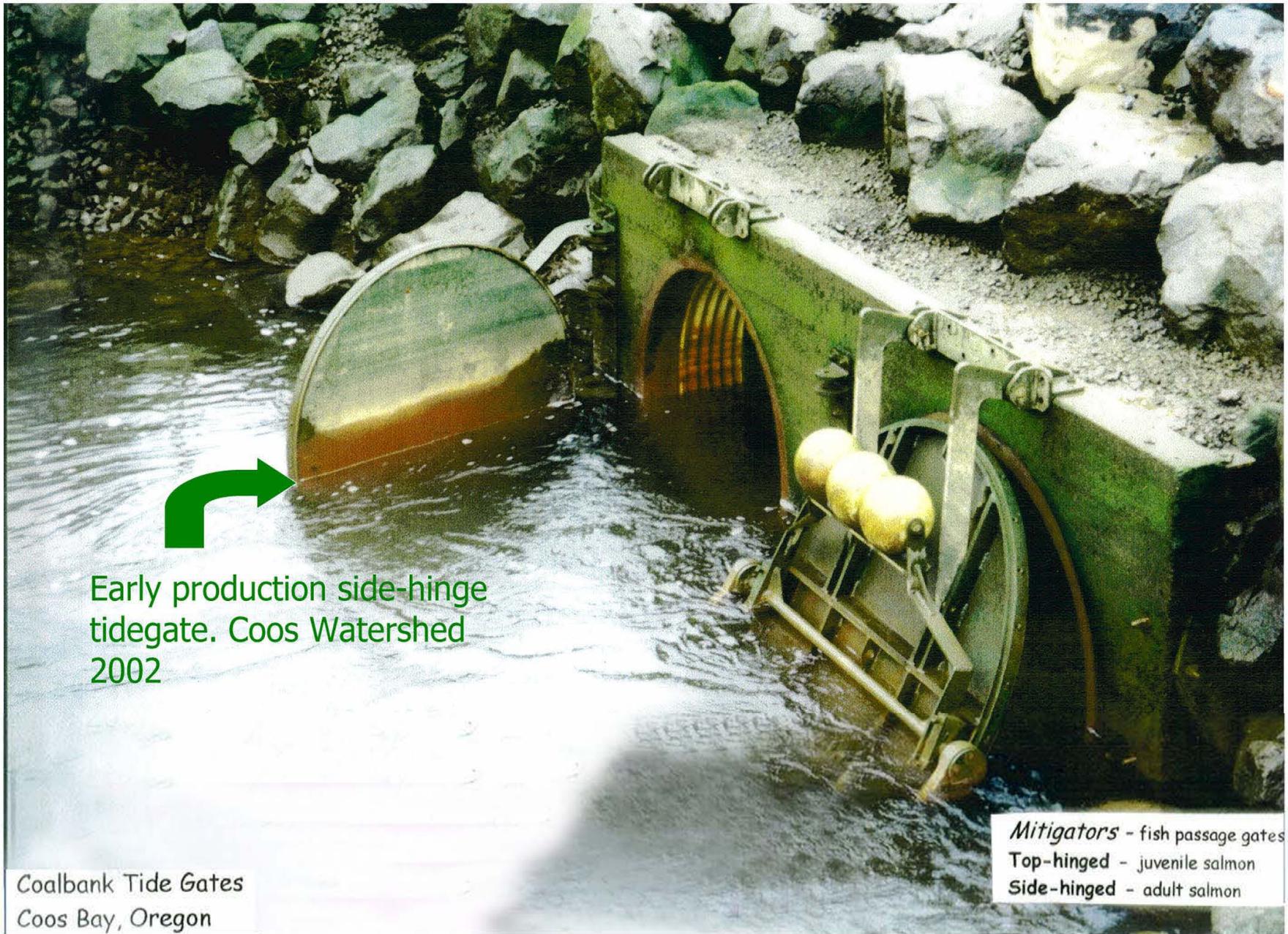
Ehab Meselhe
Director of Natural Systems Modeling and Monitoring
The Water Institute of the Gulf
225-227-2717, emeselhe@thewaterinstitute.org

Sidehinge Tide Gates & Muted Tidal Regulators



Leo Kuntz
Tidegate Specialist
Nehalem Marine Manufacturing
Nehalem, Oregon

July 17, 2014

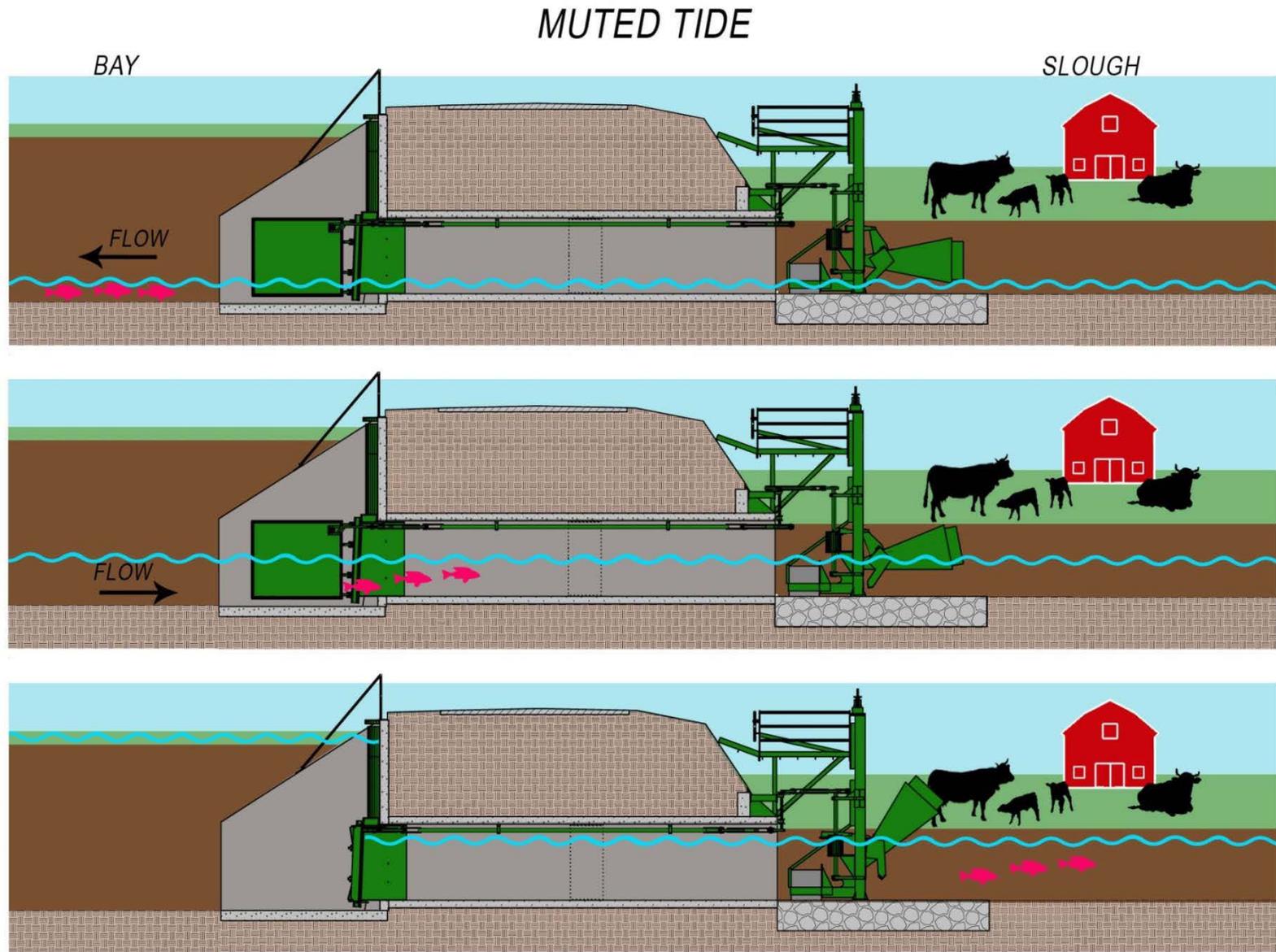


Early production side-hinge tidegate. Coos Watershed 2002

Coalbank Tide Gates
Coos Bay, Oregon

Mitigators - fish passage gates
Top-hinged - juvenile salmon
Side-hinged - adult salmon

An illustration of a typical muted tidal cycle showing how the tidegate remains open during incoming tide until the interior inundation level is reached.



MTR Controlled Auxiliary Door



Location: USFW
Humboldt Bay
National Wildlife
Refuge

Little Pompey Before Restoration



Little Pompey After Restoration



Muted Tidal Regulator (MTR) System



Pheylane MTR

Location: Pheylane
is 8 miles east of
Florence, OR on
the Siuslaw River.

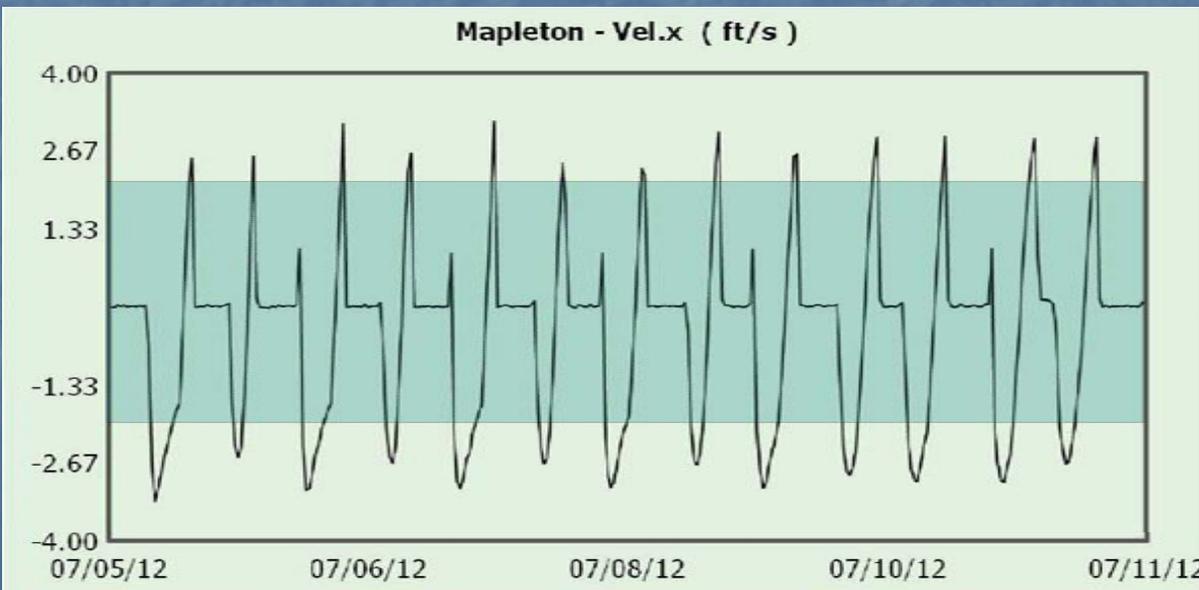
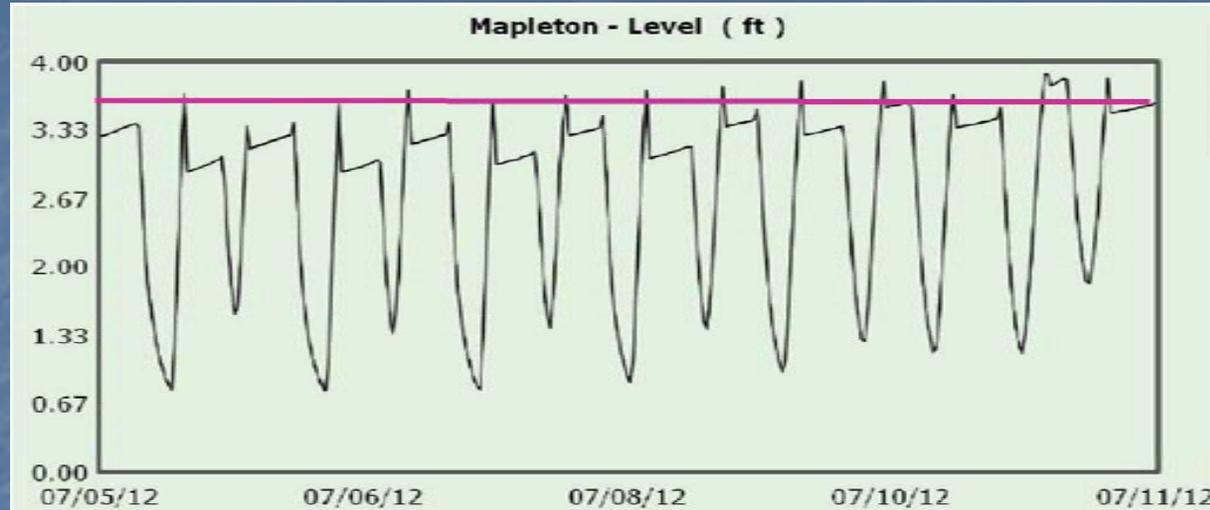


Pheylane

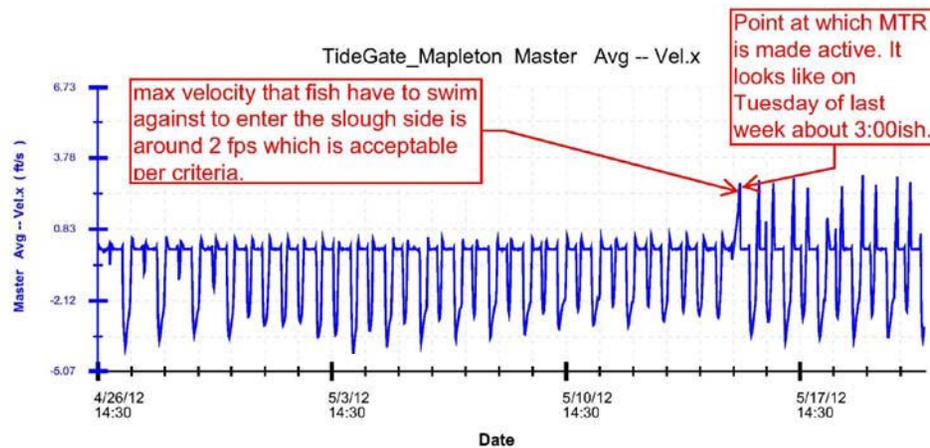


PheyLane Monitoring

MTR regulating interior inundation level (Peaks indicate water level where gate is closing)
Inundation level set for 3.50'.



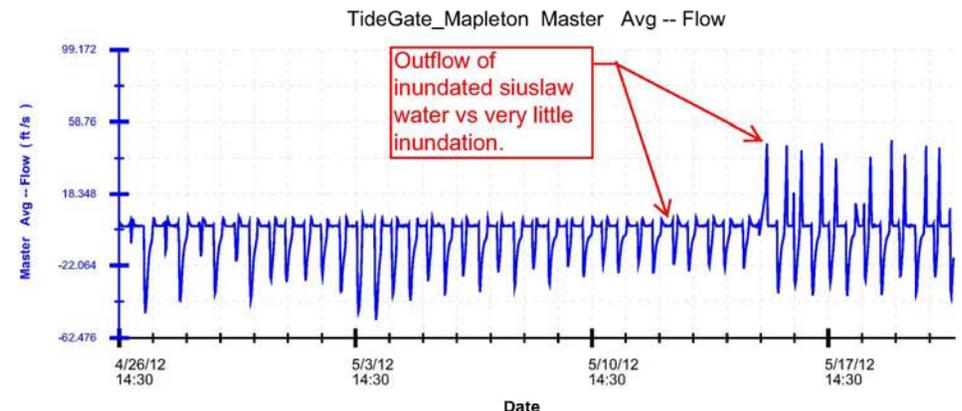
Graph showing that the system is meeting ODFW velocity requirement of 2fps.



These graphs are a great data collection of a side-hinge gate operating w/out a regulator then the same gate operating with a regulator. As the data is a direct comparison (same gate, same waterway) it is very telling.

We obtained this data as the MTR for this gate was unhooked for modifications (beginning of graphs) then re-activated (end of graphs)

(Pheylane tidegate. Slides from Ryan McCormick ODFW)



Fish Passage @ Pheylane

Coho entering OCTH through MTR side-hinge tidegate. They are presumed to be from upper Siuslaw Watershed and seeking OCTH.



Kentuck Tidegates

Early MTR system. Kentuck Slough, Coos Bay for Coos County Roadway Dept. (site of electronic monitoring station installed early 2012)



Top Hinge Side Hinge Array with MTR

Kentuck Tidegates Monitoring Data



Main Screen Display.

Note: North gate is MTR equipped.

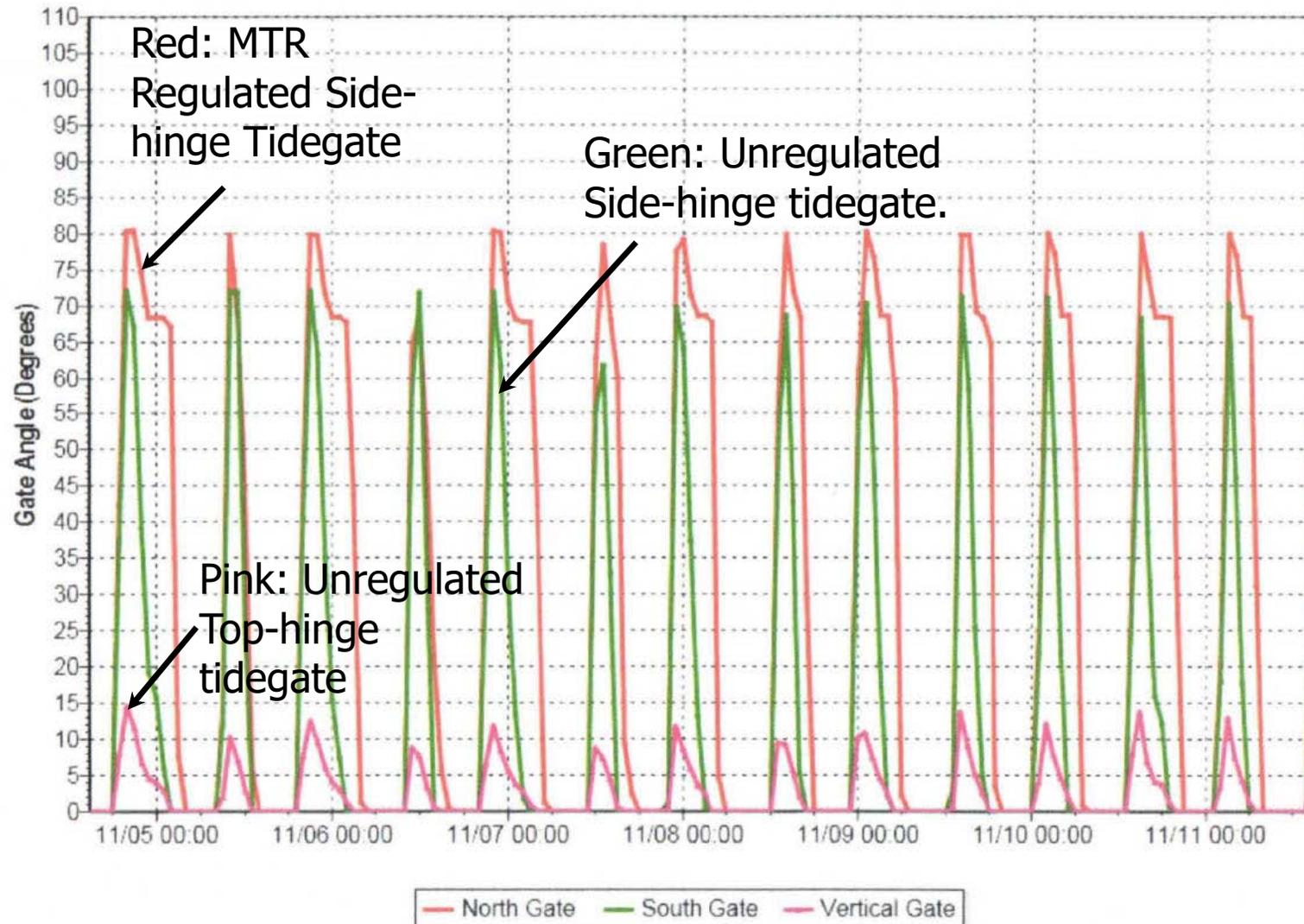
Kentuck Tidegates Monitoring Data

Nehalem Marine Manufacturing

Kentuck Inlet

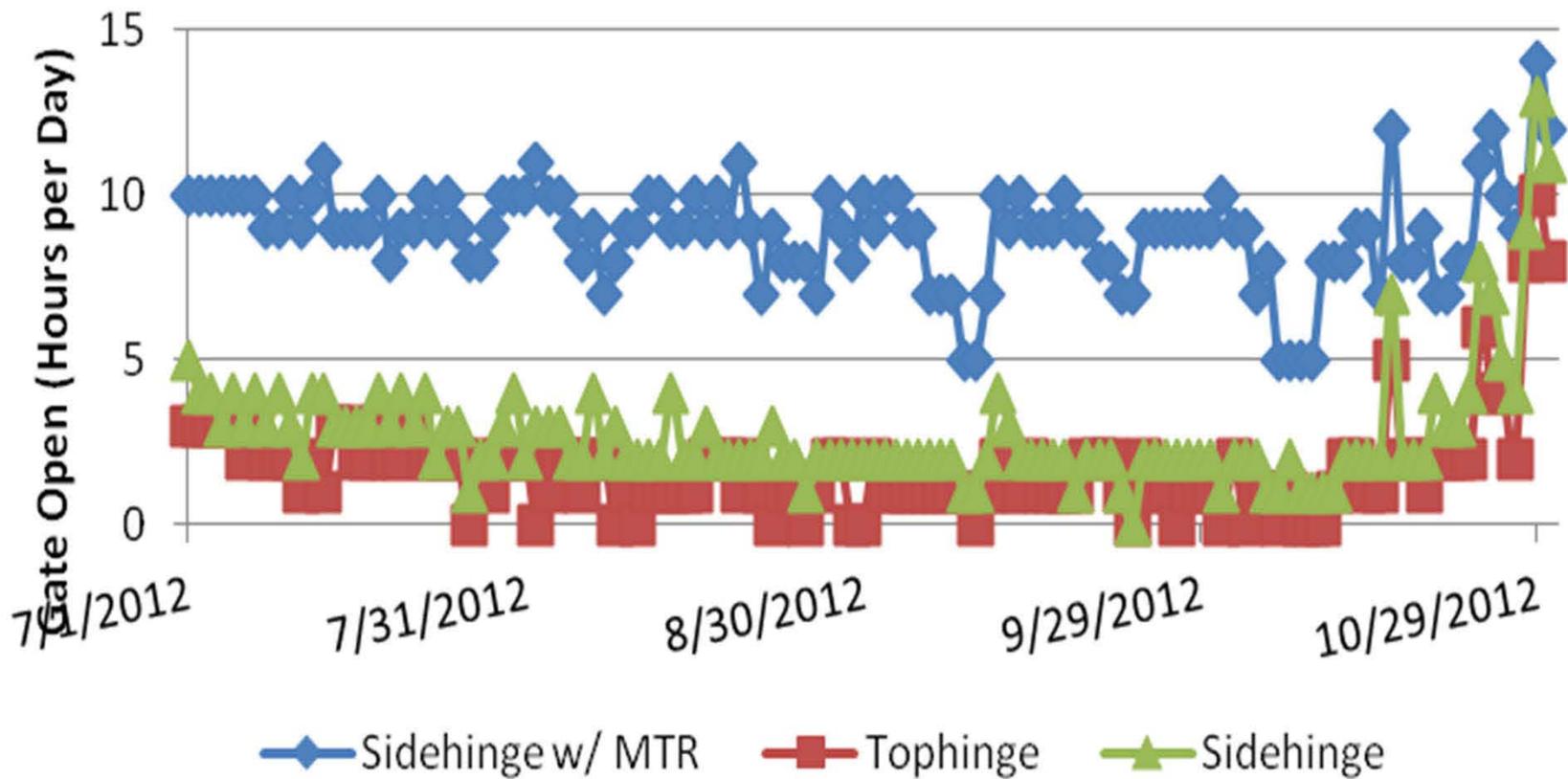
Graph showing how far the gates open.

Weekly Trend



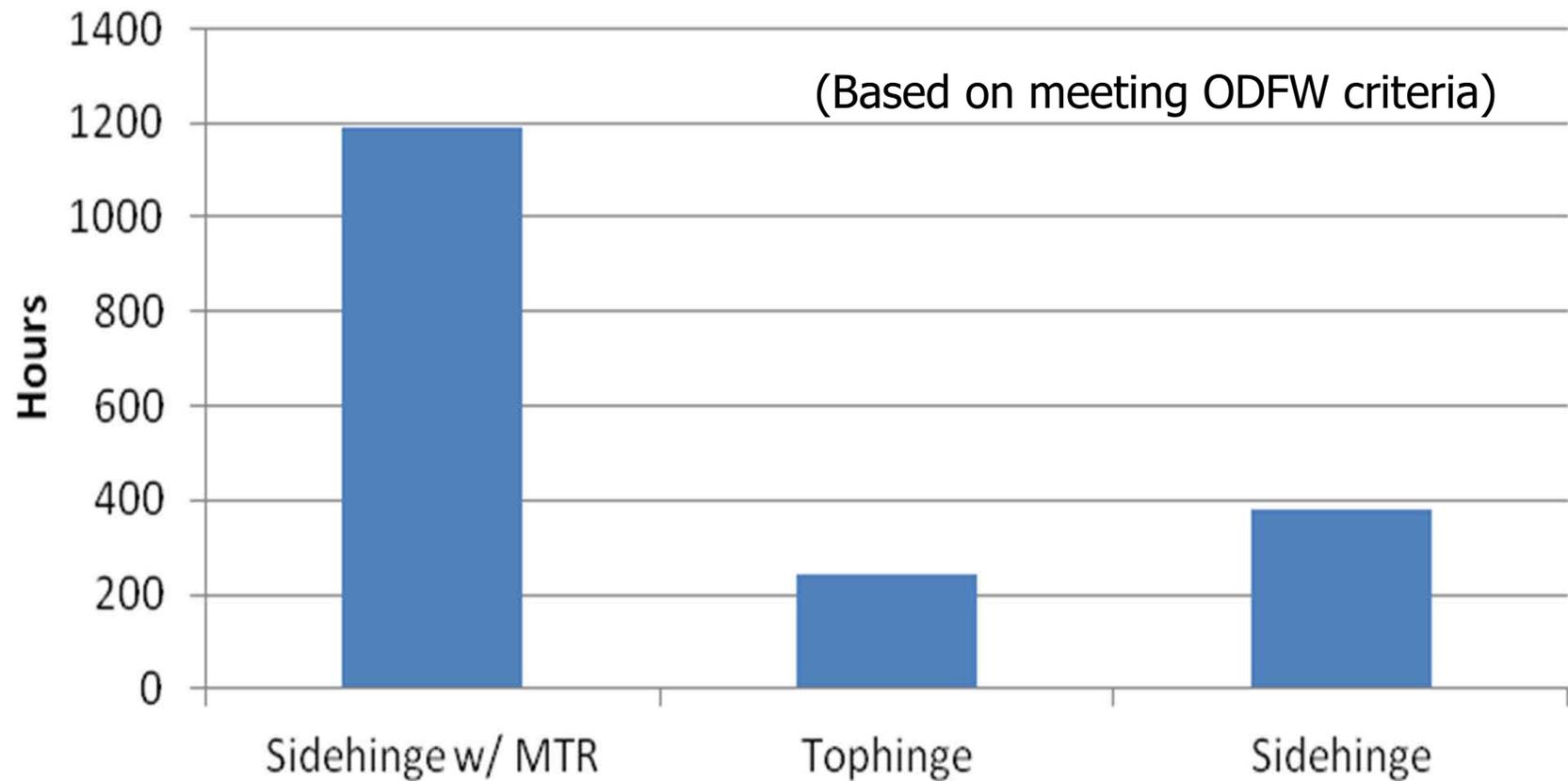
Kentuck Tidegates Monitoring Data

Tidal Gate Fish Passage Duration Jul 1- Oct 31, 2012



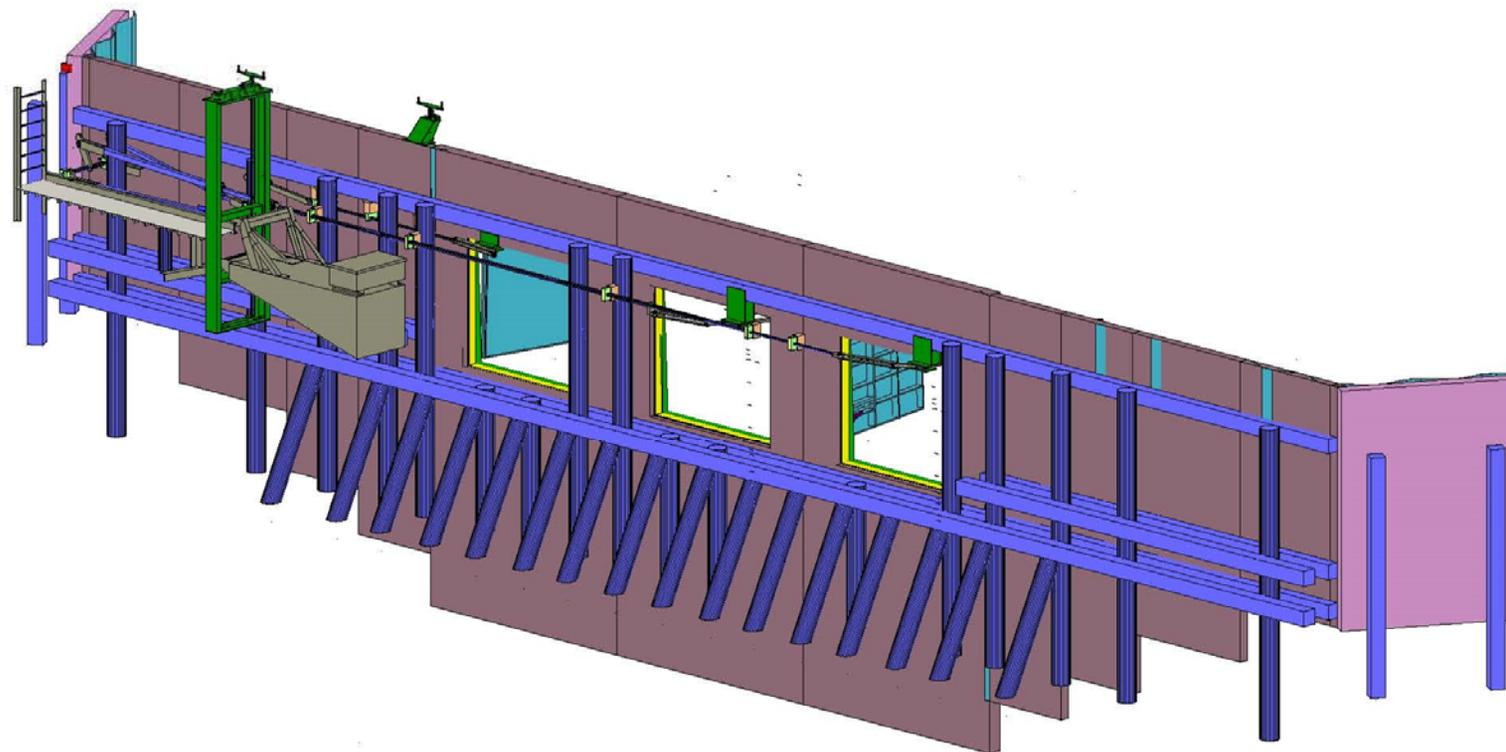
Kentuck Tidegates Monitoring Data

Fish Passage Time Hours from July 1 to October 31



Fisher Slough Restoration





Fisher Slough Compatible Restoration

- **This photo is intended to show restored/wet habitat adjacent to a growing commercial potato crop. This photo was taken as the water receded after three weeks of very high water in June and early July this year. The river had been near flood stage so the floodgates were closed much of the time and tributaries were also high. The dike and drainage measures we installed seemed to work great; the field was dry and the crop did fine. This was not the case in other fields in the delta.**



North Slough tidegates
under construction at
the shop.

Existing North Slough
tidegates to be
replaced. (01-23-13am)

North Slough tidegate
replacement project
01/23/13 mid-day.

North Slough tidegate
replacement project
01/23/13 early
afternoon.

North Slough MTR
installation on interior.

North Slough 01/23/13
afternoon, operating
normally.

Agricultural/Fish Passage

A typical 4' side-hinge tidegate
"ready to install" unit.

Typical 4' side-hinge
tidegate unit
installed.

Fornsby Slough



Tidegate & MTR system at slack low-Tide.

Small note: Failed culverts and SRT have been replaced with sidehinge gate and MTR, mark on bank at target inundation level



Target
inundation
level.



Tide flooding in.



Nearing inundation level.



Tidegate closing.



Tidegate MTR system at full
Inundation level.

Note: The high-value agricultural
land in the back ground.



Tidegate closed.

