Tide Gate & Tidal Wetland Monitoring

Guidance & Protocols
for Estuary Practitioners

2024

Funded by the Oregon Watershed Enhancement Board (OWEB) in collaboration with the Coquille Watershed Association (CoqWA), The Nature Conservancy (TNC), and the Tillamook Estuaries Partnership (TEP).

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List of Acronyms

ANOVA	analysis of variance
AU	animal unit
AUM	animal unit month
BACI	Before-After Control-Impact
BACIPS	Before-After Control-Impact Paired Series
BLM	U.S. Bureau of Land Management
CoqWA	Coquille Watershed Association
CPUE	catch per unit effort
CSA	channel cross-sectional area
DEQ	Oregon Department of Environmental Quality
DST	data storage tag
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESU	evolutionarily significant unit
GIS	geographic information system
LTWG	Lamprey Technical Workgroup
MAMP	Monitoring and Adaptive Management Plan
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
NAVD88	North American Vertical Datum of 1988
NDMC	National Drought Mitigation Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OAR	Oregon Administrative Rules
ODFW	Oregon Department of Fish and Wildlife
OSU	Oregon State University
OWEB	Oregon Watershed Enhancement Board
PIT	passive integrated transponder
PLCI	Pacific Lamprey Conservation Initiative
PMEP	Pacific Marine & Estuarine Fish Habitat Partnership
PTSC	PIT Tag Steering Committee
PVC	polyvinyl chloride
RTK	real-time kinematic
SAP	Sampling and Analysis Plan
SRT	self-regulating tide gate
TARP	Tidal Area Restoration Program
TEP	Tillamook Estuaries Partnership
TNC	The Nature Conservancy
USGS	U.S. Geological Survey
WMP	water management plan
WSE	water surface elevation
WVDEP	West Virginia Department of Environmental Protection

1. Introduction

1.1. Tide Gates and Their History

Tide gates are structures used to control water flow in and out of coastal areas, estuaries, or other water bodies. They are typically installed in tidal or coastal embankments and designed to regulate water movement to prevent flooding during high tides or storm surges and to manage water levels in areas prone to tidal influence. Tide gates often have hinged barriers or gates that can be opened and closed to allow water to drain off working lands and prevent it from impacting land and infrastructure.

In the early 1900s, European settlers in the Pacific Northwest drained wetlands and converted lowlands to agricultural, industrial, and urban uses. In the process, tide gates served as a critical engineering tool to limit and control the extent of water movement across the landscape. Tide gate installations numbered in the thousands, ranged in size from small wooden structures to large concrete barriers, and were primarily used to regulate water levels in marshes and estuaries. Until recent inventory efforts, the numbers and locations of much of this infrastructure were unknown — and as a result, the aggregated effect of the loss of tidal marsh and estuarine connectivity and its impact on ecosystem health was also largely unknown (Oregon Tide Gate Partnership n.d.). In recent years, the science linking tidal connectivity barriers to their harmful effects on fish habitat and life cycle has been mounting, with specific attention focused on the substantial impact of tide gates (Souder *et al*. 2018). Poorly functioning tide gates have detrimental effects on water quality (pH, temperature, dissolved oxygen, etc.), plant communities, channel complexity and connectivity, and general ecosystem function. Critically, tide gates can restrict fish passage, often limiting access to critical habitat during key life stages.

Handbook Goals

1. Establish consistent and comparable monitoring methods across projects to promote the distribution of knowledge across geographies and enable practitioners to share information and experiences, allowing for a more comprehensive understanding of the challenges and opportunities associated with tide gate projects.
2. Create monitoring methods appropriate for any tide gate project, regardless of scale, location, or funding level, to ensure monitoring is accessible to all practitioners, regardless of available resources.
3. Ensure monitoring results inform tide gate projects' future design and ongoing adaptive management by monitoring and evaluating the performance of the projects, thus enabling the tide gate community to identify areas for improvement and make necessary adjustments to ensure the long-term success of these projects.

1.2. Improved Standardization

While tide gate removal is ideal for fish passage and estuary function, replacing derelict tide gates with updated fish-friendlier designs is more frequently used as a balanced solution between ecosystem improvements and existing working lands. These upgrades can be very expensive and are often funded with public money. Current understanding of the effectiveness of these projects, however, has not kept pace with the number of new tide gates being installed along the West Coast (Figure 1).

A publication funded by the Oregon Watershed Enhancement Board (OWEB), *Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis* (Souder *et al*. 2018), specifically identified the need for statewide standardization of tide gate monitoring parameters and protocols.

Well-designed tide gate monitoring answers myriad questions focused on baseline requirements for permits, adaptive management of implemented projects, and restoration effectiveness. Yet, few, if any, standard monitoring protocols or established practices currently exist to guide project managers through monitoring strategies. This lack of guidance limits the tide gate community's ability to compare results from different sites or from the same site through time. It also inhibits the easy transfer of institutional knowledge and lessons learned from previous successes or setbacks and limits the capacity to monitor results to inform adaptive management practices. A clear need exists for a cohesive statewide tide gate monitoring strategy.

1.3. Purpose

This handbook aims to establish a statewide standard for recordkeeping and monitoring that unites the restoration community under a single well-defined set of reporting standards, protocols, and procedures to monitor tide gate upgrade and replacement projects. It sets a minimum monitoring expectation for project success and provides clear guidance on what to monitor and when.

The datasets derived from monitoring activities will build a baseline understanding and common language that allow practitioners, agencies, and academia to more effectively evaluate tide gate performance, inform adaptive management strategies, pass on lessons to future projects, and compare tide gates across multiple estuaries.

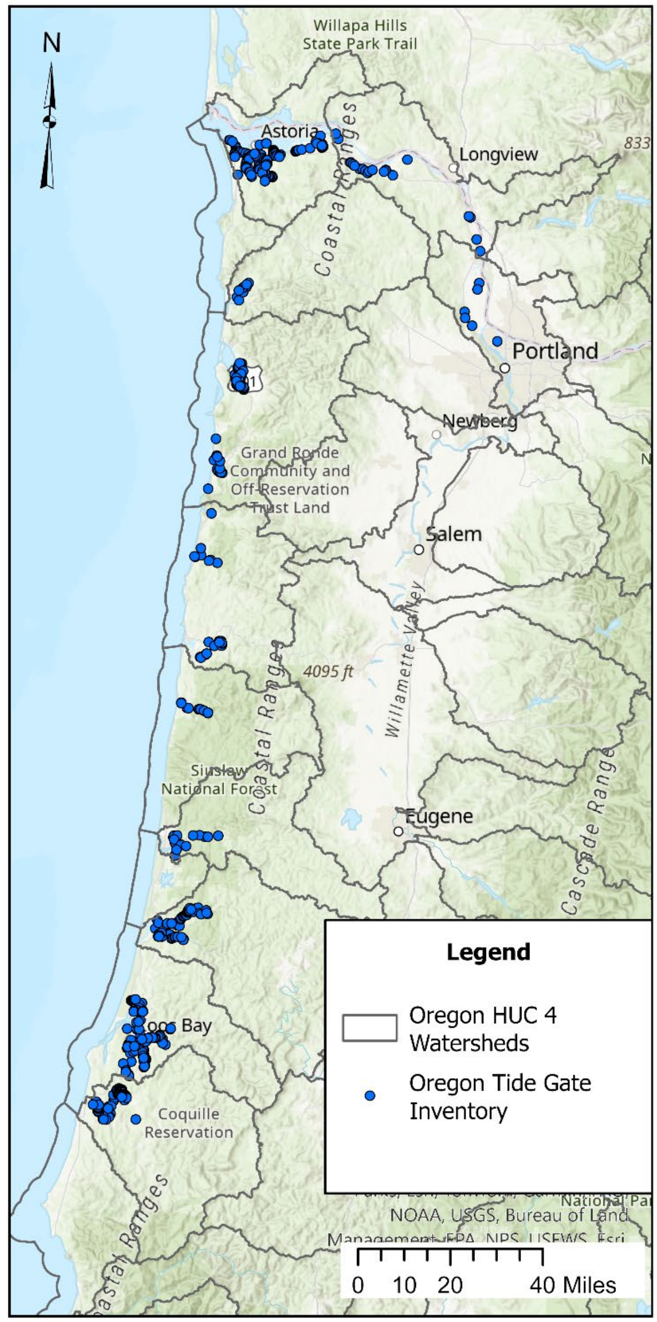


Figure 1. Map of approximately 660 tide gates in Oregon. Source: Coquille Watershed Association (CoqWA; 2023).

1.4. Content and Layout

This document was developed while keeping in mind watershed councils, private landowners, researchers, and others interested in upgrading tide gates. It provides a simple and flexible framework that consolidates practical information for all stages of tide gate upgrade and replacement projects. The handbook can also be used for projects of all sizes as an educational resource to identify different monitoring options, associated financial and labor costs, and how to link broad restoration goals with boots-on-the-ground monitoring.

The informational core of the handbook is found in the next four chapters. (Figure 3 diagrams the handbook user's basic workflow.) Chapters 2–4 house datasheets and decision matrices. Chapter 5 presents a collection of protocol sheets describing standardized monitoring methods and materials. Protocol sheets provide consolidated, easy-to-access information for more than 35 monitoring parameters. They describe best practices for general field design, materials needed, methods, and field tips and tricks, and they include additional resources and corresponding literature.

The handbook layout uses a tiered approach based on the tide gate project scale and divides monitoring into three main tiers: **implementation**, **compliance**, and **effectiveness**. Each monitoring tier increases in extent and complexity as projects scale in size. See Figure 2 for definitions.

Implementation Monitoring

Information gathered to assess whether a tide gate project was built as designed.

Compliance Monitoring

Monitoring to determine whether a tide gate project is functioning as designed and meeting permit requirements.

Effectiveness Monitoring

Monitoring that seeks to critically evaluate a project's performance and restoration efficacy.

Figure 2. Monitoring tier definitions.

Follow Table 1 to determine a tide gate project's scale and identify recommended tiers of monitoring. Monitoring tiers are additive, so a Tier 2 project is one that should complete both Tier 1 and Tier 2 monitoring.

Each monitoring tier is described in detail within its own upcoming chapter, which outlines primary monitoring goals and the process for developing a monitoring design within that tier.

Implementation monitoring (Chapter 2) is the most basic level of monitoring and is recommended for the simplest of projects with no formal monitoring plan. Examples include but are not limited to projects with interior field gates, gates with minimal habitat behind them, no self-regulating tide gates (SRTs), and no water management plan (WMP). Implementation monitoring uses a simple standardized datasheet to record basic build information common to all tide gate projects. If your tide gate project does not involve an SRT, this is the extent of recommended monitoring, though more monitoring is not discouraged.

Compliance monitoring (Chapter 3) is the next tier up and should be completed for projects with SRTs. This monitoring is intended to determine if a tide gate project is functioning as designed. Through interviews, surveys, and literature reviews, five key monitoring parameters were identified as the most relevant for assessing tide gate function. These five monitoring parameters are highly recommended when determining if a tide gate project is functioning as designed and meeting permit criteria. For each parameter, a protocol sheet guides practitioners through planning, executing, and analyzing field measurements (see Chapter 5 for protocol sheets).

Effectiveness monitoring (Chapter 4) is recommended for the largest, most complex tide gate projects with extensive habitat and/or projects with an associated Monitoring and Adaptive Management Plan (MAMP). Effectiveness monitoring is useful for projects seeking to critically evaluate performance and restoration efficacy. Large projects with multifaceted objectives and goals require flexible monitoring strategies. So, the decision matrix in Chapter 4 (Table 3) provides users with a plug-and-play approach to develop a monitoring design suited to their project's specific needs.

The decision matrix seeks to align project requirements, interests, and goals with specific monitoring by offering 36 monitoring parameters housed within seven broad project-goal categories, with example restoration questions for each parameter. It also includes basic quantity, duration, and frequency estimates across two funding levels for each parameter to expedite resource requirement estimates. Additionally, as with compliance monitoring, each effectiveness monitoring parameter is associated with a one- to two-page protocol sheet (Chapter 5) to guide practitioners through planning, executing, and analyzing field measurements.

Protocol sheets provide consolidated, easy-to-access information on best practices for general field design, materials needed, methods, field tips and tricks, additional resources, and corresponding literature.

Note: All projects, regardless of size, may have additional monitoring requirements outlined by funding and/or regulatory agencies. These requirements are not outlined in this document.

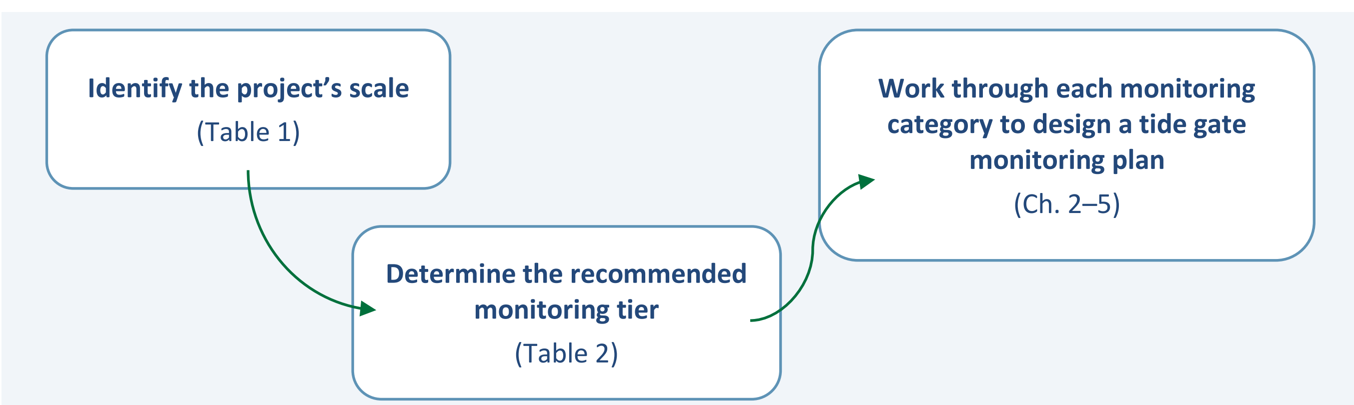


Figure 3. Basic workflow for an individual using this handbook.

Use Table 1 to determine the project scale and identify the extent of recommended monitoring. Monitoring is cumulative, so as projects increase in scale, additional monitoring is added. Each of the three monitoring tiers — implementation, compliance, and effectiveness — are described in subsequent chapters, providing a modular approach to overall monitoring plans.

Table 1. Recommended monitoring matrix for tide gate upgrade and replacement projects

		Recommended Monitoring		
Project Scale		Tier 1 Implementation	Tier 2 Compliance	Tier 3 Effectiveness
Scale I:	Simple and small non-SRT upgrades or replacements with no formal monitoring required, minimal fish and wildlife habitat, and no WMP	Recommended	Optional	Optional
Scale II:	Tide gate upgrades or replacements with SRTs, fish and wildlife habitat, WMPs, etc.	Recommended	Recommended	Optional
Scale III:	Large, complex tide gate upgrade or replacement projects with extensive habitat and/or projects with an associated MAMP	Recommended	Recommended	Recommended

2. Implementation Monitoring

> **Implementation Monitoring**
> Information gathered to assess whether a tide gate project was built as designed

Implementation monitoring is a vital component of successful project management that consolidates as-built design data, identifies deviations from design plans, and provides valuable data for statewide databases.

This tide gate handbook recommends implementation monitoring for all projects (Scales I–III). Moreover, implementation monitoring is the only monitoring tier recommended for simple and small non-SRT upgrades or replacements with no formal monitoring required, minimal fish and wildlife habitat, and no WMP.

This monitoring standardizes recordkeeping on the most valuable aspects of a tide gate project's information, site characteristics, and as-built measurements.

Monitoring consists of completing the simple two-page datasheet that begins on the next page. It is intended to be completed by a project manager or design engineer. The datasheet consolidates project information, allowing funders and regulators to quickly identify key implementation parameters and easily cross-reference standardized information between different tide gate projects.

Please complete the Tide Gate Implementation Monitoring Datasheet (found on the following two pages) within six months of project completion and include it with OWEB final reports.

Tide Gate Implementation Monitoring Datasheet

Please complete this sheet within six months of project completion.

Site name:	Report date:
Tide Gate Inventory ID #:	
Project manager/organization:	

Project Information

Project engineer firm and engineer name:		
Was the Pipe Sizing Tool* used for this project?		
Year of tide gate installation:		
Tide Gate Characteristics		
Style:	Model (if known):	# of gates:
Implementation date of other project elements (riparian planting, channel formation, etc.):		
Is compliance and/or effectiveness monitoring being conducted?		

Site Characteristics

Primary watershed name:			
Watershed area (acres):			
Miles of channel habitat upstream of tide gate:			
Tide gate coordinates as latitude/longitude in decimal degrees: (example: 43.176514, -124.228959)			
Water surface elevation at MHHW** at tide gate outlet (NAVD88*** feet):			
Water surface elevation at MLLW**** at tide gate outlet (NAVD88 feet):			
Area of project inundation at MHHW (acres):			
Area of project inundation at MLLW (acres):			
Project area elevation (NAVD88 feet):	Mean:	Min:	Max:

* The Oregon Tide Gate Pipe Sizing Tool (Oregon Tide Gate Partnership 2024) is a model intended to serve both landowners and technical support organizations to properly size and install a tide gate pipe that fulfills fish passage regulations from both the State of Oregon and the federal government.

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

*** NAVD88 – North American Vertical Datum of 1988.

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

As-Built Measurements

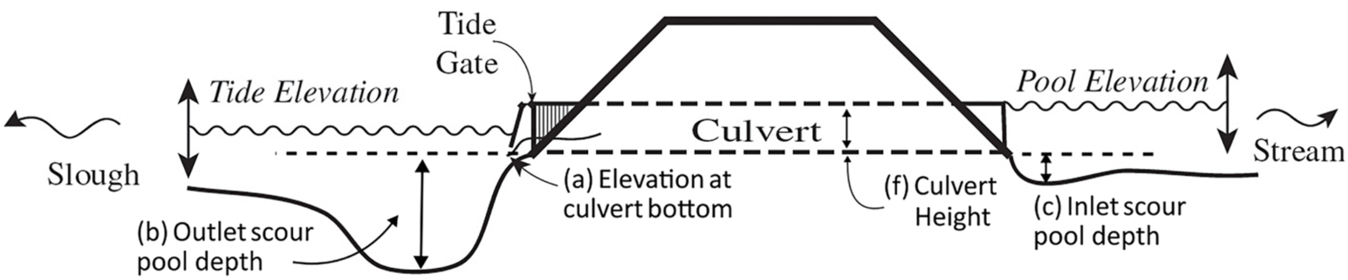
Refer to the tide gate schematic plan and side view on the next page for the reference measurement locations indicated by this section's superscript letters ([a], [b], etc.).

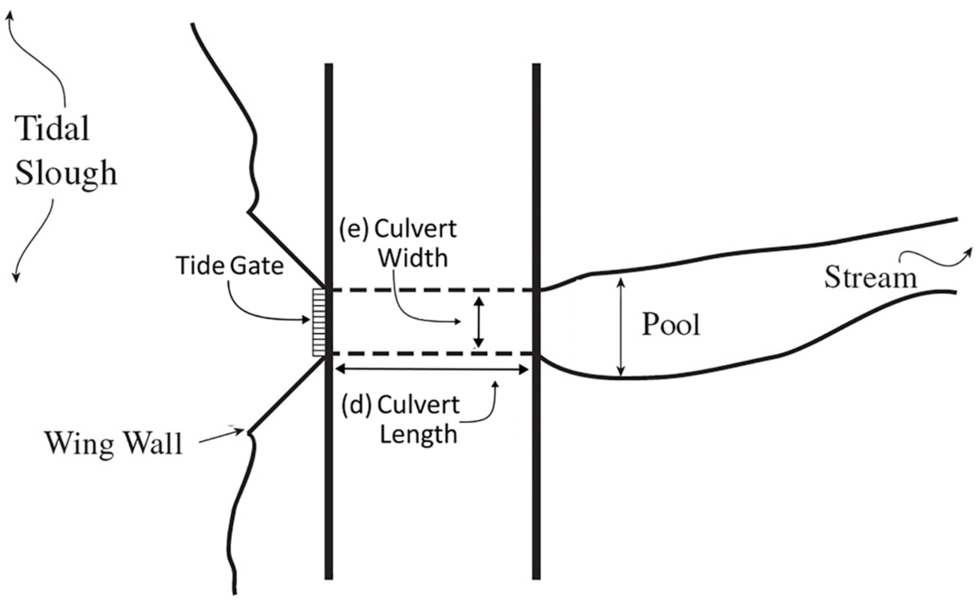
Elevation of culvert at culvert bottom [a] (NAVD88 feet):
Outlet scour pool depth [b] (feet):
Inlet scour pool depth [c] (feet):
Culvert length [d] (feet):
Culvert width/diameter [e] (feet):
Culvert height [f] (feet):
Culvert shape (rectangular/circular):
Culvert slope (percent):
Culvert material (composite, concrete, plastic, etc.):
Primary tide gate door type (e.g., hinge, collar & attachment):
Does the door have a mitigator, regulator, or other fish-friendly appurtenance?
Auxiliary tide gate door type, if any:
Channel width 200 ft upstream of tide gate (feet):
Bank slope 200 ft upstream of tide gate (ratio):

- Please attach as-builts if available.
- Please provide a PDF of the surveyed engineering report showing channel cross sections.

Overall Design

Has the project been constructed according to specifications and permit requirements?	☐ Yes ☐ No
If the project was not built as designed, please briefly describe how and why it differs from the approved design:	





Tide gate schematic plan and side view. Match superscripts in the [Tide Gate Implementation Monitoring Datasheet] to location measurements within this schematic. Source: Adapted from "The Effects of Tide Gates on Estuarine Habitats and Migratory Fish" (ORESU-G-04-002), by G. R. Giannico and J. A. Souder, 2004, (https://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/sgpubs/onlinepubs/g04002.pdf). Copyright 2004 by Oregon State University.

3. Compliance Monitoring

For tide gate upgrade and replacement projects, compliance monitoring aims to ensure that the restoration effort meets regulatory and legal requirements. There are five monitoring parameters, and all are expected to be completed in compliance monitoring to achieve several important purposes.

Firstly, compliance monitoring helps verify that the new tide gate design effectively alters the local ecosystem in accordance with the project's intended goals. Secondly, it fosters transparency and accountability by providing regulators, stakeholders, and the public with an objective assessment of project progress and the degree to which project goals are met. Additionally, compliance monitoring assists in risk management, as it facilitates adaptive management through the early detection of potential issues or deviations from the remediation plan, enabling prompt corrective actions to be taken.

This handbook recommends compliance monitoring for Tier 2 and 3 projects, as defined in Table 1. These are projects with one or more of the following: SRTs, available habitat behind the tide gate, and/or a WMP. Monitoring includes the channel water level, tide gate door openness, water temperature, velocity, and before-and-after photos. This suite of recommended monitoring parameters is rooted in the state and federal regulations listed in Table 2. They have been identified as fundamental to determining whether a tide gate project is functioning as designed. Each parameter's importance is as follows:

- The **channel water level** directly impacts the available habitat behind tide gates. Larger habitats correlate with lower fish densities and increased growth rates.
- The extent of **tide gate door openness** indicates how often fish passage is possible. It is intricately linked to water level; higher interior water levels, as dictated by the WMP, result in longer door-open durations, whereas lower water levels lead to shorter durations.

Compliance Monitoring

Monitoring to determine whether a tide gate project is functioning as designed and meeting permit requirements

- Monitoring **water temperature** is imperative, as salmonids require cool water for rearing. It provides insights into periods with suitably cool temperatures throughout the year.
- The **velocity** of water impacts whether fish can access habitat behind a tide gate. Modeling during the design phase should ensure that tide gate size and associated culvert dimensions allow

velocities to remain below 2 ft/s. Monitoring ensures the tide gates function as designed. Once implemented, there are limited post-restoration actions available to modify velocities.

- Recognizing the erosion potential in projects that constrain flow, the inclusion of **before-and-after photos** becomes paramount for water quality and infrastructure protection. These visual records serve to document any erosion occurrences, facilitating adaptive management strategies during the post-restoration phase.

Use the Compliance Monitoring Matrix (Table 2) as a quick reference to identify the general scope of monitoring. It describes the required equipment, each parameter's monitoring frequency and duration, performance standard goals, and any relevant regulations. Each parameter's protocol sheet is identified by the Protocol ID number and located in Chapter 5.

This handbook recommends that Tier 2 and 3 projects complete Tier 1 implementation monitoring. Remember to include the Tide Gate Implementation Monitoring Datasheet in your monitoring plan. Also, note that projects may have additional monitoring requirements outlined by funding and/or regulatory agencies.

The Compliance Monitoring Matrix (Table **2**) presents some of the same protocols as those used for effectiveness monitoring; however, the specifications may differ (e.g., different monitoring approaches, quantities, etc.). Note that the table's color coding follows the Effectiveness Monitoring Matrix found in Table **3**.

Table 2. Compliance Monitoring Matrix

Protocol ID [a]	Parameter	Monitoring Approach	Quantity	Frequency	Duration [b]	Performance Standard	Reference
1.2	Channel Water Level	Water level logger above tide gate	1 logger	Every 15 min	Years 1,2	Maximum channel water level is reached before tide gate door closes, or tide gate operates in accordance with WMP	ODFW Fish Passage Standard (OAR 635-412); NMFS TARP approvals (NMFS WCR-2018-8958)
1.3*	Gate Openness [c]	Water level logger above and below tide gate	2 loggers	Every 15 min	Years 1,2	Tide gate is open 51% of time	ODFW Fish Passage Standard (OAR 635-412)
1.4*		Gate Angle Logger	Each tide gate	Every 15 min	Years 1,2		

Protocol ID [a]	Parameter	Monitoring Approach	Quantity	Frequency	Duration [b]	Performance Standard	Reference
2.1*	Water Tempera-ture	Temperature logger above tide gate	1 logger	15 min	Years 1,2	Seven-day average daily maximum temperature does not exceed 18 °C	EPA Temperature Criteria (2003); ODFW Temperature Standard (OAR 340-041-0028)
4.6*	Velocity [d]	Float measurement	1 location	2/yr	Years 1,2	Velocity does not exceed 2 ft/s	ODFW Fish Passage Standard (OAR 635-412)
4.7*		Flowmeter	1 location	2/yr	Years 1,2		
5.2	Before-and-After Photos	Photo monitoring	Inlet/ outlet	1/yr	Years B,1	Identify unforeseen tide gate infrastructure deterioration	OWEB Photo Monitoring Guide

* Refer to the compliance section in the associated protocol sheet for additional performance standard information and compliance reporting requirements.

a - Find the full protocol sheet in Chapter 5 using the Protocol ID.

b - Monitoring duration: Year B indicates pre-project monitoring — to establish baseline reference values, pre-project monitoring should be conducted before infrastructure construction begins. Year 1 starts after infrastructure construction is completed, and monitoring continues through Year 2, 3, or longer as appropriate.

c - Gate openness can be monitored through direct gate tilt loggers or water level loggers above and below the gate. Choose the approach that best suits your project's resources.

d - Velocity can be monitored through float measurements or flowmeter measurements. Choose the approach that best suits your project's resources.

4. Effectiveness Monitoring

Effectiveness monitoring assesses the success of projects by measuring whether their intended goals have been achieved. It ensures accountability, informs resource allocation, supports regulatory compliance, and enables continuous improvement.

Tide gate restoration projects vary in scale and scope; as such, this effectiveness monitoring section is recommended for projects seeking a deeper understanding of their restoration efforts and those with an associated MAMP (Scale III). Projects of this scale are varied, can have multiple interconnected goals, and can be associated with larger restoration efforts that need flexibility when developing a monitoring design. Also, projects of any scale are encouraged to consider aspects of effectiveness monitoring to enhance their restoration efficacy.

Table 3 presents the Effectiveness Monitoring Matrix, an array of monitoring parameters grouped by restoration goals and monitoring question categories. Example monitoring questions are posed, and each question is paired with a measurement parameter linked to a specific monitoring protocol. Two funding scales ($ and $$$) provide guidance on quantity, frequency, and duration, thus allowing project designers to quickly assess necessary resources and take a plug-and-play approach to designing a monitoring strategy based on intended goals, available funding, and project requirements. A column labeled "Advanced Monitoring" identifies additional parameters and monitoring approaches to consider for monitoring above and beyond standard practices.

Some parameters in the Effectiveness Monitoring Matrix require pre-project monitoring for best results, while others require a reference site for comparative analysis. Superscripts indicate these parameters in the matrix.

Each parameter has an associated protocol sheet found in the protocols chapter (Chapter 5). Protocols are color-coded and indexed to match the Effectiveness Monitoring Matrix. Protocol sheets provide standardized methods and materials, tips and tricks, and additional references to help design and execute a successful effectiveness monitoring campaign.

Effectiveness Monitoring

Monitoring that seeks to critically evaluate a project's performance and restoration efficacy

If a project is large enough to incorporate effectiveness monitoring, the recommendation is to also include implementation and compliance monitoring. Please find details for these additional monitoring tiers in Chapter 2 and Chapter 3, respectively.

Projects may have additional monitoring requirements outlined by funding and/or regulatory agencies. Note, when monitoring activities include ground disturbance, consult with your local Tribal Historic Preservation Office to ensure cultural resource compliance is met. Additionally, if you are installing large bore permanent groundwater wells, contact the Oregon Water Resources department regarding permitting prior to breaking ground.

This handbook recommends forming a monitoring team consisting of appropriate technical experts. A multidisciplinary team pools experience from different aspects of restoration and monitoring work allowing for more efficient planning and increasing the likelihood of achieving monitoring goals. Ideal teams consist of members from local and state agencies, funding bodies, and potentially other practitioners with previous experience.

Data collected during monitoring must be robustly evaluated to assess project effectiveness and provide actionable information for adaptive management. Before monitoring activities take place, it is critical to design a project that allows monitors to discern the impact of restoration. While many methods of statistical analysis, tests, and number crunching exist, Before-After Control-Impact (BACI) is the most reliable framework for monitoring restoration. BACI is well suited to differentiate the impacts of restoration from background changes, such as climactic shifts, seasonality, or extreme events. Progressive-change Before-After Control-Impact Paired Series (BACIPS) expands on the BACI framework by comparing the restored site to multiple untouched reference sites.

From Kidd *et al*. (2023):

> "The foundational concept behind BACIPS is the Before-After Control-Impact (BACI) design. This method involves comparing a restoration site (impact site) with one or more control sites that have not undergone restoration, both before and after the restoration intervention (Green 1979; Stewart-Oaten and Bence 2001; Connor *et al*. 2016). By contrasting these differences, any changes due to the intervention can be isolated from those that occur naturally or from other external influences."

When implementing BACI design, baseline monitoring should be conducted for at least one year on all chosen metrics before restoration at the tide gate or restoration site and at one or more least-disturbed reference sites. Further information on BACI and BACIPS methodology and on incorporating design into your projects can be found in the resources and references listed here, with full references provided at the end of this handbook:

- *Protocols for Monitoring Juvenile Salmonid Habitats in the Lower Columbia River Estuary* (Kidd *et al*. 2023)
- "Progressive-Change BACIPS: A Flexible Approach for Environmental Impact Assessment" (Thiault *et al*. 2017)
- "Temporal and Spatial Variation in Environmental Impact Assessment" (Stewart-Oaten and Bence 2001)
- *Sampling Design and Statistical Methods for Environmental Biologists* (Green 1979)

Use Table 3 to identify tide gate restoration goals and associated monitoring parameters and measurement protocols. Example monitoring questions are provided to provide context for each parameter. Basic quantity, frequency, and duration information for two funding levels is provided to expedite initial field design decisions. Advanced monitoring is suggested for research-grade investigations or longer-term validation monitoring.

Table 3. Effectiveness Monitoring Matrix

			$ - Less Funding			**$$$ - More Funding**			
Example Monitoring Question	**Protocol ID – Parameter**	**Monitoring Approach**	Quantity	Frequency	Duration*	Quantity	Frequency	Duration*	**Advanced Monitoring**
Goal: **Restore Hydrological Function**									
Monitoring Question Category: **Groundwater Connectivity**									
Is groundwater retained on-site during summer?	1.1 – Groundwater Level	Water level logger in shallow well(s)	1 logger	Every 15 min	Year 2	1+ logger(s)	15 min	Year B,2,3,4+	Paired well study, off-site well monitoring
Has groundwater salinity increased after restoration?	1.1 – Salinity	Conductivity logger	-	-	-	1+ well(s)	15 min	Year B,2,3,4+	
Monitoring Question Category: **Tidal Connectivity**									
Is the minimum water level behind the tide gate meeting the WMP?	1.2 – Water Level	Water level logger above and below tide gate	2 loggers	Every 15 min	Year 2	2+ loggers	15 min	Year B,2+	Direct area of inundation measurements with temp. loggers, aerial mapping with drones
How much of the tide cycle does the habitat experience during each phase of the WMP?	1.3 – Gate Openness (Indirect)	Water level logger above and below tide gate	2 loggers	Every 15 min	Year 2	2 loggers	15 min	Year 2,3,4+	
Is the tide gate open at least 51% of the time when species of interest are present?	1.4 – Gate Openness (Direct)	Gate angle logger	-	-	-	Each tide gate	15 min	Year 2,3,4+	
Does the tide gate create a saline barrier for fish passage?	1.5 – Salinity (Handheld)	Handheld conductivity meter	-	-	-	2+ locations	15 min	Year B,2,3+	

			$ - Less Funding			$$$ - More Funding			
Example Monitoring Question	**Protocol ID – Parameter**	**Monitoring Approach**	Quantity	Frequency	Duration*	Quantity	Frequency	Duration*	**Advanced Monitoring**
How much land is inundated during mean water of each phase of the WMP?	1.6 – Area of Inundation	GIS mapping through water level	-	-	-	1	1/yr	Year B,2,3+	
How many stream miles are accessible during winter flows?	1.6 – Floodplain Connectivity	GIS mapping through water level	-	-	-	1	1/yr	Year B,2,3+	

Goal: **Improve Water Quality**									
Monitoring Question Category: **Water Quality**									
Does the tide gate create a thermal barrier for fish passage?	2.1 – Water Temperature	Continuous temperature logger	2 loggers	Every 15 min	Year B,1,2	2+ loggers	15 min	Year B,1,2,3+	Total suspended solids, dissolved oxygen, pH, bacteria, nutrients
How far above the tide gate does saline water (> 0.5 PSU) penetrate during rearing periods?	1.5 – Salinity (Handheld)	Handheld conductivity meter	2+ locations	1/yr	Year B,1,2	-	-	-	
What are the maximum salinity levels observed in the project site compared to the reference?	2.2 – Salinity (Continuous)	Continuous conductivity logger	-	-	-	1+ logger(s)	15 min	Year B,1,2,3+	

Example Monitoring Question	Protocol ID – Parameter	Monitoring Approach	$ - Less Funding			$$$ - More Funding			Advanced Monitoring
			Quantity	Frequency	Duration*	Quantity	Frequency	Duration*	
Goal: **Restore Wetland Vegetation**									
Monitoring Question Category: **Wetland Vegetation Development**									
Is plant community structure trending toward reference conditions?	3.1 – Vegetation Development	Photo points	6+ points	1/yr	B,1,2,3	6+ points	1/yr	Year B,1,2,3+	Net primary production, aerial monitoring (drone)
Is the overall cover increasing for plant communities dominated by native species?	3.2 – Vegetation Development	Mapping via aerial photo analysis	-	-	-	entire area	1/yr	Year B,2,4+	
Is native woody plant density at least 300 trees & shrubs per acre?	3.3 – Woody Plant Density	Stratified random sampling – stem count	-	-	-	10 plots/ha	1/yr	Year B,1,5,10+	
Does native plant cover exceed 50% within five years of restoration?	3.3 – Herbaceous Plant Community Composition	Stratified random sampling – species cover	-	-	-	20 plots/ha	1/yr	Year B,1,3,5+	
Is there a 60% or higher survival rate for native plantings?	3.3 – Revegetation Success	Stratified random sampling – survivorship	-	-	-	Various, See Protocol	1/yr	Year 1,2,3+	
Monitoring Question Category: **Invasive Species**									
Are invasive species recolonizing this site?	3.4 – Invasive Species Extent	Photo points	1+ per infesta-tion	1/yr	B,1,2,3+	1+ per infesta-tion	1/yr	Year B,1,2,3+	-
Are plant communities dominated by invasive species decreasing in treatment areas?	3.5 – Area of Infestation & Treatment	GIS mapping	-	1/yr	B,1,2,3+	-	1/yr	Year B,1,2,3+	

Example Monitoring Question	Protocol ID – Parameter	Monitoring Approach	$ - Less Funding			$$$ - More Funding			Advanced Monitoring
			Quantity	Frequency	Duration*	Quantity	Frequency	Duration*	
Goal: Improve Native Fish Populations									
Monitoring Question Category: **Fish Presence/Absence**									
Are juvenile salmonids using the project site during rearing periods?	4.1 – Presence/Absence	Snorkel surveys	1+ location(s)	1+/yr	Year B,2	-	-	-	Density
Are juvenile salmonids using the project site during rearing periods?	4.2 – Presence/Absence	Seine netting	1+ location(s)	1+/yr	Year B,2	1+ location(s)	3+/yr	Year B,2,3+	
Monitoring Question Category: **Fish Abundance**									
Has the number of juvenile salmonids using the site increased?	4.3 – Catch Per Unit Effort	Seine netting	-	-	-	1+ location(s)	3+/yr	Year B,2,3+	Density
What fish species (native/non-native) are using the site?	4.4 – Community Composition	Seine netting	-	-	-	1+ location(s)	3+/yr	Year B,2,3+	
Monitoring Question Category: **Fish Growth**									
Are salmonids growing faster on-site than a similar life cycle monitoring site managed by the Oregon Department of Fish and Wildlife (ODFW)?	4.5 – Fork Length	Seine netting	-	-	-	1+ location(s)	3+/yr	Year B,2,3+	Genetics
What is fish growth after restoration?	4.5 – Weight	Seine netting	-	-	-	1+ location(s)	3+/yr	Year B,2,3+	

Example Monitoring Question	Protocol ID – Parameter	Monitoring Approach	$ - Less Funding			$$$ - More Funding			Advanced Monitoring
			Quantity	Frequency	Duration*	Quantity	Frequency	Duration*	
Monitoring Question Category: **Fish Passage**									
What range of water velocities do fish prefer during passage?	4.6/4.7 – Velocity	Use velocity monitoring protocols for compliance monitoring	-	-	-	-	-	-	Continuous velocity, passive integrated transponder (PIT) arrays, video arrays
Monitoring Question Category: **Fish Habitat**									
Have the number and distribution of complex channel features increased over time?	4.8 – Channel Morphology	Side channel morphology	-	-	-	1+ locations	1/yr	Year B,2,5+	Channel morphology via main channel profile
How have mussel populations responded to tide gate upgrades in existing channels?	4.9 – Presence/Absence	Freshwater mussel survey	1+ location(s)	1/yr	Year B,2	2+ locations	1/yr	Year B,2,3,5	Macroinvertebrates

Goal: **Support Climate Mitigation**									
Monitoring Question Category: **Carbon Sequestration**									
How does increased tidal salt water influence or change the soil carbon content?	(no ID) – Soil Carbon Content	±	-	-	-	-	-	-	Greenhouse gas flux with eddy covariance tower, methane studies
Do changes in species composition impact aboveground biomass and carbon storage?	(no ID) – Aboveground Biomass	±	-	-	-	-	-	-	

			$ - Less Funding			$$$ - More Funding			
Example Monitoring Question	**Protocol ID – Parameter**	**Monitoring Approach**	Quantity	Frequency	Duration*	Quantity	Frequency	Duration*	**Advanced Monitoring**
Goal: **Enhance Climate Resilience**									
Monitoring Question Category: **Sediment Processes**									
Is the site gaining or losing elevation for the purpose of maintaining estuary habitat types?	5.1 – Accretion Rate	Sediment accretion plots	-	-	-	5+ plots	1/yr	B,5+	Set tables, soil compaction
Monitoring Question Category: **Infrastructure Protection**									
Is infrastructure behind the tide gate protected during king tides?	5.2 – Inundation	Photo points: king tides & flood events	1 location	4/yr	Year B,2	1 location	4/yr	Year B,2,3,4	Model validation via crest gauge array and flood event analysis
Monitoring Question Category: **Flood Control**									
Are flood water levels below the maximum desired elevation during king tides and floods?	5.2 – Inundation	Photo points: king tides & flood events	1 location	4/yr	Year B,2	1 location	4/yr	Year B,2,3,4	Model validation via crest gauge array and flood event analysis

Example Monitoring Question	Protocol ID – Parameter	Monitoring Approach	$ - Less Funding Quantity	$ - Less Funding Frequency	$ - Less Funding Duration*	$$$ - More Funding Quantity	$$$ - More Funding Frequency	$$$ - More Funding Duration*	Advanced Monitoring
Goal: **Benefit Landowner/Community**									
Monitoring Question Category: **Community Socioeconomic Effects**									
What is the local/county/state return on investment created from project investment?	(no ID) – (no parameter)	¥	-	-	-	-	-	-	Economic benefits and/or jobs supported
Monitoring Question Category: **Agriculture Uplift/Protection**									
Has improved water management created conditions for better forage production?	6.1 – Forage Production	Forage clip and weigh	Contact your local extension agent			Contact your local extension agent			Contact your local extension agent
Has the project created opportunities to utilize pastures for additional days each year?	6.2 – Animal Unit Months	Grazing days							

Note. * Monitoring duration: Year B indicates pre-project monitoring — to establish baseline reference values, pre-project monitoring should be conducted before infrastructure construction begins. Year 1 starts after infrastructure construction is completed, and monitoring continues through Year 2, 3, or longer as appropriate.

B Baseline data collected pre-project.

¥ These monitoring questions are important but cannot be addressed in a short protocol by most practitioners and are in the advanced monitoring category.

± Protocols for this parameter are beyond the scope of this document; however, a robust field manual is provided by The Blue Carbon Initiative (Howard *et al*. 2019) and is easily found online.

5. Protocol Sheets

Each monitoring parameter outlined in the compliance and effectiveness monitoring chapters (Table 2 and Table 3, respectively) is associated with a specific protocol sheet located within this chapter. Protocol sheets are color-coded to match their associated parameters in Table 2 and Table 3 and are numbered by their Protocol IDs.

Protocol sheets include information on basic monitoring design, materials, methods, field tips and tricks, additional resources, and corresponding literature. Protocols were developed through best practices established within the literature and through feedback from practitioners and experts in the field. Although protocol sheets are robust, they are not comprehensive, and users are encouraged to view them as basic guidelines and starting points. Additional literature should be sought for a more comprehensive understanding of materials and methods.

Protocol Table of Contents

1.1. Groundwater Connectivity: Level & Salinity

An increase in tidal inundation may impact the groundwater level and salinity. Groundwater in low-elevation settings supplies water for plant root systems and is a controlling factor for plant community characteristics. This is an important consideration for wetland restoration and working lands, so groundwater monitoring may be a useful tool for demonstrating project effectiveness.

Materials

- ☐ Auger
- ☐ Polyvinyl-chloride (PVC) pipe with cap and 6 in. of well screen
- ☐ 20/40 mesh sand
- ☐ Bentonite
- ☐ Water level logger, conductivity optional

Timing Recommendations

- ☐ 15-minute sampling interval
- ☐ One-year baseline
- ☐ One to three years post-restoration

Deployment Summary

- ☐ Continuous monitoring logger installed in PVC well below ground level and sealed off from surface tidal and rainwater infiltration with a clay barrier

Other Parameters This Protocol Can Measure and Inform

- ☐ Can inform vegetation monitoring
- ☐ 2.1. Water Quality: Water Temperature

Miscellaneous

- ☐ Pre-deployment and post-deployment calibrations are required.
- ☐ Regular field audits are recommended (quarterly).
- ☐ An Oregon Department of Environmental Quality (DEQ) Sampling and Analysis Plan (SAP) might be required.

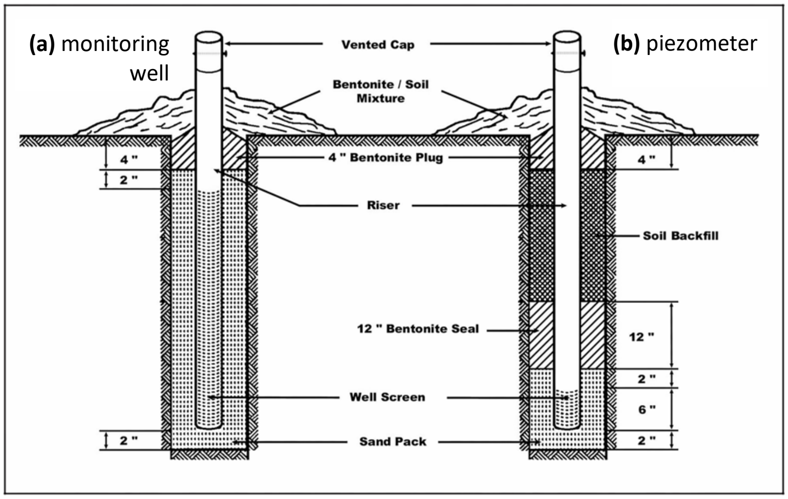


Figure. Schematic diagram of (a) shallow installed monitoring well and (b) piezometer. Source: Sprecher (2000).

Design

Field Tips

It is especially important for salinity monitoring to create a good seal around the top of a groundwater well so you are not measuring rainwater or tidal water. Bentonite clay works well.

An automated data logger — which may combine conductivity, temperature, and pressure sensors depending on project needs — is placed in a shallow groundwater well behind the tide gate. The groundwater well is dug to a depth of about 4.5 ft and placed on the working land or wetland surface behind the tide gate (Sprecher 2000).

At least one year of baseline data collection is highly recommended. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should occur when the tide gate is operating according to a water management plan, typically after a year has passed.

The basic measurement for groundwater is water level, which can be evaluated with a relatively modest material investment. If funding and capacity allow for expanded monitoring or if landowners are especially concerned about groundwater salinity, a more expensive logger incorporating conductivity is recommended. In addition, consider leaving the sensors in for a few additional years and/or adding sensors if the area behind the tide gate is large or not homogenous.

Methods

Site selection and installation: Locate the monitoring site on the wetland's or working land's surface at least 10 ft away from any channels. The sensor must be placed in a constructed groundwater well made with Schedule 40, 1.5-in.-diameter PVC pipe sunk approximately 4 ft below ground level. Pipe size may vary based on the size of the automated data logger used. Use 0.010-in. slotted screen for the bottom 6 in. of the pipe and 20/40 mesh sand for the sand pack layer. The PVC pipe should extend above the ground surface approximately 9 to 12 in. for easy access.

To install a groundwater well, auger a hole with a 3-ft bucket auger to a depth of about 4 ft and scarify the side of the auger hole if it was smeared during augering. Place 2 in. of silica sand in the bottom of the hole and insert the PVC well into the hole but not through the sand. Next, pour more sand into the hold until it is at least 2 in. above the top of the screen. Above the sand, place a 12-in. layer of bentonite; add water to expand the bentonite to form a seal. Backfill and tamp the soil into the auger hole from the top of the bentonite plug to within about 4 in. of the soil surface and place a second layer of bentonite.

Data collection: During deployment, the absolute height of the logger must be measured. Typically, the reference points (top of the pipe and ground level) are surveyed and tied to a known elevation, such as a benchmark, a point defined by real-time kinematic GPS (RTK-GPS), or the tide gate structure. Then, the reference point is used to convert relative depth to absolute water elevation.

During all field audits, deployments, and retrievals, measure and record the water level from reference point to water surface. This data verifies the accuracy of water level data during post-processing. Ensure measurement happens as the logger is recording data, typically at 15-minute intervals from the hour.

Field Tips

- A measuring tape marked with a water-soluble marker, baby powder, or chalk is a cheap and reliable way to measure groundwater levels during field audit visits. If there are multiple wells, bring a rag to wipe it off between sites.
- Ensure the logger stays in the well while performing field audits. Groundwater does not move fast enough to make up for the displaced volume of the logger. Thus, your first few days of data may be impacted by elevated water levels.

Post-processing: Correct water level data for barometric pressure and, using field-audit data, convert the relative water levels to actual elevation (NAVD88 — i.e., North American Vertical Datum of 1988). Barometric pressure can be measured on-site using a level logger or other pressure sensor installed above the maximum water level or obtained from publicly available data by the National Oceanic and Atmospheric Administration (NOAA) or another weather station (from Protocol 1.2).

Converting conductivity to salinity can be straightforward. The Solinst and HOBOware software applications provide tools for this with their data wizards. If post-processing is done by hand, conductivity data must be temperature-compensated before conversion to salinity.

Data analysis: Time series graphs of water level data are very informative. Side-by-side presentation of the groundwater level and salinity can depict how these parameters change seasonally or with changes in water management plans. A graph depicting water levels from both logger locations in the months before and after installation can demonstrate any changes in tidal connectivity. For wet and dry seasons, daily maximum or average groundwater and salinity levels can be calculated.

References

See p. 74 in Brown *et al*. (2016).

Sprecher SW (2000).

Wagner *et al*. (2006).

1.2. Tidal Connectivity: Water Level

A primary function of a tide gate is to control water levels behind the gate, and hydrology is a main controlling factor of habitat development. Water levels should meet the requirements of the water management plan (WMP) and provide sufficient depths for spawning and/or rearing salmonids, depending on the site location.

Materials

- ☐ 6-ft T-post or concrete screws
- ☐ 3-in. diameter perforated polyvinyl-chloride (PVC) pipe and cap
- ☐ Drill with ¼-in. bit
- ☐ Mallet or post pounder
- ☐ Hose clamps or zip ties
- ☐ Flathead screwdriver
- ☐ Stainless steel cable or heavy-duty string
- ☐ Two water level loggers (model options include Onset's HOBO or the Solinst Levelogger)
- ☐ Real-time kinematic GPS (RTK-GPS) for a one-time survey (or existing benchmark)
- ☐ Measuring tape or stadia rod

Timing Recommendations

- ☐ 15-minute sampling interval
- ☐ One year before restoration, with deployment continuing for at least three years post-restoration

Deployment Summary

- ☐ Two water level loggers: one upstream and one downstream of tide gate structure

Other Parameters This Protocol Can Measure and Inform

- ☐ 2.1. Water Quality: Water Temperature
- ☐ 2.2. Water Quality: Salinity (Continuous)
- ☐ 1.3. Tidal Connectivity: Gate Openness (Indirect)

Design

Field Tips

The stilling well needs to be just tall enough to be accessible for data retrieval.

Automated data loggers (i.e., pressure sensors) are placed in the water column to measure water depth. One sensor installed upstream of the tide gate can track whether water depth behind the tide gate is sufficient for fish habitat and provide information on whether self-regulating tide gate doors open and close at the appropriate channel water depths to meet WMPs. An additional sensor installed downstream of the tide gate is recommended to capture information about how tides and freshets impact the main river channel relative to the tide-gated system.

At least one year of baseline data collection is highly recommended. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should start when the tide gate is operating according to a WMP, typically after a year has passed. If funding and capacity allow for expanded monitoring design, consider leaving the sensors in for a few more years and/or adding sensors at least 1000 ft above the tide gate to track the hydrology pattern in the channel network. Sensors can be placed at other instream features of interest, such as beaver dams, pools, large wood placements, confluences with other channels, or sites for channel cross-section monitoring.

Methods

Site selection and installation: It is best to place the sensor within a perforated PVC pipe (stilling well). If possible, install it on the concrete wing walls of the tide gate structure. Use plumbing tape or pipe straps and concrete screws or anchors to attach PVC pipe to the structure. Alternatively, install the loggers on the edge of the inlet and outlet scour pools with a T-post. Drill a minimum of twenty ¼-in. holes in the PVC stilling well to allow enough water exchange to avoid creating a microclimate of warmer or cooler water within the pipe. Also, the stilling well should have a bolt across the opening at the bottom so the logger cannot accidentally fall out. After the PVC stilling well is securely attached to the wing wall or T-post, install the logger by hanging it off a PVC cap with a cable, eyebolt, and cable clamps — all stainless steel — (Kidd *et al*. 2023).

Install the logger infrastructure during low tide and place it as low as possible in the channel to capture low water levels. If possible, ensure the bottom of the pipe is at least 8 in. below the lowest tide level and the sensor is at least 6 in. above the pipe's bottom. Installing the logger within a stilling well is important in areas with high velocity to ensure the logger remains vertical and to dampen surges in water level.

Measure the absolute height of the logger during deployment. Typically, the reference point (top of pipe, post, or stop-bolt) is surveyed and tied to a known elevation (e.g., benchmark, RTK-GPS point, or the tide gate structure). The reference point is used to convert relative depth to absolute water elevation.

Field Tips

Avoid installations on banks with high levels of erosion, a high probability of large woody debris damaging the housing, or a high probability of vandalism or theft.

Data collection: During all field audits, deployments, and retrievals, measure and record the water level from the reference point to the water surface. This data verifies the accuracy of water level data during post-processing. Ensure measurement happens as the logger is recording data, typically at 15-minute intervals from the hour.

Post-processing: Correct water level data for barometric pressure and, using field-audit data, convert the relative water levels to actual elevation (NAVD88 — i.e., North American Vertical Datum of 1988). Barometric pressure can be measured on-site using a level logger or other pressure sensor installed above the maximum water level or obtained from publicly available data by the National Oceanic and Atmospheric Administration (NOAA) or another weather station data. See Kidd *et al*. (2023) for more detailed guidance.

Data analysis: Time series graphs of water level data are very informative. Side-by-side presentation of the water level upstream and downstream of the tide gate, using particular snapshots in time, can depict how the tide gate functions. A graph depicting water levels from both logger locations in the months before and after installation can demonstrate the return of tidal connectivity.

Water level data analysis can determine how much of the tidal cycle the upstream habitat is experiencing by comparing tidal amplitudes to other loggers. For wet and dry seasons, daily maximum or average water levels can be calculated. When a WMP is in place, data should be reviewed to ensure that the minimum water level behind the gate meets the plan's requirements.

Compliance monitoring: The prescribed channel water level behind the tide gate must be reached before the tide gate door closes, ***or*** the tide gate must operate per the WMP (Oregon Department of Fish and Wildlife [ODFW] Fish Passage Standard [OAR 635-412; 2023]; National Marine Fisheries Service (NMFS) Tidal Area Restoration Program (TARP) approvals [WCR-2018-8958; 2018]). Ensure the interior water level logger consistently reads a water level equal to or greater than the prescribed level during high-water events.

References

Janousek *et al*. (2022).

Kidd *et al*. (2023).

OAR 635-412 (2023).

NMFS WCR-2018-8958 (2018).

Roegner *et al*. (2009).

1.3. Tidal Connectivity: Gate Openness (Indirect)

Salmonid access to habitat, hydrological exchange, and interior water quality all depend on how long a tide gate remains open. Gate openness can be calculated using data from water level loggers on either side of a tide gate.

Analysis

A simple analysis of tide gate openness uses water surface elevation (WSE) data collected from water level loggers inside and outside of the tide gate structure (Protocol 1.2), using date-time and WSE data. Data do not need to be converted to true elevation; relative data will work well for this exercise. Data for each water level logger are classified as falling, flat, or rising using the following Microsoft Excel formula:

[Condition] = IF(WSE-previous ≥ WSE-current, “FALLING”, WSE-previous = WSE-current, “FLAT”, “RISING”)

Since all tide gates leak to some degree, it can be useful to replace the “FLAT” term with the following:

WSE-previous = (WSE-current + .05)|(WSE-current + 0.5), “FLAT”, “RISING”

Tide gate doors are open when tidal elevation and pool elevations rise or fall together. To evaluate this status in Excel, paste the two datasets next to each other, carefully ensuring the date-times correspond exactly. Manually identify open periods by marking as open any periods where the Condition (Rising, Falling, Flat) are the same in each column. See the figure on the right for a graphical representation of a typical gate-open period. Sum each open period in a new column titled Time Open by subtracting the starting time from the ending time. For ease, you can choose to convert fractional days to minutes by multiplying the total by 1440 (the number of minutes in a day). Then, sum the total open time depending on your monitoring objectives. Common intervals of interest are annually, seasonally, or monthly.

The percentage of open time can be obtained by dividing the total open time by the total time of interest (e.g., one year, three months, or one month).

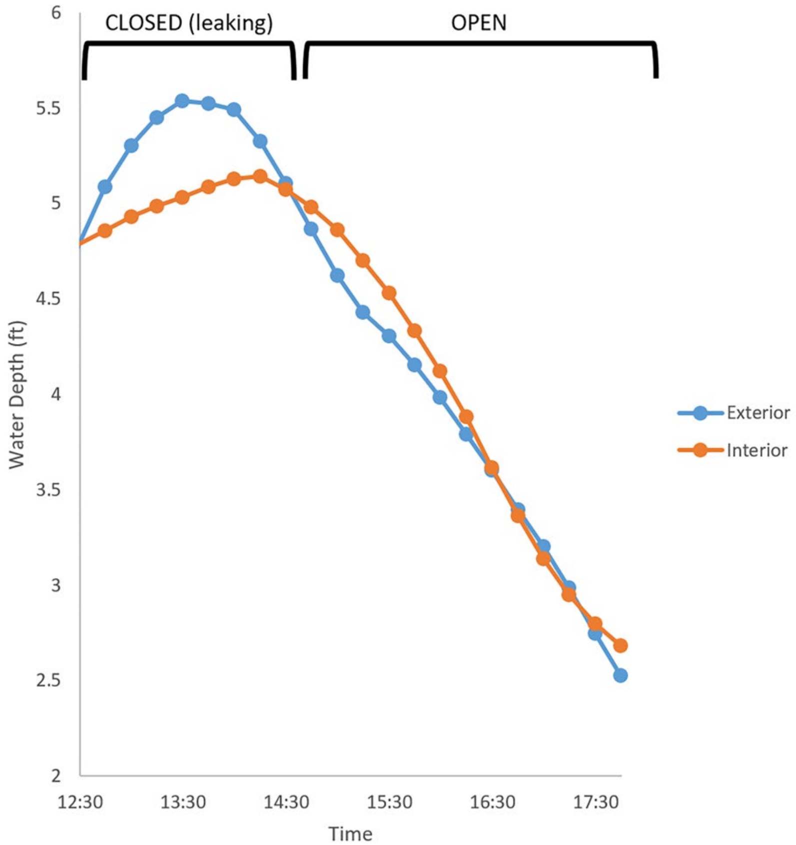


Figure. Graph of a typical gate-open period.

Compliance monitoring: The Oregon Department of Fish and Wildlife (ODFW) Fish Passage Standard (OAR 635-412; 2023) requires tide gates to be open 51% of the time. Calculate as described above.

References

OAR 635-412 (2023).

1.4. Tidal Connectivity: Gate Openness (Direct)

Salmonid access to habitat, hydrological exchange, and interior water quality all depend on how long a tide gate remains open. Monitoring gate openness helps determine whether tide gates are functioning per design or per a water management plan. Gate openness measurements before and after a tide gate upgrade project can demonstrate the effectiveness of improved fish passage.

Materials

- ☐ Star-Oddi Data Storage Tag (DST) Compass Magnetic
- ☐ Hose clamps or other fixture methods
- ☐ Protractor or compass

Timing Recommendations

- ☐ Install during low to mid-tide when the door is more accessible

Deployment Summary

- ☐ One small instrument called a magnetic compass logger is affixed to the tide gate.

Miscellaneous

- ☐ A small electrical junction box with a lid can be attached to the tide gate door. The logger can be housed inside with foam insulation to keep the position set.
- ☐ The Star-Oddi DST Compass Magnetic is expensive and manufactured in Australia. Plan for a long lead time. Additionally, corresponding software and a communication box need to be purchased.
- ☐ A tiltmeter (e.g., Onset HOBO Pendant G Data Logger) can be used on top-hinge gates.

Design

A magnetic compass logger is mounted on the tide gate door to directly measure door angle and openness. The open time is calculated as the percentage of time the compass angle reads more than 0° open or the calibrated open level. Typically, a side-hinge gate will open to a maximum of 80°, but the velocities are usually gentle enough that passage is possible until the door is closed. Time series data should be analyzed for the seasons of interest, including spawning, juvenile use, and land management.

Field Tips

An inexpensive option is to use an Onset HOBO Pendant G Data Logger, but it requires you to convert horizontal movement to vertical movement (see references).

At least one year of baseline data before restoration efforts is highly recommended. Most tide gates are operated modestly immediately after installation to facilitate ecosystem recovery. So, monitoring after the tide gate upgrade should start when the tide gate is operating according to a water management plan, typically after a year has passed.

Methods

Site selection and installation: Using a protractor, test the compass logger on a mock tide gate door before using it in the field. Affix the compass logger to the tide gate door so that it is orientated to measure the angle of the door's openness. The logger can be affixed to the hinge arms of the door or bolted on using an existing hole in the door. Hose clamps can be useful for this approach.

Calibrate the installation during a tide cycle where the gate is open to its minimum fish passage amount and record the compass bearing of the door and time of reading; any angle under the minimum angle for fish passage will be considered closed in calculations.

Data collection: It is safest to access the compass logger when gate doors are closed. Therefore, appropriately time the tide cycle to install, audit, and retrieve the logger. Downloading the data requires a computer. If your site is far from the office, plan to use a laptop and prepare for weather-related contingencies.

Data analysis: Data can be analyzed in Microsoft Excel spreadsheets. Use an IF statement to determine if the door angle is open or closed. The time of openness is calculated by summing the "open" logger readings for the time of interest (weekly, monthly, seasonally).

Compliance monitoring: The Oregon Department of Fish and Wildlife (ODFW) Fish Passage Standard (OAR 635-412; 2023) requires tide gates to be open 51% of the time. Calculate as described above.

References

Bass (2010).

Greene *et al*. (2012).

OAR 635-412 (2023).

Onset Computer Corporation (2013).

1.5. Tidal Connectivity: Salinity (Handheld)

Closed tide gates limit the transfer of saline and brackish water behind them in low-lying areas, including farmlands, exposed to water from a salty river, estuary, or coastal body. During migration and rearing, salmonids benefit from a salinity gradient as opposed to a salinity barrier. Basic channel salinity measurements can help elucidate the impact of a tide gate on salinity in the system.

Materials

- ☐ Handheld refractometer
- ☐ Handheld salinity meter (e.g., YSI Pro30)
- ☐ Deionized or distilled water
- ☐ Pocketknife to adjust the refractometer
- ☐ Eye dropper

Timing Recommendations

- ☐ At least once per year, during the period of juvenile rearing interest
- ☐ Additional readings can happen during different seasons of the water management plan
- ☐ At high tide or over a tidal cycle

Miscellaneous

- ☐ If you do not have a salinity meter, consider borrowing one from a partner organization.

Field Tips

- ☐ Shading a refractometer often helps to see a clear, crisp line for better precision.
- ☐ Refractometers measure salinity directly, while conductivity meters calculate temperature-compensated salinity from conductivity measurements.
- ☐ Channel salinity can sometimes vary with depth. If there is a large, deep pool and you are using a handheld meter, consider sampling both deep and shallow points in the pool.

Design

Design for handheld salinity measurements depends on your project goals. Some projects are interested in the profile of channel salinity upstream of a tide gate, while other projects just want to know how salinity varies at a tide gate across one tidal cycle. Sampling can employ a refractometer or a handheld salinity meter.

For channel salinity, samples are taken at high tide. Since sampling is simple and not time-consuming, you may take as many samples as you like, though at least three are required. Take one sample outside/downstream of the tide gate. Take another sample in the pool upstream of the tide gate. Then, take samples at intervals up the main channel. Water is considered fresh when salinity drops below one part per thousand. Intervals can be as low as 50 ft or more than a mile, depending on your site.

For projects interested in tidal salinity fluctuations at the tide gate, measurements every half hour across a tidal cycle are needed. Only two sites are needed in this case: inside/upstream and outside/downstream. At least one year of baseline data collection is highly recommended. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, post-installation monitoring should start when the tide gate is operating according to a water management plan, typically after a year has passed.

If funding and capacity allow for expanded monitoring design or if your site is more complex, consider measuring salinity in side channels or multiple times per year. Winter salinities are typically very low due to freshwater input.

Methods

Instrumentation: Handheld refractometers take measurements in parts per thousand, symbolized by ‰. Refractometers with at least up to 40‰ should be used. Typically, these instruments are precise to about 0.5‰. Handheld salinity meters are more precise but expensive. Before fieldwork, the instrument should be calibrated with deionized or distilled water, which should read 0‰, and at least one known salinity solution.

In the field, instruments must be re-zeroed and wiped clean before each sample since the readings can be impacted by changes in instrument temperature.

Data collection: Obtain a sample of channel water using an eye dropper, rinsing the eye dropper with sample water before measurement. For a refractometer, drop one drop onto the surface of the refractometer and carefully close the flap cover, ensuring no bubbles are present on the surface. Adjust the eyepiece until the refractometer text is clear, then take a reading to the nearest 0.5‰.

For conductivity meters, place the sensor in the water and record salinity.

1.6. Tidal Connectivity: Area of Inundation & Floodplain Connectivity

Salmonid habitat behind a tide gate includes the channel, as well as wetland areas adjacent to the channel during high-water events. For projects with a goal of increasing salmonid habitat, it can be useful to estimate the acreage of habitat gained or lost by upgrading, replacing, or removing a tide gate structure.

Background & Considerations

The wetland area behind tide gates that floods during normal tide gate operations can provide good habitat for many species, including juvenile salmonids. A proposed benefit of some tide gate upgrade, replacement, or removal projects is an increase in the area of inundation and floodplain connectivity and, therefore, an increase in available habitat. To determine if projects are meeting their goals, these parameters can be calculated in combination with water level measurements inside the tide gate.

Measuring the total inundation area before and after tide gate work helps assess project effectiveness, but further considerations can increase the analysis's relevance. For example, juvenile salmonids are unlikely to interact with extremely shallow habitat, so consider only counting acreage as habitat if it is commonly deeper than 18 in. Habitat quality changes with vegetation and other factors; a combination of vegetation cover and inundation mapping may help describe where high-quality habitat will be located.

Analysis

ArcGIS or another geographic information system can be used to map the area of inundation. However, due to the wide variety of software options available, what is described here are strategies for measuring acreage instead of specific instructions. One strategy involves a digital surface model of the area behind the tide gate. The observed pre- and post-project operating water levels, obtained through water level monitoring, are used to select the digital surface model's areas by elevation attribute. The resulting polygon can be analyzed for area and channel length.

Typically, this analysis only needs to be performed twice: for the observed operating high-water condition and for the designed high-water condition. However, if water level monitoring shows that levels under actual operating conditions significantly differ from the design, the area of inundation should be measured again.

For most practitioners, it is cost-effective to include this calculation in the engineering design work since it is a routine analysis for engineers. If further post-construction analysis is required, it may also be included in a contract.

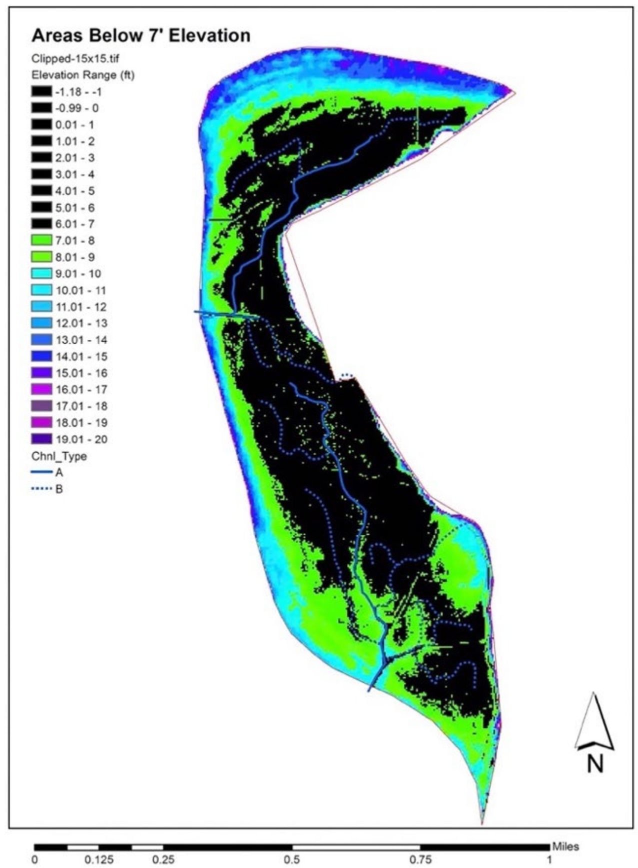


Figure. Tidal inundation depiction with muted-tide-regulator tide gate settings at elevation 7.0 ft NAVD88 (North American Vertical Datum of 1988). Source: CoqWA (2017).

2.1. Water Quality: Water Temperature

Temperature is a critical factor for salmonids, especially during summer months when juvenile salmonids may be stuck in the habitat behind a tide gate. Temperature monitoring can help describe the water quality conditions behind the tide gate and the water's suitability for juvenile salmonids.

Materials

- ☐ Water temperature loggers (Onset HOBO or similar)

For deep installations:

- ☐ 6-ft T-post (optional)
- ☐ Polyvinyl-chloride (PVC) pipe and cap
- ☐ Mallet or post pounder
- ☐ Hose clamps
- ☐ Flathead screwdriver
- ☐ Metal cable or heavy-duty string

For upstream shallow installations:

- ☐ 8-in. nails
- ☐ Hammer
- ☐ Zip ties

Timing Recommendations

- ☐ 15-minute sampling interval
- ☐ One year before restoration, with deployment continuing for at least three years post-restoration

Deployment Summary

- ☐ As many temperature loggers as needed to answer monitoring questions; at least one upstream of the tide gate structure

Other Parameters This Protocol Can Measure and Inform

- ☐ With an upgraded logger:
  - 2.2. Water Quality: Salinity (Continuous)
  - 1.2. Tidal Connectivity: Water Level

Design

Field Tips

Field audits ensure temperatures are accurate across the sampling period. Schedule them quarterly.

Automated temperature loggers placed in the water column measure water temperature. One sensor installed in the pool upstream of the tide gate can track whether water temperatures meet state standards for salmonid habitat. Additional sensors can be placed further upstream to determine habitat quality from a temperature standpoint.

At least one year of baseline data collection is highly recommended. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should start when the tide gate is operating according to a water management plan, typically after a year has passed.

If funding and capacity allow for expanded monitoring design, consider leaving the sensors in for a few more years and/or adding sensors at least 1000 ft above the tide gate to track temperature in the channel network. Sensors can be placed at other instream features of interest, such as beaver dams, pools, large wood placements, confluences with other channels, or sites for channel cross-section monitoring.

Methods

Site selection and installation: In deep pools, it is best to place the sensor within a PVC pipe (stilling well) to ensure it is protected from sunlight and damage. If possible, install it on the concrete wing walls of the tide gate structure. Use plumbing tape or pipe straps and concrete screws or anchors to attach PVC pipe to the structure. Alternatively, install the loggers on the edge of the inlet and outlet scour pools with a T-post. Drill a minimum of twenty ¼-in. holes in the PVC stilling well to allow enough water exchange to avoid creating a microclimate of warmer or cooler water within the pipe. Also, the stilling well should have a bolt across the opening at the bottom so the logger cannot accidentally fall out. After the PVC stilling well is securely attached to the wing wall or T-post, install the logger by hanging it off a PVC cap with a cable, eyebolt, and cable clamps — all stainless steel — or as shown in Protocol 1.2 (Roegner *et al*. 2009).

Install the logger infrastructure during low tide. Ensure the bottom of the pipe is at least 8 in. below the lowest tide level and the sensor is at least 6 in. above the pipe's bottom. Installing the logger within a stilling well is important in areas with high velocity to ensure the logger remains vertical.

Field Tips

Pre- and post-deployment calibration baths verify that the temperature logger is reading accurately.

Upstream temperature loggers are simpler to deploy. In a well-mixed area of the stream, loggers can be affixed to the channel substrate with an 8-in. nail. The nail should be hammered in at least 7 in., and the logger can be zip-tied to the nail. If water is shallow and clear, encase the logger in a short, open section of PVC or place a large rock over the dark logger so it does not warm due to solar radiation.

Data collection: During all field audits, deployments, and retrievals, measure and record the temperature of the water. This data verifies the accuracy of temperature data during post-processing. Ensure measurement happens as the logger is recording data, typically at 15-minute intervals from the hour.

Field Tips

A Sampling and Analysis Plan (SAP) approved by the Oregon Department of Environmental Quality (DEQ) might be required.

Compliance monitoring: The U.S. Environmental Protection Agency Temperature Criteria (EPA 2003) and the Oregon Department of Fish and Wildlife (ODFW) Temperature Standard (OAR 340-041-0028; 2023) describe that a seven-day average daily maximum temperature should not exceed 18 °C. To calculate this, take the highest observed temperature for each day, then average it with the highest observed temperatures from the prior six days. This can be done by hand, using pivot tables in Microsoft Excel, or with a coding language such as R.

References

EPA (2003).

OAR 340-041-0028 (2023).

Roegner *et al*. (2009).

2.2. Water Quality: Salinity (Continuous)

Closed tide gates limit the transfer of saline and brackish water behind them in low-lying areas exposed to water from a salty river, estuary, or coastal body. During rearing, salmonids benefit from a salinity gradient as opposed to a salinity barrier. Continuous salinity measurements behind a tide gate can help elucidate the impact of a tide gate on salinity in the system.

Materials

- ☐ 6-ft T-post
- ☐ Polyvinyl-chloride (PVC) pipe and cap
- ☐ Mallet or post pounder
- ☐ Hose clamps
- ☐ Flathead screwdriver
- ☐ Metal cable or heavy-duty string
- ☐ Automated conductivity, water level, and temperature data loggers (e.g., Solinst LTC series)

Timing Recommendations

- ☐ 15-minute sampling interval
- ☐ One year before restoration, with deployment continuing for at least three years post-restoration

Deployment Summary

- ☐ Two salinity and water level loggers: one upstream and one downstream of tide gate structure

Other Parameters This Protocol Can Measure and Inform

2.1. Water Quality: Water Temperature

1.2. Tidal Connectivity: Water Level

Miscellaneous

- ☐ Onset demonstrates how to build a PVC housing on their web page: "Monitoring Wetlands With Data Loggers: A Best Practices Guide" (https://www.onsetcomp.com/resources/white-papers/monitoring-wetlands-data-loggers-best-practices-guide).
- ☐ Choose a logger that combines water level and conductivity.

Design

The methods and design for continuous salinity measurements are closely related to continuous water level methods (Protocol 1.2). Automated data loggers — which measure conductivity, water level, and temperature — are placed in a water column that is submerged year-round. One sensor installed upstream of the tide gate can track how much salt water is reaching beyond the tide gate. An additional sensor installed downstream of the tide gate is recommended. It provides information about how tides and freshets impact the main river channel relative to the tide-gated system and provides context on river or estuarine salinity. Comparing salinity values inside and outside the tide gate can also provide information on whether a salinity barrier exists at the gate or sufficient mixing occurs to create a salinity gradient.

Field Tips

Install in the low-flow season and choose the deepest spot possible inside/upstream of the tide gate so that the salinity logger stays submerged year-round.

At least one year of baseline data collection is highly recommended. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should start when the tide gate is operating according to a water management plan, typically after a year has passed.

If funding and capacity allow for expanded monitoring design, consider leaving the sensors in for a few more years and/or adding sensors at least 1000 ft above the tide gate to track the salinity pattern in the channel network. Sensors can be placed at other instream features of interest, such as beaver dams, pools, large wood placements, confluences with other channels, or sites for channel cross-section monitoring.

Methods

Site selection and installation: It is best to place the sensor within a PVC pipe (stilling well). If possible, install it on the concrete wing walls of the tide gate structure. Use plumbing tape or pipe straps and concrete screws or anchors to attach PVC pipe to the structure. Alternatively, install the loggers on the edge of the inlet and outlet scour pools with a T-post. Drill a minimum of twenty ¼-in. holes in the PVC stilling well to allow for enough water exchange to avoid creating a microclimate of warmer or cooler water within the pipe. Also, the stilling well should have a bolt across the opening at the bottom so the logger cannot accidentally fall out. After the PVC stilling well is securely attached to the wing wall or T-post, install the logger by hanging it off a PVC cap with a cable, eyebolt, and cable clamps — all stainless steel — (Roegner *et al*. 2009).

Install the logger infrastructure during low tide. Ensure the bottom of the pipe is at least 8 in. below the lowest tide level and the sensor is at least 6 in. above the pipe's bottom. Installing the logger within a stilling well is important in areas with high velocity to ensure the logger remains vertical and to dampen surges in water level.

Absolute elevation needs to be measured for the loggers. The top of the PVC pipe can be surveyed by the project engineers or with a real-time kinematic GPS (RTK-GPS) unit with centimeter-scale accuracy. Then, the distance from the top of the pipe to the stop bolt is measured, and sensor elevation is calculated.

Pre-processing: Before installing the logger in the field, purchase conductivity standard solutions and run them through the automated calibration wizard in the Solinst or HOBOware software.

Data collection: During all field audits, deployments, and retrievals, use a handheld conductivity meter to measure the conductivity next to the stilling well at the same depth as the logger. YSI instruments are popular, reliable options. This data verifies the accuracy of salinity data during post-processing. Ensure measurement happens as the logger is recording data, typically at 15-minute intervals from the hour.

Field Tips

As with water level loggers, barometric compensation is required. Data from weather stations within 15 mi may be used confidently, or another pressure sensor can be placed outside of the water.

Post-processing: Converting conductivity to salinity can be straightforward. The Solinst and HOBOware software applications provide tools for this with their data wizards. If post-processing is done by hand, conductivity data must be temperature-compensated before conversion to salinity.

Field Tips

A Sampling and Analysis Plan (SAP) approved by the Oregon Department of Environmental Quality (DEQ) might be required.

Data analysis: Time series graphs of salinity data are very informative. Side-by-side presentation of the water level upstream and downstream of the tide gate, using particular snapshots in time, can depict how the tide gate functions. A graph depicting salinity from both logger locations in the months before and after installation can demonstrate the return of tidal connectivity.

References

Janousek *et al*. (2022).

Roegner *et al*. (2009).

Wagner *et al*. (2006).

3.1. Wetland Vegetation Development: Photo Points

Photo point monitoring: Capturing before-and-after photos is a simple, low-cost method to document changes in vegetation over time. It can be a powerful communication tool for demonstrating progress in the structural change of plant communities after planting or seeding a project site. Photo locations can be selected to track other restoration elements, such as channel morphology and stability.

Materials

Required:

- ☐ Camera or smartphone
- ☐ GPS device or smartphone with location tracking
- ☐ Field notebook or other way to record photo details

Optional:

- ☐ Tripod or stable platform for consistent camera positioning
- ☐ Compass, GPS, or phone app with orientation capabilities
- ☐ Reference and identifying items to include in photo frame, such as dry-erase board or measuring/stadia rods

Timing Recommendations

- ☐ Take a baseline photo before restoration or planting. Repeat photography every one to two years for at least three years. If possible, continue long-term to capture the vegetation's structural development.
- ☐ Take photos during the same season. Plants are at peak growth in summer. In winter, deciduous plants will be bare and allow views of channels or highlight evergreens. If water stress is a concern, taking photos at the end of the growing season (late September) can help identify which plants died due to a lack of water.

Other Parameters This Protocol Can Measure and Inform

- ☐ 5.2. Infrastructure Protection & Flood Control: Inundation

Photo #	Compass Direction	Subject
3.3	225°	Riparian plantings where dike was lowered

(a) (b) (c) (d)

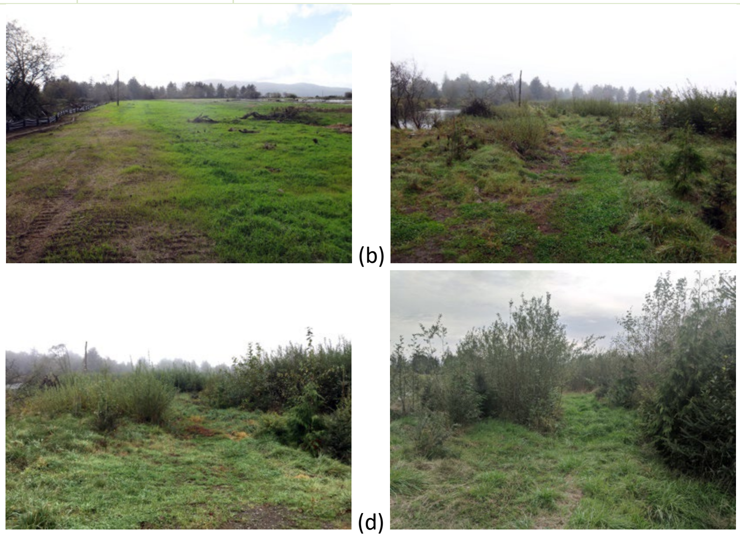


Figure. Sample metadata record and photos of the same point taken in (a) 2015, (b) 2017, (c) 2018, and (d) 2020.

Site Selection for Baseline Photos

Aerial photography, restoration designs, or planting plans can be used to select photo point sites. Select areas of interest, such as vegetation transitions or plant communities of interest. Ensure enough photo points are established to document changes expected to occur. Make sure they can easily be accessed after restoration work is completed.

Document GPS coordinates, the date of the baseline photos, the number of photos taken at each location, compass bearings, narrative descriptions of the photo subjects, important landmarks or reference points, and observations.

Repeat Photography

- Return to each photo point at the scheduled intervals.
- Ensure the camera is positioned at the same spot and orientation as the baseline photo.

- Take a new photograph of the site, capturing the same landmarks and reference points as in the baseline photo.
- Record the date, time, GPS coordinates, and any changes or observations. Collect the photo's file name information from the camera so it can be identified and matched to the photo point once you return to the office.

Data Management

- Organize and store all photographs and associated data in a well-structured database or file system.
- Create a metadata record for each photo, including date, location, orientation (compass reading), and details of habitat observed.
- Create maps for future photographers to easily return to the project location and photo points.
- Display before photos and after photos adjacent to each other in reports. See Hall (2002b) for guidance on repeat photo analysis.

Field Tips

- Mark photo point locations permanently with polyvinyl chloride (PVC) pipe or capped rebar so photos can be taken from the same location in the future. Note: Cows will destroy your PVC pipe.
- Include identifiable permanent landmarks, like telephone poles, barns, or mountain ranges, as in-photo references for consistent photography. Including about a third of the sky in the photo view can help with capturing the same perspective for future photos.
- Include reference objects in the photo frame to provide scale. Use something with standard measurements, like a telescoping measuring pole, or a standard-sized common item, like a shovel. Capture future photos from the same distance away from the item.
- Include a dry-erase board or other information board in the photo frame to include reference information in the photo, such as the photo point number, date, and descriptions of location or restoration status.
- Include photos from a high point for landscape views of the site when possible.
- Locate photos where there will be sufficient distance from the vegetation directly in front of the camera, like on a path. When photos are taken too close to plantings, the future plant growth can make it challenging to return to the photo point or capture much in future photos besides a tangle of branches.
- Photo point data, such as point name, compass bearing, and location notes, can be stored in the attributes of the GPS files for photo point locations.

References

Ciannela *et al*. (2021).

Hall (2002a).

Hall (2002b).

Roegner *et al*. (2009).

3.2. Wetland Vegetation Development:
Aerial Photo Analysis

Mapping via aerial photo analysis: Aerial imagery can be used to characterize vegetation into broad classifications over an entire project site. This information can help track large-scale changes over time or target monitoring areas, such as vegetation cover sampling plots or photo points.

Materials

- ☐ High-resolution satellite imagery is easily and freely accessible, but the timing of photographs cannot be controlled. Photography from airplanes or drones can be contracted for closer images at desired times.

Timing Recommendations

- ☐ Interpret baseline imagery to collect information on pre-project conditions.
- ☐ The first post-restoration image analysis of vegetation should be conducted two years after project completion to allow for site recovery from the disturbance.
- ☐ Future analysis can be done at intervals of two to five years to allow time for plant communities to respond to changing conditions.

Other Parameters This Protocol Can Measure and Inform

- ☐ 3.3. Wetland Vegetation Development: Stratified Sampling
- ☐ Channel morphology (landscape scale evolution)

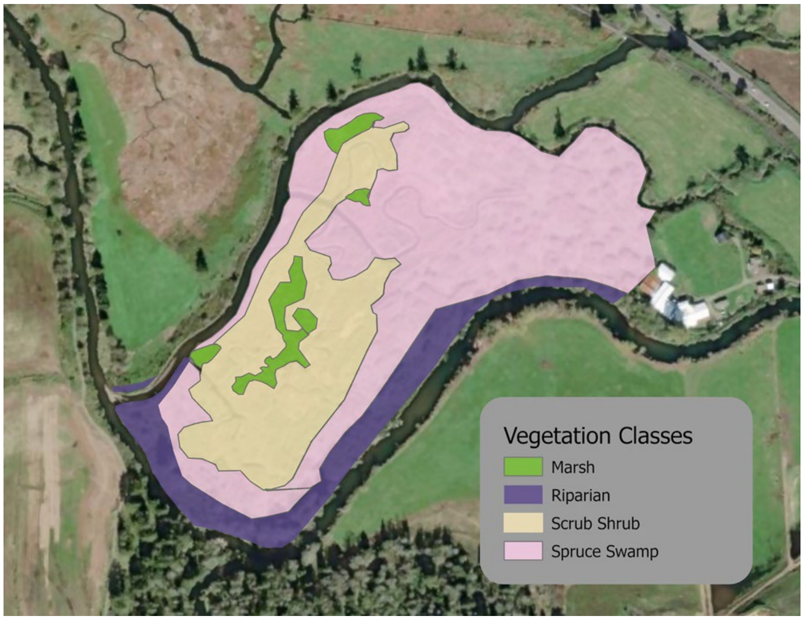


Figure. The Nature Conservancy's (TNC's) Kilchis Estuary Preserve.

Summary

First, a vegetation classification and minimum mapping size must be set. A field visit before aerial photo interpretation can be helpful to gain familiarity with the site's suite of vegetation classes. On a computer screen (or physical copies of maps), the interpreter delineates polygons of discrete vegetation classes using indicators such as color, texture, and shadow. These areas must then be groundtruthed to identify or confirm the classification.

Field Tips

- Images should be examined at a scale of 1:1200 to 1:3600.
- Typical maximum mapping unit sizes are 0.5 acres.

Resources for Aerial Imagery

- Oregon Explorer Imagery website: https://spatialdata.oregonexplorer.info/geoportal/imagery. It offers the finest-resolution imagery (0.5 m) available to the public but must be downloaded into a geographic information system (GIS), and the transfer is not rapid.

- Google Earth Engine: https://earth.google.com. You can download the free version.
- Oregon Geospatial Enterprise Office Online: https://www.oregon.gov/geo/Pages/imageryframe.aspx
- U.S. Department of Agriculture Geospatial Data Gateway: https://datagateway.nrcs.usda.gov. Digital orthophotos for every U.S. county are available as free downloads but must be viewed with a GIS or other image-processing software.

Field Tips

Slope and elevation can be important driving factors for vegetative communities. Overlaying the image on a digital elevation model can be helpful while mapping.

Vegetation Classification Systems

The **Cowardin classification system for wetlands** is tied to wetland function and provides coarse information on vegetative communities. It includes classifications that describe the structure of plant communities (e.g., emergent wetland, scrub-shrub wetland, and forested wetland). See Dahl *et al*. (2020) for guidance on mapping using this system.

The **National Vegetation Classification Standard** is another classification system that allows for flexibility in the level of detail that can be mapped. Multiple levels of classification are available. Coarser levels are similar to Cowardin in their description of vegetation (e.g., wet shrubland), but there are also levels for specific floristic identification of plant associations (e.g., *Salix hookeriana-Spiraea douglasii* shrub swamp). Typically, coarser classifications can be identified through aerial photo interpretation, and field verification is required to get to finer classifications. See TNC and Esri (1994) and Brophy *et al*. (2014) for more information on using this classification system. The vegetation classification for Oregon can be found online at NatureServe Explorer: https://explorer.natureserve.org/.

Data Analysis

On a GIS, the area of each vegetation class can be calculated to compare relative size. Changes in the extent of these classifications can be tracked over time.

References

Brophy *et al*. (2014).

Dahl *et al*. (2020).

Marshall (2007).

TNC and Esri (1994).

3.3. Wetland Vegetation Development: Stratified Sampling

Stratified sampling design is recommended for plot placement when collecting quantitative measurements of vegetation. Parameters to measure vegetation can include woody stem density, survivorship of plantings, or percentage cover. Monitor to track vegetation development relative to project goals, such as overstory development to shade channels or growth toward reference site conditions.

Materials

- ☐ Fiberglass measuring tapes
- ☐ 1-m^2 plot frames (for herbaceous vegetation cover monitoring)
- ☐ Datasheets
- ☐ GPS
- ☐ Physical markers, like polyvinyl chloride (PVC)

Timing Recommendations

- ☐ Monitoring should be conducted during peak growth in summer.
- ☐ For woody stem density: baseline and Years 1, 5, 10, and beyond if possible
- ☐ For herbaceous vegetation: baseline and Years 1, 3, 5, and beyond if possible
- ☐ For survivorship of plantings: Years 1, 2, and 3 after planting

Recommended Sample Sizes and Plot Sizes

For sites up to 5 ha:

- ☐ 10 woody vegetation plots per hectare. Each plot should be an 8-m-diameter circle. An 8-m tape can be laid perpendicular to the transect to delineate plot quadrats. Or a 4-m radius can be pivoted around the plot's center if the monitor does not mind working around tree trunks.
- ☐ 20 herbaceous plots per hectare. Each plot should be a 1-m^2 quadrat centered on cross-transect tape so that the tape divides the quadrat frame into halves.

For sites larger than 5 ha:

- ☐ Cap samples at 50 woody plots and 100 herbaceous plots.

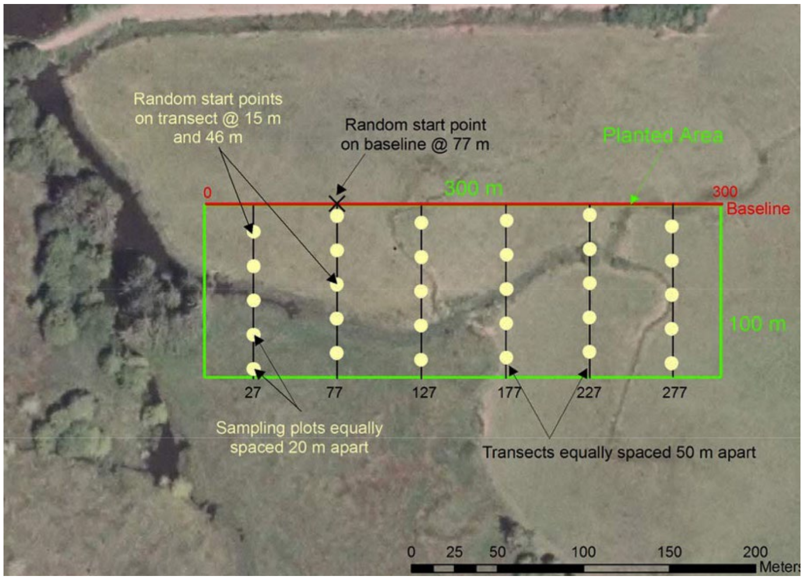


Figure. Example of a woody vegetation planting site showing the location of sample area, baseline, transects, and sample plots (example only; not an actual planning site). Source: Roegner *et al*. (2009).

Design

Stratification: Divide the area of interest into discrete monitoring strata. These are macroplots of a somewhat homogenous habitat, where vegetation will be similar within a stratum and quite different than the other strata. Dividing sampling by strata reduces variability between subsets of samples so that meaningful changes can be measured between strata and over time. Select strata-defining characteristics that are not anticipated to change over time, such as major vegetation types, elevation bands, soil type, or aspect. If the site does not have meaningful habitat zones, conduct random sampling over the entire site.

Samples within strata will be summarized together. Sampling units can be allocated in proportion to the size of each stratum.

Systematic sampling with a random start within strata: For each stratum to be monitored, establish a baseline that spans the entire monitoring site. Mark the baseline's end locations with GPS and a physical marker, like PVC or rebar, to easily return to the locations in future monitoring years. Sometimes, site topography or conditions do not allow for the establishment of a simple baseline.

Field Tips

Daubenmire cover classes are used for estimating species cover in plots.

Class	Cover (%)
1	0 – 5
2	6 – 25
3	26 – 50
4	51 – 75
5	76 – 95
6	96 – 100

Transects should be placed perpendicular to the baseline. Sampling plots fall along transects. The distribution of plots on transects depends on the size and shape of the monitoring area and sample size. Transects and plots should be placed systematically with a random start (e.g., evenly every 5 m, starting at a randomly selected point between 0 and 5 m).

Data Collection

Herbaceous plantings: Identify all species occurring in the plot. Then, visually estimate the percentage area occupied by each species. Record the estimate using Daubenmire cover classes.

Woody stem density: Identify and count all “plants” in the plot by species. For certain trees and shrubs, a single plant is easily defined and will have a single trunk. For many shrubs, it is most straightforward to count each individually rooted stem as a separate plant.

Optionally, the monitor can also record plant vigor, the diameter at breast height of the stem closest to the plot’s center, and/or canopy cover readings using a densiometer.

Planting survivorship: Complete the method for woody stem density and also record whether each plant is alive or dead.

Analysis

For herbaceous plant cover, summarize data using Daubenmire calculations and summary forms on pp. 57-62 in Couloudon *et al*. (1996). Calculate cover by species and native versus non-native species. Richness (the number of different species present) can also be calculated.

For woody stem density, calculate the average live stems per plot in each stratum. Calculate density by dividing the mean number of stems by the plot’s area. Convert to stems per acre. Basal area can be calculated from the diameter at breast height. Compare to the reference site if feasible.

Field Tips

Herbaceous-cover plots and woody-stem-density plots can be located along the same transects in habitats that support both vegetation types. Monitoring can be conducted for both methods simultaneously.

For planting survivorship, calculate the average survival of plantings for all plots in a habitat stratum. Report with confidence intervals. Survival rates between 50%–70% reported with 80% confidence are typically considered successful. It can be informative to calculate survival rates by species. Conduct a one-way analysis of variance (ANOVA) to test for significance. To compare means over time, plot the values.

References

Couloudon *et al*. (1996).

Elzinga *et al*. (1998).

Janousek *et al*. (2022).

Roegner *et al*. (2009).

Field Tips

For field datasheet templates, see Couloudon *et al*. (1996) and Elzinga *et al*. (1998).

3.4. Invasive Species: Invasive Species Extent

Photo point monitoring can be an effective way to monitor and document changes in infestations of specific invasive species. It can be an effective way to visually document the large (or potentially large) infestations of invasive species and the effectiveness of treatments. It can also be used to track changes in newer or priority invasive species.

Materials

Required:

- ☐ Camera or smartphone
- ☐ GPS device
- ☐ Resources to identify the project's invasive species of concern
- ☐ A way to record notes

Optional:

- ☐ Tripod or stable platform for consistent camera positioning
- ☐ Compass, GPS, or phone app with orientation capabilities
- ☐ Physical markers, such as polyvinyl chloride (PVC) or rebar, to return to photo point locations
- ☐ Reference and identifying items to include in photo frame, such as dry-erase board or measuring rods

Timing Recommendations

- ☐ Timing as per the species life cycle, treatment schedules, and capacity.
  - **Monthly, quarterly, or semi-annually**: Multiple photographs per year may be appropriate for invasive species that spread rapidly, have distinct growing seasons, or exhibit seasonal variability — also appropriate for early detection and rapid response programs.
  - **Annual monitoring** is typically sufficient for slow-growing invasive species or when the primary goal is to track long-term trends or assess the effectiveness of management efforts.
- ☐ Continue monitoring long-term to track changes and trends in invasive species presence and impact.

Site Selection and Baseline Photos

- Choose a study site where invasive species are known to be present or where there is a potential for invasion. Invasive species surveys can be completed through regular walks through the project area or as part of systematic vegetation monitoring (see Protocol 3.3).
- Photograph not only the invasive species but also the surrounding vegetation, landscape, and ecosystem to provide context.
- Take photographs from different angles and distances to comprehensively document the infestation.
- Mark the location with PVC or rebar so photos can be taken from the same location in the future (optional).
- Document the GPS coordinates, date, number of photos taken at each location, compass bearings, narrative descriptions of the photo subjects, important landmarks or reference points, and observations.

Repeat Photography

- Return to the photo point at the scheduled intervals.
- Ensure the camera is positioned at the same spot and orientation as the baseline photo.

Field Tips

For more tips on taking repeatable photos, check Protocol 3.1.

- Take a new photograph of the site, capturing the same landmarks and reference points as in the baseline photo.
- Record the date, time, GPS coordinates, and any changes or observations. Collect photo file name information from the camera so it can be identified and matched to the photo point once in the office.
- Document the location and density of invasive species in the photo, as well as any relevant environmental conditions.
- Note any control or management actions taken in response to the infestation.

Field Tips

Photo point data, such as point name, compass bearing, and location notes, can be stored in the attributes of the GPS files for photo point locations.

- Note the effects of treatments, presence of biocontrols, or vigor of plants.
- Note any native species that may be impacted by the infestation.

Data Management

- Organize and store all photographs and associated data in a well-structured database or file system.
- Create a metadata record for each photo, including date, location, and details of habitat observed.
- Create maps for future photographers to easily return to the project location and photo points.
- Display before photos and after photos adjacent to each other in reports. See Hall (2002b) for guidance on repeat photo analysis.

Invasive Species Identification Resources

Develop a list of priority invasive species to watch for in your project area. Visit websites or reach out to experts at your state noxious weed board, county extension office, or Cooperative Weed Management Area (in Oregon).

Gather resources for identifying priority invasive species specific to your area. Carry field guides, smartphone apps, or laminated identification cards when visiting the site or conducting other monitoring.

Some helpful apps:

- EDDMapS
- iNaturalist
- Seek
- PlantNet
- Federal Noxious Weeds Key

References

Ciannela *et al*. (2021).

Hall (2002a).

Hall (2002b).

3.5. Invasive Species: Area of Infestation and Treatment

Geographic information system (GIS) mapping: Invasive species can negatively impact the quality of natural habitats by outcompeting native flora and fauna, disrupting food webs, and altering physical landscape processes. Mapping an inventory of invasive species infestations is an early stage for any approach to treating potentially troublesome infestations.

Materials

- ☐ GPS device or smartphone
- ☐ Field resources to identify invasive species of concern, such as field guides, laminated identification cards, or some of these helpful smartphone apps:
  - EDDMapS
  - iNaturalist
  - Seek
  - PlantNet
  - Federal Noxious Weeds Key

Timing Recommendations

- ☐ Before restoration, conduct a site assessment to determine if control is necessary to avoid spreading invasive species throughout the site.
- ☐ Disturbed areas are prone to invasive species infestations, so the first three years of a project require vigilant monitoring. However, invasive species monitoring is a long game and should ultimately be conducted by the long-term land manager.
- ☐ Frequent visits are required to discover new invasive species occurrences, which can be critical for early detection and rapid response. Search for invasive species at least annually. Quarterly is better. Every visit to the site is an opportunity to search for invasives. Carry a GPS when visiting the site or conducting other monitoring.

Figure. New Zealand mud snails — extremely small aquatic invasives. Source: U.S. Geological Survey (USGS; n.d.-b).

Before Monitoring

Before any monitoring, develop a list of invasive plants and animal species that could potentially occur on the site. The Oregon Department of Agriculture's Weedmapper tool and Natureserve's iMapInvasives interactive maps can provide good information. Better yet, reach out to experts at your state noxious weed board, county extension office, and Cooperative Weed Management Area, as well as other land managers. Research identifying characteristics of these species and their look-alikes. Collect resources to bring into the field to aid identification.

Data Collection

A GPS or smartphone with a means to collect waypoints, such as Esri FieldMaps or Avenza Maps, is recommended for collecting location data. Sometimes, drawing on a paper map can be helpful for a

Field Tips

Since morphological differences between certain native and invasive species are subtle, correct identification is important before implementing controls. The app PlantNet can pull up photos of look-alike plant species to aid in identification.

backup plan. When collecting infestation information, it is helpful to record the date, estimated size of the patch, density or percentage covered, and phenology or life stage. When it is possible to walk around an infestation completely, collecting polygon data can help compare total size to future observations. However, each case is different, and sometimes, points or lines are more practical ways to collect infestation data. Organize and store all geospatial data and associated notes in a well-structured database or file system.

Field Tips

Invasive species may be present onsite before beginning restoration work, or they can be introduced during restoration activities through the disturbance caused by construction activities or from plant materials. Invasive species can also enter sites in subsequent years from flood events, wind, animal movements, vehicle traffic, or field gear. Roads, trails, and waterways are effective vectors for weed seeds and propagules.

While any GPS program can work, there are a couple of well-designed platforms specifically for mapping invasive species and managing the geospatial data. The two apps mentioned below also automatically report occurrences to coordinated invasive species networks. This information aids collective efforts to control their spread. They both can track survey areas, even when a search produces no invasives. Some benefits of each follow:

- **iMapInvasives Survey123**: Capable of tracking treatment data. Compatible with ArcGIS Online and other Esri products.
- **EDDMapS**: Includes regional invasive species field guides with distribution maps and identification resources, including high-quality photos.

Treatments

The objective of mapping is to inform and track an invasive species management plan. When choosing how to address invasive species populations, consider different approaches to prioritizing treatments. An early-detection rapid-response approach toward invasive species is often the most effective way to deal with new invasions, as it can enable managers to treat potentially troublesome infestations before their control requires considerable time and money.

When dealing with large populations of preexisting non-native invasive species, eradication may not be realistic. As a long-term goal, establishing native vegetation may change site conditions to reduce the vigor of invasive species and promote the natural recruitment of native species. Effective approaches to invasive species control in these cases include localized containment of an infestation and control around planting zones or immediately adjacent to individual plantings. When there are large preexisting infestations, a local soil and water conservation district can often help with a control plan.

Resources

- The Oregon Invasive Species Council's info hub website has species profiles for many high-priority invasive species to look out for: https://www.oregoninvasivespeciescouncil.org/infohub.
- Invasive plants in Oregon are classified by the Oregon Department of Agriculture: http://www.oregon.gov/ODA/programs/Weeds/Pages/AboutWeeds.aspx
- Invasive animals are listed by ecoregion in the Oregon Conservation Strategy (ODFW [Oregon Department of Fish and Wildlife] 2016) — specifically on the invasive species web page: https://oregonconservationstrategy.org/key-conservation-issue/invasive-species.
- Welch *et al*. (2014) provide a guidebook for the early detection of and rapid response to invasive plants: http://dx.doi.org/10.3133/sir20125162.
- The Invasive Plant Management Decision Analysis Tool can help managers develop site management plans based on project goals and financial resources: https://www.ipmdat.org.

4.1. Fish Presence/Absence: Snorkel Survey

Many tide gates are replaced to improve fish passage and increase access to habitat behind the gate. The specific tide gate, along with the project's water management plan, determines how easily fish can pass through the structure. Snorkeling is an inexpensive and low-tech method to determine fish presence.

Materials

- ☐ Wet suit or dry suit with hood, gloves, and wading boots
- ☐ Mask and snorkel
- ☐ Data recorder (dive slate or plastic cuff) and grease pencil
- ☐ Underwater flashlight
- ☐ Thermometer

Timing Recommendations

- ☐ Snorkel surveys can be performed during the day at water temperatures above 9 °C, but complete them at dusk when below 9 °C.
- ☐ Schedule surveys to coincide with the peak abundance of species of interest. For salmonids, juvenile rearing season is the typical target timing.

Field Summary

- ☐ Snorkel sites should be 50 m in length and have a time limit of 20 min.
- ☐ Perform snorkel surveys against the current (move from downstream to upstream).
- ☐ The survey can include snorkeling sites below the tide gate.

Other Parameters This Protocol Can Measure and Inform

- ☐ 4.4. Fish Relative Abundance: Community Composition

Miscellaneous

- ☐ Snorkeling does not require a permit, as it is a passive monitoring technique.
- ☐ When snorkeling in cold water, wear enough warm base layers and keep safety first.

Design

Capturing juvenile salmonids in a complex wetland habitat is no small feat. An easier method to determine species presence is snorkeling, assuming water clarity allows for it (additional benefit: little disturbance to the target species).

A minimum of one location should be snorkeled during baseline data collection. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should start when the tide gate is operating according to a water management plan, typically after one year has passed, and snorkeling post-restoration should occur in Year 2. Time snorkeling events with the peak presence for the species of interest. For example, juvenile coho presence peaks in freshwater tidal zones in March for the Oregon Coast evolutionarily significant unit (ESU). Reach out to your local contact at the Oregon Department of Fish and Wildlife (ODFW) or a tribal fish biologist for advice on the best timing.

Field Tips

Snorkel surveys are difficult and less accurate in water bodies with poor visibility, such as water with high tannin or turbidity levels.

If funding and capacity allow for expanded monitoring design, consider snorkeling at multiple locations behind the tide gate and one location in front of the tide gate. In addition, snorkeling multiple times throughout the season ensures a more representative dataset because salmonids move in pulses.

Methods

Site selection: Site selection is paramount to completing a successful snorkel survey. Possible snorkel sites should have visibility of greater than or equal to 1.5 m, a minimum depth of greater than or equal to 20 cm, and a site length of approximately 50 m. To help select a snorkeling site, monitor locations for surface feeding during calm winds and choose a site based on the greatest feeding activity.

Snorkeling procedure: If the water temperature is below 9 °C, fish are generally inactive, so snorkeling should occur after dusk. When snorkeling during daylight, the hours from midmorning to midafternoon offer the best visibility. Snorkeling is typically conducted in a single downstream-to-upstream pass. One snorkeler is needed for channels less than 2 m wide, two snorkelers for 2- to 5-m channels, and three or more snorkelers for channels more than 5 m wide. As a group, enter the channel downstream of the site and approach slowly to minimize fish disturbance. Begin the snorkel survey at the downstream boundary and snorkel upstream, ensuring all snorkelers are moving at the same speed.

If the water depth becomes excessively shallow and floating is impossible, crawl to each small pool to visually survey until the water returns to floating depths. When sites are deeper than the depth of visibility, do not dive to site the fish. Diving causes a great amount of disturbance and will scare fish away from the site. Each site should be surveyed for no longer than 20 minutes but long enough to fully survey preferred habitat features, such as log jams, side channels, or undercut banks.

Field Tips

Permits are not required to perform snorkel surveys.

Field Tips

Mark survey boundaries with flagging before entering the water. If sampling units will be resurveyed in the future, mark the boundaries permanently with stakes.

When the survey requires two snorkelers, the snorkelers should be positioned toward the middle of the channel, looking toward their respective banks. Record all species observed on a dive slate or plastic cuff.

If desired, collect additional metadata at each site, such as GPS location, temperature, dissolved oxygen, weather conditions, water clarity, channel surface area surveyed, and habitat type (channel, pool, tidal depression, etc.).

Data analysis: Fish presence data requires minimal analysis, especially if only one survey is completed. If surveying occurs over multiple sites or days, creating maps can be a useful approach to visualize the spatial distribution of species presence/absence across the project site.

References

O'Neal (2007).

ODFW (2002).

Juvenile Salmonid Identification Guides

McConnell and Snyder (1972).

Pollard *et al*. (1997).

4.2. Fish Presence/Absence: Seine Netting

Many tide gates are replaced to improve fish passage and increase access to the habitat behind the gate. The specific tide gate design, along with the water management plan, determines how easily fish can pass through the structure. Sampling for salmonid presence can indicate whether fish can access habitat above the tide gate at times of interest.

Materials

- ☐ Beach seine net (size depends on habitat)
- ☐ Waders
- ☐ Hand bait net
- ☐ 5-gal. bucket with battery-operated bubbler

Timing Recommendations

- ☐ Seine during the tide cycle that provides sufficient depth and minimal velocities, usually flood tides.

Field Summary

- ☐ Seining locations should be established ahead of time.
- ☐ Ideal locations will have gradual banks with minimal vegetation or large woody debris.
- ☐ Seining can include sites below the tide gate.

Other Parameters This Protocol Can Measure and Inform

- ☐ 4.4. Fish Relative Abundance: Community Composition
- ☐ 4.5. Fish Growth: Fork Length & Wet Weight

Miscellaneous

- ☐ At least three people are required to seine. The larger the seine, the more field hands needed.
- ☐ An Oregon Department of Fish and Wildlife (ODFW) permit is needed to handle fish not listed under the Endangered Species Act (ESA).
- ☐ A National Oceanic and Atmospheric Administration (NOAA) permit is needed to handle ESA-listed fish.

Design

Capturing juvenile salmonids in a complex wetland habitat is no small feat. Careful planning is required to ensure that the seining event(s) are representative of actual fish populations.

A minimum of one location should be seined during baseline data collection before the tide gate replacement or upgrade. Seining post-restoration should occur in Year 2 after the land-recovery phase is complete and the tide gate is operating according to the water management plan. Conduct seining event(s) during periods when peak species of interest are expected to be present. For example, juvenile coho presence peaks in freshwater tidal zones in March.

Field Tips

If you are seining minimally, ask your local ODFW fish biologist about aiding in your monitoring activities. They could help supply materials, and the monitoring would fall under their permit.

If funding and capacity allow for expanded monitoring design, consider seining at multiple locations behind the tide gate and one location in front of the tide gate. Also, seine multiple times throughout the season to account for salmonids moving in pulses. This approach will ensure a more representative dataset.

Permitting: To capture and handle fish in Oregon, a scientific take permit is required. If the expected fish are ESA-listed, a 4(d) permit is needed and can be obtained through NOAA. When monitoring includes minimal seining, a permit is unnecessary if your local ODFW representative is in attendance.

Methods

Site selection: As restoration sites mature, seining becomes more difficult due to riparian vegetation growth on channel banks and aquatic vegetation within the channel. Site selection is paramount to successfully capturing juvenile salmonids during seining. Ideal sites are a minimum of 3 ft deep and have minimal current, few obstructions, and gradual banks. Observe each possible site during calm wind for the prevalence of surface feeding and choose seining sites based on the greatest fish activity.

Seining procedure: Place one end of the seine net at the water's edge. Anchor it to vegetation or have a person hold it. Extend the net across the channel perpendicular to the shoreline, ensuring it spans the width of the target habitat. Use one or more people to walk slowly in a semi-circle, gradually moving away from the starting point and bringing the other end of the seine net back to the shoreline. Ideally, seining occurs during slack tide (high or low depending on water depth), but when seining with a current, set the net from downstream to upstream. Carefully enclose the target habitat within the net. Slowly pull in both ends of the seine at a similar rate (see the field tips). When most of the net is on the bank, pull the lead line up to cradle the captured fish in a pen made from the seine net and filled with water. By hand or with a hand net, carefully remove fish from the net pen. Count all fish species and immediately release. If further data is desired, such as fork length and weight, keep species of interest in a holding bucket with a battery-powered aerator.

Field Tips

- When pulling the seine in, be careful not to trap fish in the folds of the net. To avoid this situation, keep the net taut between the float and lead lines on each end of the seine. With a team of three people, one person in the middle accounts for both lead lines while the other two people focus on managing the float line from either end of the seine.
- Make sure the seine's lead line stays on the channel bed to ensure no fish escape. An easy way to accomplish this is to pull the float line until there is slack in the lead line, then pull out the slack of the lead line.

If desired, collect additional metadata at each site, such as GPS location, temperature, dissolved oxygen, and habitat type (channel, pool, tidal depression, etc.).

Data analysis: The presence of species of interest requires minimal analysis, especially if sampling only occurs once. If sampling occurs over multiple sites or days, create maps to visualize the spatial distribution of presence or absence across the project site. Furthermore, if sampling occurs below the tide gate, a simple statistic can be calculated to show the percentage of presence above the tide gate when presence occurs below the tide gate.

References

Hahn *et al*. (2007).

Kinzer (2017).

Juvenile Salmonid Identification Guides

McConnell and Snyder (1972).

Pollard *et al*. (1997).

4.3. Fish Relative Abundance: Catch Per Unit Effort

Catch per unit effort (CPUE) can be used to measure the abundance of salmonids pre- and post-restoration to determine the efficacy of tide gate upgrades. Data from fish capture methods, such as seine netting (Protocol 4.2), are used to calculate CPUE.

Design

CPUE is calculated using results from seining described in Protocol 4.2. A minimum of one location should be seined during the pre-restoration baseline data collection. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should start when the tide gate is operating according to its water management plan, typically after one year has passed. Post-restoration seining should start in Year 2. Conduct seining event(s) when the peak presence for species of interest is expected. For example, juvenile coho presence peaks in March in many coastal freshwater tidal systems. Consistent nets and deployment methods should be used to compare sampling data over time.

Catch Per Unit Effort (CPUE)

CPUE is calculated for each fish species by dividing the total number of fish by the length of shoreline seined for each seine pull. CPUE values from before and after tide gate upgrades can be compared.

$$CPUE = \frac{Total\ Number\ of\ Fish}{Length\ of\ Shorline}$$

Example Datasheet

Site Location/Name:	________________
Date:	________________
Weather Conditions:	________________
Tide Stage or Time:	________________
Seine Dimensions:	________________

Seine Pull 1	
Species 1:	________________
Total Number Captured:	________________
Species 2:	________________
Total Number Captured:	________________
Length of Shoreline:	________________
CPUE:	________________

Seine Pull 2	
Species 1:	________________
Total Number Captured:	________________
Species 2:	________________
Total Number Captured:	________________
Length of Shoreline:	________________
CPUE:	________________

Seine Pull 3	
Species 1:	________________
Total Number Captured:	________________
Species 2:	________________
Total Number Captured:	________________
Length of Shoreline:	________________
CPUE:	________________

Monitoring Approach Associated With This Parameter

☐ 4.2. Fish Presence/Absence: Seine Netting

References

Hubert and Fabrizio (2007).

4.4. Fish Relative Abundance: Community Composition

Individual fish species have different capacities to pass through tide gate structures. Analyzing community composition above and below a tide gate helps inform how effective the tide gate upgrade and associated water management plan are at allowing fish passage for different species. Data from fish capture methods, such as seining (Protocol 4.2), are used to calculate community composition.

Design

Analyzing fish sampling data to calculate community composition is a fundamental step in ecological research and fisheries management, helping to assess the health and dynamics of aquatic ecosystems. Analyze the community composition data to draw conclusions about the fish community's structure and diversity. Compare baseline results with data after tide gate replacement or with reference values to assess changes over time or between locations.

Keep in mind that sampling methods and gear selection impact the fish size and diversity of species collected for the following calculations. Since every method has its limitations, it is most important to maintain consistency across sampling efforts.

Species Richness

Species richness is a measure of the total number of different fish species present in the sample. Count the number of unique fish species in your dataset.

Species Abundance

Species abundance refers to the number of individuals of each species present in the sample. Count the number of individual fish for each species in your dataset.

Relative Abundance

Relative abundance is the proportion of each species relative to the total number of fish in the sample. It is typically expressed as a percentage.

Calculate the relative abundance of each species by dividing the number of individuals of that species (i.e., Species X) by the total number of fish captured and multiplying by 100.

$$Relative\ Abundance\ (\%) = \left(\frac{Number\ of\ Individuals\ of\ Species\ X}{Total\ Number\ of\ Fish\ Captured}\right) * \ 100$$

Monitoring Approach Associated With This Parameter

☐ 4.2. Fish Presence/Absence: Seine Netting

References

Hubert and Fabrizio (2007).

4.5. Fish Growth: Fork Length & Wet Weight

Many tide gates are replaced to improve fish passage and increase access to habitat behind the gate. Juvenile salmonids grow at a faster rate in these off-channel wetland habitats. Measuring the fork length and the wet weight of juvenile salmonids yields key metrics to illustrate whether the body conditions of fishes have increased in these restored and accessible habitats.

Materials

- ☐ Waterproof gram scale
- ☐ Measuring board
- ☐ 5-gal. buckets (two to four)
- ☐ Battery-operated bubblers (two to four)
- ☐ Hand bait net
- ☐ Anesthetic (MS-222)
- ☐ Datasheet

Field Summary

- ☐ Sample fish captured by seining (Protocol 4.2) or other means.
- ☐ Anesthetize fish before handling.
- ☐ Allow fish to fully recover in a freshwater recovery bucket before release.

Miscellaneous

- ☐ A measuring board can be purchased or made with a 4-in. polyvinyl-chloride (PVC) pipe, a cloth measuring tape, and fiberglass resin.
- ☐ An Oregon Department of Fish and Wildlife (ODFW) permit is needed to handle fish not listed under the Endangered Species Act (ESA).
- ☐ A National Oceanic and Atmospheric Administration (NOAA) permit is needed to handle ESA-listed fish.

Design

The wet weight and fork length of juvenile salmonids are essential biometrics of their growth and health. Fish should be captured and measured upstream of the tide gate from a minimum of one location during baseline data collection. Refer to the seine netting protocol (4.2) in this handbook for fish capture methods. Most tide gates are operated modestly immediately after installation to allow the land to recover. So, monitoring should start when the tide gate is operating according to a water management plan, typically after a year has passed, and monitoring of fish biometrics post-restoration should start in Year 2. For year-to-year comparison, sample at a similar time each year so that sampled fish are of similar age.

> **Field Tips**
>
> State and federal permits are required to anesthetize and handle juvenile salmonids.

If funding and capacity allow for expanded monitoring design, consider seining and measuring fish at multiple locations behind the tide gate and one location in front of the tide gate.

Permitting: To capture, handle, and anesthetize fish in Oregon, a scientific take permit is required. Furthermore, if the expected fish are ESA-listed, a 4(d) permit is needed and can be obtained through NOAA.

Methods

Procedure: Keep all captured fish in freshwater holding tanks (5-gal. bucket or similar) equipped with a battery-powered bubbler to ensure adequate dissolved oxygen.

Set up a waterproof gram scale on a flat surface; use a small, wetted plastic tray with the scale. Tare the scale to account for tray weight. Set up the measuring board on the ground, on a table, or on top of a 5-gal. bucket. Place a small amount of water on the measuring board so the fish stay wet.

When setup is complete, mix 5 mL of a 60 mg/L MS-222 solution into 2.5 gal. of water in a 5-gal. bucket outfitted with a bubbler. When all personnel are ready, place 10 fish in the anesthetizing bucket. Once the first anesthetized fish has stopped swimming, remove it from the bucket with a hand net. Place the fish on the scale and record the weight to the nearest 0.1 g. Move the fish to the measuring board and measure from the tip of the snout to the fork in the tail (i.e., the V-shaped indentation where the caudal fin splits into two lobes). Record the length in millimeters. Move the fish to the freshwater recovery bucket. Repeat with all remaining fish in the anesthetic bucket, and continue processing all fish in batches of 10. Fish are ready for release back to the capture location once they are active and the anesthetic has worn off, roughly 20 minutes.

Field Tips

- To improve fish recovery, intermittently swirl the water of the recovery bucket to pass freshwater through the gills of the recovering fish.
- Windy conditions make scale readings inaccurate. Temporary windbreaks can be created using sampling gear, or the scale can be placed in an extra bucket lying on its side.

Data analysis: To compare multiple years of data, use various statistical tests and techniques. For example, a one-way analysis of variance (ANOVA) test is a simple approach to determine if fork length or weight differs significantly from year to year. Organize the data by year and sampling period (so similar-aged fish are compared). Run a one-way ANOVA test in Microsoft Excel or R for each sampling period. The ANOVA test produces an F-statistic and a p-value. A p-value of less than 0.05 indicates there are statistically significant differences in the weights and lengths from year to year.

References

Feldhaus and Wilson (2021).

PTSC (PIT Tag Steering Committee; 2014).

4.6. Fish Passage: Velocity (Float Method)

Velocity is a driving criterion for tide gate design. In Oregon, flow velocities within tide gate culverts are required to stay below 2 ft/s to allow adequate passage for juvenile salmonids. Velocity measurements help determine if new tide gate structures are functioning as designed.

Materials

- ☐ Six highly visible buoyant objects (oranges, tennis balls, etc.)
- ☐ Stopwatch
- ☐ Measuring tape
- ☐ Stake or marker
- ☐ Datasheet

Timing Recommendations

- ☐ Sample twice per year during peak velocities.
- ☐ Take measurements during rising and falling tides.

Survey Summary

- ☐ Measure the time for the floating object to travel 20 ft.

Miscellaneous

- ☐ This method is considered less accurate but can be used as a last-means method when flow velocities are too high to safely enter the water or a flowmeter is unavailable.

References

EPA (U.S. Environmental Protection Agency; 1997).

OAR 635-412 (2023).

WVDEP (West Virginia Department of Environmental Protection; 2018).

Design

Tide gates are designed to allow for adequate fish passage of juvenile salmonids. A critical design criterion is peak water velocity through the tide gate to accommodate juveniles, which have lower threshold capacities than adult salmonids. Capturing representative velocity measurements is difficult. Velocities within tide gate culverts vary due to rainfall events and daily and monthly tide cycles. Furthermore, it is often unsafe to measure peak velocities within the tide gate culvert itself. Although less accurate, the float method allows velocity measurements to be estimated safely at peak flows.

Field Tips

- Sample during spring tides when velocities will be greater than during neap tides.
- Oranges work best as the floating object. They are highly visible, available year-round, and biodegradable. If you want to eat them after measurement, place a kayaker and hand net downstream to collect them.

Methods

Site selection: Take velocity measurements through the tide gate.

Data collection: Measure the culvert's length if unknown. If the culvert is less than 20 ft long, measure and mark a distance from the tide gate door upstream 20 ft. Throw your floating object (orange or otherwise) into the channel upstream of the tide gate culvert or upstream of the 20-ft marker. Start the timer when the floating object passes the upstream marker or enters the culvert. Stop the timer when it appears on the downstream side of the culvert. Record the elapsed time. Repeat at least six times in quick succession for both rising and falling tides. Do not forget to record the date and time to match velocity measurements to tide height.

Data analysis: Calculate $velocity = time \div distance$. If velocities are greater than 2 ft/s, contact your local Oregon Department of Fish and Wildlife (ODFW) representative immediately.

Compliance: The ODFW Fish Passage Standard (OAR 635-412; specifically, the Fish Passage Criteria, OAR 635-412-0035) requires velocities to be below 2 ft/s. The velocity measurements, along with tidal data, should be reported annually to the ODFW Fish Passage Program Coordinator.

4.7. Fish Passage: Velocity (Flowmeter)

Velocity is a driving criterion for tide gate design. In Oregon, flow velocities within tide gate culverts are required to stay below 2 ft/s to allow adequate passage for juvenile salmonids. Velocity measurements help determine if new tide gate structures are functioning as designed.

Materials

- ☐ Flowmeter (e.g., acoustic Doppler, electromagnetic, or propeller-type)
- ☐ Wading rod
- ☐ Measuring tape
- ☐ Waders and boots
- ☐ Personal flotation device
- ☐ Datasheet

Timing Recommendations

- ☐ Sample twice per year, during safe water levels.
- ☐ Take measurements during rising and falling tides.

Survey Summary

- ☐ Take measurements at the upstream edge of the culvert or at mid-culvert.
- ☐ Face the flowmeter against the current.
- ☐ The measurement depth varies with water depth.

Miscellaneous

- ☐ If your organization does not own a flowmeter, contact your local fisheries biologist at the nearby Oregon Department of Fish and Wildlife (ODFW) field office. If ODFW capacity does not allow for assistance, measure velocity with the float method (Protocol 4.6).

Design

Tide gates are designed to allow for adequate fish passage of juvenile salmonids. A critical design criterion is peak water velocity through the tide gate to accommodate juveniles, which have lower threshold capacities than adult salmonids.

Capturing representative velocity measurements is difficult. Velocities within tide gate culverts vary due to rainfall events and daily and monthly tide cycles. Furthermore, it is often unsafe to measure peak velocities within the tide gate culvert itself. To overcome these two issues, collect velocity profile measurements twice per year during the low-flow months, even though this approach might not be reflective of when juvenile salmonids are present. If flow velocities allow for safe entry into the channel, this protocol recommends taking measurements during spring tides.

Field Tips

Safety first! If water is swift, wear a personal flotation device or measure velocity with the float method (Protocol 4.6).

If funding and capacity allow for expanded monitoring design, consider increasing the number of velocity profiles measured during varying tidal cycles.

Methods

Site selection: Only measure velocity via flowmeter when it is safe to stand in the channel or culvert. Take the velocity profile at the upstream edge of the culvert. If it is safe and feasible, the velocity can also be taken in the middle of the culvert. Take note of any potential safety hazards or obstacles in the area.

Data collection: Follow the instructions for velocity reading in the user's manual of your flowmeter. To start, measure the width of the culvert and record which side of the culvert is the starting point for the profile. Remember, stream banks and culverts are referenced from the viewpoint of looking downstream (*river right* or *river left*). Measure velocity at 1-ft intervals across the width of the culvert. Be sure to stand at least 18 in. diagonally downstream of the flowmeter to avoid altering velocity readings. If the water depth is less than 1.5 ft at the measurement point, take a single reading at 40% depth from bottom. If the water depth is greater than 1.5 ft, take two measurements, the first at 80% depth from bottom and the other at 20% depth from bottom. Record horizontal distance, total depth, measurement depth, and velocity at each interval. Additionally, record the start and end time of the survey to correlate velocity measurements with water level and tidal cycle. For each survey, measure the velocity profile during both the rising and falling tide.

Field Tips

Stand with your feet perpendicular to the flow (toes pointed toward a stream bank) to minimize effects on velocity readings.

Data analysis: If velocities are greater than 2 ft/s contact your local ODFW representative.

Compliance monitoring: The ODFW Fish Passage Standard (OAR 635-412; specifically, the Fish Passage Criteria, OAR 635-412- 0035) requires velocities to be below 2 ft/s. The velocity measurements, along with tidal data, should be reported annually to the ODFW Fish Passage Program Coordinator.

Field Tips

Sample during spring tides when velocities will be greater than during neap tides.

References

OAR 635-412 (2023).

WVDEP (West Virginia Department of Environmental Protection; 2018).

4.8. Fish Habitat: Channel Morphology

Channel morphology surveys yield valuable insights into the dynamic evolution of interior channels in response to heightened flow and velocity conditions resulting from upgraded tide gates. Although some channel movement is expected, a relatively stable channel network benefits fish populations by promoting long-term vegetative growth, which results in reduced levels of erosion.

Materials

- ☐ Laser level or auto level
- ☐ Tripod
- ☐ Stadia rod
- ☐ Meter tape
- ☐ Endpoint marker (T-post, rebar, or wooden stakes)
- ☐ Post pounder or mallet
- ☐ Datasheet
- ☐ Waders or dry suit

Timing Recommendations

- ☐ Survey once annually.
- ☐ Conduct surveys during low-flow conditions, typically at the end of summer or spring tides.

Field Summary

- ☐ Each site should have permanent endpoint markers.
- ☐ Measurement intervals decrease at low slopes and increase at high slopes.

Miscellaneous

- ☐ Deep-water channel cross sections are difficult and less accurate.
- ☐ If multiple years of surveys will be conducted, use similar equipment to improve accuracy.
- ☐ Cross sections generate relative elevations. Use a real-time kinematic GPS (RTK-GPS) if exact elevations are required.

Design

Channel stability and change in morphology are assessed through channel cross-sectional surveys. Sediment accretion and scouring happen over both short and prolonged periods. Therefore, channel morphology surveys should be conducted at the time of construction (new channels) and during Years 2 and 5 post-restoration. If new channels are not created during tide gate upgrades, baseline surveying should be conducted before tide gate replacement. While there is no universal rule of thumb applicable to all situations, the number of cross sections needed will vary from one or two for small projects to as many as six to 10 for larger, more complex projects.

> **Field Tips**
>
> Channel cross sections are difficult and less accurate in deep water.

Methods

Site selection: Choose sites in both the main channel and side channels that would experience the highest amount of scour or deposition. These areas are typically found where velocities are highest: around bends and meanders in the channel or just downstream of large confluences.

Surveying procedure: First, establish the transect by installing both endpoint markers 5 m (or less in small channels) beyond bankfull on each side of the channel being surveyed. Take the GPS locations of both endpoint markers. Set up the level and tripod beyond one of the endpoint markers. Stretch the measuring tape from each endpoint marker, ensuring the zero-meter mark is at the endpoint nearest the level. Record which river bank is at 0 meters. *River left* or *river right* is determined from the viewpoint of looking downstream.

Starting at 0 m, use the stadia rod to measure the height of the top of the endpoint marker to the level. Next, record the height from the stadia rod (on the bank) to the level line and the horizontal distance measured with the measuring tape. Take measurements by working your way across the channel until you reach the other endpoint marker. Typically, measurement intervals vary from 1-2 m when slopes are low to 0.25-0.50 m when slopes are steep.

Leave survey stakes in place. In future years, be sure to start surveys from the same endpoint marker and use the same intervals to take measurements across the channel.

Data analysis: Multiple years of channel cross sections can be plotted on top of each other to visually see channel movement. These can be used to create difference plots, which consist of subtracting before from after elevations to highlight areas of accretion (positive values) and areas of erosion (negative values).

Furthermore, the channel cross-sectional area (CSA) can be estimated by calculating the area of a trapezoid using the median width, depth, and bank. The geometric equation for the CSA (i.e., trapezoid area) is

$$CSA = \frac{(b1 + b2)h}{2}$$

where *b1* is the recorded bankfull channel width, *b2* is the width of the channel bed, and *h* is the channel depth.

Field Tips

- If cattle are present, ensure your endpoint markers are short and stout enough to handle rubbing. If cattle are absent, make sure your endpoint markers are long enough to stand out in tall grass.
- Leave stakes in place and use the same cross-section transects year after year.

References

Roegner *et al*. (2006).

USGS (U.S. Geological Survey; 2011).

4.9. Fish Habitat: Freshwater Mussel Presence

Note: Monitoring for mussels only applies to tide gates located in freshwater. Freshwater mussels are unable to inhabit brackish water.

Freshwater mussels are a group of species sensitive to abrupt changes in water flows and levels, especially drying habitat, scour, and deposition (Blevins *et al*. 2017). As long-lived animals that can form dense beds (hundreds per square meter), populations can be inordinately impacted by routine maintenance and construction instream, even when these activities occur over a relatively small footprint. Because freshwater mussels are important for the health of the ecosystem and native fish, monitoring for their presence in or near tide gates can ensure tide gate maintenance, development, or removal is protective of the ecosystem services mussels provide.

Materials

- ☐ Snorkel and mask with defogging liquid, aqua viewer, or glass-bottomed bucket
- ☐ Waterproof flashlight
- ☐ Thermometer
- ☐ Waders, wet suit or dry suit, and wading boots
- ☐ Camera and ruler or calipers
- ☐ Mussel identification guide (The Xerces Society for Invertebrate Conservation n.d.)

Timing Recommendations

- ☐ Survey between June 1 and September 30. This period generally falls during appropriate flow, visibility, and temperature conditions. Also, this period generally corresponds to baseflow water levels (although exceptions exist) when streams can be safely navigated.
- ☐ Visibility must be a minimum of 0.5 m (~ 20 in.) or visible to the bottom if shallower than 0.5 m. In order to conduct a visual survey that minimizes errors associated with imperfect detection, basic visibility requirements must be met.
- ☐ Water temperature must not be too cold, as freshwater mussels may burrow more deeply and be less visible. Aim for a combined water and air temperature of at least 100 °F (38 °C).

Methods

Under conditions where a waterbody can be snorkeled, snorkeling is considered the optimal method for detecting freshwater mussels. Examine a wide range of microhabitats and positions (underbank, within aquatic rooted plants, under boulders, etc.). The larger of the following two areas should be surveyed: (1) 5 m above and below the tide gate location or (2) the area of impact for dewatering, maintenance, construction, or other activities.

Navigate to the starting location. If surveying in a downstream direction reduces visibility, surveyors should survey working upstream. Record the following information:

- The technique used to conduct the survey
- Information about conditions at the time of survey, including flow, visibility, and water temperature
- The number of surveyors
- The area surveyed, including what portions of the channel above and below the tide gate

- Whether the survey was conducted (1) across the entire width, from bank to bank, by zigzagging or (2) for the whole stream because it was narrow enough to cover it completely

Field Tips

It can take several years for mussels to repopulate a newly constructed channel, which will happen more quickly if there is a close upstream or downstream population.

Conduct the survey in this manner until the first live freshwater mussel is observed. Note that a shell should be documented as an incidental observation if no live mussels are observed. Count each live mussel up to at least 100 individuals of each species and record the species' identities. Take voucher photos of freshwater mussels for species documentation; see the Quick ID Guide (Xerces Society n.d.) for examples of good photographs. Do not handle the mussels, as this is stressful for them.

When more than 100 individuals of a mussel species are present, surveyors may estimate the number observed and select the appropriate estimate range provided on the data form (e.g., 101–500 or > 500). Surveyors may also report a larger estimate than > 500 individuals per mussel species under the "other" category if preferred.

Document the general location of live mussels instream, whether *left bank*, *right bank*, or *in the middle* (when the surveyor is oriented downstream). Also, estimate the number of shells present within the segment if applicable.

Field Tips

If mussels are found, report them to the Oregon Department of Fish and Wildlife (ODFW) and the Xerces Society for Invertebrate Conservation for incorporation into the Western Freshwater Mussel Database: https://www.xerces.org/endangered-species/freshwater-mussels/database. With appropriate photographs, mussels can be identified by experts.

References

Blevins *et al*. (2017).

The Xerces Society for Invertebrate Conservation (n.d.).

5.1. Sediment Processes: Accretion Rate

Feldspar marker horizons: Surface elevation in tidal wetlands drives many aspects of ecosystem structure and function, such as hydrology, vegetation, and soil conditions. Subsidence in tidal wetlands can result from the disconnection of sediment inputs. Sediment deposition processes can be restored with improved tidal exchange and floodplain reconnection. Accretion rates can be monitored to assess how site elevations are changing, especially relative to anticipated sea level rise.

Materials

- ☐ White feldspar mineral (powder)
  - "G200" or "Minspar 200" is available from ceramic supply houses.
- ☐ Polyvinyl-chloride (PVC) pipe markers
- ☐ Laser level or real-time kinematic GPS (RTK-GPS)
- ☐ Knife

Timing Recommendations

- ☐ To document baseline accretion rates (needed to determine restoration effects), at least one sample event must occur before restoration. So, establish plots at least one year and preferably two years before restoration. Post-restoration sampling every two to three years provides good information on accretion rates. Too long an interval between samples (e.g., five years) can make locating plots difficult.

Summary

- ☐ The feldspar marker horizon technique is useful for monitoring sediment accretion over short time frames (years to a decade or two). Place feldspar (a white powdered mineral) on the soil surface within permanently marked plots. During monitoring, remove cores and measure the soil thickness accumulated above the marker horizon. Protect the plots from disturbance (machine operations, trampling by livestock or people, etc.) since it would disrupt the feldspar layer.

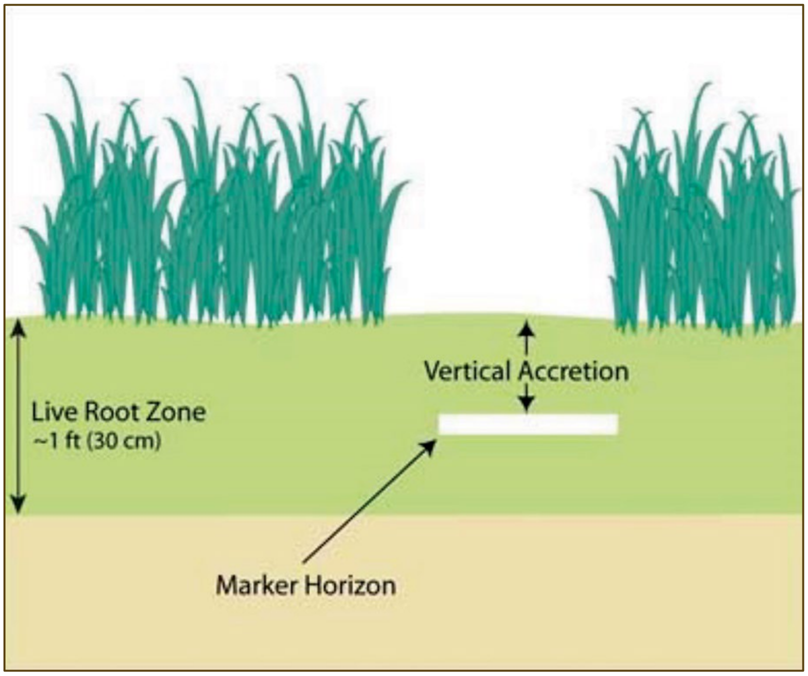


Figure: Diagram of vertical accretion measurement and a marker horizon. Source: Maryland-Delaware-DC Water Science Center (USGS [U.S. Geological Survey] n.d.-a).

Design

Plots should be placed at random within project strata (for more information on stratified random sampling design, see Elzinga *et al*. 1998). Strata can be defined by elevation, different land uses, or proximity to geologic features. Separate areas highly influenced by floodplain processes from those impacted by primarily tidal forces.

Methods

Site selection and installation: Use short sections of PVC pipe to mark four corners of each 1-m^2 study plot. Place white feldspar mineral (powder) in a layer about 0.5 to 1.5 cm thick in the central 0.25-m^2 area inside the larger 1.0-m^2 plot; about 2.7 kg is required per plot. Existing vegetation should be left undisturbed unless it prevents the establishment of a coherent feldspar layer. (In some cases, it may be necessary to remove dead plant matter and/or fibrous root mats; however, this will affect deposition rates, so it should be avoided in general.) Place additional tall markers more widely around the plot to help prevent trampling or disturbance.

Use a laser level or RTK-GPS to measure the ground surface elevation at the edge of each plot.

Data collection: During monitoring, use a knife to remove one to three soil wedges from the central 0.25-m^2 area. Record the location of each wedge so future sampling avoids sampling the same location. On each soil wedge, the distance from the top of the soil (top of wedge) to the top of the feldspar layer is measured on all sides that show a distinct feldspar layer (up to four sides per wedge). The absence of a white layer indicates erosion.

Field Tips

With the knife, cut down at an 80° angle to ensure relatively straight sides and a deep enough cut to reach the feldspar layer. It can be useful to have multiple knives of different lengths.

Data analysis: Average the measurements for each soil wedge, then average the measurements from all wedges sampled from each plot. To determine the average annual accretion rate, divide the total deposition by the time elapsed since plot establishment. Analysis of variance (ANOVA) and pairwise tests of differences among means can be used to compare accretion rates between strata and sites. Linear regression can be used to test the influence of other factors on accretion rates, such as wetland surface elevation or distance from tidal channels.

Figure. Feldspar marker horizon (white layer), Nisqually National Wildlife Refuge. Source: Nisqually Delta Restoration (2010).

Field Tips

Rod surface elevation tables are highly precise instruments that can measure surface elevation changes relative to a deep benchmark. Feldspar marker horizons measure accretion — just the surface layer of sediment depositions. When the two methods are paired, elevation change measurements due to below-ground processes, such as deep subsidence, can be teased out from surface accretion.

References

Elzinga *et al*. (1998).

Janousek *et al*. (2021).

Lynch *et al*. (2015).

Whelan and Prats (2016).

5.2. Infrastructure Protection & Flood Control: Inundation

Photo monitoring can be an effective way to document a tide gate installation or water levels during king tides and flood events. Photos can help document erosional problems around a new tide gate installation. Photos can also be used to evaluate the success of flood control objectives on adjacent landscapes or structures.

Materials

Required:

- ☐ Camera or smartphone with sufficient memory and resolution
- ☐ GPS device or smartphone with location tracking
- ☐ Field notebook or other way to record photo details

Optional:

- ☐ Tripod or stable platform for consistent camera positioning
- ☐ Compass or GPS with orientation capabilities
- ☐ Physical markers, such as polyvinyl-chloride (PVC) pipe or rebar, to return to photo points
- ☐ Reference and identifying items to include in photo frame, such as dry-erase board or measuring rods
- ☐ Past photographs for reference

Timing Recommendations

- ☐ King tides are the highest winter tides each year. When paired with a large storm surge, it may be possible to document flooding events. Capturing photos at these times can demonstrate what future tide levels may look like under climate change conditions with sea level rise and increased precipitation.
- ☐ Flooding events are times of interest. They provide opportunities to record how high water levels during winter storm surges impact infrastructure or a restoration area.

Site Selection and Baseline Photos

Choose a photo site where structures or landscapes of interest can be captured *safely*. Consider selecting a location accessible during flooding conditions. Do not stand in fast-moving water!

Mark the location with PVC or rebar so photos can be taken from the same location in the future. In the photo above, a railroad spike is spray painted (optional). Document GPS coordinates, date, the number of photos taken at each location, compass bearings, and narrative descriptions of the photo subjects, important landmarks or reference points, and observations.

Compliance Monitoring

Take photos showing the inlet and outlet of the tide gate soon after installation. Try to capture photos during low water levels to show as much of the channel banks as possible. Err on the side of too many photos to have options for comparison to unforeseen erosional issues in the future.

Repeat Photography

Return to the photo point location. For photography at king tide, arrive before the high tide to set up. Ensure the camera is positioned at the same spot and orientation as the baseline photo. Record the date, time, tide level, and height or flow of the closest river.

Data Management

Organize and store all photographs and associated data in a well-structured database or file system. Share data with an organization collecting king tide photos, such as the Oregon King Tides Project.

Selecting the Right Time to Photograph

Tides: Local tide prediction information can be found on the National Oceanic and Atmospheric Administration's (NOAA's) website Tides & Currents: https://tidesandcurrents.noaa.gov/tide_predictions.html.

Flood events: The U.S. Geological Survey (USGS) measures water levels in many rivers and provides real-time streamflow conditions on their website Water Data for the Nation: https://waterdata.usgs.gov.

Field Tips

Photographs that document one-off events or interesting landscape features, such as erosion, should be included as additional photos, even if there is no baseline image.

USGS hydrographs label flood stages to provide context for the water-level measurements on each river:

- **Action stage**: Banks of rivers are overflowing.
- **Minor flood stage**: Floods with a five-year to 10-year recurrence interval. Causes flood advisories but minimal to no property damage is expected.
- **Moderate flood stage**: Floods with a 15- to 40-year recurrence interval. Flood warnings are issued, and flooding is expected to occur in infrastructure and roads near streams.
- **Major flood stage**: Floods with a 50- to 100-year recurrence interval. Flood warnings are issued, and extensive inundation of structures and roads is expected.

Field Tips

USGS river gauges are typically located above tidal influence. The combined factors of tide and river level will impact water levels in the estuary. However, in estuaries at a flood stage, river levels dominate and often dictate water levels.

References

Ciannela *et al*. (2021).

Hall (2002a).

Oregon King Tides Project: https://www.oregonkingtides.net

6.1. Agricultural Uplift: Forage Production

After tide gate upgrade projects, improved water management is expected to support better pasture conditions and forage production. Increased forage production can increase ranch and farm profitability by improving current livestock's body condition or increasing stocking rates.

Materials

- ☐ Clipping frame: ¾-in. polyvinyl-chloride (PVC) frame with 37 3⁄16 in. x 37 3⁄16 in. interior dimension (follow the link in the references section at the end of this protocol for construction tips)
- ☐ Datasheet
- ☐ Paper bags
- ☐ Grass shears
- ☐ Gram scale

Timing Recommendations

- ☐ Coordinate with the landowner and livestock operations.
- ☐ Sample six to seven times during the forage-year season.

Field Summary

- ☐ Select representative sites.
- ☐ Take 9–15 samples per pasture.

Other Parameters This Protocol Can Measure and Inform

- ☐ 6.2. Agricultural Uplift: Animal Unit Months

Design

Forage production is measured by removing all the current vegetation from a sample frame and weighing the dried material. Showing a change in forage production is a tremendous uplift to landowners and an enticing reason to upgrade an older tide gate.

At least a year of baseline data is recommended to smooth annual variation in forage production. Monitoring post-restoration should occur starting in Year 2 to allow the pasture to recover from heavy equipment and any fill that was thin-spread.

To produce accurate measurements, it is best to enclose the sampling plots in a temporary fence to dissuade livestock and wildlife from consuming the forage.

Field Tips

Safety first! Never turn your back on livestock.

Methods

Site selection: Select sites randomly throughout the pasture but ensure they are representative of the micro-topography and forage density. Sample between nine and 15 sites depending on pasture size and variation in forage species and height. For example, if the pasture is 70% high, 20% intermediate, and 10% low production,

Field Tips

Coordinate with the landowner to collect samples during a non-irrigation period.

take seven samples of high-production sites, two of intermediate-production sites, and one of a low-production site.

Sampling procedure: At each sampling location, collect its GPS data. Place the clipping frame on the ground and slide all plants not rooted inside the frame to the outside. Take a photo to document the plot. Label a paper bag with the plot number, date, production level (high, intermediate, or low), and species, if known. Clip all forage within the clipping frame at ground level and place it into the paper bag. Replace temporary fencing if used.

Bring all samples back to the office or lab and weigh each bag with the "wet" forage. Record the weight on the datasheet and the bag. Open all bags and let the forage air-dry for two weeks — longer during humid weather. Or dry in a 140 °F convection oven until the bags have a consistent weight.

After two weeks, weigh the dried forage and bags combined. Empty the forage from the bags and weigh just the bag to determine the final mass of dried forage in grams.

In future years, ensure sampling locations are the same.

Data analysis: Available forage can be calculated for a point in time or averaged over a longer period, such as a grazing season or an entire year. To calculate available forage in pounds per acre at a single point in time, multiply the dried forage weight (in grams) by 10. Note that the calculated available forage is only for that plot. To obtain available forage for the entire pasture, average all the individual plots together.

Field Tips

Record your weights in grams. Contact your local Natural Resources Conservation Service (NRCS) Office or Extension Service if you have further questions.

To calculate the available forage for an entire year, add all the dried forage weights from a single plot for the entire year (six to seven samples) and multiply by 10. Again, if you want annual available forage for the entire pasture, find the average of all the individual plots.

References

NDMC (National Drought Mitigation Center; n.d.).

OSU (Oregon State University; n.d.).

6.2. Agricultural Uplift: Animal Unit Months

After tide gate upgrade projects, improved water management is expected to support better pasture conditions and forage production. These improvements can benefit ranch or farm profitability by increasing the body condition of current livestock or increasing the stocking rate. An animal unit month (AUM) standardizes stocking rates across diverse livestock classes and is used to measure potential post-restoration production benefits.

AUM is defined as the amount of forage required by one animal unit (AU) for one month.

To standardize it across multiple species of livestock, an AU is defined as:

- One mature, non-lactating cow weighing 1100 lb and fed at the maintenance level, or equivalent, expressed as body weight.
- In other kinds or classes of animals, AU is based on the average daily consumption of 25 lb of dry matter per day.

Public land management agencies often use AU to refer to a 1000-lb cow with one calf, or five dry ewes.

Recommendations

- ☐ Project managers need to work closely with the local producer(s) and have access to pre-project AUM production numbers in order to compare post-project AUM results.
- ☐ Resources and knowledgeable staff are often available for support at your local Natural Resources Conservation Service (NRCS) Office or Extension Service.

Animal Unit Month (AUM)

AUM is calculated by dividing the *forage availability* by the *forage demand*. Forage availability is calculated when monitoring for *forage production* (see Protocol 6.1) and has a unit of pounds/day. The forage demand per month is 750 lb of dry matter. AUM values from the year(s) before the completion of tide gate upgrades can be compared to AUM once the tide gate has been replaced.

$$AUM = \frac{Forage\ Availability\ (lb/day) * 30\ (days/month)}{Forage\ Demand\ (750\ lb/month)}$$

Monitoring Approach Associated With This Parameter
6.1. Agricultural Uplift: Forage Production

References

Shewmaker and Bohle (2010).

6. Additional Resources

6.1. Lamprey

Photo credit: Amanda Anderson.

Many tide gates are replaced to improve fish passage and increase access to the habitat behind the gate. Although habitat restoration for the Pacific Lamprey has gained attention, good monitoring data are lacking, and no protocols are available relative to tide gates for any life stages. Design criteria for tide gates and associated culverts are based on salmonid criteria and may not protect smaller-bodied fishes. It is important to ensure that projects focused on salmonids do not limit or harm lampreys. In addition to passage through tide gates, any alteration of salinity regimes can influence the lamprey's abilities to osmoregulate, especially at the larval and juvenile life stages. However, SRTs can provide lampreys more time to osmoregulate. Considering lampreys in the early planning, implementation, and post-monitoring phases of in-water work can be beneficial with little added effort or cost (Streif 2009).

Tide gate project teams should include planners and practitioners who possess knowledge of lamprey ecology. If local resources are unavailable, the primary resource to consult is the Lamprey Technical Workgroup (LTWG), the technical advisory committee of the Pacific Lamprey Conservation Initiative (PLCI). The LTWG is a large, diverse, active committee with members representing a variety of organizations from across PLCI's geographic range (Alaska, Washington, Idaho, Oregon, and California). The following section lists several good sources for lamprey ecology and monitoring.

Additional Lamprey Resources

LTWG (2020a).

LTWG (2020b).

LTWG (2023).

PLCI, PMEP (Pacific Marine & Estuarine Fish Habitat Partnership), and California Fish Passage Forum (2021).

Streif (2009).

6.2. Coastal and Migratory Birds

Estuarine habitat loss and ecosystem degradation have resulted in critical losses for coastal bird populations. No known studies have assessed the effects of tide gates or tide gate replacements on the avian community. However, the expected long-term benefits of tide gate replacements should benefit avian species. These include improving water quality, increasing tidal wetland habitat complexity and availability, and enhancing ecological function.

Photo credit: George Suennen.

The Salish Seas Estuaries Avian Monitoring Framework is a new resource that should be consulted in early planning, implementation, and post-monitoring phases. Its ecological goal is to determine regionally specific avian habitat associations and patterns of estuary habitat use that can be used to inform site protection, restoration, and conservation efforts; evaluate avian response to management; and model to predict the effects of climate change. The practical goal is to create a shared set of field protocols for use throughout the Salish Sea that can leverage disparate monitoring efforts toward a common, shared goal.

The Salish Seas Estuaries Avian Monitoring Framework is a standardized protocol for monitoring estuary birds and was developed collaboratively by Ecostudies, Audubon WA, the Washington Department of Fish and Wildlife, and the Stillaguamish Tribe. Though the focus of the framework is Puget Sound, the protocols are generally applicable in the Pacific Northwest. Included are four modules for surveying the full suite of species (waterfowl, shorebirds, secretive marsh birds, and land birds) across their annual life cycles (wintering, migration, and breeding) using two survey methods (transects and point counts).

An additional resource for avian monitoring is the guide supported by the U.S. Bureau of Land Management (BLM; 2020), which offers a summary of online bird monitoring resources that are valuable for those involved in bird conservation efforts. While not exhaustive, it includes numerous helpful links and sources for monitoring avian populations.

Additional Coastal and Migratory Birds Resources

BLM (2020).

Summers *et al*. (2023).

eBird online database: https://ebird.org — eBird's goal is to "gather this information in the form of checklists of birds, archive it, and freely share it to power new data-driven approaches to science, conservation and education" (see the "About eBird" web page to read about this goal and more: https://ebird.org/about).

References

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Dahl TE, Dick J, Swords J, *et al*. 2020. Data collection requirements and procedures for mapping wetland, deepwater, and related habitats of the United States. Falls Church, VA: U.S. Fish and Wildlife Service (USFS). https://www.fws.gov/sites/default/files/documents/data-collection-requirements-and-procedures-for-mapping-wetland-deepwater-and-related-habitats-of-the-united-states.pdf.

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