Proceedings of the
West Coast Symposium on the Effects of Tide Gates on Estuarine Habitats and Fishes

October 31–November 2, 2006

South Slough National Estuarine Research Reserve
61907 Seven Devils Road, Charleston, Oregon

Editors:
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Rick Cooper

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Program of Events

West Coast Symposium on the Effects of Tide Gates on Estuarine Habitats and Fishes

October 31–November 2, 2006
South Slough National Estuarine Research Reserve

Tuesday, October 31

8:30 a.m. – Registration, coffee, and refreshments

9:00 a.m. – Opening remarks

- *Welcome* – Mike Graybill **(**Manager, South Slough National Estuarine Research Reserve)
- *Symposium purpose and goals* – Guillermo Giannico (Fisheries Extension Specialist, Dept. Fisheries and Wildlife, Oregon State University)
- *Program organization and overview* – Guillermo Giannico
- *Introduction of speakers* – John Bragg (Coastal Training Coordinator, South Slough National Estuarine Research Reserve)

Session I: Estuaries and the Environmental Effects of Tide Gates

9:30 a.m. – *Analysis of Tide Gate Opening Sequences for Effectiveness Monitoring of Fish Passage Performance* – Jon Souder (Executive Director, Coos Watershed Association, Charleston, Oregon)

10:00 a.m. – *Questions*

10:15 a.m. – *Break*

10:30 a.m. – *Pacific Northwest Estuarine Wetlands 101* – Laura Brophy (Green Point Consulting, Corvallis, Oregon)

11:00 a.m. – *Coho Use of Tidal Channels in Winchester Creek, Oregon* – Craig Cornu (South Slough National Estuarine Research Reserve, Charleston, Oregon)

11:20 a.m. – *Juvenile Salmon Rearing in Tidal Channels of the Salmon River Estuary: Examples of Salmon Behavior in an Un-gated Estuary* – David Hering (Oregon Department of Fish and Wildlife, Salem, Oregon)

11:40 a.m. – *Questions*

12:00 noon – *Lunch*

1:00 p.m. – *Juvenile Chinook Salmon Use of a Large River Estuary and Adjacent Nearshore Habitat Within Puget Sound* – Eric Beamer (Skagit River System Cooperative, LaConner, Washington)

1:45 p.m. –*Smokehouse Floodplain/Fornsby Creek Habitat Reconnection Project* – Steve Hinton (Skagit River System Cooperative, LaConner, Washington)

2:20 p.m. – *Fish Use and Water Quality in Select Channels Regulated by Tide Gates within the Snohomish River Estuary* – Dan Tonnes (NOAA Fisheries – Habitat Conservation Division, Seattle, Washington)

2:40 p.m. – *Questions*

3:00 p.m. – *Break*

3:10 p.m. – *Tide Gate Design Alternatives with Consideration for both the Engineering and Human Social Dimensions: Past Experiences Lead to Innovative Solutions* – Jeff Rogers (Center for Coastal Studies, Provincetown, Massachusetts)

3:55 p.m. – *Questions*

4:10 p.m. – *Break*

4:30 p.m. – *Panel Discussion*

5:30 p.m. – *End of Day 1*

Wednesday, November 1

Session II: The Right Tide Gate for the Job: Criteria & Tools

7:45 a.m. – *Coffee and refreshments*

8:00 a.m. – *Introduction to Day 2* – Guillermo Giannico

- Review of goals and objectives of symposium
- Review of Day 1
- Introduction to Day 2

8:10 a.m. – *Current NOAA Criteria for Fish Passage at Tide Gates* – Larry Swenson (NOAA Fisheries, Portland, Oregon)

8:30 a.m. – *Oregon's Fish Passage Requirements for Tide Gates* – Tom Stahl (Oregon Department of Fish and Wildlife, Salem, Oregon)

8:50 a.m. – *Washington Fish Passage Criteria Related to Tide Gates* – Bob Barnard (Washington Department of Fish and Wildlife, Olympia, WA)

9:10 a.m. – *A Tide Gate Replacement Practitioner's Tools To Meet the Current Regulatory Environment* – Leo Kuntz (Nehalem Marine, Nehalem, Oregon).

9:40 a.m. – *Questions*

9:55 a.m. – *Break*

10:10 a.m. – *Is There a Role for Managed Tidal Wetlands in Sustainable Estuarine Management?* – Steve Crooks (Philip Williams and Associates, San Francisco, California)

11:00 a.m. – *Questions*

11:15 a.m. – *The Tribal Role in Building Community Support for a Self-regulating Tide Gate on the Skagit River, Washington* – Steve Hinton **(**Skagit Valley Cooperative, LaConner, Washington)

11:45 a.m. – *Questions*

Session III: Field Trip to Coos Bay-area Tide Gates

12:30 p.m. – *Depart for Larson Slough, Palouse Slough, and Coalbank Slough Tide Gates*

4:00 p.m. – *Return to South Slough Reserve*

4:15 p.m. – *Panel discussion*
Moderator: Jon Souder
Panelists: Larry Swenson, Tom Stahl, Leo Kuntz, Steve Hinton, Steve Crooks, and others

5:30 p.m. – *End of Day 2*

Thursday, November 2

Session IV: Adaptive Management and Monitoring of Tide Gates

Presenters: Larry Swenson, Susan Novak, NOAA Fisheries Center, Portland, Oregon; Laura Brophy, Green Point Consulting

7:45 a.m. – *Coffee and refreshments*

8:00 a.m. – *Introduction to Day 3* – Guillermo Giannico

8:10 a.m. – *Feasibility of Using Fish Passage Data from Other Flow-moderated Systems to Develop Hydraulic Criteria for Tide Gates* – Bob Barnard (Washington Department of Fish and Wildlife, Olympia, Washington)

8:40 a.m. – *Using HEC-RAS 3.1.3 to Model and Design Tide Gate Systems* – Susan Novak (NOAA Fisheries, Portland, Oregon)

9:10 a.m. – *Questions*

9:30 a.m. – *Near-field Hydraulic Conditions Affecting Fish Passage at Tide Gates in Estuaries* – Larry Swenson (NOAA Fisheries, Portland, Oregon)

10:00 a.m. – *Questions*

10:15 a.m. – *Break*

10:30 a.m. – *Ecological Monitoring for Tide Gate Design and Evaluation* – Laura Brophy (Green Point Consulting, Corvallis, Oregon)

11:15 a.m. – *Questions*

11:30 a.m. – *Panel Discussion*
Facilitator: Guillermo Giannico and Jon Souder
Panelists: All Symposium speakers

12:00 noon – *Lunch*

1:00 p.m. – *Adjourn*

Analysis of Tide Gate Opening Sequences for Effectiveness Monitoring of Fish Passage Performance

Jon A. Souder[1]

Installation and replacement of tide gates are regulated by state departments of fish and wildlife[2] (ODFW 2007) and the federal National Oceanic and Atmospheric Agency (NOAA 2005) because they affect anadromous fish passage. Over the past 10 years, there has been significant progress in designing gates that are “fish-friendlier.” These are generally defined as (1) the gates are open for passage over a longer duration of the tidal cycle, (2) flows and turbulence are suitable for adults and juveniles to pass through the gates, and (3) a mixing of salinity in the pool is created upstream from the tide gate (Giannico and Souder 2005). This paper describes our analysis of opening and closing sequences for the Larson Slough tide gates as part of a larger analysis of the effectiveness of tide gate placements that includes thermal and salinity monitoring, aquatic vegetation changes, and sediment movement. The results presented here will address part of the objective of improving fish passage, i.e., how the improved design affects the time available for fish to pass through the tide gates.

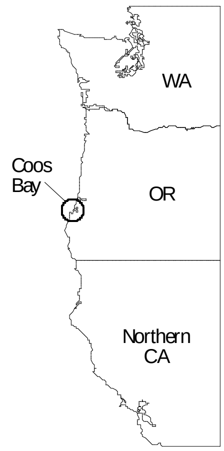

Figure 1. Location of the Larson tide gate.

The Larson Slough tide gate on the Coos Bay estuary (Figure 1) was redesigned during a bridge replacement project, and new gates were installed in September 2001 (Figure 2). The objectives for the improved structure were to increase fish passage for adult coho salmon (*Oncorhynchus kisutch*) and to allow sediment to be transported downstream through the tide gates. The former objective was designed to be accomplished by replacing traditional top-hinged gates, each 12 ft. (3.85 m) wide by 10 ft. (3.2 m) tall, with side-opening gates, each 10 ft. (3.2 m) wide by 8 ft. (2.56 m) tall. The new Larson tide gates open on a hydraulic head difference of approximately one inch (0.08 ft., or 2.5 cm.) higher “water surface elevation” (WSE) on the inside of the gate, compared to the tidal WSE on the outside of the gates. Our objective to increase sediment transport was designed to be met through lowering the invert (or bottom) elevation of the structure by three feet.

The results presented here are based on a meta-analysis of four years of transducer data, representing 551 opening and closing cycles. This analysis examines only the opening and closing cycles; no data are included on the degree of opening or the velocity distributions throughout the cycle. However, based on observations of the open conditions, it is apparent that velocities and turbulence are suitable for

Figure 2. Before (l) and after (r) tide gates at Larson Slough, Coos Bay, Oregon.

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[1] Dr. Jon A. Souder is Executive Director of the Coos Watershed Association, P.O. Box 5860, Charleston, OR 97420 U.S.A. (www.cooswatershed.org). Funding for this monitoring was provided by the Oregon Watershed Enhancement Board, Grants 204-289 and 206-244.

[2] At this time, Washington has no state statutes requiring fish passage at tide gates on agricultural properties, Laws 2005 Ch. 146, §605; R.C.W. 77-55-281.

passage when the gates are open. The results and techniques presented here can be utilized to respond to the concerns of tide gate manufacturers and regulatory agencies for the component of the design process that focuses on the amount of time that gates are open during the tidal cycle.

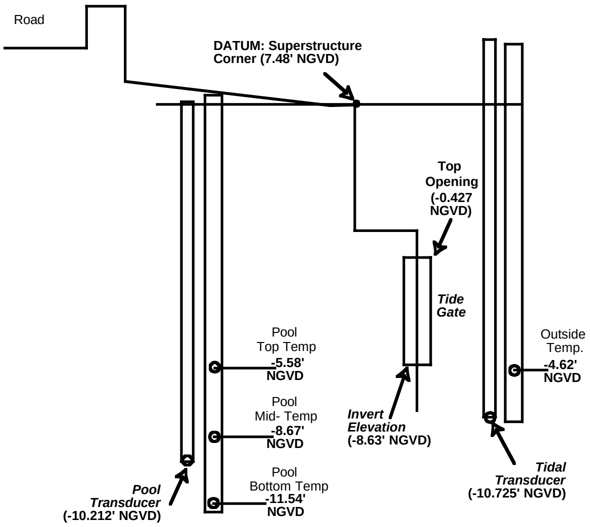


Figure 3. Schematic of the water surface elevation transducers and temperature sensors at the Larson tide gate, October 2006.

Methods

Tide gate operations are evaluated using a system of two pressure transducers that measure water surface elevations. One transducer is located on the Haynes Inlet side of the Larson tide gates to provide measurements of tide cycles. A second transducer is located on a bridge bent inside of the Larson tide gates to measure water surface elevations in the reservoir pool behind the tide gate. Figure 3 shows a representation of the Larson transducers with data on their elevations above sea level (National Geodetic Vertical Datum—NGVD). Elevations were determined from the "as-built" Oregon Department of Transportation (ODOT) plans for the Larson Slough Bridge, taken at the northeastern corner of the wingwall and face of the tide gate structure. A laser level was used to determine the top point of the PVC pipes that hold the pressure transducer data loggers, and a measuring tape was used to determine the length from the top of the data logger to the bottom of the pressure transducer. These measurements were then used to determine the relative transducer heights, as well as the invert elevation of the tide gates.

Global Water Pressure Transducers (Model WL15-003) supply three items of data: the time of a water elevation reading, the water surface elevation, and the temperature of the probe. The raw data is output in ASCII "comma-separated values" (.csv) format that can be easily imported into a Microsoft Excel spreadsheet. Time readings are provided as numeric days consistent with the Windows date-numbering scheme (Day 1 = January 1, 1900). Hours, minutes, and seconds are represented as fractional equivalents for the day (e.g., each hour is 1/24th of a day [0.04167], while each minute is 1/1440th of a day [24 * 60, or 0.000694]). Times can be added or subtracted using this system. Water surface elevations can be stored in either English or metric units. Storage of temperature data is optional, and was not done during most periods for this study because it reduced the amount of WSE data that could be stored.

The general format for the spreadsheet was of two columns: date and WSE. No additional processing is needed if the desired task is to simply classify tide gate opening and closing sequences. There is a three-part routine for this procedure.

First, it must be determined if the water level is rising, stable, or falling. This can be done using the following Excel formula:

$$= \text{IF}(\text{WSE}_{t-1} \geq \text{WSE}_{t}, \text{"FALLING"}, \text{IF}(\text{WSE}_{t-1} = \text{WSE}_{t}, \text{"FLAT"}, \text{"RISING"}))$$

where: WSE_{t-1} = the water surface elevation at the previous reading; and
WSE_{t} = the water surface elevation at the current time

The WSE condition is calculated for each row (other than the first row) in the dataset by copying and pasting the formula into an empty column of the spreadsheet. Status of the water surface elevation can be calculated for both the inside and outside pressure transducers. These results are compared side-by-side by consolidating the two datasets, being careful to match the measurement times and intervals. There is no need to adjust WSE to their true elevations to determine opening cycles.

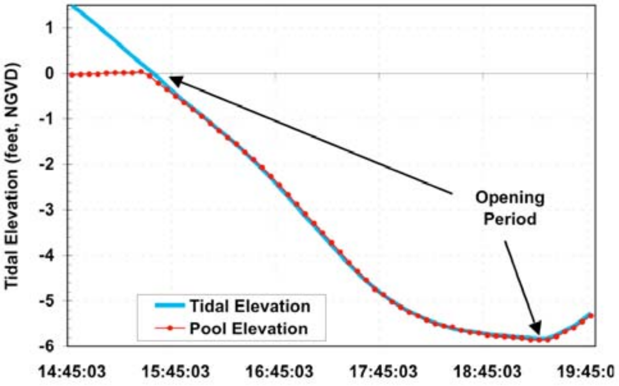


Figure 4. Opening cycle illustrated using water surface elevation transducer data.

The duration of the open cycle is determined by evaluating the sequence of WSE conditions. Figure 4 shows tidal elevation readings outside the tide gate, as well as backwater pool elevations on the inside of the tide gate. Pool elevation readings are represented as circles in Figure 4 to indicate the interval between water surface elevation measurements. Tidal elevations and pool elevations will rise and fall together, albeit at different rates. The basic heuristic is to examine both the tidal and pool conditions: While the tidal condition can be “Falling” for a significant time before the two WSE are roughly equivalent, once the pool condition changes to “Falling” the tide gates have opened. The gates will remain open until the tidal condition changes to “Rising,” at which point the pool condition will typically be either “Flat” or “Rising” (see Figure 4). Depending upon wind and wave action, and the interval between measurements, there may be fluctuations or oscillations in the WSE, i.e., rising, flat, or falling conditions outside the regular cycles. These are generally of a transitory nature of a single measurement, and do not represent inflections in the overall cycles. There will be a very clear sequence of “Falling” WSEs for the inside of the tide gate. These will then transcend to “Flat” and/or “Rising,” while at the same time the tidal WSE will be “Rising.”

Identifying the latest period when the WSE indicates that the tide gate was open serves as the “brute force” method to determine the period (or time) that the tide gate is open. Start by inserting a blank column to the right of the WSE Condition column called “Time Open.” Then, in the cell in the Time Open column just to the right of the last open period, insert the following Excel formula:

$$= (T_{End} - T_{Begin})*1440$$

where: T_{End} = the last time the gate is considered open;
T_{Begin} = the first time the gate is considered open; and
1440 = the number of minutes in a day (i.e., to convert
the fractional day to minutes).

Once this process is completed for a complete dataset, insert a new Worksheet called "Open & Close Cycles" into the file. Select all the records from the original dataset (including the column headings), and Paste Special into the new Worksheet using the Values and Number Formats option. This provides a data set with just the values without formulas to avoid problems with cell references. Once the Paste operation is complete, Sort the entire data set using the Time Open column as the sort criterion. Delete rows with blank Time Open entries by either (a) copying only those rows where there is a non-blank (or non-zero) Time Open value into a new Worksheet, or (b) highlighting the rows with blank Time Open entries (which will end up at the bottom of the Worksheet after the Sort operation) and delete them. You will be left with a much smaller file containing only those rows that contain entries for Time Open.

Sort this Worksheet again, using the Date+Time field as the sort criterion. At this point, you will have the sequential record showing the ending time and previously open period for each tide gate opening sequence in the dataset. In order to utilize all the data on openings, a record of the last open time from a previous dataset it should be pasted into the first row of this Worksheet, if it exists. Next, insert a new column to the right of the Time Open column and title it "Time Closed." To determine the time that the tide gate was closed prior to an Open cycle, use the following Excel formula in the second row of the Worksheet:

$$= ((T_t - T_{t-1}) - (T_{Open} * 0.000694))*1440$$

where: T_t = the last time the gate is considered open;
T_{t-1} = the first time the gate is considered open;
$694^{10^{-6}}$ = the fractional equivalent of a minute; and
1440 = the number of minutes in a day (i.e., to convert the fractional day to minutes).

The Time Open and Time Closed minute values can be divided by 60 to display the values as hours.

Results

We conducted a metadata analysis of the water surface elevations to obtain information on the duration of tide gate openings as a first step toward understanding the effects of tide gates on anadromous fish. Table 1 shows the period for which tidal cycle records were analyzed. Water surface elevations inside and outside the Larson Slough tide gates were measured

Table 1. Periods of water surface elevation measurement to determine tide gate opening cycles.

Pressure Transducer Deployment Period	Opening Cycles
8/3/2002 to 10/17/2002	79
8/29/2003 to 3/15/2004	255
4/29/2004 to 9/2/2004	142
8/5/2006 to 10/18/2006	75
Total	551

intermittently over the period from 2002 through 2006. Measurements were not continuous, due to equipment malfunctions that either resulted in data losses or precluded deployment. All told, we were able to obtain opening and closing times for 551 tide cycles over this period, with measurement intervals ranging from 1 to15 minutes.

The primary concerns related to fish passage at tide gates are the percentage of time that the gate is open, and the percentage of time during openings when flows are suitable for fish passage. Our pressure transducer data provide good information to answer the former question, but not the latter. Figure 5 and Table 2 provide the results of an analysis of the 551 opening cycles, to determine monthly average percentages of times that the tide gates were likely open. It is clear from this analysis that the period during which salmon are migrating upstream to spawn (considered to be mid-November through late February) corresponds to the period when the gates are open most, or approximately 24 percent of the time. Conversely, during the late summer and early fall, the tide gates are open the least amount, approximately only five percent of the time (see Table 2). Periods during which the tide gate was open for smolt out-migration (from March through May) show declining available passage as winter rains taper off in the spring. However, there are few good records for April (*n* = 3), hence the large standard error for that month.

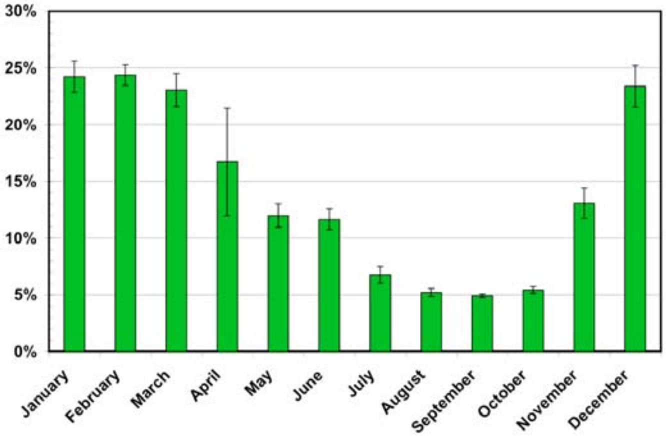


Figure 5. Percent opening periods at the Larson tide gate by month (with standard error bars).

Table 2. Summary data for the Larson tide gate opening cycle analyses.

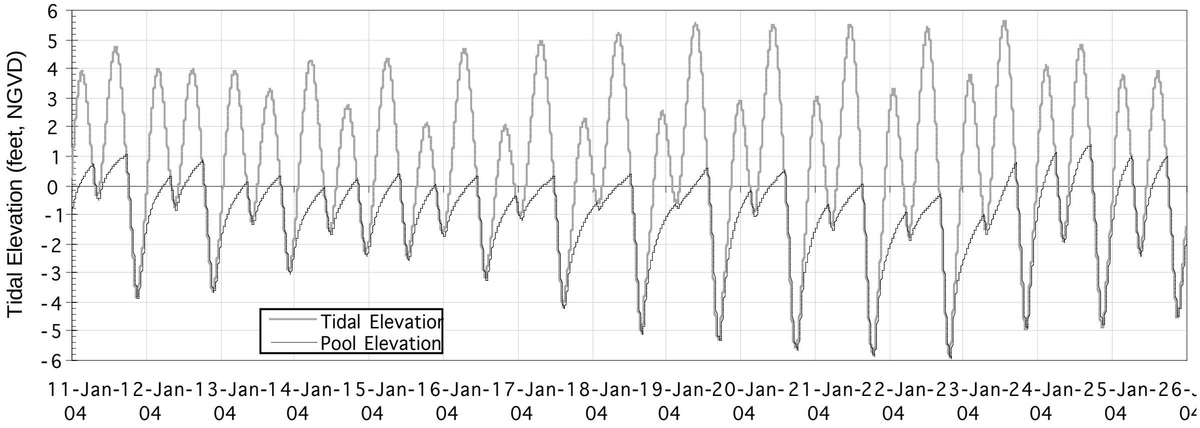
		January	February	March	April	May	June	July	August	September	October	November	December
Percent Time Open	Samples (n=)	42	55	28	3	43	35	30	82	99	68	38	26
	Average	24%	24%	23%	17%	12%	12%	7%	5%	5%	5%	13%	23%
	Stanard Deviation	0.089	0.067	0.077	0.082	0.069	0.053	0.040	0.031	0.015	0.024	0.082	0.093
	Standard Error	0.014	0.009	0.015	0.047	0.010	0.009	0.007	0.003	0.002	0.003	0.013	0.018
Open Time (Hours)	Samples (n=)	42	55	28	3	43	35	30	83	100	68	38	26
	Average	2.98	3.09	2.92	2.39	1.83	2.10	1.51	1.20	1.04	1.14	2.19	3.12
	Standard Deviation	1.13	0.95	1.04	1.39	0.66	0.66	0.59	0.40	0.30	0.39	0.97	1.15
	Standard Error	0.17	0.13	0.20	0.80	0.10	0.11	0.11	0.04	0.03	0.05	0.16	0.22
Closed Time (Hours)	Samples (n=)	42	55	28	3	43	35	30	83	100	68	38	26
	Average	9.32	9.56	9.82	11.58	15.50	17.45	23.36	25.45	20.79	21.72	17.11	10.71
	Standard Deviation	1.40	1.85	2.54	2.25	6.23	5.96	5.47	11.59	5.27	6.39	6.51	3.99
	Standard Error	0.22	0.25	0.48	1.30	0.95	1.01	1.00	1.27	0.53	0.78	1.06	0.78

The amount of time that a tide gate is open, shown as a percent of total time, provides one measure of the effects of tide gates on fish passage. However, the amount of time during which the gates are open varies temporally by month based on hydrological patterns, as well as by where the specific date falls within the 14-day spring tide/neap tide cycle. Figure 5 shows the effects of the first temporal factor based on the relative amounts of freshwater inflow into the reservoir pool behind the Larson tide gate. As is apparent in

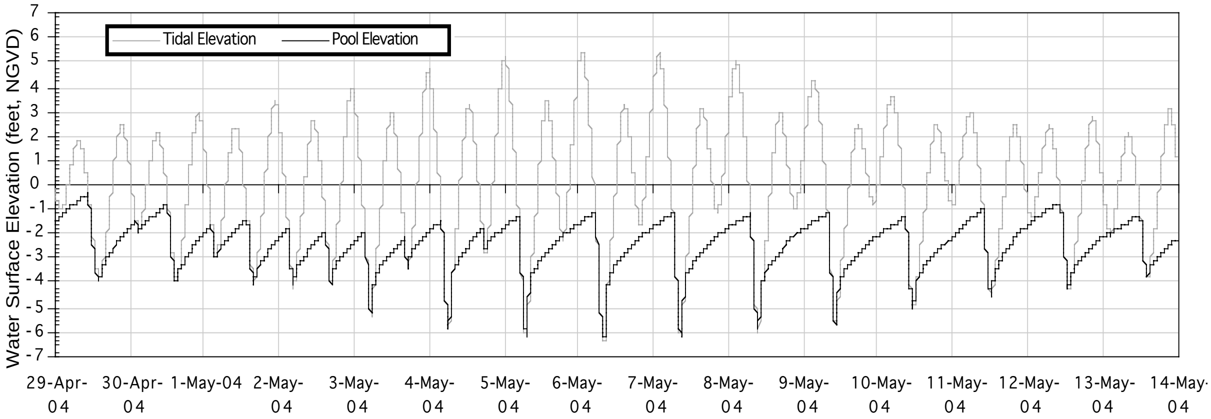
Figure 5, the relationship between open and closed cycles differs between those times of the year when there are significant variations in flows from Larson Creek into the reservoir pool behind the tide gate.

Figure 6 shows tidal cycles at the Larson tide gate for three different seasons over a spring tide/neap tide sequence. Figure 6a provides a representative example for tidal cycles during the salmon spawning season, which generally lasts from late November through February. The 14-day cycle in January includes the spring tides that begin around January 15 and extend through January 24. The graph shows the highest high and lowest low tides, while the neap tide cycle, from January 1 to 15 and 25 to 26, shows tides of relatively equal magnitude. During the winter spawning period, the Larson tide gates open at least for a short time during both diurnal tide cycles. At the maximum extent of the spring tides, these openings can be of relatively short duration (see January 18 and 19 on Figure 6a). While the opening period is relatively short of the higher of the low tides, the opening period for the lower of the low tides is significant; at times this period corresponds by as much as five hours (the highest measured opening was for 5.2 hours), or approximately 30 percent of the tidal cycle. During the neap tide sequence in the winter spawning period, openings are of shorter duration, but more equivalent in length between the higher and lower of the low tides (see January 15 and 16). For example, the duration of the second opening cycle for January 14 was 2.9 hours (at 23:10); for January 15 it was 2.8 hours (at 12:35); and the two openings on January 16 were 2.6 hours and 3.1 hours, respectively.

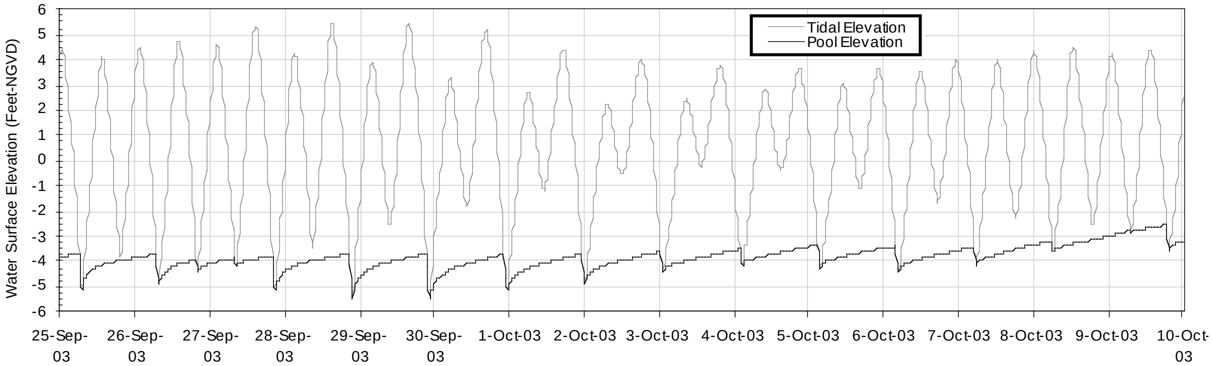
As flows decrease in the spring, the Larson tide gates opening sequences begin to reflect substantial differences between diurnal tidal cycles during the period when coho smolts are out-migrating to the estuary and the ocean. This period lasts generally from March to May in Larson Slough and Creek. As shown in Figure 6b, a typical sequence for the latter part of this period indicates that the gate opening is more influenced by the spring tide/neap tide pattern than during the winter. During this time of year, the tide gates typically open only once daily during spring tides, and the reservoir pool behind the Larson tide gates fills at an insufficient rate to raise its elevation enough to match the higher of the low tides and thus provide the hydraulic head difference needed to open the gates. As during the winter, tide gate openings during the neap tide cycle occur twice daily. However, the length of time the gates are open varies from slightly less than 25 percent in March down to about 12 percent in May.



6a. Representative sequence of Larson tide gate openings for a 14-day tidal cycle during the spawning season.



6b. Representative sequence of Larson tide gate openings for a 14-day tidal cycle during the smolt out-migration season.



6c. Representative sequence of Larson tide gate openings for a 14-day tidal cycle during the early fall juvenile rearing season.

Figure 6. Effects of seasonality and spring tide/neap tide semi-diurnal cycle on the dynamics of the Larson Tide Gate opening sequences.

The third significant period where tide gate openings may affect fish passage and usage of the Haynes Inlet estuary and Larson Creek freshwater is during the summer rearing period. Miller and Sadro (2003) found that in a particular life history of coho salmon, age 0+ juveniles migrated down to the upper estuary from March through October prior to returning upstream to rear in the winter. If this life history is/was present in Larson Slough, then coho juveniles would need to be able to move upstream during the late fall. As Figure 6c shows, movement would be significantly constrained by the Larson tide gates. During this period of extremely low flows, the Larson tide gate opens only once a day throughout most of the spring tide/neap tide cycle, due to low reservoir inflows, the high drainage capacity of the side-hinged gates, and the low invert elevation. Opening periods run between one and two hours, with only about one hour opening on average during September. Usually only one opening occurs per day.

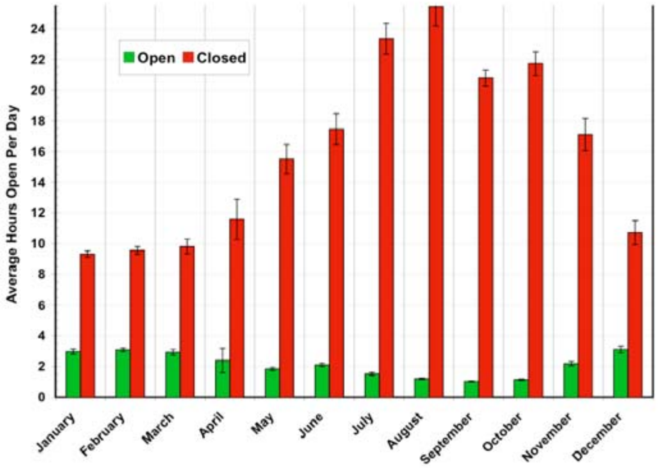


Figure 7. Average open and closed intervals, by month, at the Larson tide gates, 2002–2006.

The overall pattern of Larson tide gates opening and closing cycles is characterized by the greatest extent of fish passage occurring during the salmon spawning period from November through March. Figure 7 shows this occurrence on an average tide cycle basis. Recognizing that there are usually two opening cycles daily, each opening is approximately three hours in length, separated by about nine hours when the gate is closed and fish passage is blocked. The pattern for the remainder of the year is one of shorter openings and longer periods when the gates are closed. Beyond the effects of tide cycles discussed above, the primary causal factor for the seasonal change in tide gate opening periods is related to freshwater inflow into the reservoir pool behind the Larson tide gates. This inflow refills the reservoir pool after it has drained during the previous opening cycle. The tide gate will not open during the next low tide if this inflow is insufficient to raise the pool elevation at least to the level of the low tide. The length of opening is reflected by how much higher the pool elevation is, compared to the ultimate level at the next low tide.

Natural flows into the reservoir pool at the Larson tide gate result from rainfall in the approximately 5,000-acre (2,023 ha) watershed that drains into Larson and Sullivan creeks. Based on models developed by the Oregon Department of Water Resources (OWRD, 2007), estimated Larson Creek monthly flows in cubic feet per second (cfs) at the tide gate are shown in Figure 8. Winter flows, from December through March, typically are above 45 cfs, with flows highest in February averaging about 60 cfs. Conversely, natural flows during the late summer and early fall, July through October, are usually less than 5 cfs. These “natural” flow estimates do not include water withdrawn for irrigation upstream in Larson Creek, which, at times, will largely deplete streamflows.

The pattern seen in Figure 8 is almost exactly the opposite of the number of hours that the tide gates are closed, as shown in Figure 7. Similarly, there appears to be a close relationship between natural streamflows and the number of hours that the tide gates are open. These relationships are defined by using a linear regression between the percent time that the gates were open (Figure 5) compared to the natural flows in Larson Creek (Figure 8). Figure 9 shows the results of this regression.

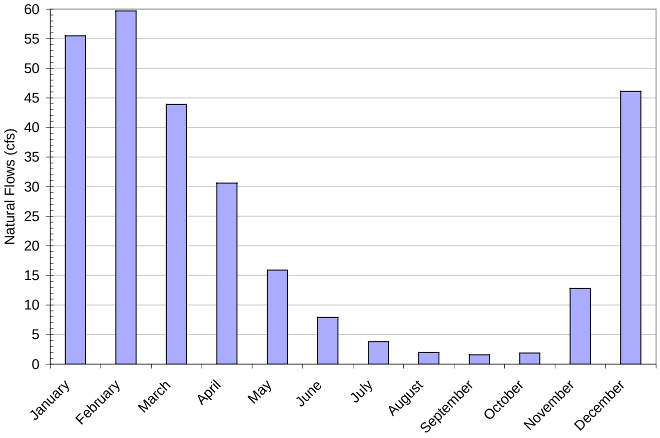


Figure 8. Natural freshwater inflows in Larson Creek at the Larson tide gate.

As can be seen in Figure 9, there is a strong correspondence between flows in Larson Creek and the average monthly percent of a tide cycle that the gates are open. For these two variables, the amount of natural flow explains approximately 95 percent of the average opening time (r^2 = 0.951). A slightly more sophisticated non-linear regression equation raises the r^2 to 0.986 by fitting a curve to the data points in Figure 9. In either case, the influence of stream flow on the tide gates’ opening sequence is significant because it defines the level of the reservoir pool required to provide the hydraulic head difference needed to open the tide gates during ebbing tide cycles, and it also defines the recovery of the pool.

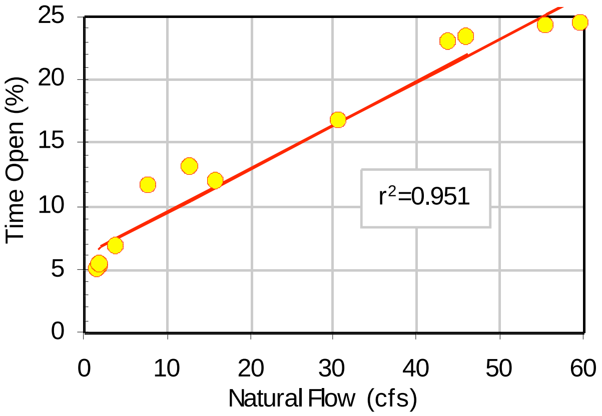


Figure 9. Correlation between natural stream flows in Larson Creek and the monthly average time that the Larson tide gate is open.

Discussion

The techniques described here for measuring the opening and closing cycles for tide gates provided information useful for performance evaluation for fish passage. The double transducer arrangement provides a relatively simple and reliable means to achieve these goals if two criteria are met. First, the tide gates must open (and remain open) only when there is a positive hydraulic head difference between the inside and the outside water surface elevations. The dual-transducer arrangement described here will not be effective in cases where there are “mitigators,” “pet doors,” or other mechanisms that allow the gate to remain open during flood times. Second, the tide gate must be the only route for upstream and downstream fish movement at the specific location. This second criterion may not be met if there is significant leakage through or around the gates and their supporting structure. At both the pre-replacement Larson Slough tide gates and the Palouse Slough tide gates in an adjacent drainage, the high placement of the tide gates resulted in hydraulic "piping" underneath the supporting structures, which opened multiple holes of approximately 1 ft. (0.3 m) diameter. In these cases, fish, especially juveniles, may be moving upstream and downstream through these holes even when the gates themselves are closed.

Application of the transducer technique allowed for evaluating the performance of the Larson tide gates. Given the design of the Larson tide gates in which no provision for back flows was provided, the theoretical maximum opening period would, in the best of situations, be only about 50 percent (i.e., when tides were ebbing). Monitoring at the Larson tide gates indicates that during the spawning period the gates are typically open on average slightly less than a quarter of the time, and that these openings occur in about three-hour increments, twice daily. As stream flows decrease in the spring and early summer (the time when coho salmon smolts out-migrate), the percentage of time that the tide gates are open and the number of openings per day decrease. During the March through May smolt out-migration period, average monthly opening cycles decrease from about 23 percent of the time to only about 12 percent, and from about three hours per opening to under two hours per opening. At this same time, the cycle of tide gate openings changes from twice daily during the entire spring tide/neap tide cycle to twice daily during the neap tides but only once daily during spring tides. Summer provides almost a complete barrier for fish passage at the Larson tide gates. Opening periods are on the order of one to two hours per tide cycle, with generally only one opening per day. If juvenile salmon desired to use the upper estuary in Haynes Inlet, their passage downstream to the estuary and back upstream during the late fall would be almost entirely precluded.

The operation of the Larson Tide Gate could be improved by a couple of fairly simple and inexpensive equipment and operational measures. First, opening times could be increased during the late spring, summer, and fall by simply locking one of the two gates closed. This would require the installation of a latch mechanism and active management in the spring to lock the gate and in the fall to unlock the gates. Additional passage, as well as mixing of brackish and freshwater, could be accomplished by adding a "mitigator"-type device that would hold the gates open for a period of time during flooding tides. This device could be operated by a float mechanism and would probably need to be seasonally adjusted. These two improvements are compatible with each other and would provide the most effective means to improve fish passage at the Larson tide gates, particularly for out-migrating smolts and rearing juvenile coho salmon.

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Pacific Northwest Estuarine Wetlands 101

Laura Brophy[1]

Basic Characteristics of Pacific Northwest Tidal Wetlands

Tidal wetlands have unique characteristics due to the tidal forces that create them. These characteristics vary by landscape position and estuary type, but all tidal wetlands share some basic characteristics in common.

Hydrology

Tidal hydrology is the key factor in defining tidal wetlands. The mixed semi-diurnal tides of the Pacific Northwest include two high tides per day, of which one is the "higher high" tide. Most definitions of tidal wetland require periodic inundation of the wetland surface by tidal flows, but groundwater levels can be affected by the tides even if surface inundation does not occur. Definitions of tidal wetlands are still evolving, with new knowledge generated through research and with changes in the regulatory environment.

Salinity

Surface flows in tidal wetlands may be salt, brackish, or fresh. The lower portion of the estuary has the highest salinities in general, but freshwater input from precipitation and the adjacent watershed can result in brackish or variable salinity even in tidal wetlands near the ocean. Salinities in tidal wetlands in the brackish zone can be surprisingly high if structures or features such as dikes and restrictive culverts cause impoundment of incoming brackish water, allowing evaporation and concentration of salts.

Most definitions of tidal wetlands include all wetlands subject to tidal forces all the way from ocean to head of tide, including freshwater tidal wetlands in the upper estuary. The freshwater tidal zone is subject to tidal forces, but beyond the reach of ocean salinity.

In addition to tidal flows, many wetlands in the upper estuary have freshwater inflows from the surrounding watershed. These nontidal flows can be major factors in hydrology and channel development processes. Freshwater flows onto tidal wetlands can be channelized, such as streams, or diffuse, such as hillslope seepage. These flows can create internal salinity gradients within sites, providing diversity in vegetation, soil biology, and fish habitat.

Soils

Tidal wetland soils—like all wetland soils—are saturated and anaerobic during a substantial part of the growing season. The source of the saturation is generally tidal flow, but nontidal flows can also contribute to soil saturation, particularly in the upper estuary. Tidal wetland soils may have considerable porewater salinity, depending on the salinity regime of tidal flows in the area. Soils in tidal wetlands often have high organic content due to the slow decomposition of plant materials under anaerobic conditions.

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Within most tidal wetlands of Oregon, soils are fine-textured (silt or clay), but sand or even gravel substrates are found in higher-energy portions of the estuary.

Vegetation

Tidal wetlands include unvegetated areas such as mud flats; eelgrass beds and algae beds; and taller vegetation such as grasses, shrubs, and forests. This presentation focuses on the areas where tide gates are usually installed—tidal marshes and tidal swamps. Tide gates were installed in these areas quite early during coastal settlement, to increase agricultural productivity and allow other human uses.

Tidal marsh is the most easily recognizable type of tidal wetland in the Pacific Northwest. This vegetation type is dominated by low-growing, nonwoody vegetation, usually grasses, sedges, and rushes, but with increasing proportions of forbs (broadleaved plants) in the upper estuary. Tidal marsh—also called "salt marsh"—is classified as "emergent wetland" in the Cowardin classification system.

Two main types of tidal marsh are broadly recognized in the Pacific Northwest: Low marsh and high marsh.

Low marsh, generally flooded daily, is dominated by salt-tolerant succulents such as pickleweed (*Salicornia virginica*), marsh jaumea (*Jaumea carnosa*), and seaside arrowgrass (*Triglochin maritima*); and grasses and sedges such as seashore saltgrass (*Distichlis spicata*) and Lyngbye's sedge (*Carex lyngbyei*).

High marsh floods less often—once to several times a month—and is often dominated by tufted hairgrass (*Deschampsia caespitosa*), with a diverse mix of other species, often including Pacific silverweed (*Argentina egedii*) and Baltic rush (*Juncus arcticus v. balticus*). In the freshwater tidal zone, tidal marsh may be dominated by typical freshwater wetland species such as slough sedge (*Carex obnupta*) and skunk cabbage (*Lysichiton americanus*). In Oregon, tidal marsh in middle estuaries and freshwater-flow dominated systems may have extensive communities of softstem and/or hardstem bulrush (*Schoenoplectus tabernaemontani* and *Schoenoplectus acutus*) as well as Lyngbye's sedge, which has a broad salinity tolerance.

Tidal swamps have more than 30 percent cover of trees or shrubs. These wetlands are classified as "forested" or "scrub-shrub" wetlands in the Cowardin classification system. Tidal swamps were once a major component of Pacific Northwest estuaries but are now very rare. Common woody species in brackish tidal swamps in Oregon include Sitka spruce (*Picea sitchensis*), black twinberry (*Lonicera involucrata*), and Pacific crabapple (*Malus fusca*). In the freshwater tidal zone, red alder (*Alnus rubra*), willows (*Salix spp.*), Douglas spiraea (*Spiraea douglasii*), and colonial dogwood (*Cornus sericea*) are typical additions to the mix. The freshwater tidal zone may also have stands of cottonwood (*Populus balsamifera v. trichocarpa*) and Oregon ash (*Fraxinus latifolia*), but these species are less common.

Physical Features and Landscape Setting

In the drowned river mouth estuaries of Oregon, tidal marshes and swamps are generally characterized by highly sinuous channels with a deep, steep-sided profile and low width-to-depth ratio. Tidal channels in high-energy areas (e.g., large watersheds, steep watershed gradients, major flood zones) may have low sinuosity. Many tidal wetlands in the middle and upper estuary have substantial *natural levees*—linear, elevated features along the riverbank where floodwaters drop sediments as their velocity slows. These natural levees can be confused with dikes; distinguishing the two features requires research into land use history, topography, and soil profiles.

Tidal inundation varies by season in upper-estuary tidal wetlands. These brackish and freshwater tidal wetlands are more frequently inundated in winter, when high river flows and high tides coincide. Thus, high river flows, as well as tides, may be critical "controlling factors" in channel development and other site characteristics in these upper estuary tidal wetlands.

Ecological Functions of Pacific Northwest Tidal Wetlands

Tidal wetlands provide habitat for a variety of wildlife, such as marine invertebrate larvae; amphibians; anadromous, marine, and resident fish; a great variety of birds; and even large mammals such as elk and bear. Other valued functions include water quality (sediment detention, nutrient and contaminant detention and processing, water temperature moderation), organic matter production and export, support of native plant communities, and flood and storm protection. Functional levels vary by tidal wetland type and landscape position, but all tidal wetlands perform valuable functions.

Alterations to Pacific Northwest Tidal Wetlands

A high percentage of Pacific Northwest tidal wetlands have been altered by human land uses. The most common alterations are diking, ditching, installation of tide gates or restrictive culverts, and fill. Each alteration type affects tidal wetlands differently, and each alteration type presents different restoration opportunities. Alterations may have unintended consequences that present challenges to land management, restoration design, and adaptive management.

The goals of *diking* are to exclude tidal flows and salt water. One common unintended consequence of diking is soil subsidence ("sinking" of the soil surface) behind the dike. Subsidence is caused by oxidation of highly organic tidal wetland soils, compaction by livestock or machinery, and loss of flotation when the water table drops after diking and drainage. Subsidence often results in the ground surface dropping by one to several feet compared to pre-diking elevation; the resulting low ground can become a nontidal freshwater wetland if the water table is near the surface. Another unexpected result of diking can be impoundment of surface flows behind the dike, including diffuse (nonchannelized) flows, which may not have been noticeable before diking. Impoundment makes subsided areas even wetter. Other unintended consequences can include invasion of weedy non-native plants (often encouraged by soil disturbance), and sedimentation of channels due to hydrologic change.

Ditching is intended to speed water flow off a tidal wetland. The most prominent unintended consequence is a reduction in fish habitat quantity and/or quality. Fish habitat effects of ditching are complex, but the main effects are related to changes in channel length, channel morphology (sinuosity, profile, width:depth ratio), water temperature, and water quality. Other unintended effects can include altered water flow speeds, and sedimentation or scouring (depending on landscape setting and other alterations).

Tide gates and *culverts* are intended to eliminate or reduce tidal flows and exclude salt water. Culverts may allow nearly complete tidal exchange if they are sufficiently large, but tide gates too small to allow full tidal exchange are referred to as "restrictive culverts." Unintended consequences of tide gates and restrictive culverts may include blockage of fish passage, water impoundment behind the restrictive structure, and altered flow velocities with associated changes in sediment regime (scouring and/or sedimentation).

The effects of dikes, ditches, tide gates, and restrictive culverts are, of course, closely interrelated, since these structures are usually built together. Their effects may extend off the directly altered sites to neighboring wetlands, because of the broader hydrologic changes associated with these alterations.

Many other types of alterations exist in tidal wetlands, including extensive fill (such as dredged material disposal), channel dredging, contamination, road crossings, dams, riprap, and introduction of invasive species.

Pacific Northwest tidal Wetland Losses and Conversions

A high proportion of tidal wetlands in the Pacific Northwest have been lost or converted to other uses or other wetland types. Current estimates of tidal wetland losses in Oregon range from 60 to over 90 percent, depending on wetland type. Losses of a similar magnitude have occurred in Washington and California. These losses have led to considerable interest in tidal wetland restoration.

Future Directions

We still have a great deal to learn about Pacific Northwest tidal wetlands. Many tidal wetland types have been little studied, and many of the functions of Pacific Northwest tidal wetlands are not yet well understood. Tidal wetland restoration is still a new science, and parallel monitoring of tidal wetland restoration and reference sites is not yet widespread or standardized. Every project—whether a tide gate improvement, tide gate removal, or other tidal wetland restoration project—provides an important opportunity to expand our knowledge. When designing such projects, it is important to consider unintended consequences of earlier alterations, as well as possible unintended consequences of the planned action. Knowledge of the cultural, regulatory, and economic setting of the project is vital to project effectiveness. Baseline and follow-up monitoring are critical (see final section on monitoring in Brophy 2007). Sharing data and lessons learned will be key to improving our results.

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Juvenile Salmon Rearing in Tidal Channels of the Salmon River Estuary: Examples of Salmon Behavior in an Ungated Estuary

David Hering,[1] Kim Jones,[1] and Daniel Bottom[2]

The Salmon River estuary is remarkable among Oregon estuaries because the sequential removal in 1978, 1987, and 1996 of three tide-gated dikes has restored tidal processes to most of the estuary's historic wetlands (Figure 1). In 1997, Oregon Department of Fish and Wildlife (ODFW), the University of Washington, Oregon State University, and NOAA Fisheries began a long-term research project to monitor the ecology of natural and recovering wetlands in the estuary, with a particular focus on wetland use by salmon. Among other activities, this work has included monitoring the distribution and abundance of juvenile salmon in several tidal marsh channels and using both mark-recapture sampling and Passive Integrated Transponder (PIT) telemetry to describe the fine-scale movements of salmon within tidal habitats. These efforts have resulted in a description of juvenile salmon behavior in ungated tidal channels, which we hope will provide context for discussing the effects of tide gates on estuarine fish communities and for evaluating the utility of tide gate modification to benefit fish passage.

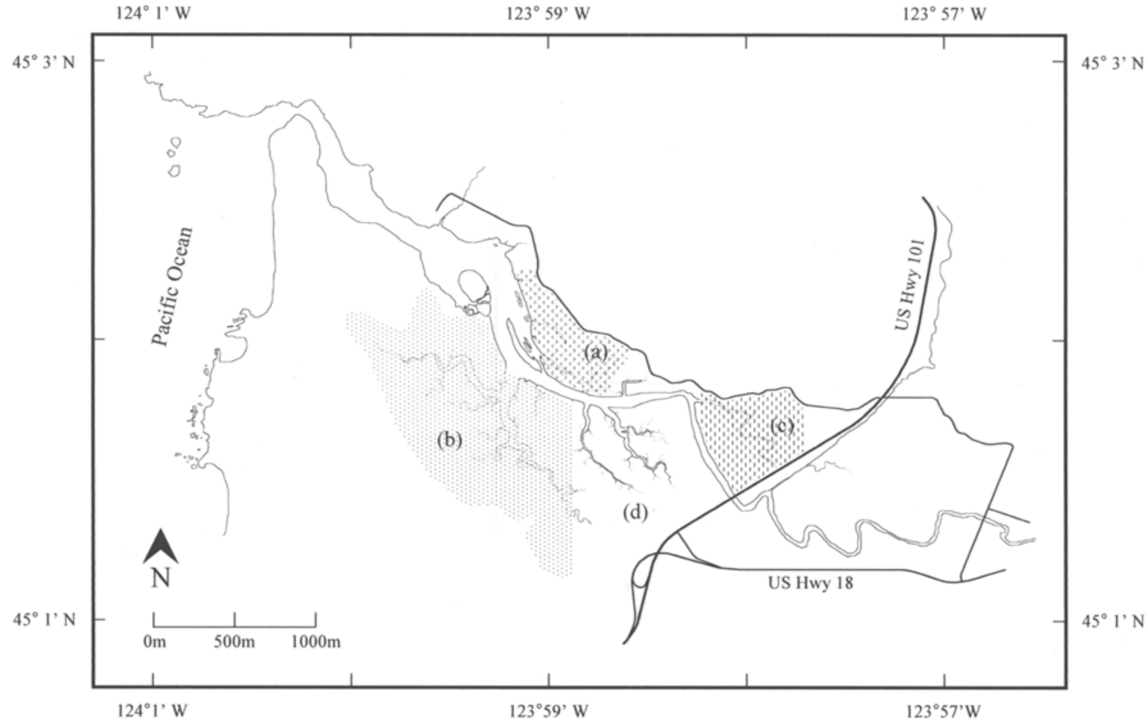

Figure 1. Map of Salmon River estuary, showing wetland areas restored to tidal inundation by dike and tide gate removal in (a) 1978, (b) 1987, and (c) 1996. The remaining wetland channel system (d) was never diked and was the location of the PIT tag detector used to monitor Chinook salmon movement.

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Salmon River supports fall Chinook, coho, and chum salmon, steelhead, and coastal cutthroat trout. In the estuary, Chinook and coho occupy intertidal channels from February through at least October, with peak densities in spring and early summer. Chum salmon are found in the marsh channels during a shorter period, from March through May. Limited sampling in December has indicated that Chinook may continue to use the marsh channels into the winter (T. Cornwell, ODFW, unpublished). Thus, it is reasonable to conclude that the Salmon River tidal channels may provide juvenile salmon habitat at any time during the year. Sub-yearling coho primarily occupy the most oligohaline of the marsh channels (salinity typically <10 PSU) that was restored through dike removal in 1996. Contrary to the conventional view that estuarine-rearing coho exhibit poor survival (e.g., Crone and Bond 1976), 18 percent of returning adult coho from the 1998 brood year had scale patterns indicating they may have reared in the estuary and migrated to sea as sub-yearlings (Cornwell et al. 2001). Although trout are seldom captured within intertidal wetland habitats (Cornwell et al. 2001), cutthroat trout rear throughout the summer in habitats adjacent to the mouths of wetland channels (Krentz, in prep).

Mark-recapture experiments indicate that individual Chinook salmon rear in the estuary for prolonged periods. The median travel time of marked fish from the head of tide to the mouth of the Salmon River was five weeks (Bottom et al. 2005), but individuals tagged within two tidal channels in the upper estuary remained and were recaptured in the same channels up to four months after initial capture. While rearing in tidal channels, recaptured Chinook exhibited significant positive growth (mean growth rates 1.3–2.3 percent body weight x day^{-1} and 0.3–0.6 mm x day^{-1}). The average documented residence time in marsh channels was 10 days in 2004 (Hering, in prep).

Catch data from seining within marsh channels are consistent with the idea that salmon move into tidal channels during flood tides and exit the channels as the tide ebbs. In two marsh channels sampled, the catch-per-unit-effort of Chinook during high tides declined with distance from sub-tidal habitats in the mainstem estuary. Chinook density also appeared to be positively correlated with tidal magnitude during the summer, when more salmon were captured during spring tides than neap tides (Hering, in prep).

During the summers of 2004 and 2005, we operated a stationary Passive Integrated Transponder (PIT) antenna at the mouth of one intertidal channel and monitored the movement of PIT-tagged Chinook into and out of the channel. Frequency of tag detection peaked between one and two hours before high slack tides and between three and four hours after high slack tides, corresponding with fish moving into the study channel on flooding tides and out of the channel on the ebbing tides. Median residence time of individuals within the study channel was 4.9 hours per tidal cycle. Few fish were detected when water depth in the channel was less than 0.4 meters, and no fish were observed to remain in the study channel through low slack tide. Many individuals exhibited fidelity to the channel and were detected on successive tidal cycles over several weeks (Figure 2). Other fish used the site infrequently, but over a period of up to 109 days. PIT technology may be useful for monitoring fish passage through tide gates, although limited tag detection in high-salinity water poses technical challenges to this approach.

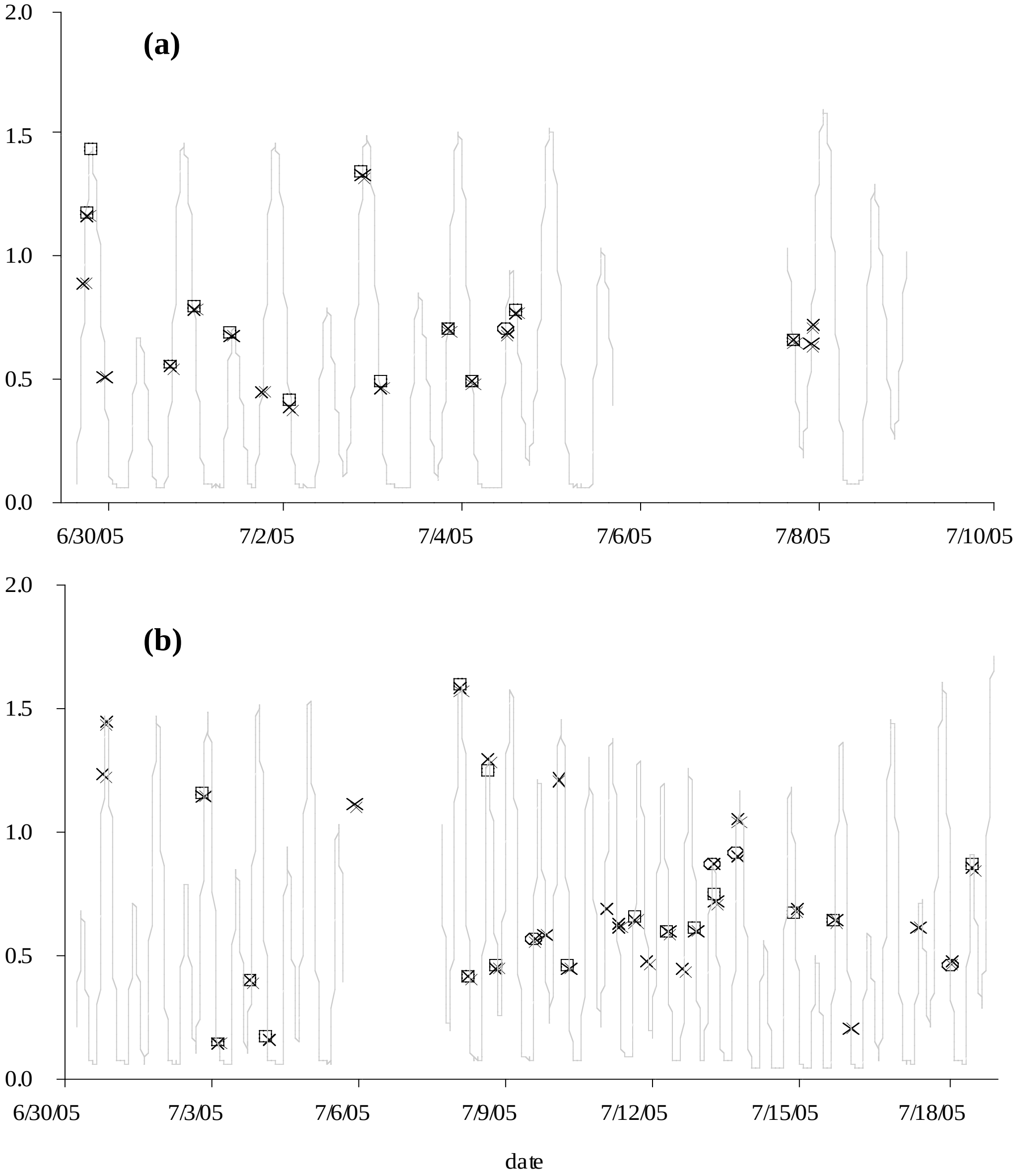

Figure 2. Detections of two individual PIT-tagged Chinook that demonstrated fidelity to a Salmon River tidal channel. The fish in panel (a) was tagged 6/28/05 at length 86 mm and weight 7.3 g. The fish in panel (b) was tagged 6/30/05 at 74 mm and 4.2 g. Two detectors were deployed in the channel, spaced approximately 20 meters apart. O and X indicate detection on the downstream and upstream detector, respectively. The grey line indicates water depth at the PIT detector. Breaks in the line indicate periods when the detector was not operating.

Our experience with the Salmon River confirms that "off-channel" estuarine tidal habitats provide substantial benefits to salmon migrating downstream from spawning and rearing areas higher in the river basin. We have observed individuals moving tidally into and out of marsh habitats for several weeks and deriving significant positive growth while rearing in tidally accessible habitats. The patterns of individual fish movement observed in Salmon River suggest that tide gates likely alter the behavior of estuarine-rearing salmon unless the tide gates allow natural tidal fluctuations and fish passage at all times. In the

Pacific Northwest, tide gates likely have the greatest effect on Chinook, chum, and some coho salmon that are adapted to rear in tidal habitats as sub-yearlings.

Limiting access to tidally inundated wetland habitats can have a measurable effect on salmon populations and estuarine productivity. Our work with the Salmon River suggests that restored access to tidal wetland habitat has increased life-history diversity of Chinook in the watershed by allowing expression of estuarine rearing life-history types that were rare or absent in the watershed when dikes blocked tidal channels in the 1970s (Bottom et al. 2005). By spreading the risks posed by environmental disturbance over multiple alternative behavioral strategies, such life-history diversity may reduce the chance of brood-year failure and contribute to the resilience of salmon populations.

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Smokehouse Floodplain/Fornsby Creek Habitat Reconnection Project

Steve R Hinton,[1] Todd Mitchell,[2] and Rachel Lovellford[2]

Abstract

This project, conducted by the Swinomish tribal community of LaConner, Washington, focused primarily on the goal of providing fish passage at tide gates located on reservation lands. The project replaced traditional, top-hinged "flap style" tide gates in 2005 with a vertically hung, hydraulically controlled gate design that was first installed and tested in the Aberdeen area of Washington State by the Army Corps of Engineers. In addition, the project included several floodplain and riparian elements designed to improve habitat quality in preparation for use by aquatic species. Funded by the Washington State Salmon Recovery Funding Board, the U.S. Fish and Wildlife Service (USFWS), and the National Resource Conservation Service (NRCS), the project began baseline data collection in 2003. The project went fully operation during the salmonid out-migration period in early 2006. In doing so, the project opened over five miles of historic channel habitat to use by a variety of aquatic species that had been excluded from the area since it was isolated by the Army Corps of Engineers in 1937 as a part of the Swinomish Channel Navigation Project. This paper provides a summary of the project and initial monitoring results from data collected on fish use, groundwater effects, surface water, and salinity movement through the 2006 migration season.

Introduction

Reservation waters support a vast fisheries resource that tribal members rely on for subsistence and commercial harvest and ceremonial use. Salmon are particularly culturally significant, playing a central role in the community and spiritual life of the tribe. Aquatic vegetation is also important to the tribe, as it provides critical habitat to aquatic species, including salmonids and their prey. Estuarine habitat, particularly pocket estuary habitat, is increasingly recognized as critical and limiting to salmonid populations in the region (Beamer 2000a).

Located on the Swinomish Reservation in LaConner, Washington, the project site was isolated from tidal influences in 1937 when the Army Corps of Engineers (ACOE) implemented a massive navigation project directed at opening Swinomish slough for commerce between Skagit at Padilla Bays (SITC 1999). For decades, local merchants and regional authorities had been pushing congress to implement a project on this otherwise mundane distributary channel of the Skagit River. Staring at the turn of the century, incremental navigation improvements were being made to the channel. These efforts culminated in the 1937 project, which established the modern-day channel morphology. Over 11 miles in length, the Swinomish Channel was once a complex system of braided distributary and blind tidal channels, historically used by tribal fisherman for decades as productive sites for well-established, generational fish weirs and traps (SITC 1999).

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1. Skagit River System Cooperative, PO Box 368, LaConner, WA 98257.
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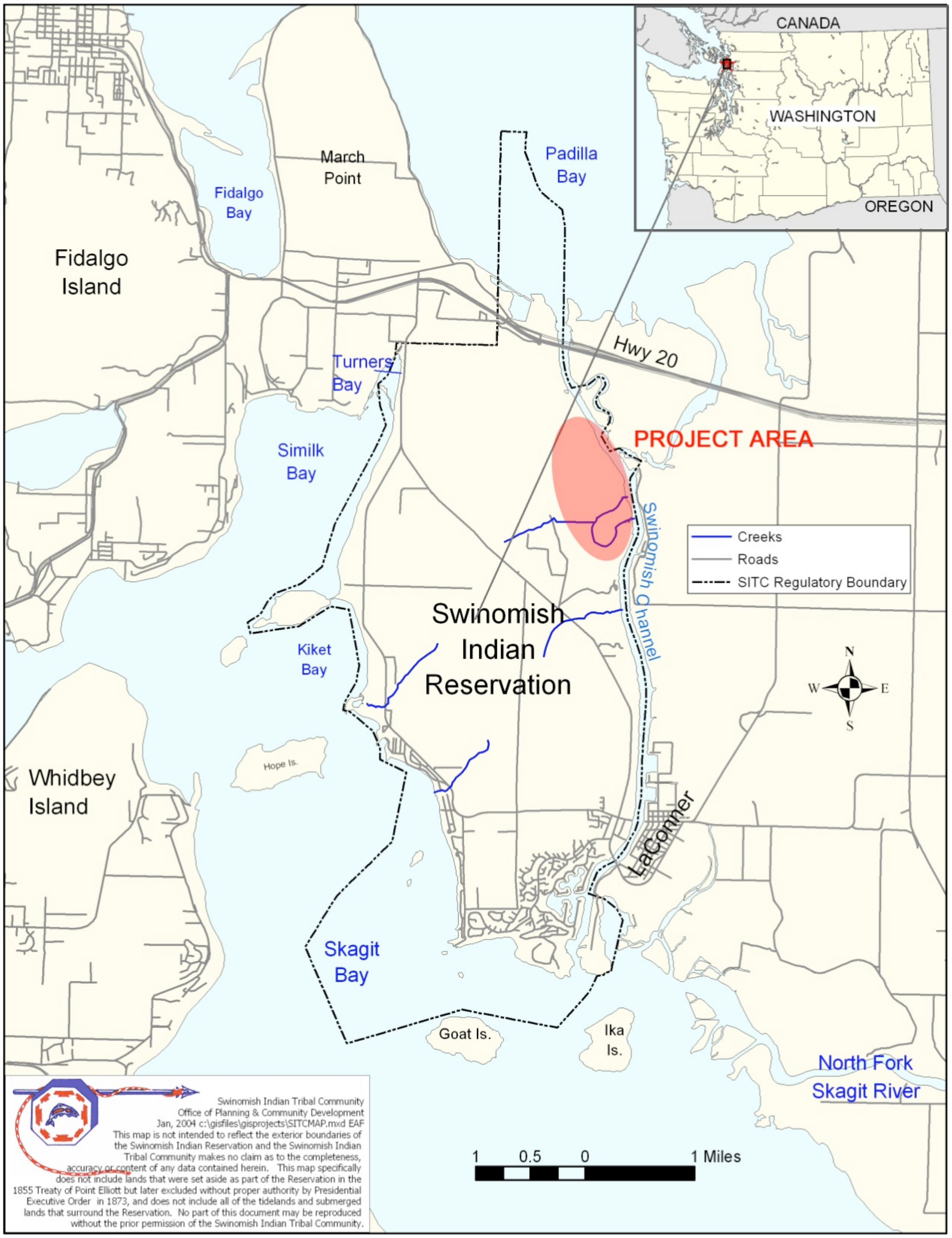

Swinomish Indian Tribal Community
Office of Planning & Community Development
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This map is not intended to reflect the exterior boundaries of the Swinomish Indian Reservation and the Swinomish Indian Tribal Community makes no claim as to the completeness, accuracy or content of any data contained herein. This map specifically does not include lands that were set aside as part of the Reservation in the 1855 Treaty of Point Elliott but later excluded without proper authority by Presidential Executive Order in 1873, and does not include all of the tidelands and submerged lands that surround the Reservation. No part of this document may be reproduced without the prior permission of the Swinomish Indian Tribal Community.

Figure 1. Project location.

The ACOE project involved dredging and straightening the entire length of the Swinomish Slough, using the spoils to dike a dewater surrounding tidal marsh, and improving a rock jetty at the southern end of the channel to divert Skagit River flows away from the navigation channel. When successfully completed, the project had impacted tribal reservation lands by dumping well over a million cubic yards of dredge spoils on reservation marshlands. Wetland filling destroyed 105 miles of tidal sloughs and resulted in a 56 percent loss of historic channel and 75 percent loss of mudflat, salt marsh, and sea grass habitat in the area. Pre-project remnant channels were used as drainage ditches fitted with top-hinged, flap-style tide gates, isolating channel habitat from use by aquatic dependent species and eliminating what had been an accustomed fishery for thousands of years (SITC 1999).

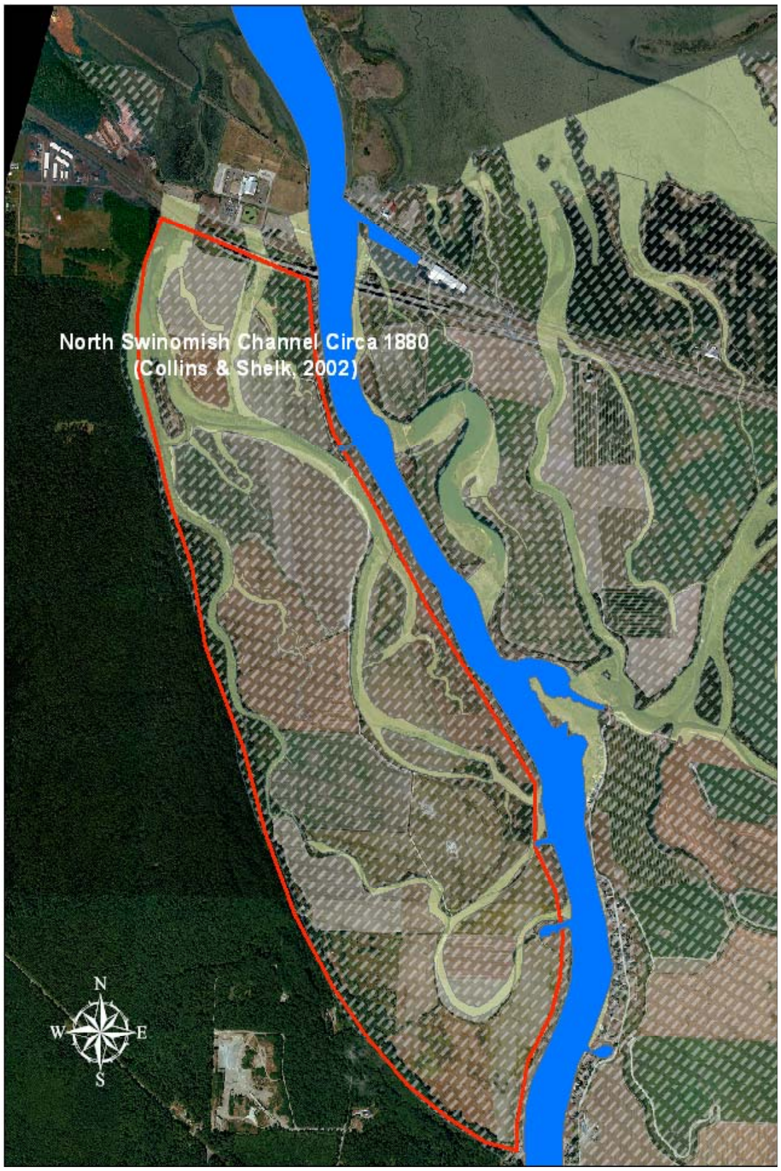


Figure 2. Northern Swinomish Channel, circa 1880. Area highlighted with blue indicates modern-day channel; green indicates predicted channel. Recreated by Collins & Shelk from GLO surveys.

Decades of attempts to have officials recognize and redress the impacts realized by the Swinomish tribal community and the fisheries have yielded few results. Finally, in 1999, Puget Sound Chinook were listed as threatened under the Endangered Species Act (ESA), leading to invigorated efforts to find ways and means by which the once-abundant “Tyee” of salmon could be saved for future generations.

Several planning efforts have recognized the role tide gate structures have played in blocking the migration of fish, both juvenile and adult, to areas that were historically available to this species (ODFW 2004; People for Puget Sound 2000). However, it has not been until recently that we have seen scientific literature that truly examines the ramifications of this loss (Beamer 2000; Hood 2004). The Swinomish tribal community has been at the forefront of investigations into these impacts and has been a strong advocate for implementing federal and state regulations requiring tide gate facilities to implement passage solutions for aquatic-dependent species. In response to the tribal pressure, local agricultural interests successfully lobbied the state legislature to pass legislation in the 2003 session that effectively ended the state’s mandate to seek or require passage at tide gate structures (Washington State Legislature HB 1418, 2003).

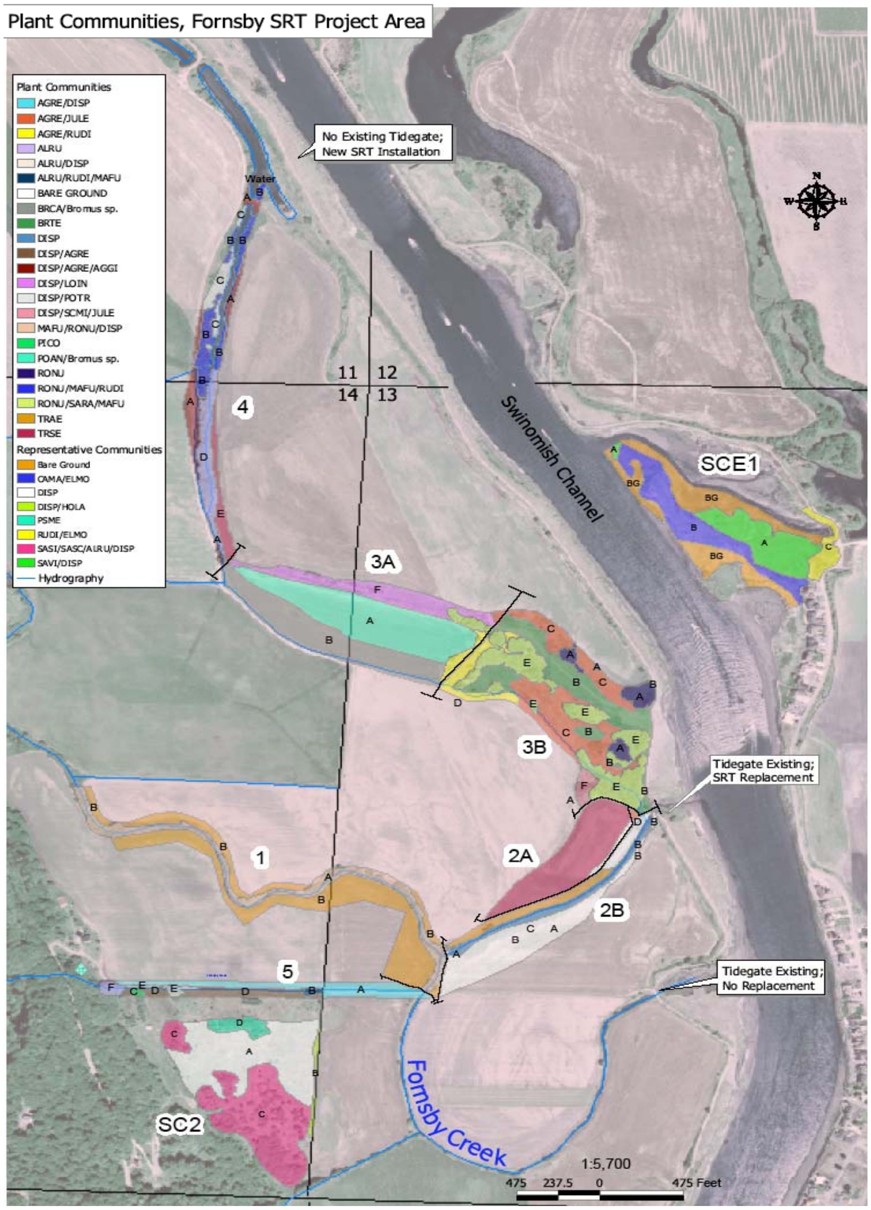


Figure 3. Pre-project condition showing dominant plant communities.

Undeterred, Swinomish tribal leadership called for the implementation of a passable tide gate structure at tide gates located on the Swinomish Reservation. Three tide gate structures had been recently returned to tribal control through a sizeable fee-simple land purchase in the year 2000. The acquisition involved over 350 acres of agricultural lands on the reservation that had once been the productive marshes along Swinomish Slough. This brought the total acreage under tribal and/or native allotee control to approximately 750 acres, of approximately 950 acres that are arable lands within the reservation boundaries.

Working with the remaining fee-simple owners, restoration ecologists working for the Skagit River System Cooperative and the Swinomish Planning Department swiftly secured funding from a variety of sources to implement what has become known as the Smokehouse Floodplain/Fornsby Creek SRT Habitat Project.

Project Design and Implementation

The project can be broken down into three overlapping phases: pre-restoration ("baseline") monitoring, active restoration/construction, and post-restoration monitoring. Baseline monitoring began in autumn 2003 and includes monitoring of existing hydrologic conditions, habitat, and fauna. Active restoration began in autumn 2004 and included replacement of two tide gates with designs capable of passing fish, channel shaping and grading, culvert removal, and a variety of native riparian plantings. The monitoring activities initiated for baseline observation are maintained to provide ongoing baseline data in areas not yet under active restoration and post-restoration monitoring in those areas that have been modified.

The baseline monitoring program for this project includes biological surveys, hydrologic monitoring, and limited soils studies. The spatial distribution of designated monitoring stations are shown in Figure 4. More than 70 acres of riparian habitat were surveyed for existing vegetation to inform a restoration planting plan.

Fish use was documented by bi-monthly beach seining at three sites within the project area. We used small net beach seine methods to sample six sites for the Fornsby Tidegate Restoration Project (Figure 9). Small net beach seine methodology uses an 80' (24.4 m) by 6' (1.8 m) by 1/8" (0.3 cm)-mesh, knotless nylon net. The net is set in "round haul" fashion by fixing one end of the net on the beach, while the other end is deployed by wading the net "upstream" against the water current using a floating tote or boat, and then returning to the shoreline in a half circle. Both ends of the net are then retrieved, yielding a catch.

Data collected for each beach seine set include:

- Time and date of set
- Tidal stage (ebb, flood, high-tide slack, low-tide slack)
- Water surface area seined
- Surface and bottom water temperature of area seined using YSI meter
- Surface and bottom salinity of area seined using YSI meter
- Maximum depth of area seined
- Substrate of area seined
- Vegetation of area seined
- Complete fish catch records by species
- Sub-sample of individual fish lengths

Channel morphology, sediment grain size, and flow rates were assessed before any modifications were implemented. Surface water levels and water temperatures are continuously monitored at 12 sites, and surface water-quality parameters (pH, conductivity, dissolved oxygen, salinity, turbidity, and chloride) are sampled bimonthly. Groundwater levels are monitored continuously at seven pairs of monitoring wells, and groundwater quality parameters (pH, conductivity, dissolved oxygen, salinity, and chloride) are sampled monthly. Soil salinities have been measured and mapped, in cooperation with the USDA, along transects parallel to well transects in both wet and dry seasons, using electromagnetic induction methods.

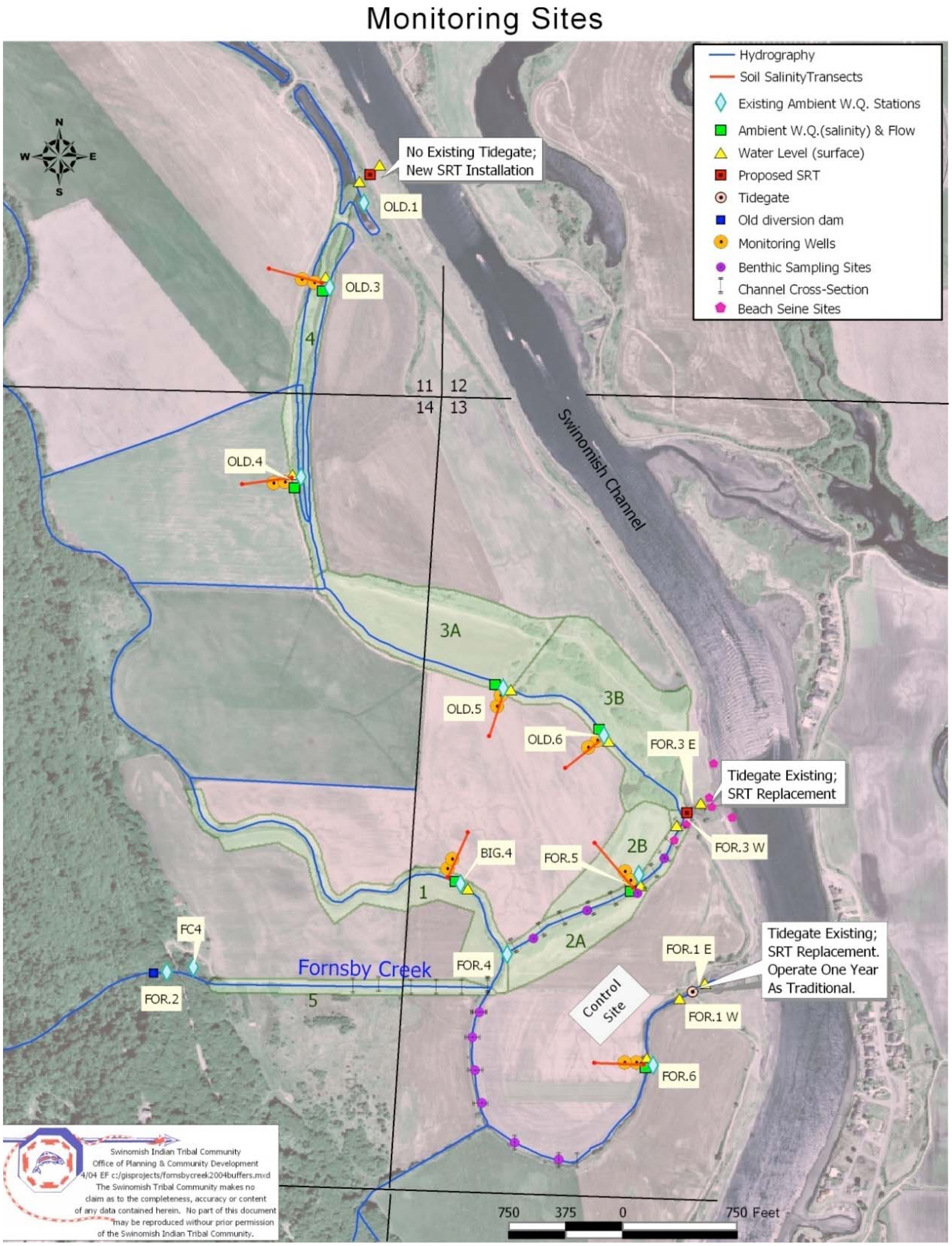


Figure 4. Project area layout, showing monitoring locations and riparian reserves.

Restoration activities implemented under this project include installation of two passable tide gate structures; channel restoration, modification and/or enhancement; culvert removal; and native riparian plantings. The cornerstone of the project was installation of a hydraulically controlled, vertically hung tide gate at the area designated FOR3W in Figure 4. This gate replaced a more traditional flap-style tide gate. In addition to this gate, a second gate was installed in a nearby location designated as FOR3E in Figure 4. This gate was fitted with a removable, top-hinged flap gate for emergency use and a typical screw-gate design at the inland opening. This design allowed for tidal exchange to occur throughout the tidal cycle and added one additional access point for fish along an antiquated and abandoned channel.

In concert with the treatment area, an existing gate at the location FOR1 was refitted with a new top-hinged, flap-gate lid that was convertible to a float design typical of what is known as the “Waterman” style tide gate. Installed at the southernmost site (FOR.1) in autumn 2004, FOR1 is being operated in a traditional manner for five years to provide a control within the monitoring design. The second and third tide gate located at FOR3E and FOR3W were installed in autumn of 2005 at the FOR.3. A third tide gate is proposed for construction at OLD.1 in August 2008.

In an effort to improve connectivity between the floodplain and channel, we moved more than 80,000 cubic yards of soil by grading and modifying more than two miles of channel and floodplain habitat. Much of this material was used to establish berms at the outer edge of the designated riparian areas, to prevent surface water connection to the adjacent fields. Grading and shaping were begun in autumn 2004 along segments 1 and 2 (Figure 3). Segments 3, 4, and 5 were graded in 2005. All grading work was completed prior to the installation of passable tide gates.

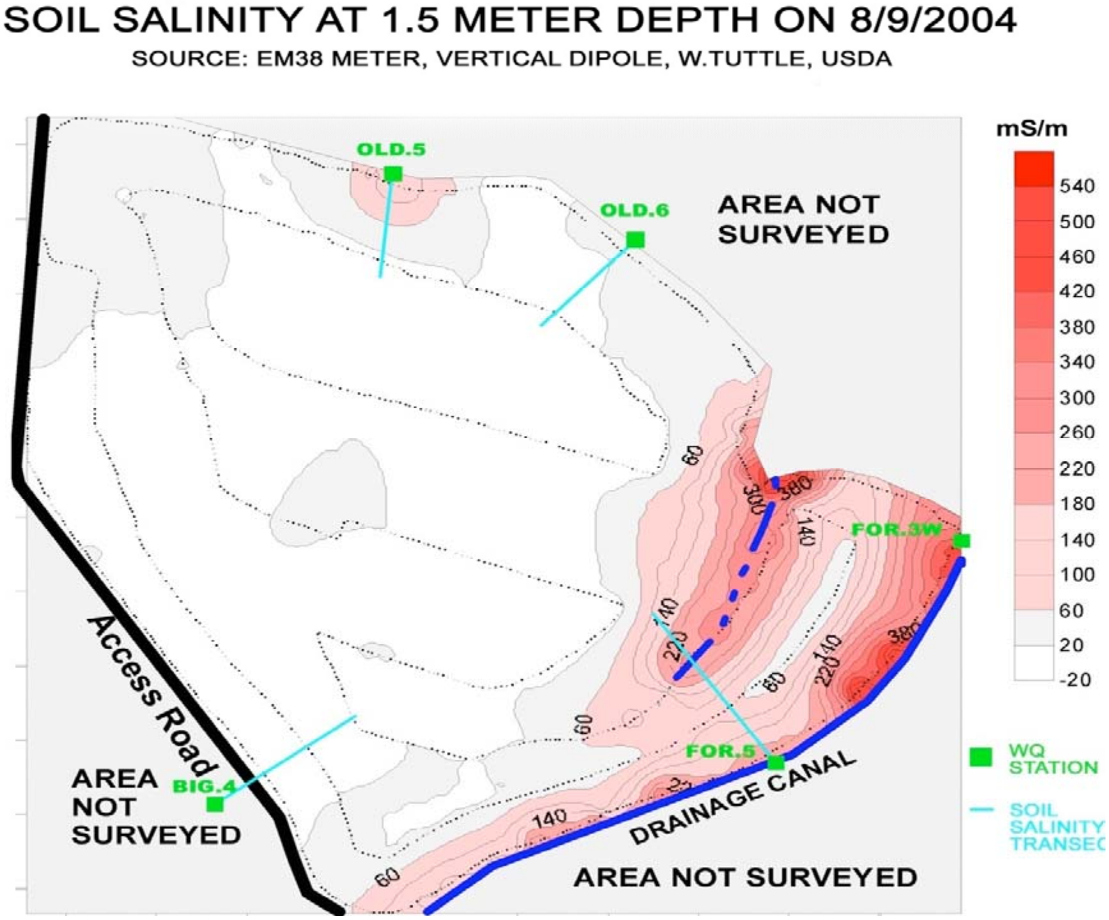
Once the gates were in operation, native plants were selectively installed in locations adjacent to, but not within, zones influenced by tidal flux. Areas that had consistent tidal influence were allowed to passively reseed. Native plantings over the past two years have targeted approximately 25 acres of adjacent riparian habitat as a buffer for the restored channel. All plantings have been recorded with Trimble GPS for monitoring survival.

Post-restoration monitoring will mirror the baseline monitoring and utilize the same monitoring stations and sampling methods. Monitoring efforts will effectively continue without alteration in the activities, with simply different implications for the resultant data. A minimum of two years of data will be collected after active restoration is complete, though some monitoring activities may be continued indefinitely.

Results and Discussion

Techincal review of the project via funding requests focused on questions regarding the location and extent of the mixing zone between salt and freshwater. The amount and extent of freshwater exchange was important, given the degraded water quality associated with agricultural drainage ditches and the lack of water exchange especially during the low-flow periods of the year. While extensive predictive modeling was neither required nor conducted in advance of project implementation, funding approval was granted based on a monitoring design that incorporated surface and ground water components that would be used to inform project adaptation and application.

In spite of general concerns, the project received favorable support from a variety of stakeholders in both local and regional review (SRFB 2003). Judging from cursory literature reviews, few, if any, projects of this nature have been attempted in the Pacific Northwest. Passable tide-gate projects generally have been isolated to areas where conditions are limited to salinities of 5 ppt or less (Charland 1998). This location was considerably more extreme than the norm having salinities ranging from 18–24 ppt. (Hood et al. 2002). Exchanging any volumes of water with these densities of salt would be both politically and economically challenging if the land base were to be controlled by any other entity.


SOIL SALINITY AT 1.5 METER DEPTH ON 8/9/2004

SOURCE: EM38 METER, VERTICAL DIPOLE, W.TUTTLE, USDA

Figure 5. Pre-project soil salinities taken 8/9/2004 in vicinity of tide gates, using a EM38 Vertical Dipole meter.

Working diligently to secure funding tribal staff secured over $500,000 in commitments from the Salmon Recovery Funding Board (SRFB), the Natural Resource Conservation Service (NRCS), and the U.S. Fish & Wildlife Service (USFWS) by the end of 2003. Desiring immediate and meaningful relief to habitat constraints within Swinomish

Channel, the tribal community swiftly moved to implementation, foregoing more-detailed and specific studies and detailed project designs.

Using limited resources made available by the commitment of tribal resources and, to some extent, grant funding, the project was able to implement an array of groundwater wells and surface-water stations, which have been monitored on a monthly basis since 2004. Pre-project WQ data supported our working hypothesis that saltwater was already present in the system. Supporting this hypothesis was data collected by vegetation surveys revealing that several saltwater-tolerant species were already well established in channel corridors prior to re-establishing saltwater exchange.

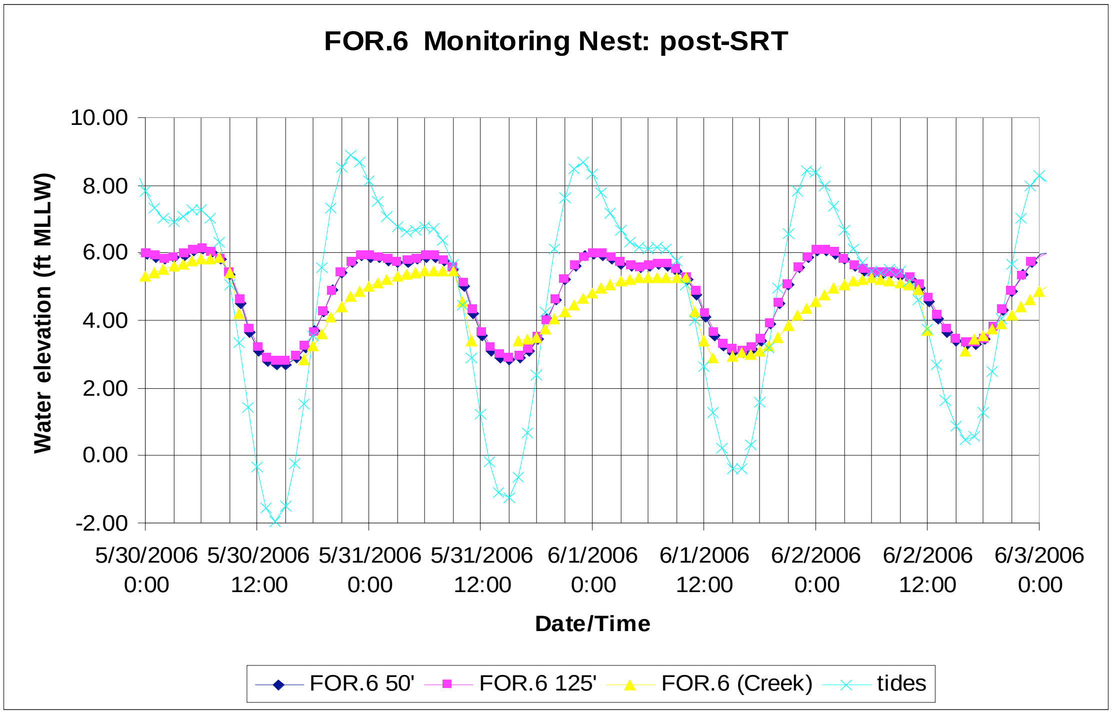


Figure 6. Water surface elevations with both gates functioning.

The project, successfully implemented during the construction season of 2005 (June–September), was immediately successful in realizing progress toward all of the project objectives: (1) water exchange within the treatment area was improved dramatically; (2) water quality parameters improved significantly; (3) the composition of aquatic dependent species utilizing the isolated channels changed dramatically; (4) juvenile Chinook were among the species benefiting from the treatment; and (5) agronomic impacts, minus riparian reserves, were minimal (less than 10 percent precondition).

Project managers have been pleasantly surprised by the magnitude, rate and extent of tidal exchange throughout the site. In particular, we found that tidal water entering the project site followed a net north flow pattern that mimicked the Swinomish Channel waterway itself. The result was tidal waters flowing through the entire five miles of available channel at flows of one to two feet per second. Therefore, the entire site became predominantly occupied by marine waters.

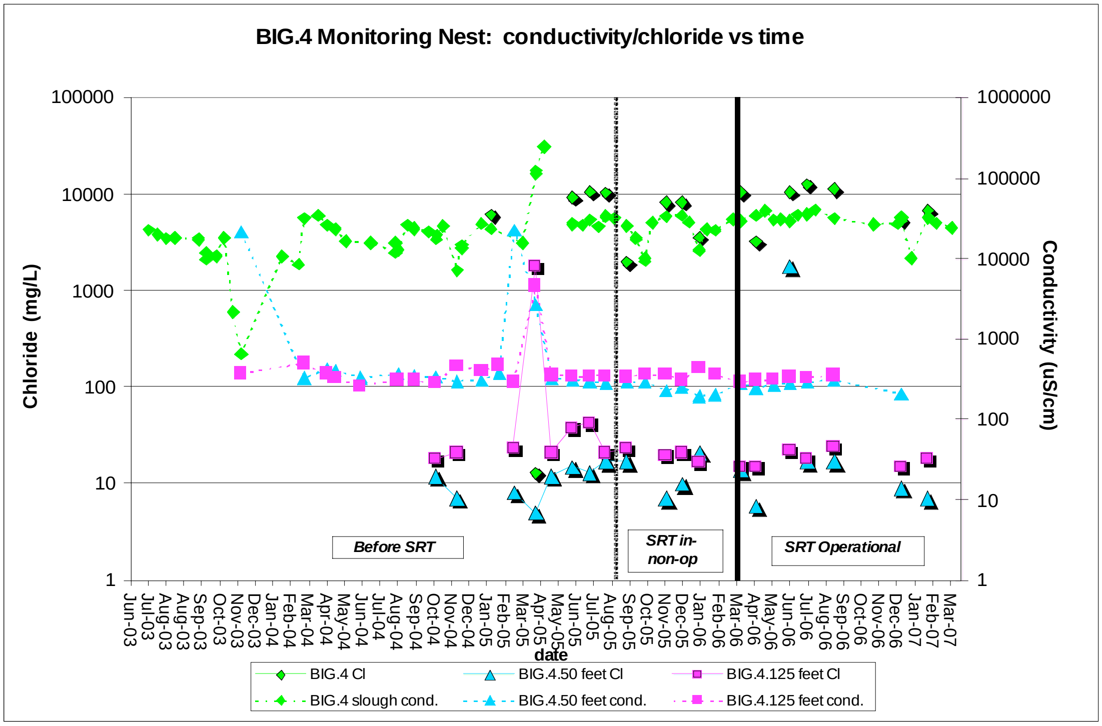


Figure 7. Big 4 monitoring nest chloride concentrations, before and after SRT operations.

In spite of this turnover in water from predominantly fresh to salt, we have seen limited impacts in the agricultural fields. Agronomic activity is still the dominant land use (Figure 8) and continues to be for the foreseeable future. From the outset, surface water connections have been actively and successfully managed between riparian areas and cultivated fields. Given this surface-water disconnect, we concentrated on the groundwater wells as our primary indicator of salt intrusion into the fields and the underlying groundwater table. While our data set is limited to only one year post-project, the results are promising. Figure 7 shows the results from one monitoring nest showing little change between pre- and post-project conditions within the groundwater table.

Unfortunately, positive post-construction trends were offset by a design failure occurring in July 2006 that effectively ended the tide gate being operated at optimal conditions. Due to design and fabrication errors, the hydraulic controls providing resistance to tidal flows catastrophically failed, ending controlled operations and necessitating tide gate operations without regulation, i.e., the gate was operated passively in what would be considered a “traditional manner.” In spite of this failed condition, design improvements (e.g., vertically hung, AKA “barn door,” design) outperformed the traditional top-hinged gate previously in place in terms of hydraulic exchange and temporal availability to aquatic species. This failed condition was also mitigated by the presence of the “screw gate” design at the FOR3E location.

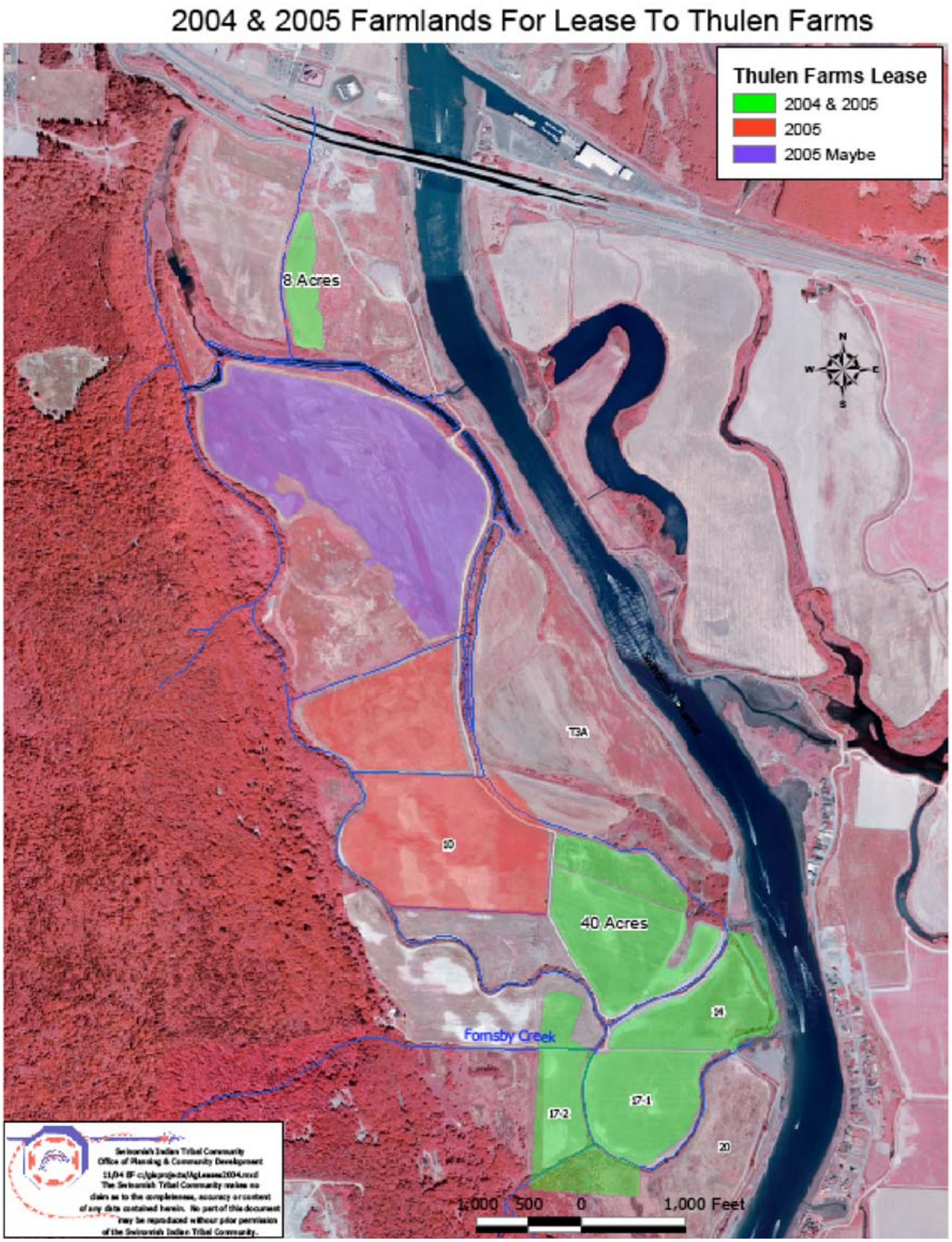


Figure 8. Agronomic activity.

Throughout this period of investigation, patterns of species colonization expressed by the vegetative community have been generally favorable. Saltwater-dependent species have predominated the targeted floodplain areas and few noxious weeds have been identified within these target zones (Greg Hood, personal communication). Passive colonization has been quite successful, and few, if any, invasive species (e.g., spartina) have been identified within the project site tidal floodplains. However, in bermed areas, we have seen some progression of undesirable thistle stands, which may pose a nuisance to agricultural operations and might necessitate mechanical or chemical treatment as the site matures. Control-site vegetation remains generally unchanged.

Fish utilization of the site has been monitored in both pre-project and post-project conditions. Albeit of limited scope, our results have been favorable. Species composition has changed as a result of project actions, including the use and occupation of the site by juvenile Chinook, as predicted. However, the extent and the magnitude of this colonization is unknown, due to the limited scope or our sampling and mechanical failures experienced at the end of the first year of operation.

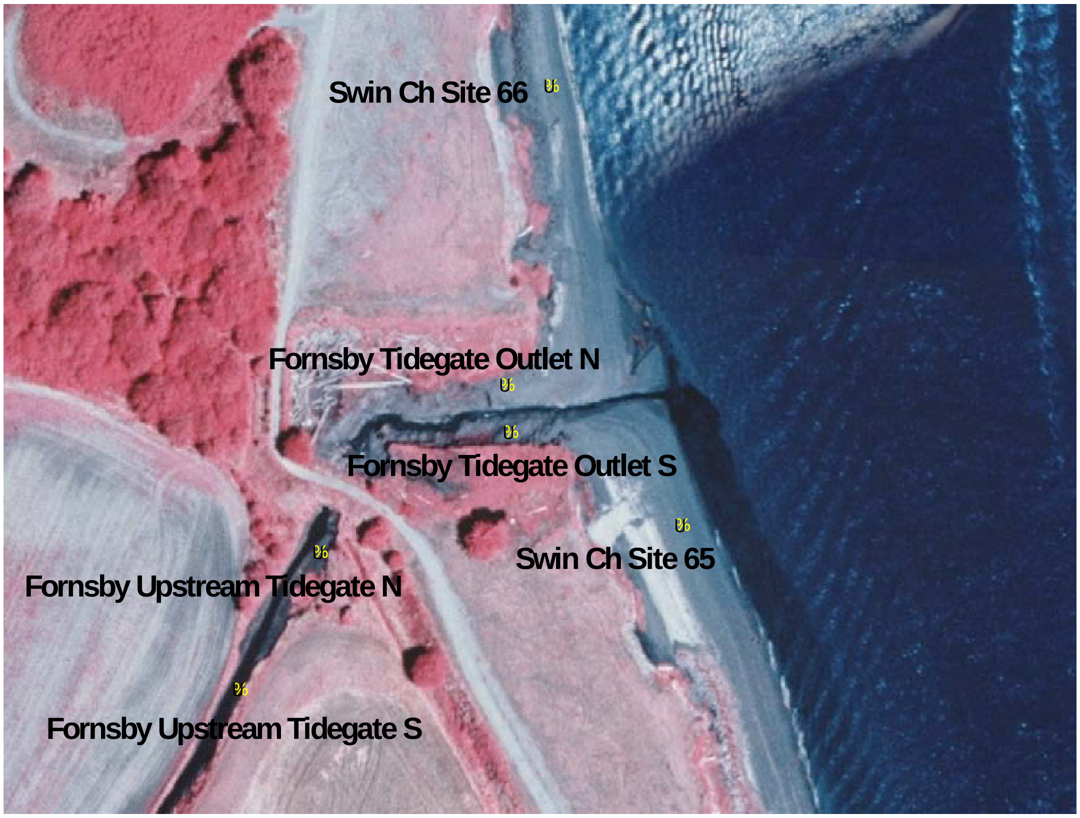


Figure 9. Beach seine monitoring locations.

Recommendations

Our initial evaluation of the project indicates that all objectives are at least being partially met. In some cases, results indicate that some objectives are being exceeded beyond expectations. However, resources for monitoring activities are limited and could be improved or expanded to address several aspects of the project that have been unanticipated. For example, the rapid occupation of the site by juvenile Dungeness crab was not predicted. However, this resource and its response to improved site conditions could be as critical as the project's contribution to salmonid recovery goals. Aquatic-dependent species and the habitats that are essential to sustaining their populations are at the heart of tribal management objectives.

This project clearly has an incredible story yet to tell. We believe this is a story that affects the region and future generations. If successful, we hope to see evidence that agricultural and fishery objectives are not mutually exclusive. This project seeks to inform that very question with specific, real-time data over a meaningful spatial and temporal scale. To that end, it is imperative that project monitoring is supported with the resources necessary to enable a statistically meaningful inquiry into the change and implications wrought by its implementation. To this end, the Swinomish tribal community will advocate for resources to continue the dedicated monitoring plan currently being implemented for no less than 10 years. Furthermore, we will advocate for expanded monitoring capacity for examination of a variety of aquatic species, including but not limited to all species of salmon, interdependent mammals, raptors, migratory waterfowl, shorebirds, crustaceans, and mollusks. Furthermore, we hope to expand our effort to examine agronomic variables such as yield by crop species, micro-climate effects, water table and water yield changes, and market implications.

Given the long history of how the Swinomish Channel has been managed both by indigenous peoples and subsequent settlers, we believe this project has significant implications for regional, if not global, resource managers. The Swinomish tribal community remains committed to finding resource-management solutions that look to future generations. This project is targeted toward the recovery of Chinook salmon, but it can, and will, provide extensive insight toward the compatibility of diverse resource-management objectives. The sustainability of fisheries and farming are not necessarily mutually exclusive. Toward this end, the Swinomish tribal community seeks to explore the ways and means by which tribal fishers can continue to farm the sea for the sustenance of generations, while cultural settlers can share the same resources to meet the ever-increasing demands of our growing populations.

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Fish Use and Water Quality in Select Channels Regulated by Tide Gates within the Snohomish River Estuary

Daniel M. Tonnes[1]

Lost and isolated estuarine habitat has been identified as a factor in diminished salmonid production in the Snohomish River (Haas and Collins 2001) and many other Puget Sound and Pacific coast rivers (Spence et al. 1996).[2] In the Snohomish River, tidal influence on much of the historic habitat is blocked from levees, dikes, tide gates, and other water-control structures. Conventional tide gates have no structural provisions to enhance water exchange or fish passage, and they reduce habitat connectivity through partial or complete blockage of fish passage, altered water chemistry composition through suppressed mixing of fresh and salt water. They also degrade water quality through thermal loading (Hanson et al. 2003). This pilot study of several channels within the Snohomish River estuary, in spring and summer 2003, was initiated to assist in addressing the paucity of data regarding how tide gates may affect fish distribution and habitat conditions. Water exchange within two of these channels is regulated by dike and tide gate systems, while the reference channel has no tidal regulation and is in near-historical condition.

Study sites included two blind channels regulated by conventional top-hinged tide gates, one located within Smith Island (termed the Smith channel) and one located within Ebey Island (named Deadman Slough), within the Snohomish River estuary. Both tide-gated channels have very little shade, and vegetation along channel banks is generally limited to reed canary grass and Himalayan blackberry. A blind channel located on Otter Island served as the reference site for the Smith Island channel fyke netting and as a water-quality reference site for both tide-gated channels. Otter Island is bordered by Ebey and Steamboat Sloughs, has not been altered by a levee system, and has extensive native tree and shrub and emergent vegetation communities. The channel has multiple pieces and accumulations of woody material and overhanging shrubs and trees. The reference site was chosen because of its intact condition and close proximity to the Smith Island and Deadman channels.

Fyke nets were used to sample for fish presence at each site. Fyke net use followed those described in Levy and Northcote (1982) and Hayman et al. (1996). An 1/8-inch knotless nylon net with an attached fyke tunnel 80 feet long and 10 feet high was used. The net was set across the outlet of the channel and fished throughout the ebbing tide. The net captured fish exiting each habitat area as the tide ebbed, and was deployed within one hour of high slack and fished to low slack, approximately five to seven hours. Fyke sampling occurred from March through June 2003, to coincide with the peak period of migration and rearing of juvenile salmonids within the estuary. Captured Chinook were

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anesthetized with MS222 in five-gallon buckets, and fork lengths were collected. Other fish were identified and enumerated to species without anesthetizing. Fish were then allowed to fully recover and volitionally leave sample buckets downstream of the site.

Water-quality data gathered at each site include data loggers that record temperatures every 30 minutes to one hour from March through September. Onset Hobo® temperature loggers were attached to rebar and placed near the bottom of each channel to maximize time they were covered with water. Loggers were not submerged into bottom substrates. In 2003, water temperatures were recorded within all sites. Specific conductivity (umhos) and salinity were measured at the waters surface at each sampling site, using a YSI Model 85 meter. Dissolved oxygen (DO) was measured with a YSI Model 518 meter at the water’s surface. Conductivity, salinity, and DO were measured at high and low tides. Dissolved oxygen, conductivity, and salinity were also recorded in Union Slough near the outlet of the Smith channel tide gate.

The March–May and June–September temperature data were analyzed separately. These periods were delineated due to distinct temperature regimes in terms of relative mean, maximum, and minimum temperatures. Juvenile salmonids occupy the Snohomish estuary throughout these time periods (Williams et al. 1975), and for purposes of analysis, temperature regimes within each channel were related to biologically relevant temperatures related to growth, stress, and lethality for juvenile Chinook and other salmonids.

Results

Fish abundance (with the exception of three-spine stickleback) and species richness were very limited within the tide-gated channel fyke net catches. A total of nine species of fish were collected within the tidally influenced channels, compared to three within the regulated waterways.

No salmonids were captured within the Smith blind channel behind the tidegate (Table 1). Simultaneous catches of salmonids within the Otter blind channel reference site ranged from 1 to 270 fish captured per sampling event. Three-spined stickleback (*Gasterosteus aculeatus*), was the only species captured within Smith, while non-salmonids captured within Otter included three-spine stickleback, starry flounder (*Platichthys stellatus*), and pea mouth chub (*Mylocheilus caurinus*).

Table 1. Reference (Otter) and Smith Fyke Catch Totals

Species	**Otter reference blind channel**	**Smith blind channel w/tide gate**
Chinook (*Oncorhynchus tshawytscha*)	44	0
Chum (*O. keta*)	774	0
Coho (*O. kisutch*)	17	0
Cutthroat (*O. clarki*)	1	0
Three-spine stickleback (*Gasterosteus aculeatus*)	16	418
Starry flounder (*Platichthys stellatus*)	2	0
Pea mouth chub (*Mylocheilus caurinus*)	20	0

A total of nine salmonids were captured within the fyke installed on the outlet of the tide-gated portion of Deadman Slough (Table 2). Simultaneous catches of salmonids within the tidally influenced portion of Deadman Slough ranged from one to 364 fish captured per sampling event. Three-spined stickleback was the only non-salmonid species captured exiting the Deadman tide gates, while three-spine stickleback and starry flounder were captured within the tidally influenced portion of Deadman Slough.

Table 2. Deadman Slough Fyke Catch Totals

Species	**Deadman Slough w/tidal influence**	**Deadman Slough w/tidegate**
Chinook (*Oncorhynchus tshawytscha*)	4	0
Chum (*O. keta*)	642	6
Coho (*O. kisutch*)	35	3
Cutthroat (*O. clarki*)	2	0
Steelhead (*O. mykiss*)	2	0
Three-spine stickleback (*Gasterosteus aculeatus*)	36	3
Starry flounder (*Platichthys stellatus*)	4	0

Temperature Results

The Otter Island reference channel had the lowest mean temperature throughout the March–September sampling period. From March through May, the Otter reference channel was an average of 1°C degree colder than Deadman, and 3.1°C colder than Smith.

Temperatures were recorded at the bottom of each channel. Due to possible temperature stratification, the recorded temperature regimes likely represent an aggregate of the coldest available temperatures within each channel. Armour (1991) reported that, if prey is available, growth of juvenile Chinook can occur between 4.5°C and 19.1°C. Temperatures between 19.1°C and 23°C can be generally characterized as stressful,[2] to salmonids, and from 23°C to 26°C as potentially lethal.[3]

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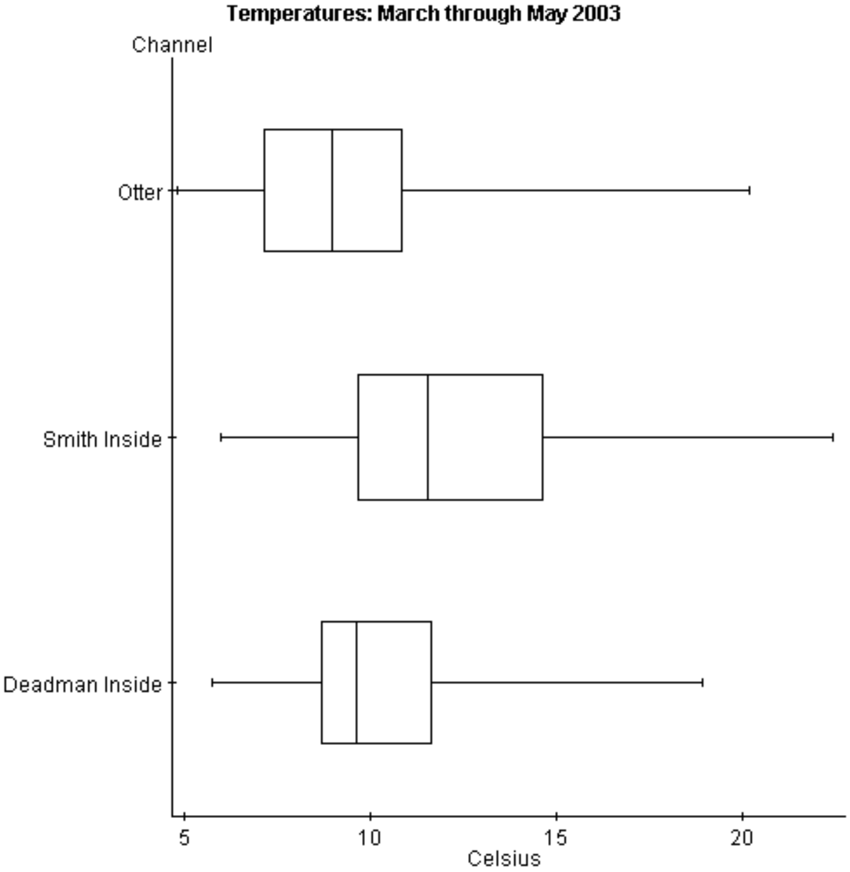
3. Stressful temperatures for juvenile salmonids may increase susceptibility to disease, reduce food conversion, etc., as summarized from McCullough et al. (1999).



Channel	Mean	Q1	Q3	Max	Min
Deadman	10.2	8.7	11.7	18.9	5.8
Smith	12.3	9.7	14.6	22.4	5.9
Otter reference channel	9.2	7.3	10.9	20.2	4.8

Figure 1. N: 4126. Deadman and Smith confidence intervals related to the Otter reference channel. Differences between means are all $p<0.0001$.

The Otter Island reference channel also had the lowest mean temperature throughout the June–September sampling period. From March through May, the Otter reference channel was an average of 0.7°C colder than Deadman, and 1.7°C colder than Smith.

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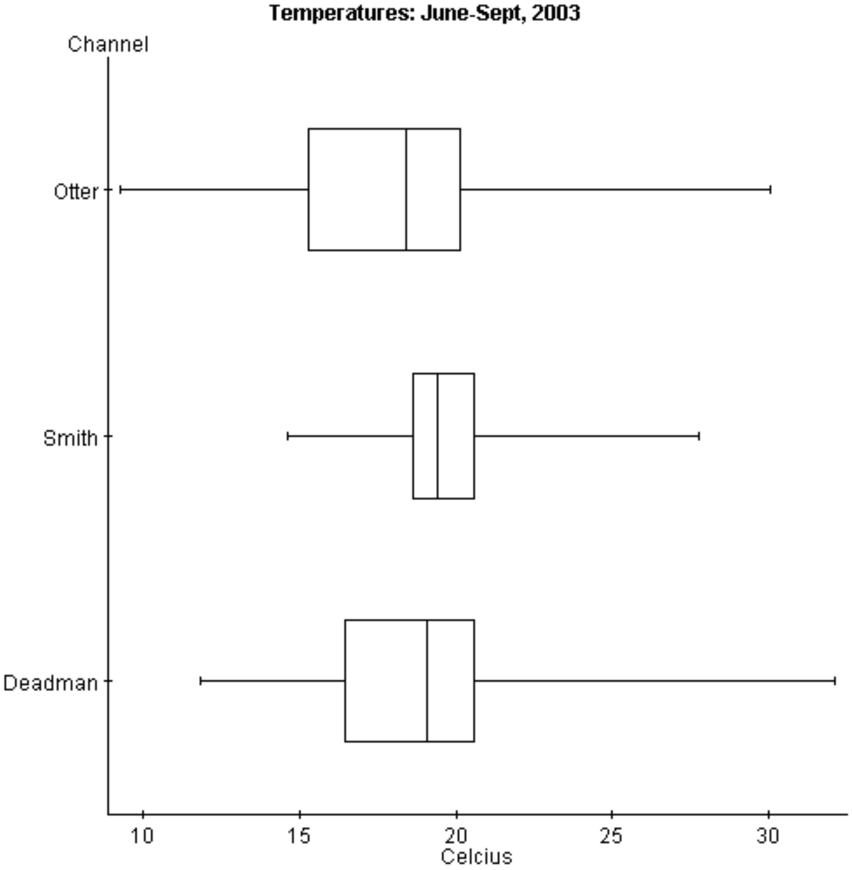
4. This temperature range may lead to death (juvenile salmonids), depending upon the acclimation temperatures prior to exposure, as well as the length of exposure, among other factors (EPA 2001).

Table 3. March–May Temperatures Related to Biological Response for Juvenile Chinook

Channel	**Lower Growth Boundary (4.5°C–10.0°C) % Time**	**Optimal Growth Boundary (10.0°C–15.6°C) % Time**	**Upper Growth Boundary (15.6°C–19°C) %Time**
Otter	64	35.3	0.007
Smith	31.1	49.5	19.9
Deadman	55.1	38.2	6.4



Channel	Mean	Q1	Q3	Max	Min
Deadman	18.6	16.4	20.6	32.1	11.8
Smith	19.6	18.6	20.6	27.7	14.6
Otter reference channel	17.9	15.3	20.1	30.1	9.2

Figure 2. N: 4172. Deadman and Smith confidence intervals related to the Otter reference channel. Differences between means are all $p<0.0001$.

Table 4. June–September Temperatures Related to Biological Response for Juvenile Chinook

Channel	Lower Growth Boundary (4.5°C–10.0°C) % Time	Optimal Growth Boundary (10.0°C–15.6°C) % Time	Upper Growth Boundary (15.6°C–19°C) % Time	Stressful (19°C–23°C) % Time	Potentially Lethal (23°C–26°C) % Time
Otter	1.6	27.0	32.5	38.9	0.1
Smith	0	0.02	36.4	57.9	5.7
Deadman	0	19.7	33.9	43.3	3.5

Temperature regimes within tidal channels can be influenced by a number of factors, including sun exposure/shade, width and depth of the channel, groundwater and hyporeic flow, and the amplitude and regularity of tidal exchange. Tide gates can influence temperature regimes through arresting tidal and river height exchange, which in turn decreases the wetted perimeter (and depth) of the channel. Indirectly, tide gates can enable land-use and management near regulated waterways that reduce or eliminate riparian vegetation that can provide shade. Though fish use of the tide-gated channels was limited to non-existent for all but one species at one site (three-spined stickleback within the Smith channel), temperature regimes in these channel remain biologically relevant; during ebbing tides, water drains out of these tide gates to shallow-water habitats that fish regularly occupy.

Conductivity, Salinity, and Dissolved Oxygen Results

Conductivity and salinity values within Smith increased through the sampling period.

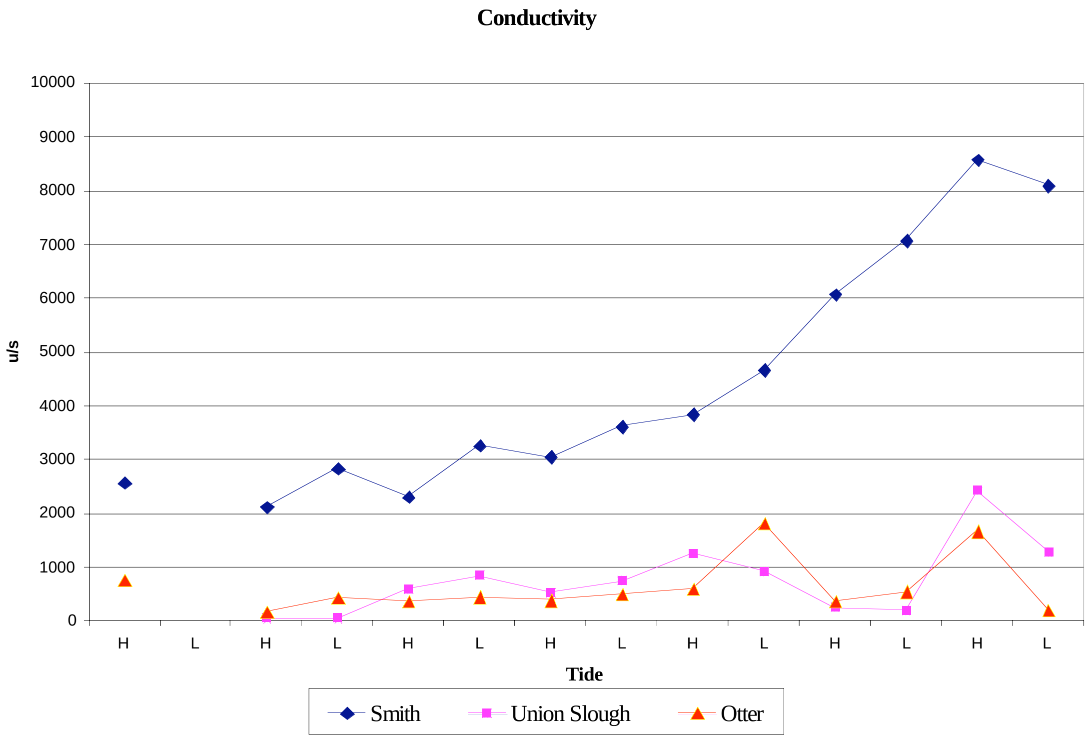


Figure 3. 2003 conductivity values. Differences between means of Smith and Union Slough, and Smith and Otter, are all p<0.0001.

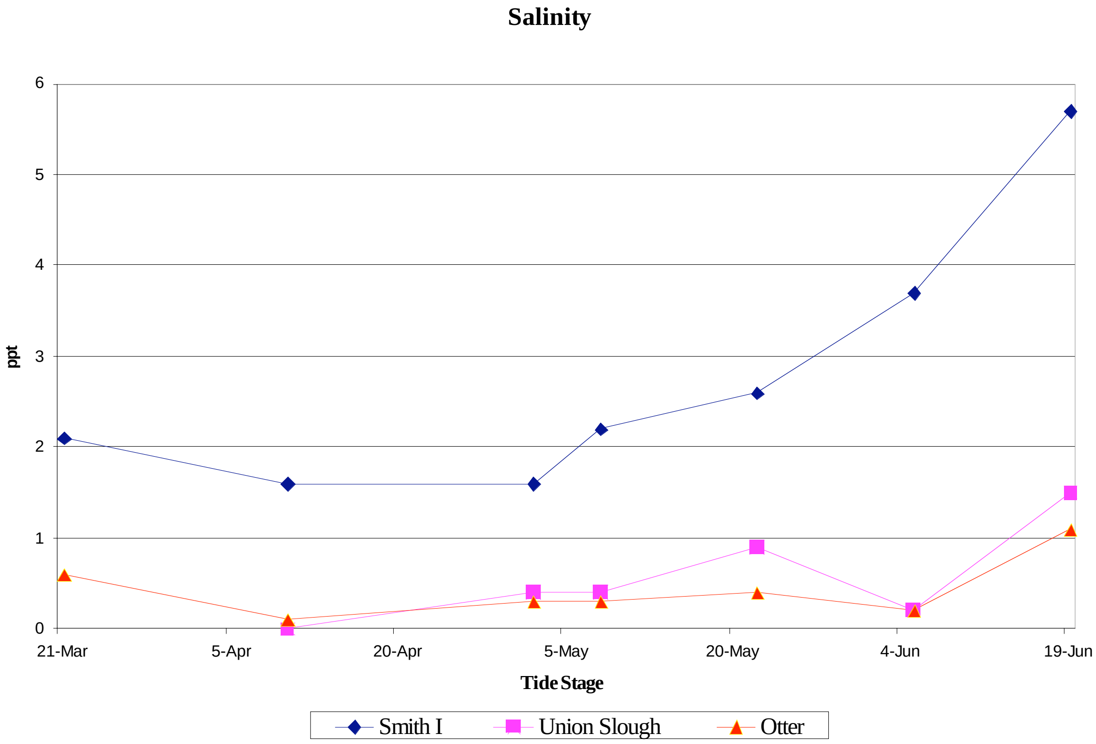


Figure 4. 2003 salinity values. Differences between means of Smith and Union Slough, and Smith and Otter, are all p<0.0001.

Dissolved Oxygen Results					
Channel	**Mean**	**Q1**	**Q3**	**Max**	**Min**
Smith	7.6	6.0	9.5	10.2	3.8
Otter reference channel	9.4	9.2	9.8	10.6	7.3

Figure 5. N: Smith 12 and Union: 10, Differences between means of Smith and the Otter reference channel is (p< 0.02). All values are mg/l.

Management Implications

Tidal dispersion is vital for juvenile salmonids, as it provides access to small channels and sand/mud flats. These areas can provide predation refuge (Simenstad and Miller 1997; Simenstad et al. 1983; McMahon and Holtby 1992) and access to a greater volume of habitat for feeding opportunities, while simultaneously reducing juvenile salmonid density and cohort competition for food. (Simenstad and Miller 1997; Neilson et al. 1985). Habitat restoration projects (such as dike breaching or tide gate removal or modification) and channel creation have improved water quality and enabled increased fish distribution in a number of estuaries (Beamer and LaRock 1998; Miller and Simenstad 1997; Ryan and Levings 1987; Levings and Nishimura 1997). Less is known about the biological and water quality responses after conventional tide gates are replaced with tide gates that are intended to enhance fish passage and tidal exchange. To partially reestablish habitat connectivity and attenuate poor water quality, the replacement of conventional tide gates with designs that increase tidal exchange may be necessary in areas where habitat access will improve rearing and/or spawning ground access, and in instances where flood protection and drainage need to be accommodated landward of the gate. In these circumstances, increasing tidal and river level exchange to facilitate enhanced juvenile and adult fish passage may in part attenuate and address possible poor water-quality conditions or abrupt temperature, DO, or salinity gradients between the inside and outside of the gate. However, careful project planning, monitoring, and adaptive management may be needed to ensure that water quality conditions and transitions are sufficient, that adequate passage conditions exist when the gate is open, and that the passage occurs during a long enough time period to provide sufficient habitat connectivity.

Future studies should explore a greater number of tide gate sites and channel types, as well as velocities and widths of openings. In addition, studies should also investigate passage affects to adult salmon that must traverse through tide gates to access spawning habitat. Depending upon their location and operation, tide gates may cause abrupt temperature, salinity, or dissolved oxygen transitions to fish moving through the structure. As such, monitoring of the severity of these parameters relative to tide gate design and operation is prudent. Analysis of new tide gates designed to enhance fish passage and tidal exchange is warranted. Water quality studies that further investigate possible stratification within natural channels and regulated channels could assist future tide gate project designs and performance standards.

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Oregon’s Fish-passage Requirements for Tide Gates

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History

Oregon has a long history of supporting fish passage at artificial structures.[2] The first fish-passage laws in Oregon were established prior to statehood in 1859, within the 1848 Oregon Territorial Constitution. Section 12 of the 1848 Oregon Territorial Constitution stated that:

> “The rivers and streams of water in said territory of Oregon in which salmon are found or to which they resort shall not be obstructed by dam or otherwise, unless such dams or obstructions are so constructed as to allow salmon to pass freely up and down such rivers and streams.”

Subsequent laws had essentially the same message: fish passage is required without exception. However, in many locations these laws were not followed. So, after several years of development, new fish-passage statutes were passed in 2001. These laws are generally found in Oregon Revised Statutes (ORS) 509.580 through 910. Follow-up administrative laws were passed in 2002, 2003, 2004, and 2006. These laws are found in Oregon Administrative Rules (OAR) chapter 635, division 412. The January 2006 administrative rules included new fish-passage criteria, which address tide gate requirements. In general, the intent of the new fish-passage laws is to reassert the importance of fish passage, but also incorporate collaboration and flexibility, especially in dealing with pre-existing artificial obstructions, some of which may have erroneously been allowed by the state without fish-passage provisions.

Current Applicability

Under the current laws, fish passage must be addressed at an artificial obstruction, including tide gates, in locations where native migratory fish are currently or were historically present and when a “trigger event” will occur. There are also other times that the Oregon Fish and Wildlife Commission (OFWC) can require fish passage at a site, but these are rarely (if ever) utilized because the cooperation, collaboration, and flexibility of the new laws have been effective to date.

“Trigger events” include construction, a fundamental change in permit status, or abandonment of an artificial obstruction, with construction being the primary trigger event that applies to tide gates. Construction includes the installation of new tide gates, the complete replacement of existing tide gates, and repairs to existing tide gates that, through time, add up to over 50 percent of the gate material. The structure upon which

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[1] Oregon Department of Fish and Wildlife

[2] Disclaimer: This report does not address other agencies’ requirements or needs.

the gate is fitted is also included in the 50 percent measure, as long as it is not a road-stream crossing (i.e., culvert). "Trigger events" for roads and culverts are separate.

Fish passage must be addressed with the Oregon Department of Fish and Wildlife (ODFW), or in some cases the OFWC, prior to a "trigger event." Options for addressing fish passage include:

a. *Providing fish passage.* ODFW must approve a fish-passage plan prior to implementation. This typically occurs on a site-by-site basis, but for those involved with a large number of artificial obstructions, a programmatic approval and agreement may be provided.

b. *Obtaining a waiver.* Waivers are used for situations where providing fish passage would benefit native migratory fish under current conditions. If passage will not be provided at a site, then mitigation, which is a net benefit to native migratory fish, must be provided. The amount of mitigation may be reduced if there is some level of partial passage at the site in question. In other words, if full passage criteria cannot be met, the benefit of providing partial passage for native migratory fish may still be claimed, to the benefit of the owner/operator. Since there is typically some level of fish passage at many tide gates, those that do not meet full ODFW criteria will likely have a reduced level of mitigation needed when they are in a waiver situation. Waivers remain in effect until the next trigger event, which in most cases is indefinitely.

c. *Obtaining an exemption.* Exemptions are used primarily for situations where there would be no benefit to providing fish passage at a site due to the current conditions. The presence of other barriers and/or degraded habitat is a typical reason for obtaining an exemption. No mitigation is needed for an exemption, but if the benefit of providing passage changes (e.g., barriers are removed or habitat improves), exemptions may be revoked and passage must be addressed at that time.

d. *Obtaining a deferral for a structural emergency that may affect human safety.* If an artificial obstruction has created an urgent or emergency situation where human safety may be impacted, ODFW may allow a deferral to addressing fish passage until a later date. Typically, passage is deferred only until the end of the next in-water work period, but this decision is made at the discretion of the approving biologist. At the end of the deferral period, some form of fish-passage approval must be obtained (i.e., passage plan is approved, a waiver is obtained, or an exemption is obtained).

These options provide considerable flexibility in fish-passage approval. Even though there is some process involved, social needs such as limiting flood events can be accomplished while still addressing fish passage.

Note that the separation of tide gate and culvert triggers is in place because, in many cases, tide gates and culverts have different owners and/or operators; legally, triggers include individual artificial obstructions, which are defined by ownership or operation. This means that only the triggering structure needs to address fish passage, which prevents one owner/operator's actions from legally involving another owner/operator in the costs and requirements of fish passage. However, it does cause some practical passage questions when separately owned artificial obstructions are connected, such as with tide gates. With tide gates, the main issue with replacing either the tide gate or the culvert without addressing passage at the other structure is one of size: what is needed for fish passage may or may not differ from the current size of the structure. Thus, the structure that is not triggering the law may be of a different size than the replacement for the other structure, which can present a mechanical problem since these structures are typically sized to fit together. Options to deal with this issue include:

a. *Obtaining an exemption.* The exemption would be obtained for the structure triggering the law, which would be replaced in kind so the other structure not triggering the law can still be used. When the structure not triggering the law does trigger it in the future, both structures would then be replaced to fish-passage standards. Absent other reasons for an exemption, this scenario assumes that the structure not triggering the law does not provide fish passage, which would be the basis for the exemption of the triggering structure.

b. *Obtaining a waiver.* The waiver would be for the structure triggering the law, requiring mitigation. This scenario assumes that the structure not triggering the law does provide fish passage andthat there are no other justifications for an exemption.

c. *Devising and installing an adapter.* The adapter would make a union between the two differing-sized structures until the structure not triggering the law does so and is replaced with one of an appropriate fish-passage size.

d. *Providing passage at both.* This entails voluntarily replacing the structure that is not triggering the law. Because there is no legal requirement to do so, grant funds may be available for replacement of the voluntary structure. In the long run, this may be the most practical and least-expensive solution.

Finally, when a fish-passage structure is installed, it is required by law to maintain passage at that site. In addition, if mitigation is provided instead, that mitigation must also be maintained for the life of the waiver. Maintenance includes monitoring the structure to ensure it is functioning as designed and approved, operating the structure if needed, and repairing it to keep it in good working condition. Relative to tide gates, this mostly applies to mechanical assistance devices used for opening or keeping open the gate (e.g., floats, hydraulics, cams, and secondary doors), which need to be cleaned and kept functional and mobile.

Criteria

When fish passage is being provided at a tide gate, ODFW will determine the native migratory fish species, life history stages, and period requiring passage. This survey will affect the exact hydraulic criteria described later that need to be met. If fish passage will still be provided, ODFW may also allow exceptions (different from exemptions) to criteria noted below, on a site-specific basis. ODFW will coordinate passage requirements on a site-specific basis with any federal requirements that also apply to the site. Water control, impacts to fish, and passage will also need to be addressed on a site-specific basis during the construction period for tide gates and associated structures.

For specific tide gate criteria, ODFW distinguishes between situations where there is a stream upstream of the tide gate and where there is not. For situations where there is a stream, upstream and downstream passage must be considered. ODFW's criteria for sites with streams are based on fish needs, rather than structure details. A simple way to translate these fish needs into structure criteria has not yet been developed, but the requirement is being considered. ODFW criteria for tide gates for locations with streams are:

a. Tide gates shall be a minimum of four feet wide, and

b. Tide gates shall meet hydraulic criteria within the design streamflow range and an average of at least 51 percent of tidal cycles, excluding periods when the channel is not passable under natural conditions.

Hydrologic and hydraulic analyses should be completed to show whether passage is being provided 51 percent of the time. Fifty-one percent was chosen to increase the probability that tide gates are open for some portion of flood tides, in addition to slack and ebb tides. Also note that this percentage of time when passage is required is not only for situations when the tide gate is open. Thus, it is a different measure than the percentage of time passable when open that the National Marine Fisheries Service (NMFS) has discussed.

The amount of time fish passage is being provided in an average daily tidal cycle[3] at the high and low fish passage design flows (or stream conditions) should be calculated. The high and low fish-passage design flows are defined as the mean daily average discharges from the stream that are exceeded by 5 or 95 percent respectively, of the time during the period when ODFW requires fish passage at a given location. The conditions that should be met for passage during this time include: (1) the tide gate should be open at least 12 inches, (2) the hydraulic drop across the gate should not exceed six inches, or 12 inches if

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[3] Using the mean higher-high, lower-high, lower-low, and higher-low waters.

only adult salmon or steelhead require passage, (3) water velocity through the gate should not exceed eight feet per second (fps), and (3) a jump pool of at least two feet in depth should be present if there is a hydraulic drop across the gate. The jump pool should have sufficient volume to dissipate enough energy to allow a non-turbulent approach to the drop. In addition, if a culvert is associated with the tide gate and passage is being addressed at it, the water velocity in the culvert should not exceed 2 fps and the water depth should be a minimum of 12 inches, or six inches if only juveniles require passage. In some cases, this requirement may reduce passage time relative to the minimum four-foot wide opening for tide gates, and exceptions to this criteria will be allowed.

In locations where there is no stream present above the tide gate, the primary concern is with fish egress (i.e., seaward) from the protected area. Water quality in these areas is also potentially poor, exacerbating the need for fish egress. In these situations, pooling (depressions) within the protected area should be limited, so there should be a wetted connection with four inches of water depth back to the estuary when the area is draining. Upstream passage may be needed if there is any fish habitat landward of the tide gate. Additional requirements for egress flows exist for locations where water is intentionally being impounded landward of a water-control structure, such as a “reverse tide gate.”

Guidance and Next Steps

ODFW realizes that completion and funding of the extensive hydrologic and hydraulic analyses necessary will be a burden, especially for private landowners. ODFW also realizes that inconsistencies with NMFS criteria may cause confusion. Therefore, ODFW intends to develop guidelines and/or tools in conjunction with NMFS that, if met, will take the place of demonstrating the requirement of allowing passage 51 percent of the time.

When developed, these guidelines will be available on ODFW’s fish-passage Web site (http://www.dfw.state.or.us/fish/passage/). In addition, a fish-passage plan application for tide gates needs to be developed that people can use to provide ODFW the necessary information for making an approval decision for a specific site’s passage plan. Currently, the Web site contains a process overview, a passage application for road-stream crossings, and waiver and exemption applications.

For further information, ODFW’s Fish-passage Coordinator can be contacted at 503-947-6228. ODFW district fish biologists can also be contacted at ODFW’s local field offices.

Using HEC-RAS 3.1.3 to Model and Design Tide Gate Systems

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Abstract

As estuary restoration progresses, it is impossible to overlook the importance of proper tide gate design. Most tide gates in use today are broken, ill-fitting, or do not function to meet current design criteria for fish passage. Habitat and marine life standards and issues must be taken into account when designing these in-stream structures. Pursuant to this task, NOAA engineers and biologists have developed a set of design criteria for fish passage at tide gates, modeled on NOAA's draft culvert criteria. These criteria are still in the writing process and have not been rigorously used or tested yet. Numerical modeling programs such as HEC-RAS 3.1.3 can be used to accurately model tide gates in estuarine systems. A representative test set of tide gate scenarios and tidal data was run in HEC-RAS to examine differences in hydraulic characteristics. The results showed that for the scenarios tested, NOAA criteria could be simultaneously satisfied only about 10 to 50 percent of the time the gate was open. This was demonstrated by a case study performed by West Consultants on Kentuck Slough near Coos Bay, Oregon. The modeling also indicates that the percent time passable may be increased by improving the hydraulic efficiencies in the culvert inlet, exit, and in the tide gate opening.

Introduction

Tide gates have been used for hundreds of years as a means to drain fields and improve farming along coastal regions. Tide gates not only improve soil quality and usability for farming but also increase the amount of farmable land. Unfortunately, this practice has devastating effects on marine life and habitat in estuarine zones.

It is therefore necessary to design tide gates to meet farmers' needs while minimizing the negative impact on the native species inhabiting the land. The purpose of this research was to examine a particular tide gate scenario over a range of flows and geometries to determine whether there is a concise, efficient, numerical method for determining tide gate design parameters for a wide range of systems, using general physical and hydrologic data.

The results were evaluated for optimal tide gate sizing for a given tidal basin that best meets the needs of the landowner and the environment, while remaining in step with NOAA criteria. A case study done by West Consultants on Kentuck Slough in Coos Bay, Oregon, is included to illustrate the usefulness of this type of numerical modeling in tidal systems.

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NOAA criteria are currently being drafted but are in use internally. The tide gate-culvert system is considered “fish passable” when the following criteria are met for 90 percent of the time the tide gate is open:

- Velocity in the culvert < 1 ft/s
- Water surface drop across tide gate < 0.5 ft (for juvenile passage) or < 1ft (adult passage)
- Depth in culvert > 1ft

The tide gate is considered “open” when it is open 1.5 feet or more. For more details on the criteria and additional measures that should be taken, consult the NMFS draft fish passage criteria document.

Development

HEC-RAS vs. Visual Basic

Initial development involved writing an unsteady one-dimensional flow program in Visual Basic to describe the hydraulic conditions surrounding the tide gate. This method was chosen based on its wide availability, its ease of use, and its common applications.

The program that was proposed would be specific to tide gate hydraulics, tide gate culvert interactions, and estuarine systems. However, it was simplistic in its applications and narrow in its scope. In addition, the coding required to utilize unsteady equations would have required more time and resources than the project would have allowed.

The U.S. Army Corps of Engineers (USACE) program HEC-RAS (Hydrologic Engineering Center River Analysis System) version 3.1.3 is a one-dimensional flow analysis system that has the capabilities for unsteady flow modeling. It was chosen for this project based on its versatility, wide availability, flexibility, and efficiency. However, RAS is not currently set up to handle tide gates specifically. The program was utilized in a way to simulate a tide gate system to the best of its capabilities.

HEC-RAS can examine both steady and unsteady flow circumstances. Because this project requires flow inputs from both upstream and downstream, the unsteady features were used. In this mode, RAS can handle both temporal and spatial variations in flow simultaneously.

Unsteady flow is governed by conservation of mass and momentum. It can be shown that the differential forms of these fundamental equations are as follows:

Continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0$$

Momentum equation

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0$$

Where Q denotes flow, A is total flow area, q_l denotes lateral inflow, S_f is friction slope, and g is acceleration due to gravity. The continuity equation states that the net rate of flow into a control volume is equal to the rate of change of storage inside that control volume. The momentum equation is similar in concept, and states that the net rate of momentum entering the control volume, plus the sum of all external forces on the control volume, is equal to the rate of accumulation of momentum. Together, these equations are known as the St. Venant equations, and can be rearranged and simplified:

$$S_f = S_o - \frac{\partial h}{\partial x} - \frac{\overline{u}}{g}\frac{\partial \overline{u}}{\partial x} - \frac{1}{g}\frac{\partial \overline{u}}{\partial t} + \frac{\hat{q}_l}{gA}(\overline{u} - u_l)$$

In this equation, u denotes channel velocity and S_o is bedslope. This equation defines the energy grade slope, the bed slope, the pressure gradient due to backwater, the velocity head gradient due to backwater and changes in channel width, the local acceleration, and external momentum. All of these terms are important in the development of unsteady flow models, and are quite complex to implement. HEC-RAS was coded to utilize linearized finite difference approximations of these equations. The theoretical basis for unsteady flow is described in more detail in the Hydraulic Reference Manual put out by the USACE.

Trials

For this study, a tide gate system, which consists of an underground culvert (usually situated under a roadway) and a tide gate, was simulated. A long, narrow, open channel with a lid was used as the closed square culvert. A single side-hinged tide gate was represented by a vertical sluice gate at the center of a very wide dike at the outlet of the culvert. The estuary was represented just downstream of the tide gate as a very wide channel. The channel upstream of the culvert was described as a long rectangular channel. The setup was modeled similarly to the Kentuck Slough case study presented in a later section (Figure 1).

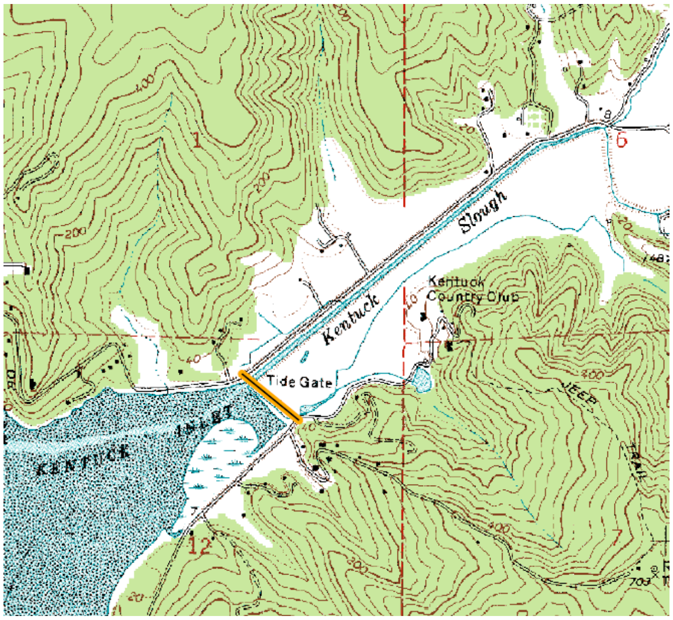


Figure 1. USGS topographical map of Kentuck Slough near Coos Bay, Oregon.

HEC-RAS was run for many scenarios, which varied the dimensions of the culvert and tide gate and of the upland channel (Table 1). These dimensions were chosen to represent a fairly wide variety of situations and to create a broad perspective.

	upland basin			Gate Dimensions				
Run	**L**	**W**	**S**	**w**	**h**	**Tide Start**	**Tide Min**	***Notes***
1	30000	50	0.0005	6	4	4.5	-0.228	*Original runs*
		100	0.0002	9	6			
		200	0.0001	12	8			
2	30000	50	0.0005	6	4	2	-0.228	*Original runs with tide cycle shifted to start at 2 feet and ebbing*
		100	0.0002	9	6			
		200	0.0001	12	8			
3	30000	50	0.0005	0.38(w/W1)	8	2	-0.228	*Same as #2, with gate changes to reflect an estimation of what will produce 0.5-ft or less of headloss*
		100	0.0002	0.54(w/W2)	8			
		200	0.0001	0.73(w/W3)	8			
4	5280	50	0.0001	6	4	2	-0.228	*Same as #2 with shorter channel length*
		100		9	6			
		200		12	8			
5	30000	50	0.0001	W	8	2	-0.228	*Same as #2 with gate widths equivalent to respective channel widths*
		100						
		200						
6	5280	50	0.0001	n/a	n/a	2	-0.228	*A natural state model (no structure)*
7	30000	50	0.0001	6	4	2	1	*Same as #2, with tide cycle cutting off at 1ft.*
		100		9	6			
		200		12	8			

Table 1. Compilation of physical variations used in study. *L* is upland channel length, *W* is upland channel width, *S* is upland channel slope, *w* is gate width, and *h* is gate height. For example, for Run 1, three different upland widths and slopes yielded nine runs, each with three different gate dimensions, totaling 27 different scenarios.

Additional inputs included a Manning's *n* value for the upland channel of 0.05, a discharge coefficient for the side-hinged gate of 0.7, a culvert length of 50 feet, a distance from the gate to the tidal data station of 20 feet, and a gate perch height of 0.5 feet. "Perch height" is the vertical distance from the base of the culvert to the bed of the estuary-side channel. Generally, this is to be no more than six inches. These values were consistent for each trial.

A small representative inflow (1cfs) was used as the upland inflow to keep the program stable. In real-life scenarios, an input hydrograph would be useful to simulate normal storm conditions for the modeled region. The tidal cycle used was that of Coos Bay for two days in August of 2006 (Figure 2).

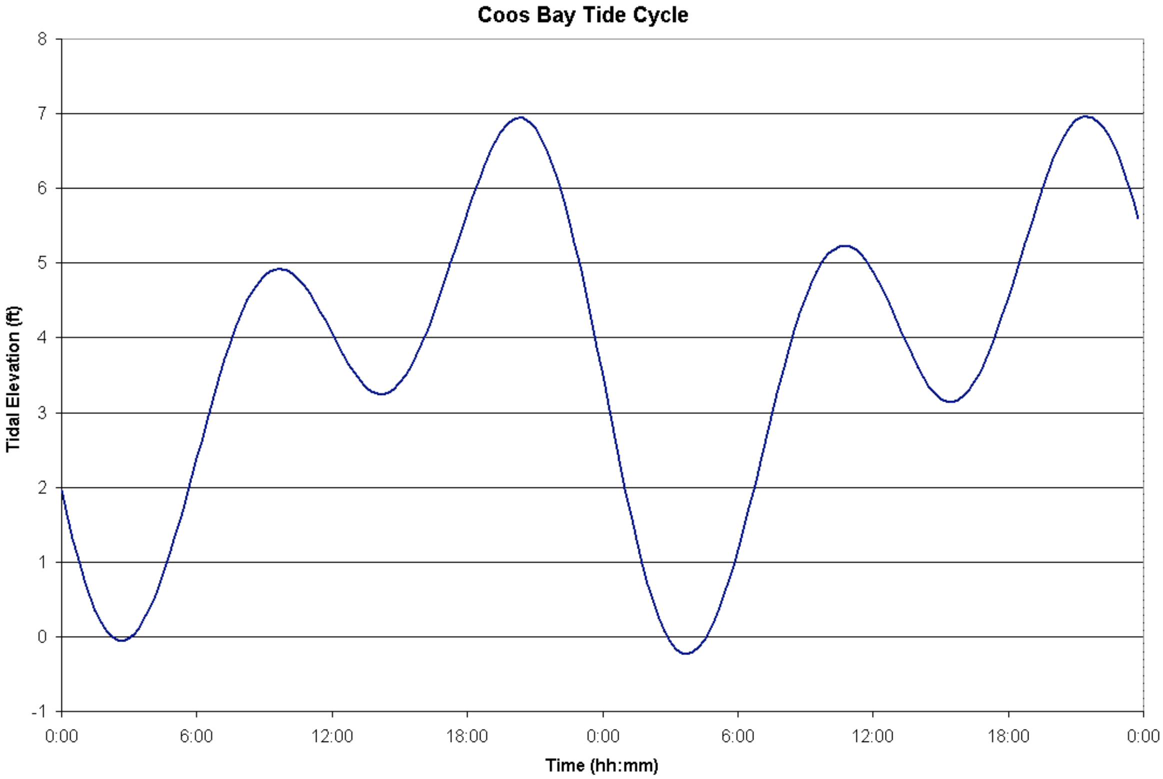


Figure 2. A 48-hour tidal cycle at Coos Bay, Oregon, used for HEC-RAS runs.

Gate control was a challenge, as HEC-RAS currently has only limited capabilities in this area. A two-phase approach was taken to meet the desire of multi-criteria functionality of the gates. Initially, the model was set to run based on water surface difference (upland to bay). In other words, when the upland elevation was higher than the bay (positive head), the gates would be opened and would remain open until the bay elevation exceeded the upland elevation (negative head), at which point the gates would close. This worked quite nicely in the modeling effort. However, it was also desirable to have the gates remain open even under negative head until the upland elevation reached a set design tide inundation elevation (DTIE) of two feet (typical value for this type of system). This provides additional fish passage time as well as an opportunity for saline bay water to mix with the fresh slough water. To accomplish this type of gate operation, the first-phase gate openings were exported from the output data of HEC-RAS to a spreadsheet. In that spreadsheet, the gate openings were manually adjusted so that they remained open until the upland water surface hit its target. Then that gate opening schedule was imported to

HEC-RAS as a time-series gate opening scheme for the second phase. By changing the gate opening times, the rates of filling and emptying of the upland changed. Therefore, two or three trial-and-error runs were required to hit the target mark.

Results

The simulations were run for 48-hour tidal cycles, and the results were imported into spreadsheets where the gate water-surface drop, culvert velocity, and water-surface elevations were analyzed and plotted. Temporal velocity and water-surface drop relationships were analyzed to define the points where maximum drop and velocity occur (Figures 3 and 4).

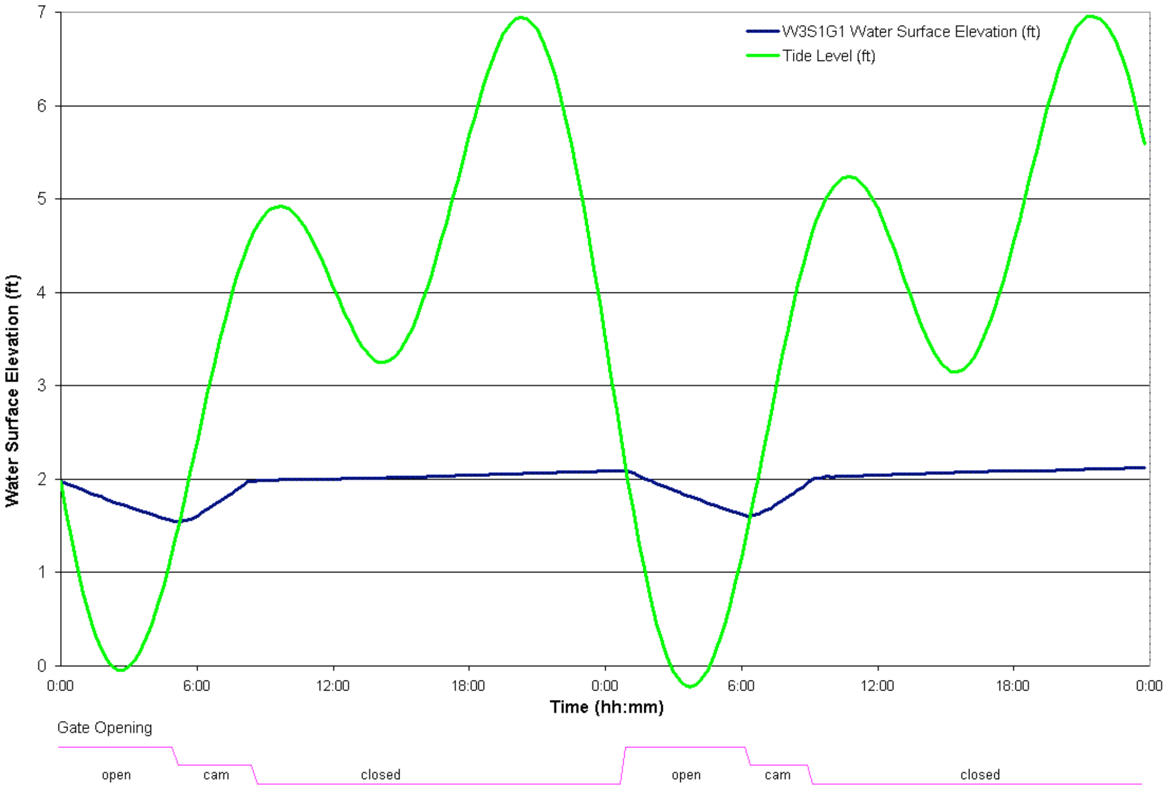


Figure 3. Upland and tidal depths for run W3S1G1. DTIE for these runs was set at two feet. The naming system for each file denotes the width, slope, and gate number of the test. W3S1G1 stands for a 200-foot wide channel with a slope of .0005 and a gate width of six feet. Upland depths were taken at the station 60 feet upstream of the culvert.

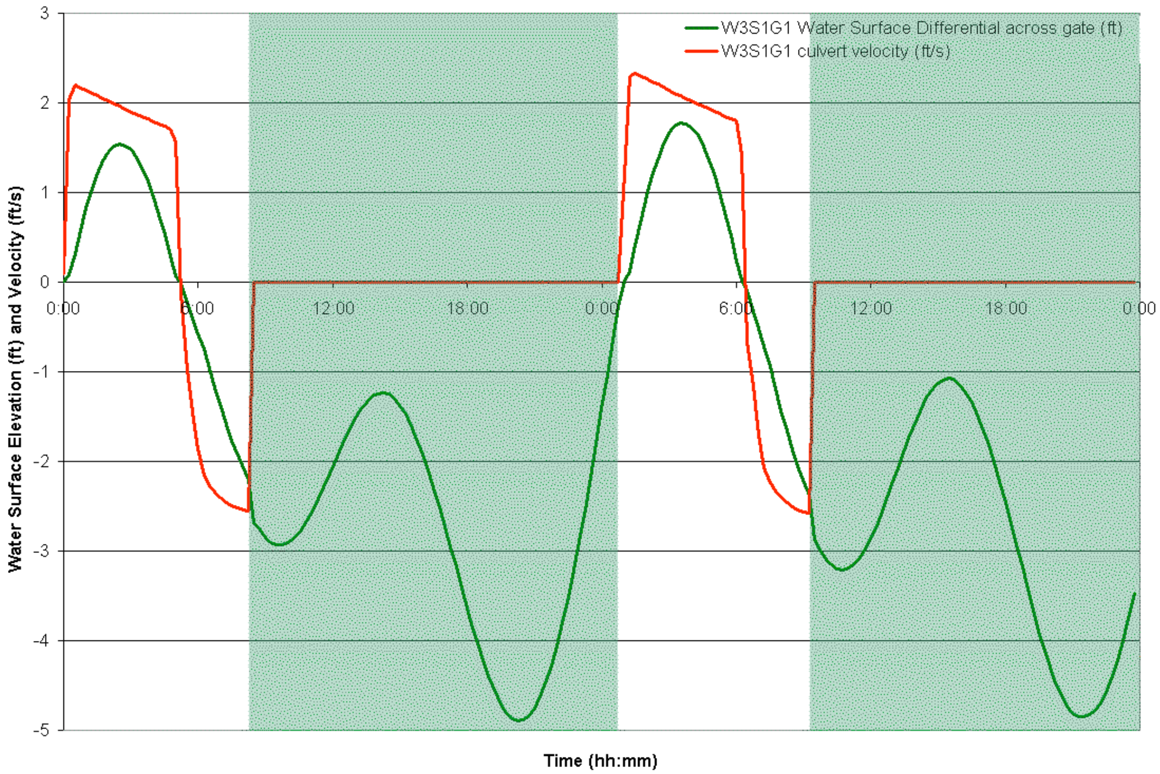


Figure 4. Velocity and water surface drop over a 48-hour period for run W3S1G1. Negative velocity values indicate flow moving upland due to a flooding tide. Negative drop indicates tidal value higher than upland value. The green shaded area indicates times when the tide gate is closed and the water surface differential is irrelevant.

Relationships between gate dimensions, upland channel dimensions, and the percent time passable were developed in Figure 5. The red box indicates the range of percent time passable values that were modeled in the Kentuck Slough case study, detailed in a later section.

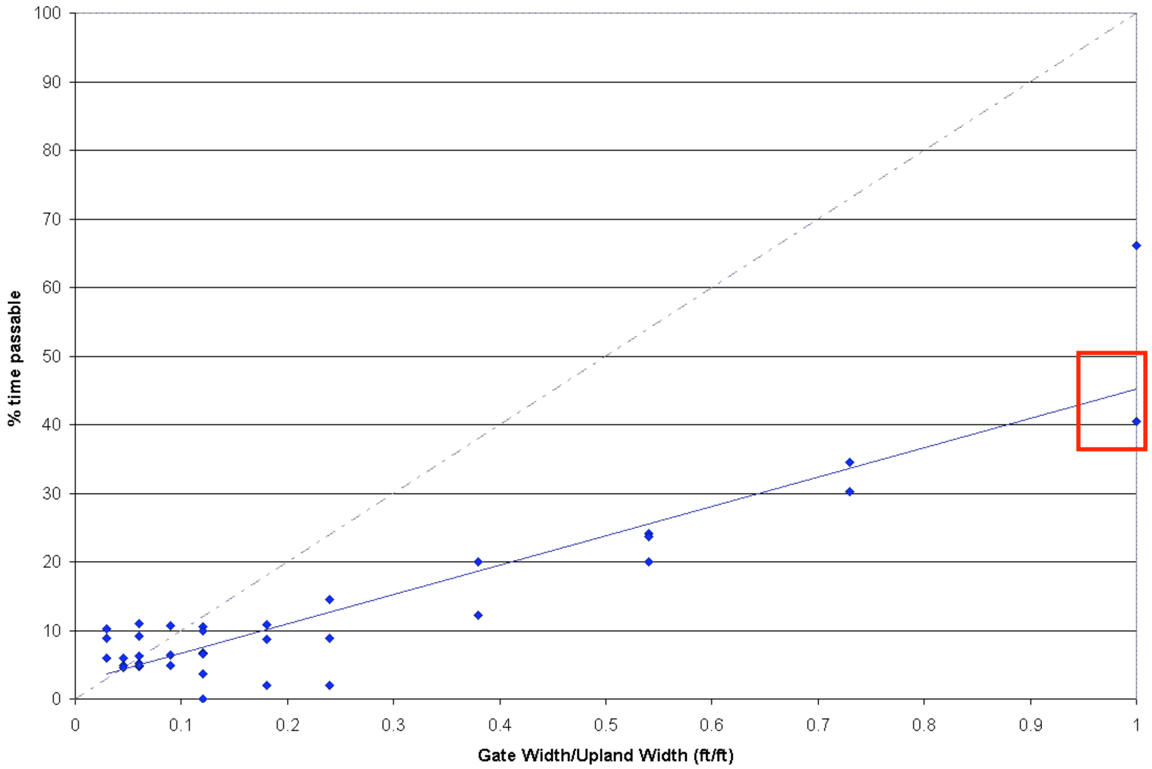
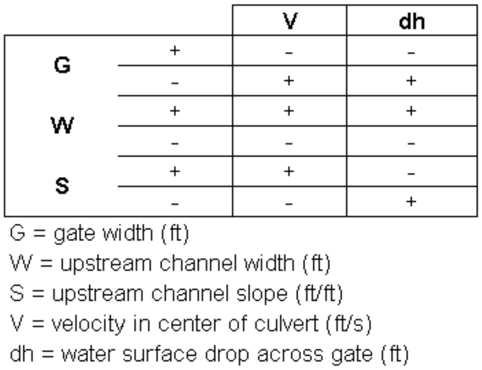


Figure 5. The relationship between gate width and upland channel width proved to be the most useful ratio when determining the trend for characteristics affecting percent time passable conditions. The red box indicates the range of values Kentuck Slough modeling produced. In a theoretical, frictionless, perfect system, the grey dotted line indicates a 1:1 relationship between the geometry ratio and the percent time passable.

From the trend line fitting the data in Figure 3, it is clear that 90 percent time passable is not possible in this scenario. Even if the gate is as wide as the upland channel, inherent losses due to the structure itself will not allow criteria to be met 90 percent of the time the gate is open. This type of effect has been seen in other hydraulic situations, such as box culverts and bridges. This effect is also seen in the Kentuck Slough, shown in red. The gates for Kentuck Slough have nearly as much cross-sectional area as the channel itself. However, due to inherent losses in the structure, passage criteria are compromised.

Changes in upland channel width, upland slope, and tide gate dimensions were varied to examine changes in culvert velocity and water-surface differential across the gate (Table 2).



		V	dh
G	+	-	-
	-	+	+
W	+	+	+
	-	-	-
S	+	+	-
	-	-	+

G = gate width (ft)
W = upstream channel width (ft)
S = upstream channel slope (ft/ft)
V = velocity in center of culvert (ft/s)
dh = water surface drop across gate (ft)

Table 2. Relationships between gate dimensions and upland channel dimensions are shown with respect to velocity and water-surface differential through the culvert.

The geometry and hydrology for this research were chosen to be very simplistic so that the results can be widely applied. However, for each individual tide gate design, it would be beneficial for the designer to model the targeted site in HEC-RAS to determine what percent time passable can be reached. Design data that may be taken into account when developing a model for the site include, but are not limited to:

- Tide cycle data
- Distance from gate to location of tide cycle data
- Gate size/shape/number
- Gate perch height
- Gate cam closure angle
- Allowed upland inundation elevation
- Upland inflow hydrograph
- Upland basin type (e.g., stream channel, slough with inflow, slackwater)
- Upland channel dimensions
- Networks of water bodies, networks of gates
- Manning’s *n* values
- Discharge coefficient values for the gates

Limitations and Error

HEC-RAS has several limitations in this application. The simulated tide gate system is not a direct representation of actual conditions. The side-hinged tide gate, in reality, has three-dimensional flow components, but it is represented in RAS as one-dimensional flow. The vertical sluice gate being used to represent the tide gate removes another degree of accuracy, as the gates have different mechanical operations, and only one discharge coefficient may be specified over the span of openings.

The upland channel in this case is a long, narrow, rectangular channel. For many applications, this is not a realistic shape. As the upland inundation elevation increases, this issue becomes more important. For this study, however, the upland inundation elevation was only two feet, which usually does not break onto the floodplain, so a rectangular channel was an acceptable design.

One of the most important inputs into this program is the discharge coefficient for the tide gate. Currently, only one discharge coefficient may be specified for the entire span of openings. To date, no studies have been done to estimate the discharge coefficients for side- and top-hinged tide gates during both ebbing and flooding tides. It was therefore estimated using the RMA2 model at West Consultants. For this project, it was set at 0.7 for each gate, which was an average value modeled for this type of gate. Future research and lab testing of different types of tide gates will yield more-accurate discharge coefficients for each application.

Case Study

Kentuck Slough Bridge, in Coos Bay, Oregon, is currently under replacement construction. Included in the reconstruction efforts is the installation of new tide gates to replace the old standard, top-hinged style gates. The new gates are vertically hinged and open like a door. They are designed to meet current federal and state fisheries standards, which provide for maximum interaction time between the slough and the bay while keeping velocities at a passable level for the resident fish species, as well as protecting the private lands adjacent to the slough. West Consultants in Salem, Oregon, developed the hydraulic design for Kentuck Slough Bridge.

Data Collection/Calibration

Field data were collected in an effort to understand the existing hydrologic conditions at Kentuck Slough, as well as to calibrate the HEC-RAS model. In this case, a crew spent two days taking flow and stage measurements upstream and downstream of the tide gates and at the upstream end of the slough. The HEC-RAS model was then constructed with cross sections defining the slough, an inline structure to define the bridge and tide gates, and the bay as the downstream tidal boundary. By adjusting the coefficient of discharge of the vertical-lift gates in the model, the performance of the existing top-hinged tide gates was simulated quite well (Figure 6). The opening times of the tide gates, known from the data-collection effort, could be programmed directly into the model as time-series data. This step was important because it indicated that the complex hydraulics of a leaky top-hinged gate could be adequately simulated in HEC-RAS using a vertical-lift gate with an adjustment of the discharge coefficient.

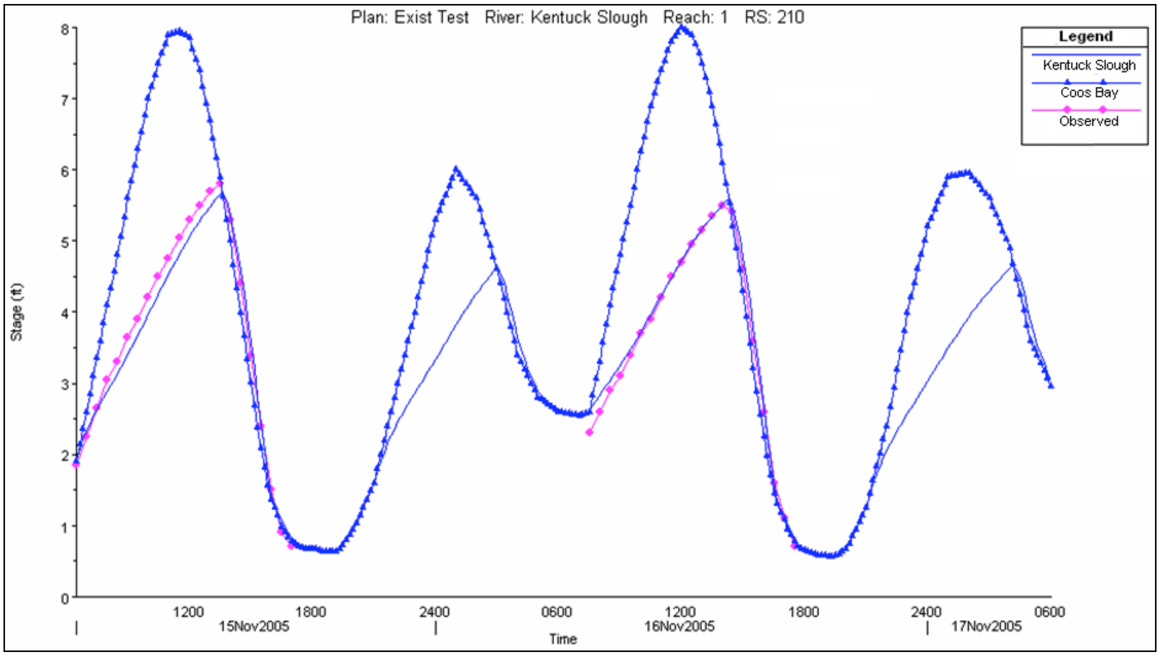


Figure 6. Comparison of observed and computed water surface elevations in Kentuck Slough.

Proposed Gates

A standard vertical lift gate was used to hydraulically model the proposed side-hinged gate design in HEC-RAS. Because no calibration data were available, the discharge coefficient was approximated, based on a two-dimensional computational flume test run with RMA2, a two-dimensional, finite-element hydraulic model. The model included a representative upstream flume, with a gate structure and a downstream tank to simulate the bay. The gate structure was constructed in the model to represent various openings of a side-hinged gate. The energy losses of flow through the gate are built into the two-dimensional flow equations used in this model, so no discharge coefficient was required. However, by running the model and noting the computed water surface drop from upstream to downstream of the gate, a discharge coefficient could be back-calculated to be used in the HEC-RAS model. There are uncertainties included in this type of two-dimensional modeling, but the resulting discharge coefficient made sense from a physical standpoint. A better approach would be to design and implement a physical model study of side-hinged tide gates to determine their true performance.

Conclusions

The Kentuck Slough project demonstrated that, even with its limitations, HEC-RAS could be used to simulate side-hinged tide gates with complex operational schemes. Further refinements and upgrades to HEC-RAS will make this even easier in the future. For example, the next version of HEC-RAS will allow for the definition of gates using a family of rating curves, rather than a geometric representation. This will allow the user to model any type of gate, as long as a rating curve for that gate is known. It is also anticipated that more functionality of the gate-control routines will be incorporated in the future.

Near-field Hydraulic Conditions Affecting Fish Passage at Tide Gates in Estuaries

Larry Swenson, PE[1]

Abstract

Culverts with tide gates are constructed in levees for the purpose of draining estuarine wetlands and tidal marshes. The traditional design approach produces structures that are either partial or complete barriers to fish passage. Tide gates can create the following conditions: (a) openings that are too small for fish to swim through; (b) debris dams; (c) water velocities that exceed the swimming ability of the fish; (d) insufficient flow depth; and (e) excessive jump heights, flow accelerations, and turbulence. These factors are related to the hydraulic design. A rigorous hydraulic analysis and design must be performed to construct a facility that can significantly improve passage conditions. The locations and severity of the barriers vary during flooding, ebbing, and slack tides. Diagrams show the hydraulic trouble spots that occur in and near the structure throughout the tidal range. Through modeling, the hydraulic performance of a proposed design must be compared to the fish passage criteria for the species of interest to assess the likely relative passage success of the facility.

Introduction

The purpose of this paper is to shine a light on several potential hydraulic trouble spots in some tide gate and culvert concepts that have been applied to improve fish passage in estuary restoration projects. The usual problems are: (a) water velocities that exceed the swimming ability of the fish; (b) insufficient flow depth; and (c) excessive jump heights, flow accelerations, and turbulence. The nature, location, and degree of blockage change continually throughout the tidal cycle.

Dikes and tide gates have been constructed in many of the estuaries in California, Oregon, and Washington to convert tidal salt marshes to other agricultural, transportation, and municipal land uses. The traditional approach to the design and installation of tide gates creates structures that are near-complete barriers to fish passage. When certain estuary restoration opportunities are identified, governmental fisheries managers, conservation groups, watershed councils, and landowners seek to improve fish passage by replacing old tide gates with new ones having features that are more conducive to fish passage.

The sole purpose of a tide gate is to control inundation of the low-lying areas upland from the dike. However, when landowners are partners in restoration projects, it is possible to design tide gates that can automatically provide water inflow inside the levees up to, and not higher than, elevations that are in accord with the landowners' land use requirements.

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This paper discusses gates that: (a) have devices that hold gates (with or without an orifice) open until the flooding tide reaches a predetermined water level; and (b) lack hold-open devices but include orifices. The discussion is relevant for top-hinged and side-hinged gates. Plates 1 and 2 show examples of these types of gates. Heavy, top-hinged gates without orifices should be reserved for applications in which the goals are to block fish passage and prevent inundation by seawater.

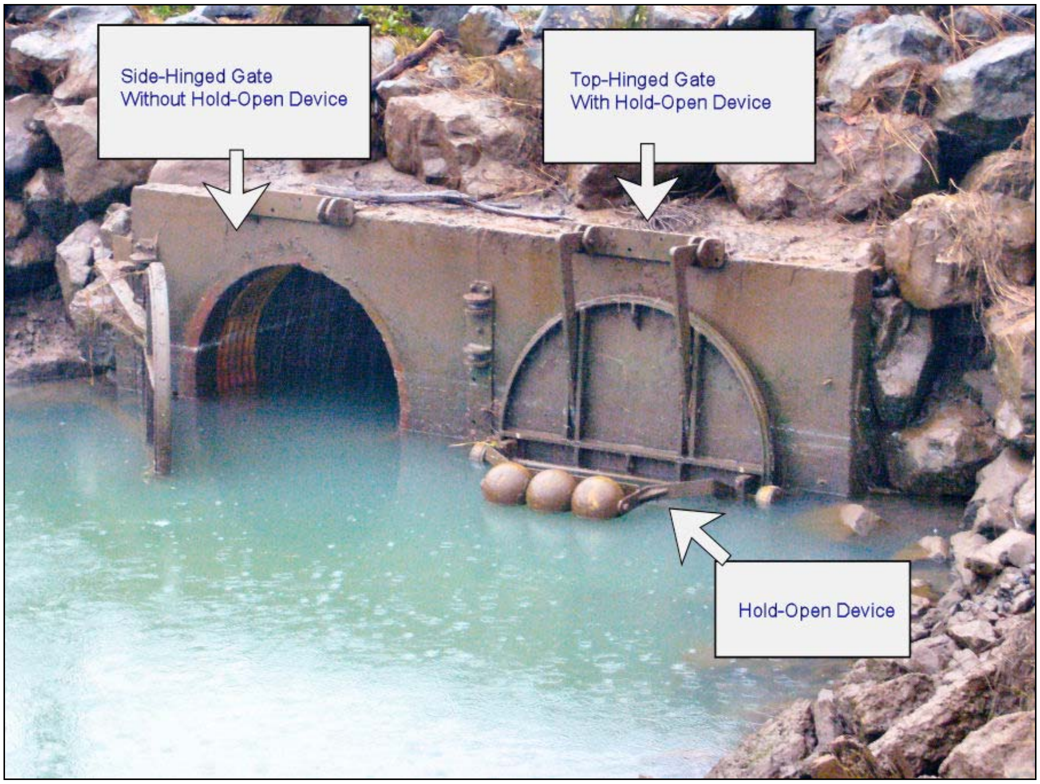


Plate 1. Side-hinged and top-hinged tide gates.

Fish Passage Precepts

NOAA’s current draft fish passage guidelines address passage for juvenile and adult salmon and steelhead. The guidelines for fish ladders, surface-flow bypass facilities, culverts, and water-diversion intake screens are based on known passage traits for those fish. When followed, the guidelines generally result in hydraulic flow fields in which the juvenile and adult salmonids are able to *volitionally* move from point to point to perform whichever life history function must be completed *at that particular location and in that particular moment*.

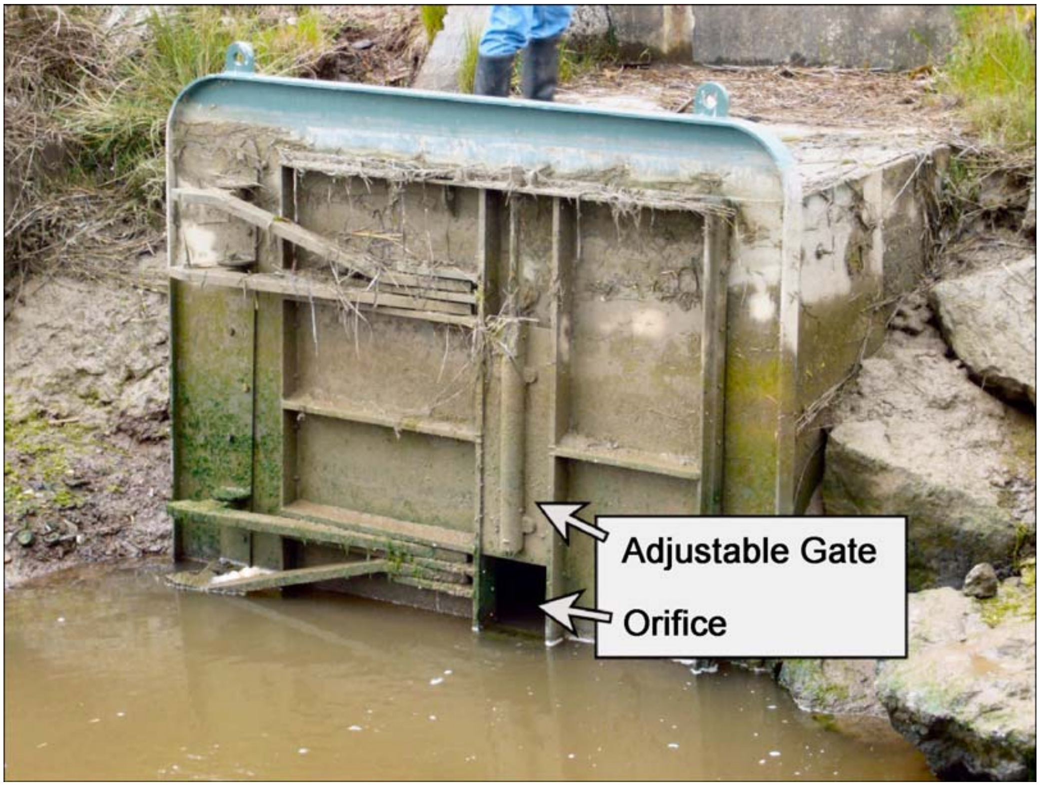


Plate 2. Side-hinged tide gate with adjustable orifice.

Many in-stream fish-passage structures, including those designed according to the guidelines, also cause fish to delay, i.e., to spend more time and energy to pass the structure than they would have spent in a natural setting. Additional mortality due to the increased risk of predation is a direct byproduct of delay. Except for fish traps and other barriers designed to block fish passage, the NOAA guidelines are focused on minimizing delay by salmonids to the extent possible. Although the effect of delaying fish movement through tide gate structures has not been evaluated, it would appear prudent to design tide gates to minimize delay to the extent possible.

A thought experiment: If fish were seen on the upland side of a tide gate yesterday—and fish are seen on the seaward side of the gate today—is that "fish passage?" Not necessarily. There are many cases that must be considered before this question can be answered. Here is a partial sample:

a) High velocities in the culvert exceeded the capability of the fish to avoid being transported through the gate.

b) The only suitable habitat for that species is upland of the gate.

c) The fish needed to move upstream at night but the gate was closed.

d) The channel seaward of the gate drains completely dry during low tides.

e) Were the observed fish the target fish—or were they different fish that are stronger/weaker swimmers?

f) The velocities were suitable, but local accelerations or the darkness in the culvert created behavioral barriers.

The author’s opinion is that the presence of fish on both sides of a tide gate does not imply that fish passage is being provided. Providing fish passage at a tide gate for a target fish species and life stage means that the gate and culvert are creating the necessary hydraulic conditions—as well as other environmental stimuli that could affect behavior—to enable the target fish to move volitionally, in either direction through the system, in the same way and at the same time as would be possible with no tide gate-culvert present.

Percentage of Time Passable

The above definition of fish passage is appropriate for designing tide gates because it makes possible a scheme to estimate the projected relative fish passage effectiveness of alternate tide gate designs, based on the following rationale:

1. Unlike normal upland stream culverts in which the flow conditions remain reasonably constant for many days at a time, the flow conditions near a tide gate change continually. Conditions that are passable at one time can be impassable an hour later.

2. The biological design process can benefit from a methodology that calculates the amount of time in each tide cycle that the tide gate-culvert system can meet passage criteria.

3. The hourly tide heights at a site are predictable to a high level of accuracy.

4. The hydraulic engineers can calculate flow depths, velocities, and jump heights in and around the gate and culvert for each time step throughout the tidal cycles.

5. It is possible to compare the computed hydraulic conditions with the passage criteria for the target species, and to estimate the number of time steps that would meet criteria and the number that would not, throughout typical tide cycles.

6. Based on the above approach, biologists can determine the approximate percentage of time that the system can meet passage criteria for the species of interest.

7. This technique allows ready comparison of the expected relative effectiveness of alternative tide gate designs.

This approach assumes that the fish biologists possess information about the behavioral traits, habitat utilization, and swimming capabilities of the target fishes. Lacking this information, it may be necessary and sufficient to substitute the velocity and depth characteristics of the natural habitat (in the absence of tide gates) for specific fish-passage criteria. The biologists can then utilize rationale statements 5, 6, and 7, above.

Passage Trouble Spots in the Tide Gate-Culvert Structure

Analyzing the flow conditions that are relevant to fish passage in a tide gate-culvert structure can be managed by dividing the time span of each tide cycle into four zones. These four zones were selected based on the following approach:

a) Zone 1—Flooding tide, gate open (gate may or may not include an orifice);

b) Zone 2—Flooding tide, gate closed (gate may or may not include an orifice);

c) Zone 3—Ebbing tide, gate open; and

d) Zone 4—Tide level is below invert (bottom) elevation of the culvert

The following sections present a qualitative, zone-by-zone treatment of the hydraulic interactions between a generic tide gate-culvert and the flow in the channel at and between both ends of the structure during a representative tide cycle. The discussion is based on gates that

a) have devices that hold gates open until the flooding tide reaches a predetermined water level (gates may or may not include an orifice), and

b) lack hold-open devices but include orifices, and

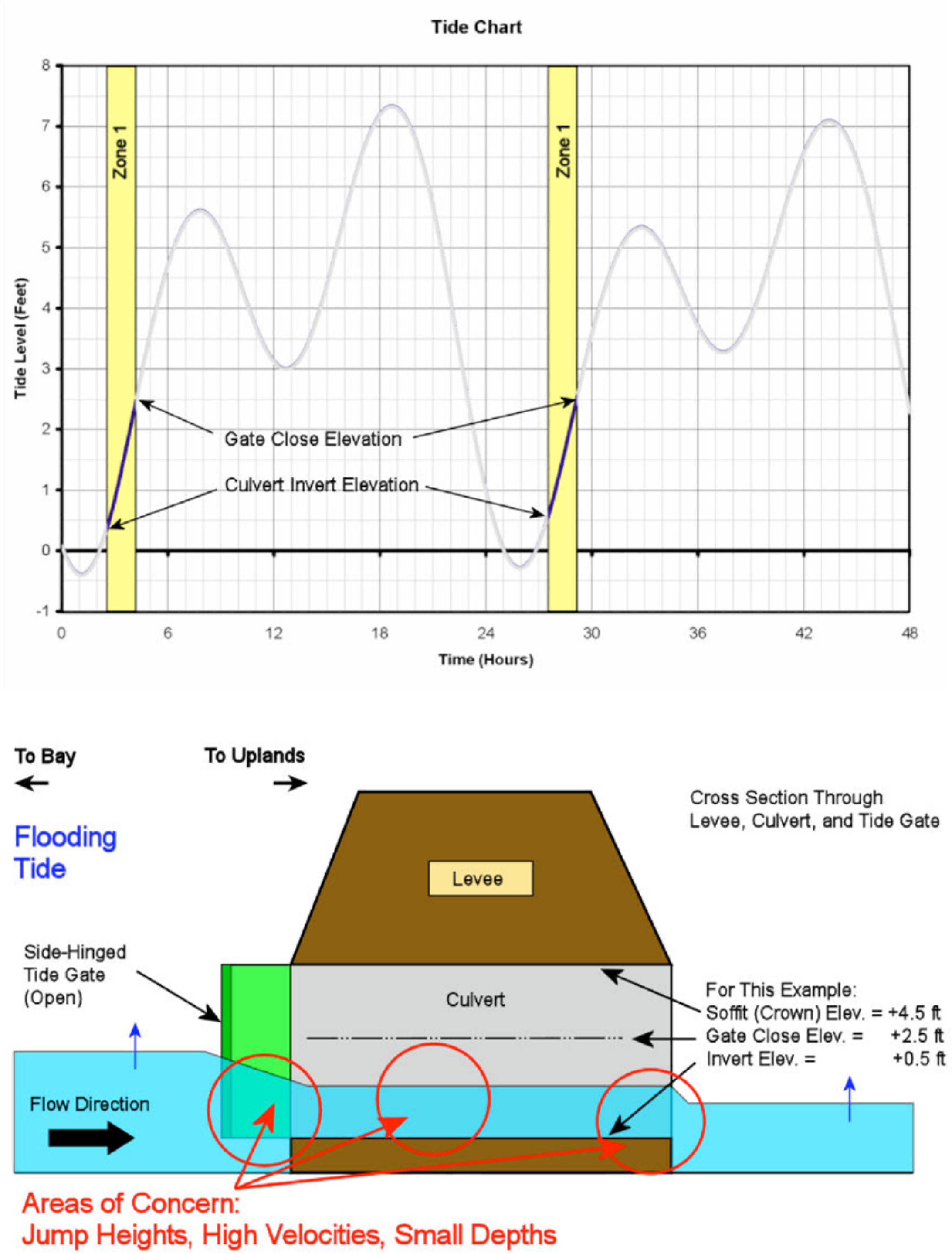
c) have either top-mounted or side-mounted hinges.

The predetermined water level at which the hold-open devices allow the gate to close during the flooding tide is called the Design Tide Inundation Level (DTIE).

Passage Zone 1

Zone 1 represents the span of time when the flooding tide level is higher than the invert elevation of the culvert, higher than the upland water-surface elevation, and lower than the elevation at which the hold-open device is set to allow the gate to close, the DTIE. The upper portion of Figure 1 shows a generic plot of tide elevation versus time. The highlighted Zone 1 segments of the plot show the times when the flow is in the direction toward the upland areas. The lower portion of Figure 1 is a schematic representation of the water-surface profile through the gate and culvert.

Figure 1 - Passage Zone 1 (Culvert Invert to Gate Close)



The three hydraulic design rules-of-thumb for minimizing velocity and jump-height barriers to fish passage for juvenile salmonids in Zone 1 are

a) Minimize the energy losses and flow accelerations at the upstream downstream ends of the culvert.

b) Keep the Froude Number, **F**, much less than 1.0 everywhere throughout the structure. **F** is the ratio of the water velocity, V_{water}, to the shallow water wave velocity, $V_{\mathbf{wave}}$, according to:

$$\mathbf{F} = V_{water} / V_{wave} = V / (g^*\text{Flow Depth})^{1/2}$$

where g = gravitational acceleration.

c) The gate opening should be wider than the minimum dimension that could cause fish to reject the opening.

To put it even more simply: *the downstream water surface in the upland channel should lag the water surface upstream of the gate by the smallest vertical distance possible, consistent with the swimming capabilities and behavioral traits of the target fish.*

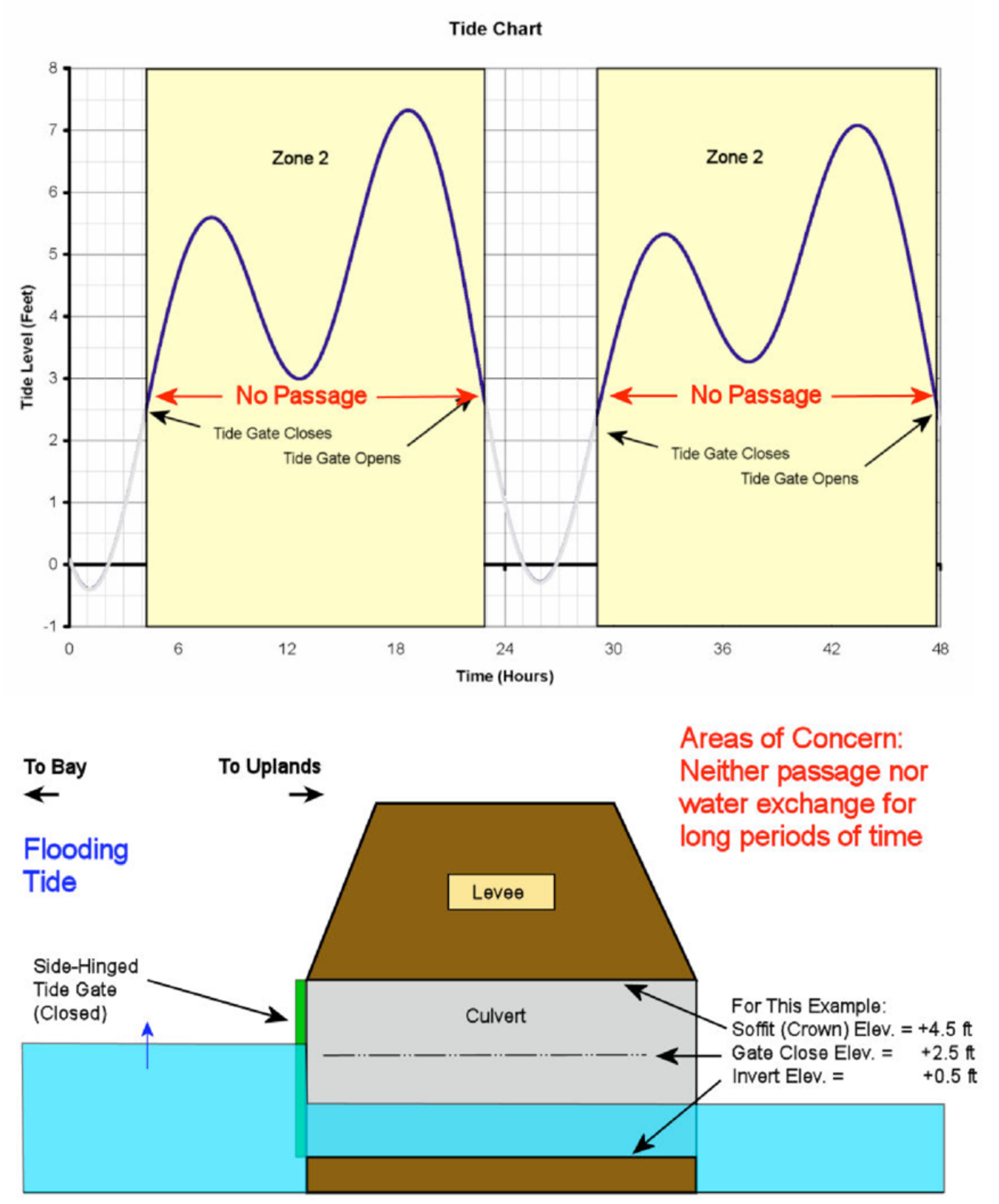
Passage Zone 2

The tide height in Passage Zone 2 has exceeded the DTIE and the upland water level, as shown in the upper portion of Figure 2(a). The gate is closed. The lower portion of this figure represents the case where there is no orifice in the gate. The upland water level can receive new water in Zone 2 only if a stream enters the upland area or if the gate leaks.

The schematic in Figure 2(b) shows an orifice in the tide gate. The orifice allows additional water to pass into the upland area. The orifice is likely to be volitionally passable bi-directionally for small fish only during those few minutes when the head loss across the gate is small.

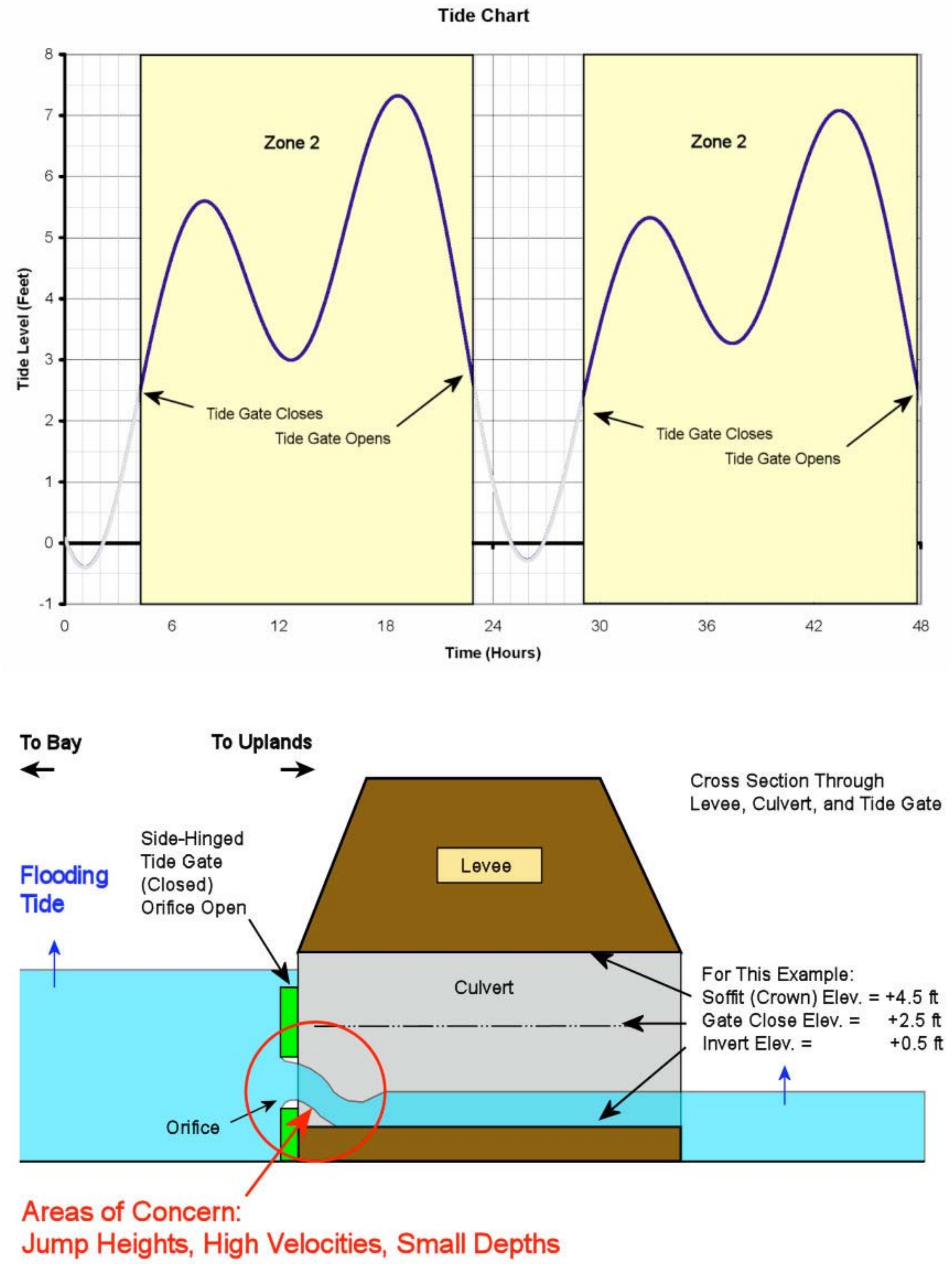
Weak-swimming fish near the upstream side of the orifice may not be able to avoid the relatively strong currents in this area. They can be swept through the gate into the upland channel. Depending on the species and life-history strategy for that part of the tide cycle and time of day and season, this may or may not be a favorable outcome.

Figure 2 (a) - Passage Zone 2 (Gate Close to Gate Open)



Cross Section Through Levee, Culvert, and Tide Gate

Figure 2 (b) - Passage Zone 2 Modification: Orifice in Gate



Passage Zone 3

Passage Zone 3 is the reverse of Passage Zone 1. The upland water level exceeds the tide level, and the gate is open, as shown in Figure 3. The three hydraulic guidelines recommended in Zone 1 apply in Zone 3.

Zone 3 has the advantage that a properly balanced side-hinged tide gate should swing wide open during the outgoing tide. The minimum gate opening width should never be an issue in this part of the tide cycle, with a carefully designed side-hinged gate.

Several serious passage problems can occur in Zone 3 if the hydraulic capacity of the culvert is too small:

a) The entrance and exit head losses, and the culvert velocities, will be high.

b) The water depths in the tidal channel downstream of culvert can be significantly less than the depth in upland channel upstream of the culvert.

c) Fish that are moving downstream will be rapidly transported from a reach with sufficient depth to one with insufficient depth.

d) The depths, velocities, and jump heights below the culvert can be barriers and prevent fish from re-entering the culvert and moving into the upland channel.

The final draining moments in Zone 3 are related to the design considerations of Passage Zone 4, as discussed below.

Passage Zone 4

The main characteristics of Passage Zone 4, as shown in Figure 4, are that the tide is out and the upland water level has reached its minimum possible elevation. This usually occurs a short time after the tide has receded to a level lower than the invert of the culvert.

The designer of a tide gate-culvert replacement project normally has several choices for placing the invert of the new tide gate:

a) Raise the culvert invert a distance above the channel bed, as shown in Figure 4(a). This would be done if there is an ecological requirement to maintain a pool of water above the tide gate.

b) Place the invert at the same elevation as the channel bed, as shown in Figure 4(b). This may be the preferred choice in cases where the channel drains completely in the natural condition.

c) Rarely, there may be an opportunity to construct the culvert invert lower than the low tide, as shown in Figure 4(c). This arrangement allows bi-directional fish passage through the gate and culvert at low tide.

Figure 3 - Passage Zone 3 (Gate Open to Culvert Invert)

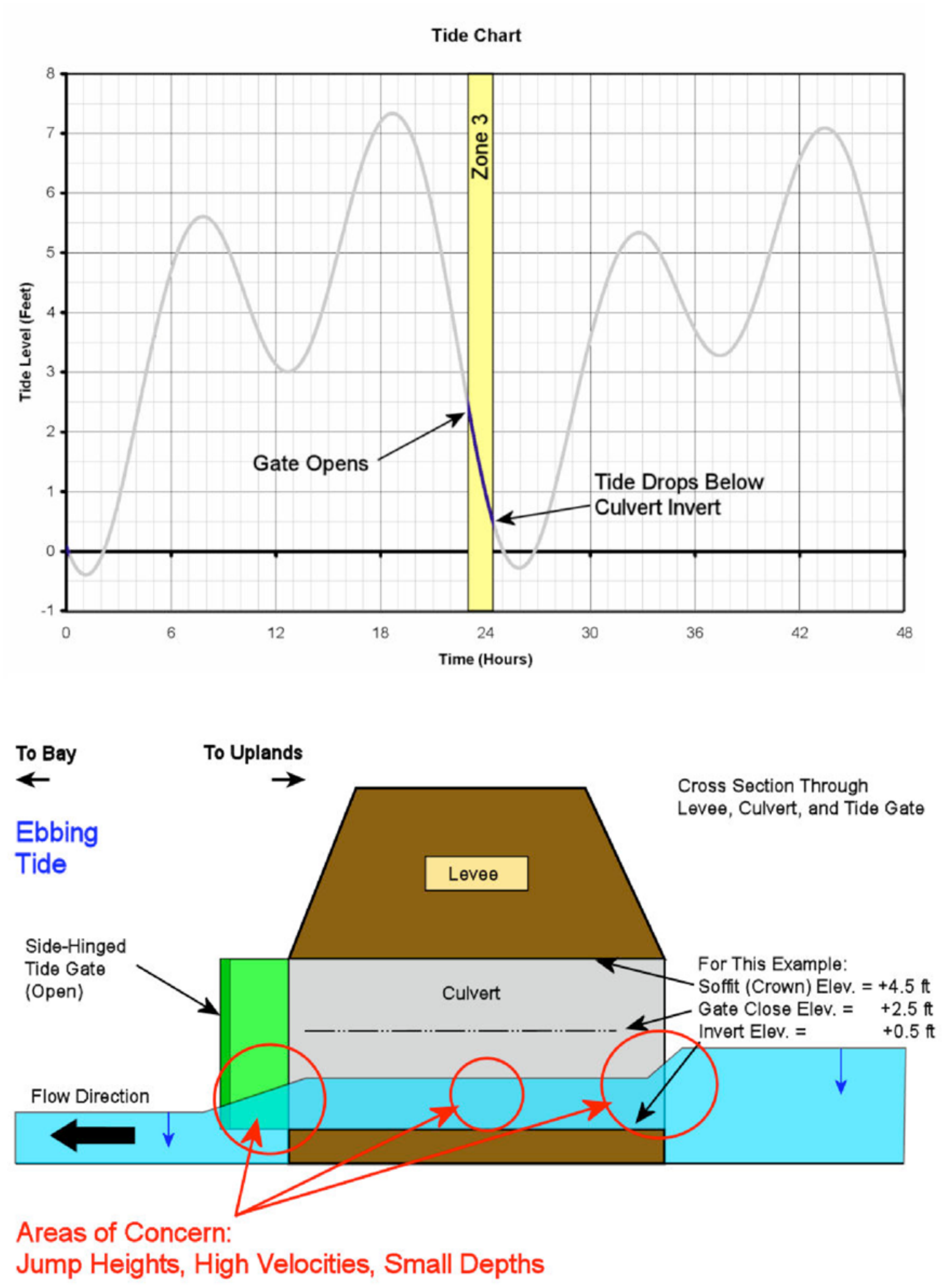


Figure 4 (a) - Passage Zone 4 (Tide Below Culvert Invert)

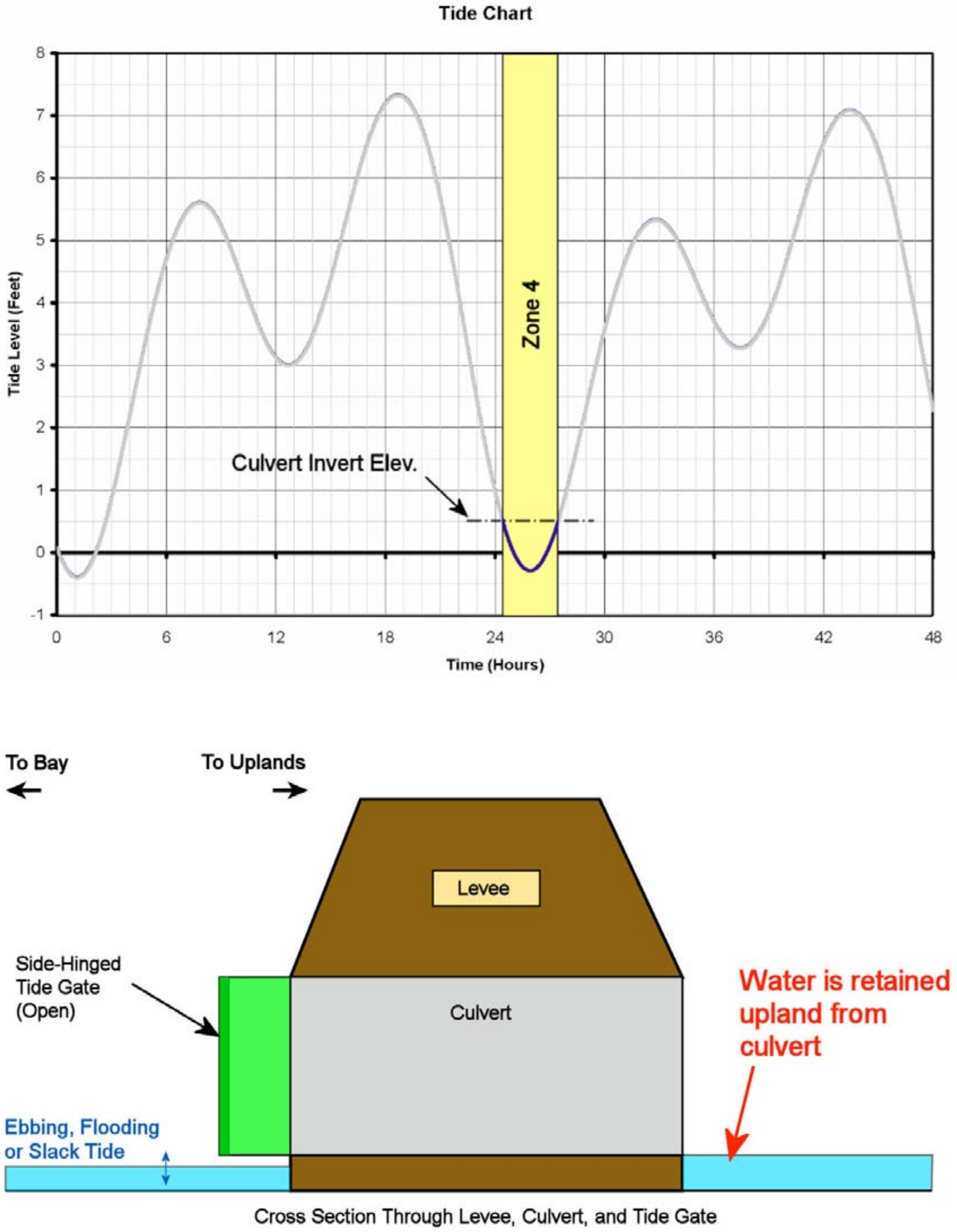
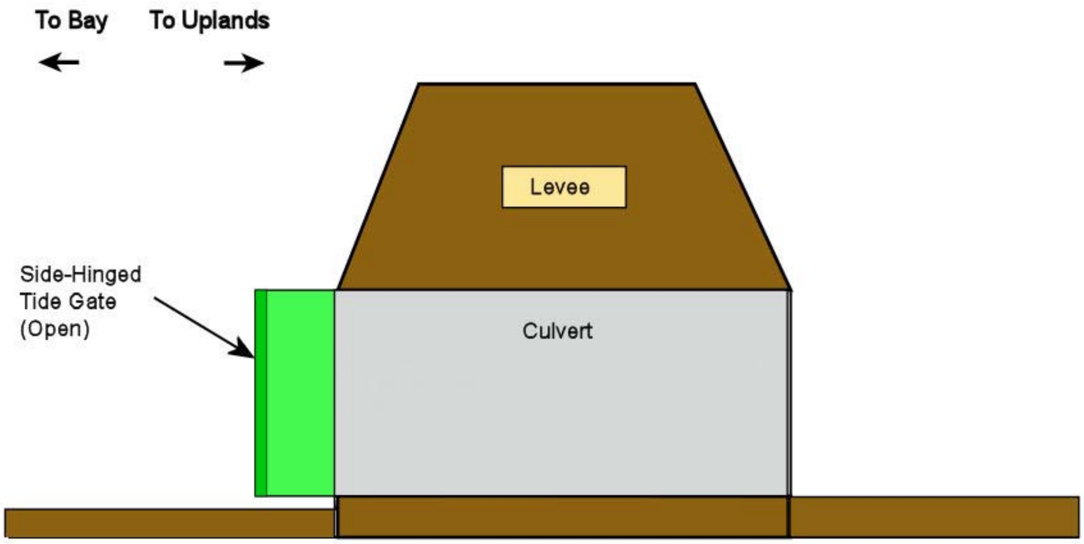


Figure 4 (b) - Passage Zone 4 - Variations

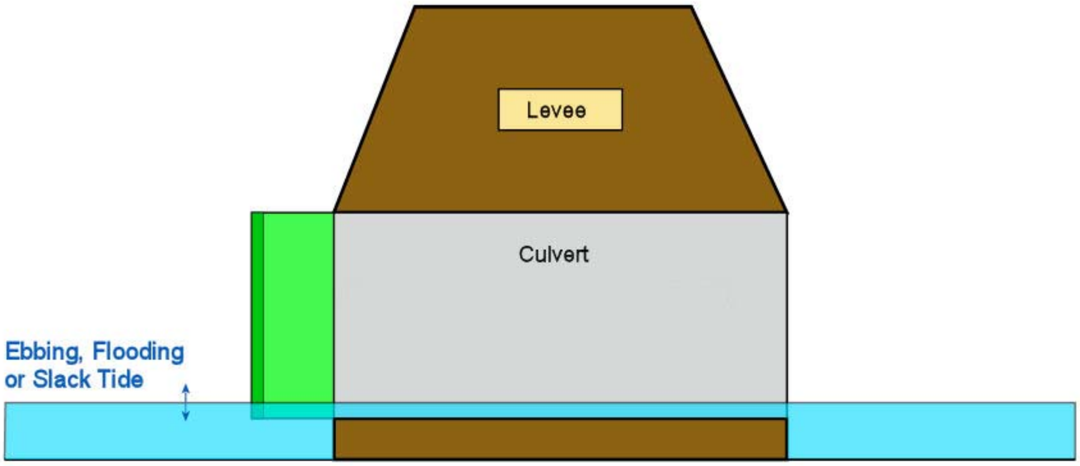
Channel Drains Completely at Low Tide



Cross Section Through Levee, Culvert, and Tide Gate

Figure 4 (c) - Passage Zone 4 - Variations

Culvert Invert Below Low Tide



Cross Section Through Levee, Culvert, and Tide Gate

Conclusions

The hydraulic analysis of flow conditions relevant to fish passage in a tide gate-culvert structure can proceed in a logical order by dividing each tide cycle into four zones because:

a) The flow direction and calculation algorithms are similar throughout the time duration of each zone.

b) Each zone has different passage issues in different locations in the structure, and this system may help designers focus on improved passage solutions relevant for each portion of the tidal cycle.

c) This nomenclature may help facilitate communication between the biological and civil designers.

Our knowledge of the daily and seasonal travel requirements of estuary fishes is extremely limited. We have good information about the swimming speeds and passage requirements for salmonids. Research is being conducted regarding how juvenile salmonids utilize the estuaries over various time scales.

Despite the lack of detailed fish-passage information for estuary fishes, there are three factors that work in bioengineers' favor that can be used to significantly improve the probabilities for successful fish passage in a given project:

a) It is possible to measure and calculate the flow velocities and depths in natural estuary tidal channels—with no flow-control structures.

b) The engineers can design tide gate-culverts to create those velocities and depths—over a wider proportion of the tidal cycle than is presently being done in most tide-gate replacement projects. The designers can calculate the percentage of time that the structure creates the target velocities and depths. This provides the ability to compare alternate designs.

c) It is possible to conduct detailed monitoring and evaluation of new projects to learn more about the passage effectiveness of the design for the species that use the habitat surrounding the structure. This information can be incorporated into the designs of future projects. The state of the art of tide gate fish-passage design can be gradually improved by using this process.

Recommendations for Hydraulic Research

A physical hydraulic model study should be conducted to develop discharge-rating curves for top-hinged and side-hinged tide gates that are operating in the modes of Zone 1 and Zone 3. The study should also include the development of rating curves for the upstream end of the culvert operating in the mode of Zone 3.

A series of numerical model studies should be conducted using HEC-RAS 4.0 to determine the spatial scale at which unsteady flow modeling is preferred over steady flow modeling when designing replacement tide gate projects.

Speakers' Bios

West Coast Symposium on the Effects of Tide Gates on Estuarine Habitats and Fishes

October 31–November 2, 2006

South Slough National Estuarine Research Reserve
61907 Seven Devils Road, Charleston, Oregon
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South Slough National Estuarine Research Reserve

Thanks to the speakers who participated in the symposium:

Bob Barnard, Engineer
Washington Department of Fish and Wildlife
Habitat Engineering Technical Assistance
Olympia, Washington

Bob Barnard is an engineer with the Washington Department of Fish and Wildlife. His primary areas of expertise are fish passage, particularly culvert design, and estuary restoration. Over the past 11 years, Bob has observed, evaluated, or designed hundreds of culverts; written guidance on the stream simulation design method, fords, sediment traps, and road-impounded wetlands; and conducted a study on stream-simulation culvert effectiveness.

His main task, which is to provide technical assistance to regulatory personnel and design assistance to project sponsors, keeps his attention on tide gates. While not really regulated by Washington Department of Fish and Wildlife, tide gates have been a recurring area of interest during his career. Bob provides site-specific solutions for fish passage and habitat restoration, provides guidance on design, and evaluates the performance of various tide gates.

Speakers' Bios

Eric Beamer, Director of Research
Skagit River System Cooperative
LaConner, Washington

Eric Beamer is director of the research program for the Skagit River System Cooperative, where he has worked at examining salmon freshwater and estuarine ecology since 1984. He is the principal investigator on several Skagit watershed projects, including monitoring Chinook salmon in the tidal delta and nearshore, studies of the use of non-natal estuaries by juvenile Chinook salmon, and recent research that directly links estuarine and nearshore habitat to recovery of wild Skagit River Chinook salmon populations. Eric received a B.S. in marine biology with a minor in chemistry from Western Washington University in 1983.

Laura Brophy, Ecologist
Green Point Consulting
Corvallis, Oregon

Laura Brophy is the founder and owner of Green Point Consulting in Corvallis, Oregon. She has 27 years' experience in applying ecological principles to resource management problems, with emphasis on the conservation and restoration of Pacific Northwest coastal wetlands and watersheds since 1994.

Laura's local-scale projects include onsite wetland restoration design, monitoring, and implementation; regional-scale projects include strategic planning for resource management, and educational workshops and publications. She also conducts field research in wetland ecology to improve our understanding of structure-function linkages and to increase resource-management effectiveness.

Steve Crooks, Geomorphologist
Philip Williams and Associates
San Francisco, California

Steve Crooks is a senior associate with Philip Williams and Associates (PWA). Trained as a geomorphologist, Steve has spent much of the past 15 years seeking to integrate science into the sustainable management of wetland systems. At PWA, Steve's projects range from estuarine-scale geomorphic assessment and interdisciplinary scientific investigation of wetlands processes to the monitoring, modeling, and restoration design of tidal and seasonal wetlands. In cooperation with the U.S. Army Corps of Engineers and the California Coastal Conservancy, Steve developed the design of tidal-managed wetlands, including the setting of science-based success criteria for adaptive management planning.

Steve has published for and contributed to a number of international research and policy groups and committees and has provided evidence to the United Kingdom Parliament on the management of coastal wetlands under European Union biodiversity policy.

Speakers' Bios

David K. Hering, Aquatic Inventories Project Biologist,
Assistant Project Leader, Columbia River Estuary Project
Oregon Department of Fish and Wildlife
Corvallis, Oregon

Dave Hering has worked for Oregon Department of Fish and Wildlife since 1999. For the past several years, he has conducted research on Oregon's Salmon River estuary, leading toward a master's degree in fisheries science at Oregon State University.

Dave's current work includes research of migratory coastal cutthroat trout and coho salmon in the estuary and tributaries of the lower Columbia River. He has a broader interest in mechanisms underlying behavioral and life history diversity within fish populations. Dave lives in a 135-year-old house in Albany, Oregon, with his wife Daisy, his daughter Violet, and his dog Roosevelt.

Steve Hinton, Director of Habitat Restoration
Skagit River System Cooperative
LaConner, Washington

Since 2000, Steve Hinton has worked as the Director of Habitat Restoration for the Skagit River System Cooperative, a natural resource-management agency working on behalf of the Sauk-Suiattle and Swinomish Indian communities, based in LaConner, Washington. He is responsible for the restoration programs and projects conducted by the tribal cooperative. He also served as program director.

Prior to joining the cooperative, he was senior habitat biologist for Snohomish County, Washington, and field coordinator for Oregon Trout. Steve has worked as a private consultant, providing research, planning, and coordination to conservation projects. Steve is a member of the American Benthological Society, the American Fisheries Society, and the Society for Ecological Restoration, and he holds an NAUI Open Water Diver certification.

Leo Kuntz, Tide Gate Designer
Nehalem Marine Manufacturing
Nehalem, Oregon

Leo Kuntz specializes in the design, manufacture, and installation of tide gates. Doing business as Nehalem Marine Manufacturing, Leo has designed marine equipment for 29 years. Originally, the company's emphasis was design and manufacture of deck machinery and rigging, shipyard and boat building activities, marine salvage, and underwater repair, including underwater tide-gate installation and repair. In the early 1990s, the company began developing marine technology for flood control and restoration.

Leo's experience working with steel and aluminum in a marine environment led to a series of successful innovations in the installation and manufacture of tide gates and water-control structures. Nehalem Marine developed and manufactures a line of tide gates that are fast becoming the standard for excellence and dependability in the industry. Nehalem Marine, in cooperation with the Tillamook National Estuary Project, has invented, developed, and manufactured the Mitigator fish-passage device as a tide-gate accessory to improve juvenile fish passage and water quality within levied agricultural lands; as well as a revolutionary, new, side-hinged tide gate that provides excellent adult fish passage. The company's latest invention, the muted tidal regulator (U.S. Patent #6988853), allows extremely high levels of restoration in areas where full tidal reconnections are not possible.

Susan Novak, Hydraulic Engineer
NOAA Fisheries
Portland, Oregon

Susan Novak is a hydraulic engineer who has worked for NOAA Fisheries in Portland, Oregon, since January 2006. Susan studied physics and mathematics at Colorado State University and received a master's degree in civil engineering in December, 2005. She works on tide-gate projects along the Oregon coast, conducts fishway inspections on mid-Columbia River dams, and reviews fish-passage designs for diversion projects in Oregon and Washington. Currently she is developing criteria for designing rock ramp fishways.

Susan is a Gemini and hates tofu.

Jeff Rogers, Geologist
Center for Coastal Studies
Provincetown, Massachusetts

Jeff Rogers received his B.A. in geology from Boston University in 1996 and a master's in geological sciences in 1999 from the University of Maine, Orono, researching sub-marine pockmark fields. Jeff's background includes coastal geology, wetland science, geographic information systems (GIS), and remote sensing. From 2000 to 2006 he was a geologist and GIS manager at GeoSyntec Consultants in Acton, Massachusetts, where he worked on water resources and coastal restoration projects nationwide.

A Provincetown Cape Cod native, Jeff has recently returned home and joined the Provincetown Center for Coastal Studies, located on the tip of Cape Cod, Massachusetts, as an adjunct research scientist. He is currently a Ph.D. candidate at the University of New Hampshire, researching the use of remote sensing (LiDAR and Hyperspectral) in salt marsh environments.

Tom Sibley, Fisheries Biologist
National Marine Fisheries Service
Seattle, Washington

Tom Sibley is branch chief for the North Puget Sound Branch in the Washington State Habitat Office. His work at National Marine Fisheries Service (NMFS) includes consultations for a variety of federal actions under the Endangered Species Act and the Magnuson-Stevens Fisheries Conservation and Management Act, development and implementation of habitat conservation plans, and implementation of salmon recovery plans.

Prior to joining NMFS, Tom served on the faculty of the University of Washington, School of Fisheries, from 1978 to 2000.

Jon A. Souder, Executive Director
Coos Watershed Association
Charleston, Oregon

Jon Souder has been executive director of the Coos Watershed Association in Charleston, Oregon, since 2000. The association is a 501(c)(3) non-profit, organized in 1994 to restore coastal salmon and improve water quality in the 610 square-mile basin. With a budget of approximately $1 million per year, the Coos Watershed Association conducts watershed assessments, implements restoration actions on a voluntary basis with landowners and managers, and monitors the projects' effectiveness in an adaptive-management framework. The association is governed by a 19-member board, in which all decisions are made by consensus.

Jon received a B.S. in biology from Marlboro College, Marlboro, Vermont; a master's degree in forest management and a Ph.D. in natural resources economics, policy, and law from the University of California, Berkeley. He was a Ciriacy-Wantrup Post-doctoral Fellow in Natural Resources Economics at the Haas School of Business, UC-Berkeley, prior to joining the Northern Arizona University faculty. Between his undergraduate and graduate educations, Jon was employed for 10 years by the federal government as a fisheries biologist in three different departments (State, Defense, and Interior).

Tom Stahl, Fish Passage Coordinator
Oregon Department of Fish and Wildlife
Salem, Oregon

Tom Stahl began working for the Oregon Department of Fish and Wildlife (ODFW) in January 2001, as the STEP/R&E Coordinator. Since 2003, he has been the statewide Fish Passage Coordinator, working on a range of fish-passage policy issues and new statute implementation. His work includes development of procedures, criteria, and guidelines; regulatory review of fish passage projects; development of a statewide fish-passage inventory; review of funding requests for fish screening and passage projects; information dissemination; and assistance in the resolution of other fish-passage issues.

Prior to coming to work at ODFW, Tom worked for three years at Oregon State University, conducting research into the physiological and behavioral factors affecting smolt migration and survival through estuaries and into the ocean. Tom is a native of New York. He earned an undergraduate degree in biology from the University of Notre Dame, and a master's degree in aquatic ecology from Ohio State University.

Speakers' Bios

Larry Swenson, Hydraulic Engineer
NOAA Fisheries
Portland, Oregon

Larry Swenson is a hydraulic engineer with over 33 years of operations, analysis, and design experience. Within this period, he has over 19 years' experience in fish-passage design for juvenile and adult salmonids. Larry has been working with NOAA Fisheries in Portland since 1997 on fish passage projects in Oregon and Washington. He supports the fish biologists in NOAA's Habitat Conservation Division and in the Hydropower Division. The scale of his projects ranges from culverts on small streams to irrigation diversions on tributary rivers such as the Walla Walla River, to large U.S. Army Corps of Engineers hydroelectric projects and privately owned (FERC-licensed) hydroelectric dams on the Columbia River.

Larry received his B.S. in civil engineering from the University of Washington in 1973. After serving more than five years in the U.S. Navy (as an engineering officer aboard ships and in the Civil Engineer Corps), he attended Colorado State University and earned his master's degree in civil engineering, specializing in hydraulic engineering (and emphasizing hydromachinery and river mechanics). Larry is a registered professional engineer in Colorado, Alaska, and Washington.

Dan Tonnes, Biologist
National Marine Fisheries Service
Washington-Oregon Habitat Conservation Division
Seattle, Washington

Dan Tonnes has worked as a biologist within the Washington and Oregon Habitat Conservation Division of the National Marine Fisheries Service (NMFS) since 1999. His work has included development of habitat conservation plans, estuarine research related to tide gates, and consultation within the Endangered Species Act and Magnuson-Stevens Fishery Conservation Act.

Prior to working for NMFS, Dan worked as a water-quality specialist with the Washington Department of Ecology. He is a Coast Guard-licensed boat captain. He is currently attending graduate school at the University of Washington's College of Ocean and Fishery Sciences.