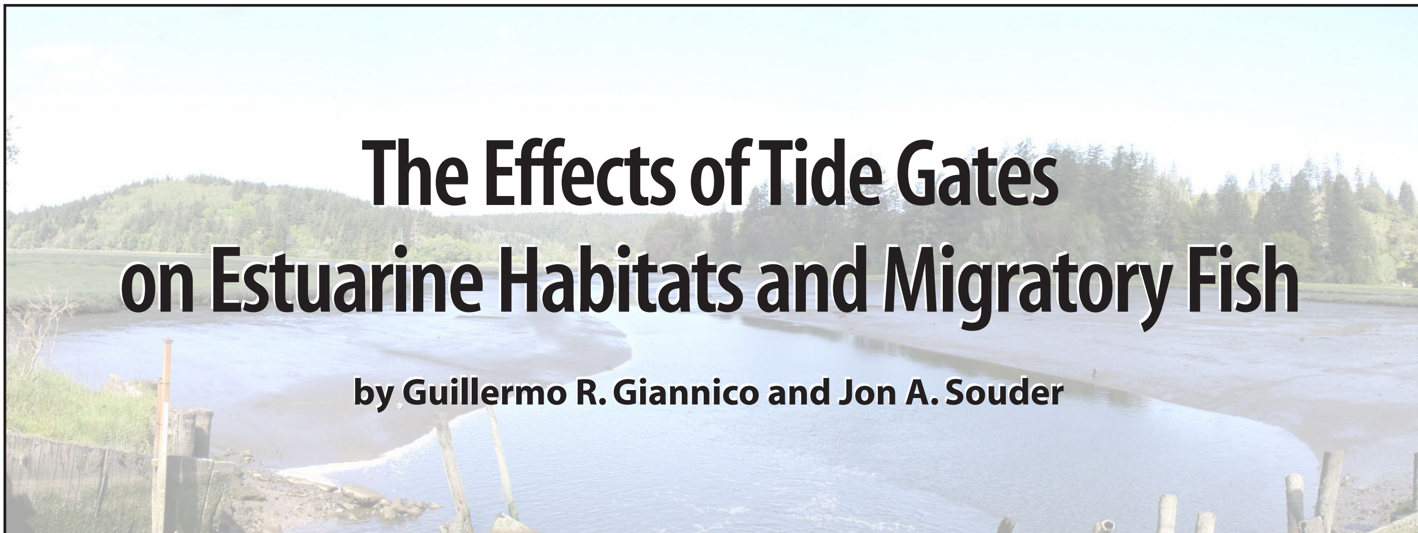


# The Effects of Tide Gates on Estuarine Habitats and Migratory Fish

by Guillermo R. Giannico and Jon A. Souder

Dikes and tide gates have been used worldwide for several centuries to drain wetlands, both in estuaries and in the lower sections of rivers, which are influenced by tides. Wetland draining has been carried out either to convert lands into agricultural use, to control populations of mosquitoes and other insects, or to allow urban development on low-lying coastal zones (Daiber 1986; Middleton 1999; Doody 2001). In the Pacific Northwest region of North America, the draining of estuarine wetlands began approximately two hundred years ago (Dahl 1990). Tidal marshes close to seaports and urban centers have been particularly vulnerable to conversion, with losses of 50 to 90 percent reported for many estuaries in Oregon and Washington (NRC 1996). Many of these marshes have been isolated from the adjacent estuaries by dikes (Frenkel and Morlan 1991) and in some cases completely or partly filled in to accommodate a variety of land uses (for example, agricultural, recreational, residential, and industrial). In areas like Coos Bay, Oregon, almost 90 percent of tidal marshes have been permanently lost to dikes and landfills (Schultz 1990), and in parts of Puget Sound, Washington, over 95 percent of tidal wetlands have been lost (Gregory and Bisson 1997).

Dikes are elevated earthen embankments raised along tidally influenced channels in estuaries and coastal sections of rivers to keep low-lying lands from being flooded during high tides. Structures known as *flood boxes*, or *tide boxes*, are installed in dikes to control the flow of upland water through creeks or sloughs into estuaries or rivers. A flood box might be as simple as a single culvert running through a dike wall or as complex as a small, bridge-sized, concrete structure that includes two or more culverts, deflection wing walls, and upstream and downstream pilings (see figures 1a and 1b). In all cases, doors or lids are attached to the discharge ends of the culverts to control water flow. These doors are commonly referred to as *tide gates*, or *flap gates* (figure 1b). Tide gates close during incoming (flood) tides to prevent tidal waters from moving upland. They open during outgoing (ebb) tides to allow upland water to flow through the culvert and into the receiving body of water. Figure 2 illustrates the entire gate cycle as water levels change.

Tide gates tend to be effective at maintaining low water levels on the upland side of dikes. Unfortunately, by altering water flow they have some undesirable side effects that can be classified into three main—but interrelated—categories: physical, chemical, and biological.

The physical effects of tide gates include elimination of upland tidal flooding and changes in the velocity, turbulence, and pattern of freshwater discharge that fluctuates between water stagnation and flushing flows. In turn, these changes in the circulation of water between both sides of a dike cause alterations in water temperatures, soil moisture content, sediment transport, and channel morphology (Vranken and Oenema 1990; Charland 1998).

*Guillermo R. Giannico is on the faculty of the Department of Fisheries and Wildlife at Oregon State University, and Jon A. Souder is executive director of the Coos Watershed Association.*

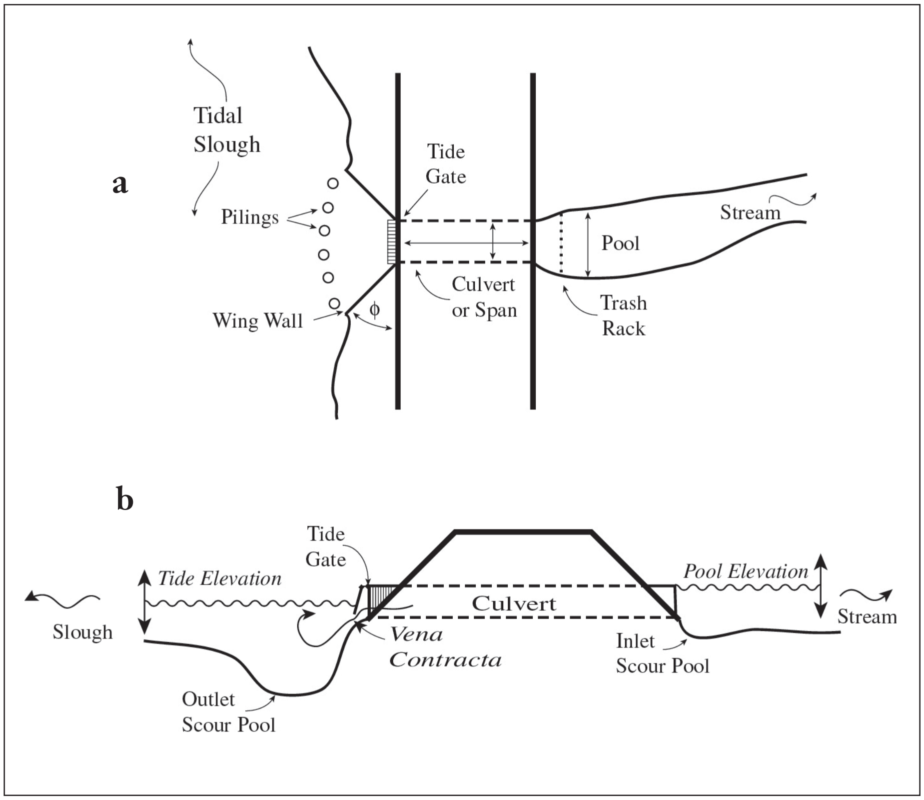



***Figure 1.** Flood box (culvert with tide gate) installed in dike's wall: **(a)** top view; **(b)** side view.*

The chemical effects of tide gates consist of upstream increases in water nutrient concentration, turbidity, and heavy metal suspension and reductions in dissolved oxygen and pH (that is, water alkalinity) (Portnoy 1987; Vranken and Oenema 1990). Soil salinity is also reduced because tide gates prevent brackish tidewaters from reaching past dikes, and the freshwater that is allowed to drain toward the estuary removes salts from soils over time (Dreyer and Niering 1995).

The biological effects of tide gates come in the form of obstruction to fish migration, changes to the composition of aquatic plants, and pulses of coliform bacteria into estuarine waters during low tides (Eliasen 1988; Charland 2001).

Although the tide gate itself is what stops water and fish movement, it is important to recognize that the design of the entire flood box affects the circulation of water and fish passage. Thus, the effect that flood boxes have on the aquatic environment depends on a combination of things: culvert diameter relative to the upstream channel; culvert surface roughness; channel bottom characteristics both upstream and downstream from the flood box; culvert bottom (also known as *invert* or *sill*) elevation relative to the channel bottom and to tide levels; type of tide gate; wing wall orientation; presence of pilings in the channel; and other features of the flood box (figures 1a and 1b).

There are many different types of tide gates, but the traditional configurations have either a heavy lid (made of treated wood) suspended from the top of the culvert by either a bar with hinges or chains (figure 3a), or a metal lid (usually of cast iron or steel) double hinged from above (figure 3b). Alternative designs include side-hinged gates (figures 4a–c) and top-hinged gates with small "pet doors" (figure 5) (Charland 2001). Tide gates open and close because of water level differences between the downstream and the upstream sides of the gate. Water level differences are caused by (1) tidal cycles (and magnitudes), (2) inflow into the reservoir pool that forms on the upland side, and (3) the extent to which this reservoir pool has been drained during previous gate-opening cycles.

The amount of water level difference required to open a tide gate is determined by the "effective weight" of the gate. For top-hinged gates, both the amount of time and the degree of opening are functions of the weight and area of the gate and the pressure force generated by the difference in water level between both sides of the gate (Raemy and Hager 1998). Thus, the difference in water level needed to open a gate is greater the larger the gate and the more it weighs (USACE 2001). Conversely, for side-hinged gates, the effective weight of the gate is a function of the resistance of its hinges and the degree to which the door is tilted downward. In general, and because of the opening force caused by their tilt, side-hinged gates open wider and for longer periods with less upland water pressure than equivalently sized top-hinged gates. Top-hinged tide gates may have "pet doors" that are hinged at the top, side, or bottom. These smaller doors remain open for longer periods than the large gates they are part of and, as a result, they facilitate fish passage (Charland 2001).

Unfortunately, tide gates can easily be jammed by floating pieces of wood, and, over time, they tend to hang twisted from their hinges. This changes the way the gates operate and creates problems in terms of both fish passage and flood control. Regular inspections are recommended to avoid this type of problem.

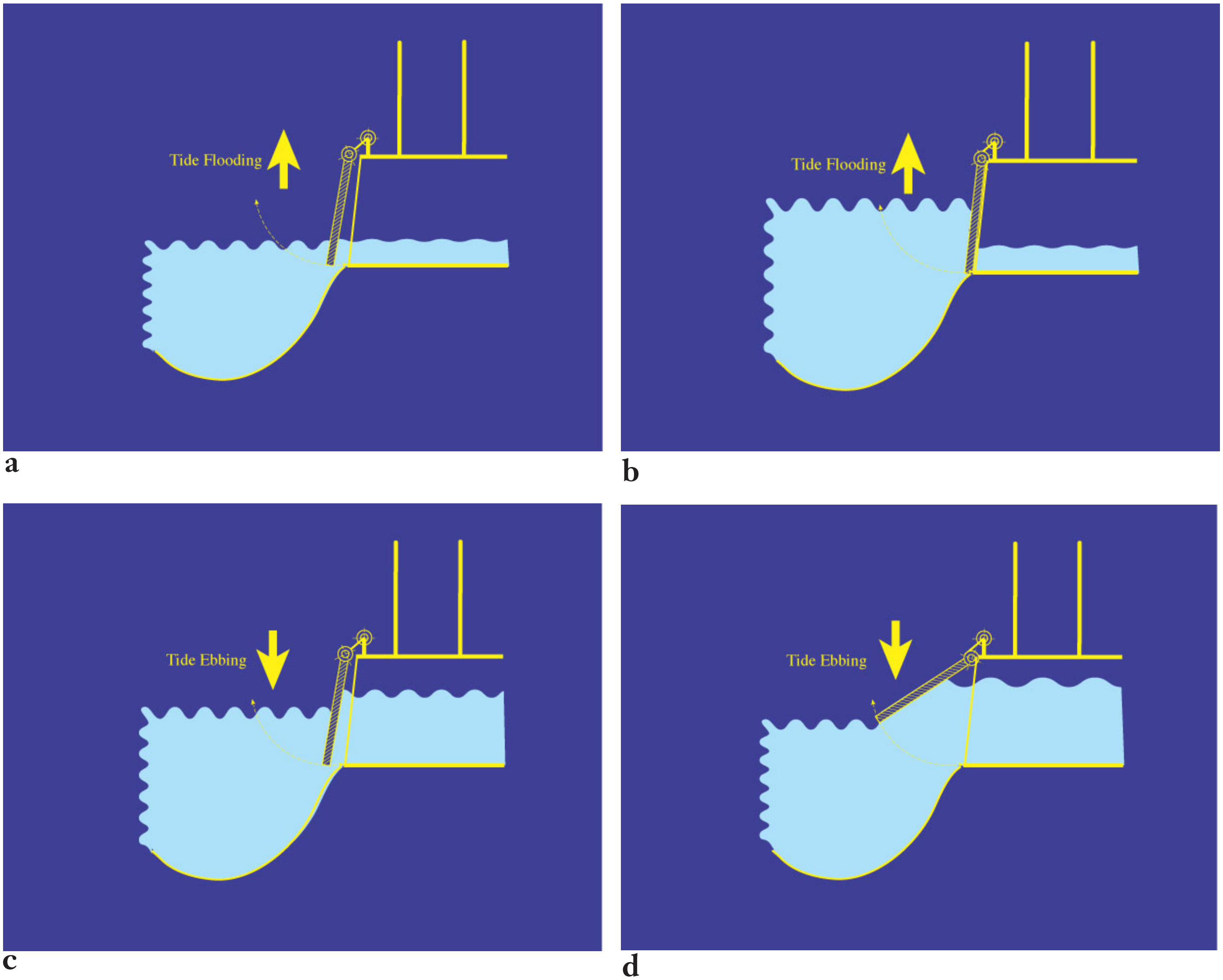



***Figure 2.*** *Side view of tide gate:* ***(a)*** *closing, as upstream water level drops and tide level (see arrow) begins to increase;* ***(b)*** *closed, as tidal water level gets higher (see arrow) than upstream freshwater level;* ***(c)*** *opening, as tidal water level becomes lower (see arrow) than the freshwater level inside culvert;* ***(d)*** *open, during low tide (see arrow) before upstream water level begins to decline.*

# Physical Effects of Tide Gates

## Changes to Channel Morphology

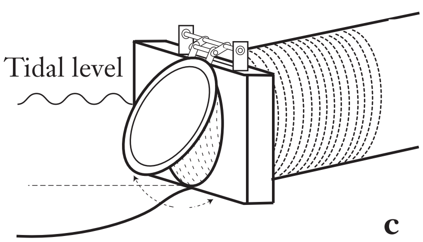
Channel morphology is altered by tide gates in two ways. First, upstream scour tends to form an inlet pool, and the water jet through the culvert forms a deep scour pool on the outlet end. Second, if the flood box is replaced and the bottom of the culvert is set at a lower level, then upstream erosion of the accumulated sediments could result in changes to the channel morphology.

## Changes to Water Temperature

Water temperature not only plays a critical role in affecting the speed at which many chemical processes occur (Richardson and Vepraskas 2001), but it is also extremely important in determining the suitability of habitat for different aquatic organisms. Water temperature criteria are established under the Clean Water Act for salmon and trout spawning (55°F) and nursery (64°F) habitats (ODEQ). In Oregon and Washington, limiting temperatures in coastal streams typically affects summer nursery habitat. This is because water temperatures during the spawning periods are below the spawning temperature standard. Because tide gates cause freshwater stagnation and restrict tidal inflow, they tend to increase upstream water temperatures. The increased period of water circulation allowed by side-hinged gates may result in lower water temperatures by reducing freshwater stagnation and augmenting cooler estuarine inflow.

a

b




c

***Figure 3.** Top-hinged tide gates **(a)** suspended with chains, **(b)** held in place by metal arms, and **(c)** illustrated.*

# Chemical Effects of Tide Gates

## Changes to Water Salinity

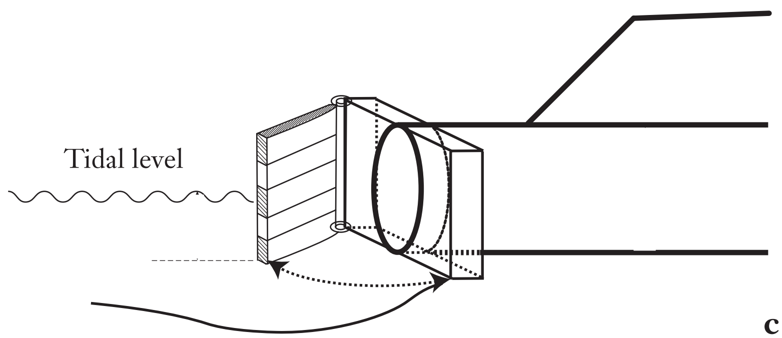
Salinity in wetland soils determines their oxidation-reduction potential, ultimately controlling soil pH. Soil pH, in turn, affects the sequestration and liberation of heavy metals.

Water salinity in estuaries varies daily and seasonally. Daily variations are influenced by tides, as water with higher salinity flows from the mouth of the estuary inland during flood tide and back toward the ocean during ebb tide. The extent of brackish water upstream is determined by the amount of tidal exchange (that is, the difference between high and low tides for any specific cycle) and by the amount of freshwater entering the estuary from tributary streams. In the Pacific Northwest, freshwater flow into estuaries varies by season, with high flows during the winter and spring and low flows during the summer and fall. Because salt water has a greater density than freshwater, it tends to occupy the lower portion of the water column. Thus, incoming salt water dives below the outgoing freshwater and creates a wedge that moves along the bottom. The size and shape of this wedge depend on the volume of freshwater that enters the estuary, the shape of the estuary, and the prevailing coastal currents.

A tide gate prevents the flooding of upland channels by brackish water. As a result, a dramatic difference in salinity exists between one side of the gate and the other. When the gate opens, pooled freshwater moves into

a b

*Figure 4.* ***(a)*** *On the left is a side-hinged round gate and on the right, in the same photo, is a top-hinged gate with a mitigator fish-passage device;* ***(b)*** *a side-hinged rectangular gate; and* ***(c)*** *(right) diagram of an open side-hinged gate.*




c

the estuarine channel, creating a tongue of fresher water that, through turbulence, mixes as it moves down the estuary. The speed of the salinity mixing—and the extent of the freshwater tongue—is related to the type and size of the gate, the amount of freshwater pooled upstream, and the relative difference in salinity between fresh and brackish water in the area (Jay and Kukulka 2003).

Over time, all tide gates begin to leak. Leaks occur if the seal between the gate and the supporting structure is uneven or if material is caught when the gate closes. Leaks are also common when culverts corrode or crack upstream from the gate. In addition, leaks may happen when salt water percolates through a dike's fill material because of the hydraulic pressure caused by high tides. Whenever brackish water enters the upland side of a dike, it occupies the bottom layer of water in upstream pools. This water may form residual pools of brackish water if the fresh-water outflow when a tide gate opens is insufficient to create the velocity needed to mix both layers of water.

## Changes to Heavy-Metal Concentration in Water

Soils in estuarine marshes are naturally anaerobic (that is, they lack oxygen). When the operation of tide gates begins to lower the salinity of soils on the upland side of dikes and periodically desiccate them, these soils become exposed to air, and a variety of aerobic (that is, oxygen-on their effects comes entirely from tide gate manufacturing companies.

### Tide Gates as Physical Barriers to Fish Passage

Two factors influence the degree that a tide gate represents a physical barrier for fish. One is the length of time the gate is closed and the other, the size of the opening.

Any tide gate represents a total barrier to fish passage during the time it remains completely closed. The length of this period depends on the magnitude of the tidal exchange (the difference between high and low tides), the water inflow into the upstream pool between opening cycles, and the degree to which this pool emptied during the previous cycle. Under normal conditions, top-hinged tide gates will not open until the water level inside the culvert is higher than the water level on the downstream side. These gates will close only when the water level on the downstream side is equal to or higher than the water level inside the culvert. Because tidal cycles are approximately 12 hours long and tides flood (flow in) about half of that time and ebb (flow out) the other half, top-hinged tide gates are expected to remain closed at least 50 percent of the time (that is, 6 hours within each cycle, assuming the upstream pool empties completely during each cycle and the gate closes by the combined effects of its own weight and slack tide). However, depending on how they are installed and the characteristics of the area they drain, gates may remained closed for longer periods. For example, Scalisi (2001) reported that during February 2001 the tide gate in Larson Slough, Coos Estuary, Oregon, opened 4 hours after the beginning of ebb tides and closed at slack tide, thus, representing a total barrier to fish passage 75 percent of the time.

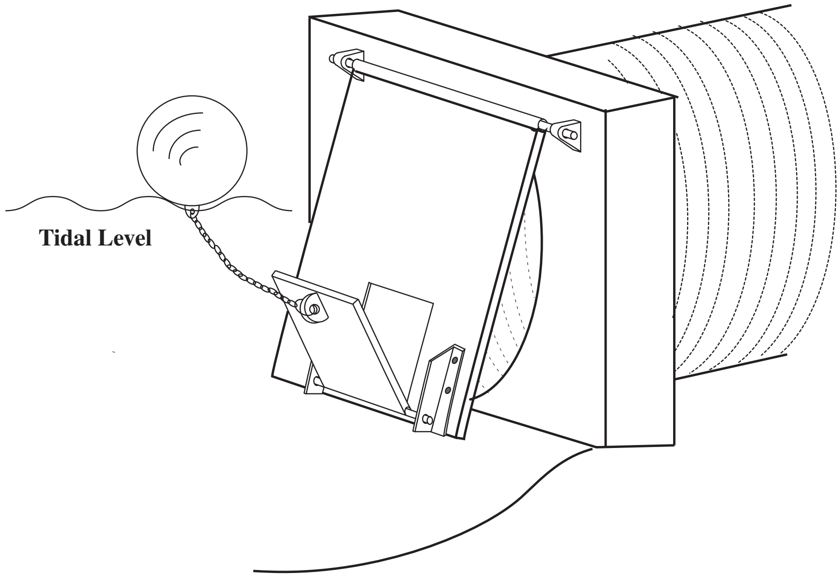



***Figure 5****. A top-hinged gate with a small "pet door" attached to floater.*

driven) processes begin in them (Richardson and Vepraskas 2001). If this occurs, immobilized, reduced sulfides combined with the soil iron are oxidized and converted into sulfates and sulfuric acid. These compounds make the soil acid (that is, lower its pH) (Anisfeld and Benoit 1997; Portnoy and Giblin 1997), and this acidification can cause the heavy metals in the soil (such as lead, copper, silver, and cadmium) to be released into the water (Anisfeld and Benoit 1997).

## Biological Effects of Tide Gates

Although tidal marshes provide critical habitat to many aquatic organisms (Healey 1982; Simenstad et al. 1982; Shreffler et al. 1990 and 1992), store upland sediments (Vranken and Oenema 1990; Portnoy 1999), and regulate floodwaters (Turner and Lewis 1997), the consequences of their alteration by diking and filling has not attracted the same attention from regulatory agencies as have other development projects. Whereas dams, roads, culverts, and water diversion projects have been the focus of many impact studies, and their construction or operations are tightly regulated, the impacts of dikes and tide gates on migratory fishes have received relatively little attention. Only recently have the effects of dikes and tide gates on salmon and trout movement and habitat access attracted the interest of agencies and watershed councils as salmonids began to decline in abundance (Nehlsen et al. 1991).

In the particular case of anadromous salmon and trout (which migrate from freshwater environments to the sea and back), tide gates are alleged to negatively affect them, not only by preventing their migration but also by deteriorating the quality and connectivity of their habitats. The notion that tide gates interfere with fish migration has encouraged the development of "fish-friendly" gate designs (Eliasen 1988; Thomson and Associates 2000). Unfortunately, studies on the effectiveness of such alternative designs have not been carried out by independent research institutions, and the limited information available

Because all tide gates block fish passage during all or most incoming tides, there is no such thing as a "fish-friendly" tide gate, only "fish-friendlier" ones. Compared to the most restrictive gates, a "fish-friendlier" installation should have a gate that opens wider and for longer periods of time, creates less water velocity and turbulence, and provides a gradual transition between fresh and salt water, with salinity refugia available for juvenile fish.

"Fish-friendlier" tide gate designs employ three mechanisms to increase the physical passage period. First, since gate weight determines the amount of water level difference required to open the gate and keep it open, the use of lighter materials such as aluminum, fiberglass, and plastics in both top-hinged and side-hinged gates will increase the time they remain open.

Second, because the "effective" weight (that is, the gate-closing force) of side-hinged gates is lower than that of top-hinged gates, side-hinged gates will open earlier and close later in a tidal cycle than top-hinged gates of equivalent size. Some side-hinged gates have been reported to require only one inch of water level difference to open up to 45° (Scalisi 2001). Such an opening angle with a small water level difference represents a significant improvement to fish passage when the width of the opening is factored in (one foot is considered the minimum for adult fish passage by the Washington Department of Fish and Wildlife).

A third mechanism employed to improve gate fish passage was designed by Leo Kuntz (personal communication). This mechanism is a float-activated cam, known as a *mitigator fish-passage device*, that is wedged between the gate and the mouth of the culvert to keep the gate open during incoming tides (see right tide gate in figure 4a). The floats regulate the amount of backflow allowed upstream before the gate closes when the cam is released by the upward movement of the floats under a rising tide. The tidal level at which the cam is released is adjustable to regulate upstream backwatering.

Tide gates not only constitute direct physical barriers to fish passage, but also create indirect obstacles to fish in the form of elevated water velocities and turbulence. Velocity criteria established for fish passage in culverts are similar to those used for tide gates. In Oregon, the water velocities recommended by the Department of Fish and Wildlife are 5 feet per second for adult salmonids in culverts 60 to 100 feet long, and 2 feet per second for juvenile salmonids (Robison et al. 1999).

Average water velocities through tide gates are a function of two things: (1) the upstream-downstream water level difference, which to a degree varies through the tidal cycle with different opening angles; and (2) the width of the opening, which also varies through the tidal cycle with different opening angles and which is influenced by the resistance of the gate to opening, depending on its weight and design. Water velocities through side-hinged gates are lower than through top-hinged gates of similar size and weight because less force is required to keep side-hinged gates open. Also, lighter aluminum gates require less force to open, and as a result, velocities through their openings are lower than with steel or cast-iron gates of comparable size.

Water turbulence results from the effects of shear forces caused by drag in water velocity at the edges of channels, through obstructions, or where differences in viscosity occur (Goldstein 1965). The width and the shape of the channel, its substrate composition, bank roughness, and protuberances in the channel all reduce the velocity of the layer of water that is in contact with the walls of the channel (or culvert, in the case of a flood box) in relation to the average velocity of the rest of the water column. When a critical threshold in the velocity difference between these layers of water is reached, turbulent flow results.

Turbulence and the associated bubbling of air in water cause vibration and noise that, depending on their magnitude, may represent obstacles to fish movement. Heavy top-hinged tide gates produce a high-velocity jet of water, called *vena contracta* (see figure 1b), which creates turbulence and bubbling (figure 3b) (Pethick and Harrison 1981). This water jet is caused by the combined effects of the upstream-downstream water level differences, the tendency of the gate to close by the effect of its own weight (or restorative force), and the size of the gate.

On the basis of our observations, turbulence seems to be lower with "fish-friendlier" side-hinged gates (figure 4b) than with top-hinged ones. Because the forces that tend to keep the gate closed are lower in both side-hinged and light-weight tide gates, the jet of water and its resulting water turbulence and bubbling are practically eliminated.

## Effects of Tide Gates on Salmon Nursery Habitats

Estuaries play a critical role in juvenile salmonid survival during the transition from fresh to salt water (Pearcy 1992). Estuarine habitats provide juvenile salmon with a productive feeding area, a refuge from marine predators, and a transitional zone for gradual acclimation to salt water (Thorpe 1994).

Because tide gates interfere with water flow in the boundary zone between estuaries and streams, they negatively affect the coastal marsh habitats of juvenile salmon. They do this not only by altering water quality and channel morphology, but also by changing the species of aquatic plants and invertebrates (for example, insects and crustaceans) that juvenile fish rely on for cover and food.

## Literature Cited


Anisfeld, S. C., and G. Benoit. 1997. Impacts of flow restriction on salt marshes: an instance of acidification. *Environmental Science & Technology* 31:1650–1657.

Charland, J. W. 1998. *Tide gate modifications for fish passage and water quality enhancement.* Tillamook Bay National Estuary Project, Garibaldi, Oregon.

________. 2001. *Alternative tide gate designs for habitat enhancement and water quality improvement.* Marine Environment Engineering Technology Symposium, Alexandria, Virginia.

Dahl, T. E. 1990. *Wetland losses in the United States: 1780s to 1980s.* U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Daiber, F. C. 1986. *Conservation of tidal marshes.* Van Nostrand Reinhold, New York, New York.

Doody, J. P. 2001. *Coastal conservation and management: an ecological perspective.* Kluwer Academic Publishers, Boston, Massachusetts.

Dreyer, G. S., and W. A. Niering. 1995. *Tidal marshes of Long Island Sound: ecology, history and restoration.* Connecticut College Arboretum Bulletin, Connecticut College Arboretum, New London, Connecticut 34:1–72.

Eliasen, R. 1988. *Side hinged flap gates: an alternative to salmonid migration barriers in flood drainage.* Department of Fisheries and Oceans, Nanaimo, British Columbia.

Frenkel, R. E., and Morlan, J. C. 1991. Can we restore our saltmarshes? Lessons from the Salmon River, Oregon. *Northwest Environmental Journal* 7:119–135.

Goldstein, S. (editor). 1965. *Modern developments in fluid dynamics: an account of theory and experiment relating to boundary layers, turbulent motion and wakes.* Vol. I. Dover, New York, New York.

Gregory, S. V., and P. A. Bisson. 1997. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. Pages 277–314 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. *Pacific salmon and their ecosystems: status and future options.* Chapman and Hall, New York, New York.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. Pages 315–41 *in* Victor S. Kennedy, editor. *Estuarine comparisons: proceedings of the sixth biennial international estuarine research conference, Gleneden Beach, Oregon, November 1–6, 1981.* Academic Press, New York.

Jay, D. A, and T. Kukulka. 2003. Revising the paradigm of tidal analysis—the uses of non-stationary data. *Ocean Dynamics* 42:1–16.

Kuntz, Leo. Personal communication. Nehalem Marine, 24755 Miami River Road, Nehalem, Oregon 97131.

Middleton, B. 1999. *Wetland restoration, flood pulsing, and distribution dynamics.* John Wiley & Sons, New York, New York.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* 16(2):4–21.

NRC (National Research Council). 1996. *Upstream: salmon and society in the Pacific Northwest.* National Academy Press, Washington, D.C.

ODEQ (Oregon Department of Environmental Quality). Chapter 340. Water pollution. Division 41. Statewide water quality management plan; beneficial uses, policies, standards, and treatment criteria for Oregon. http://www.epa.gov/ost/standards/wqslibrary/or/or_10_wqs.pdf

Pearcy, W. G. 1992. *Ocean ecology of North Pacific salmonids.* University of Washington Press, Seattle.

Pethick, R. W., and A. J. M. Harrison. 1981. The theoretical treatment of the hydraulics of rectangular flap gates. Pages 247–254 *in Proceedings, 19th congress, International Association for Hydraulic Research, New Delhi, India 1–7 February 1981.*

Portnoy, J. W. 1999. Salt marsh diking and restoration: biogeochemical implications of altered wetland hydrology. *Environmental Management* 24:111–120.

Portnoy, J. W., C. T. Roman, and M. A. Soukup. 1987. Hydrologic and chemical impacts of diking and drainage of a small estuary (Cape Cod National Seashore): effects on wildlife and fisheries. Pages 254–65 *in* W. R. Whitman and W. H. Meredith, editors. *Waterfowl and wetlands symposium: proceedings of a symposium on waterfowl and wetland management in the coastal zone of the Atlantic flyway.* Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

Portnoy, J. W., and A. E. Giblin. 1997. Effects of historic tidal restrictions on salt marsh sediment chemistry. *Biogeochemistry* 36:275–303.

Raemy, F., and W. H. Hager. 1998. Hydraulic level control by hinged flap gate. *Proceedings Insitute of Civil Engineers, Water, Maritime, and Energy* 130:95–103.

Richardson, J. L., and M. J. Vepraskas (editors). 2001. *Wetland soils: genesis, hydrology, landscapes, and classification.* CRC Press, Boca Raton, Florida.

Robison, E. G., A. Mirati, and M. Allen. 1999. *Oregon road/stream crossing restoration guide: spring 1999.* Advanced fish passage training version. Oregon Department of Forestry, Salem, Oregon.

Scalisi, M. 2001. Larson Slough tidegate study: an investigation of the hydrodynamics across the Larson Slough Inlet and water quality of Larson Slough. Second Draft Report to the Coos Watershed Association.

Schultz, S. T. 1990. *The Northwest coast: a natural history.* Timber Press, Portland, Oregon.

Shreffler, D. K., C. A. Simenstad, and R. M. Thom. 1992. Foraging by juvenile salmon in a restored estuarine wetland. *Estuaries* 15:204–213.

Shreffler, D. K., C. A. Simentstad, and R. M. Thom. 1990. Temporary residence by juvenile salmon in a restored estuarine wetland. *Canadian Journal of Fisheries and Aquatic Sciences* 47:2079–2084.

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. Pages 343–364 *in* V. S. Kennedy, editor. *Estuarine comparisons.* Academic Press, New York, New York.

Thomson, A. R., and Associates. 2000. *Flood boxes as fish migration barriers in lower mainland streams.* Prepared for the Ministry of Environment, Lands and Parks, Region 2, Vancouver, B.C.

Thorpe, J. E. 1994. Salmonid fishes and the estuarine environment. *Estuaries* 17:76–93.

Turner, R. E., and R. R. Lewis. 1997. Hydrologic restoration of coastal wetlands. *Wetlands Ecology and Management.* Special issue: Hydrologic restoration of coastal wetlands 4:65–72.

USACE (U.S. Army Corps of Engineers). 2001. *HEC-RAS river analysis system—hydraulic reference manual. Version 3.0.* U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, UC Davis, California.

Vranken, M., and O. Oenema. 1990. Effects of tide range alterations on salt marsh sediments in the Eastern Scheldt, S. W. Netherlands. *Hydrobiologia* 195:13–20.

OREGON STATE UNIVERSITY

This research and publication were funded by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration, under NOAA grant number NA76RG0476 (project number R/HBT-07-PD), and by appropriations made by the Oregon State legislature. The views expressed herein do not necessarily reflect the views of any of those organizations.

Sea Grant is a unique partnership with public and private sectors, combining research, education, and technology transfer for public service. This national network of universities meets the changing environmental and economic needs of people in our coastal, ocean, and Great Lakes regions.

## Credits

*Editing and layout:* Sandy Ridlington
*Illustrations:* Jon A. Souder
*Photographs:* Coos Watershed Association

ORESU-G-04-002