Flap Gate / Tide Gate Alternatives

This document lists many of the available alternatives for flap gates and tide gates. It also includes my opinions and observations regarding the pros and cons of each design. If you are aware of some other flap gate / tide gate alternatives, or if you have comments regarding anything in this document, please e-mail me at Jeff.Juel@Jueltide.com. I will modify and expand this document periodically.

Top Hinged Flap Gates

Photo 1- Cast iron or ductile iron flap gate by Hydro Gate

Top hinged flap gates have been in use at tide gates for centuries. Top hinged flap gates are typically made from wood, cast iron, steel, aluminum, FRP (fiber reinforced polymer), or fiberglass. Designs are produced by a number of manufacturers. I have seen or worked on numerous top-hinged flap gates including some made of treated timbers with weights attached that simply hang on heavy chains (see photo below).

Light weight varieties of top hinged flap gates have less head loss and allow upstream fish passage under some flow conditions. None of the top hinged flap gate designs allow backflow unless they leak or are tied or propped open.

The photo to the right shows one of three very large timber flap gates as it is being removed from the Highway 101 bridge where it crosses the Chinook River near Ilwaco Washington.

Photo 2 - Large timber flap gate

Pros:

- Very simple operation.
- Reasonably durable and reliable[1].
- Prevents salt water intrusion.

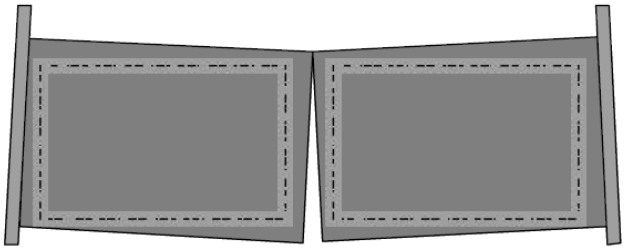
Cons:

- Does not allow tidal flushing. This dramatically degrades the water quality of upstream watercourse and also causes sedimentation in the flow channel.
- If water-tight or nearly water-tight, a flap gate dramatically lowers the surface water and ground water levels upstream[2]. During dry periods, if there is any surface water upstream from a flap gate, it will typically be stagnant with low dissolved oxygen and poor water quality. Dry & hot weather will result in significantly elevated water temperatures.
- Top hinged flap gates don't pass floating debris easily. Debris may have to be manually removed periodically.
- Heavier flap gates don't open very wide. This results in significant head loss at the flap gate which reduces the conveyance capacity of the outlet.
- Fish have difficulty passing a heavy flap gate since it is frequently closed. When open, the flap gate is only slightly cracked open, frequently precluding fish passage due to the high velocity flow at the opening.
- Aluminum flap gates open wider, but they have been reported stolen and presumably sold for scrap.
- If the metals used are subject to corrosion or if mixed metals are used, sacrificial anodes are required. Sacrificial anodes have to be inspected and replaced periodically. Failure to replace sacrificial anodes can result in severe corrosion.
- If the flap gate closes on debris and then experiences a large seating head, the wracking forces can damage the flap gate and/or hinges.

[1] Cast Iron is brittle and will shatter if over-stressed. A 60" Waterman flap gate at The Port of Umpqua catastrophically failed and broke into four pieces in January 2010.

[2] Wetlands located upstream from flap gates are effectively dewatered during dry periods.

Side Hinged Tide Gates



Large, side hinged tide gates are angled inward, providing a small closing force, and are typically mounted over large, rectangular culverts.[3]

Sketch 1 – Side Hinged Tide Gates

Pros:

- Very simple operation.
- Reasonably durable and reliable.
- Opens wide with little flow - allowing fish passage during outflow.
- Does not collect floating debris. (A trash rack is normally not required at side-hinged flap gates.)

Cons:

- Does not allow tidal flushing (unless lashed or propped open).[4]
- Fairly large forces are imposed on the hinge mechanism due to the cantilevered gate leaves.
- Large racking forces can occur if the flap gate closes on debris near the hinge.

Tide Flex Valve by RedValve

Photo 1 - Tide Flex Series TF-2 Check Valve

Tide Flex valves are also known as a "duckbill style check valve". The valve is attached to the downstream (tidal) end of a culvert. The check valve is made of a flexible synthetic material that deforms to provide an opening in the duckbill when there is a higher water level on the upstream end of the culvert.

Pros:

- Extremely simple operation
- Very durable and reliable

Cons:

- The device is virtually water-tight and does not allow any backflow for tidal flushing.
- The tide flex valve does not open very wide under low flow and only passes very small floating debris. Accumulated debris may have to be removed periodically. Manual removal of debris is very difficult.
- Rodents (muskrats) have been reported to chew on the tide gate.
- Head loss at this type of valve may be unacceptable.[5]

[3] From Tide Gate Modifications for Fish Passage and Water Quality Enhancement – Tillamook Bay National Estuary Project by Jay Charland, August 27, 1998.

[4] Someone must release the gates prior to floods or high water. If the tide gates remain lashed open during a flood, there will be liability issues.

[5] If you would like a Tide Flex valve, I have a contact with the City of Aberdeen who would love to sell a couple of Tide Flex valves that are like new and have been in storage for years. They were installed and then removed because they had excessive head loss and were nearly impossible to keep free of debris.

Sluice Gate with Electric Operator

<no photo available at this time[6]>

A motorized vertical lift slide gate or sluice gate is probably the most obvious alternative for a water control device that can be used to allow tidal flushing while preventing flooding during extreme tides. A number of suppliers are capable of providing a motorized sluice gate. A Program Logic Controller (PLC) can be programmed to operate the electric motor which raises and lowers the sluice gate. Limit switches detect when the gate is in the fully open or fully closed position. Intermediate gate positions are detected via a rheostat or some other device. Sensors monitor the water levels upstream and downstream from the sluice gate and provide input to the PCL. The PLC directs the electric motor to raise or lower the sluice gate according to the logic programmed in the PCL. The sluice gate can be fully open, fully closed, or partially open at any time depending on the water levels upstream and downstream of the sluice gate and the programming of the PCL.

There will be two operating modes with separate control schedules to address normal conditions and storm conditions. During normal operations, the gate will programmed to remain open until water levels reach a set elevation for a defined length of time, at which point it will close. In effect, natural tidal fluctuations will occur unless action is needed to prevent flooding of upstream properties.[7]

This alternative requires electric service at the tide gate.

Pros:

- The operation of the sluice gate (via the programming of the PCL) can be very sophisticated and can be modified over time if needed.
- The sluice gate can be used to impound water upstream from the tide gate[8].

Cons:

- Relatively complicated. [9]
- Relatively expensive.
- Requires reliable electrical service at the tide gate site and/or a power monitoring system with alarms and/or a backup power system.
- Requires a maintenance person capable of operating and programming the PCL.
- This device is not particularly fail-safe. Power outages, motor breakdowns, PCL programming errors, etc can result in the sluice gate being open when it should be closed and vice versa.
- Someone will be responsible to pay a monthly electric bill.

[6] This alternative is currently being considered for a project that is under design by Vine Associates. I am not aware of any existing tide gates that utilize this design. Similar systems are used in sewage treatment plants.
[7] E-mail correspondence from Gregory Robbins, Vine Associates, December 2009.
[8] This will reduce tidal flushing and negatively affect water quality. It will also preclude fish passage during part of the tide cycle while the sluice gate is closed.
[9] The PLC and motor control device is normally provided by a different supplier than the motorized sluice gate.

Waterman / Nekton Self-Regulating Tide Gate

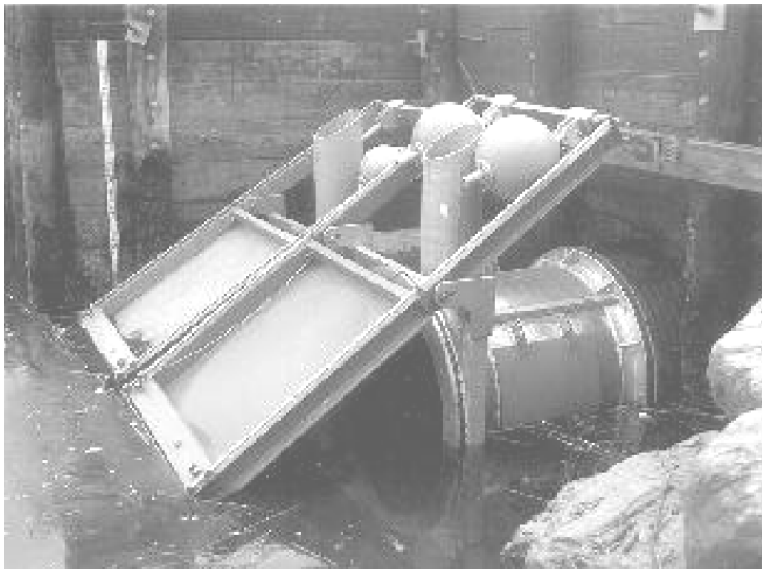


Photo 2- Self Regulating Tide Gate by Waterman Industries

This is the original "Self Regulating Tide Gate" (or "SRT") which has been produced by Waterman Industries for at least 20 years. The flap gate is top-hinged and uses a buoyant plate (the "lid") along with floats which are secured to the frame above the culvert. The position of the spherical floats controls when the tide gate closes on a rising tide. The buoyant tide gate lid floats open with the rising tide. As the water level continues to rise, at some point the floats above the culvert become submerged and their buoyancy forces the lid to close, stopping the backflow through the culvert. For the configuration shown in the photo above, the "trip elevation" (the water level at which the gates close) must be higher than the top of the culverts. The culverts are vented to prevent water hammer when the lid slams shut during pipe-full flow.

The buoyant lid works to open the flap gate; the float above the gate and the draft force caused by the water flowing through the culvert work to close the flap gate.

Pros:

- Relatively simple operation.
- Floating debris is usually swept from the gate by high flows.
- Allows substantial volumes of tidal flushing.

Cons:

- Floating debris could become tangled in the frame above the culvert and interfere with the operation of the flap gate.
- Adjusting the floats to change the elevation at which the gate closes is difficult and limited to a small range.
- This type of flap gate can slam shut[10]. If the pipe can be flowing full when the gate closes, a vertical vent should be installed in the culvert behind the SRT to prevent a high pressure shock wave caused by water hammer. After the gate slams shut, surges can cause the gate to open and close several times.
- During very high water levels, the submerged vent tubes will pass flood water upstream.
- A Waterman SRT was installed at Edison Slough in Skagit County WA around 2003. It could not be made to operate properly and was removed in 2006[11].

[10] I have never watched this type of tide gate in operation. I suspect that it always slams shut. The associated noise may be unacceptable if the tide gate is located in a populated area and closes with regularity.

[11] For some strange reason, Golden Harvest included a photograph of the Waterman SRT installed at Edison Slough in their on-line tide gate catalog. They didn't provide the tide gate and it didn't work properly.

Mitigator Fish Passage Device, by Nehalem Marine / Leo Kuntz

Photo 3 - Coalbank Slough

What makes this tide gate different from other traditional top-hinged tide gates[12] is the Mitigator Fish-Passage Device that is attached to the tide gate. The Mitigator Fish-Passage Device is a float-operated, cam-lock system that prevents a portion of the tide gate from closing during the lower part of the flood tide. [13]

In the photo to the left, the entire top-hinged flap gate is only slightly cracked open due to low flow on the outgoing tide. Later, when the flap gate seats against the headwall, the cam will force the lower half of the flap gate to swing open about a horizontal hinge axis – the "armed position". The cam will hold the gate open 4 to 5" for the first part of the flood tide. When the floats become submerged during the flood tide, the Mitigator shaft rotates to the closed position and the lower half of the flap gate will close.

This prevents excessive flooding of the interior but still provides the interior with a muted tidal flush. (Note: The flap gate in the background is simply a free-swinging side-hinged flap gate that opens wide on the ebb tide.

Pros:

- Very inexpensive
- Allows some degree of interior muted tide & flushing – "up to 25% of the ebb flow".
- There are probably more tide gates equipped with Mitigators than any other fish passage device - yet not a single report of a failed unit.[14]

Cons:

- Adjustment very limited - door opening limited to range of the Mitigator cam.
- Adjusting the floats to change the elevation at which the gate closes would be difficult.
- Floating debris could potentially damage or interfere with the operation of the floats. (See below.)

This photo was taken at a headwall which has an old-fashioned top-hinged flap gate. This is an extreme case, but large floating debris is not unheard of at tide gates.

Apparently this has not happened anywhere, but it is not unreasonable to presume that a large log floating in the area during a high tide is capable of interfering with or destroying the float mechanism on a Mitigator Fish Passage Device.

[12] This device can also be used with side-hinged flap gates. (e-mail from Leo Kuntz)
[13] From Tide Gates in the Pacific Northwest - Operation, Types, and Environmental Effects (page 17) by Guillermo Giannico and Jon A. Souder.
[14] E-mail from Leo Kuntz.

Guiotine Door, by Nehalem Marine / Leo Kuntz

The gate on the left in this photo is a standard rectangular top hinge flap gate that is mounted on a concrete headwall. The hinge is mounted on a lead screw and the entire door just crawls up the wall for an adjusted aperture.

The aperture results in more backflow occurring during unusually high tides and on days where the higher low water is unusually high.

This design is operationally similar to Golden Harvest's model GH 52-SC. (See page 10.)

Pros:

- Allows some degree of interior muted tide & flushing
- Can be fully open, fully closed, or any setting in between

Cons:

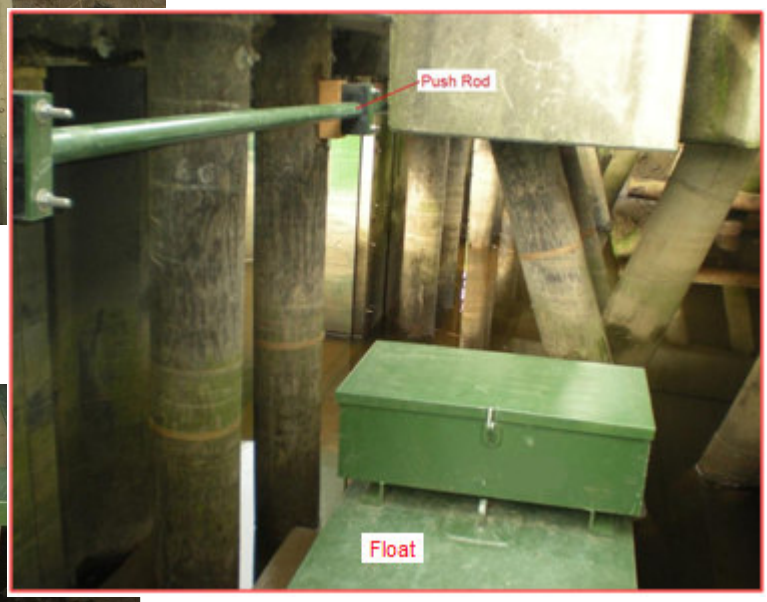
- Requires hands on management (frequent adjustments to prevent upstream flooding)

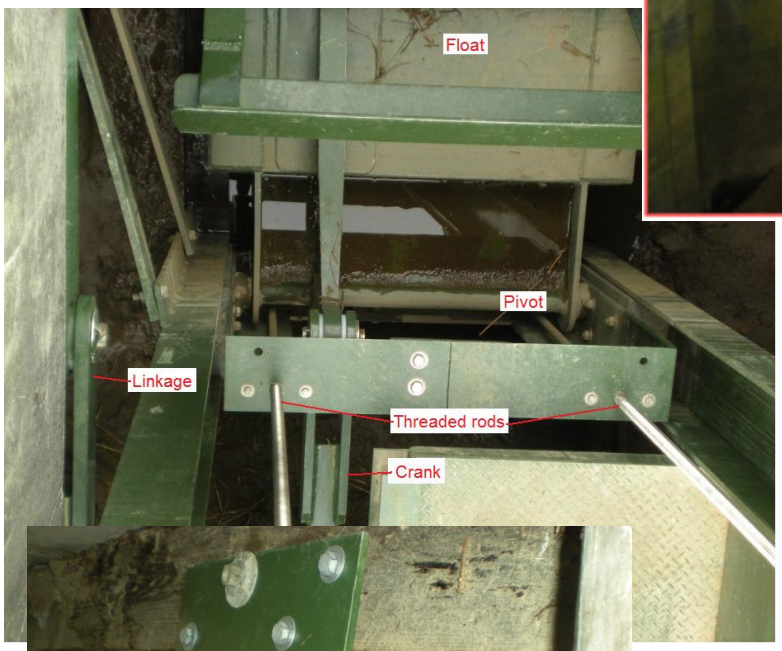
Muted Tide Regulator, by Nehalem Marine / Leo Kuntz

These photos are of the Muted Tide Regulator Installed at Fisher Slough near Conway in Skagit County in 2009.

This structure has three large side-hinged flap gates. A large float located on the protected side of the tide gate pivots about a horizontal hinge with the changing water levels. The hinge elevation can be raised or lowered to adjust the interior inundation level to a very exact level.

As the float falls, levers and linkage move the arms (one arm is shown/circled in the photo above) so as to push the gate open.





The photo to the left is looking down on the frame and pivot axis for the float. The threaded rods allow the hinge pivot for the float to be raised or lowered.

The float (at the top of photo) rotates about the hinge axis thereby moving a crank arm that operates a mechanical linkage system.

The push rod moves right or left as the float rises and falls moving the arms such that the flap gates are allowed to close or are pushed open, respectively. The photo to the left shows a pivot mechanism. The push rod moves the lever to the left which moves the arm which pushes the tide gate open, or retracts and allows the tide gate to close.

Pros:

- Allows tidal flushing.
- The design is well built and installed by a competent and ethical company.
- The only system available in US and Canada that is controlled by interior inundation level.[15]
- Allows a large range of fish passage and controlled tidal flooding
- Provides a default "open" tide gate system (tide gates are in the open position any time the interior level allows it)
- Operates without hydraulics, external power, cables etc.
- Large range of adjustment and making adjustments is relatively easy.
- Requires no ebb flow to open. (The weight of the float will force the gate open even against a small head pressure.)

Cons:

- The system is expensive and contains many moving parts
- The paint system[16] is less desirable than unpainted stainless steel, fiberglass, or rigid copolymer.

Armtec Side Opening Flap Gate

Photo 4 - Side Opening Flap Gate at Nanaimo BC

The photo to the left is a side-hinged flap gate installed at Namaimo BC. The tide gate was installed with a torsion spring on the hinge. The spring was initially installed and tensioned “for closure assistance”. As an afterthought, the spring was tensioned to hold the tide gate open - thereby allowing some backflow. The spring began corroding badly and in 2009 the spring was replaced with a very expensive stainless steel spring.

The trash rack is potentially problematic. Accumulated debris on the trash rack will reduce flow at the structure, potentially exacerbating flooding. Accumulated debris will have to be removed periodically. Floating debris can get inside the trash rack where it will wash back and forth with the ebbing and flooding tides. This trapped debris could interfere with the flap gate and prevent the tide gate from closing completely. A long tree limb could pass partially through the trash rack and protrude into the culvert. This would prevent the tide gate from closing completely and could cause significant backflow and flooding.

Pros:

- Allows some tidal flushing.
- Minimal head loss during outflow.

Cons:

- Mixed metals in salt water - the gate was fabricated using 304 stainless steel and aluminum. If the insulated connectors fail, severe corrosion may occur.
- 304 stainless steel was used – this is not the best grade of stainless steel for salt water exposure. 316 stainless steel is a superior choice.
- The gate doesn’t open very wide.
- The stiffness of the spring is not adjustable.
- Apparently this tide gate requires a trash rack which must be cleared of debris periodically.

[15] The hydraulically controlled tide gate (the Aberdeen / GH-850) could easily be set up so that the float senses the interior water level. This is largely an academic point. See my web site at www.jueltide.com for a discussion on this subject.

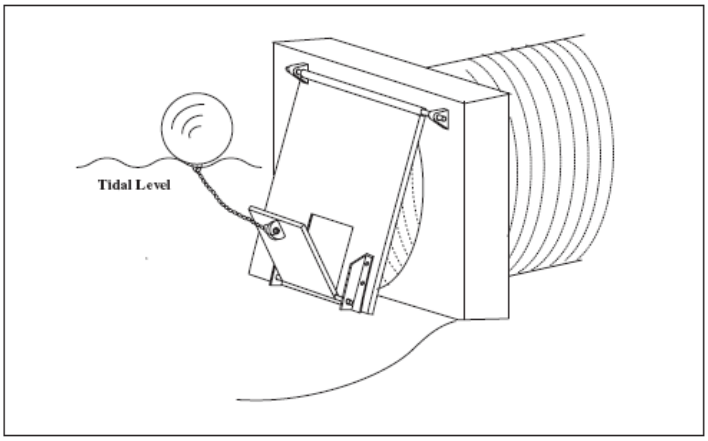
[16] The paint may be purely aesthetic. If it protects the metal, it will require touch-up and recoating periodically - unless it is indestructible paint.

Tide Gates Produced By Golden Harvest

Kevin Buchanan, the owner of Golden Harvest, boasts that with his collection of tide gate designs, he is "like a paint store selling several colors of paint".[17] In my opinion, the various designs are simply a parade of Golden Harvest's multiple attempts to produce, copy, or steal a viable self regulating tide gate design. But you can be the judge.

The following tide gates are currently produced, or have been produced by Golden Harvest:

Bottom-Hinged Pet Door



On a rising tide, the large flap gate is closed and the smaller gate – the "pet door" – eventually closes when the water level is high enough to float the ball on the chain. [18] This design is the brain-child of OSU graduate student Jay Charland[19]

When the pet door is partially submerged, the backflow through the open "pet door" is effectively the flow over a weir. The amount of flow is proportional to the head differential (ΔH) to the 3/2 power.

As the tide rises, the flow increases dramatically as the table below shows:

ΔH	$\Delta H^{3/2}$
1	1.0
2	2.8
3	5.2
4	8.0
5	11.2

When the opening is completely submerged, the backflow is proportional to the tail water height above the invert (h) times the head differential to the ½ power $(H-h)^{1/2}$.

The dramatically increasing flow rate caused by a rising tide and growing head differential is a recurring problem with Golden Harvest's Pet Door, Fish Flap, and Combination Gate (GH-52 SC) designs. A tide cycle having a sustained high water level due to a high low tide between two high tides pushes considerably more water through the opening than an average tide. This can result in excessive water levels upstream.

Pros:

- Very simple operation.
- Fish can pass through the "pet door" - until it gets plugged with debris.
- Allows some tidal flushing - until the door closes.

Cons:

- The "pet door" tends to get plugged with debris.
- The "pet door" is too small to allow much tidal flushing and flow velocities through the pet door are very high through most of the rising tide. I suspect that the pet door is drawn closed early during the flood tide by the draft of the back flow. The ball and chain is probably irrelevant.
- It will not work in most (any?) locations.[20]
- Golden Harvest produced this device for the Tillamook Bay area, but it appears that they no longer actively sell this device since it is not mentioned in their on-line tide gate catalog.

[17] Personal Conversation, June 2008.
[18] The Effects of Tide Gates on Estuarine Habitats and Migratory Fish by Guillermo R. Giannico and Jon A. Souder
[19] OSU Develops Fish Friendly Tide Gate (2/18/98) http://oregonstate.edu/dept/ncs/newsarch/1998/Feb98/tidegate.htm
[20] Top-hinged tide gates with bottom-hinged pet doors have been installed in Tillamook Bay, Oregon (Charland 1997). "*However, as in the case of the tide gates with top hinged pet doors in Tillamook Bay, the gates with bottom hinged pet doors failed and were replaced with traditional top-hinged tide gates.*"

Golden Harvest GH-52SC Combination Gate

This tide gate is essentially a top-hinged flap gate mounted on a frame with a mechanical lift that allows the flap gate to be raised and lowered. When completely lowered, this is simply a top hinged flap gate that allows no backflow.

When partially raised, the flap gate allows throttled backflow through a submerged orifice when the tidal water level downstream is higher than the water level upstream from the flap gate. The backflow passes beneath the bottom edge of the partially raised (and closed) flap gate. There can several feet of differential head driving the flow beneath the flap gate. The backflow rate increases rapidly with the rising tide.

When fully raised, the flap gate is completely above the opening in the headwall, allowing unimpeded tidal exchange.

In September of 2006, two large GH-52SC tide gates were installed[21] where the Chinook River passes beneath Hwy 101 southeast of Ilwaco WA.

Photo 5 - Combination Gates were installed to replace existing timber flap gates on Highway 101 Bridge crossing the Chinook River.

Pros:

- The aluminum flap gate is very light weight and opens wide under moderate out flow.
- Golden Harvest does not show this tide gate in their on-line tide gate catalog. (It does not function well at the Chinook River, so they presumably do not market this design.)
- If/when the tide gates are removed, the aluminum can be recycled.

Cons:

- At present, the tide gate is raised to allow backflow only during summer months.[22]
- When partially (or fully) raised, the amount of backflow and the upstream water level will vary dramatically with variations in the tide levels downstream. Extreme high tides will result in very high backflow rates and excessive water levels upstream.
- Tides that are high for extended periods of time will result in a large volume of water passing beneath the tide gate.
- While allowing backflow, floating and water-logged debris could be drawn into and hang up on the partially raised flap gate. This could prevent the gate from being lowered manually.
- The flap gate must be manually raised and lowered to increase or decrease the amount of backflow.
- Raising and lowering the gate is labor-intensive and requires a large hydraulic power operator on a trailer.
- Sacrificial anodes must be checked and replaced periodically.

[21] Jeff Juel designed the stainless steel tapered boxes that the flap gates are mounted to (for Quigg Brothers – the contractor who installed the flap gates) and also assisted with the installation of these flap gates. He had no involvement in the design of the gates themselves.

[22] Personal communication with Kyle Guzlas, Washington Dept. of Fish & Wildlife, December 2009.

Golden Harvest Model GH-35

Photos 6 & 6- Golden Harvest Model GH-35

This tide gate is identical to the Waterman SRT[23]. Golden Harvest has told people that they purchased the rights to this design from Waterman Industries around 2004.[24] The photo above on the left was copied from Golden Harvest's on-line tide gate catalog, however this particular tide gate was actually an SRT fabricated by Waterman Industries and delivered to Skagit County in 1998.[25]

In the photos above, the floats have been removed from the attachment points on the frame above the culvert and instead are attached to arms extending behind/down and alongside the culvert. The reason for revising the location of the floats was to cause the tide gate to close earlier during a rising tide – thereby reducing the upstream water level. The tide gate did not function properly and sporadically flooded the upstream property owner. [26] In 2006 (after this photo was taken), Skagit County let a contract to remove the GH-35 and replace it with a regular top-hinged flap gate. A Golden Harvest model GH-850 (see the photo on page 16) was then installed on the culvert to the right of this culvert. It failed to operate properly and was stuck shut continuously.[27]

Pros:

- Same as for the Waterman SRT.
- Should be competitively priced. If you are interested in this tide gate alternative, be sure to also get a price from Waterman Industries at (800) 331-0808.

Cons:

- Same as for the Waterman SRT

[23] If you compare Golden Harvest's on-line tide gate catalog http://www.goldenharvestinc.com/pdfs/catalogs/tide_gate_cat.pdf to Waterman Industries' documentation regarding their Self Regulating Tide Gate http://watermanusa.com/PDF/SRT.pdf it is obvious that Golden Harvest not only copied Waterman Industries' tide gate design, they also plagiarized much of the documentation.

[24] *"…it is my understanding that the Golden Harvest Company bought out Waterman Industries about 6 to 8 years ago, including Waterman's patents and marketing material."* - E-mail from Tom Slocum (Washington Conservation Districts Northwest Region Engineer) to Jeff Juel dated December 8, 2009. In an e-mail dated December 8, 2009, the CEO of Waterman Industries informed me (Jeff Juel) that this is patently false.

[25] E-mail from Waterman Industries CEO dated 22 December 2009.

[26] Personal communication with Duane Eitreim, the upstream property owner.

[27] Personal communication with Duane Eitreim, the upstream property owner.

- Golden Harvest (or Waterman Industries?) was not able to get this design to work properly at Edison Slough.[28] The upstream property owner at this site (located in the town of Edison in Skagit County Washington), reports that he observed the tide gate slam shut and then pop open 21 times on a single tide. This particular flap gate flooded the upstream property several times.[29] The tide gate was eventually removed and a Golden Harvest Model GH-850 was installed. (See page 16.)

Golden Harvest Model GH-37[30]

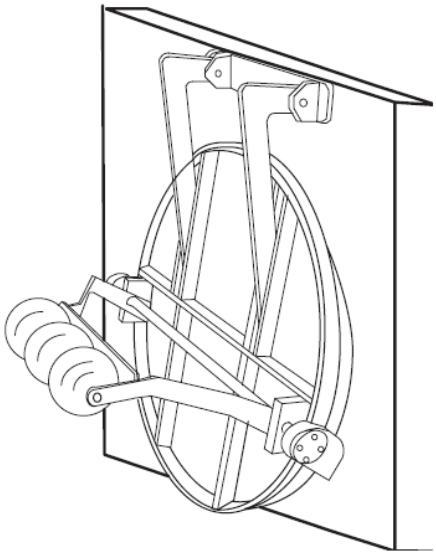


Photo 7 – Golden Harvest Model GH-37 at Beaufort SC

The photo above is from Golden Harvest's on-line tide gate catalog. This tide gate is not identical, but is operationally similar to the Mitigator Fish Passage device produced by Leo Kuntz - which is shown to the right of the photo[31]. In both designs, the floats activate a cam that allows the lower half of the tide gate to close when the floats are lifted by the rising tide.

I do not have first-hand knowledge regarding the operation of this type of tide gate

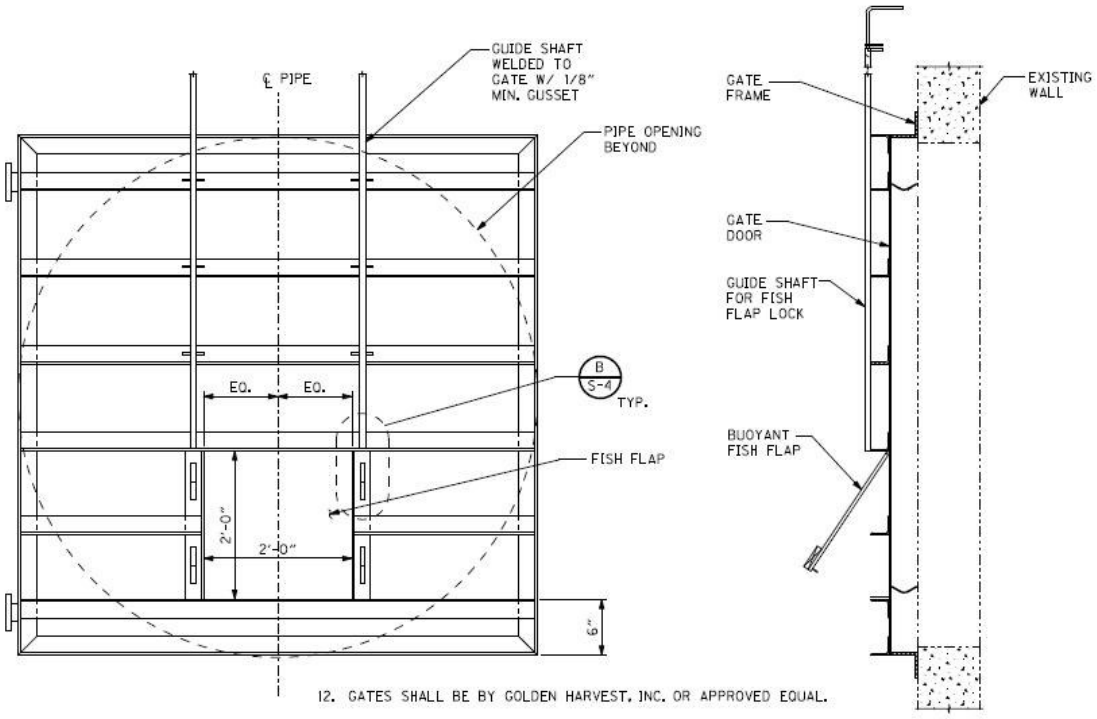
I presume that the pros and cons that apply to the Mitigator Fish Passage Device (produced by Leo Kuntz) also apply to the Golden Harvest Model GH-37.

What will they think of next???

[28] In spite of this particular tide gate installed at Edison Slough not being theirs, not working properly, and ultimately being removed, Golden Harvest uses a photo of this tide gate in their on-line Tide Gate Catalog.
[29] Personal communication with Mr. Duane Eitriem, January 2009.
[30] Manufactured exclusively by Golden Harvest, Inc. Under GHI patent #US 6,779,947 filed on 8/21/2003
[31] In November 2009, I met Leo Kuntz and I asked him about the similarities between his tide gate design and the Golden Harvest GH-37. He replied that he was aware of Golden Harvest and "their" tide gates, but he didn't pay too much attention to them. He felt that Golden Harvest has difficulties producing working self regulating tide gates - so they are actually not much of a threat. He told me that he just ignores them.

Answer:

Golden Harvest "Fish Flap"



The above drawing is from a design by KPFF[32] for the Portland District USACE for a tide gate for the Tenasillahe Island Restoration Project. The drawing included a note reading: "Gates shall be by Golden Harvest, INC. or approved equal[33]." It is likely that Golden Harvest provided the tide gate design to KPFF. The drawing was stamped and signed on January 11, 2007[34]. This design is an obvious variation of Golden Harvest's bottom hinged "pet door" design (see page 9). The "pet door" is now hinged on top and is set in a side-hinged flap gate rather than a top-hinged flap gate. For this incarnation it's called a "Fish Flap" rather than a "Pet Door"[35]. Golden Harvest had to have known that their "Pet Door" designs installed at Coos Bay years earlier were a bust. What made them think this variation would work any better?

One of the problems with the Coos Bay "pet door" tide gates was that the velocity through the pet door was excessive on the rising tide. This should not have come as a surprise. The analysis is fairly simple.

Imagine that the low tide on a given date is below the invert of the culvert. As the flood tide progresses, the buoyant "fish flap" opens as the water level rises. The quantity of water passing through the 2'-0" wide opening is small relative to the storage volume upstream from the tide gate, hence a head differential will develop at the "fish flap" opening. When the opening is partially submerged by the flood tide, the flow through the opening is defined by the equation for

[32] KPFF is a very reputable A/E firm, however, tide gates are such an obscure engineering topic that even a capable A/E firm like KPFF will have difficulty producing a viable design – or recognizing a design that has fundamental flaws. For some reason, even the Portland District USACE thought this tide gate design had merit.

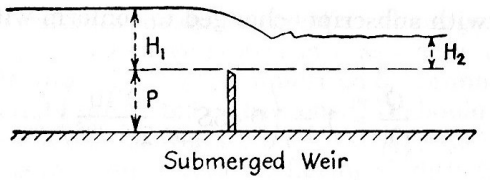
[33] Good luck being an approved equal (see footnote 55 on page 17).

[34] This was only one month after the end date of the contract to install Golden Harvest's newly acquired GH-850-R tide gates at Edison Slough (which didn't work) and McElroy Slough (which worked). If they had used the GH-850 for this project, statistics suggest that they would have had a 50/50 chance of it working.

[35] This design looks exactly like a pet door, so why the name change?

the discharge over a submerged broad crested rectangular weir,

$$\frac{Q}{Q_1} = \left[1 - \left(\frac{H_2}{H_1}\right)^{3/2}\right]^{0.385}$$



Where: Q is the flow over the weir, Q_1 is the free discharge over the weir (when the orifice is not completely submerged), and H_2 and H_1 are the water levels above the invert of the "fish flap" opening downstream and upstream respectively.

Q_1 can be approximated[36] as:

$$Q_1 = CLH^{3/2}$$

H (ft)	Q_1 (cfs)
0.0	0.00
0.2	0.32
0.4	0.91
0.6	1.67
0.8	2.58
1.0	3.60
1.2	4.73
1.4	5.96
1.6	7.29
1.8	8.69
2.0	10.18

(The above flows are for free flow over a sharp crested weir.)

For flow over the submerged weir, consider:

for H_1 = 1.0

& H_2 =	Q	V (ft/s)
0.2	3.47	8.7
0.4	3.22	4.0
0.6	2.83	2.4
0.8	2.22	1.4
1.0	0.00	0.0

for H_1 = 1.6

& H_2 =	Q	V (ft/s)
0.2	7.16	17.9
0.4	6.92	8.7
0.6	6.59	5.5
0.8	6.16	3.8
1.0	5.60	2.8
1.2	4.87	2.0
1.4	3.78	1.3
1.6	0.00	0.0

[36] This ignores the fact that the opening is not "sharp-crested" and the analysis ignores minor adjustments for velocity of approach, equivalent weir length and height.

The velocities will be slightly greater than those listed above since the calculated velocities (V=Q/A) do not account for the drop in the water level as it flows over the submerged weir. The velocities in excess of about 2 feet per second are disconcerting. It should have been obvious that very high velocity flow would occur through the" fish flap" on a rising tide. Changing the name from a "pet door" to a "fish flap" would not change this. Calling it a "fish blaster "would have been more appropriate – assuming fish would go anywhere near it. The high flow velocity and the substantial draft force probably caused the fish flap to suddenly slam shut not long after water began blasting through the opening[37]. I speculate that the backflow lasted for at most 45 minutes before the fish flap slammed shut.

Fortunately, a detail for a "Fish Flap Lock" was included in this design. The lock can be engaged to lock the "fish flap" in the closed position. I speculate that this feature came in very handy since the "fish flap" was probably locked in the closed position soon after it was installed and they witnessed the high velocity flow and slamming "fish flap".

Pros:

- Could be relatively inexpensive since there is not much to this.
- Very simple operation – unless you allow the" fish flap" to actually flap.
- Thrill seeking fish can rocket through the "fish flap" - until it gets plugged with debris or is locked shut.[38]
- Allows a miniscule amount of tidal flushing - until the "fish flap" gets plugged with debris, slams shut, or is locked shut.
- Golden Harvest had the good sense to include the "fish flap lock" mechanism in the design.
- It appears that Golden Harvest no longer actively sells this device since it is not mentioned in their on-line tide gate catalog.[39]

Cons:

- The flow velocity through the "fish flap" on a rising tide will be excessive.
- Leakage due to debris stuck in the closed "fish flap" could be a problem.
- If actually allowed to flap, the fish flap will probably break after it slams shut a few dozen times.
- It does not work – unless the fish flap is locked shut. (In which case, you may as well just buy a regular flap gate.)

You have to admire Golden Harvest's tenacity and refusal to give up.

What will they think of next???

[37] I wish I could have been there to see this. The suspense must have been incredible.

[38] At Tenasillahe Island, the flap gate was locked shut soon after it was installed. (Personal communication with the contractor who installed this tide gate. Feb 22, 2010.)

[39] Who knows? Maybe in a few years they'll forget that this thing doesn't work, give it a new name, and they'll sell it to an unsuspecting victim who doesn't know any better.

Answer: They didn't think of anything! A design fell in their lap![40]

Golden Harvest Model GH-850-R

Photo 8 - Golden Harvest Model GH-850 at Edison Slough

The photo to the left is at Edison Slough, Skagit County WA. The photo is also from Golden Harvest's on-line tide gate catalog. The culvert in the bottom left corner of this photo (only the tops of the hinges are showing) is the culvert that used to have the Golden Harvest model GH-35 flap gate. (See page 11.) It was removed[41] and replaced with a normal top-hinged flap gate when the model GH-850-R was installed[42].

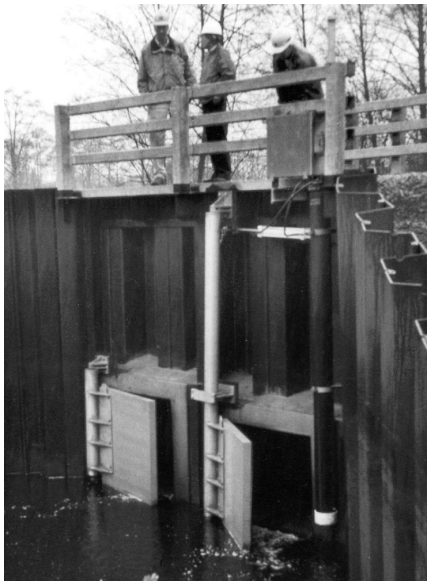
At this particular site, the tide gate was reported to always be closed.[43] In fact it is closed in this photo. The photo was taken when the tide was falling and the water level is well below the high tide level - so it should be open. Golden Harvest has a working copy of their GH-850 at McElroy Slough, so their model GH-850 (my Aberdeen design) can be made to work – at least at some locations.

Pros:

- Works reliably in some locations and allows tidal flushing.
- Montesano Office Fish and Wildlife Manager Bob Burkle (back in 1996) said: "I've never seen a tide gate as good."[44]

Cons:

- Somewhat complicated[45] and not completely fail-safe. In 1995 when I explained how my proposed tide gate design would work to Aberdeen's City Engineer Ron Merilla, he quipped: "It's kind of Rube Goldberg, but I can't see why it wouldn't work." It does work, but it is overly complicated.
- This is an overly expensive knock-off.[46] If you are interested in this particular tide gate alternative, be sure to get a price from Juel Tide Gates at (206) 300-4204.
- The stainless steel gate leaf has a large surface area with many nooks and crannies for marine organisms to attach. Cleaning the gate leaf will be difficult.[47]
- Requires sufficient outflow for the gate to open fully – otherwise "Tide Gate Entropy Death" may occur.
- Golden Harvest did not succeed in getting this design to work – at least at Edison Slough. In January 2009, this tide gate was retrofitted with a VBFGTM control mechanism by Juel Tide Gates. It's been working flawlessly since then[48].



For comparison, to the left is a photo of the Aberdeen Tide Gate designed by Jeff Juel in 1995. Juel Tide Gates can provide this design with the hydraulic control mechanism - however it costs more and has no advantages over an identical side-hinged flap gate using the new VBFG™ control mechanism.

[40] A well-meaning unnamed person handed a copy of my Aberdeen tide gate design to Golden Harvest. What a wind-fall.
[41] The winning bidder's cost for removal and disposal of the malfunctioning model GH-35 was $10,000.
[42] Per the bid schedule, the winning bidder's cost for the new (and dysfunctional) model GH-850 was $62,000.
[43] Personal Communication with Duane Eitriem, the property owner located just upstream at Edison Slough.
[44] Quote from article about South Aberdeen and Cosmopolis Flood Control Project in 1996. (This article was published nine years before Golden Harvest attempted to copy this tide gate design.)
[45] The hydraulic control mechanism includes a large number of components: hydraulic cylinder, hoses, directional control valve, pressure-compensating flow control valve, check valves, and a hand pump.
[46] On a large tide gate project bid in June 2009, the fabricator of the Aberdeen design (Plasti-Fab) submitted a bid to supply the original tide gates as an equal. Their bid was 33% less than the bid submitted by Golden Harvest.
[47] My original design uses a gate leaf with flat surfaces.
[48] Personal Communication with Duane Eitriem, November 2009.

Self Regulating Tide Gates by Golden Harvest - A Recap:

If at first you don't succeed,

(In 1998, Golden Harvest fabricated the Bottom-Hinged Pet Door)…

Try… the GH-52CS[49],

Try… (actually steal) Waterman Industries' SRT design – and call it) the GH-35[50],

Try… the GH-37[51],

Try… the Fish Flap[52],

Try… (actually copy) Jeff Juel's Aberdeen Tide Gate – and call it the GH-850[53]… again! [54]

Eight years of persistence (1998 thru 2006) eventually paid off. It took two tries, but in 2006 Golden Harvest eventually succeeded in getting my Aberdeen tide gate design to work. Now they feel like they've paid their dues[55] so they'll go to great lengths to keep control of my tide gate design[56].

There's this thing called "Karma"… Golden Harvest's pride and joy – the GH-850 - has been made obsolete by the Juel Tide Gates VBFG™ tide gate design (patent pending). The Juel Tide Gates VBFG™ tide gate fabricated by Plasti-fab is:

- Much less complicated (the operating mechanism is incredibly simple).
- 100% reliable and virtually indestructible.
- Fail safe (if anything breaks, no backflow occurs).
- Less expensive[57] than my Aberdeen Tide Gate Design and significantly less expensive than the GH-850.
- Produced by a company with high ethical standards.

  (See http://www.jueltide.com/images/04_23_2010_PDFs/Juel_Tide-Ethical_Standards.pdf)

[49] The Montesano Office of the Washington Department of Fish & Wildlife is not satisfied with how the GH 52-CS tide gates are working at the Chinook River. I have offered to retrofit these tide gates with my control mechanism.
[50] This tide gate was a dismal failure at Edison Slough. This project resulted in wide-spread resistance to future SRTs in Skagit County and the State of Washington.
[51] This design is patented so I presume it really works. Three copies exist at the "Balsa (sic) Chica Wetlands" in Southern California. If this design works well, why did Golden Harvest continue to develop and/or copy other tide gate designs?
[52] This tide gate installed at Tenasillahe Island was another dismal failure.
[53] The first try at a copy was at Edison Slough – it was a dismal failure (see http://www.youtube.com/watch?v=b7obU2-Wgv0),
[54] The second try was at McElroy Sough. It actually worked!!! Imagine the excitement!!!
[55] In a desperate attempt to supply the tide gates for the Julia Butler Hanson Tide Gate project and prevent me from producing my tide gate design, after the bid opening, Golden Harvest reduced their quote by over $100,000 to match my fabricator's (Plasti-fab) price.
[56] In May of 2009, Golden Harvest's lawyer composed a letter and succeeded in coercing Tapani Underground into using them rather than Plasti-fab to provide the tide gates for the Julia Butler Hanson Tide Gate Project. (Plasti-fab originally fabricated my tide gate design back in 1995 – a few years before Golden Harvest began their string of tide gate failures.)
[57] My new control mechanism replaces about $10,000 worth of hydraulic components.

Side-Hinged Variable Backflow Flap Gate (VBFG™) by Juel Tide Gates

The photo to the left shows the patent pending VBFG™ tide gate control mechanism retrofitted on the side-hinged flap gate at Edison Slough. The tide gate is controlled by tension in rigging that is continually pulling the tide gate open. During a rising tide, the backflow through the culvert generates a "draft force" drawing the gate closed. This draft force is resisted by the tension in the rigging.

The draft force grows at an increasing rate with the rising tide due to: 1) the growing area of the submerged portion of the gate leaf – "the sail"; 2) the increasing flow velocity due to the growing differential volume of the tidal prism that is being filled by the rising tide; & 3) the growing differential head.

When the magnitude of the draft force is large enough to overpower the tension in the rigging, the gate closes. When tuned properly, the tension regulator in the control mechanism increases the tension as the gate closes, thereby preventing the gate leaf from slamming shut.

It's a bit counter-intuitive, but the tide gate closes very consistently with little variability regardless of the variations in the tides.[58] If the high tide is slightly higher than the normal closing tidal elevation, the differential head at the flap gate is reduced slightly as the tide crests. This results in the flap gate staying open longer and allowing water levels that are an inch or two higher than normal. This only happens sporadically – a few times a year. When this does happen, the flood tide is on the verge of cresting, so the tidal water level will fall very soon after the tide gate closes. The gate then opens on the ebb tide and the pool drains. This is totally innocuous.

At the six locations where tide gates have been retrofitted and are operating with the VBFG™ mechanism, the amount of variability in the water level when the gate closes is reasonably small (at most two or three inches) and is inconsequential.

Pros:

- Extremely durable corrosion-resistant heavy duty 316 stainless steel[59] and copolymer gate leaf (on new tide gates).
- Remarkably simple control mechanism with very reliable operation.[60]
- It will work at any site.[61] Five retrofitted side-hinged tide gates have been operating without fail since January 2009.
- The tide gate is either wide open (70-90 degrees from the headwall) with very minimal head loss, or is fully closed.
- Does not require any outflow to open. The rigging pulls the gate open when there is no seating head.
- Debris rarely (never?) hangs up on the open tide gate.
- Fail-safe unattended operation. If any part of the control mechanism breaks, the flap gate simply opens and closes and does not allow backflow.
- Much less expensive than other more complicated tide gates.

Cons:

- Very minor variations in the upstream water surface elevation at which the tide gate closes.[62]

[58] Duane Eitreim can check the predicted tides and predict the time that the Edison Slough flap gate will close to within a few minutes – sometimes within a few seconds. (See http://www.youtube.com/watch?v=b7obU2-Wgv0)

[59] 304 Stainless Steel may be used in fresh water locations to reduce fabrication costs.

[60] The four operating side-hinged tide gates retrofitted with this control mechanism have been operating unattended with minimal intervention for over a year as of January 2010.

[61] No outflow is required for the tide gate to open on a falling tide. It is therefore immune to Tide Gate Entropy Death. (See www.jueltide.com for information on Tide Gate Entropy Death.)

Top-Hinged Variable Backflow Flap Gate (VBFG™) by Juel Tide Gates

The photo to the left shows the patent pending VBFG™ tide gate control mechanism operating with a top-hinged fiberglass flap gate at Fornsby Creek.

A mechanical hand winch is located above the high water level in the upper right corner of the photo. The inclined tube encloses and protects the tension regulator. Two lengths of stainless steel wire rope pass over four sheaves located at the top and the base of the inverted "V" shaped support which is secured to the concrete above the end of the culvert.

The wire ropes are anchored to the tops of the two fiberglass vertical angles on the flap gate that extend above the culvert.

The tension in the rigging pulls the flap gate open when there is no seating head acting on the flap gate. During the flood tide, the draft force drawing the open flap gate closed increases as the tide rises. The draft force increases: 1) as more of the flap gate becomes submerged, and 2) due to the growing differential head and the increasing flow velocity. When the draft force exceeds the tension in the rigging, the flap gate closes.

The photo to the left shows the water level upstream from the flap gate immediately after the flap gate closed during the flood tide.

The channel was dry at the beginning of the flood tide. The flap gate closed during flood tides when the water level reached the level in this photo. Increasing the tension in the rigging would cause the tide gate to remain open longer during the flood tide. Reducing the tension in the rigging would cause the tide gate to close earlier on the flood tide.

Pros:

- A remarkably simple control mechanism with very reliable operation.
- Fail-safe design.
- The rigging reduces the head loss through the flap gate thereby increasing conveyance on the ebb tide.
- A very cost-effective environmentally-friendly tide gate alternative.

Cons:

- The fiberglass flap gate could be damaged when subjected to large racking forces if floating debris hangs up on the open flap gate during the flood tide.[63]

[62] The amount of variation depends on the tidal prism of the site. To date, the variation is minimal and inconsequential at all of the tide gates using this control mechanism.

[63] A side-hinged heavy duty steel and copolymer tide gate by Juel Tide Gates / Plasti-fab is virtually indestructible and is recommended if large woody debris could impact the open flap gate.