FLOOD PLAIN MANAGEMENT SERVICES PROGRAM

STRAITS POND TIDAL FLUSHING STUDY

HULL, COHASSET AND HINGHAM, MASSACHUSETTS

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HULL, COHASSET AND HINGHAM, MASSACHUSETTS

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1. SUMMARY

Straits Pond is a 91.4-acre impoundment at the head of the Weir River estuary on the border of Hull, Hingham, and Cohasset. It has severe water quality problems during the summer due to prolific growths of algae, aquatic weeds, and insects. Manually operated tide gates at the bridge under Route 228, controls flow into and out of the pond. Operation of these gates allows some flushing at the pond while also providing important protection from tidal flooding. The Route 228 bridge is deteriorating and is in need of replacement, and Coastal Zone Management (CZM) along with Town of Hull requested the US Army Corps of Engineers, New England District (Corps) to evaluate possible benefits from replacing the existing 4 by 4-foot and 5 by 5-foot gates with two 7 by 5-foot or larger gates.

Based on the results of the HEC-RAS computer simulations, the Corps found that gate width is the major factor limiting tidal flushing in Straits Pond. Using gates larger than 7 by 5 feet would further increase flushing with likely additional improvements in water quality, but when the total gate width approaches 20 feet, the high point in the channel between the gate and the pond may start to limit the amount of flushing that can be achieved in one tide cycle. The Corps did not attempt to quantify the expected improvements in water quality due to specific increases in flushing, but assumes that any increase in flushing will improve water quality, and the greater the flushing, the greater the improvement.

The Corps also briefly examined gate controls, and flooding on the estuary side of the Route 228 bridge. Automatic gate controls with manual overrides would probably work best for maximizing flushing, while minimizing flooding around the pond and labor costs associated with strictly manual controls. The Corps also concluded that changing the gates or their operation would not likely affect water levels on the estuary side of the bridge, but no modeling work was done to confirm this.

2. PURPOSE

Study purpose was to investigate the possibility of increasing tidal flushing of Straits Pond by changing the number and size of gates on the Route 228 bridge over the Weir River to improve water quality while continuing to provide protection from flood damages to the surrounding properties. The Town of Hull is planning to replace the Route 228 bridge, at which time they will also need to replace the tide gates. Under the authority of the Flood Plain Management Services Program (Section 206, Flood Control Act of 1960), the Corps agreed to simulate the existing and alternative gate sizes to provide some assistance to the Towns of Hull, Cohasset and Hingham for the design of replacement gates. Inherent in this study is the assumption that any increase in tidal flushing would alleviate some of the water quality problems, and the greater the amount of flushing, the greater the improvement. However, the Corps did not attempted to quantify the expected water quality improvements, as that was beyond the scope of this study.

3. DESCRIPTION OF STUDY AREA

Straits Pond is located near the base of the Hull peninsula, and is partially in Hull and partially in North Cohasset, but also borders on Hingham (figure 1). It is at the upper end of the Weir River estuary but separated from the estuary by gates, under the Route 228 bridge, which are manually operated to allow some tidal flushing while preventing high tides from flooding properties around the pond (photos 1 through 3). Straits Pond was created by a dam in the nineteenth century, that was constructed to provide hydropower for a mill. It has a drainage area of 740 acres, and Rattlesnake Run is the only significant tributary. Land use in this watershed is high density residential with a large percentage of impermeable surfaces. Many storm drains from the peripheral residential areas of Cohasset empty into the pond.

During the summer, the pond experiences prolific growth of Widgeon grass and algae blooms, most likely nourished from nutrients in land runoff and pond sediments. This combination forms dense mats that decay, releasing foul odors and providing breeding areas for swarms of midges. Although the midges do not bite humans, they are a big nuisance to the pond's neighbors. Nuisance aquatic weed growth has been a problem in Straits Pond since at least the early 1900's, and chemical treatment for weed and insect control has been used since the 1950's.

Increasing the size of the gates to allow more tidal flushing would provide at least some reductions in the severity of the algal blooms and associated water quality problems. However, too much fluctuation in the pond's level would also be a problem because, when the pond level drops to around elevation 1 foot, NGVD, areas of inter-tidal mud flats are exposed. On the other hand, removing the gates and the hydraulic restrictions associated with the current bridge would increase tidal flooding of properties around the pond.

4. EXISTING CONDITIONS

Straits Pond is maintained at a level of about 3.3 feet, NGVD, by two slide gates, one is 4 by 4 and the other is 5 by 5 feet. The larger gate is actually a double gate, like a double-hung window, that allows water to be drawn off the top, bottom, or some combination. Both gates have inverts at -2 feet, NGVD. These gates are manually controlled and currently operated by Bill McNamara, a retired resident of Hull with property that borders the pond. He regulates the pond using a protocol developed as part of an ENSR flushing study and included in their May 2002 report, "Weir River Estuary Flow Study: Hull, Hingham, and Cohasset, Massachusetts;" however, he often deviates from this protocol based on his years of experience. He sends reports of all gate operations to the Hull Town Manager's office. He tries to maximize flushing while preventing high tides from flooding surrounding properties, which begins around elevation 4 feet, NGVD. He also lowers the pond to provide extra storage when storms approach. Experience has shown that an inch of rain can cause the pond to rise close to half a foot, depending on antecedent conditions. During severe coastal storms, waves can overtop Crescent Beach and raise the level of Straits Pond to flood levels.

Operation of the existing gates can lower the pond about 1 foot during a tide cycle. Additional lowering of the pond can be achieved over successive tide cycles by closing the gates when the tide shifts and start to rise, but this will expose the inter-tidal mudflats for longer periods of time. Mr. McNamara will, nonetheless, sometimes lower the pool and keep it down for a tide cycle to allow the algae released with the water from Straits Pond to get further down the Weir River estuary, so that when he does open the gates, a higher quality water will be let back in.

While the tide gates are the main hydraulic restriction between the pond and the Weir River, there is a high point in the channel between the bridge and the pond that becomes a significant hydraulic restriction when the pond is dropped more than a foot or two from its normal level of 3 feet, NGVD, and that ultimately limits draw down. This study included an examination of the effects of this restriction on pond levels and flushing.

The Route 228 bridge is deteriorating and is in serious need of repair. Constructed around the beginning of the 20th century, its rubble masonry walls are slowly falling into the channel. Mr. McNamara restricts the gate openings, limiting the amount of pond flushing to reduce water velocities through the bridge to limit damage to its walls. The bridge is owned by Hull, Cohasset and Hingham. Plans are underway to replace the bridge, and this study provides the opportunity to recommend changes to the gates that would improve flushing of the pond.

5. DATA SOURCES

Sources of data included field trips to the site, review of previous reports, water level data collected by CZM, survey data developed by the Corps, information provided by Mr. William McNamara, photographs and other information from CZM's Jason Burtner, tide tables, and USGS and local maps. The Corps made field trips to the site on 23 January and 13 April 2003. The January trip provided little more than a basic introduction to the site, because the pond was thoroughly frozen over (photo 4). During the April trip, the pond was observed while being brought down and raised again over a tide cycle. Reports reviewed for this study included, *Straits Pond Reclamation Study and Program, Towns of Hull and Cohasset*, April 1980, by IEP; *Midge Management Recommendations for Straits Pond, Towns of Hull and Cohasset, Massachusetts*, February 2002, by Environmental Science Services, Inc; *Weir River Estuary Flow Study: Hull, Hingham, and Cohasset, Massachusetts,* May 2002, by ENSR; and excerpts from an evaluation of the bridge and replacement options by Vanasse, Hangen, Brustilin, Inc that was prepared around 2001.

CZM installed automatic water level recorders in Straits Pond and the Weir River below the Route 228 bridge. The transducer on the estuary side of the bridge was attached to a horizontal timber, at the base of the bridge, at elevation –0.79 feet, NGVD. They collected data at 3-minute intervals over 20 days, from 1506 hours on 14 May to 1227 hours on 2 June 2003. Although almost 3 weeks of data were collected, results were only useable for periods when both data loggers were operational. Due to a problem with the rechargeable batteries for the recorders, the longest period of useable simulation data was from 1500 hours on 20 May to 1800 hours on

22 May 2003, and this was used in the simulation (figure 2). Using Tide Tables 2003, High and Low Water Predictions printed by the National Imagery and Mapping Agency, the Corps determined that this period was close to a typical spring tide.

To provide basic information on the channel high point between the bridge and Straits Pond, the Corps surveyed two cross sections of the pond on 31 March 2003. One cross section was across the channel high point, and the other was northerly across the pond from an area near Jerusalem Road west of Rattlesnake Run towards Crescent Beach (figure 1). In addition, the Corps installed a water level gage, set to NGVD, near the channel restriction formed by the south end of the peninsula extending from the west end of the pond. This gage is accessed by the driveway between 715 and 725 Jerusalem Road, and crossing property owned by Vin and Katie Dunn.

Bill McNamara explained how he operated the gates, and described observed flow conditions in the pond. He has an interest in reducing algae and weed problems and offered to perform special gate regulations if needed for this study. He also provided photographs of the pond under different conditions.

In addition to general information about the site, and the stage-data information, Jason Burtner (CZM) provided photographs of the channel restriction between the bridge and the pond. These photographs were taken during the week of 20 October 2003 after the pond had been drawn down to about elevation 1 ft, NGVD (photos 5 – 7). As described by Mr. Burtner, "In order for the pond level to be dropped to the elevation depicted in the photographs, the tide gates were opened at low tide to allow water to exit the pond and closed during the incoming tide to prevent water from returning to the pond. The gates were operated in this manner for several weeks in order to drop and maintain the level of the pond to what is depicted in the photos." These photographs were important for estimating the effects of the channel restriction on pond drawn down. Mr. Burtner also provided some photographs of flooding on the estuary side of the bridge in November of 2002 and 2003 (photos 8 – 10).

6. MODELING EXISTING CONDITIONS

Using the data from the estuary tide gage for the period 20 May 2003 at 1500 hours to 22 May at 1800 hours, the Corps was able to replicate the record at the Straits Pond gage with an average absolute error of less than 0.06 ft and a maximum error of 0.19 feet, which was very good for this sort of computer model. Errors did not accumulate during the model run, which was also good.

Technical modeling details are as follows. Version 3.1.1 of HEC-RAS from May 2003 was used in the unsteady mode. Dimensions for the Route 228 were taken from a report by Vanasse Hangen Brustlin, Inc. (VHB) that described it as having a 12-foot span, 8.5-foot rise, and 57 foot length. The VHB report and field observations show water, sewer, and gas lines under the bridge, which were accounted for in the model with Manning's "n" values and gate coefficients. The channel invert under the bridge was –2, and the crown of the bridge opening was elevation 7.13 feet, NGVD. The vertical timber in the center of the estuary side of the bridge (photo 11) was represented as a pier. Manning's "n" values generally ranged from 0.012 for the new concrete wall on the estuary side of the bridge to 0.03 for rough channel below this wall; however, in some places these values had to be raised to prevent the program from erroneously calculating highly supercritical flow conditions.

The gates were modeled as inline structures with inverts at elevation –2 ft, NGVD. One gate was entered as 4 by 4 and the other as 5 by 5 feet. It was beyond the limits of the existing software to model the complex "window-like" operation of the larger gate; instead, they were both assumed either completely open or closed. Reasonable values for gate coefficients were selected, and these were then modified to get the model to closely replicate observed water levels in Straits Pond using the observed estuary levels as input. The adopted gate coefficients were 0.52 for a discharge coefficient, 0.72 for an orifice coefficient, and 0.5 for a head exponent. Although the tide gates are literally against the pond side of the bridge, HEC-RAS does not allow inline structures directly against bridges, and the gates were entered as 3.5 feet away from the bridge.

Straits Pond was represented by a 100-foot channel leading to a storage area. Channel dimensions were taken from the Corps survey, field observations and a USGS map. The volume of Straits Pond was computed by surface-area relationships. A May 2002 ENSR report, *Weir River Estuary Flow Study: Hull, Hingham, and Cohasset, Massachusetts*, describes Straits Pond as having an area of 91.4 acres, depth of 3.3 feet, volume of 302 acre-feet, and having a relatively uniform water depth. Based on this, the Corps survey, and USGS mapping, the surface-area to elevation ratio in table 1 was estimated and entered into the model, which used them to compute volumes. This table is based on the best information available; however, there are anecdotal observations that the water surface area at elevation 1 ft is far less than half that at elevation 3 ft, NGVD; this points to the need to obtain high-resolution bathymetry to allow more accurate estimates of how the pond level will fluctuate with new gates installed.

Table 1
Straits Pond
Elevation-Surface Area Relationship

Elevation (ft, NGVD)	Water Surface Area (acre-feet)
5	465
3	302
1	154
0	91.4
-1	35
-2	0.1
-3	0

The record from the CZM estuary tide gage from 20 May 2003 at 1500 hours through 22 May at 1800 hours was entered as 3-minute data. As shown on the right-hand side of figure 3, there was a period on 22 May at about noon when the recorder gave anomalously low readings;[1] these were increased to keep them in line with the other readings. Before entering the data into HEC-RAS, all elevations were increased by 100 feet so that results would not include negative elevations. The model was run with a 15-second computation interval.

The HEC-RAS model in the unsteady mode handled the reversing flows through the tide gate well. The best simulation reproduced recorded Straits Pond levels with an average absolute error of 0.059 feet and a maximum error of 0.186 feet. Simulation results overestimated the fluctuation in pond levels with the largest error occurring with the model predicting a higher pond level than actually recorded. The Corps considered these results to be good and to show that the model could be used to evaluate the effects of new gates.

7. MODELING NEW GATES

The model from the calibration run was modified to evaluate the effects of a new bridge and gates. A design for the new bridge has not been prepared, but it was estimated to have a 20-foot span and a low chord elevation of 7 feet, NGVD. Because this low chord elevation would not be submerged by the recorded tide elevations, the bridge could be modeled as channel sections, which had two advantages. The first was that the gates could be immediately upstream of the simulated bridge opening; the second was that the unsteady flow model could handle reversing flows through a gate and channel sections better than through a gate and a bridge. To control the model's tendency to compute highly supercritical flows during falling tides, the transition on the estuary side from bridge opening to a channel, which occurs abruptly in reality, was transitioned over a longer distance. Finally, the channel section on the pond side of the bridge, which had previously ended at the channel high point, was extended to simulate better the effects of this high point on low pond water levels. Otherwise, the model for the larger gates was basically the same as used in the calibration runs.

This study assumes, quite reasonably, that increasing the flushing of Straits Pond will improve its water quality, and the more the pond is flushed the greater the improvement will be. However, we have neither estimates of how much flushing would be required to improve water quality to acceptable levels nor descriptions of what "acceptable" levels would be. Also, the water level at which flooding around Straits Pond will not change, so the only acceptable way to increase flushing is to reduce the pond level or increase the frequency of tidal exchange. Consequently, in evaluating the effects of new gates or channel modifications, the assumed measure of success was the ability to draw the pool down in one tide cycle, and the lower the pond was drawn down, the better. The Corps did not look at drawing the pond down over successive cycles, by closing the gates at one low tide and not reopening until the tide dropped below the pond level, because new gates that could draw the pool down more in one cycle would also be more effective in multiple cycles. Also, flushing and refilling the pond in one cycle to minimize the time the mudflats are exposed would obtain the best results.

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[1] The anomalously low reading was due to a brief tide gate closure so that the culvert could be inspected in order to determine whether the high rate of tidal exchange was impacting the culvert structure.

There are endless combinations of gate dimensions and channel configurations that could be examined with unlimited resources, but the Corps concentrated on the effects of replacing the existing gates with two 7-foot wide by 5-foot high gates, as suggested by CZM's Jason Burtner. The Corps used these gates to compare the effects of variables such as eliminating the upstream channel restriction (the high point in the channel), lowering the gate inverts, using higher gates, using wider gates, and lowering the water level on the estuary side. Table 2 summarizes these runs.

An evaluation of the possible benefits of double-hung gates was beyond the extent of the computer program. Double-hung gates were initially installed on the presumption that water in the pond and estuary were highly stratified, but comprehensive monitoring showed that this was not the case. The double-hung gates reportedly had some advantages in discharging algal mats from the pond, but the new gates will provide more flushing, which should reduce the algae problems.

Investigations of four gate sizes are reported in table 2. "Observed" refers to the water level record in Straits Pond from 20 May 2003 at 1500 hours to 22 May at 1800 hours. "Existing" refers to the results from the modeling of the existing 4 by 4 and 5 by 5-foot gates, and is the relative basis against which others are compared. The new gate sizes looked into were two 7-foot wide by 5-foot high, two 7 by 7-foot, and one 20-foot wide by 5-foot high. Most of the runs were done with the existing invert of –2 ft, NGVD, but the effects of lowering the invert a half a foot were also investigated.

Table 2
Summary of Computer Simulations of Gates, Channel Conditions, and Tides

Run Number	Gate Sizes	Gate Invert (ft, NGVD)	Channel Restriction	Gate Closure Elev (ft, NGVD)	Estuary Tide Data	Min Pond (ft, NGVD)	Max Pond (ft, NGVD)
	Observed				From gage	1.83	3.05
1	Existing	-2	Initial	Open	From gage	1.70	3.12
2	New two 7x5	-2	Initial	Open	From gage	0.94	3.74
3	New two 7x5	-2	Photo-Modified	Open	From gage	1.08	3.78
4	New two 7x5	-2	None	Open	From gage	0.93	3.74
5	New two 7x5	-2.5	Photo-Modified	Open	From gage	1.03	3.83
6	New two 7x7	-2	Photo-Modified	Open	From gage	1.08	3.99
7	New two 7x5	-2	Photo-Modified	4	From gage	1.02	3.06
8	New two 7x5	-2	Photo-Modified	Open	-1 ft, NGVD	1.03	3.74
9	New 20x5	-2	Photo-Modified	Open	From gage	1.05	4.34
10	New 20x5	-2	None	Open	From gage	0.89	4.32

Three channel restrictions were examined in table 2. "Initial" refers to the restriction based on the Corps survey cross section. However, photographs taken by Jason Burtner when the pond was lowered over successive days to elevation 1 foot, NGVD (photos 5 – 7) appear to show a more restrictive section than the Corps survey indicates. Consequently, a second more restrictive channel section was estimated from the Corps survey and these photographs; this is the "Photo-Modified" channel restriction in table 2. The third case assumed the channel restriction (the high point) was completely removed; this is the "None" channel restriction in table 2.

For most runs, gates were left fully open at all times. However, the effect of an automatic gate, such as a self-regulating tide gate, was investigated in run 7. A cursory examination of the water levels in the pond and estuary indicated that Straits Pond generally had risen to elevation 3 by the time the estuary reached elevation 4 ft, NGVD. This shows that a much larger net gate opening would be required to keep the pond and estuary at about the same level, which would be necessary if an automatic gate were to be used to prevent flooding around the pond while maximizing flushing. Controls for automatic gates are discussed in section 11.

For most runs, the estuary tide data came from the gage installed by CZM from 20 May 2003 at 1500 hours to 22 May at 1800 hours. However, this had the disadvantage that the recorded water level on the estuary side never went below –0.79 ft, NGVD, the elevation at which the transducer was installed. The actual water level in the estuary gets lower than this, but we don't have a record of how low or for how long. Consequently, we also looked at the effects of estimated lower minimum water levels in the estuary. Using the record from Boston Harbor, we altered the tide record from 20 May at 1500 hours to 22 May 2003 at 1800 hours, so that it smoothly dropped to a minimum of –1 ft, NGVD (figure 4). This was used in run 8.

The minimum and maximum pond levels are the extremes observed during the simulations. Multiple tide cycles were examined during each simulation and the minimum and maximum pond levels varied, but the levels recorded in table 2 are the extremes observed at any time during these simulations and were not necessarily the range observed during any one tide cycle.

8. RESULTS

Results show that the net width of the gate openings is the most important factor controlling flushing in the pond. Increasing the net width of the gate openings to 14 feet should allow an extra three-quarters of a foot of pool fluctuation in one tide cycle, which should be enough to benefit water quality in the pond. If the net gate open width is increased much beyond 14 feet, the channel restriction between the pond and Route 228 will start to limit flushing. Better surveying of this channel restriction would be required to determine at what point it becomes controlling, but it appears that there would be minimal benefit to increasing the net gate opening beyond 20 feet without also addressing the channel restriction.

Increasing the height of the gates to 7 feet had little effect, which is not surprising because 5-foot high gates are submerged during only a relatively small part of the tide cycle. Lowering the gate invert increases pond draw down by only a small amount. Removing the channel high point on the pond side of the bridge has surprisingly little effect on the minimum pond levels achievable with two 7 by 5-foot gates, at least on one tide cycle. If the gates were to be operated to drop the pool over two or more tide cycles by closing them during a rising tide, the channel restriction would become more important. Closing the gate during high pool levels aids slightly in lowering the minimum pool, and lowering the water level in the estuary also had a small effect.

The simulations shows that using a 20-foot wide by 5-foot high gate has essentially negligible benefits over two 7 by 5-foot gates; however, the simulations tend to overestimate pool fluctuations and this effect is probably greater with smaller gates. Therefore, it is likely that the benefits of a 20 by 5-foot gate would be greater than these simulations indicate, but they are not likely to be dramatically greater.

Results from individual runs are discussed in the following sections. All the runs after the first assume a new bridge with a span of at least 20 feet and a low chord no lower than elevation 6 feet, NGVD. Note that table 2 shows computed pool levels to 0.01 feet, but the best simulation of existing conditions had an average absolute error of 0.06 feet and a maximum error of 0.19 feet. Consequently, in comparing results in this table, differences of less than 0.1 feet may actually have little real meaning. Based on modeling results for existing conditions, it is likely that these runs overestimate the amount of pond fluctuation that would occur, but they are still good for comparing relative increases in flushing.

Run 1. This is discussed in the "Modeling Existing Conditions" section.

Run 2. This looks at replacing the existing gates with two 7-foot wide by 5-foot high gates at invert –2 feet, NGVD. It uses the upstream channel cross section from the Corps survey and the estuary tide levels from CZM's stage recorders. It shows the pond level going down to a minimum elevation of 0.94 feet, NGVD, which is 0.76 feet lower than the computed existing condition (run 1). It also shows the pool level rising 0.62 feet higher, indicating that the gates would need to be operated more frequently to protect properties bordering the pond from flooding.

Run 3. This takes the two 7-foot wide by 5-foot high gates from run 2 but uses the higher upstream channel invert estimated from photographs. It shows this upstream channel restriction affecting water level fluctuations such that the minimum pond level is 1.08 feet, NGVD, which is 0.14 feet higher than in run 2 but still 0.62 feet lower than existing conditions. It also shows the pond level rising slightly higher than in run 2, which could be due to higher initial pond levels from the previous tide cycle during the next rising tide.

Run 4. This takes the two 7-foot wide by 5-foot high gates from run 2 but eliminates the upstream ridge that causes a low-water channel restriction. This shows virtually identical conditions to run 2, which indicates that if the Corps survey is an accurate representation of the channel restriction geometry, then the channel restriction would have no effect on the draw down that two 7 by 5-foot gates could achieve in one tide cycle. However, run 3 shows that if the modifications to the channel restriction geometry based on photos 5 through 7 are correct, then it would limit draw down. A more complete survey of the channel high area is needed to determine if it would have any affect on Straits Pond water levels during a single tide cycle with two 7 by 5-foot gates.

Run 5. This takes the two 7-foot wide by 5-foot high gates from run 3 but lowers the gate invert by 0.5 foot. This is not much of a lowering, but it's not clear if even this would be practical based on the limitations of the natural channel configuration. In any case, it has little effect, lowering the pond only 0.05 feet more than in run 3.

Run 6. This is similar to run 3 except that two 7 by 7-foot gates are used. It has no effect on the minimum pond level but increases the maximum. This is not surprising since the top of the 5-foot high gates openings is at elevation 3 feet, NGVD, which means it would be more of a restriction on letting water into the pond but a minimal restriction on letting it out.

Run 7. This takes the two 7-foot wide by 5-foot high gates from run 3 but closes the gates completely whenever the estuary water level exceeds 4 feet, NGVD. It shows a small lowering of the minimum pond surface, which is likely due to the pond starting from a lower level during a falling tide. The maximum pond level was 3.06 feet, NGVD, which was just slightly higher than the target maximum pond level for this simulation of 3 feet, NGVD. This appears to be quite good; however, as shown in figure 5, which compares runs 3 and 7, the pond level in run 7 twice peaked around elevation 2.5, which means that less flushing would be achieved than would occur if the gates did not close until the pond level reached elevation 3 feet, NGVD.

Run 8. This takes the two 7-foot wide by 5-foot high gates from run 3 but uses lower estimated minimum estuary water levels down to–1 foot, NGVD. This achieves only a slight decrease in minimum pond levels from run 3. This indicates that backwater effects from the estuary are not a major factor in controlling how low Straits Pond could go, at least with 7 by 5-foot gates, and there is great need to record estuary water levels at a different point further from the bridge.

Run 9. This is similar to run 3 except that one 20-foot wide by 5-foot high gate is used instead of two 7 by 5-foot ones. Little improvement in lowering the pond level is achieved because the channel restriction becomes controlling at low pond levels.

Run 10. This takes the 20 by 5-foot gate from run 9 and removes the channel restriction. While this gives the lowest pond level of all simulations, it is a surprisingly small improvement. It lowers the pond only 0.19 feet more than run 3, with two 7 by 5 gates and the channel restriction, and only 0.04 feet lower than two 7 by 5 gates without the channel restriction in run 4.

As a rough check on the results of these simulations, the Corps looked at average flows and critical depth. In order to get 3 feet of pond flushing, from elevation 3 to 0 feet, NGVD, 208 acre-feet of water would have to move through the gates in the period between high and low tides, which is roughly 6 hours. This means an average flow of 418 cfs. The minimum energy required to move this much flow through a rectangular gate opening would occur at critical depth, when the velocity head is equal to half the depth. Adding the depth of flow and velocity head to the gate invert gives the required minimum average energy elevation, which would have to be less than the average pond level to achieve this flow. For a 20-foot gate, critical depth for a flow of 418 cfs occurs with a water depth of 2.38 feet, giving a velocity of 8.77 fps and a velocity head of 1.19 feet. Adding the 2.38-foot depth of water to the 1.19 feet of velocity head to a gate invert of –2 feet gives a required minimum average energy level of 1.58 feet, NGVD. However, the average pond level between 0 and 3 feet is 1.50 feet, NGVD, which is less than the calculated required minimum of 1.58 feet. When the effects of gate and channel hydraulic losses and backwaters from the estuary are added in, the required minimum average energy level would be even higher. That the required minimum average energy level of 1.58 feet is less than the available average of 1.50 feet shows that no matter how much excavation is done to the channel on either side of the Route 228 bridge and no matter how hydraulically efficient the gates are, it simply will not be possible to get the pond to drop from elevation 3 to 0 in one tide cycle with a 20-foot opening.

Table 3 compares required minimum energy levels for various gate sizes and desired pond fluctuations. The "gate width" is the total width of all gates, and for this rough analysis it does not matter whether it is achieved with one or more gates. Table 3 shows that about a 30-foot gate opening would be required to get a 3-foot pool fluctuation from elevation 3 to 0 in one tide cycle, but a 2-foot drop from elevation 3 to 1 should be possible with a 20-foot opening, and might be achieved with a 14-foot opening.

An examination of the results in table 2 shows rough agreement with the predictions in table 3. Table 2 shows pool fluctuations of over 2 feet with two 7-foot gates and over 3 feet with a 20-foot gate; however, this does not contradict results in table 3, because the large pool fluctuations in table 2 occurred by going higher than elevation 3 and thereby increasing the available average energy level. Table 2 also shows a pool fluctuation from 3.06 to 1.02 feet in a tide cycle with two 7 by 5-foot gates. While table 3 shows this a theoretically possible, the small 0.38-foot difference between the required and available heads makes it seem unlikely that it would actually occur. An examination of the record shows that, due to tidal variations at the time, this drop actually occurred over 7.5 hours instead of the 6 hours assumed in table 3; increasing the time period significantly reduces the energy requirements to move the water, but the average time from high to low tide is not much more than 6 hours.

Table 3
Using Critical Depth as a Rough Estimation of the
Required Gate Opening to Achieve 2 to 3-foot Fluctuations in Straits Pond

Net Gate Width (feet)	Critical Water Depth (feet)	Velocity (fps)	Velocity Head (feet)	Minimum Average Energy Level	
				Required (ft, NGVD)	Available (ft, NGVD)
3-foot Pond fluctuation from 3 to 0 ft, NGVD					
20	2.38	8.77	1.19	1.58	1.50
14	3.03	9.85	1.51	2.54	1.50
9	4.06	11.44	2.03	4.09	1.50
30	1.82	7.66	0.91	0.73	1.50
2-foot Pond fluctuation from 3 to 1 ft, NGVD					
20	1.90	7.84	0.95	0.85	2.00
14	2.41	8.83	1.21	1.62	2.00
9	3.24	10.22	1.62	2.86	2.00
30	1.46	6.80	0.72	0.18	2.00

9. ESTUARY FLOODING

As reported by Jason Burtner, and shown in photos 8 – 10, properties on the estuary side of the Route 228 bridge experience flooding in association with astronomical or storm tides that exceed 12 feet, MLW (7.5 ft, NGVD). The property owners perceive this problem as increasing with time. This prompted Mr. Burtner to ask that if the tide gates were operated in a manner that allowed a more normal ebb and flow of the tide (i.e. the tide gates more or less constantly open), would that reduce the current high tide elevation? In other words, would allowing the incoming tide to enter Straits Pond, thereby acting as a hydraulic reservoir, reduce the peak high tide elevation and reduce potential flooding to the adjacent properties, rather than having the incoming tide being halted against a closed tide gate? Mr. Burtner noted that such an effect appears to be occurring at Musquashcut Pond in Scituate.

To determine the effects of Straits Pond on water levels in the Weir River would require expanding this study to include modeling the Weir River, which is well beyond the current scope. However, it seems unlikely that installing larger gates and leaving them open to natural flows would reduce water levels in the estuary. Such a concept would only work if there were some hydraulic restriction limiting tidal flows into the estuary. Figure 3 shows that the peak tide level in the estuary during the period 20 - 22 May 2003 was only slightly less than in Boston Harbor, indicating there was no significant restriction under those tide conditions. It is possible that at higher tides there is a greater difference in water levels between the harbor and estuary, but this seems unlikely unless there is a bridge whose low chord becomes submerged such that it becomes a relatively greater restriction to higher flows. Furthermore, the opening to Straits Pond would have to be large enough such that it was less of a restriction than the downstream hydraulic control. Finally, a reduction in flooding in the Weir River would likely only be achieved with an increase in flooding around Straits Pond, and there's a good chance it would increase flooding around Straits Pond without reducing it in the Weir River.

10. EFFECTS OF RAINFALL

The Corps performed a cursory assessment of rainfall runoff and found that Mr. William McNamara's conclusions that an inch of runoff can raise the pond half a foot seemed reasonable, as does his practice of lowering the pond in anticipation of heavy rain. We did not include rainfall in the gate simulations because there was neither an identified event nor a specific water quality condition for which we needed to design the new gates. The effects of rainfall runoff on water quality in the pond are unknown; runoff increases flushing of the pond, which would be a benefit unless the runoff is loaded with nutrients or promotes aquatic weed growth by reducing salinity in the pond. However, even if rainfall runoff is a net problem for Straits Pond requiring additional flushing after storm events, the larger gates recommended for tidal flushing will also help drain runoff from the pond. If rainfall runoff is a net benefit to water quality in the pond, larger gates will not cause any problems.

11. AUTOMATIC VS. MANUALLY CONTROLLED GATES

There is some question about what type of controls should be used for the new gates. Manual controls have the advantages of maximizing flushing, drawing down the pond in anticipation of storms, and ensuring that clogging from debris, algal mats, or winter ice is promptly corrected. Manual controls have the disadvantage of being labor intensive and requiring operations at odd hours of the day as well as weekends and holidays. Automatic gates require less attention; however, they would require sophisticated controls to work best. There are gates that can be set to close at a specific water level, and these work well where tidal flushing is desired but it is important not to exceed a certain water level. Figure 6 shows an example of self-regulating tide gates that are controlled by floats. At Straits Pond, it is important to maximize flushing without exceeding the flood level, and this could not be achieved by controlling the gate from only one water surface. Typical self-regulating gates (as shown in figure 6) would have to be on the estuary side and controlled by the water level in the estuary. The desired maximum water level in Straits Pond has not been determined, but if it was 3.0 feet, NGVD for example, a gate set to close when the estuary reached 3.0 feet would not allow the pond to get that high, and therefore would limit flushing. If the gate were set to close when the estuary rose to a higher elevation, such as 4 feet for example, the pond would still not rise to 3.0 feet on every high tide but would also occasionally exceed 3.0 feet. What would be needed ideally would be a gate controlled by water level sensors in the pond and estuary that would close the gate when the pond reached the desired maximum level and open the gate when the estuary level dropped below the pond level. This would likely require electronic controls that would need more maintenance than the float-controlled gates in figure 6. Automatic gates would also require some type of manual override if it were necessary to draw the pond down in anticipation of heavy rain or coastal flooding. An automatic gate with simple manual override controls would provide the best performance, but reliability and maintenance would be issues that would need to be considered with evaluating the suitability of this technology for the given application.

A second issue with the use of an automatic gate is the maintenance of a minimum water level in Straits Pond. Under certain tide conditions, an automatic gate would have the potential to draw the pond down to levels that exposed areas of inter-tidal mud flats. However, the channel high point upstream of the gate will act as a natural weir to help maintain a minimum pool level. Occasional manual overrides of the automatic gate may be necessary to keep the pool from going too low, but for most tide conditions this natural weir would likely maintain a satisfactory minimum water level in Straits Pond in conjunction with an automatic gate.

12. CONCLUSIONS

Net gate width is the major factor controlling flushing in Straits Pond, and it matters little whether it is obtained with one or a few gates. Ideally, the new gates should be as wide as practical, and automatically controlled with manual overrides. Replacing the existing gates with two 7-foot wide by 5-foot high gates would significantly increase flushing in the pond, which would improve water quality. However, the Corps has no way to relate specific increases in flushing to specific improvements in water quality. Using gates with a net width greater than 14 feet would further increase flushing with likely additional improvements in water quality, but when the total gate width approaches 20 feet, the high point in the channel between the gate and the pond may start to affect the minimum pool level. The single cross section the Corps surveyed across this channel high point may not be enough to define it properly, and additional surveys would be necessary to determine when this high point becomes controlling. Changes to the gates are not likely to affect water levels on the estuary side of the Route 228 bridge. Automatic gate controls with manual overrides would provide the best performance, but reliability and maintenance considerations would need to be evaluated when selecting a control mechanism. Making the gates more than 5 feet high adds little to their ability to flush the pond, but does not cause problems either if higher gates were desired for boat access or other reasons.

Figure 1: Location of Straits Pond

Figure 2
Straits Pond Tidal Data

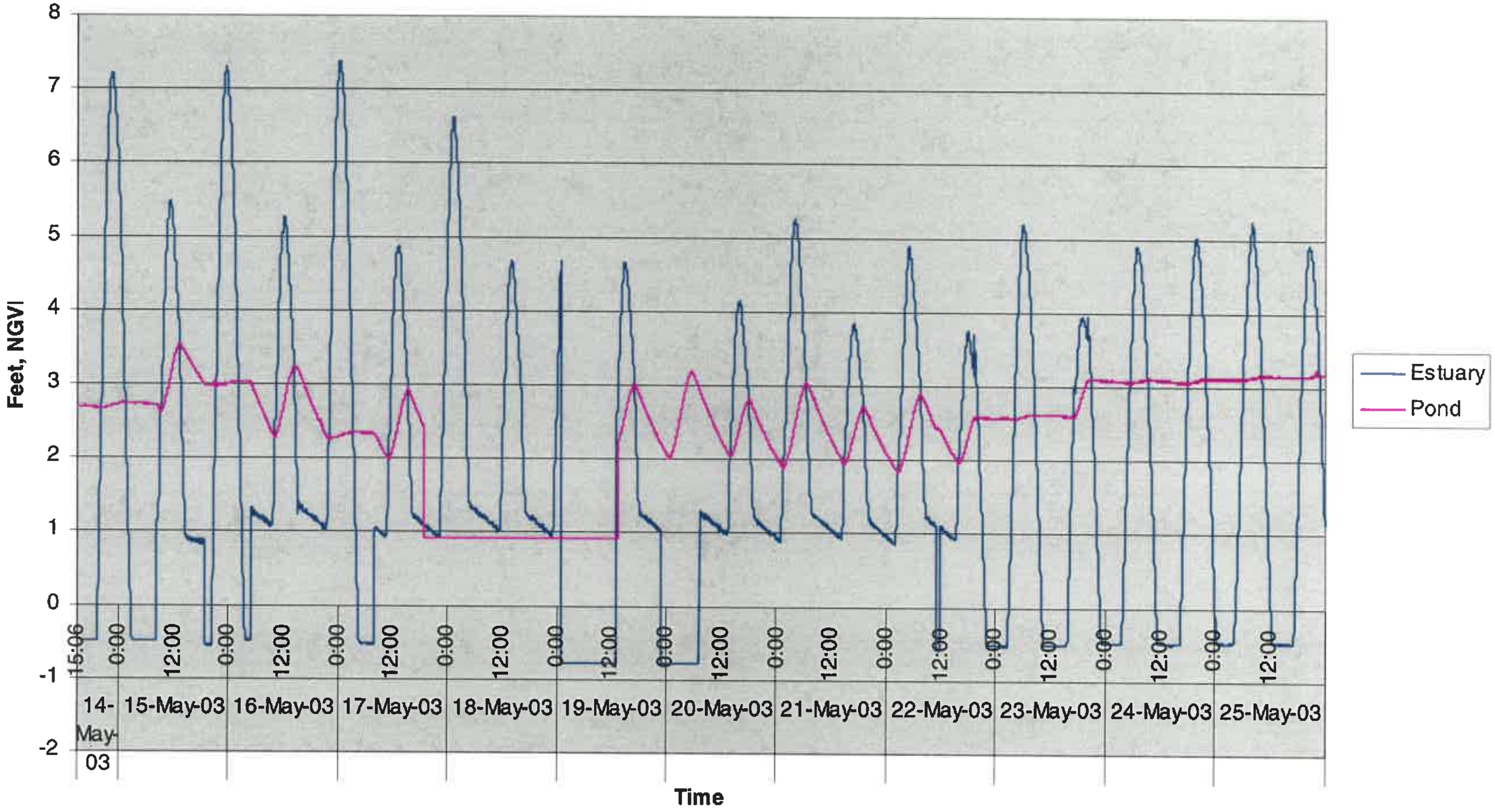


Figure 3
Estuary vs. Pond vs. Boston Harbor Tide Levels

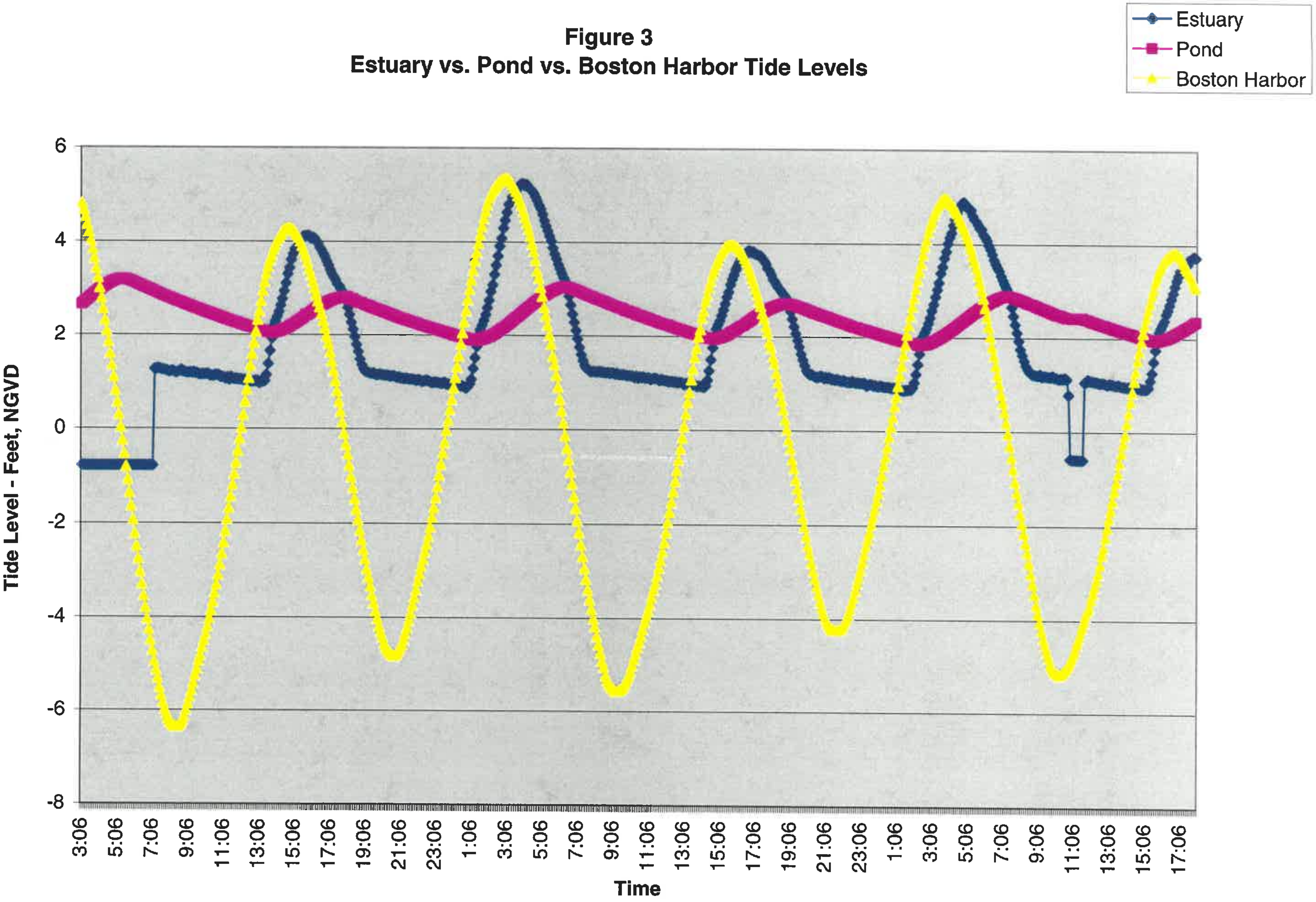


Figure 4
Estuary vs. Pond vs. Boston Harbor Tide Levels

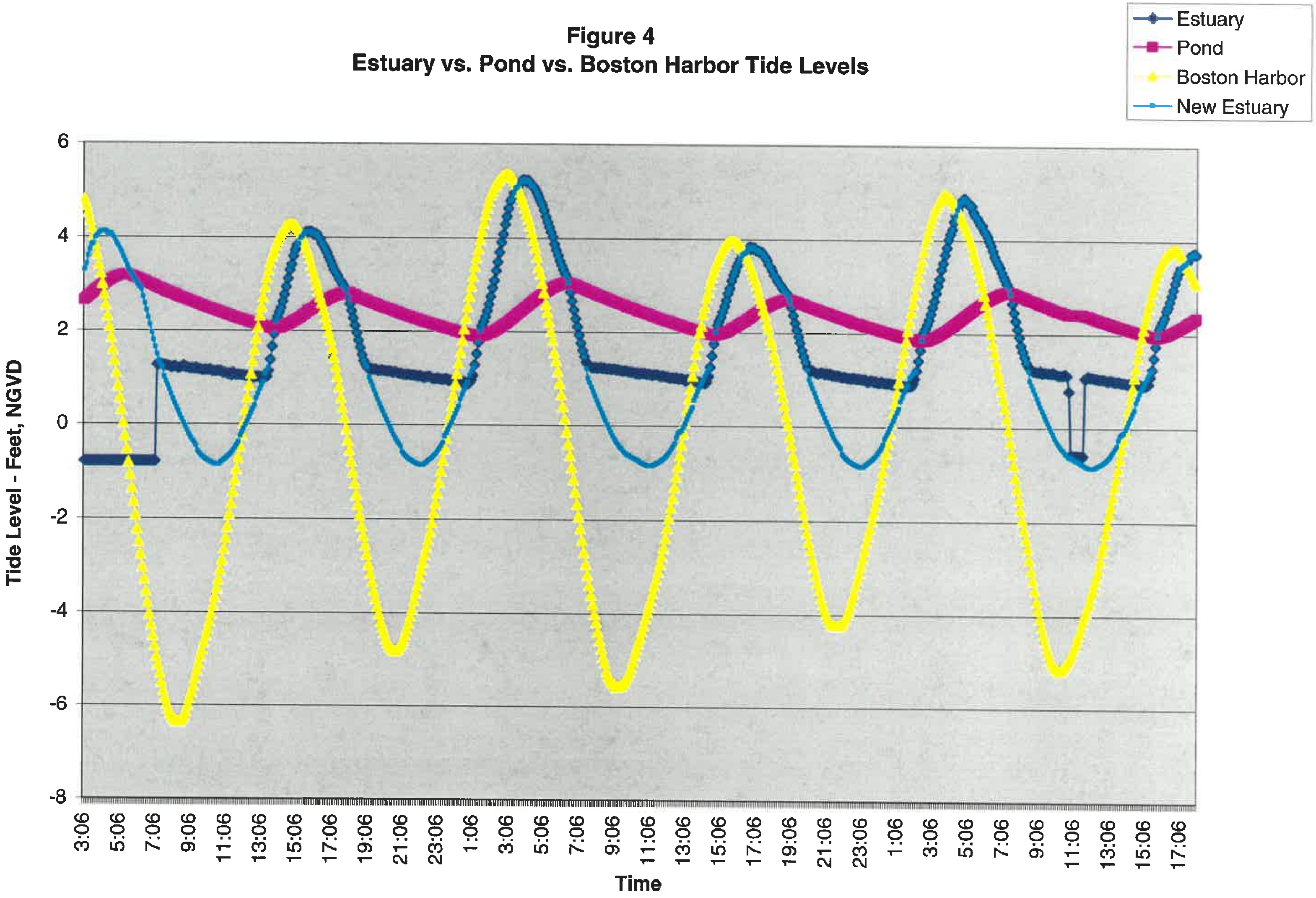
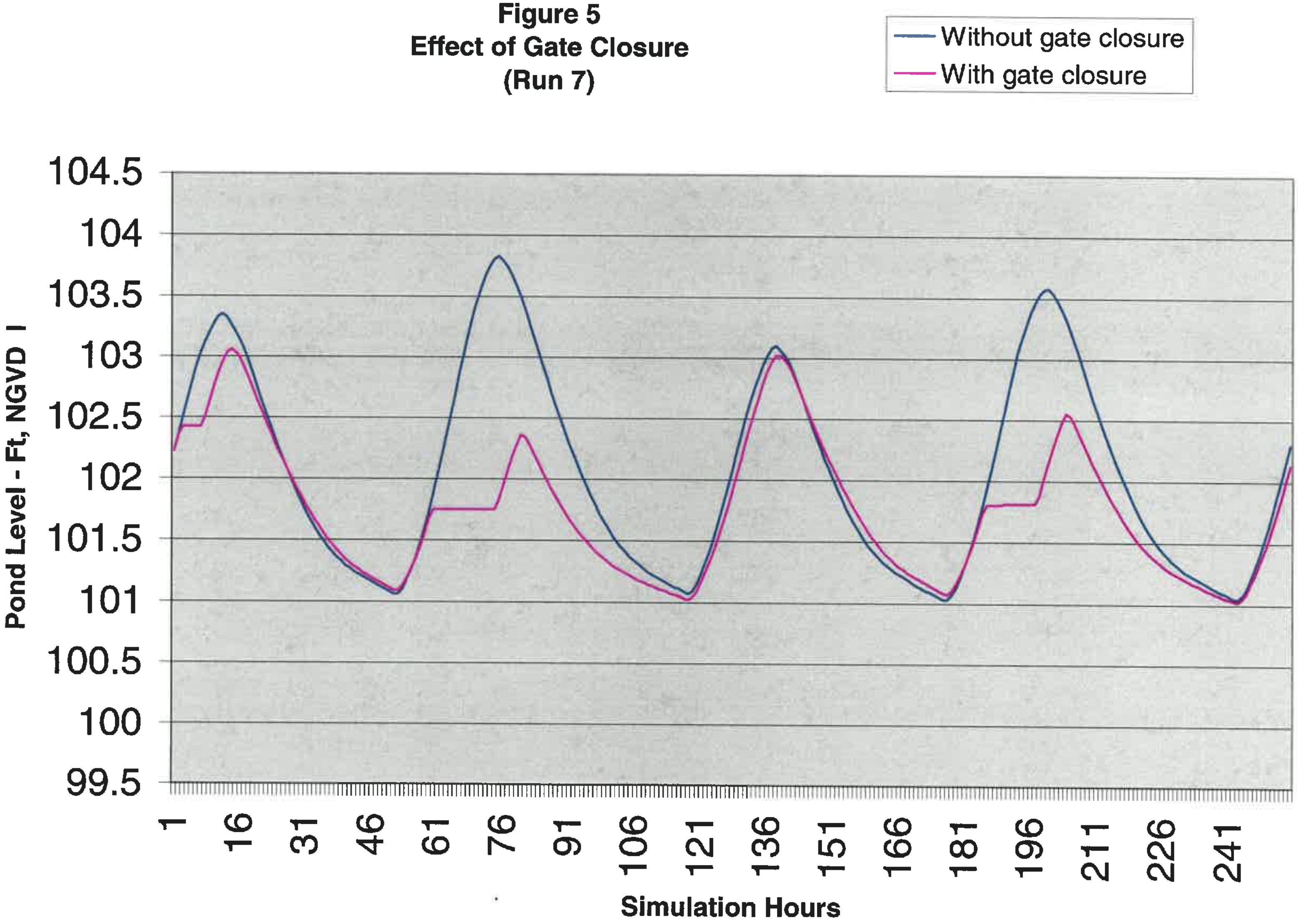
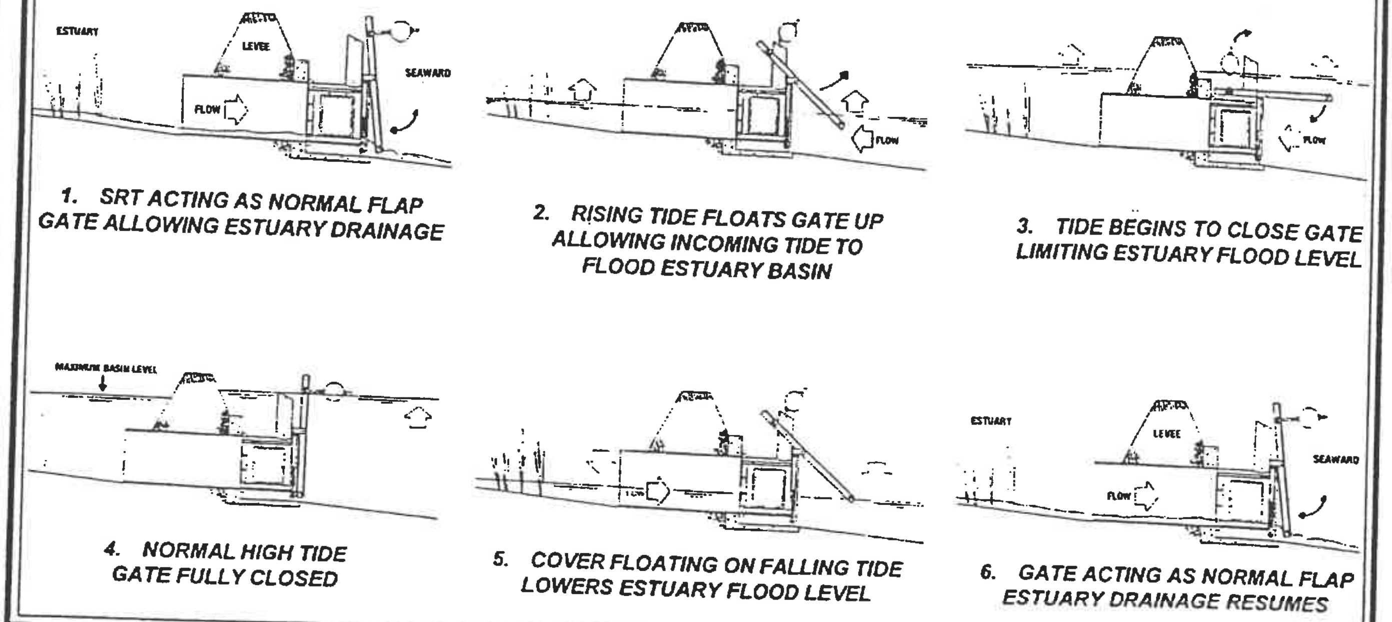


Figure 5
Effect of Gate Closure
(Run 7)



SRT IN NORMAL TIDE SEQUENCE



1. SRT ACTING AS NORMAL FLAP GATE ALLOWING ESTUARY DRAINAGE

2. RISING TIDE FLOATS GATE UP ALLOWING INCOMING TIDE TO FLOOD ESTUARY BASIN

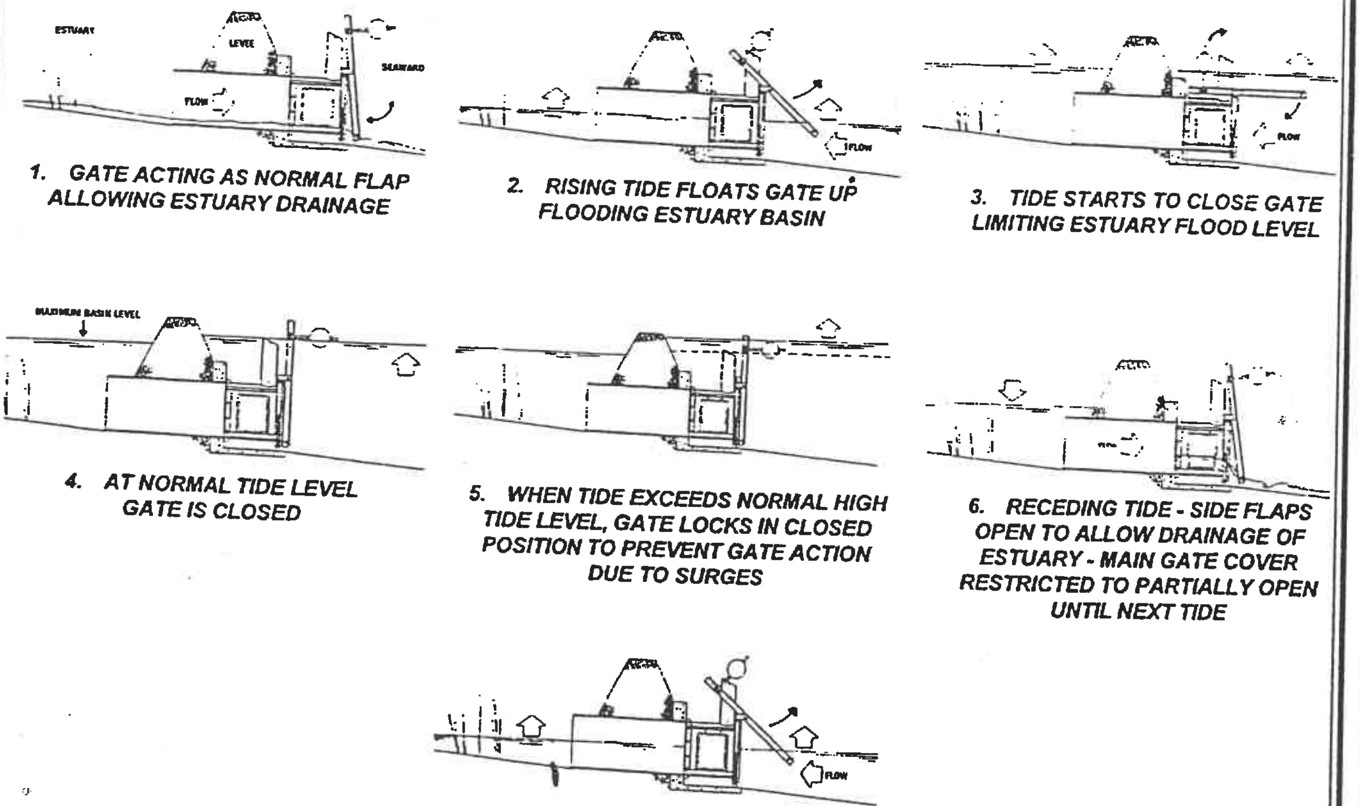
3. TIDE BEGINS TO CLOSE GATE LIMITING ESTUARY FLOOD LEVEL

4. NORMAL HIGH TIDE GATE FULLY CLOSED

5. COVER FLOATING ON FALLING TIDE LOWERS ESTUARY FLOOD LEVEL

6. GATE ACTING AS NORMAL FLAP ESTUARY DRAINAGE RESUMES

*SRT IN STORM SEQUENCE **



1. GATE ACTING AS NORMAL FLAP ALLOWING ESTUARY DRAINAGE

2. RISING TIDE FLOATS GATE UP FLOODING ESTUARY BASIN

3. TIDE STARTS TO CLOSE GATE LIMITING ESTUARY FLOOD LEVEL

4. AT NORMAL TIDE LEVEL GATE IS CLOSED

5. WHEN TIDE EXCEEDS NORMAL HIGH TIDE LEVEL, GATE LOCKS IN CLOSED POSITION TO PREVENT GATE ACTION DUE TO SURGES

6. RECEDING TIDE - SIDE FLAPS OPEN TO ALLOW DRAINAGE OF ESTUARY - MAIN GATE COVER RESTRICTED TO PARTIALLY OPEN UNTIL NEXT TIDE

7. NEXT INCOMING TIDE - GATE UNLOCKS & RESUMES NORMAL TIDE SEQUENCE

** Note that a maximum level is not exceeded on the estuary side of SRT during any phase or condition.*

Figure 6

Photo 1. Straits Pond, October 2003. Route 228 bridge is on the left with the gate enclosure on the right side of the bridge. The pond elevation about 2 feet, NGVD.

Photo 2. Route 228 bridge from the estuary side during the midpoint of a falling tide, April 2003.

Photo 3. Gate control mechanism.

Photo 4. Straits Pond, 23 January 2003.

Photo 5. Straits Pond, October 2003, showing the high point in the channel with the pond around elevation 1 ft, NGVD.

Photo 6. Straits Pond, October 2003, close up showing the high point in the channel with the pond around elevation 1 ft, NGVD.

Photo 7. Straits Pond, October 2003, close up showing the high point in the channel with the pond around elevation 1 ft, NGVD.

Photo 8. Estuary flooding, November 2003.

Photo 9. Estuary flooding, November 2002.

Photo 10. Estuary flooding, November 2002.

Photo 11. Timber supporting beam on estuary side of bridge.