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MEMORANDUM

Date: **September 25, 2009**

To: **Carole Ridley, Pleasant Bay Alliance**

From: **Sean Kelley, P.E.**

Subject: **Muddy Creek Culvert Scenarios**

An hydrodynamic analysis of Muddy Creek was performed to determine the optimal with of the inlet channel under Route 28. The existing stone structure (Figure 1) that connects Muddy Creek to West Pleasant Bay has two 3-foot-wide culverts with a length of 100 feet. This culvert structure restricts tidal exchange between the creek and the Bay, which has a direct effect on water quality in the creek.

Widening the channel under Route 28 would improve tidal flushing and lower nitrogen concentrations in the creek. These improvements would potentially offset the amount of watershed nitrogen load reduction required (through sewering or other means) to achieve the habitat restoration goals required by the Mass DEP TMDL (Total Daily Maximum Load) for the creek (MDEP, 2007).

A. Model Development

The hydrodynamic model used as the basis of this analysis was originally developed as part of a Chatham town-wide evaluation of estuarine water quality and nitrogen loading (Applied Coastal, *et al*., 2001). The two-dimensional finite element code RMA-2 is used to simulate tidal circulation in the creek using a model grid mesh created for the creek (Figure 2). This grid file contains information about the spatial coverage and bathymetry of the modeled embayment system. Other inputs to the model include the time-varying water surface elevation at the open boundary, and estimates of surface roughness for the different regions of the system. These roughness coefficients are used as tuning parameters to calibrate the model.

The model of Muddy Creek was modified in order to reflect changes to the Pleasant Bay system since the time that the model was originally developed. The 2007 breach of the north inlet has slightly increased the tide range in Pleasant Bay (Kelley and Ramsey, 2008). An updated tidal boundary condition was developed using a calibrated post-breach (2007) hydrodynamic model of Pleasant Bay. Tide data measured by the Town of Chatham at the Chatham Fish Pier (Keon, 2009) show that the present tide range similar to the measured range during the November 2007 Pleansant Bay model calibration period. Therefore, it was determined that it was appropriate to extract the

West Pleasant Bay tidal boundary condition of the Muddy Creek model from the 2007 post-breach simulation.

A survey of the inlet channel on the Pleasant Bay side of Route 28 was conducted in June 2009 to measure changes in its depth and location compared to the year 2000 time basis of the original model. Data from this survey are shown in Figure 3. Shoreline measurements indicate that the position of the channel has not changed significantly. The measured depths were used to update the model bathymetry.

Figure 1. Pleasant Bay entrance of the existing Muddy Creek culvert. The culvert has two 3-foot-wide channels that span the 100-foot distance under the Route 28 roadway.

B. Culvert Scenarios

After updating the muddy creek model to reflect 2009 conditions, several different culvert scenario runs were performed to determine how tidal hydrodynamics and system flushing would change as the culvert width was increased. The main goal modeling the different inlet scenarios was to determine the optimum channel width that would maximize tidal exchange but also would have channel velocities that were swift enough to naturally prevent the channel from shoaling. If the channel width made wider than the optimum width there would be little additional tidal flushing benefit and channel maintenance costs would increase. Channel maintenance is a particular concern for culvert and bridge crossings, where structure prevents easy access to the channel by dredging equipment.

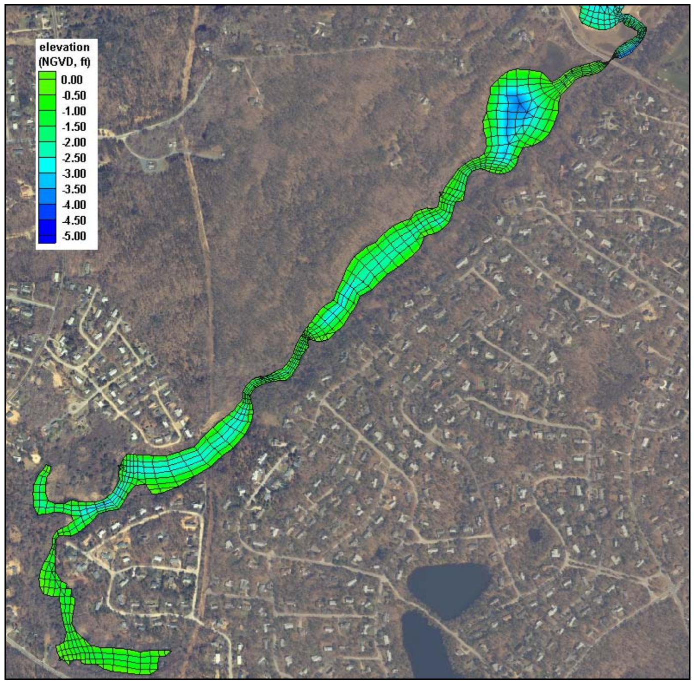

Figure 2. Model grid of Muddy Creek, showing grid mesh and bathymetric contours.

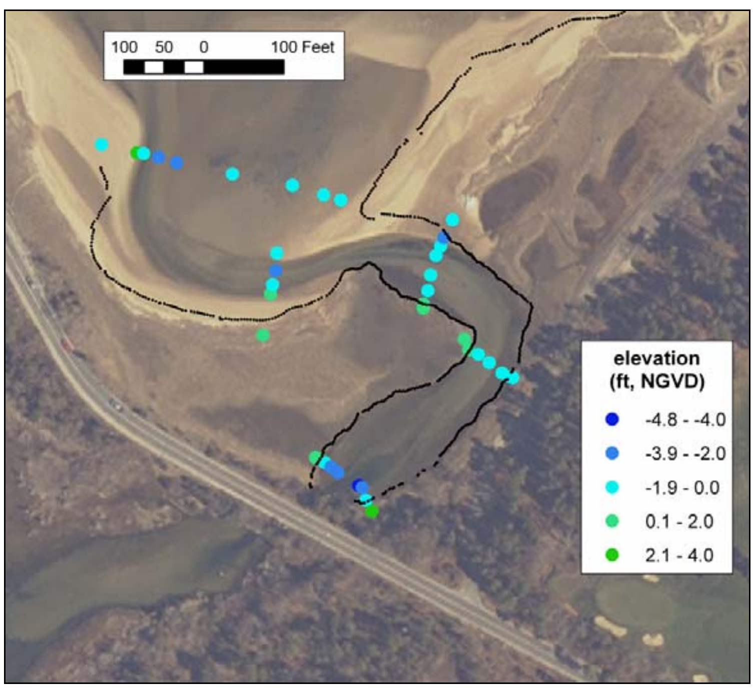

Figure 3. 2005 aerial orthophoto of the Muddy Creek inlet channel with overlain results of the June 2009 survey. Colored points indicate measured depth along cross-channel transects. The measured shoreline is indicated by the dotted black lines.

The general guideline for channel design in a sandy environment is that maximum velocities should not be less than 3 ft/sec. Velocities less than this indicate that the channel is not stable and has the potential to shoal. Velocities much larger than this indicate that there is potential for scour for unarmored channels. For this study, based on discussions with the Pleasant Bay Alliance (PBA) the target channel velocity was set at 4 ft/sec to ensure the self maintenance capability of the channel.

The channel scenarios that were run in the model include channel widths of 6, 12, 24, 36 and 44 feet. All these scenarios have single channels, unlike the present culver structure. It is likely that the wider channel scenarios would need to be constructed as a single bridge crossing, or using multiple culverts. In each case, the channel depth under the Route 28 roadway was set at -1.3 feet NGVD, as it is presently. Mean low water (MLW) in West Pleasant Bay is approximately 0 ft NGVD. Each model run was made using the same tidal boundary condition so the model results are directly comparable.

Tide elevations from the molded scenarios are shown in Figure 4. In this plot, the tide range increases along with the channel width. For the alternatives that are 24 feet wide or wider, the elevation of the high tides is nearly equal to the tide in Pleasant Bay. Table 1 shows the standard tide datums computed for the simulation period. From the table, it is seen that the tide range increases from 0.5 ft for present conditions to 3.5 ft for the 48-ft culvert option, which is only 0.7 ft less than the tide range in Pleasant Bay.

A comparison of maximum tidal velocities in each modeled channel is shown in Figure 5. The results show that the 48-foot crossing is wide enough that maximum velocities drop below the 4 ft/sec threshold. The greatest velocities occur in the 12-foot-wide crossing scenario. This indicates that the channel would scour to a deeper depth if its bottom was not armored. The results of the 6-foot-wide channel indicate that tidal exchange is more efficient in this alternative compared to present conditions even though the cross sectional area of the two culverts is the same. This is due to increased hydrodynamic drag along the divider wall of the existing culvert.

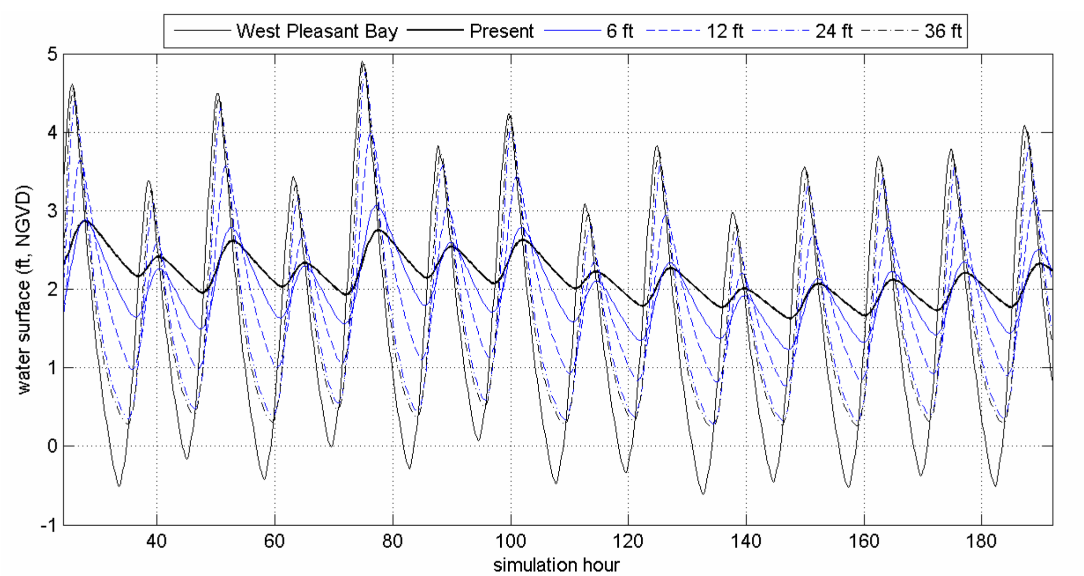

Figure 4. Comparison of model output for the modeled Muddy Creek inlet channel scenarios. The West Pleasant Bay boundary condition is with tides computed in the main basin of the creek.

Table 1. Tide datums computed for existing conditions and five modeled inlet scenarios. Elevations are in feet, NGVD. Percent change of tide range compared to present conditions is also provided.

	WPB open boundary	**2009 present**	**6 ft single culvert**	**1 2ft single culvert**	**24 ft single culvert**	**36 ft single culvert**	**44 ft single culvert**	**48 ft single culvert**
Maximum Tide	4.9	2.9	3.1	4.0	4.8	4.9	4.9	4.9
MHHW	4.2	2.5	2.6	3.4	4.0	4.2	4.2	4.2
MHW	3.9	2.4	2.4	3.0	3.6	3.8	3.8	3.8
MTL	1.8	2.2	2.0	2.0	2.0	2.1	2.1	2.1
MLW	-0.3	1.9	1.5	0.9	0.4	0.3	0.3	0.3
MLLW	-0.5	1.9	1.5	0.9	0.4	0.3	0.3	0.3
Minimum Tide	-0.6	1.6	1.2	0.8	0.3	0.2	0.2	0.2
Mean Range	4.2	0.5	0.9	2.0	3.2	3.4	3.5	3.5
Percent Change		-	+80	+300	+540	+580	+600	+600

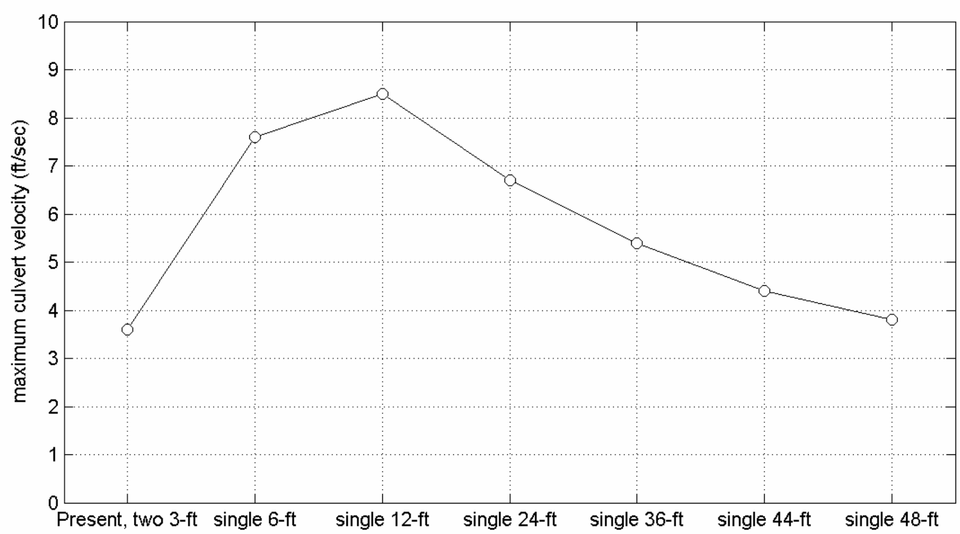

Figure 5. Maximum modeled culvert velocities for present conditions (two 3-foot culverts) and five single culvert scenarios for Muddy Creek.

Table 2 shows a comparison of creek mean volume and mean tide prism, and the resulting flushing rate for present conditions and the modeled alternatives. The mean system volume initially decreases as the low tide elevation decreases more than the high tide increases. The change in mean tide volume is not large for any of the alternative (approximatley 5%). However, the tide prism does change greatly as the channel is widened. The result is a dramatic change in system flushing time for the creek, which drops from 3.9 days for present conditions to 0.5 days for the scenarios with channels 24-foot and wider. This indicates a significant improvement in tidal flushing conditions, and possible great water quality improvements.

The results presented in Table 2 also show that the flushing benefit does not increase further for the scenarios that are wider than 24 feet. Because there is little additional benefit from the wider scenarios, the 24 foot crossing may be considered to be optimum since it maximizes flushing with the minimum channel width.

Table 2. Comparison of computed mean volume (ft^3), mean tide prism (ft^3), and system residence time (days) for present condition and modeled alternatives.

Scenario	**2009 present**	**6 ft single culvert**	**1 2ft single culvert**	**24 ft single culvert**	**36 ft single culvert**	**44 ft single culvert**	**48 ft single culvert**
Mean Volume	5,337,000	5,069,000	5,056,000	5,145,000	5,210,000	5,227,000	5,228,000
Mean Prism	713,000	1,442,000	3,157,000	4,972,000	5,281,000	5,382,000	5,361,000
Flushing Rate	3.9	1.8	0.8	0.5	0.5	0.5	0.5

C. References

Applied Coastal Research and Engineering, Inc., Applied Science Associates, Inc., and School of Marine Science and Technology, University of Massachusetts at Dartmouth (2001). Water Quality Analyses of Coastal Embayments in Chatham, MA. Mashpee, MA.

Kelley, S.W., J.S. Ramsey (2008). Hydrodynamic Model of Chatham Harbor/Pleasant Bay including 2007 North Breach. Technical Memo. Applied Coastal Research and Engineering, Mashpee, MA. 24 pp.

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