Report to:

Coastal America Foundation and Cape Cod National Seashore (National Park Service)

Entitled:

Simulations of Wide Sluice Gate Restoration Option for Herring River

Prepared by:

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1. Scope of Work:

In response to a request from the National Park Service(NPS), Cape Cod National Seashore, we have performed additional simulations with the Herring River hydrodynamic and salinity distribution models (described in Spaulding and Grilli, 2002) to investigate the impact of a restoration option in which a series of sluice gates are installed at the current location of the Herring River dike and restriction to tidal flows are removed at High Toss Road. The study tasks used to complete the work are summarized below.

2. Tasks:

- 1. Perform simulations for a vertically unrestricted (culvert height at least 2m above NGVD) culvert with widths of 10, 20, 30, 40, 60, 100 and 120 m at the current dike location (7 cases). Mean tidal forcing, Herring River storage capacity including unrestricted access to Mill Creek and above High Toss Road (Basin B3) and a culvert invert of 0.84 m NGVD will be assumed. The results of these simulations will be reported in terms of the high and low water levels on the seaward and landward side of the culvert for each case. NPS personnel and their collaborators will select one of the above culvert width cases that will allow unrestricted tidal flow to the river.
- 2. Evaluate the sensitivity of the hydrodynamic model predictions to frictional losses for the culvert width selected by NPS in Task 1 (5 cases). Summarize the results in terms of high and low water levels, seaward and landward of the culvert.
- 3. Given the culvert width selected by NPS in Task 1 and assuming mean tidal forcing and B3 basin geometry, perform simulations for sluice-gate openings of 0.1, 0.4, 0.8, 1.4, 2.0, and 3.0 m, relative to the present culvert invert (6 cases). The 3-m height will allow a spring tide (~2.0 m-NGVD) to pass unrestricted, given the invert of 0.53 m -MLW (= -0.84 m-NGVD). Simulations for 0.1, 0.4 and 3.0 m opening-height cases (3 cases) will be repeated with 100 yr storm forcing. Frictional dissipation from both the culvert and the sluice gate will be included in the simulation. The results of these simulations will be reported in terms of the high and low water levels on the seaward and landward side of the culvert for each case.
- 4. Apply an inlet basin model to estimate the width, height and elevation of an opening through High Toss Road to remove all restrictions to tidal flow at that point in the system. The model will treat the area above High Toss Road as a single basin and will be driven by mean tidal water levels in Herring River determined from Task 2 for the NPS selected culvert width, without vertical restriction. A box culvert with invert at -0.8 m-NGVD and top at 2.0 m-NGVD, height of spring tides below the Chequesset Neck dike, will be assumed. Simulations will be performed assuming culvert widths of 2, 5, 10 and 20 m (4 cases). The 20 m wide case corresponds to the most probable pre-dike

width of the channel. Results will be reported in terms of high and low water levels seaward and landward of High Toss Road.

5. For three NPS selected cases from the above simulations, time series of the tidal elevations landward and seaward of the culvert will be prepared over one tidal cycle. In addition model predicted images of the water level plan views and salinity distribution will be prepared at high and low tide.

3. Task Results

The results for each task are presented below in order by task number.

Task 1 Summary of sensitivity to sluice gate width.

Simulations were performed with the Herring River inlet basin hydrodynamic model developed by Spaulding and Grilli (2001). Simulations were performed assuming that the width of culvert increased from 10 m to a maximum of 120 m. The following conditions were assumed for the simulation:

Basin Geometry: B3 - unrestricted access to Mill Creek and above High Toss Road

Tidal Forcing: average $[0.46 + 1.19 \sin (2\pi/T)]$ (m) (Garvine, Spaulding and

Grilli)

Culvert: Vertically unrestricted culvert height, existing length (20 m),

varying width between 10 and 120 m

Model predicted low and high tide levels, referenced to NGVD, are provided in Table 1.1 for average tidal forcing for each case. Figure 1.1 shows a plot of the surface elevation versus time in Herring River for each case over several tidal cycles. Also shown for reference is the ocean tidal forcing. The simulations show that the low (high) water level decreases(increases), and asymptotically approaches the ocean forcing conditions, as the sluice gate width increases. The tidal range increases as the sluice gate width increases. For sluice gate widths in excess of 30 m the tidal conditions in Herring River (low and high tide levels and tidal range) are effectively the same as for the ocean forcing.

Table 1.1 Summary of low and high water levels and tidal range predicted for various sluice gate openings.

Sluice Gate Width

	Forcing	10m	20m	30m	40m	60m	100m	120m
Low (m)	-0.73	-0.37	-0.50	-0.69	-0.71	-0.72	-0.73	-0.73
High (m)	1.65	1.45	1.60	1.64	1.65	1.65	1.65	1.65
River Tidal	2.38	1.82	2.10	2.33	2.36	2.37	2.38	2.38
Range (m)								
% Seaward	100	76.4	88.2	97.8	99.2	99.6	100	100
Tidal Range								

Herring river: unrestricted access to Mill Creek and above High Toss Road area (B3) Sensitivity of water elevation to culvert width Average forcing

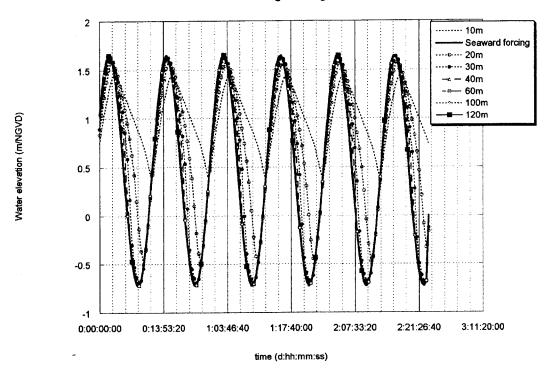


Figure 1.1 Time series of the model predicted water level (m) referenced to NGVD in Herring River for various sluice gate widths. The ocean forcing is also shown for reference.

Task 2 Sensitivity to frictional losses

Predicted high and low tide elevations in Herring River (m, relative to NGVD), assuming a 30 m width inlet, B3 basin geometry, and a range of Manning coefficient varying between 0.02 and 0.09, are provided in Table 2.1. The predicted time series in Herring River are shown in Figure 2.1.

Table 2.1 Sensitivity of high and low tide levels in Herring River (m, relative to NGVD) to Manning friction factor, n.

Manning coefficient	n = 0.09	n = 0.06	n = 0.04	n = 0.03	n = 0.02
High (m)	1.58	1.63	1.65	1.65	1.65
Low (m)	-0.69	-0.71	-0.72	-0.73	-0.73
Tidal Range (m)	2.27	2.34	2.37	2.38	2.38

The ocean forcing has a high tide level of 1.65 m and a low tide level of -0.73 m and a range of 2.38 m.

The predicted tidal range is relatively insensitive (less than 5 %) to friction factor for the specified culvert opening.

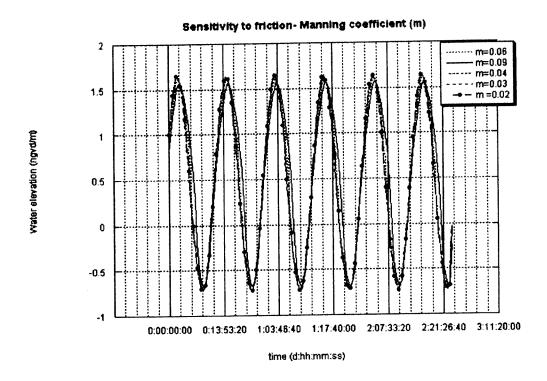


Figure 2.1 Herring River water elevation time series for various Manning friction factors

Task 3 Summary of sensitivity to sluice gate opening

The hydrodynamic model was used to simulate the water levels in Herring River for various vertical sluice gate openings, six (6) cases with openings varying from 0.1 m to 3.0 m. The simulations assumed mean tidal forcing; a rectangular inlet/culvert 20 m length, 30 m width, with a 30 m width sluice gate; a Manning friction coefficient of 0.06, and B3 basin geometry. Simulations were repeated for three (3) opening cases, 0.1, 0.4, and 3.0 m, for the 100 year storm forcing. In these simulations the flow is assumed to be vertically unrestricted until it reaches the sluice gate. The current culvert invert is -0.84 m NGVD and is used in the present simulations.

Table 3.1 and 3.2 provide the average high and low water levels (referenced to NGVD) in Herring River, for each case for mean tidal and 100 year storm forcing, respectively. High and low tide levels for the forcing are also provided. Figure 3.1 shows the water level time series in Herring River for the mean tidal forcing case and various vertical sluice gate openings.

Figure 3.1 and Table 3.1 show that high water level and tidal range increase and low water level decrease as the sluice gate opening height increases. The time lag between high/low tide in the river, relative to the forcing function, decreases as the gate opening increases. For gate openings larger than 1.4 m the tidal range and phase in the river is the same as for the forcing.

Simulations for 100 year storm forcing show similar trends to the mean tidal forcing cases. The principal difference is that even at the largest sluice gate opening the water level range in the river is only 64 % of the level in the ocean.

Table 3.1 Sensitivity of high and low tide levels in Herring River (m, relative to NGVD) to various vertical levels of sluice gate opening for mean tidal forcing.

		Gate opening (m)						
Water Tidal Elevation Forcing (m) (m)	Forcing	0.1	0.4	0.8	1.4	2.0	3.0	
Low	-0.73	-0.62	-0.68	-0.71	-0.69	-0.69	-0.69	
High	1.64	1.25	1.27	1.49	1.59	1.63	1.64	
Range	2.37	1.87	1.95	2.20	2.28	2.32	2.33	
% Forcing Range	100	78.9	82.3	92.8	96.2	97.9	98.3	

Table 3.2 Sensitivity of high and low tide levels in Herring River (m, relative to NGVD) to various vertical levels of sluice gate opening for 100 yr storm forcing.

Water Elevation (m)	Tidal Forcing (m)	Gate opening (m)				
		0.1	0.4	3.0		
Low	- 2.26	-0.74	-0.73	0.93		
High	3.13	1.68	1.74	2.55		
Range	5.39	2.42	2.47	3.48		
% Forcing	100	44.9	45.8	64.6		
Range						

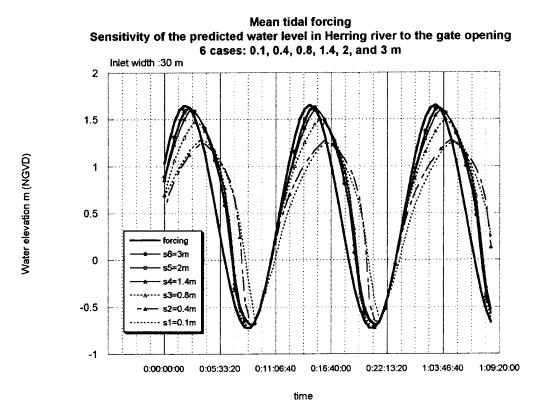


Figure 3.1 Herring River water elevation time series for various vertical sluice gate opening widths, mean tidal forcing.

The sensitivity of model predictions to variations in the Manning friction coefficient (0.06 and 0.03) are provided in Table 3.3 for the two smallest gate opening cases (0.4 and 0.8 m). The model predicts only a small difference between the two cases.

Table 3.3 Sensitivity of high and low tide levels in Herring River (m, relative to NGVD) for various Manning friction coefficients for two vertical levels of sluice gate opening for mean tidal forcing.

Water Level (m) and Gate opening (m)	Manning friction coefficient (n=0.06)	Manning Friction coefficient (n=0.03)
Sluice gate opening = 0.4		
m		
Low	-0.68	-0.73
High	1.27	1.29
Tidal Range	1.95	2.02
Sluice gate opening = 0.8		
m		
Low	-0.71	-0.73
High	1.49	1.53
Tidal Range	2.20	2.26

Task 4 Summary of sensitivity to box culvert width at High Toss Road

An inlet basin hydrodynamic model was applied to predict the elevation in the area north of High Toss Road for varying box culvert widths (2, 5, 10, and 20 m). The culvert invert was assumed at -0.8 m (NGVD) and the top at 2 m (NGVD), with a length of 10 m (existing length of culvert). The basin storage capacity versus elevation (hypsographic curve) (Figure 4.1) north of High Toss Road was generated from a topographic map of the area and assumed no restrictions to flows in the area. This is the same data used to characterize the storage capacity in the B3 basin used in prior simulations of the entire Herring River area.

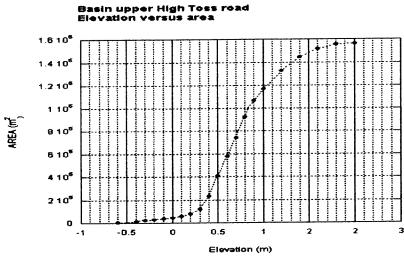


Figure 4.1 Water surface area (m²) versus elevation (m), referenced to NGVD, for the marsh area north of High Toss Road.

A Manning friction coefficient of 0.03 was assumed. The model was forced assuming the Chequesset Neck dike provided no restriction to tidal flows.

Table 4.1 shows model-predicted high- and low-water levels, tidal range and percent change in tidal range, relative to ocean forcing, north of High Toss Road for each of the four culvert-width cases. Figure 4.2 shows the model predicted time series for each case.

The simulations show that the low (high) water level decreases (increases), and asymptotically approaches the ocean forcing conditions, as the box culvert width increases. The tidal range, hence increases as the box culvert width increases. For widths of 10 m the tidal conditions north of High Toss Road (low and high tide levels and tidal range) are effectively the same as for the ocean forcing.

Table 4.1 Summary of low and high water levels and tidal range predicted above High Toss Road for various box culvert widths.

Water	Culvert width at High Toss Road							
Elevation (m)	forcing	2 m	5 m	10 m	20 m			
Low (m)	-0.73	0.54	-0.56	-0.72	-0.72			
High (m)	1.64	1.24	1.54	1.64	1.65			
Tidal Range (m)	2.37	0.70	2.10	2.36	2.37			
% Ocean Tidal Range	100	29.5	88.6	99.6	100			

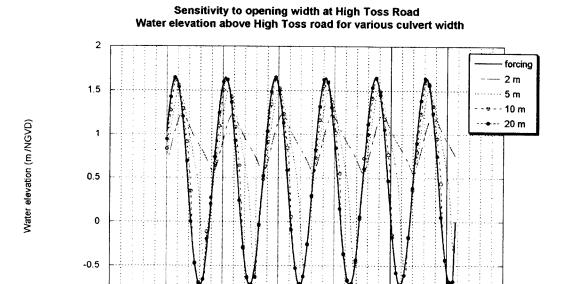


Figure 4.2 Time series of the model predicted water level (m), referenced to NGVD, above High Toss Road for varying box culvert widths. The ocean forcing is also shown for reference.

0:13:53:20 1:03:46:40 1:17:40:00 2:07:33:20 2:21:26:40

time (d:hh:mm:ss)

-0:13:53:20 0:00:00:00

Task 5 High and low tide and mean salinity plan view plots and water level time series

For the three NPS selected cases, below, time series of the tidal elevations landward and seaward of the culvert were prepared over one tidal cycle. They are provided in the form of Excel spreadsheet. In addition model predicted images of the water level plan views were prepared at high and low tide and for tidal mean salinity distribution.

- Case 1: Mean tidal forcing, 30-m wide culvert, opening height of 0.1 meters.
- Case 2: Mean tidal forcing, 30-m wide culvert, opening height of 1.4 meters.
- Case 3: Mean tidal forcing, 30-m wide culvert, opening height of 3.0 meters.

References

Spaulding, M. L. and A. Grilli, 2001. Hydrodynamic and Salinity Modeling for Estuarine Habitat Restoration at Herring River, Wellfleet, Massachusetts, National Park Service, Cape Cod National Seashore, Wellfleet, Massachusetts.