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A Report to Superintendent Herbert Olsen

Cape Cod National Seashore

"Tidal Height Model Application to Hatches Harbor"

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Tidal Height Model Application to Hatches Harbor

by Richard W. Garvine

1. Model adaptation

I adapted the model previously developed for application to the Herring River (Roman, 1987) for use in evaluating culvert properties for Hatches Harbor. The model predicts tidal height upstream of a barrier or dike of given properties for given downstream tidal heights vs. time. The basin upstream is assumed to have small dimensions compared to the relevant tidal wavelength so that little phase difference, say in time of high water, occurs within the basin.

Because similar culvert design to the Herring River is expected for Hatches Harbor, I set the directional model parameter M , Manning's coefficient, at the same value found empirically to best fit observations of the Herring River, $M = 0.090$. To establish the sensitivity of the results to M , I also ran the model for half that value, $M = 0.045$. The bathymetry of the basin was set to conform with the elevation data supplied. Otherwise, the model was unchanged from its prior form.

Unlike the former application, however, the tidal height time series for the downstream side, Hatches Harbor, differed markedly from that of adjacent Cape Cod Bay. Evidence for this is clear in the time series obtained by Dr. Portnoy for one tidal cycle on both 27 February and 4 November, 1987. While near high water the height in Hatches Harbor followed that predicted for the Bay, except for a half hour phase lag, for mid-stage and low water

the Harbor simply fell to and remained at a nearly constant height of about 7.3 ft (MLW). Such response is, in fact, typical of tidal lagoons behind narrow inlets. Hatches Harbor has such an inlet, in contrast to Wellfleet Harbor where the tides nearly follow the Bay throughout the tidal cycle.

Because modeling Hatches Harbor tides was a task well beyond this project, I instead adopted the following simplified method for specifying them. First, I lagged the Harbor tide 0.5 h behind the predicted (or measured) Bay tide, then I equated the Harbor tidal height to that of the Bay for those times when it exceeded 7.3 ft. Once the lagged Bay tide fell to 7.3 ft, I kept the Harbor tide constant at that level until the lagged Bay tide again rose to and above that level, after which I again equated the Harbor tide to it. The Harbor tides then were above 7.3 ft only during part of flood tide for the Bay, typically about 4.5 h.

2. Model results

I conducted two types of model runs, the first simulating a recurrence of the 7 February, 1978 storm tidal heights, the "100 year" storm of record, and the second a simple harmonic tidal height series for the Bay representing average tidal conditions. For both types I simulated two culvert designs, one rectangular and the other circular in vertical section. Both had fixed invert heights of 6.3 ft MLW, the same level as the present 2 ft diameter circular culvert; both were assumed to be of 50 ft length, as is the present one. I assumed both had concrete wetted surfaces, as

the Herring River dike does. I specified the top of the rectangular culvert at 13 ft (MLW), 6.7 ft above its invert, while the top of the circular culvert was necessarily set by its diameter. I varied the culvert width or diameter between 1 ft and 10 ft. No tide gate, flapper gate, or sluice gate was present.

The principal design criterion is that for a "100 year" storm the maximum water height $y_{\max}$ upstream of the culvert not exceed 10 ft (MLW). Figure 1 shows the model results for a simulation of the 1978 storm relative to that criterion. Maximum height $y_{\max}$ is plotted vs. culvert width (or diameter, if circular). Curves are given for both culvert types for two values of the Manning coefficient M , the "best" estimate obtained from the Herring River study, $M = 0.090$, and a more conservative value to show the sensitivity of the results, $M = 0.045$ (half the friction of the "best" estimate). As one would expect, all curves rise steeply for increased width, reduced M gives greater heights, and, for given width, the rectangular culvert allows greater heights. For the "best" value of M , $y_{\max} = 10$ ft (MLW) for a width of about 4.6 ft for the rectangular culvert and about 5.6 ft for the circular culvert.

The model also predicts current speeds in the culvert averaged over the cross-section. Again, these reach extreme values for the "100 year" storm. For $M = 0.090$ rectangular culverts had a maximum speed of 7.9 ft/s when the width was 5 ft and circular culverts had 8.0 ft/s when the width was 6 ft. These speeds increase slowly

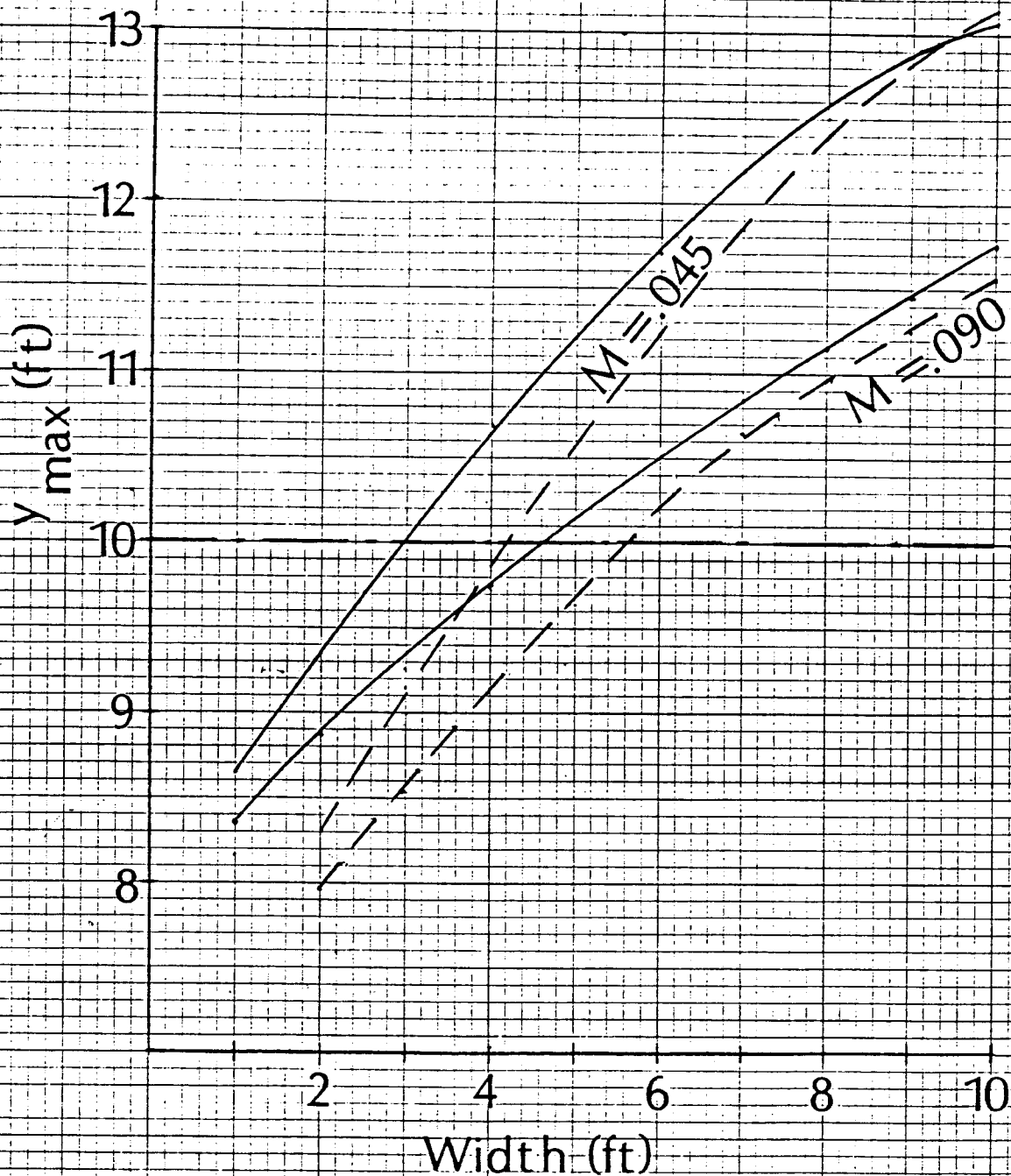


Figure 1: Maximum water height $y_{\max}$ upstream of culvert in feet (MLW) vs. culvert width for rectangular culvert (solid curves) and circular culvert (dashed curves) for two values of the Manning coefficient M . The dash-dot line gives the design limit for $y_{\max}$.

for increasing width reaching 9.9 ft/s and 10.0 ft/s for 10 ft wide rectangular and circular culverts, respectively.

For average tidal variations, neither neap nor spring tides, and in the absence of storm surges the upstream heights reduce considerably, for given culvert width. Table 1 shows typical levels for rectangular culverts. Note the low tidal range, only 0.33 ft for 5 ft width, for example. The intertidal volume, the volume of water exchanged during one cycle, is then $4.8 \times 10^5 \text{ ft}^3$. The bathymetric data supplied indicate, in comparison, that the tidal volume of water resident in the basin above the dike is $5.8 \times 10^5 \text{ ft}^3$ at the 8 ft level and $11.5 \times 10^5 \text{ ft}^3$ at the 8.5 ft level.

Table 1

Upstream Tidal Properties for Rectangular Culverts

Culvert Width (ft)	Low Water (ft)	High Water (ft)	Range (ft)	Intertidal Volume (ft^3)
3	7.96	8.17	0.22	2.3×10^5
4	8.02	8.30	0.28	3.5×10^5
5	8.04	8.37	0.33	4.8×10^5
6	8.05	8.44	0.39	6.2×10^5
7	8.03	8.48	0.45	7.5×10^5
8	8.00	8.54	0.54	8.9×10^5
9	7.96	8.58	0.62	10.3×10^5
10	7.92	8.63	0.71	11.8×10^5
12	7.84	8.72	0.88	14.5×10^5
15	7.75	8.83	1.07	18.5×10^5
→ 20	7.50	9.00	1.50	25.1×10^5
50	7.30	9.68	2.38	49.6×10^5

Normal tide

For standard tidal range of 7.8 ft in ocean with minimum level of 7.3 ft (MLW) in Hatches Harbor and $M = 0.090$.

The average horizontal area flooded at the 8.25 ft level, roughly the mean level, is about $1.2 \times 10^6 \text{ ft}^2$ or about 27 acres. While this area is modest, the fractional tidal volume exchange is large,

about 60% of the mean volume. At the 8.75 ft level the area flooded increases further to about 2.1×10^6 ft². The tidal range and intertidal volume would increase with spring tides and decrease with neap tides.

The contrast above in the response of the system upstream of the dike is large between mean tidal forcing (9.9 ft (MLW) peak) and the 1978 storm forcing (14.8 ft (MLW) peak), because the forcing is so different. Selecting the culvert size to fit the storm forcing normally reduces the response to weak levels for mean tidal forcing. If greater response were desired for mean conditions, restriction of excessive tidal flooding that would otherwise result above the 10 ft (MLW) level during extreme events can be affected by selecting the rectangular culvert but reducing its height below 6.7 ft, the value used to produce the results in Figure 1 and Table 1. Table 2 shows results for the 1978 storm when the width is 20 ft and $M = 0.090$ with diminishing culvert height.

Table 2

Response to Storm for Diminished Culvert Height

<u>Culvert Height (ft)</u>	<u>High Water (ft)</u>	<u>Max. Current (ft/s)</u>
6.7	13.29	11.9
5.0	12.19	10.6
4.0	11.47	8.3
3.0	10.56	6.5
2.5	10.18	5.9
2.0	9.73	5.3

Culvert width = 20 ft, invert height = 6.3 ft. $M = 0.090$.

Note that the general design criterion that high water be less than 10 ft is nearly met for a culvert height of 2.5 ft. Maximum flow speeds are reduced to about 6 ft/s. Meanwhile, as Table 3 shows, response to the standard tidal range is reduced very little from that for the culvert height of 6.7 ft. This is because for standard range, unlike the storm, the culvert remains less than full except for a small part of the tidal cycle. High water is 8.75 ft, sufficient to cover a large part of the marsh upstream.

Table 3

Response to Standard Tidal Range for Diminished Culvert Height

<u>Culvert Height (ft)</u>	<u>Low Water (ft)</u>	<u>High Water (ft)</u>	<u>Range (ft)</u>	<u>Intertidal Volume (ft³)</u>	
6.7	2.04	7.50	9.00	1.50	25.1 x 10 ⁵
→ 3.0	0.91	7.50	9.00	1.50	25.1 x 10 ⁵
2.5	0.76	7.36	8.75	1.39	18.3 x 10 ⁵
2.0	0.61	7.31	8.51	1.20	13.9 x 10 ⁵

Culvert width = 20 ft, invert height = 6.3 ft, M = 0.090.

Thus, an optimal selection might be a wide, but shallow rectangular culvert. It would have the attraction of diminished response to occasional high water from storms while still passing a large part of the tidal energy for standard tidal range.

Reference

Roman, C. T. An evaluation of alternatives for estuarine restoration management: The Herring River ecosystem. Center for Coastal and Environmental Studies. Rutgers, The State University, New Brunswick, 1987.



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20 Sept.

John,

Enclosed is a table giving the model predictions for a parallel array of circular culverts, side by side, each of 3' diam. and with $N = .045$, as you requested. The format is the same as in the report earlier. The first table gives 178 storm tide results, the second those for the standard tide. (N_{CUL} = no. of culverts.) While not as good in performance as the rectangular culvert of reduced height, use of 4 or 5 circular ones might be nearly as good and more economical to install.

Rich Jaworski

Done 9/19/88

HATCH 2 (round culvert)

$D = 3'$

$N = .045$

78 Storm Hrs.

NCHL	Hi water (ft)	max current (ft/s)
1	8.99	9.6
2	9.54	9.2
3	9.86	9.1
4	10.13	9.0
5	10.36	9.0
6	10.54	8.9

HATCH 2S (round culvert)

$D = 3'$

$N = .045$

mean (std.) harmonic Tides

NCHL	Lo	Hi	Range	Int. vol. ($\times 10^5$)
1	8.04	8.35	0.29	3.8
2	7.96	8.46	0.50	7.8
3	7.85	8.59	0.74	11.5
4	7.72	8.69	0.97	15.0
5	7.59	8.78	1.18	18.3
6	7.47	8.87	1.42	21.5

PARALLEL CIRCULAR CULVERTS

Model predictions of water heights, volumes and velocities at Hatches Harbor for a parallel array of 3-ft diameter culverts arranged side by side ($M = .045$). Results of both mean harmonic (standard) tide and 1978 storm heights are listed. Personal communication, R. Garvine, 19 Sept. 1988)

No. of culverts	<u>Mean height (ft)</u>			Intertidal vol. $\text{ft}^3 \times 10^5$	<u>Storm maxima</u>	
	Low	High	Range		Ht (ft)	Current (ft/s)
1	8.04	8.35	0.29	3.8	8.99	9.6
2	7.96	8.46	0.50	7.8	9.54	9.2
3	7.85	8.59	0.74	11.5	9.86	9.1
4	7.72	8.69	0.97	15.0	10.13	9.0
5	7.59	8.78	1.18	18.3	10.36	9.0
6	7.45	8.87	1.42	21.5	10.54	8.9