Tidal Fluctuations in Groundwater Level Normal to a Salt-marsh-fringed Shoreline, Herring River Estuary, Wellfleet (Massachusetts)

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In preparation for some level of tidal restoration in Wellfleet's diked Herring River, structures that occur within the 6-ft-NGVD contour are being individually assessed for potential impacts. This study was prompted by concerns for land-surface flooding at a house (hereafter "Nieski house") located near Snake Creek at the edge of the Mill Creek flood plain, which is tributary to Herring River (Figure 1). The study was specifically designed to assess whether an impermeable berm placed on the wetland surface adjacent to the Nieski house would be effective in preventing flooding of the yard, ranging in elevation from 2 to 5.5 ft-NGVD, assuming that spring high tides in Herring River and Mill Creek were restored up to 6-ft-NGVD. The working hypothesis was that the river's tidal fluctuations would be dampened in the groundwater system such that the high-tide groundwater rise behind the berm would not reach the wetland or yard surface. The hypothesis was tested by monitoring groundwater fluctuations for 15 days (a full spring-neap cycle) in wells at various distances from the river bank just seaward of the Herring River dike, where tidal range is about nine feet. In other respects, i.e. peat depths and hydrology, the study site is very similar to Mill Creek. With tidal restoration, the expected tidal range in Mill Creek would be much smaller; therefore, observed groundwater effects should be considered a worst-case scenario with reference to properties on Mill Creek.

Figure 1. Location (yellow circle) of Nieski house on Snake Creek, tributary to Mill Creek and Herring River, Wellfleet

Methods

In May 2006, we installed four 1.25-inch ID PVC wells by hand auguring and driving the slotted points at least two feet into the water table along a transect perpendicular to the Herring River main stem and about 100 feet seaward of the Chequesset Neck Dike (Figure 2). The four wells, numbered 1 through 4 respectively, were spaced 125, 261, 320 and 385 feet from the river's salt-marsh peat bank. The elevations (ft-NGVD29) of casing-top measuring points and groundwater levels were determined by differential leveling from a FEMA benchmark on the dike. Well 1 was placed in the wetland proper, and screened throughout its length, i.e. both in marsh peat and underlying sandy soils; well 2 was at the marsh-upland edge; wells 3 and 4 were in the upland. Well-water levels were recorded at 10-min intervals using automatic data loggers deployed from 23 May to 8 June 2006.

Figure 2. Observation well locations normal to the salt-marsh-fringed Herring River main stem just seaward of the Chequesset Neck Dike.

Results

Throughout the 15-day study period, a semi-diurnal tidal signal was generally observed in all four wells located up to 385 feet from the river bank (Figure 3). One exception is the well in the marsh proper (Well 1) during neap tides when high tides failed to reach the marsh plain and porewater levels were more affected by precipitation and evapotranspiration (Figure 3). Otherwise, tidal amplitude decreased consistently with distance from the river. Groundwater levels were approximately one foot higher in Well 2 (closest to the wetland edge) during spring tides than during neap tides.

Most striking in the record is the consistently large difference in water level between Well 1 in the marsh proper and Wells 2, 3 and 4, with water level in all three of the latter marsh-edge and upland wells averaging 3.1 feet below marsh water levels. The higher observed water levels in Well 1 are largely a result of the ability of the fine-grained marsh sediments to retain water at low tide.

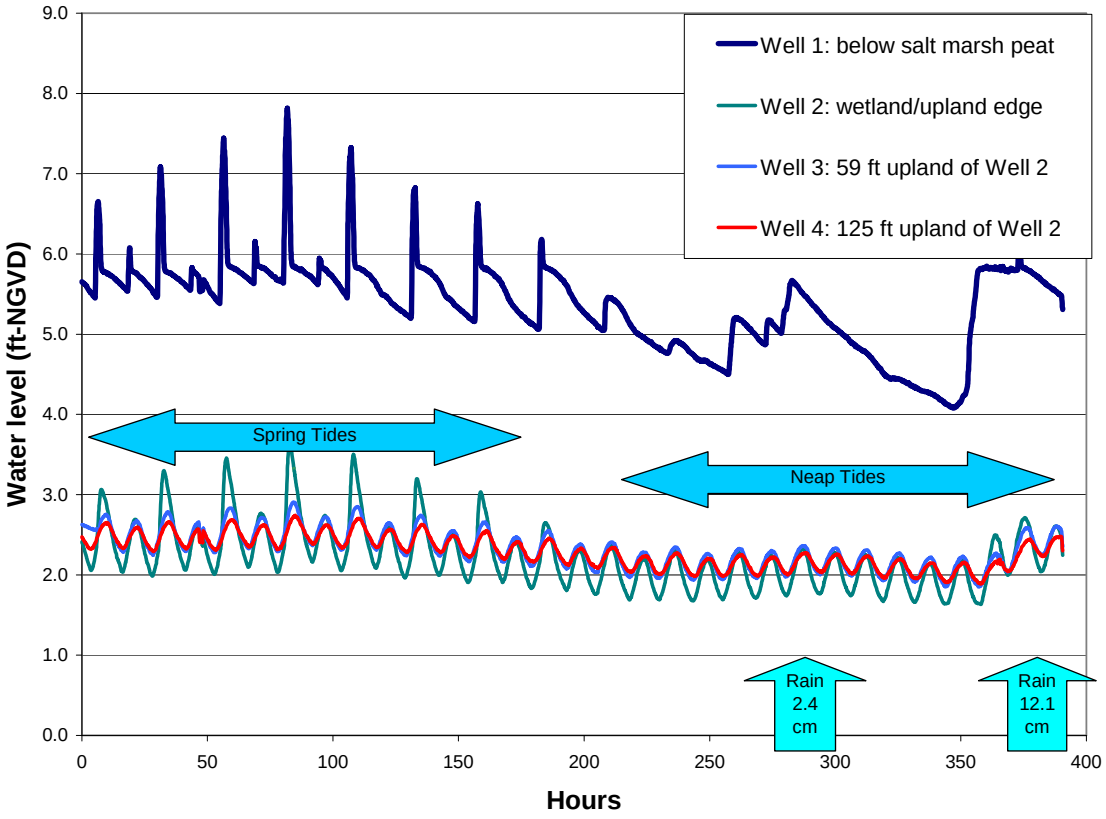

Figure 3. Water level fluctuations in four wells along a transect normal to the Herring River just seaward of the Chequesset Neck Dike.

Cross sections of the marsh-fringed shoreline transect, showing land-surface elevation, well horizontal locations and the ranges of groundwater fluctuations for both low and high tide are shown in Figure 4. Note that high-tide water levels in the river are greatly dampened, by about 3 feet, even in Well 2 at the marsh-upland edge.

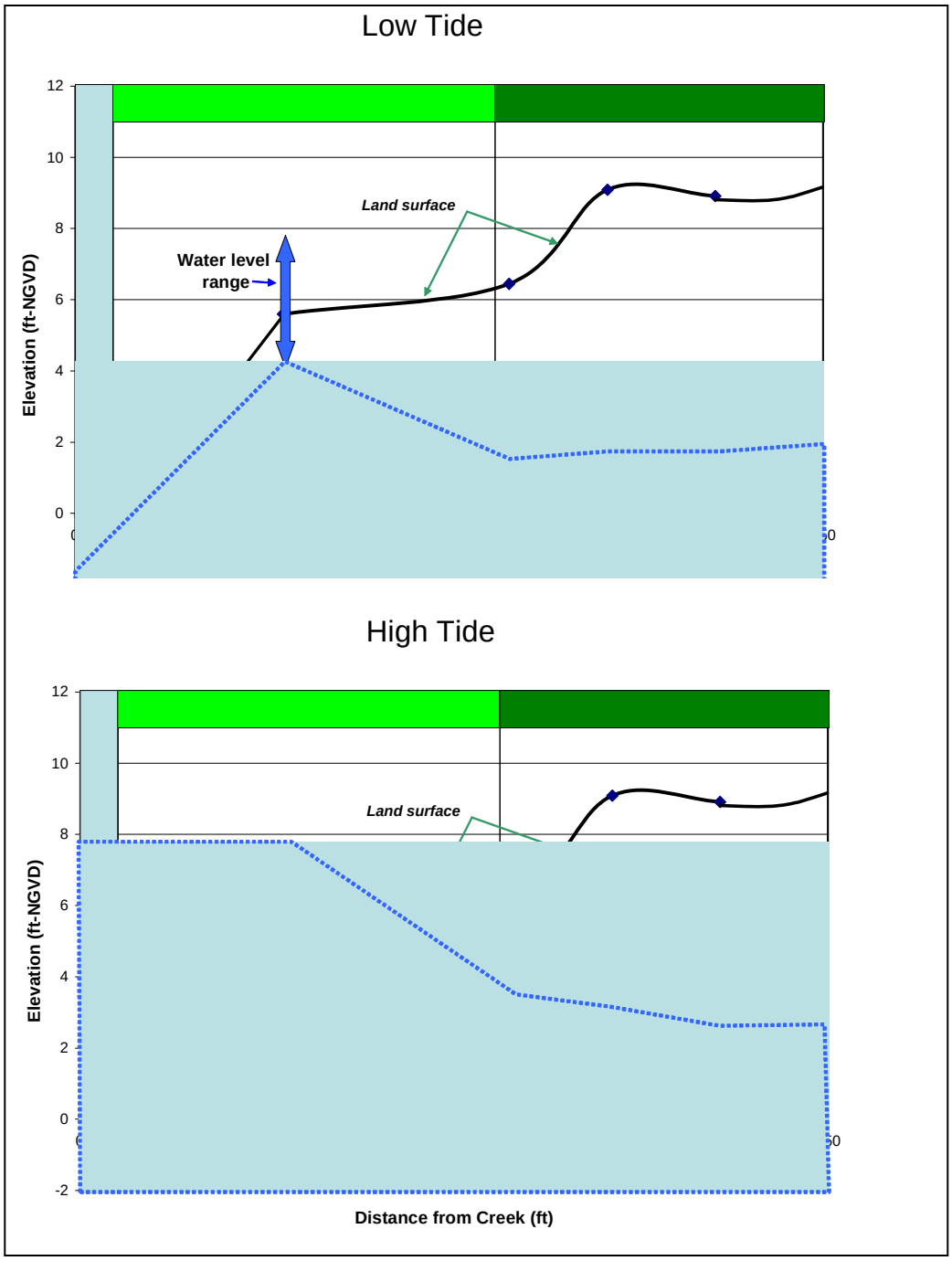

Figure 4. Profile of well locations and surface water and groundwater relationships at low and high tide.

Discussion and Application to Nieski Property

Fetter (2001) discusses the effect of tidal fluctuation on groundwater levels in aquifers adjacent to tidal bodies (equation 8.10). The amplitude of the fluctuation is greatest at the coast and diminishes in the inland direction. The response of the hydraulic head in the aquifer to tidal changes decreases exponentially with distance from the coast. At any distance inland from the coast, the amplitude of tidal fluctuation in the aquifer can be predicted by:

$$H_x = H_0 \exp\left(-x\sqrt{\pi S / t_0 T}\right)$$

Where;

H_x is the amplitude of the tidal fluctuation in the aquifer at distance, x, from the shore
H_0 is the amplitude of the tidal change
t_0 is the tidal period
x is the distance from the shore line
S is the aquifer storativity
T is the transmissivity of the aquifer

Analysis of the predicted tidal fluctuation of the water table at the Nieski property is simplified by ignoring the low-permeability sediments in the near-surface associated with the wetland. These sediments are probably underlain by sand comprising the cape Cod aquifer. Tidal fluctuation in the sand aquifer would be transmitted under the wetland sediments to areas inland of the wetland. Ignoring the presence of the low-permeability sediments makes the computations much easier and if anything, slightly overestimates the tidal amplitude of the water table in the aquifer inland of the wetland.

The tidal amplitude downstream of the dike is about 9 feet, ranging from -2 to +7 feet NGVD. The tidal period is 0.26 days. Average values of T= 17,000 ft^2/day and S=0.14 for the Cape Cod aquifer were used to estimate the tidal fluctuation in groundwater at various distance from the shoreline.

Ho	x	S	t0	T	Hx feet
9	0	0.14	0.26	17,000	9.00
9	50	0.14	0.26	17,000	5.47
9	100	0.14	0.26	17,000	3.32
9	150	0.14	0.26	17,000	2.02
9	200	0.14	0.26	17,000	1.22
9	250	0.14	0.26	17,000	0.74
9	300	0.14	0.26	17,000	0.45
9	350	0.14	0.26	17,000	0.27
9	400	0.14	0.26	17,000	0.17
9	450	0.14	0.26	17,000	0.10
9	500	0.14	0.26	17,000	0.06

Increasing the storativity (S) will reduce the tidal amplitude in the aquifer. Decreasing the transmissivity (T) will also reduce the tidal amplitude.

With this theoretical background, we apply above field observations from seaward of the Herring River dike, where Wellfleet Harbor tides are unrestricted, to predict the effects of tidal restoration on groundwater levels at the wetland-upland edge adjacent to the Nieski house on Snake Creek. Importantly, water level observations since 2005 in an observation well just 100 ft west of the Nieki property, and about the same distance from the wetland edge as the Nieski house, show that the depth to groundwater (3-4 ft) is comparable to that observed at the study site seaward of the dike.

We assume that an impermeable berm is placed between the house and the wetland to block the surface flow of tidal waters from reaching the structure. We then transfer groundwater tidal fluctuations observed below the dike to a hypothetically bermed Nieski property to see if groundwater is likely to rise above land surface behind the berm and flood the yard or structure. During low tide, water levels in both creek and groundwater system are well below land-surface elevations in the wetland south of the house (Figure 5, top). At high tide, even with an unrestricted Wellfleet Harbor tide of

nearly 8-ft NGVD, the groundwater level fails to reach the land surface behind the protective berm (Figure 5, bottom).

These results also have implications for the sensitivity of the Nieski water-supply well to salt-water intrusion. Recent work by one of the authors (Martin 2007, http://www.nps.gov/caco/naturescience/upload/CACO%20Herring%20River%20Report%20LJM.pdf) has shown that private wells around the Herring River flood plain that presently provide high-quality drinking water are unlikely to be affected by tidal restoration, provided they are not directly flooded by saline surface water. As an example, water in our Well 2 has a very low electrical conductance (245 µS/cm), typical of fresh groundwater, despite biweekly seawater inundation of the salt marsh surface only 59 ft away.

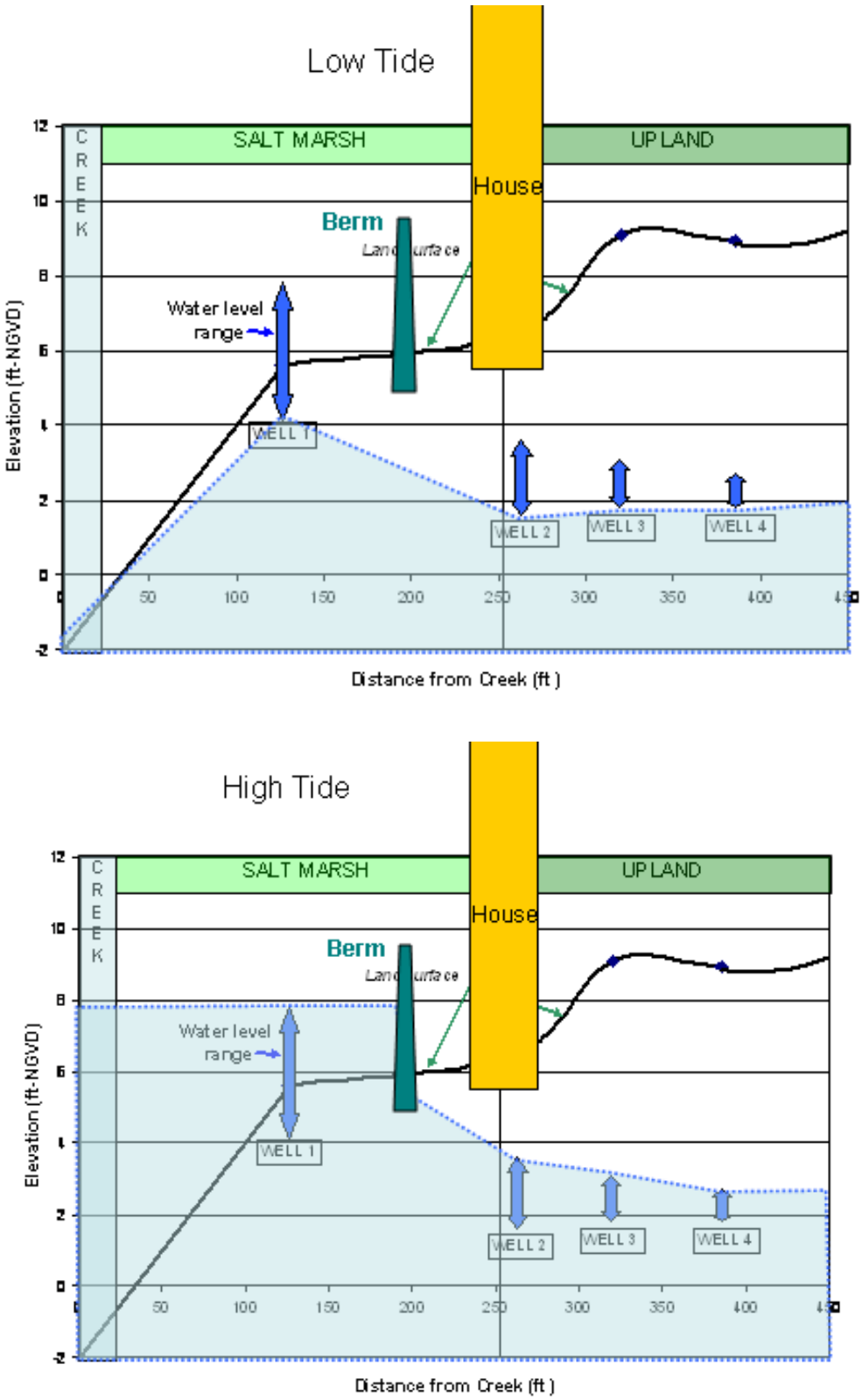

Figure 5. Projected groundwater levels at low tide (top) and high tide (bottom) adjacent to the Nieski house with restored tides in Mill and Snake Creeks and a flood-protection berm seaward of the structure.