PART THREE - NAMSKAKET MARSH

The Potential Impact of the Proposed Disposal Area on Namskaket Marsh

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Description of the Wetland

The area designated for construction of a proposed septage and/or septage-sewage treatment plant, "area 4" (LEA, 1981b), is north of the Orleans Town Highway Department garage, at the landward end of Namskaket Marsh (Fig. 50). The wetland expected to receive the effluent is known as "Hurley's Bog" (Orleans Assessor's Map) and is of 4 to 5 acres (16,000 to 20,000 m^2) extent (depending on which map one uses), of which most lies within the site boundary. Members of our staff visited the area on three occasions: July 9, July 15 and October 15, 1982.

Hurley's Bog is one of two small lobes of Namskaket Marsh that were separated from the main body of the marsh by the construction of a railroad embankment (now a bicycle path) in the late nineteenth century. Restricted flow of water between these areas and the main marsh occurs through a single culvert under the embankment for each lobe. Hurley's Bog is at present a fairly typical, moderately dry freshwater marsh, showing influences of seawater flooding along the ditches that cross its surface. The edges of the marsh are occupied by a combination of reed (Phragmites) and cattail (Typha), along with some of the shrubs characteristic of such environments, like red maple and sweet pepper bush. In the center of the marsh, where the seawater influence is more apparent, there is "three-square grass" (Scirpus), black rush (Juncus) and traces of spike grass (Distichlis) and of Spartina patens. The most conspicuous indication of the influence of brackish water is marsh

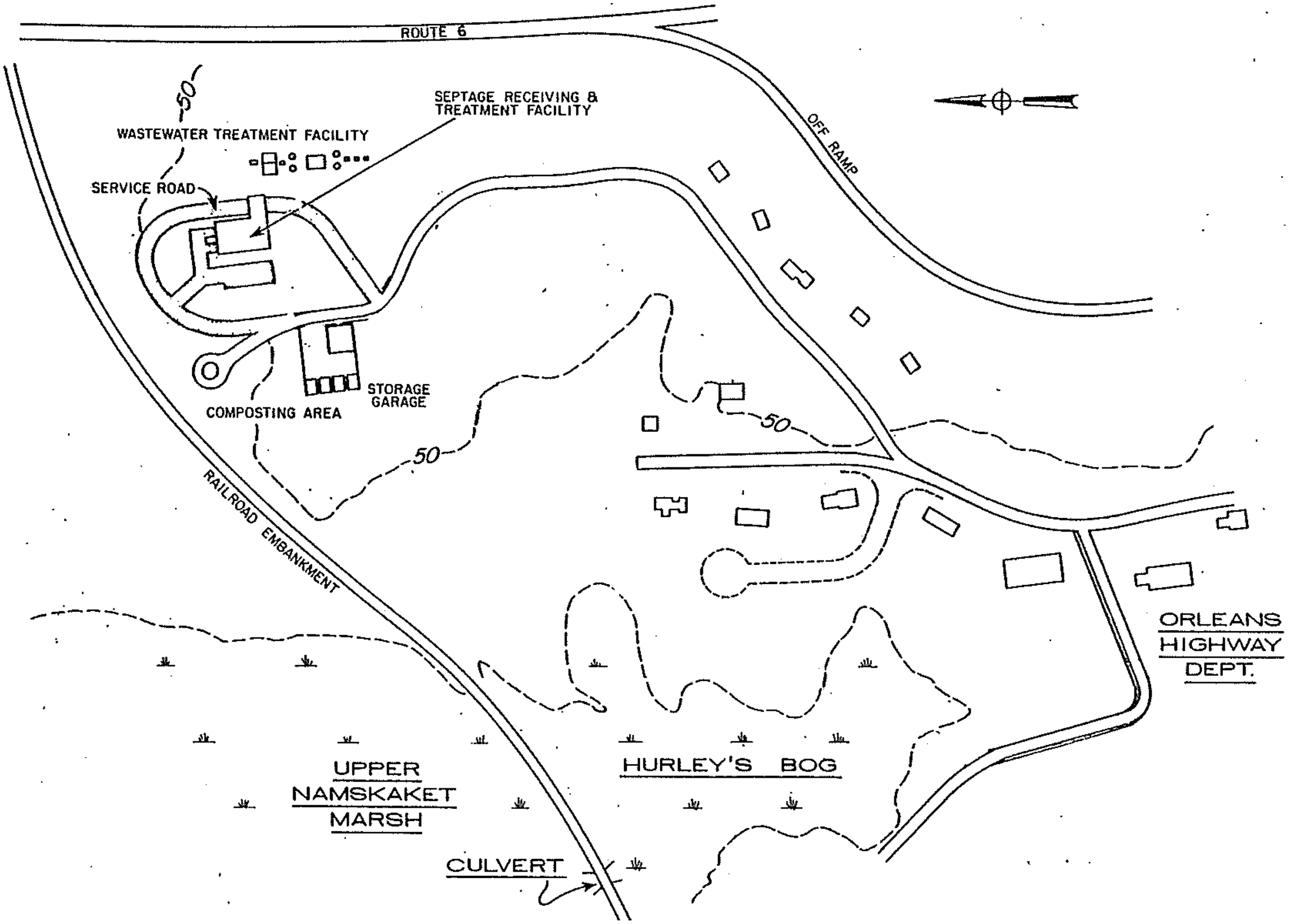

Figure 50. Site 4, the location of the proposed septage or septage/sewage treatment plant adjacent to Hurley's Bog and Namskaket Marsh, Orleans, Massachusetts. Recent changes in the site plan are not shown.

elder (Iva frutescens). The tide range in ditches in Hurley's Bog appears to be 30 to 50 cm. During one visit, water was coming underneath the railroad embankment through what appears to be a wooden culvert about 18" in diameter; the water had a salinity of about 4 o/oo; the water level in the outer salt marsh at the time had not quite reached the level of the marsh top. On another occasion water ebbing from this wetland ditch was fresh.

Namskaket Marsh has an area of about 232 acres (9.39×10^5 m^2). The upper reaches of Namskaket Marsh, west of the railroad embankment, show strong influence of fresh water, although to a lesser degree than Hurley's Bog. The plants around the border of the marsh include Spartina, but Typha mixed with marsh mallow, three-square grass and reed predominate. Along the creek banks there is very vigorous growth of reed (Phragmites). Spartina alternaflora occurs along the edges of the creek banks and in certain places is mixed with Phragmites. Spartina patens, the predominate plant of this genus, occurs in relatively small and isolated patches which look quite healthy. Water in the ditch along the railroad embankment had a salinity of 6 o/oo in October 1982.

There is a very large amount of wrack and debris in this portion of Namskaket Marsh, evident throughout the summer. Deposits are sufficiently heavy that large areas of vegetation on the marsh table have been smothered. On one visit it looked as though a recent high tide had moved a lot of the wrack leaving bare mud exposed. Elsewhere in upper Namskaket Marsh we observed a typical marsh panne, devoid of grasses, containing brackish water (8 o/oo) and smelling of sulfide. It is impossible to say from a few visits whether the marsh is changing; but it is obvious that it is a transition area, a brackish marsh, somewhere between being a fresh water and a salt water marsh.

Impact of the Proposed Effluent

Based on our experience and familiarity with the literature on this and related topics, marshes and wetlands can be said to have a large capacity to take up nutrients, such as nitrogen, compared, for example, with natural bodies of water. Freshwater swamps with standing water have been used throughout the world for removing nutrients from sewage and there is an appreciable literature dealing with this topic. In our opinion, the combination of fresh and salt water wetlands present at the proposed site offers an opportunity to make probably the best possible use of wetlands in a sewage effluent treatment system.

Potential impacts on Hurley's Bog and Namskaket Marsh can be categorized as a) effects of fresh water, b) effects of nutrient loading, and, c) effects of pollutants (e.g., toxins). To some extent, all three categories of impact depend not only on quantities of leachate and nutrients involved but also on how the effluent enters the marsh system. The concept of "marsh engineering" ought to be considered in the event control of the delivery, distribution and/or standing level of effluent in the wetland becomes desirable.

According to LEA (Weisman, 1983):

a) Leachate from the sewage treatment facility is not expected to break out onto the slope between the recharge beds and Hurley's Bog (as suggested in an earlier analysis; cf. LEA 1981b);

b) Leachate is not expected to pass under the wetland into Cape Cod Bay;

c) Leachate is expected to enter the fresh and saltwater wetland system. "The best available information showing direction and width of the leachate plume is contained in Part II, Section II-B of our facilities plan, Fig. 7. This figure indicates that most of the leachate will discharge to the freshwater wetland. It would be necessary to develop and execute field studies and detailed analysis beyond the scope of our current design in order to define more precise estimates of the leachate fraction discharging to the freshwater wetland."

Our discussion of impacts of the leachate may be invalidated in part if the path or quantity of leachate were significantly different from that described by LEA.

A. Fresh Water

Effluent volumes estimated for the proposed septage treatment plant range from 16,000 to 77,000 gallons per day, depending on the season and day of the week, but on average are between about 16,000 and 35,000 gallons per day. Flows from a combined septage/sewage plant would vary from 99,000 to 1,780,000 gallons per day, depending upon the above factors as well as the phase of sewering and extent of hook up of developable lots in the service area (Weisman, 1983). On average days these predicted flows narrow to from 88,000 to 272,000. In comparison, according to figures of Metcalf and Eddy (1983), current water use in the core area is about 85,000 gallons per day. If freshwater discharge to the Namskaket Marsh system is similar to that of Town Cove, natural discharge would be about 2,000,000 gallons per day.

If the effluent primarily enters the ditch or creek system of Hurley's Bog and exits directly via the culvert, the bog soils and vegetation may have only limited exposure; both the impact and the opportunity for removal of nutrients would be low. Greater exposure may occur naturally, or could be encouraged by controlling the water level in Hurley's Bog (according to LEA, this is not planned at present). With more exposure, it might be expected that the wetland community would change toward an assemblage of species more typical of the standing water swamp, characterized by the cattail, Typha, and the reed. This change could be immediately obvious and would result in loss of the low grasses and Iva. This area also might then become more attractive to forms of wildlife such as muskrats. As mentioned above, freshwater swamps with standing water have been used throughout the world for removing nutrients from sewage; in terms of impact, however, a decision would need to be made whether the floristic change and associated responses are acceptable.

Freshwater leaving Hurley's Bog would also be expected to affect adjacent areas of Namskaket Marsh, increasing the cattail and reed marsh portion and diminishing the present salt marsh plant component. That would mean the grasses would be taller, attract different wildlife and present a different scenic aspect. It would not necessarily be accurate to imply the area becoming a more brackish marsh constitutes a degradation, but it would definitely be a change.

B. Nitrogen

The consequences of putting moderate amounts of nutrient rich freshwater into the fresh water swamp would be to enrich the area and enhance its productivity. Under the wastewater/septage plan LEA projects that the concentration of nitrogen (primarly ammonia) reaching the recharge beds will be 25-30 mg/l (Weisman, 1983), a range that appears reasonable. Typical wastewater contains 15-60 mg/l nitrogen and about 25% of this is removed by treatment as sludge. Under the septage-only plan LEA projects that the nitrogen concentration will be 75 mg/l and again we feel that this is a reasonable assumption.

The indicated concentration of total nitrogen reaching the wetlands is 0-10 mg/l nitrogen in the wastewater/septage plan and 0-15 mg/l in the septage-only plan. There are only three ways in which nitrogen can be apparently lost between the recharge beds and the wetlands: 1) dilution by groundwater low in nitrate, 2) adsorption of ammonia by the soil, and, 3) denitrification. We will address these three mechanisms because we do not think the loss of nitrogen will be as large as indicated above.

1) Dilution - this will only change the concentration of nitrogen in the groundwater; it will not change the overall loading of nitrogen to the wetland. It does not represent a real loss of nitrogen.

2) Adsorption - Initially, there could be some adsorption of ammonia onto soil particles. Soil has a limited capacity for adsorption, and in sandy soils this capacity is quite low. We have calculated the nitrogen loading, assuming in the steady state there is no loss by this process.

3) Denitrification - Denitrification represents a real loss of nitrogen and unlike adsorption it could continue throughout the life of the treatment plant. From the evidence presented to us, and from information we have gathered on rapid infiltration, however, we find no evidence that there will be a large loss of nitrogen by this process in the leaching beds. Our conclusion is based upon several factors:

a) Denitrification requires two steps: first, ammonia must be oxidized to nitrate. This process requires oxygen and occurs in well drained sands. Second, nitrate must be denitrified to N_2 gas. This process occurs in the absence of oxygen, usually in waterlogged soils. Achieving efficient denitrification requires that leaching beds are managed on an alternating scheme of wastewater loading and drying. Optimum rates can only be achieved after studying local soil conditions and by careful management. LEA has not proposed any scheme to manage the beds in this manner, although this could be considered.

b) Both steps, nitrification and denitrification, have temperature and pH requirements (EPA, 19**). Rates are exceedingly low at pH's below 5.5 and temperatures below 5°C. We have no data on the pH of these soils, but for a significant portion of the year the temperature will be below 5°C.

Denitrification requires carbon. Approximately 2 mg/l total organic carbon is required to denitrify 1 mg/l nitrogen (EPA design manual). For this reason it is difficult to achieve denitrification in secondarily treated effluent since the organic carbon content is low. If the BOD_5 in the effluent is approximately 30 mg/l and we assume an oxygen to carbon ratio of 1, then there is only enough carbon present to denitrify 15 mg/l of nitrogen under optimum conditions.

For these reasons we do not expect much nitrogen removal in the leaching beds. As a result, we have made our calculations on the impact of nitrogen on the wetlands assuming no nitrogen removal. It does appear to us that there is potential for achieving some nitrogen loss in the beds by regulating the application rates and possibly by supplementing carbon. The costs and benefits of this would have to be considered.

Hurley's Bog is approximately 5 acres in area (20,000 m^2). Under the sewage/septage plan if 272,000 gal/day ("future summer average") is discharged to the leaching beds and we assume there is no nitrogen removal in the beds (N content = 30 mg/l) the nitrogen loading to Hurley's Bog would be 1.5 g N/m^2/day; at a flow rate of 88,000 gallons per day ("initial winter average") nitrogen loading would be 0.5 g N/m^2/day. Under the septage-only plan assuming an average loading of 39,000 gal/day of effluent containing 75 mg/l nitrogen the nitrogen loading would be 0.55 g N/m^2/day.

We have conducted experiments where, for 13 years, we have added nitrogen to salt marshes at several rates (Valiela and Teal, 1974). Our levels of nitrogen addition have ranged from 0.1 N/m^2/day to 1.1 g N/m^2/day, applied for a 6 month period during the summer. These levels of nitrogen stimulate the growth of grasses on our experimental plots. At the highest level of treatment we saw dramatic increases in biomass and some changes in species composition. Consumption of the plants by animals also increased. From these experiments and studies done elsewhere (Chalmers, 1982; Sullivan and Daiber 1974; Broome et al., 1975), the addition of 0.5 to 1.0 g N/m^2/d should cause noticable changes in the vegetation of Hurley's Bog. The production of plants should increase as well as the species present, and to an extent the amount of change will increase with increased nitrogen loading. We anticipate there will be some removal of nitrogen in the bog, before the effluent enters Namskaket Marsh, and because the marsh is much larger than the bog we doubt that any pronounced changes in the marsh from nitrogen loading will be evident.

As mentioned above, freshwater swamps with standing water have been used for this purpose throughout the world; our research on salt marshes on Cape Cod has shown their potential to transform nutrients in sewage into productivity. This process can enhance coastal productivity, eventually serving as food for young fishes or shellfish. The possibility of combined use of fresh and salt brackish marshes also would greatly increase the treatment capacity of the wetland system---this may be important if Hurley's Bog is inadequate for treating the peak effluent volume.

C. Other Impacts

Problems in sewage disposal can arise from certain pollutants, such as petrochemicals and chlorinated petrochemicals (insecticides, PCB, etc.) as well as metals, such as lead, zinc, and cadmium. Because of the primarily domestic and commercial nature of the potential users of a septage or septage-sewage plant here, we do not feel this should pose special problems at Namskaket Marsh. Pathogenic bacteria and coliform bacteria are generally removed effectively by sewage treatment plants, although there is evidence that viruses may not be. Based on the literature on virus removal by rapid infiltration (EPA, 1980; Gerber, 1983) the reduction of pathogens occurs at several stages of the sewage treatment process.

Wastewater contains about 10^5 pathogens/l. Removal by secondary treatment can eliminate 90-99% of them and disinfection by chlorine or ozone can remove 25-99% of those remaining. This represents a tremendous removal rate but it is still possible for significant numbers of bacteria and viruses to remain in the effluent. When the effluent is applied to rapid infiltration beds there is a further reduction in pathogens. Bacteria and viruses are removed by adsorption onto soil particles. They are also killed or inactivated by drying and exposure to ultraviolet light, and grazed upon by certain animals such as worms. Under optimum conditions all the pathogens may be removed within a few centimeters of the surface of a rapid infiltration bed. It is known that bacteria are removed more efficiently than viruses, although both have been isolated from rapid infiltration sites many meters away. In those sites where viruses have been isolated, the effluent being applied was not a secondarly treated and had not undergone disinfection. Viral research in wastewater is a relatively new area of research since it is only recently that good techniques for isolating viruses have been developed. The treatment scheme proposed for Orleans involves considerably more treatment than wastewater often receives before direct disposal into estuaries, in many parts of the country. The potential for contamination of Namskaket marsh by pathogens from the treatment scheme seems exceedingly low if the hydrologic analysis is correct.

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APPENDICES

Appendix I Geographic and Hypsometric Statistics for Town Cove, Orleans Quadrangle, Massachusetts.

Depth (m)	Projected Area (m2) a/	Depth Interval	Volume m3	Including Channel
0.0	1.4 X 10^6	0.0-0.5	0.73 X 10^6	0.78 X 10^6
0.5	(1.3) " b/	0.5-1.0	0.49 "	0.54 "
1.0	0.68 "	1.0-1.5	0.32 "	0.38 "
1.5	0.60 "	1.5-2.0	0.29 "	0.34 "
2.0	0.55 "	2.0-2.5	0.27 "	
2.5	0.52 "	2.5-3.0	0.24 "	
3.0	0.45 "	3.0-3.5	0.21 "	
3.5	0.38 "	3.5-4.0	0.17 "	
4.0	0.29 "	4.0-4.5	0.12 "	
4.5	0.18 "	4.5-5.0	0.061 "	
5.0	0.071 "	5.0-5.5	0.019 "	
5.5	0.014 "	5.5-6.0	0.002 "	
6.0	0.0 (assumed)			

Entrance Channel in Town Cove:
Projected Area: 0.114 X 10^6 m^2
Volume: 0.228 X 10^6 m^2 (assume uniform 2 m depth)

Volume of Town Cove: 3.13 X 10^6 m^3.

Average Depth (A/V): 2.2 m.

Projected recharge areas (square meters)

Total Town Cove and the outer Nauset embayment:	27.6 X 10^6
Outer Nauset embayment:	18.1 X 10^6
Terrestrial:	10.3 X 10^6
Estuary (including marsh):	7.9 X 10^6
Town Cove:	9.4 X 10^6
Terrestrial:	7.9 X 10^6
Estuary:	1.4 X 10^6

Perimeter of Town Cove: 6,200 meters

a/ Relative areas determined from bathymetric chart of Aubrey (this report), using USGS (1974) topographic map for the Orleans Quadrangle for surface areas.

b/ Value estimated.

Appendix II - Calculation of fluxes from porewater gradients

The flux of material from the sediment to the water column can be calculated using porewater gradients. The methods, assumptions and limitations of this approach have been widely discussed and are summarized by Berner (1980).

The expression used for calculating flux is:

$$J_i = C_o J_s/p_s(X/1- X) - \ {}_oD_s$$

where:

J_i = flux of dissolved constituent i between sediment and overlying water

J_s = flux of solid particles by deposition

C_o = concentration at the sediment water interface

p_s = density of sedimenting particles

X = porosity at depth X below which porosity is constant

${}_o$ = porosity at sediment water interface

D_s = diffusion coefficient in the sediment of the ion of interest.

= concentration gradient at the sediment water interface.

The first term of the equation is to calculate the flux due to compaction. Since the sediment is being buried faster than the water there is a net flow of water upward. In Town Cove sediments where

C_o= max value of 20×10^6

J_s = .566 g cm^{-2} y^{-1}

p_s= approximately 1.3 g/cm^3

X = .6

Therefore the flux due to burial is equal to less than 1 uM M^2 y^{-1} and can be neglected. Only the second term needs to be considered.

${}_o$ = varied in the cores and was measured (Table)

D_s = D_o/ F'

where D_o is the diffusion coefficient in free solution and F' is the formation factor.

D_o for NH_4^+ $=(19.8 \quad .4(T-25)\mathrm{x}10^{-6}$ cm^2 s^{-1} Krom and Berner 1980b

F' = was approximated by using $^{-2}$ and neglecting the temperature dependent differences in viscosity between sea water and distilled water.

APPENDIX III Tidal Harmonic Constants for Goose Hummock Station

Table A III-1 lists the tidal harmonic constants derived from a computer analysis of 29 days of tide gage data from Goose Hummock, Orleans, Ma, starting on 22 July 1982. The method used was based on that of Boon and Kiley (1978), modified by us to provide the specific information of interest. The columns indicated in the table represent:

NOS NO.: Constituent reference number assigned by the National Ocean Survey.
CONST.: Abbreviation for each tidal constituent.
SPEED: Number of degrees per hour that a particular constituent travels. A large number indicates a diurnal or faster tide; small numbers indicate longer period tide constituents.
H: The amplitude of each harmonic constituent, which is one half of the range of each. Units are meters. These numbers have been corrected for the nodal factors for the particular location and period of time.
KAPPA: Constituent phase relative to a local epoch.
KPRIME: Constituent phase relative to Greenwich phase.
ZETA: Tidal phase of constituent referred to the beginning of the time of record.
°/o TSS: Percent of total sum of squares accounted for by each tidal constituent, a measure of the importance of each constituent at a specific location.

For a more complete description of the methods and terms discussed here, refer to Schureman (1971).

Estimates for the mean tidal range at this location over a month's period can be made from the value of the total sum of squares. If we let TR be the mean tidal range over the month's period, we can calculate this quantity by the following calculations.

SStotal = total sum of squares in series
SStide = total sum of squares accounted for by tidal motions
= SStotal x °/o TSS (total percent sum of squares).

The tidal range is:

$$TR=2 \quad 2(SStide)/n$$

where n is the number of observations (697 in our case).

For Goose Hummock, this calculation yields:

$SStotal=120.9\ m^2$

$SStide = 0.9439 \times 120.9 = 114.1\ m^2$

$TR = 2 \quad 2(114.1)/697 = 1.14$ m Mean Tide Range = 3.75ft.

During Spring tides the total range will be greater, while during Neap Tides the tidal range will be less.

APPENDIX III (Cont.)

Tidal Harmonic Constants for Goose Hummock Station.

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HAMELS-HARMONIC ANALYSIS METHOD OF LEAST SQUARES

STATION GH        41.80     69.99 75W     YEAR  1982
29 DAY-SERIES-STARTING   7  22    9.6 HRS     697 OBSERVATIONS

NOS NO. CONST.  SPEED       H      KAPPA    KPRIME       ZETA    O/O TSS
      1    M2    28.9841  0.521   156.87    151.9      115.48     79.33
      2    S2    30.0000  0.064   207.23    197.2      119.21      1.17
      3    N2    28.4397  0.115   105.28    103.1      112.87      3.87
      4    K1    15.0411  0.083   255.26    250.0      189.91      2.71
      5    M4    57.9682  0.116   251.15    241.3      168.38      4.01
      6    O1    13.9430  0.094   241.97    242.2      261.80      2.46
      7    M6    86.9523  0.017   358.11    343.3      233.96      0.09
      9    S4    60.0000  0.002   252.33    232.3       76.29      0.00
     12    S6    90.0000  0.001   281.55    251.5       17.49      0.00
     36    M8   115.9364  0.005   156.32    136.6      350.78      0.01
     11   NU2    28.5126  0.020   133.50    130.9       87.68      0.11
     13   MU2    27.9682  0.013   106.51    106.6     -250.34      0.05
     14   2N2    27.8954  0.014   102.88    103.4     -200.55      0.05
     15   OO1    15.1391  0.004   268.56    257.9      -53.71      0.00
     16  LAM2    29.4556  0.004   180.24    172.9      -36.71      0.00
     18    M1    14.4967  0.007   248.62    246.1      118.15      0.01
     19    J1    15.5854  0.007   261.86    253.9      151.67      0.02
     25  RHO1    13.4715  0.004   236.26    238.9     -108.34      0.00
     26    Q1    13.3987  0.018   235.37    238.4      -55.82      0.09
     27    T2    29.9589  0.004   205.21    195.4      -45.21      0.00
     28    R2    30.0411  0.001   209.24    199.0      103.63      0.00
     29   2Q1    12.8543  0.002   228.78    234.5      -13.44      0.00
     30    P1    14.9589  0.023   254.27    249.5      240.49      0.22
     33    L2    29.5285  0.015   183.86    176.2      -83.70      0.10
     35    K2    30.0821  0.017   211.31    200.9      -99.48      0.08

SERIES MSL    0.66   SLOPE -0.000093                                94.39
TOTAL SUM OF SQUARES IS 120.930260
```

APPENDIX IV. Equations used in Town Cove computer model.

TWO-DIMENSIONAL EQUATIONS:

The two-dimensional depth-averaged equations are presented below with non-linear terms analogous to the one-dimensional case underlined (e.g., Dronkers, 1964).

$$\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial x} \underset{\text{I}}{\underline{(h+\zeta)\,\overline{u}}} + \frac{\partial}{\partial y} \underset{\text{I}}{\underline{(h+\zeta)\,\overline{v}}} = 0 \qquad \text{Continuity}$$

$$\frac{\partial \overline{u}}{\partial t} + \underset{\text{II}}{\underline{\overline{u}\frac{\partial \overline{u}}{\partial x} + \overline{v}\frac{\partial \overline{u}}{\partial y}}} = -g\frac{\partial \zeta}{\partial x} - \underset{\text{III}}{\underline{\frac{C_D\, q\, \overline{u}}{(h+\zeta)}}} \qquad \text{X - Momentum}$$

$$\frac{\partial \overline{v}}{\partial t} + \underset{\text{II}}{\underline{\overline{u}\frac{\partial \overline{v}}{\partial x} + v\frac{\partial \overline{v}}{\partial y}}} = -g\frac{\partial \zeta}{\partial y} - \underset{\text{III}}{\underline{\frac{C_D\, q\, \overline{v}}{(h+\zeta)}}} \qquad \text{y - Momentum}$$

where

$$\overline{u} = \frac{1}{(h+\zeta)} \int_{-h}^{\zeta} u\,dz$$

$$\overline{V} = \frac{1}{(h+\zeta)} \int_{-h}^{\zeta} v\,dz$$

h = undisturbed water depth

ζ = tidal elevation perturbation

$q = (\overline{u}^2 + \overline{v}^2)^{\frac{1}{2}}$

C_D = drag coefficient

The underlined non-linear terms can be described as follows:

I) divergence of volume flux associated with region between undisturbed water depth and tidal free surface elevation.

II) advection of momentum

III) quadratic friction.

APPENDIX IV (Cont.) Equations used in Town Cove computer model.

The momentum equations neglect Coriolis terms (linear) and horizontal diffusion of momentum (generally taken as linear).

RESIDUAL CURRENTS--DEFINITIONS

This section defines residual currents which result from a time-average of non-linear terms in the equations of motion. Consider the instantaneous depth-integrated flux in a rectangular channel:

$$q = (h+\zeta)\overline{u} \qquad (1)$$

where

$$\overline{u} = \frac{1}{(h+\zeta)} \int_{-h}^{\zeta} u(z)dz$$

We may consider the depth-mean flow as consisting of a time-averaged and periodic component

$$\overline{u} = u_E + u_p$$

$$u_E = \frac{1}{T}\int_0^T \overline{u}dt \qquad T = \text{tidal cycle}$$

u_p = periodic mean velocity component

similarly with ζ,

$$\zeta = \zeta_E + \zeta_p$$

$$\zeta_E = \frac{1}{T}\int_0^T \zeta dt$$

We take a time average of (1) over a tidal cycle:

$$\langle q\rangle = h \cdot u_E + \langle\zeta_p \cdot u_p\rangle$$

Dividing by h yields the Lagrangian mean velocity,

$$\frac{\langle q\rangle}{h} = u_E + \frac{\langle u_p\ \zeta p\rangle}{h}$$

APPENDIX IV (Cont.) Equations used in Town Cove computer model.

We find that the Lagrangian mean velocity consists of the Eulerian residual flow, u_E, and the stokes drift, $\frac{\langle \zeta_p u_p \rangle}{h}$, resulting from non-zero correlations between sea surface elevation and velocity. Defining $\frac{\langle q \rangle}{h} = u_L$ we may define a flushing time for a coastal channel of length L:

$$T_f = \frac{L}{u_L}$$