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HYDROGEOLOGY | SITE EVALUATIONS

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April 2, 2013

WASTEWATER MOUNDING AND TRANSMISSION ANALYSIS
CLIFF ISLAND SEPTIC SYSTEM ASSOCIATION
CLIFF ISLAND (PORTLAND), MAINE

INTRODUCTION:

The purpose of this study is to determine the extent of mounding and wastewater effluent movement beneath proposed engineered subsurface wastewater disposal fields serving the Cliff Island Septic System Association. The total design flow of the proposed subsurface wastewater disposal fields is 5,120 gallons per day. The disposal field design by Pinkham and Greer Consulting Engineers, test pit logs by Mark Hampton, S.E. 263, and available literature were used to estimate the parameters used for these calculations.

SUBSURFACE WASTEWATER DISPOSAL SYSTEM:

The proposed subsurface wastewater disposal fields each consist of 176 Eljen In-drains covering an area of 91 feet by 31 feet. The two disposal fields are separated by 75 feet. The design flow of each disposal field is 2,560 gallons per day (gpd). The uniform infiltration rate of 2,560 gpd over a 31 foot by 91 foot area is 0.126 feet per day (ft/day). The ground surface slope beneath the disposal fields average 3% then increases to 11% ten feet downslope of the northernmost disposal field, based on existing grade contours shown on the disposal field design.

WASTEWATER MOUNDING AND TRANSMISSION ANALYSIS:

Groundwater mounding is anticipated to occur beneath the proposed disposal fields due to the presence of a low hydraulic conductivity layer (bedrock) beneath the disposal field. The following analysis is a three-step approach used to estimate the height of a groundwater mound beneath a wastewater disposal field on a sloping site and estimate the size of a fill extension to prevent wastewater breakout. The first step is to use an analytical model (Khan *et al.* 1976) to estimate the geometry of a groundwater mound assuming that the ground surface below the disposal field is level. The second step is to evaluate the analytical modeling results using Darcy's Law. The third step is to use the analytical modeling results to determine the appropriate down-slope fill extension length.

Step 1 - Analytical Model:

Khan *et al.* (1976) presents an analytical model that can be used to estimate the extent of groundwater mounding on a low hydraulic conductivity layer in the vadose zone below a wastewater disposal field. The conceptual model and a spreadsheet with all calculations are presented in Appendix A. Khan *et al.* (1976) used the following assumptions to simplify the model:

- The conceptual model is for a two-dimensional vertical cross-section with a disposal area (W). The half-width (w) is assumed to be much smaller than the length of the disposal area (if the half-width is not much smaller than the length of the disposal area, then the model will provide a more conservative estimate of mounding).
- The low hydraulic conductivity layer (K_2) and high hydraulic conductivity layer (K_1) interface is the sole cause of mounding (the seasonal high water table is below the interface).
- The soil in each hydraulic conductivity layer is homogeneous and isotropic. $K_1 > K_2$. The K_1/K_2 interface is horizontal.
- The infiltration rate of wastewater (q') is greater than the hydraulic conductivity of the lower layer (K_2). Infiltration is assumed to be constant.

The following equations, based on the conceptual model illustrated in Appendix A, were used to calculate the estimated maximum groundwater mounding and the distance from the center of the disposal field where groundwater mounding becomes negligible (the required extent of fill material downgradient from the disposal field to contain the mounded groundwater).

The height of the mound, H (ft), is calculated by:

$$H = w\left[\frac{K_2}{K_1}\left(\frac{q'}{K_2}-1\right)\left(\frac{q'}{K_2}-\frac{x^2}{w^2}\right)\right]^{1/2}$$

where,

w = ½ width of the disposal area (ft) - *full width used for this analysis*,
q' = uniform recharge rate into the disposal area (ft/day),
K_1 = hydraulic conductivity of the upper soil layer (ft/day),
K_2 = hydraulic conductivity of the lower soil layer (ft/day),
x = distance from center of disposal field (ft).

The maximum height of the mound, H_{max} (ft), is calculated by setting the distance from the center of the disposal field (x) to zero.

The ground surface below the proposed disposal fields slopes easterly toward the ocean at an initial slope of 3% then at 11% starting 10 feet from the disposal field and ending at the wetland 245 feet away. Since all wastewater will flow predominately in one direction (down-slope), rather than uniformly around the disposal field in all directions, the one-half width of the disposal field (w) is assumed to be the actual width of the disposal field parallel to the direction of groundwater flow (31 feet). Hydraulic conductivity K_1 is estimated to be 275 ft/day, based on values found in literature and previous constant head permeameter tests of septic system sand from gravel pits in Southern and Central Maine completed by Sweet Associates. The existing soil was assumed to be too thin to be of consequence in the calculation.

Based on the values of the abovementioned parameters, the maximum height of the mound above the K_2 layer at the center of the disposal field (H_{max}) is 1.96 feet.

Step 2 - Validate Analytical Model Results:

The low conductivity layer beneath the disposal field is sloping, which violates an assumption of the analytical model. Darcy's Law will be used to examine whether the calculated mound height from the analytical model is appropriate. Darcy's Law is expressed as:

$$Q = K\,i\,A$$

where,

Q = flow of water (cubic feet per day)
i = hydraulic gradient (unitless) - in this case the ground surface slope
A = cross section area (square feet)

Given a design flow of 2,560 gpd (684.4 ft^3), a hydraulic conductivity of 100 ft/day and a hydraulic gradient of 3%, the required cross-sectional area of sand fill below the disposal field is 200 ft^2. The results suggest that a 2.28 foot groundwater mound would occur beneath the downslope margin of the disposal field. This result is considered to be in the same order of magnitude as the Khan model.

Step 3 - Estimate Length of Down-Slope Fill Extension:

The length of the fill extension required to prevent the possibility of wastewater breakout on nearby side slopes can be determined by rearranging and solving the Khan *et al.* (1976) equations for a distance where the height of the mound is zero (Poeter *et al.*, 2005):

$$L = w * (q'/K_2)\,,$$

where,

L = length of fill extension required from center of disposal field (ft),
w = ½ width of the disposal area (ft) - *full width used for this analysis*,
q' = uniform recharge rate into the disposal area (ft/day),
K_2 = hydraulic conductivity of the lower soil layer (ft/day).

L is calculated to be 310 feet long. Since the average 11% slope of the hillside is 245 feet from the edge of the closest disposal field to the relatively flat wetland. Any fill should stop at the edge of the wetland. Because this is an island site, we are recommending installation of a wood chip fill surface at least 12-inches thick from the downslope edge of the toe of the fill of the lowest disposal field shown on the site plan to the upslope edge of the wetland. The hydraulic conductivity of the wood chips should more than exceed the designed hydraulic conductivity of the sand fill used in the calculations.

CONCLUSIONS:

According to the assumptions and parameters used in this mounding and transmission analysis, the maximum groundwater mound height above the bedrock surface at the bottom edge of each disposal field is 1.96 feet. The proposed base of the disposal field should be at least 1.0 foot above the top of the groundwater mound or 2.96 feet above the bedrock surface, which is in compliance with the minimum one foot separation distance. The sand fill used under the disposal field and for the fill extensions should have a hydraulic conductivity of at least 275 feet per day.

Two 4-inch diameter monitoring wells should be installed down to the bedrock surface and located at the toe of the lowest disposal field fill and 10 feet into the wetland directly downslope from the disposal fields. These wells should be measured for water depth and lab tested for nitrates and fecal coliform in September each year the system is used.

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APPENDIX A

Khan *et al.* (1976) Model Description and Calculations

GREEN Cells for Data Entry | RED Cells for Solutions

Khan Mounding Model (Khan et al, 1976)

K1 (ft/day)	K2 (ft/day)	*1/2 Width of Field* w (ft)	*Flow into Field Footprint* q' (ft/day)	*Distance from Center of Field* x (ft) - Use 0 for Max Mound
275	0.01	31	0.11	0

	3.63636E-05		
EQUATION TERMS	*10*	**Mound Height**	
	11	1.960612149	feet
	0.063245553		

Length of Fill extension required to prevent the possibility of wastewater breakout on side slopes

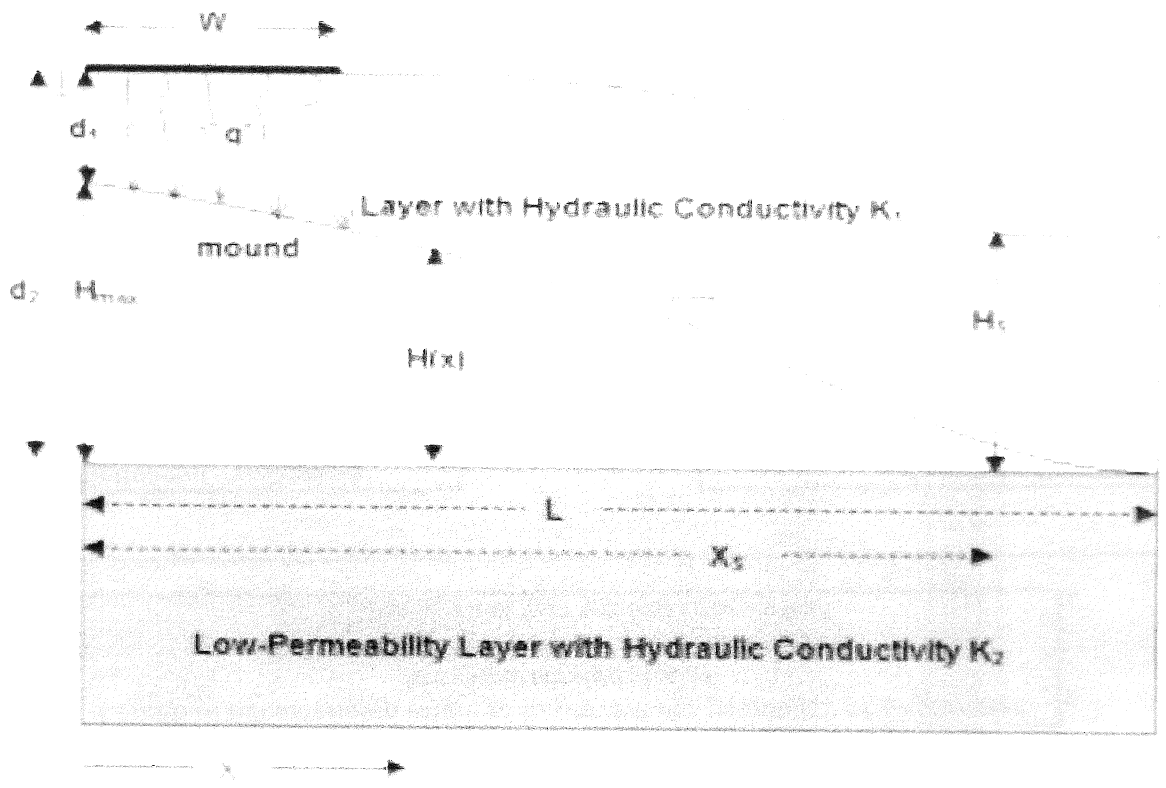
L=	341	feet from middle of disposal field
	310	feet from edge of disposal field

Calculate Equivalent Hydraulic Conductivity of Two Layers

Layer 1	Thickness	1.5	ft
	Hydraulic Conductivity	275	ft/day
	Transmissivity	412.5	ft2/day
Layer 2	Thickness	100	ft
	K	0.01	ft/day
	Transmissivity	1	ft2/day
	Equivalent Hydraulic Conductivity	4.073891626	ft/day

Calculate Flow into Field Footprint (q')

Design Flow	2560	gpd
Field Length	100	
Field Width	31	ft
Flow into Field Footprint (q')	0.110387174	ft/day


W
d1
q
Layer with Hydraulic Conductivity K1
mound
d2
Hmax
H(x)
Hs
L
Xs
Low-Permeability Layer with Hydraulic Conductivity K2
x

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April 2, 2013

GROUNDWATER IMPACT STUDY
CLIFF ISLAND SEPTIC SYSTEM ASSOCIATION
CLIFF ISLAND (PORTLAND)

INTRODUCTION:

The purpose of this study is to make an assessment of the hydrogeologic conditions of the abovementioned site and estimate the groundwater quality impact caused by the proposed on-site subsurface wastewater disposal system serving the houses currently on the Association overboard discharge system. The proposed disposal field location is shown on the site plan. Data used for this project includes a site plan provided by Pinkham and Greer Engineers, soil evaluations done by Mark Hampton, S.E., and existing regional maps and literature.

DISPOSAL FIELDS AND WATER WELLS:

The proposed disposal field is designed for a total wastewater flow of 5,120 gallons per day. All houses to be connected to this system are served by private, individual septic tanks and by individual or community drilled wells.

SURFICIAL GEOLOGY AND TOPOGRAPHY:

The site is located on the *U.S.G.S. South Harpswell, Maine Quadrangle 7.5 Minute Series*. The *Surficial Materials* and *Surficial Geology Maps of the South Harpswell Quadrangle* show that the entire island is underlain by a thin layer of glacial till overlying shallow bedrock. This soil is identified as Hollis very rocky fine sandy loam by the Soil Conservation Service. There is no *Significant Sand and Gravel Aquifer Map of the South Harpswell Quadrangle* and no sand and gravel aquifer is present on the Island.

HYDROGEOLOGY:

Precipitation falling on this site enters the open pore spaces in the upper soil horizons, and percolates vertically downward through the sandy loam till until the water table and or bedrock is encountered. Thereupon, flow is largely downslope or downgradient following the slope of the underlying bedrock surface. An unknown percentage of the precipitation captured by the soils will enter the fractured bedrock and the remaining water will move through the soil above the bedrock surface. Wetlands and the ocean will be discharge points for the groundwater moving through the soil. It is assumed that the groundwater in the bedrock will also discharge to wetlands, however, some percentage of the bedrock groundwater may not discharge until reaching the ocean. We are assuming that all surface water, groundwater in the soil, and bedrock groundwater will move downslope to the ocean starting at the highest point of land which represents the start of the watershed. At this site, the proposed disposal fields are situated on an east facing slope with the beginning of the watershed slightly to the west, which means surface water and groundwater flow will flow toward the east shore of the island as shown on the site plan.

The soil is mapped as Hollis very rocky fine sandy loam by the Soil Conservation Service and the permeability is rated at greater than 12.6 feet per day. We have assumed a conservative permeability of 10 feet per day.

The groundwater seepage velocity is used to calculate the extent of groundwater impact downgradient and has been calculated utilizing the following equation:

$$\mathbf{v = K\textit{i}/n}$$

where,

v = groundwater seepage velocity (ft/day)
K = hydraulic conductivity (ft/day)
i = hydraulic gradient (ft/ft)
n = effective porosity (dimensionless)

CONTAMINATION POTENTIAL:

It is assumed that the worst potential for contamination is the nitrate-nitrogen (NO_3-N) released from wastewater disposal fields. NO_3-N is known to cause methemoglobinemia in infants and is a suspected cause of stomach cancer. The average NO_3-N concentration value of untreated septic tank effluent entering a disposal field is assumed to be 40 milligrams per liter (mg/L). The Federal and State Drinking Water Limit for NO_3-N in public water supplies is 10 mg/L.

The primary mechanism of NO_3-N concentration reduction is through dilution in groundwater and surface water. Since groundwater is always slowly flowing beneath a disposal field, the NO_3-N intercepting the water table below a disposal field mixes and dilutes in the groundwater and moves in the direction of groundwater flow in the form of a plume. NO_3-N is more concentrated in the center than near the edges of a plume. A source that emanates a constant quantity of potential contaminants into groundwater will eventually reach a "steady state." The plume can then be characterized with regard to size, shape, and distribution of concentration.

The method of analysis used to assess the impact of the septic systems on groundwater is an analytical model used to simulate individual plumes. Analysis of the results of this model is instructive in assessing the possible shape and size of wastewater plumes. The model was developed by Baetsle (1969) to depict the migration of radionuclides in porous media, which is adapted here to represent the subsurface migration of NO_3-N. It is a three-dimensional transport model of plumes generated by continuous, point sources in a uniform groundwater flow field. Variables employed include seepage velocity (hydraulic conductivity multiplied by hydraulic gradient, divided by effective porosity), nitrate mass, time, and dispersivity. The concentration of NO_3-N is calculated at a downgradient point at a specified time by use of the following equation:

$$C(x,y,z,t)=\left[\frac{CoVo}{8(\pi t)^{1.5}\sqrt{DxDyDz}}\right]\exp\left[-\frac{(x-vt)^2}{4Dxt}-\frac{y^2}{4Dyt}-\frac{z^2}{4Dzt}\right] \; ;$$

where,

C(x,y,z,t) = NO_3-N concentration at specified location and time (mg/L)
x = specified distance from source parallel to the direction of groundwater flow (ft)
y = specified distance from source perpendicular to the direction of groundwater flow (ft)
z = specified vertical distance from source (ft)
Co = initial concentration at the source (mg/L)
Vo = volume of source (ft^3)
t = time elapsed (day)
Dx,Dy,Dz = dispersion coefficient along the x,y,z axes (ft^2/day)
v = average linear velocity (ft/day).

Assuming that groundwater flow is horizontal, the dispersion coefficient can be calculated as follows:

$D_{x,y,z}$ = $v\ _{x,y,z}$;

where $_{x,y,z}$ is dispersivity (ft).

The contaminant velocity of a solute subject to sorption/adsorption is calculated as follows:

V_p = v/R_d;

where V_p is the contaminant velocity (ft/day) and R_d is the retardation factor (unitless). The retardation factor for NO_3-N is equal to one, however, so the contaminant velocity is equal to the average linear velocity ($V_p = v$).

Dispersivity is estimated by an equation based on a weighted least-squares statistical analysis of collected longitudinal dispersivity data versus scale (Xu, Eckstein, 1995). Longitudinal dispersivity can be estimated based on the following calculation:

$_x$ = $(0.83)[\log_{10}(L_p)]^{2.414}$;

where $_x$ is longitudinal dispersivity (ft), and L_p is the plume length (ft). The plume length is a function of the elapsed time and is calculated by the following equation:

L_p = V_pt.

It has already been established that for NO_3-N, the contaminant velocity (V_p) is equal to the average linear velocity (v). Thus, $L_p = vt$.

The transverse and vertical dispersivities are related to the longitudinal dispersivity, as shown below:

$_y$ = $_x/3$
$_z$ = $_x/20$.

This method is used to calculate a downgradient NO_3-N concentration at a specified elapsed time for a single release of NO_3-N. However, by applying the superposition technique, the estimated concentration of NO_3-N downgradient at a specified time can be calculated for reoccurring daily NO_3-N releases to simulate the NO_3-N plume of a septic system (Chang, *et al.* 1998).

In the main equation, CoVo is represented as a daily mass of nitrate-nitrogen loaded into the subsurface wastewater disposal systems. This is estimated by multiplying the design flow volume of effluent by the assumed NO_3-N concentration in the effluent. The simulations were run based on average annual precipitation during drought conditions (60% of average annual precipitation). The NO_3-N concentration of the wastewater is diluted by the rainfall infiltrating the disposal fields during drought conditions. The rainfall is assumed to have a NO_3-N concentration of 0.5 mg/L. The percent of rainfall infiltrating the soils above the disposal fields is estimated based on the soil type and ground surface slope (Maine Department of Environmental Protection, 1991).

Parameters and results for the disposal field are displayed on the Groundwater Impact Site Plan. The resulting 10 mg/L NO_3-N concentration plume length for the combined disposal fields is 340 feet. Other factors affecting the plume are the variable slope the plume will move through, the thin soil cover from the disposal fields to the wetland, and the treatment value of the wetland on the nitrates. It is likely that the plume will be higher in concentration upon reaching the wetland than the calculations show due to the thin soil cover, and the inorganic high carbon content of the wetland will denitrify the plume faster than shown. For these reasons, we feel that the calculated nitrate plume is reasonable.

CONCLUSION:

The nitrate plume of 10 mg/L shown on the site plan is calculated to drop to safe levels within the wetland as shown.

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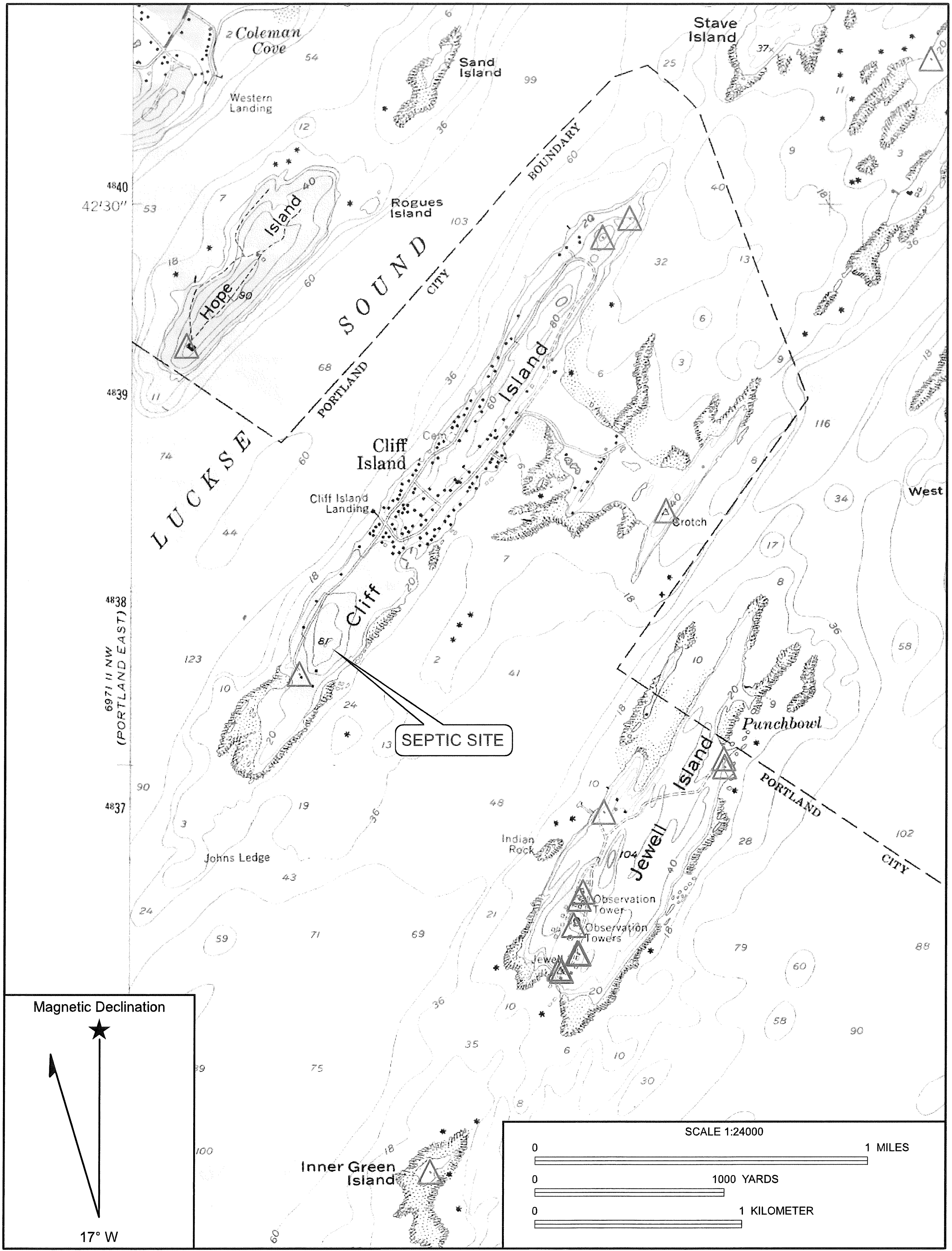
APPENDIX A


Coleman Cove
Western Landing
Sand Island
Stave Island
Rogues Island
Hope Island
LUCKSE SOUND
PORTLAND CITY BOUNDARY
Cliff Island
Cliff Island Landing
Cem
Crotch
West
SEPTIC SITE
Punchbowl
Jewell Island
Indian Rock
Johns Ledge
Observation Tower
Observation Towers
Jewell
Inner Green Island
4840
42'30"
4839
4838
4837
6971 II NW (PORTLAND EAST)
Magnetic Declination
17° W
SCALE 1:24000
0
1 MILES
1000 YARDS
1 KILOMETER

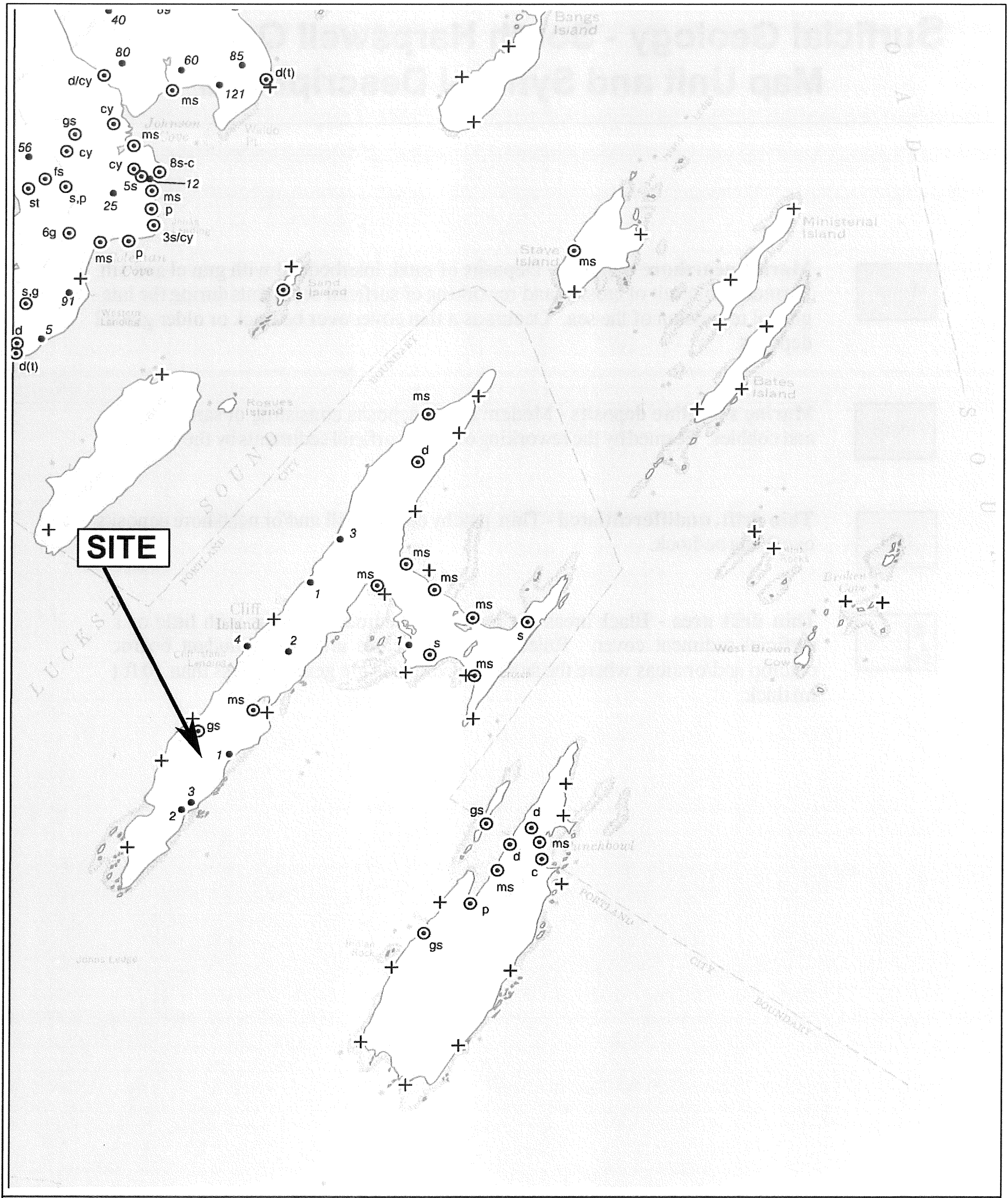
0 2000 4000

Feet - 1:24,000

Surficial Geology
South Harpswell Quadrangle

Surficial Geology - South Harpswell Quadrangle
Map Unit and Symbol Descriptions

Pmn	**Marine nearshore deposits** - Deposits of sand, interbedded with gravel and silt. Formed as a result of erosion and reworking of surficial sediments during the late-glacial regression of the sea. Occurs as a thin cover over bedrock or older glacial deposits.
Hms	**Marine shoreline deposits** - Modern beach deposits consisting of sand, pebbles, and cobbles. Formed by the reworking of older surficial sediments by the ocean.
Ptd	**Thin drift, undifferentiated** - Thin, patchy cover of till and/or nearshore deposits overlying bedrock.
▨	**Thin drift area** - Black areas are individual bedrock outcrops with little or n surficial sediment cover. Ruled pattern indicates areas of abundant bedroc outcrop and/or areas where the surficial sediments are generally less than 10 ft (m) thick.



0 2000 4000

Feet - 1:24,000

Surficial Materials
South Harpswell Quadrangle