Evaluation of a Control Gate for a Salt Pond Estuary

by

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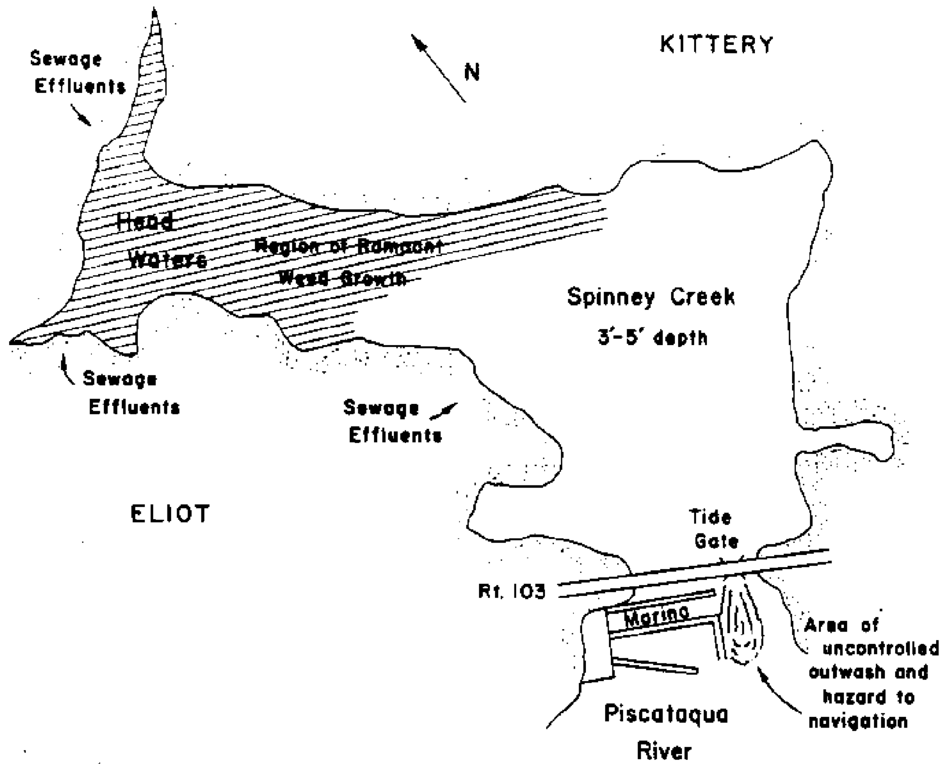

Figure 1: Chart of Spinney Creek. The major points of interest to this study are indicated.

1 Introduction

There are many small bays and estuaries in New England which are nearly closed off from either the ocean or a major river by a causeway, dam, or flood control gate. Spinney Creek in Eliot, Maine, is a typical example in which several problems are caused by its embayment. Problems which affect the aesthetic value, n recreational and commercial uses, and safety are associated with the control of the water level behind the causeway.

Spinney Creek is a 125-acre salt pond which was formed when the Maine State Route 103 causeway was constructed across its mouth (see Figure 1). Prior to the construction of the causeway, Spinney Creek was an intertidal mud flat with a small channel in the middle. Although the causeway does have an opening, it has greatly restricted the exchange of water with the Piscataqua

River. The water level in Spinney Creek is maintained at three to five feet by a manually controlled tide gate.

This tide gate was installed by the Maine Department of Transportation to control the water level in Spinney Creek. The gate is located in the Piscataqua River end of a sluiceway constructed in the causeway. It is hinged at the top and swings down to fully close the sliceway to a height of 1.8 m. When the water level in the Piscataqua River exceeds the height of the gate, water flows over the top of the gate into Spinney Creek. If the level in Spinney Creek exceeds the height of the tide gate, then it flows out. Otherwise, any flushing is controlled by manually opening the gate for a specified amount of time and allowing the water in Spinney Creek to flow out.

It is desirable to flush Spinney Creek from time to time because of the existing physical conditions. Spinney Creek is a shallow body of water which is quickly heated by solar radiation in the summer. Several small feeder streams bring fresh water and rain water runoff to the estuary. Also, sewage effluents enter the creek through these feeder streams and increase the nutrient load. The combination of shallow water, substrate located well within the photic zone, solar heating, reduced circulation, and nutient overloading create an environment of high primary productivity. Rampant weed growth in the shallow northern portion of Spinney Creek accumulates and further restricts circulation there.

The combined effects of poor circulation, excessively warm water, and biological demand on oxygen reduce the dissolved oxygen content, thereby causing a major stress on any marine life in Spinney Creek. This ecological problem is further accentuated during periods of respiration and decomposition of the large resident biomass which has accumulated during periods of high primary productivity. Finally, marine life, and especially intensive aquaculture, is adversely affected by low dissolved oxygen and restricted circulation. The ecological balance of the estuary is altered and no longer reflects a healthy estuary.

To promote flushing of the estuary during the summer, the tide gate is opened for one 24-hour period during each fortnightly tidal cycle. When the gate is opened, the water runs freely out into the Piscataqua River, draining the estuary. This complete flushing of the estuary drops the water level so dramatically that marine life and aquaculture are adversely affected, and recreational activities are interrupted. When the flats at the northern end drain, marine life (which is adapted to a subtidal environment) is exposed and consequently suffers. More disturbing to shore front property owners is the accumulation of undiluted sewage effluents which cause noxious odors, thereby destroying the natural enjoyment of the estuary.

Finally, the uncontrolled rush of water out of the flume causes strong currents in front of Jerry's Marina which are a danger to navigation. These currents undermine the footings of the flume and causeway, and they create billows of foam which are not only a nuisance but also damage boats in the marina.

The problem of the control of water in Spinney Creek breaks down into four requirements:

1. To keep the water level in Spinney Creek at or above a certain level to (a) preserve the recreational value of the estuary by having enough water on which to boat, (b) preserve the aesthetics and natural beauty inherent in the estuary, (c) prevent detriment to marine life, (d) prevent major damage to the commerical clam and oyster beds, and (e) dilute sewage effluents.

2. To constantly flush the estuary in order to (a) bring the cooler Piscataqua River water into the estuary to keep the temperature lower during the warm summer months, (b) remove the excess buildup of nutrients and sewage effluents which pollute the estuary and contribute to the odor problem, (c) inhibit the accumulation of weeds that restrict circulation within the estuary, and (d) improve the water quality and recreational value of the estuary.

3. To improve the safety in the area by decreasing the (a) strong current associated with the present flushing of the estuary and its hazard to small boat traffic at Jerry's Marina, (b) strong currents flowing at times of flushing which could cause a danger to fishing and boating on Spinney Creek near the causeway, and (c) damage caused to the boats in the marina due to high foam buildup associated with high flow during periods of flushing.

4. To reduce town and state manpower requirements necessary for the manual operation of the existing gate in order flush the estuary.

2 Prototype Control Gate

To address the problems outlined above, Jerry's Marina and the Spinney Creek Oyster Company secured permission from the Town of Eliot and the State of Maine to install and test a new control gate in the fall of 1985. They proceeded to build and install a prototype control gate which they believed would solve many of the perceived problems. Its effects were monitored during the fall of 1985. This prototype control gate was again installed for a full season's evaluation during the summer of 1986.

The new control gate operates on water level differences and requires no manual attention. It operates continuously, exchanging part of the water in Spinney Creek on each tidal cycle. The currents associated with the new control gate are smaller, and the safety in the area is improved.

The new control gate (Figure 2) is located in the opposite end of the flume from the original gate (which could still be operated if necessary in the event of a failure of the new gate.) The new control gate does not close off the flume completely but rather is opened a fixed amount at the bottom. This lets water continually flow out of (or into) the creek when the water in the river is below

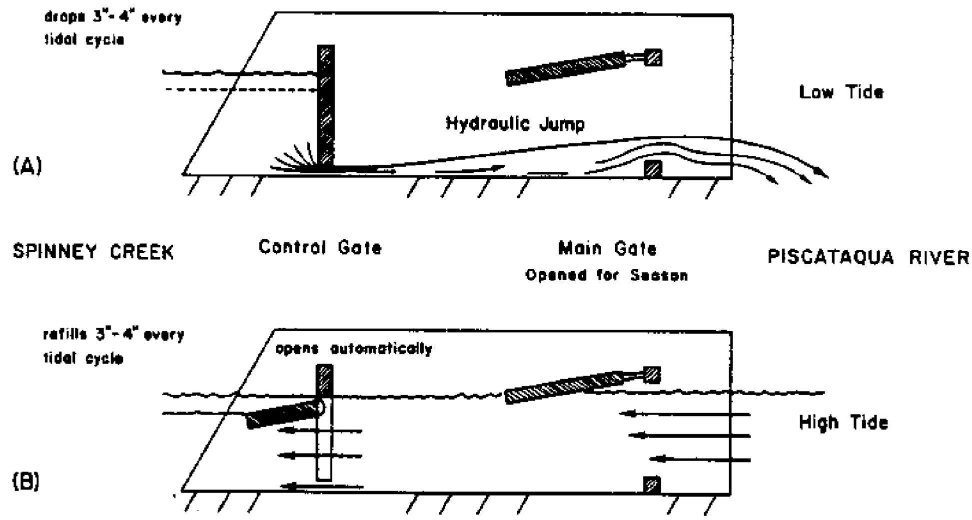

Figure 2: The control gate and flume. The old manually operated gate is shown at the right. The new control gate is at the left. At low tide, when the water level is lower in the Piscataqua River, water runs out under the gate as shown. At high tide, the door in the new control gate opens to let water into Spinney Creek.

(above) that in Spinney Creek. The rate of flow is controlled by the difference between the water levels in Spinney Creek and the Piscataqua River. The continual outflow of water on each tidal cycle contributes to the flushing of the estuary.

In addition, the new control gate has a smaller internal gate which automatically opens to allow water to flow into Spinney Creek when the water level is higher in the Piscatauqa River than in the creek. This gate shuts when the water level in Spinney Creek is higher than that in the river. The area of the inner gate is larger than the area of the continually open section at the bottom of the new gate, so the water can flow into Spinney Creek at a greater rate than it can flow out. Because of this difference in the rate of flow into and out of Spinney Creek, the water level in the creek can be maintained at a nearly constant level while flushing the estuary. Achieving this balanced state of affairs requires proper design adjustment of the openings relative to the size of the creek and tide in the river.

When the new control gate is properly adjusted, it should: (a) maintain a minimum acceptable water level in Spinney Creek, (b) produce a constant and daily flushing of the estuary on every tidal cycle to keep a steady interchange of water with the Piscataqua River, (c) require little effort and maintenance on the part of the town or businesses concerned, and (d) reduce the strong currents associated with the previously scheduled periodic drawdown and flushing of Spinney Creek.

2.1 Observations

In 1986, the Spinney Creek Oyster Company and the University of New Hampshire's Physical Oceanographic Research Team (PORT) undertook to evaluate the performance of the prototype control gate. They began an effort to model, on computer, the behavior of the new control gate, and to monitor the water levels in Spinney Creek and the Piscataqua River to observe the operation of the new control gate and validate the computer model. To monitor the water level, two bottom pressure instruments were borrowed from PORT and installed for a three-week period in the fall of 1986, and were removed only when ice formation threatened to prevent instrument recovery before spring.

During the past ten years, UNH has been developing both the technology and the techniques to measure and interpret pressure measurements in the ocean. Their instruments are self-contained internally recording pressure gauges which digitize and record on cassette tape the temperature and pressure at the bottom as a function of time. In order to make reliable pressure measurements, the instrument must be fixed firmly on the bottom. For the deployment in the Piscataqua River and Spinney Creek, special anchors were built which held the pressure tubes containing the sensors and electronics firmly in place on the bottom (Figure 3).

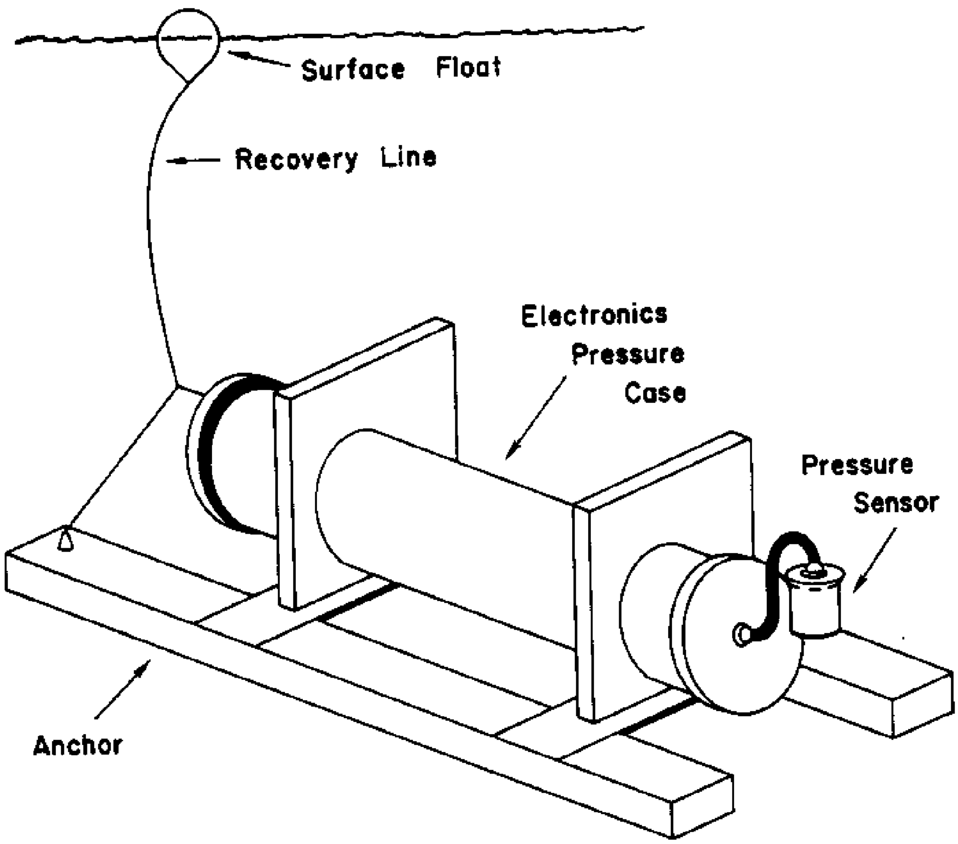

Figure 3: The bottom pressure instrument.

In these instruments, pressure is measured with Paroscientific quartz pressure sensors which were calibrated at UNH. These sensors are capable of resolving a change in pressure equivalent to 1 mm of water surface elevation. However, in order to obtain this accuracy, special calibration and processing of the data is required (see Brown, Irish and Erdman, 1983). The basic recording system is manufactured by Sea Data Corporation of Newton, Massachusetts. For this experiment the instruments were set to record the temperature and pressure every 7.5 minutes. To correlate the measurements from the two instruments, accurate quartz clocks controlled the sampling. After recovery, the data was read from the cassettes into the UNH research computer for subsequent analysis.

The pressure that each instrument measured at the bottom, P_b, is an indirect measure of the water level since the pressure at the bottom is the total weight of the water and atmosphere above the sensor. Thus, the pressure is the sum of several parts. The first is the atmospheric pressure at the water surface, P_a. The average atmospheric pressure of about 1000 mbar is equal to approximately 10 m of water pressure. Normal weather variations cause fluctuations of about 10 mbar, which is equal to about 10 cm of sea surface height and cannot be neglected. A second component, constant hydrostatic pressure, P_h, is due to the average amount of water above the instrument. This is a constant, depending on the mean depth of the instrument, and is important only in relating the absolute value of the measurement from one instrument to that from another. The quantity of interest in this study is the pressure fluctuations due to water level variations, P_l, about the mean. This term is the product of the average density, ρ, the acceleration due to gravity, g, and the water level, h,

$$P_l = \rho g h \quad . \tag{1}$$

Finally, there is a term due to changes in the density of the water. For this study we will neglect this term as being much smaller than the other terms mentioned above. Therefore,

$$P_b = P_a + P_h + P_l \quad . \tag{2}$$

The water level, h, is then determined by

$$h = \frac{P_b - P_a - P_h}{\rho g} \tag{3}$$

where we measure P_b and P_a and estimate the density, ρ. We remove the hydrostatic term, P_h, by subtracting the series mean from each term and using other techniques to relate the measurements taken by the two instruments.

The two instruments were deployed on 20 November 1985 for three weeks. One was deployed from Jerry's Marina's dock in about 2 m of water. This instrument measured the water level in the Piscataqua River, which represents the forcing or driving function in the computer model of the new control gate. The second instrument was deployed about 50 m from the causeway in 1.6 m of water in Spinney Creek, and measured the response of the control gate-Spinney Creek system to the river's forcing. One input influencing the Spinney Creek water level which was not measured was the fresh water input from creeks and runoff. The two instruments were allowed to remain in the water for three weeks until ice began to form on Spinney Creek.

The data were processed at UNH to produce estimates of P_b at each site (Figure 4). (For a description of the processing software used, see Irish and Brown, 1986.) Also shown in Figure 4 is the atmospheric pressure, P_a, obtained from Pease Air Force Base. Although the atmospheric pressure was not measured at exactly the same location, atmospheric pressure is a large scale phenomena which does not change significantly on the scale of the distance from Pease Air Force Base to Spinney Creek. It is obvious that there is significant contribution in P_b due to P_a in the Spinney Creek record. The Piscataqua River record is dominated by meter-high tides, so the atmospheric pressure signal is masked. The records corrected for atmospheric pressure effects (Figure 5) are now a good representation of the water level in the Piscataqua River and Spinney Creek, and do approximate the initial prediction. The sharp rise and slow fall (saw tooth shape) of the water level in Spinney Creek show that the prototype gate is performing as desired: exerting nonlinear control on the water level. The sharp rise is associated with inflow under the gate and through the inner door, and the slow fall is associated with the flow out under the gate.

Temperature was recorded by the bottom pressure instruments in order to correct for the temperature sensitivity of the pressure sensors. The temperature records (Figure 6) are interesting in that they show something of what is going on in the river and creek. The river temperature starts out slightly colder, and shows the tidal fluctuations typical of the Piscataqua River where river water and Gulf of Maine water are mixing. The steady cooling of the river water is typical of the early winter.

The creek temperature record is more interesting. It is isolated from the tidal fluctuations in the river, but is more easily cooled by radiative cooling. About 25 November there is a sudden drop in temperature, then a steady decrease until 2 December, when, as a storm passes (see atmospheric pressure in Figure 4), the temperature drops to almost the freezing point. During 5 December the water is rewarmed by exchange with the river, and we see a creek temperature which is cooler than the river.

2.2 Modeling

A computer model was created to predict the response of Spinney Creek to the new control gate so the designer could modify the parameters (i.e., dimensions of the flood gate openings) and observe changes in the results. The goal was to allow the user to choose a height for the opening which would maximize the flow of water and flushing while keeping the water level within the creek at an acceptable level. The model uses a time series of the water level in the river as

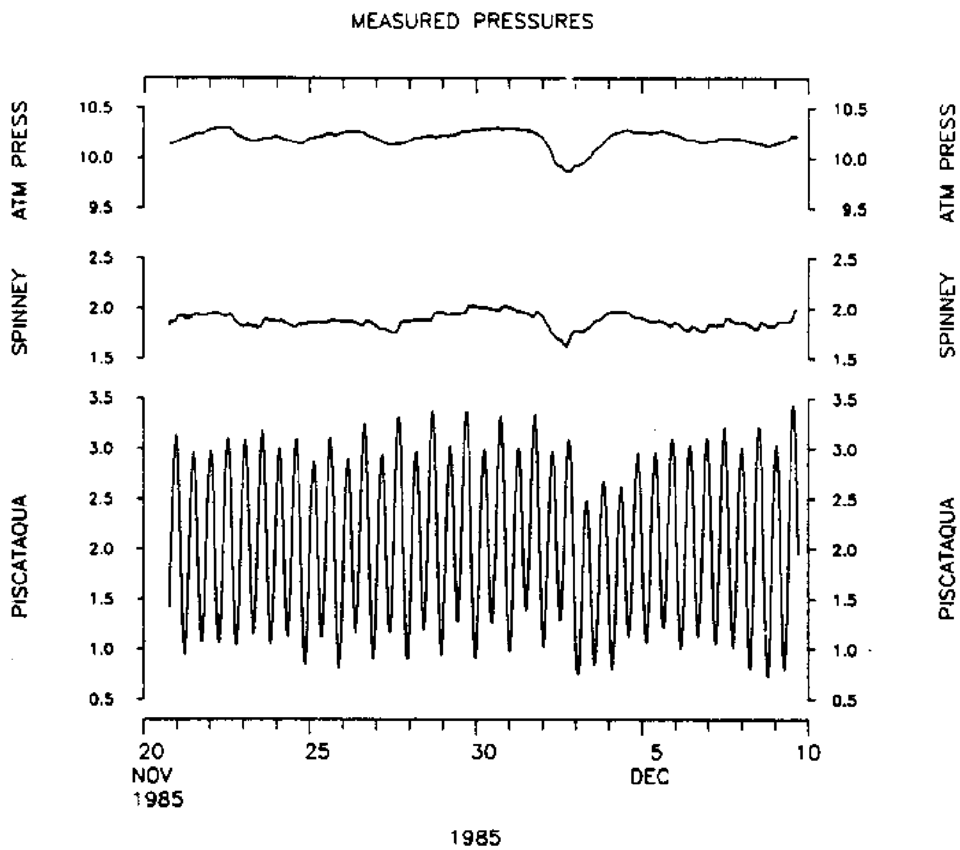

Figure 4: Measured pressures. The bottom pressure records (in dbars) in the Piscataqua River and Spinney Creek are shown at the bottom and center. The atmospheric pressure (in dbars) at Pease Air Force Base is shown at the top. The Spinney Creek and Piscataqua River records contain significant amounts of atmospheric pressure signal.

OBSERVED WATER LEVELS

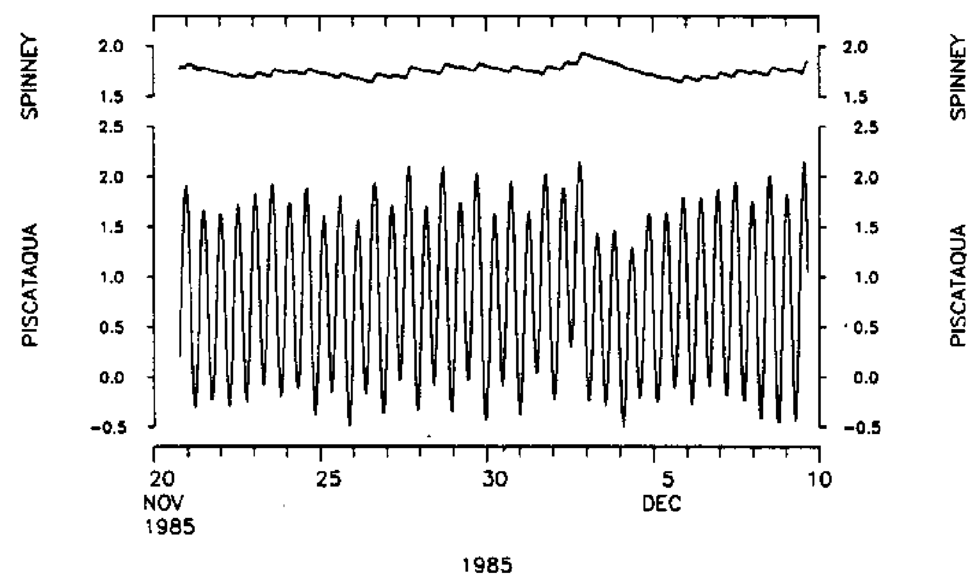

Figure 5: Observed water levels. The heights of the water levels (in meters) in the Piscataqua River and Spinney Creek are shown. These records were formed by correcting the bottom pressure records for atmospheric pressure and normalizing as indicated in Equation 3.

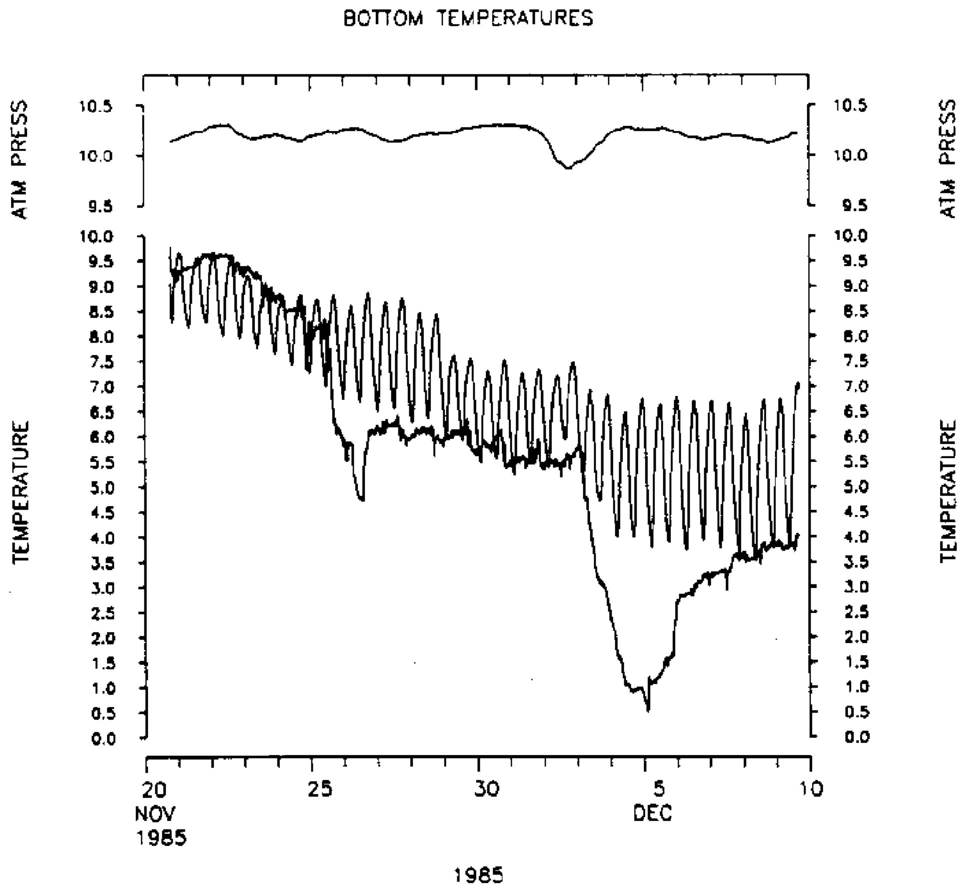

Figure 6: Bottom temperatures. The Piscataqua River record shows significant tidal fluctuations superimposed on a continuous cooling. The Spinney Creek record shows the effects of radiative cooling, storm mixing and heating by mixing with Piscataqua River water.

a driving force for the model. This input could be an observed river level from a tide gage or water level recorder of some sort, or the predicted tide at a point (although the predicted tide will not have weather-induced or runoff effects on river level included.) The model output would be the water level in the estuary and the flow through the flume, both as a function of time.

In order to simplify the model, the following assumptions were made:

1. The surface area of the creek is constant as the water level rises and falls. With the shallow water at the north end this is not true, but if the level of the estuary changed very little it would be true. For the sake of model simplicity, we will assume that the area remains constant.

2. The only source or sink of water for Spinney Creek is through the flume and the new control gate. It is obvious that there will be input from creeks and runoff which will raise the water level, but they are not accounted for in the model as it is set up. If there were significant input of other water, the model could be improved to account for it.

3. The volume rate of flow of water into and out of the creek is calculated as a function of only the instantaneous value of the water levels on either side of the control gate and the previously computed values of the volume flow rate for a given geometry of the control gate. Thus, at any instant of time, the state of the system is considered to be completely represented by the two water levels on either side of the control gate, and the previous two computed values of volume flow rate.

Given an initial state, the model proceeds in a quasi-static manner by stepping through time at discrete intervals and evaluating each new state based on the previous states and the forcing function (the water outside the gate). Specifically, the water levels of the previous state are used to estimate the volume flow rate through the channel. This single estimate of volume flow rate is integrated over the time interval betweeen states to yield an estimate of the change in volume of the creek. The change in the water level of the creek is estimated by dividing the change in volume by the assumed constant surface area of the creek. This change is used to estimate the new water level in the creek, and hence the new state for the next step in time.

The validity of the quasi-static assumption can be increased arbitrarily by decreasing the time interval between states. In practice, the estimated volume flow rates of the past three states were used to estimate the change in volume of water in the creek between the most recently computed new states.

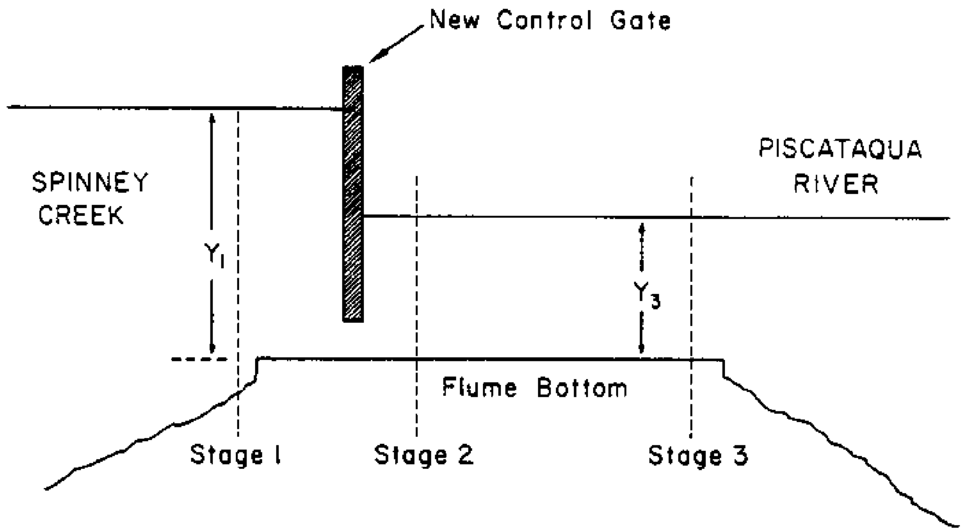

Figure 7: Outflow. The water level in Spinney Creek is Y_1 and the water level in the Piscataqua River is Y_3. The new control gate is located in the flume of constant cross section. Stage 1 and Stage 3 are in the open creek and river, respectively. Stage 2 is where the flow under the control gate necks down to its minimum thickness.

2.2.1 The Estimation of Flow Rate

The most critical estimation identified was that of volume flow rate. The equations used were adapted from Henderson (1966). Instead of using rating curves, a theoretical expression for the flow rate was developed that essentially parameterized the rating curve. The constants introduced are related to the geometry of the gate and frictional effects. The principles of conservation of mass, momentum and energy were used in deriving the expressions for flow rate. The final equations are presented below.

Two cases of water flow are considered separately.

Outflow This occurs when the water level in Spinney Creek is higher than that in the Piscataqua River (Figure 7). Y_1 is the instantaneous level of the water in Spinney Creek and Y_3 is the instantaneous level of water in the river. Both levels are with respect to the flume bottom. This case can be further divided into two sub-cases: when the water level in the river is below the bottom of the flume resulting in free flow, and when the river water is above the flume bottom resulting in submerged flow.

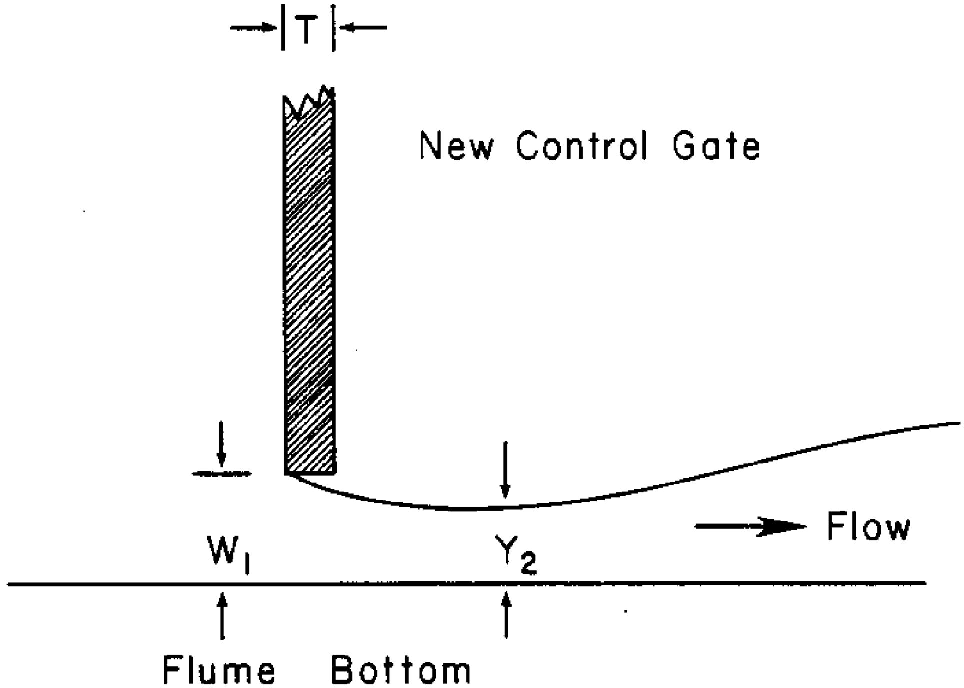

Figure 8: Free outflow. The flow under the gate, which is open a height W_1 above the flume bottom, necks down to a minimum height of Y_2.

Free Flow Free flow is pictured in Figure 8. The water freely flows out under the floodgate through the opening of height W_1 at the bottom. Since the water level in the river is below the flume bottom, the flow necks down to a height Y_2 and flows out the flume into the river. The solution for the volume flow rate per unit width of the gate, q, is

$$q = Y_1 Y_2 \sqrt{\frac{2g(Y_1 - Y_2 - A)}{(Y_1 - Y_2)(Y_1 + Y_2)}} \tag{4}$$

where Y_2 is the height of water at its minimum, some distance beyond the gate and is calculated from

$$Y_2 = c_v W_1 \tag{5}$$

where c_v is the coefficient of contraction. A is a measure of the frictional head loss and is estimated by

$$A = (aV^{1.57})/(gW_1) \tag{6}$$

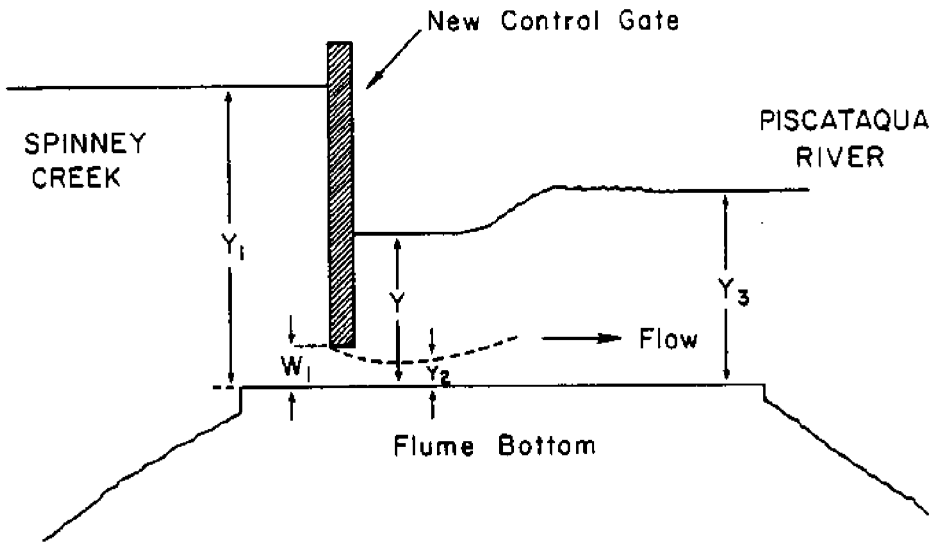

Figure 9: Submerged outflow. The level in the Piscataqua River is above the level of the flume bottom. The water level near the gate is Y, followed by a turbulent zone and a hydraulic jump downstream.

where T is the thickness of the control gate, g is the acceleration due to gravity, and a is derived from empirical equations for friction. It is initially estimated and may be modified as required. Because of the nature of Equation 4, iteration is required to calculate q. The width of the gap and flume, L, is constant, so the total rate of flow, Q, is

$$Q = qL \quad . \tag{7}$$

Submerged Outflow Submerged outflow is illustrated in Figure 9. The flow is still out of the creek, but now the water level in the river is above the channel bottom, so the jet of water flowing out under the control gate is submerged. Associated with this kind of flow is a turbulent zone accompanied by a slight but abrupt rise in water level (hydraulic jump). The solution for the flow is

$$q = Y_1 Y_2 \sqrt{\frac{2g(Y_1 - Y - A)}{(Y_1 - Y_2)(Y_1 + Y_2)}} \tag{8}$$

where

$$Y = \frac{1 \pm \sqrt{1 - 4K((Y_1 - A) - K(Y_3^2 + 2B))}}{2K} \tag{9}$$

and

$$K = \frac{1}{4} \frac{Y_3}{Y_2 Y_1^2} \frac{(Y_1^2 - Y_2^2)}{(Y_3 - Y_2)} \tag{10}$$

Again, the width of the control gate, L, is constant. Only the positive square root in Equation 9 yields physically realizable values. The quantity inside the square root of Equation 9 becomes negative for small Y_3, and this would result in complex Y. This case is interpreted as a situation when Y_3 is not high enough to result in submerged outflow, (i.e., the situation is free outflow, and Y is set to Y_2). The quantity B is a measure of the momentum lost due to friction and is calculated from

$$B = bV^{1.8}X^{0.8}/g \tag{11}$$

where X is the length along the flume between stages 2 and 3 (see Figure 7). This equation was derived from an empirical equation for the friction factor. b is a constant which is estimated from empirical expressions for frictional force. It may be modified if required.

Submerged Inflow Submerged inflow occurs when the water level in the river is higher than that in the creek ($Y_1 < Y_3$). It is observed that only submerged flow occurs, and so free inflow is not considered. This case is represented in Figure 10. In addition to the flow under the gate through the opening of height W_1, there is a second flow into the creek through the hinged gate, which has an opening of height W_2. The two cases are considered separately. The flow under the gate is calculated exactly as for the case of submerged outflow above, taking into account the change in flow direction.

The flow through the upper opening in the gate is complicated by the fact that the width of this opening is not equal to the width of the channel.

The hinged gate is assumed to open instantaneously on flow reversal, and provide no drag or restriction on the flow. The flow is then calculated from

$$q = Y_3 Y_2' \sqrt{\frac{2g(Y_3 - Y - A')}{(Y_3^2 - Y_2'^2)}}$$

$$Y = 1 \pm \frac{\sqrt{1 - 4K((Y_3 - A') - K(Y_1^2 + 2B'))}}{2K}$$

and

$$K = \frac{1}{4} \frac{Y_1}{(Y_2' Y_3^2} \frac{(Y_3^2 - Y_2'^2)}{(Y_1 - Y_2')}$$

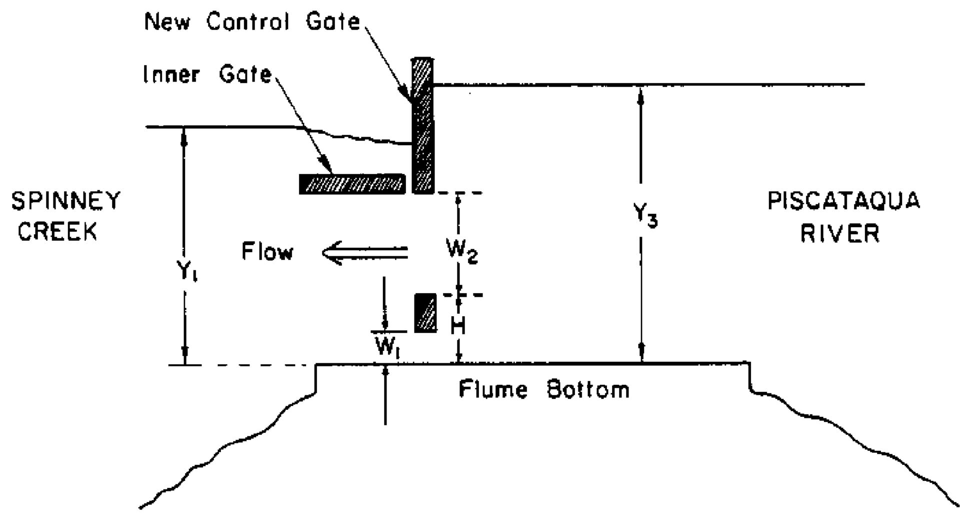

Figure 10: Inflow. The inner gate of height W_2 opens to allow water to flow into the creek in addition to the flow under the gate. The upper gate begins a distance H above the flume bottom.

$$Y_2' = c_v' c_L' \, L'/LY_2$$

where H is the height of the opening in the gate above the flume floor, c_v' is the vertical coefficient of contraction, c_h' is the horizontal coefficient of contraction, L is the width of the flume, and L' is the width of the upper opening in the gate. The frictional head loss is calculated by Equation 6 with new constant a'. Similarily, B' is calculated by Equation 11 with a new constant b'. (The primes on the constants refer to the inflow case.)

2.3 Model Predictions

The input to the model is a time series of water level in the Piscataqua River, $Y_3(t)$. The constants which describe the dimensions of the flume and gate, and the coefficients of contraction and friction are read from a separate data file. The constants used for the initial comparison are shown below in Table 1.

The program outputs a time series, $Y_1(t)$, of the water level in Spinney Creek. The model also calculates the average inflow per day during the time of the observations, and lists the maximum and minimum water levels during the time of the observations along with the time of their occurrence.

The model was run with the observed water level in the Piscataqua River as measured by the bottom instrument (Figure 5), and the output was compared

Table 1. Constants for hydraulic control gate model.

General Parameters	
Area of Spinney Creek	$5.061 \times 10^5\ m^2$
Initial creek height, $Y_1(0)$	$1.7644\ m$
Height of gate	$1.8\ m$
Thickness of gate, T	$0.08\ m$
Lower or Bottom Opening	
Width of flume, L	$3.225\ m$
Height of opening, W_1	$0.05\ m$
Coef. of contraction, c_v	0.7
Energy Loss coef., a	5×10^{-4}
Drag coefficient, b	2×10^{-5}
Inner Hinged Gate Opening	
Effective width of opening, L'	$2.21\ m$
Height of opening, W_2	$1.5\ m$
Height to opening, H	$0.25\ m$
Vert. coef. of cont., c'_v	0.65
Horiz. coef. of cont., c'_h	0.6
Energy loss coef., a'	5×10^{-4}
Drag coefficient, b'	2×10^{-5}

with the observed elevation in Spinney Creek (Figure 5) in Figure 11. It is obvious that the model is working, and the prediction is good. The slight deviations of the two curves could easily be due to river runoff which was not accounted for by the model. During the 3 to 5 December period when the weather lowered the river level, the creek was draining, and the rate of draining was controlled by the opening beneath the gate. That the predicted and observed slopes are in good agreement means that the outflow is modeled correctly. The model also predicts summary values as listed in Table 2. The computer model therefore

Table 2. Summary table for model predictions.

Start time: 20 November 1985 - 13:22:30 GMT
End time: 9 December 1985 - 16:07:30 GMT
Duration: 453.75 *hours* = 18.9 *days*
Average Inflow = 1997.88 m^3/sec
Minimum Level of 1.615 m @ 5 Dec 1985 20:45 GMT
Maximum Level of 1.917 m @ 2 Dec 1985 20:53 GMT

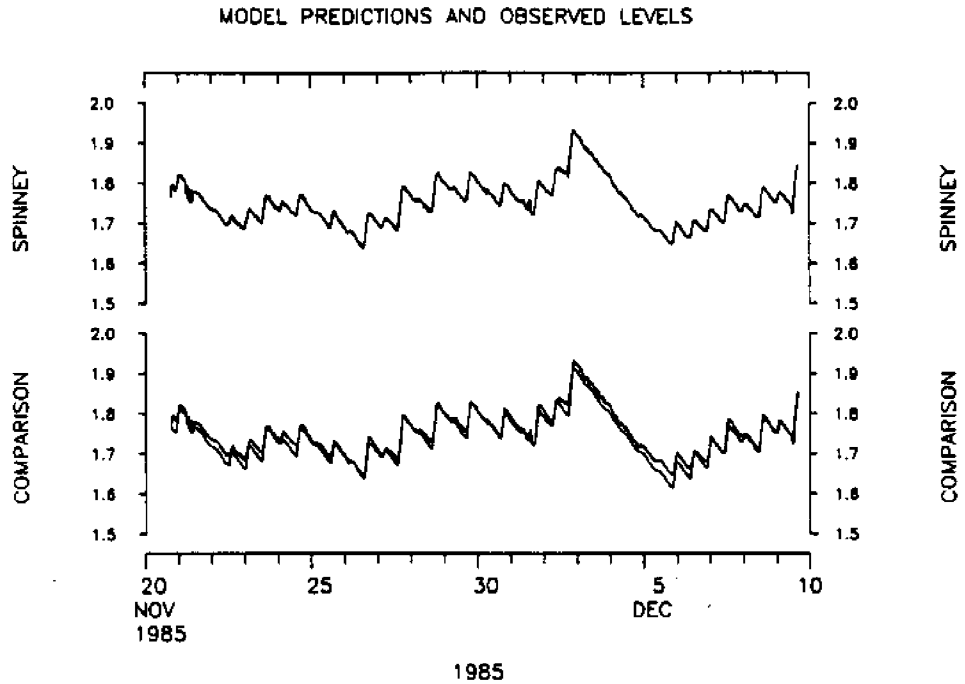

Figure 11: Comparison of the model prediction and observations. The predicted level in Spinney Creek is shown plotted with the observed water level at the bottom, and the observed water level is plotted separated above. The comparison is good.

contains the essential physics of the flow through the control gate, and can be used to predict the behavior of the gate with different openings W_1.

Adjustments to Model The amount of flushing and the water level in the creek can be controlled by varying the opening at the bottom of the gate. The model can be used to predict the behavior of the system for various gate openings. Figure 12 shows the predicted, averaged inflow rate as a function of opening W_1. (Remember that the inflow is principally dependent on the height of the inner gate opening, W_2.) Since the inflow is driven by the level in the river, it varies with each set of observations.

The predictable nature of the tides allows us to use the model to predict what happens at times that we do not have direct observations. From data analyzed by Swift and Brown (1983), we can predict at any time that part of the water level in the river which is due to the tides. There are other weather-induced level fluctuations, but from Figure 5 it is clear that the tides dominate. Therefore, a prediction of the tidal variations of the water level in the Piscataqua River was made, and this artificial tidal record was used as input to the model which predicted the level in Spinney Creek for April and May of 1986. The results are shown in Figure 13 for various openings, W_1, under the gate. The resulting creek water levels are surprisingly similar. The greater flow rate associated with the larger opening means slightly greater amplitude fluctuations with the twice daily tide. The major change was in the mean water level. The maximum, minimum and mean of the predicted records shown in Figure 13 is plotted as a function of opening in Figure 14. The range (difference between maximum and minimum) increases with the opening. The major difference is that the mean water level drops with increasing opening. Therefore, as the opening is widened to increase flushing, the average water level in the creek will fall.

Observations during 1986 The control gate was installed on April 10, 1986, and the gap was set at 8.25 cm (3.25 in). During this springtime period, the control gate operated automatically, maintained an acceptable level, and it seemed to provide a consistent flush of the embayment as witnessed by residents living along the shore. The problems of high currents and foam experienced by the marina in previous years were nonexistent. Visual clarity of Spinney Creek water was much improved, and weed growth was reduced significantly over previous years.

The salinity of Spinney Creek was 24 parts per thousand on April 10 when the control gate was installed for the season. By June 30, 1986, the salinity had increased to 32 parts per thousand. An intercomparison of sparse temperature data collected during the 1985 and 1986 seasons indicated a reduction in mean water temperature of less than 2°F from 62°F in 1985 to 60.5°F in 1986. This data consisted of 26 pairs of observations with matched dates over this period.

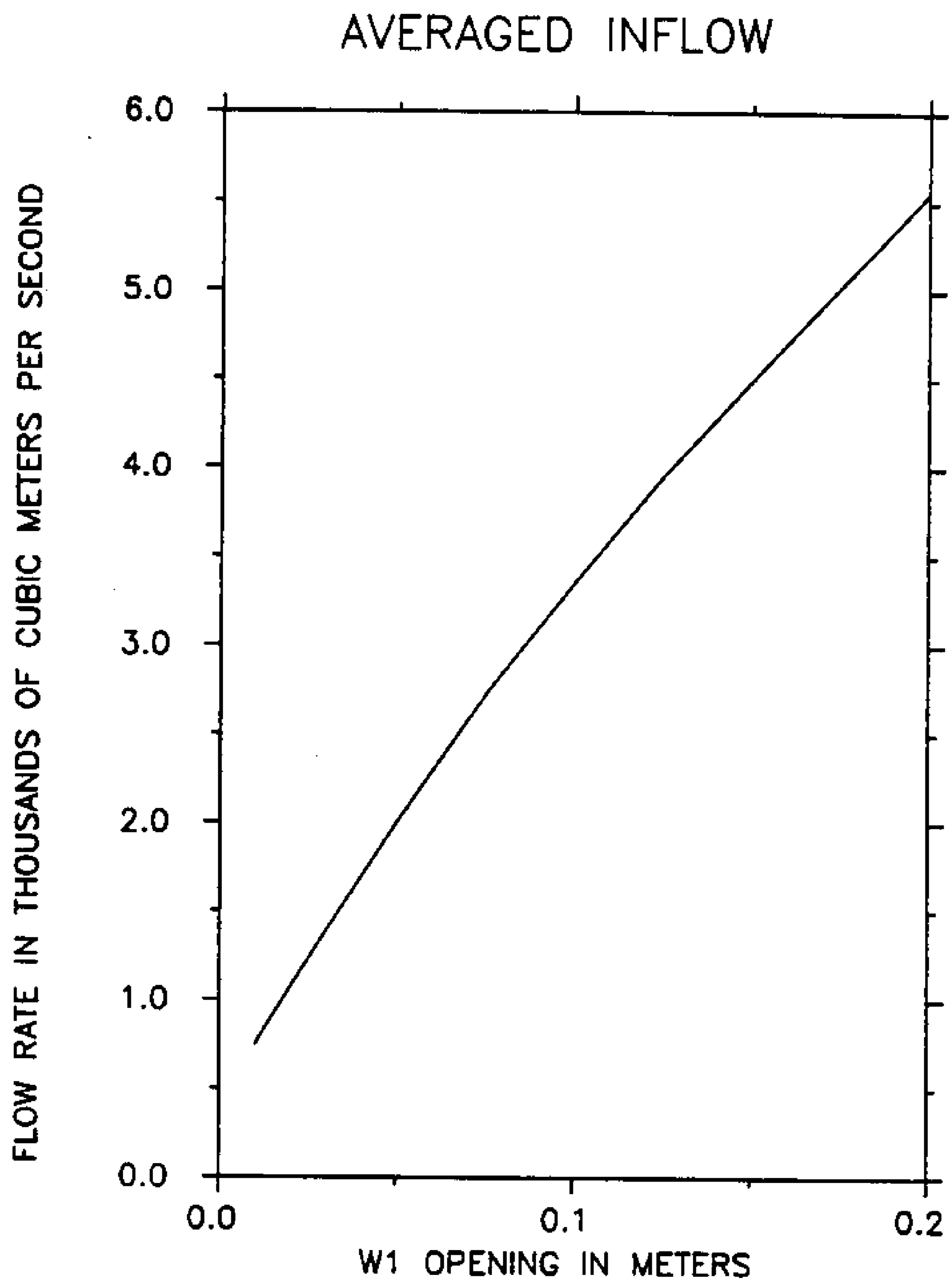

Figure 12: Average inflow. For the 19 days of the observations, the model predicted inflow is averaged over the 19 days and plotted as a function of the gap under the control gate.

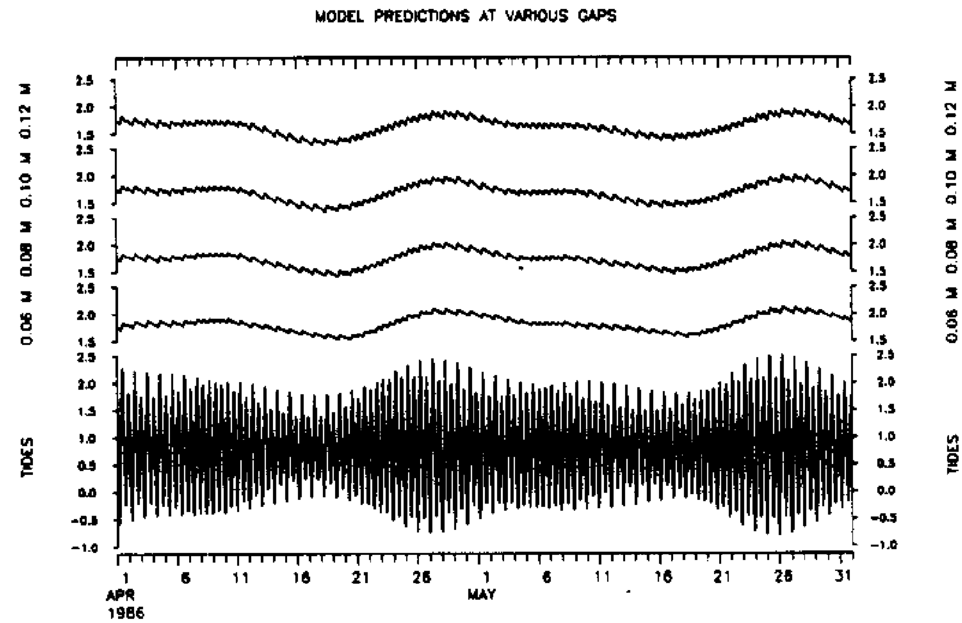

Figure 13: Model predictions. The predicted tides in the Piscataqua River are shown at the bottom. The model predictions are shown above for gaps of 0.06, 0.08, 0.10 and 0.12 m. The predictions are surprisingly similar.

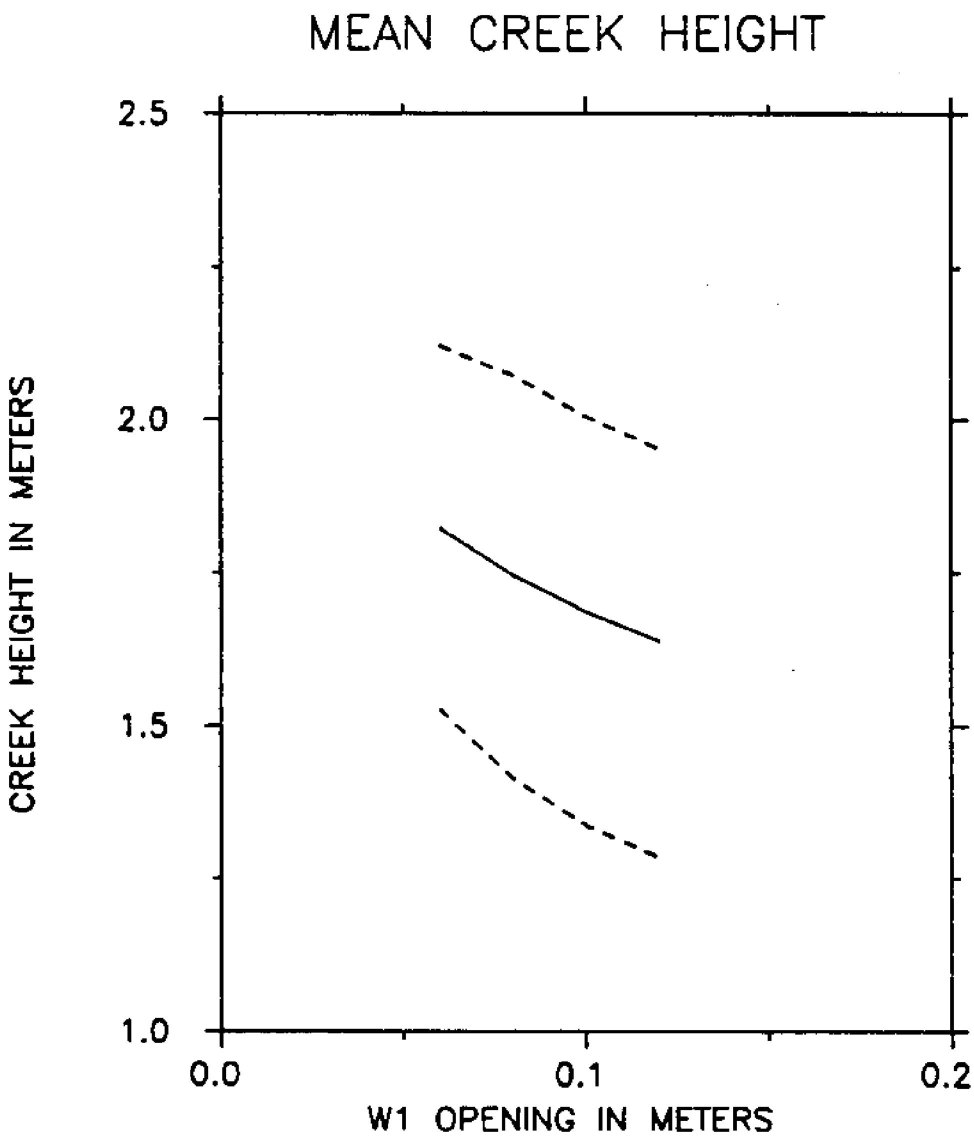

Figure 14: Mean creek height. The mean level in the creek for the model predictions shown in Figure 13 is plotted against the gap opening. As the gap increases, the mean level in the creek decreases.

During late June, production of aquatic weed, the macrophytes, was observed to be increasing dramatically. This is not a surprising observation as June is the peak season of primary productivity in Spinney Creek. Still, the overall accumulation of macrophyte biomass was estimated by Spinney Creek Oyster Company to be an order of magnitude less than in previous years. The gap was then increased from 8.25 cm to 11 cm (4.5 in) in an attempt to moderate the water temperature and control the growth of weeds.

By July 7, the salinity had quickly risen to 34 parts per thousand, which is nearly typical of Gulf of Maine water. In addition, water clarity was extremely high throughout the ensuing summer months, a result of the high flushing rate with the Piscataqua River and a seasonal low in nutrient concentrations in the seawater. The buildup of macrophyte biomass was moderated and by mid-August had started to die off and decompose. The increased gap in the control gate also decreased water level, which precipitated complaints from the abutters over the Labor Day weekend.

Periods of critically low dissolved oxygen concentrations were observed by Spinney Creek Oyster Company during cloudy, calm periods in mid-August. Significant losses of seed clams were noted during these periods, and the low D.O. conditions were held accountable. When the death of the seasonal flora occurs, the decomposition of plant tissue dramatically increases the demand on dissolved oxygen. This condition is accentuated on days when calm and cloudy conditions inhibit both the mixing of stratified water and photosynthesis, two processes whereby dissolved oxygen concentrations at the bottom can be increased. It had been hoped that the high flushing rate and the input of cool, well oxygenated river water would prevent this anoxic condition from forming. From the 1986 observations, it is clear that control gate manipulation alone is insufficient to prevent the August kills. Alternative measures such as active aeration using paddlewheel aerators will need to be employed by the aquaculture interest to prevent damage to the shellfish beds.

Phytoplankton and zooplankton concentrations as indicated by water clarity were highly reduced during the summer and early autumn. The growth rate of shellfish as observed by the Spinney Creek Oyster Company were much reduced during this period. The seasonal autumn phytoplankton bloom in Spinney Creek was not observed. This is a period of time when the nutrients which are bound up in the macrophyte biomass are released during decomposition, and primary production of phytoplankton is at a second seasonal peak. The absence of this event creates a problem for marine species whose survival over the winter is dependent on glycogen supplies produced during the autumn bloom.

High salinity predators such as starfish and green crabs appeared in high numbers during September and October, when salinity ranges were consistently high at 34 to 35 parts per thousand. Brad Sterl, area biologist for the Maine Department of Marine Resources, who has had several years of experience working with the marine life in Spinney Creek, noted that starfish and green crabs were not seen in any significant concentrations in previous years. In addition, he verified that summertime salinities in Spinney Creek were rarely higher than 27 parts per thousand. Significant losses to seed clam beds were observed as a result of the breakdown of the salinity barrier. On October 2, 1986, the control gate was removed and the main gate was closed in an effort to concentrate rainfall and runoff and thereby to decrease the salinity.

The following list shows the advantages and disadvantages of the operation of the prototype control gate during the 1986 season:

ADVANTAGES

1. Rampant weed growth was significantly reduced, and the accumulation of masses of decaying weeds, although not eliminated, was reduced overall.

2. Problems of high currents and foam at the marina were dramatically reduced, and safety at the spillway was improved.

3. Maintenance of an acceptable water level in Spinney Creek was achieved, although the larger summertime opening did generate some complaints as the mean level was lowered.

4. Aesthetic and recreational value of the creek was enhanced.

5. Marine species such as lobsters, flounders, minnows, and bird populations were not adversely affected.

6. The requirement of state and town manpower to operate the main gate for flushing the estuary was eliminated.

DISADVANTAGES

1. Salinity in the creek increased, allowing predators such as starfish and green crabs to thrive and upset the ecological balance and adversely affect aquaculture operations.

2. Water level was at times unacceptable with the larger 11 cm gap.

3. Neither dissolved oxygen nor excessive temperature problems were controlled effectively by the control gate.

4. Poor growth rate of shellfish resulted from the lack of nutrients available during the summer. Ecological damage may occur as a result of a poor autumn plankton bloom.

3 Conclusions and Recommendations

The installation of the control gate at Spinney Creek has been an overall success. Most of the initial operation and performance criteria have been met. In particular, a safe and dependable method of flushing the embayment with a minimum of manpower has been achieved. The recreational and asthetic value has been improved, the ecosystem has a more consistent environment which is self-regulating on natural cycles, and weed build-up has been reduced. The major shortcoming of the project was the control gate's inability to minimize ecological damage due to anoxic conditions.

The control gate should be installed in the 1987 season for the purpose of flushing the embayment. Several modifications to its operation are suggested as follows:

1. Salinity should be monitored routinely and the control gate periodically adjusted to maintain a salinity range between 22 and 27 parts per thousand.

2. The gap should not be opened in excess of 8 cm in order to maintain an acceptable water depth.

3. The gap should be adjusted to allow the maximum flushing possible, using criteria 1. and 2. as guidelines.

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