Cabin Point Creek Channelization Study : Final Report

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CABIN POINT CREEK CHANNELIZATION STUDY

FINAL REPORT

prepared for:

NATIONAL MARINE FISHERIES SERVICE
DEPARTMENT OF COMMERCE
NORTHEAST REGION
14 ELM STREET
GLOUCESTER, MASSACHUSETTS 01930

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by

VIRGINIA INSTITUTE OF MARINE SCIENCE
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JUNE 1987
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ACKNOWLEDGEMENTS

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Those who assisted with the Shoreline Studies included: Mike D'Amico, Cindy Fischler, Suzanne Pearce and Becky Savage. Those who helped with the Wetlands Studies included: Tom Barnard, Jeff Martorana, Jim Mercer and Bob Middleton. Those who assisted with the Water Quality Studies included: Cindy Bosco, Don Campbell, Jim Cumbee, Buddy Matthews, Steve Snyder, Nancy Courtney Wilson, Sam Wilson and Betty Salley with the laboratory analyses.

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INTRODUCTION

In the realm of environmental impact assessment and analysis the effects of a proposed project are most often referred to in the subjunctive sense because of the qualifications and probabilities related to these postulations. Seldom does the opportunity present itself to follow a project to fruition and beyond to, in fact, determine the validity of the assumptions made in arriving at the potential impacts of a project. Even less often is it possible to monitor a project from prior to construction to several years after the project has been completed to ascertain the exact nature of the projects impacts, compare pre- and post-project conditions and verify with some certainty the predicted impacts. The present study of the channelization of Cabin Point Creek is one such opportunity.

SITE DESCRIPTION

Cabin Point Creek is a small tributary of Lower Machodoc Creek which is a tributary of the Potomac River in Westmoreland County, Virginia (Fig. 1-1). It consists of a drowned ravine system separated from Lower Machodoc Creek by a prograding sand spit which evolved from the erosion of shoreline sediments upstream of the creek's mouth. The only connection with Lower Machodoc Creek was a narrow and shallow creek channel which drained across the southern terminus of the beach spit. This resulted in a very limited tide range inside the creek with mean low water perched well above mean tide level in Lower Machodoc Creek. The shoreline of Cabin Point Creek is approximately five miles long encompassing a water surface area of roughly 80 acres. The inlet entrance channel was not navigable with depths between one
Figure 1-1. Cabin Point Creek in Westmoreland County, Virginia.
and two feet. The average depth of the creek at low water is three to four feet. The wetlands areas within Cabin Point Creek comprise some 30 acres with the majority concentrated in the 18 acre barrier beach marsh and the 5 acre creek marsh adjacent to the old creek bed.

PROJECT DESCRIPTION

The original proposal to improve navigation in Cabin Point Creek dates back to 1975 when application was first made for a permit to dredge. Since then there have been two major modifications of the proposal according to VIMS' records, one in 1976 and the other in 1980. Each successive proposal contained modifications designed to reduce or eliminate various environmentally undesirable aspects of the project.

From the beginning the project contained a number of serious environmental impacts which led to opposition to the project from regulatory agencies, particularly the Corps of Engineers and its advisors the Fish and Wildlife Service, National Marine Fisheries Service and Environmental Protection Agency. A number of state agencies also expressed serious environmental reservations about the various facets of the project. These concerns centered around a number of issues, principally the following:

1. The direct loss of wetlands to dredging and filling.
2. The impact of increased development in the Cabin Point Creek watershed or water quality, particularly from upland runoff, septic tank leachate and increased boating activity.
3. The impact of the improved flushing of Cabin Point Creek with potentially degraded water quality through the new inlet on adjacent oyster resources in Lower Machodoc Creek.

4. The impacts of the channel jetties on beach erosion, littoral transport and inlet stability.

5. The impacts of increased boating activity and currents on shoreline erosion within Cabin Point Creek.

6. The impact of the increased tide range on wetland communities within Cabin Point Creek.

The original proposal dated 23 September 1975 (Fig. 1-2) requested the following:

1. Dredge approximately 71,000 cubic yards to create a channel 5400-100' long x 100' wide x 4' deep.
2. Fill approximately eight acres of wetlands for spoil disposal.
3. Construct two timber jetties 300' long adjacent to the new inlet.

The major concerns with this proposal were the loss of a large area of tidal wetlands, the width of the channel which was felt to be too wide for effective stabilization and the proximity of the inlet to oyster grounds in the Lower Machodoc Creek.

The second proposal dated 22 October 1976 (Fig. 1-3) contained a number of modifications which attempted to address these concerns. The dredging volume was reduced to 15,000 cubic yards, the channel width was reduced to 40', the inlet was moved north away from the productive oyster beds, some
Figure 1-2. Permit drawings of the original Cabin Point Creek channelization proposal dated 23 September 1975.
Figure 1-3. Modified permit drawings for the Cabin Point Creek channelization proposal dated 22 October 1976.
beach nourishment with dredged sand was proposed and the vegetated wetlands to be filled was reduced to approximately .25 acres. However, a considerable area of shallow water and intertidal flats were proposed as an alternate disposal area with excess material to go to an upland site.

Review of this proposal by the various agencies resulted in continued reservation on several issues particularly the filling of the shallow water and intertidal flat habitats and the lack of shoreline stabilization along the inlet channel.

Subsequent to the second proposal the applicant agreed to place restrictive covenants suggested by the U. S. Fish and Wildlife Service on subdivision properties limiting the proximity of buildings to the shoreline, providing for buffer strips along the shoreline and discouraging the use of vertical bulkheads as a means of shoreline stabilization. These measures were intended to help reduce the impacts of upland runoff on water quality and minimize the amount of reflected wave energy inside the creek. The applicant also agreed to place the barrier beach and marsh spit in a conservation easement precluding future development.

The final proposal dated 4 February 1980 (Fig. 1-4) which was permitted addressed the remaining environmental concerns and provided for the following:

1. Dredge approximately 15,000 cubic yards of material by hydraulic and clamshell method for a channel 40 feet wide and 4 feet deep at mean low water.
Figure 1-4. Final permit drawings for the Cabin Point Creek channelization proposal dated 4 February 1980.
2. The coarse grained material to be used for beach nourishment south of the new inlet and the fine grained material from inside the creek to be deposited in a diked upland area.

3. Two inlet jetties, one 200 feet long and the other 150 feet long with a spur approximately 30 feet long constructed on the down drift side of the jetty parallel to the shoreline and approximately 50 feet from the offshore end of the jetty.

4. To fill 100 linear feet of the old Cabin Point Creek channel to close off the old mouth and direct all tidal flow through new inlet.

5. Construct a boat ramp and attendant catwalks (Fig. 1-4).

The Corps of Engineers permit was additionally conditioned to allow for the conduct of this study including the collection of baseline information prior to construction. Also included was a requirement to perform the dredging inside Cabin Point Creek with the creek isolated from Lower Machodoc Creek by earthen dikes to help eliminate the impacts of the increased suspended solids on adjacent oyster resources.

The baseline information for this study was collected during 1980 when no construction activity had affected the Cabin Point Creek system. Activity began in the spring of 1981 with the construction of the access road, diked disposal area and clearing of the inlet site in April and May (Fig. 1-5). During May and June 1981 the jetties and riprap for the channel sides were constructed.

The first dredging commenced in July 1981 beginning offshore and working in between the jetties. The sandy dredged material was pumped south of
CABIN POINT CREEK
WESTMORELAND COUNTY
VIRGINIA

VIMS REMOTE SENSING CENTER
ALT. 2,500' APRIL 7, 1981

Figure 1-5. Initial construction activities, clearing for the inlet and diked disposal area.
the inlet on downdrift of the jetties. The beach disposal area was enclosed with a turbidity curtain to help contain suspended material. The curtain failed to accomplish this goal because the dredged material flowed onto the bottom of the curtain at low tide effectively trapping it. At high tide large sections of the curtain were completely submerged providing access for the pipeline effluent to Lower Machodoc Creek. This dredging continued on and off through September 1981 when the dredging contractor declared bankruptcy and ceased work. The new inlet to Cabin Point Creek was partially open at this point but none of the interior channels had been dredged.

Dredging did not resume until March 1982, when the second dredging contractor commenced work. Enough dredging was performed to get the dredge through the new inlet and into Cabin Point Creek. The inlet was then sealed with an earthen dike. The majority of the material dredged during this period was sand and deposited on the beach south of the jetties. The siltation curtain was not deployed during this period. Once the siltier sediments inside Cabin Point Creek were reached in late April disposal operations were shifted to the diked upland area. This area was used until sometime in early May 1982 when the second dredging contractor ceased work also declaring bankruptcy. At this juncture the entrance channel was essentially complete except for the earthen dike and approximately one third of the interior channel had been dredged (Fig. 1-6).

Cabin Point Creek remained essentially a pond from early May until the first week of June 1982 when the earthen dike between the jetties was somehow breached. By the end of the month virtually all of the dike had been
Figure 1-6. Cabin Point Creek - December 1982.
washed away by tidal currents, leaving only a shallow sill across the channel bottom. As far as the hydraulics of the new inlet were concerned the project was essentially complete at this time.

The new inlet for Cabin Point Creek remained open when the final dredging began in November 1982 because the material being dredged was going into the diked upland area. The dredging was finally completed in February 1983.

IMPACT ANALYSIS

The environmental concerns expressed by advisory and regulatory agencies prior to approval of the project were divided into several basic areas. These included the effects of the jetties on shoreline processes, the effects of the channelization on the tide range and tidal circulation inside the creek, changes in water quality and the effects of the modifications on the extensive wetlands areas within the creek system.

To address these concerns and provide pre-project baseline information necessary to assess the impacts of the channel construction on the Cabin Point Creek system, a four-pronged, four-year research and monitoring effort was initiated including the following:

a. Seasonal beach profiles both updrift and downdrift of the jetties were surveyed to determine the erosional and accretional effects of the jetties on the beach.

b. Tide gage and tidal current and discharge measurements were taken before and after the dredging to determine the effects of the new
channel on the internal tide range and post-construction inlet behavior.

c. Water quality was monitored at least bi-monthly by slack water surveys both inside and outside the creek to ascertain any changes in water quality.

d. Detailed vegetation mapping and quadrat sampling of the major marsh inside the creek were undertaken to document any changes in community structure.
SECTION 2

SHORELINE AND INLET STUDIES

by

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and

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CABIN POINT CREEK CHANNELIZATION STUDY

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INTRODUCTION

Background: The inlet modification first proposed envisioned a jettied entrance close to the position of the natural inlet (Figure 1-1), with placement of the dredged materials on the marsh forming Cabin Point spit. This inlet configuration would have resulted in a rather long entrance channel approaching the open areas of the creek. Other channel alignments with shorter channels would have higher hydraulic efficiency. A principal concern however was that the downdrift impacts of the interruption of sand supply due to the jetties would be transferred to adjacent properties of Glebe Harbor. Thus, positioning the entrance in a more northerly direction on the spit would maintain at least a partial sand supply to the downdrift properties.

The final choice of the developers was to bring the entrance channel across the spit at a position essentially halfway down its length (Figure 1-4). This selection offered the closest proximity to the 6-foot offshore water depth and provided entrance discharge directly into the open areas of the tidal embayment.

Purpose of the Shore Processes Studies: The purpose of the shore processes studies were to:

1.) Document the shoreface adjustments associated with the construction of the jettied inlet entrance, and

2.) Document the hydraulic characteristics of the new inlet and to compare these conditions with the natural inlet.
Shoreline Processes: As noted earlier, Cabin Point Creek is a small tidal embayment formed by a spit which prograded across a drowned dendritic drainage system. The source of sand to the spit is the headland reach between Kingcopsico Point and Cabin Point. The length of this headland reach and spit are respectively about 2.5 miles and 0.6 miles. Given the orientation and geometry of Lower Machodoc Creek and the headland reach, the direction of littoral drift along the spit is strongly biased to the southeast. Seelig (1976, included as Appendix A), as part of an environmental analysis of the proposed inlet modification, examined recent shore erosion rates using aerial photography of 1953 and 1972. Data from that report indicate an average erosion rate of about 2.0 ft/yr between Kingcopsico Point and the terminus of the stable portion of the spit. Accretion varying between 2.3 ft/yr and 6.6 ft/yr was noted due to spit progradation to the south.

Seelig also calculated the potential longshore transport rate at Cabin Point using wave hindcasts for 1975 for computation of the longshore wave energy flux and potential longshore sediment transport. The potential transport rate was about 7,000 cubic yards per year to the southeast. Due to limited sediment supply he suggested that the rate may be as low as 3,000 yd$^3$/yr. The calculations indicated that most transport would be expected between September and January. Seelig further noted that the transport rates south of Cabin Point (that is, along the Cabin Point spit to Glebe Point) would be expected to be smaller due to sheltering by Coles Point at the entrance to Lower Machodoc Creek.

Tidal Inlet Processes: Prior to project construction the inlet channel to Cabin Point Creek was about 2,400 feet long, 50 to 70 feet wide, and
about 1 to 2 feet average depth (Seelig, 1976). The long, shallow (and non-navigable) channel resulted in large frictional impedance to tidal flow which resulted in suppressed tidal range in the tidal basin. Based upon a measurement period of 25 hours, Seelig (1976) found the tide range within the basin (Cabin Point Creek) was about 0.25 that in Lower Machodoc Creek and that maximum current speeds were about 1 ft/sec.

Examination of aerial photographs indicates that the southerly directed littoral drift extended the spit terminus so that the spit overlapped the adjacent downdrift shore. This action extended the channel length. It is likely the active spit terminus was breeched during occasional severe storms. Such breeching provides a mechanism for downdrift sand bypassing.

Observations of the hydraulics of tidal inlets within the Chesapeake Bay (Byrne et al, 1980) indicated that the tidal prism-inlet cross-sectional area relationship for smaller inlets departed significantly from that observed for oceanic inlets. Data from 15 Chesapeake Bay inlet-lagoon systems (including Cabin Point Creek) disclose a scale influence (Figure 2-1) such that the smaller natural inlets fall between the oceanic inlets and those cases studied in small hydraulic models. The curves in Figure 2-1 thus permit the estimation of the "equilibrium" inlet channel cross-sectional area given the spring tidal prism of the lagoon. The natural inlet at Cabin Point appears to have been in morphodynamic equilibrium with a tidal prism of 1,625,000 ft$^3$ $(4.6 \times 10^4 \text{ m}^3)$ and inlet channel area of about 70 ft$^2$ $(6.4 \text{ m}^2)$.

**METHODS**

**Beach Profiles:** In order to monitor the response of the shoreline to the jettied inlet entrance six transect sites were selected and established
Figure 2-1. Tidal prism versus inlet throat cross-sectional area. Open circles are from model studies (Mayor-Mora, 1977), closed circles are Atlantic Ocean inlets (Jarrett, 1976) and crosses represent Chesapeake Bay inlets. All cases are inlets without jetties. From Byrne et al. (1980).
in August 1980 (Figure 2-2). Vertical control connected all of the profile pipes with tide gauge elevations inside Cabin Point Creek and to an outside reference tide gauge in Lower Machodoc Creek. As well, the vertical control was extended to selected points on the interior marsh so that the marsh surface could be referenced to a tidal datum. The beach profiles were executed using surveyor's tape, rod and Nikon self-levelling level with measurements obtained at points of apparent change in slope. Three transects were established on each side of the planned inlet entrance. Those on the north (P1N, P2N, P3N) were intended to "capture" the growth of the sand fillet expected to form on the north side of the inlet while those on the south the entrance (P1S, P2S and P3S) were placed to document the expected erosion induced by the sand trapping of the inlet jetty. An additional profile (PNA) was established in August 1982 at a position 90 feet north of P1N to better define the accreting sand fillet. Beach profiles were obtained on the following dates:

- 27 August 1980
- 30 October 1980
- 11 March 1981
- 8 July 1981
- 5 August 1981
- 8 December 1981
- 1 March 1982
- 11 June 1982
- 13 August 1982
- 6 January 1983
- 16 June 1983
- 19 October 1983
Figure 2-2. Locations of original beach profiles and tide gauges.
Tides: Tidal elevations were measured within Cabin Point Creek and in the Lower Machodoc Creek prior to and after inlet modification. In both cases Fisher-Porter recording tide gages were used from dock installations. Levelling between the installations was achieved using a laser level (Laser Beacon 2900). The recording periods were:

Preconstruction: October 10 to December 14, 1980
Postconstruction: March 17 to August 16, 1982.

In both recording periods a 30-day period was selected for simultaneous comparisons with Soloman's Island, MD., to establish the longer term Mean Tide Level (MTL) using the 19 year tidal epoch of 1960-1978. Swanson (1974) studied the accuracy of the determination of tidal datums using methods of simultaneous comparisons with long term stations. For a tidal observation series of one month he found that the generalized accuracy of the transferred datum, for the East Coast, was 0.13 ft. (based upon ±0).

Tidal Discharge: In order to evaluate, and to contrast, the tidal hydraulics of the pre- and post-construction inlet configurations the time history of tidal discharge was performed on 20-21 November 1980 and 21 July 1982. These measurements allow examination of phase lags between the times of maximum discharge and the vertical tides, and determination of the mean flow velocity (discharge divided by channel area). In practice, the discharge is calculated as a weighted product of channel subsection area multiplied by the local flow velocity (Troskolsanski, 1960). In our application ducted impellor current meters (Byrne and Boon, 1973) were placed along a transect across the channel at 0.6 of the water depth to estimate the local average current speed. In addition to calculation of the instantaneous discharge, graphical integration of the discharge-time curve offers an estimation of the tidal prism.
RESULTS AND DISCUSSION

Shoreline Response: Jetty construction occurred during April-May, 1981, and dredging of the inlet was initiated in June, 1981. The shoreline response to jetty emplacement was rapid. The profile beach plots are given in Appendix B. The beach profile response is summarized in Figure 2-3 wherein is plotted the position of the trace of mean tide level (MTL, Machodoc Creek) relative to the preconstruction position of August, 1980. Profile 1N, approximately 70 feet north of the jetty exhibited pronounced accretion. The increase in profile area and the advance of the beach is listed in Table 2-1. The trend of the advance is characterized by the line at MTL (MSL) minus two feet. This was chosen as being most characteristic of the beach toe. Following the trend of 1N (Figure 2-3) continuous accretion is noted with the MTL line advancing at an inferred linear rate of about 14 feet per month between April 1981 and January 1982. Figure 2-4 shows the configuration of the beach near the jetties in September 1982 (from photomosaic). It is evident that the fillet accretion had advanced to the jetty terminus.

It is of interest to estimate the littoral drift rate, assuming that the jetties constituted a complete trap. In order to arrive at this estimate it is necessary to derive a transformation which relates the extension of the beach to beach volume. This was done by examining the relationship between the length (unit longshore area) of backshore beach, using the sequential profiles (Appendix B) and the profile unit volume given for 1N in Table 2-1. For the six profile times between July 1981 and August 1982 the average value of the transformation factor is 0.16 with a range between 0.18 and 0.14. In other words there were, for profile 1N, 0.16 cubic yards of total accretion per foot (unit width) of backshore length
Figure 2-3. Beach profile response, position of MTL relative to profile origins.
TABLE 2-1. Profile Area Change and Shift of Beach Position (MSL minus two feet)

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increase. Using this factor we may then convert the area of the sand fillet shown in Figure 2-4 to an accretion volume. Application of this procedure to the photomosaic of 11 September 1982 indicates that approximately 3,000 cubic yards of sand accreted over a 24-month period, or a trapping rate of about 1,500 cubic yards per year. This is about 25 percent of the value of the potential longshore transport rate calculated from a wave hindcast by Seelig.

Between August 1982 and January 1983 the contractor transferred sand from the forward edge of the fillet in order to renew the trapping effectiveness of the jetty. The sand was stored as backshore dunes of about 6 ft height (evident in the profiles of P1N in Appendix B). During the period August 1982 and October 1983 the accretion in the fillet continued (Table 2-1) as the profile of 1N increased from 528 to 918 sq ft. The fillet also extended further north as evidenced by the seaward advance of profile PNA, located approximately 90 feet north of P1N (Figure 2-4).

Over the three year term of the observation profiles P2N and P3N exhibit a net loss in sand volume, and horizontal retreat of 3 and 5 ft respectively. Since 1982 about one-third of the headlands between Cabin Point and Kingcopsico Point here have been stabilized by rock revetments. Thus sediment supply to the Cabin Point Spit has been reduced and continuing frontal erosion on the spit may be expected. In response to this the developers have installed several low-profile groins along the spit, north of profile P3N.

Sand from the dredging of the inlet channel was placed on the downdrift shore. Initial placement was located in the vicinity of profile P2S (Figure 2-4) in July, August 1981 and additional sand was emplaced in March, April 1982 between the southern jetty and that initially placed. The response to
Figure 2-4. Beach and inlet configuration from photomosaic of 11 September 1982.
the beach nourishment is reflected in Figure 2-3 and Table 2-1. The beach configuration in September 1982 (Figure 2-4) indicated that the spur on the south jetty is operating effectively. Profile 1S intersects the spur, and after the spur notch had filled that profile has remained static. Profile 2S shows a loss of sand and retreat between January and October 1983 with a 25% reduction in profile area and a retreat of the MTL line (Figure 2-3) of about 20 feet.

With the reduction of sand supply from the headlands due to revetments, and the installation of low profile groins on the spit north of the inlet a slow retreat of the spit shore may be expected. If the jetties act as a total barrier to littoral drift the shore on the south side of the jetties will continue to retreat. It would be prudent to install a series of low profile groins or segmented breakwaters in the shoreline segment south of the inlet in order to retain as much of the beach width sand as possible.

**Tide Range:** The results concerning pre- and post-construction tide range, although inextricably connected to tidal inlet processes, is herein treated separately because the elevation of mean high water is particularly important to potential species shift in marsh vegetation. Also, the tide range determines the amount of intertidal mud flat communities.

The significant results with respect to tide range and elevation are summerized in Figure 2-5. These results are derived from measurements over a period of a lunar month and are reliable estimates. The results indicate that prior to the new inlet construction there was considerable suppression of the range of the internal tide (about 0.25 of the external range), and appreciable superelevation of mean tide level (MTL) in the lagoon (about 0.35 ft). Due to the superelevation there was a relatively small difference between the external and internal elevation of mean high water (MHW).
Figure 2-5. Tidal elevations before and after inlet construction. Reference elevation outside MTL for 19 years transferred from Solomons Island, Maryland.
Following the construction of the new inlet the internal tide range equaled the external range. Although the results indicate an apparent setdown of the internal MTL relative to the external MTL by 0.1 ft this difference is within the generalized accuracy of the method of tidal comparisons. Thus, the positions of the internal and external MTL are considered equal.

Moreover, in contrast to MTL superelevation there is no physical basis to expect a suppression of the internal MTL.

Preconstruction setup was caused, in this case, by the large relative differences in the natural inlet channel depth (and cross-sectional area) during flood and ebb currents. In such cases the outflow of water occurs through a much reduced cross-sectional area. Frictional influences retard the ebb flow and lengthen the duration of ebb flow. However, the external tide, removed from such frictional influence, continues to rise and thereby stops continued outflow. This results in a setup of MTL in the tidal basin.

Keulegan (1967) offered a first order approximation of these effects. He found that the magnitude of setup would be approximated by:

$$\frac{\Delta}{H} = \frac{1}{4} \frac{H}{r_o}$$  \hspace{1cm} \text{Eq. (1)}

where $\Delta$ = basin setup (superelevation)
$H$ = 1/2 external tide range
$r_o$ = average depth of the channel relative to the external mean tide level (MTL).

He also derived an expression relating the tidal inflow duration, $t_i'$, to the bay setup:

$$\frac{\Delta}{H} = \frac{\sin \sigma t_i'}{1 - \cos \sigma t_i'}$$  \hspace{1cm} \text{Eq. (2)}

where $\sigma = 2\pi/T$, $T = 12.42$ hr

To utilize Equation (1) in predicting $\Delta$, one must know the external tide range and the average depth (or more properly the average hydraulic radius)
along the longitudinal axis of the inlet channel. In the case of Equation (2) one must have measurements of the duration of tidal inflow, \( t_i \), as well as the external tide range.

We may test the application of Equation (2) using the pre-construction survey (20-21 November 1980) of inlet hydraulics. The results of that survey are summarized in Figure 2-6. It should be noted that on the occasion of the survey there was a storm surge so that the short term external MTL was about 0.35 ft above the long term mean tide level. As well, the survey was performed during spring tides and the tide range was 2.04 ft (Mean Tide Range 1.62 ft). Referring to Figure 2-6 we note that the duration of tidal inflow, \( t_i' \), was 5.5 hrs. Application of these values to Equation (2) results in a calculated value of \( \Delta = 0.18 \) feet. The observed value of \( \Delta = 0.16 \) feet. The correspondence between the calculated and observed values is very close, but such correspondence may be fortuitous.

As previously mentioned the application of Equation (1) requires a reasonable estimate of the channel depth along its longitudinal axis. This information was not acquired in the pre-construction surveys. The hydraulics survey for discharge and mean velocities was obtained at a transect location selected for cross-sectional depth uniformity and avoidance of the influence of channel bends (Figure 2-2). The resultant choice may not have been representative of the average depth. Nevertheless, there is value in comparing results. At the transect where the discharge survey was performed the value of \( r_0 \) was 1.1 ft. Substitution in Equation (2) results in a calculated value of \( \Delta = 0.24 \) ft (versus the observed value of 0.16 ft). It is of interest to note that a value of \( r_0 = 1.4 \) ft would result in a calculated value of \( \Delta = 0.18 \) ft. The value of \( r_0 = 1.4 \) is
Figure 2-6. Tidal hydraulics of the natural inlet.
probably not unreasonable, since Seelig (1976) observed the channel depth to be "one to two feet deep," which agrees with our own casual observations.

The setup noted from long term tide gage measurements was 0.35 ft, whereas the observed value during the hydraulics survey of 20-21 November 1980 was 0.16 ft. A reduction in setup would be expected during a surge event because the water depth of the channel would be increased. The previous discussion indicates that the magnitude of setup is strongly dependent on $r_0$.

Obviously, tidal superelevation in tidal basins can have important ramifications to wetlands management and regulations. In the case of Cabin Point Creek there was the expectation that, with the new inlet configuration, the basin tide range would increase to that of the external tide. However, due to tidal setup (superelevation) associated with the natural inlet there is only a small elevation change in mean high water after the new inlet was formed. Had there not been tidal setup one would have expected the elevation of mean high water to shift upwards by 0.5 ft. Thus, in the evaluation of potential environmental impacts the question as to whether tidal setup is potentially important should be explicitly considered. In the cases of the small tidal embayments within the Chesapeake Bay tidal setup is likely to be important in those cases when there is a significant reduction of the tide range in the basin relative to the external tide. In these cases the application of Equations (1) and/or Equation (2) could be used to provide a first order estimate of setup. Rather complete determination of setup would require measurements from internal and external tide gages over a lunar month. However, measurements over several days would provide a reasonable estimate provided no storm surge was present.
Figure 2-7. Inlet channel cross-sections.
Associated with the increase in tide range the area of intertidal habitat also increased, particularly the area between MTL and MLW. These changes should also be explicitely evaluated in the assessments associated with inlet modifications.

**Tidal Inlet Processes:** The new inlet entrance was dredged during the summer of 1981 and in spring of 1982. Our initial post-construction inlet surveys were conducted in July, 1982. On 15 July 1982, bathymetric surveys were performed at 11 cross-sections (see Figure 2-4 for locations). The cross-sectional configurations are shown in Figure 2-7. With the exception of transects 5 and 6 the nominal channel depth was 4 ft (MTL) and the nominal width was 70 ft. At transects 5 and 6 sand and rubble residue from a roadway crossing remained in the channel. These materials had been reshaped by the tidal currents, and, in particular, by the flow distribution associated with the channel curvature (Figure 2-4).

Surveys with echo sounder at the terminus of the north jetty did not indicate shoaling at the channel entrance, although the fillet was at the near capacity state. In addition the depths giving access to the channel was at least as deep as the dredging depth. With such a channel configuration the full tidal prism potential of the tidal basin was realized. That is, the basin and external tide range were essentially equal.

A tidal hydraulics survey was performed on 21 July 1982, with four current meter stations arrayed across inlet channel transect 9 (Figure 2-4). The results are summarized in Figure 2-8 wherein it may be noted that the tide range ratio is essentially unity and the phase lag between the basin and external tides is small, about one hour. Thus the frictional impedance of the channel is dramatically reduced relative to the earlier existing
Figure 2-8. Tidal hydraulics of new inlet with jetties.
natural inlet. The duration of ebb and flood currents are nearly equal. The tidal prism as determined by open water area and tide range was $6.204 \times 10^6$ cubic feet. For the mean tide range of 1.6 ft the tidal prism is about $5.7 \times 10^6$ cubic feet.

Upon completion of the dredging in the internal channels (February, 1983) the inlet channel was "dressed" to project depth and width. Another bathymetric echo sounder survey was conducted on 19 October 1983. The inlet channel centerline was at uniform depth with exception of a 2 ft depth increase between transects 4 and 6. Soundings close to the end of the north jetty did not indicate sediment bypassing into the channel entrance although the updrift sand fillet extended to the end of the jetty.

However, by December, 1984 rather pronounced changes had occurred in the inlet (Figure 2-9) and along the shoreline (Figure 2.10). The inlet width was appreciably reduced due to a shoal welded to the north jetty which appears to be due to both jetty overtopping and sand bypassing around the tip of the north jetty. The sand placed on the downdrift beach had been eroded and the spur jetty was becoming isolated (Figure 2-10). The position of the updrift low profile groins is clearly shown in Figure 2-10. These events indicate the advisability of placing additional shoreline structures groins or segmented breakwaters (Hardaway, 1985) on both the updrift and downdrift beaches.
Figure 2-9. Cabin Point Creek inlet shoaling - December, 1984.
The duration of ebb and flood currents are nearly equal. The tidal prism, as determined by mean water area and tide range was $6.20 \times 10^4$ cubic feet. For the mean tide range of 3.6 ft, the tidal prism is about $1.7 \times 10^5$ cubic feet.

Figure 2-10. Configuration of beach adjacent to Cabin Point Creek Inlet - December 1984.
References Cited


Mayor-Mora, R. E., 1977. "Laboratory Investigation of Tidal Inlets on Sandy Coasts", GITI Report 11, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., and the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.


SECTION 3

WETLAND VEGETATION STUDIES

by

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and

Gene M. Silberhorn

CABIN POINT CREEK CHANNELIZATION STUDY

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INTRODUCTION

Quantification, or even qualification, of changes in vegetation communities as a result of habitat alteration is a difficult task, especially in short-term studies. The growth dynamics of individual species represented in the cover of a study site can complicate matters by being slow to respond to these changes, often taking years to reflect environmental modifications. This delayed response can be particularly pronounced in salt and brackish marshes where the majority of the plants are perennial grasses, sedges and rushes which produce dense rhizome mats that can continue to perpetuate the species despite conditions which may have precluded their original establishment. Predicting these changes can be an even more formidable task due to the lack of long-term case studies that have documented changes in different community types under different circumstances.

The current study of channelization effects on Cabin Point Creek is an attempt to document the changes in wetland plant communities following construction activities affecting several environmental factors including salinity, tide range and tide levels influencing marsh community structure.

Cabin Point Creek is a drowned ravine creek system which prior to the dredging had been essentially isolated from the Potomac River by the formation of a barrier beach across its mouth. The only connection between the Creek and the River was a very restricted channel which drained across the barrier beach. The bed of this channel formed a sill across the mouth of the creek which limited exchange between the waters of the creek
and the river. This channel restriction had resulted in the mean low water elevation inside the creek being perched well above that in the adjacent Potomac River and an extreme phase lag between low tide levels inside and outside the creek.

The channelization of the creek by dredging a 40 feet wide inlet across the barrier beach was expected to produce a significant changes in the tide range and tide levels inside the creek. Changes in salinity levels inside the creek were also anticipated due to the increased tidal exchange caused by the new inlet.

METHODS

The primary study area within the creek was a large, approximately 18 acre, high marsh dominated by saltmeadow hay, *Spartina patens*. It is located on the landward side of the barrier beach adjacent to the new inlet (Fig. 3-1).

The initial step in the study was to prepare a vegetation map of the wetland communities present in the study site using aerial photography. The marsh was photographed several times during the 1980 growing season with VPS color print, Ektachrome 200 color transparency and Aerochrome 2443 infra-red film. This imagery was ground-truthed and used to identify and delineate the vegetation communities using a Bausch and Lomb Zoom Transfer Scope (Fig.3-2). Additional aerial photographs of the study site were taken in the spring and fall of 1981, the fall of 1982 and the summer of 1983.

The sampling strategy of the communities identified was designed to detect and monitor changes which might occur in the structure or composition of the marsh as a result of the channelization. Those areas most likely to
Figure 3-1. Study site location.
exhibit changes on a relatively short-term basis were intensively sampled with permanent transects. The other areas of the marsh were sampled with individual quadrats.

Transects A, B, C, and D (Fig. 3-2) were established along major drainage guts as determined by aerial photographs, with a series of three .25 m$^2$ circular quadrat sets at approximately equal intervals. In each set of three quadrats one was established in the center of the gut and another one meter to either side of the center on the edge of the bank. These were apparently the lowest areas of the marsh and theoretically the most susceptible to any increased tidal inundation from the channelization. Hence, any changes which might occur would most probably affect the area in close proximity to these guts.

Individual .25 m$^2$ circular quadrats, QA through QQ, (Fig. 3-2) were established away from the drainage guts in the different vegetation communities roughly in proportion to their areal extent within the study site, i.e. more quadrats in the major community types and fewer in the minor ones. This was done to ensure coverage of all of the communities in the event of any unanticipated changes.

The shrub community established along the peripheral berm was sampled using 1 x 4 m quadrats, 1 x 4 A, B, C and D, (Fig. 3-2) because the larger area is needed to more adequately sample the shrub type community.

The transects and individual quadrats were established and sampled the first time on 25 June 1980. Each was permanently marked with a wooden or PVC stake. The 1 x 4 m quadrats were established and sampled the first time on 16 July 1980. Each corner was marked with a stake with a nylon cord around each to delineate the sides of the quadrat. All of the quadrats were sampled again on 17 September 1980. In the subsequent years of the study all
Figure 3-2. Vegetation map with transect and quadrat locations.
of the quadrats were sampled twice during each growing season usually once in early summer and once in late summer or early fall.

A \(0.25\, m^2\) circle with a centering device was placed over the stake marking the transect and individual quadrats and the percent cover of each species present within the circle was estimated. Areas within the quadrat without any vegetative cover were treated as any other species in the estimates with the percent "no cover" being estimated. The percent cover was visually estimated for the entire \(1\times4\, m\) quadrat.

The elevation of each quadrat was determined relative to the local tidal datum established by the shoreline studies section of this project. The relationship of these elevations relative to mean tide levels inside Cabin Point Creek prior to the project and subsequent to the dredging of the new inlet was also defined.

The percent cover estimates for each species in each of the different quadrat types, transects, individual quadrats and \(1\times4\, m\) quadrats, were averaged for each sampling year. This information was used to select the species which appeared to be showing the greatest differences in average percent cover over time. The selected species were subjected to an analysis of variance using the Statistical Package for the Social Sciences (SPSS) program on the VIMS 850 PRIME computer.

RESULTS

Twenty-one different wetland plant species were identified in the study site marsh during the study. Seventeen of these species were represented within the quadrats sampled. The scientific and common names of these
species as well as the abbreviations for each used in the data tables are listed in Table 3-1.

The percent cover estimates for each species for all of the quadrats combined are summarized in Table 3-2 for each of the study years. The estimates for transects, individual 0.25 m² quadrats and the 1x4 m quadrats are summarized in Tables 3-3, 3-4, and 3-5 respectively. The results of the analysis of variance of the percent cover changes for the major species are presented in Table 3-6. Figures 3-3 and 3-4 graphically depict the major species percent cover relationships in the transects, Figures 3-5, 3-6 and 3-7 those in the individual 0.25 m² quadrats and Figures 3-8 and 3-9 those in the 1x4 m quadrats.

The dominant cover species during the course of the study was saltmeadow hay, *Spartina patens*. It averaged 65.30 percent cover for the entire study site over the four years of the study, ranging from 70.7 percent in 1980 to 57.4 percent in 1982 (Table 3-2). The highest average values were found in the transects (Table 3-3) with intermediate average values in the 1x4 m quadrats (Table 3-5) and the lowest average values in the individual 0.25 m² quadrats (Table 3-4).

The next most abundant "species" was no cover. It increased from a low of 6.20 average percent no cover in all the quadrats taken collectively in 1980 to a high of 27.0 percent in 1982 and then decreased to 18.1 percent in 1983 (Table 3-2). The highest average percent no cover values were found in the individual quadrats (Table 3-4) and the lowest in the 1x4 m quadrats (Table 3-5) with intermediate values in the transect quadrats.

The third most abundant species during the course of the study was saltgrass, *Distichlis spicata*. It had its highest average percent cover during the course of the study in the initial year 1980 with 10.2 percent.
Table 3-1. Wetland plant species identified from the Cabin Point Creek study site, their common names and the abbreviations used in the tables. An asterisk indicates those species observed outside the quadrats.

<table>
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<tr>
<th>Latin Name</th>
<th>Common Name</th>
<th>Abbreviation</th>
</tr>
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<tr>
<td>Spartina patens</td>
<td>Saltmeadow hay</td>
<td>SP</td>
</tr>
<tr>
<td>Distichlis spicata</td>
<td>Saltgrass</td>
<td>DS</td>
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<td>Juncus roemerianus</td>
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<td>Saltmarsh fleabane</td>
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<tr>
<td>Eleocharis parvula</td>
<td>Dwarf spikerush</td>
<td>EP</td>
</tr>
<tr>
<td>Kosteletzkya virginica</td>
<td>Marsh mallow</td>
<td>KV</td>
</tr>
<tr>
<td>Atriplex patula</td>
<td>Orach</td>
<td>AP</td>
</tr>
<tr>
<td>Amaranthus cannabinus</td>
<td>Water henp</td>
<td>AC</td>
</tr>
<tr>
<td>Hydrocotyle umbellata</td>
<td>Marsh pennywort</td>
<td>HU</td>
</tr>
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* indicates species observed outside the quadrats.
Table 3-2. Mean percent cover estimates and standard deviations for all quadrats sampled by species by year with the mean percent cover by species for the period 1980-1983.

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Table 3-3. Mean percent cover estimates and standard deviations for the transect quadrats in the Cabin Point Creek marsh.

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Table 3-4. Mean percent cover estimates and standard deviations for the individual 0.25 m² quadrats in the Cabin Point Creek marsh.

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*Statistically significant at 0.05 level.
Table 3-5. Mean percent cover estimates for the 1x4 m quadrats in the Cabin Point Creekmarsh.

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Table 3-6. Results of ANOVA for no cover and selected species between sampling years.

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**QUADRATS**

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1 x 4

| SP            | 0.276         | 0.607         | 0.631           | 0.440           | 2.104     | 0.197    | 1.543   | 0.227 | 3.128 | 0.091 |
| IF            | 1.407         | 0.255         | 0.063           | 0.806           | 0.200     | 0.670    | 0.911   | 0.350 | 2.810 | 0.108 |
| KV            | 0.375         | 0.550         | 11.776          | 0.004*          | 3.574     | 0.108    | 11.830  | 0.002* | 0.358 | 0.556 |
| AP            | 1.689         | 0.215         | 3.718           | 0.074           | 1.388     | 0.283    | 10.051  | 0.004* | 0.218 | 0.645 |

* statistically significant at .05 level
Figure 3-3. Changes in transect cover for no cover and *Spartina patens*. 
Figure 3-4. Changes in transect cover for *Distichlis spicata* and *Juncus roemerianus*.
Figure 3-5. Changes in quadrat cover for "no cover" and *Spartina patens*. 

**Legend**

- **NO COVER**
- **S. patens**
Figure 3-6. Changes in quadrat cover for *Distichlis spicata* and *Juncus roemerianus*. 
Figure 3-7. Changes in quadrat cover for Spartina alterniflora and Distichlis spicata.
Figure 3-8. Changes in 1x4 cover for *Spartina patens* and *Iva frutescens*. 
Figure 3-9. Changes in 1x4 cover for Kosteletzkya virginica and Atriplex patula.
From this point it declined steadily to average percent cover of 5.3 in 1983 (Table 3-2). Saltgrass was most abundant in the individual quadrats (Table 3-4) with slightly lower yearly average values in the transect quadrats (Table 3-3) and the lowest values in the 1x4 m quadrats (Table 3-5).

The next most common species was black needlerush, Juncus roemerianus, which averaged 4.1 percent cover in the study site over the four years of the study. Its highest average percent cover was in 1982 with 5.1 percent, and its lowest was in 1980 at 3.6 percent (Table 3-2). Again its highest average values were found in the individual quadrats (Table 3-4). The transect quadrats showed somewhat lower average values (Table 3-3). The 1x4 m quadrats provided only a very minor contribution to the average cover in the study site.

Of the balance of the seventeen species encountered in the sampling, only three, marsh mallow, Kosteletzkya virginica, orach, Atriplex patula and dwarf spikerush, Eleocharis parvula, had four-year average percent cover values over one percent (Table 3-2). Marsh mallow and orach had their highest average values in the 1x4 m quadrats (Table 3-5) while dwarf spikerush was most abundant in the individual 0.25 m² quadrats (Table 3-4).

The ten remaining species were only found in minor amounts averaging 0.5 or less percent cover over the course of the study.

To facilitate the analysis of the data base only those species displaying substantial changes in percent cover between sampling years were subjected to the analysis of variance. The results of which are given in Table 3-6. The majority of the significant variation between years was attributable to changes in the percent cover of Spartina patens (SP) and "no cover" (NC) with some significant changes in Kosteletzkya virginica (KV) and Atriplex patula (AP).
In the transect quadrats there was a significant increase in "no cover" (NC), from 12.6 percent to 25.6 percent when the two predredging years of 1980 and 1981 were combined and compared against 1982 which was the first post dredging sampling year. The percent NC declined in 1983 to the point where it was no longer significantly different from the predredging years (Fig. 3-3).

Spartina patens (SP) percent cover estimates in the transects indicated a significant decline (Table 3-6) between the 1981 and 1982 estimates of 72.3 percent and 62.7 percent respectively (Table 3-3). The decline in percent SP was also significant when the 1980 and 1981 values were combined and compared with 1982. However, the percent cover SP recovered in 1983 to where there was no significant difference with the predredging years (Fig. 3-3).

Three other species in the transect quadrats, Distichlis spicata (DS), Juncus roemerianus (JR) and Atriplex patula (AP) showed substantial variation in percent cover during the course of the study (Fig. 3-4 and Table 3-3). However, none of these differences between sampling years was found to be significant (Table 3-6).

The only "species" in the individual 0.25 m² quadrats to display any significant differences during the study was no cover (NC) (Table 3-6). The percent NC registered significant increases between 1980 and 1981, combined 1980-81 vs 1982 and 1980-81 vs 1983. These changes appeared to be mirrored by the changes in percent cover of Spartina patens (SP) in the individual quadrats. However, SP did not show any significant changes in the mean percent cover for the individual quadrats during the study (Fig. 3-5).

Several other species in the individual quadrats displayed substantial changes in mean percent cover but with no significant changes between years.
Distichlis spicata (DS) cover estimates in the individual quadrats indicated a general decline in mean percent cover from 11.1 in 1980 to 5.2 in 1983 (Table 3-4 and Fig. 3-6). Juncus roemerianus (JR) displayed a similar decline in the individual quadrats from 9.9 percent cover in 1980 to 6.4 percent in 1983 (Table 3-4 and Fig. 3-6).

The mean percent cover of Spartina alterniflora (SA) in the quadrats declined from 4.0 in 1980 to a low of 0.66 percent in 1982 and then increased to 1.1 percent in 1983 (Table 3-4 and Fig. 3-7). Additionally, two species, Atriplex patula (AP) and Amaranthus camabinus (AC), which had been absent from the individual quadrats between 1980 and 1982 appeared in the quadrats in 1983 (Table 3-4).

Only two species in the 1x4 m quadrats, Kosteletzkya virginica (KV) and Atriplex patula (AP) exhibited any significant changes in mean percent cover (Table 3-5). The mean percent cover of the KV decreased significantly between 1981 and 1982. It rebounded, however, in 1983 to 26.1 percent but the increase was not significantly above the 1982 low (Fig. 3-9). Cover values of AP in the 1x4 m quadrats showed considerable variability during the study with a significant increase in the mean percent cover between the combined years 1980-81 and 1982 (Table 3-5 and Fig. 3-9).

The dredging of the new inlet into Cabin Point Creek resulted in a marked change in both the tide range and the elevation of mean tide level (MTL) (Fig. 3-10). Table 3-7 provides the elevations of all of the quadrats sampled relative to the mean tide level in Cabin Point Creek in 1980 before the dredging and in 1982 after the dredging.

The increase in tide range and lowering of mean tide level as a result of dredging had a considerable impact on the elevation of the quadrats sampled relative to these parameters. The number of quadrats above mean
Figure 3-10. Tidal elevations before and after inlet construction. Reference elevation is outside MTL for 19 years transferred from Solomons Island.
Table 3-7. Quadrat elevations in the study marsh inside Cabin Point Creek. Datum is mean tide level in Cabin Point Creek during the year indicated.

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high water (MHW) was reduced from 40 in 1980 to 33 in 1982. Those quadrats at or below MHW increased from 17 in 1980 to 26 in 1982. The number at or below MTL decreased from 11 in 1980 to 2 in 1982. The number of quadrats at or below mean low water decreased from 4 in 1980 to 0 in 1982.

DISCUSSION

The major changes observed in the vegetation of the study marsh were significant increases in the percent "no cover" (NC) and significant decreases in the percent cover of *Spartina patens* (SP). Other notable changes in species composition occurred only in species which were minor constituents of the community and these changes, at least initially, have had only a minor impact on the overall community structure.

The apparent correspondence between the increase in percent NC and the decrease in percent SP may have been externally affected by factors other than the channelization of the creek. Observations during sampling indicate that the stake marking the permanent quadrats may have been responsible to some degree for the increase in percent NC observed. The stake appeared to influence the typical growth habit of SP, i.e. as the stem length increases the basal portion becomes unable to support the leaves and stem in an erect position. Consequently, the plant tends to assume a generally recumbent position which leads to the characteristic "cowlick" swirls observed in many monospecific stands. In the study site quadrats the stake tended to support the leaning culms of SP preventing them from assuming their normal recumbent position. This gave the appearance of an area of reduced coverage adjacent to the stake that normally would have been covered with the recumbent culms. These areas are markedly different from the more natural areas away from the
stake and tended to bias our cover estimates towards reducing the percent cover of SP in the staked quadrats. Since the majority of the quadrats were located in the SP community, as it is the dominant species in the marsh, this bias in our estimates could well have had a substantial effect on the results of the cover determinations.

The fact that this may be true is evidenced by the significant increase in percent NC noted in the transect quadrats between 1980 and 1981 (Table 3-6) which were both essentially pre-dredging samples. There was, however, only a slight decrease in percent cover of SP in the same set of samples between 1980 and 1981 (Table 3-7). Both the increase in NC and the decrease in SP became statistically significant in the transect quadrats in 1982 when compared to the combined pre-dredging years of 1980-81. By 1983 there was sufficient adjustment or recovery in SP so that its percent cover was not significantly different from the combined 1980-81 pre-dredging cover estimates.

Changes in community structure were also manifested by the appearance and disappearance of a number of species in the quadrats sampled. Altogether seven species completely disappeared from the quadrats at one time or another during the course of the study including: *Scirpus olyneyi* (SO), *Pluchea purpurescens* (PP), *Amaranthus cannabinus* (AC), *Hydrocotyle umbellata* (HU), *Phragmites australis* (PA), *Typha angustifolia* (TA) and *Polygonum punctatum* (PO). Three of these, HU, PA, and PO, had completely disappeared from the quadrats by the end of the study. HU and PA are both perennials whose disappearance seems of more import because generally more drastic environmental changes are normally needed to eliminate these than annuals like PO.
The other species, SO, PP, AC and TA, which had periodically disappeared are evenly split between perennials, SO and TA, and annuals, PP and AC. These fluctuations are virtually impossible to explain other than in light of natural population fluctuations as affected by environmental conditions during the particular growing season. With the data available, attributing these changes to the dredging of the new channel would be speculative at best.

Two other species, Kosteletzkyia virginia (KV) and Atriplex patula (AP), also exhibited interesting responses. KV had an initial percent cover of almost 2%. This decreased to approximately 0.2% by 1982 and then increased to over 2% in 1983. This sort of behavior is somewhat unusual for a perennial shrub. One would hypothesize that during the initial years the conditions were not suitable for the continued growth of existing individuals and these began to die off. However by 1983 recruitment of new individuals in response to the new environmental conditions had begun to occur bringing the population back to pre-project proportions.

AP apparently responded to the environmental perturbation in a much different pattern. Initially the species was only a very minor constituent of the overall wetland community with a percent cover of approximately 0.4%. By 1983 it had steadily expanded to a 2.7% share of the total cover in the marsh. While the change was not statistically significant, an order of magnitude increase certainly indicates that something had occurred which favored its survival. The fact that it is an annual which is a prolific seed producer may well have contributed to its rapid success.

The analysis of the changes in tide range as compared to plant zonation did not indicate any outstanding correlations. The majority of quadrats which were above MHW prior to dredging were still at or above MHW after the
dredging. Consequently little vegetation shift in the marsh vegetation in these quadrats could be expected. Those quadrats sampled in the area below MHW (1980) and below MTL (1980) which experienced the greatest change in environmental conditions did not experience any notable changes in vegetational characteristics. Our hypothesis for this phenomena is that the dominant vegetation, SP, is so well established that it can persist for a considerable number of years and also be very competitive with other both more suitable and more aggressive species, thereby thwarting most attempts at invasion by other species with the possible exception of AP. We feel that this is potentially the reason that the anticipated colonization of the low marsh, below MHW, by the normal occupant, Spartina alterniflora, has not to date occurred.

The significant change in MTL inside Cabin Point Creek from .35' above MTL in Lower Machodoc Creek before dredging to .13' below, a difference in elevation of .48', possesses the potential to have the most influence on wetland community changes, however as the study results indicate any changes have not yet become readily apparent. Important in this respect is the substantial area around the shoreline of the creek above the new MTL that will become available for colonization of wetland vegetation particularly for the regularly flooded low marsh species. The amount of area that might eventually be colonized depends on a number of factors including the slope of the intertidal zone, shading by overhanging trees and substrate type none of which were evaluated during this study. But for the purposes of discussion the planimetered shoreline of Cabin Point Creek is 5.3 miles or 27,984 feet. If the change in tide range resulted in an increase in the average width of the intertidal zone of one foot, an additional 27,984 square feet (.64 acres) would be available for low marsh establishment.
Added to this is a substantial area of mud and sand flats adjacent to the study marsh which have become intertidal since the dredging of the channel. The increase in the amount of insolation these areas receive probably results in a concomitant increase in benthic algal productivity.

**SUMMARY**

A number of significant changes in the community structure of the study marsh in Cabin Point Creek were observed during the course of the four growing seasons studied. With the exception of the percent "no cover" in the individual quadrats, no significant differences were apparent in the vegetation cover at the end of the study in 1983 as compared to the combined pre-dredging years of 1980-81.

For the most part, the changes observed appeared to be relatively short-term responses to the channelization and/or fluctuations in environmental conditions. The species present apparently were able to adjust to the new conditions sufficiently enough to maintain roughly the pre-dredging status quo within the period of a few years. However, these adjustments may be part and parcel of a longer term response which will ultimately determine the lasting changes in the community structure.

The only notable exception to this is *Atriplex patula* which exhibited a continuing increase in percent cover throughout the study. Subsequent observations in 1984 indicated a dramatic increase over the percent cover observed in 1983.

There are, we feel, two main reasons for the general lack of change demonstrated. First of all, the majority of the wetlands involved was the relatively high and more or less stable *Spartina patens* community. It is
very well established with an extensive root and peat mat which insulated the species from, or at least tempered the impacts of the channelization. This inherent stability is probably what has allowed the community to persist relatively unaffected and to successfully compete with invading species.

The other major factor affecting the wetland community was the change in the tidal regime occasioned by the dredging. Even here the *Spartina patens* community was at a distinct advantage because the most severe changes were limited to the lower portion of the tide range below the community's normal elevation zone. The lowering of mean tide level and mean low water by the channelization of the creek may portend changes in the low marsh species which have not had sufficient time to respond. If one were to try to predict what these changes might be, it would most probably be an increase in coverage of species representative of regularly flooded brackish marshes. This would be a direct result of the increased area between mean tide level and mean high water available for wetland plant colonization as a result of the channelization and increased tide range.
SECTION 4

WATER QUALITY STUDIES

by

Bruce J. Neilson

CABIN POINT CREEK CHANNELIZATION STUDY

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College of William and Mary
Gloucester Point, Virginia 23062
WATER QUALITY CONSIDERATIONS

One anticipated consequence of modifying the channel connecting Cabin Point Creek and Lower Machodoc Creek was a change in the rate at which water was exchanged between those two water bodies. A natural channel that was long (about two kilometers), rather narrow (only a few meters wide for most of its length), and shallow (less than a meter deep at low water) was to be replaced by a short (about 100 m), wide (about 20 m), dredged channel that is deep (about 2 m) relative to conditions both upriver and downriver. Given these changes in channel geometry, it was projected that the flow of water through the new dredged channel would be greater than that through the old natural channel. The altered flow regime and the construction activities both had the potential to change the water quality conditions in Cabin Point Creek. Therefore, water quality surveys of the creek were made regularly from 1980 through 1983 in order to ascertain what, if any, changes actually occurred.

FACTORS AFFECTING WATER QUALITY

Water quality conditions in an estuary, as in most water bodies, will be determined in great part by the nature of the external inputs to the system. Often there will be spatial gradients in the concentration of substances in the water. For example, the salinity levels typically decrease as one moves away from the ocean or bay which is the source of sea salts. Concentrations of silicates, on the other hand, tend to decrease from the head to the mouth of an estuary because river water usually has high concentrations of silicates relative to those typically found in the ocean.
Spatial patterns of pollutant concentration can be complex when there are multiple sources of pollutants. For the case of Cabin Point Creek, the situation is quite simple; at present no wastewaters are discharged to the creek or its tributaries. The primary pollutant sources are those diffuse or distributed sources commonly referred to as non-point source pollution. These upland inputs can be separated into overland runoff and groundwater inflow. From a water quality perspective, neither of these was expected to be polluted to any extent, because the drainage basin is only sparsely developed.

Overland Runoff: Many factors affect the quantity and quality of overland runs off from a drainage basin. Generally speaking, the quantity of runoff increases and the quality declines when there are large expanses of impervious cover. To date the roads in the Cabin Point Creek development have not been paved and there are few paved driveways or parking areas. The impervious cover consists primarily of rooftops; therefore a possible source of runoff would be the rain water coming off the house roofs. In most instances the houses are surrounded by lawns and the streets are lined by unpaved ditches. Thus there is ample opportunity for the water to infiltrate into the ground before reaching the creek. In other words, one would expect the quantity of overland runoff to be small (relative to urban or suburban areas). Storms with low rainfall intensity or small total rainfall probably produce no runoff in this setting. Furthermore, one would expect the quality of the runoff, when it happens, to be fairly high. Indeed, nothing observed in the present study suggests that overland runoff in the Cabin Point Creek basin contains high levels of pollutants or that runoff is causing any problems in the creek.
Groundwater Flows: Groundwater quality was not measured in this study. However, it is believed that present groundwater flows are of similarly high quality. Even after the community has become more developed and supports a larger population, groundwater inputs of pollutants should remain small with one possible exception. Although bacteria, metals, phosphorus and other substances in sewage tend to sorb to sediment particles and thereby be removed from the groundwater flow, nitrogenous compounds usually are oxidized to nitrates which are soluble. Thus the primary pollutant in groundwater, both now and in the future, is likely to be nitrate nitrogen. This analysis of groundwater quality is predicated on the proper design, installation, and maintenance of both the septic tanks and the subsurface drainfields used for wastewater treatment and disposal.

Potomac River: The other source of water for Cabin Point Creek is the Potomac River. Nominally Cabin Point Creek is tributary to the Lower Machodoc River, but for all practical purposes the controlling downstream source is the Potomac (See Figure 4-1). Water quality conditions there will be controlled for the most part by conditions in Chesapeake Bay and the inputs arising from the Washington, D.C. metropolitan area. During periods of moderate or low river flow, the major changes in water quality resulting from the D.C. inputs will have taken place well upstream of Ragged Point. Therefore, during low flow periods concentration gradients in the brackish reaches of the river are expected to be gradual (See HydroQual, 1981, for both field observations and math model predictions of water quality along the length of the estuary). During high flow periods, the influence of the wastewater discharges from the D.C. metropolitan area should be greater.

In summary, water quality conditions in Cabin Point Creek will be determined for the most part by conditions in the adjacent segments of the...
Figure 4-1. The Potomac River Estuary and detailed map of the lower Machodoc Creek/Ragged Point area showing Cabin Point Creek.
Potomac River and by runoff from the surrounding land. Given present land use, land runoff is believed to be of high quality; this could change as the more of the land is developed.

METHODS

The water quality monitoring employed two types of surveys - slackwater surveys and intensive surveys. Slackwater surveys give "snap shot" pictures of water quality conditions at slack tide. In many estuaries water quality conditions are worst at low water slack (slack before flood) and best at high water slack (slack before ebb), because the volume of water entering with each flood tide dilutes any pollutants that are present. Because the water depths in Cabin Point Creek are small, especially at low water, it was not possible to collect samples from boats. Instead most samples were taken from docks or piers and the remainder from the shore. Sampling locations are shown in Figure 4-2. The water temperature was measured in situ as was Secchi depth when the water column was sufficiently deep to permit the reading. Water samples also were collected, placed on ice, and returned to the lab for analysis to determine levels of salinity, dissolved oxygen, total phosphorus, chlorophyll "a", and suspended solids.

The so-called intensive surveys derive their name from the sampling intensity. In this case the purpose of the monitoring was to document water quality conditions around the clock, so that day to night differences could be observed. More specifically algae produce oxygen as a by-product of photosynthesis but also consume oxygen in respiration. During daylight periods, oxygen production usually exceeds oxygen consumption and the excess oxygen raises amount of oxygen dissolved in the water. During the night there is no photosynthesis and therefore no oxygen production.
Figure 4-2. Water quality sampling stations in Cabin Point Creek.
Consequently, oxygen concentrations are reduced by the oxygen consumption. The end result can be a marked daily cycle in dissolved oxygen concentrations with peak values occurring in late afternoon and minimum readings occurring just before dawn. The intensive surveys were conducted in late August or early September of each year. Two nearby stations were sampled for dissolved oxygen levels at roughly hourly intervals for most of the day and part of the night. Staffs were placed at the two stations so that relative tidal elevations could be recorded.

In addition three slackwater surveys were conducted. Typically one survey was made just before dawn to document conditions at the end of the dark period. A second survey at the same tidal phase was made half a day later. Comparison of the dissolved oxygen observations from these two surveys shows the day to night variations. The third survey also was made during the daylight period but with a one half tidal cycle phase difference. Thus the variations due to tidal stage could be observed from these latter two surveys. Water sampling for this portion of the intensive surveys was accomplished in the same fashion as for other slackwater surveys.

RESULTS

The data from the slackwater surveys indicate that water quality in Cabin Point Creek varies greatly. (The data are presented graphically by sampling date in the Appendix. Only general patterns will be discussed here. The reader is referred to the individual graphs for the details.) This behavior is similar to that observed in many other estuaries. Spatial patterns are difficult to discern. Water temperature, for example, usually is uniform over the sampling stations except during the spring. When water temperatures are increasing, that change is observed inside Cabin Point
Creek sooner than in Lower Machodoc Creek. This probably is due to the very shallow water depths within the creek and therefore the greater effect of solar heating. Spatial variations in salinity also were not large except during the first half of 1982 when exchange with Machodoc Creek was modified. While the inlet was plugged to keep dredging related effects within Cabin Point Creek, it essentially was a reservoir. Salinity varied by as much as 5 to 12 parts per thousand between stations during that period. Temporal variations of both salinity and temperature were strong and are described in a later section.

The variations in Total Phosphorus (TP) illustrate the natural variability inherent in estuarine systems. On some occasions, the concentrations were uniform within Cabin Point Creek, but typically, concentrations varied greatly (peak concentrations roughly twice the lowest observation) and showed no obvious spatial pattern. Stations with high concentrations on one survey often had low concentrations on the subsequent survey. Frequently, the reverse pattern would occur for nearby stations. Concentrations were, for the most part, below 0.1 mg/l, but on some surveys all values would be below 0.03 mg/l and on other surveys, all values would be above 0.05 mg/l. Extremely high concentrations (greater than 0.4 mg/l) tended to occur when suspended solids concentrations were high (especially at the Machodoc Creek stations) or when chlorophyll concentrations were high (greater than 50 ug/l). In summary, survey means and standard deviations varied greatly with neither spatial nor temporal patterns apparent.

The seasonal variation in water temperature had a marked effect on dissolved oxygen (DO) concentrations. The saturation concentration for oxygen in water is strongly and inversely correlated with water temperature, so the seasonal pattern to DO observations was expected. In order to
illustrate these temporal patterns and the differences inside/outside Cabin Point Creek, the data from the slackwater surveys have been organized into two groups. Data for stations 1 and 8 have been combined to illustrate conditions existing in Lower Machodoc Creek-Potomac River. Data from stations 4, 5, 6, and 7 (all lying near the upper ends of the branches of Cabin Point Creek) have been combined to show conditions existing inside Cabin Point Creek. The resulting data sets have been presented in two fashions: the time series for the two groups have been plotted so that inside versus outside differences can be seen (see Figure 4-3a), and the data for the four years of the study have been overlain to illustrate interannual variations (see Figures 4-3b and 4-3c).

When the dissolved oxygen data for the four years are overlaid (Figures 4-3b and 4-3c), the seasonal pattern is obvious, although considerable short term variation remains. The seasonal pattern inside Cabin Point Creek appears to be more regular than for the two stations in Lower Machodoc Creek, but this may be due to the smoothing effect of increasing sample size (four stations versus only two stations for calculating means). Year to year differences are apparent, but appear somewhat random. However, DO concentrations inside the creek consistently were lower in 1981 than during other years. The freshwater flow to the Potomac River estuary was low during this year and salinity levels were the highest for the study period (Table 4-1 and Figure 4-4c). The saturation concentration of oxygen decreases as salinity increases. The elevated salinity values may be the reason that DO concentrations were lower during 1981. Dissolved oxygen levels in Cabin Point Creek tended to be lower than in Machodoc Creek, although the difference appears to have decreased in the latter part of the study.
Figure 4-3a. Temporal variations in dissolved oxygen inside and outside Cabin Point Creek.
Figure 4-3b. The seasonal variation in dissolved oxygen outside Cabin Point Creek.
Figure 4-3c. The seasonal variation of dissolved oxygen inside Cabin Point Creek.
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**AVERAGE DISCHARGE (54-YEAR MEAN) = 11,560**
Figure 4-4a. Temporal variations in salinity inside and outside Cabin Point Creek.
Figure 4-4b. Seasonal variation of salinity outside Cabin Point Creek.
Figure 4-4c. Seasonal variation of salinity inside Cabin Point Creek.
Within the context of inter-annual, seasonal, and random variations, it is difficult to discern measurable effects of the dredging and associated activities. The salinity inside Cabin Point Creek typically was close to that observed in Machodoc Creek, with the exception of the spring of 1982. Following that period, the inside-outside differences appear to be smaller than was typical of the first part of the study. Suspended solids concentrations also showed no obvious, significant dredging impact (Figure 4-5), although the concentrations inside the creek were somewhat higher or were higher over a longer period during the first part of 1982. The concentrations for the outside stations were high on several occasions. This is believed due to wave action resuspending sediments on the beach. Total phosphorus concentrations were highest when the suspended solids concentrations were high, which can be observed when Figures 4-5 and 4-6 are contrasted. Elevated chlorophyll a concentrations, however, did not seem to affect the suspended solids concentrations appreciably (compare Figures 4-5 and 4-7).

The intensive survey data also show just how large the inter-annual variation can be (Figure 4-8). Chlorophyll concentrations, both in Machodoc Creek and in Cabin Point Creek, were much higher in 1982 than in 1981. It is somewhat surprising therefore that the difference did not greatly alter the DO regime. In both years over the diurnal cycle, dissolved oxygen varied by about 4 mg/l inside the creek and 1.5 mg/l outside the creek. The inside/outside difference is believed due to differential water depths. Photosynthesis and algal respiration affect shallow water columns more so than deep water columns.

In summary, conditions in Cabin Point Creek vary seasonally, from year to year, over the daily cycle, and also in a random fashion. Spatial
Figure 4-5. Temporal variation of suspended solids.
Figure 4-6. Temporal variation of total Phosphorus.
Figure 4-7. Temporal variation of Chlorophyll a.
Figure 4-8a. Chlorophyll a values during the 1981-1982 intensive surveys.
Figure 4-8b. Dissolved oxygen values during 1981-1982 intensive surveys.
patterns are not as pronounced, but some inside/outside differences are present. The inlet construction, dredging, and other construction activities appear to have had limited impact on the system. That is believed due, at least in part, to the very long period over which these activities occurred. A larger and more intensive work effort might have affected water quality. The end result of inlet construction appears to be a lessening of inside/outside differences.

DISCUSSION

Excessive nutrient enrichment of Chesapeake Bay and its tributaries has received much attention in recent years. No widely accepted definitions or criteria exist by which such a state can be determined. However, a number of "yardsticks" have been proposed (See review of same in Neilson, 1981). Total phosphorus concentrations of 0.033, 0.054, 0.082, and 0.05 mg/l have been suggested as indicating excessive nutrient enrichment. Similarly, 25 ug/l has been suggested as a desirable chorophyll limit while 30 to 60 ug/l has been suggested as bracketing "moderate enrichment" in low salinity areas. By virtually any of these yardsticks, Cabin Point Creek is moderately to highly enriched.

The cause of this situation is believed to be the Washington, D. C. metropolitan region. Field surveys and model studies have shown that the large volumes of wastewaters and urban runoff cause significant water quality problems in the upper tidal Potomac (HydroQual, 1981, and Md. OEP, 1987). Although these problems are greatly abated in the lower estuary, the effects remain. Water quality conditions are monitored routinely now at a number of stations along the estuary; the station nearest to Cabin Point
Creek is in the main channel of the Potomac off Ragged Point (Magnien, 1987).

Chlorophyll concentrations are on the order of 10 ug/l most of the year, but rise to about 30 ug/l in the spring. It appears that nutrients are available to support greater densities, but other factors, such as tidal mixing and turbidity, are limiting algal populations. Total Phosphorus concentrations average about 0.05 mg/l in the winter to 0.08 mg/l in the summer. Concentrations range between 0.03 and 0.18 mg/l. The higher summer values are probably due to anoxia. During the summer of 1985 DO concentrations at the bottom were below 2 mg/l in early May and stayed at low values until late September. During the summer of 1986 the depressed DO’s occurred for a shorter period, approximately three months, but were near zero most of that time. Bottom sediments typically release phosphorus when the oxygen in the overlying water is low. Thus the high summer values for total phosphorus are not surprising.

The inlet connecting Cabin Point Creek and Machodoc Creek allows freer exchange of water between these two water bodies. Because Cabin Point Creek is small, conditions in that system will be influenced more by the Potomac-Machodoc than vice versa. In particular, it is likely that nutrients will enter Cabin Point Creek from downstream. Further, the shallow depths and decreased tidal currents are likely to provide a more hospitable environment for algal growth and therefore algal densities are likely to be higher than those occurring outside Cabin Point Creek. The results of the 1983 intensive survey suggest that this is happening.
CONCLUSIONS

Water quality in estuaries responds to many factors and therefore is highly variable. Cabin Point Creek is not an exception. Water temperatures and dissolved oxygen have strong and regular seasonal variations. The seasonal pattern for salinity is less regular, and that for chlorophyll and total phosphorus even less so. Year to year variations can be pronounced. At shorter time scales random variation, due to meteorological conditions and other factors, can be large. Cabin Point Creek exhibits a marked diurnal cycle for oxygen. This results from conditions that are conducive to algal growth.

Water quality impacts from the construction and dredging activities were slight. This was due in part to the limited scale of the activities and the long time span (more than a year) over which these activities occurred. It must be noted that only strong signals could be discerned from the natural variability. The primary change appears to a shift in water quality towards that which occurs in Machodoc Creek.

Cabin Point Creek, Lower Machodoc Creek and the Potomac River estuary are nutrient enriched. That situation is likely to continue in Cabin Point Creek because the Potomac provides such a large source of nutrients. The backwater conditions in Cabin Point Creek appear to be providing a more favorable environment for algal growth. If that continues, bottom sediments in Cabin Point Creek could become organically enriched as algal cells die and settle to the bottom. This would result in further enrichment and could lead to undesirable oxygen conditions.
SECTION 5

SUMMARY
A number of concerns were raised by local, state and federal regulatory as well as advisory agencies regarding the potential impacts of the proposed channelization on various aspects of the Cabin Point Creek system. The intent of this study was to document the existing conditions and evaluate the changes in shoreline and inlet dynamics, wetlands vegetation and water quality induced by the channelization.

At the conclusion of the field work comparatively little upland development had occurred in the Cabin Point subdivision. The majority of the roads were still gravel, houses were for the most part widely separated and generally somewhat removed from the water's edge and boating activity remained at a relatively low level. All of these factors affect the potential for impacts, particularly upland runoff, septic tank leachate and erosion from boat wakes. The future will probably bring changes in these factors and their impacts on Cabin Point Creek which may alter in some fashion the conclusions of this study.

SHORELINE AND INLET STUDIES

When the inlet modification was first proposed, a principal concern was whether a species shift in the marsh would occur due to increased tidal inundation. This concern reflected the knowledge that the tide range within Cabin Point Creek was suppressed relative to that in Lower Machodoc Creek; and with the new inlet the mean high water elevation was anticipated to
increase. However, this study has demonstrated the importance of tidal superelevation in embayment systems with constructed inlets. Due to the superelevation of mean tide level the mean high water elevation did not increase appreciably with the inlet dredging. However, the post construction internal tide range did attain that of lower Machodoc Creek with the majority of the increase occurring in the lower end of the tide range. The result was an areal increase in intertidal habitat within the creek.

The results of this study indicate the need for tidal elevation measurements as a component of preconstruction environmental assessments. While internal and external tidal gauging for a lunar month is preferable measurements for a two week period would be sufficient for an estimate of tide range ratios and superelevation of internal mean tide level.

The north jetty filled with sand rapidly. During the period August 1983 to January 1983 sand was transferred from the local beach toe to form beachshore dunes. By December 1984 the inlet started to shoal as a result, at least partially, of sand bypassing the north jetty. This result demonstrates that maintenance dredging will be required to maintain the inlet.

During the course of the study the shore updrift of Cabin Point was stabilized with riprap revetments. Thus the sand supply to the downdrift shore has been diminished. These actions will necessitate increased beach stabilization along the spit north of the jettied entrance and along the beach face south of the entrance. Stabilization north of the inlet entrance will reduce the maintenance dredging requirements. However, stabilization of the shore on the south side of the inlet will be required since actions
on the north side of the inlet, as well as the inlet itself, will starve the sand supply to the southern side.

WETLANDS VEGETATION STUDIES

The major causes for concern regarding the wetlands within Cabin Point Creek were direct losses due to construction activity and changes in community structure due to a new tidal regime resulting from the dredged inlet.

Direct wetlands losses were substantially avoided by the plan finally approved. On the order of only a quarter of an acre of marsh was lost to the construction of the inlet and associated riprap.

The new inlet substantially changed the tide range inside the creek. The major changes were a lowering of mean tide level and mean low water with very little, if any, change in mean high water. This helped to minimize the impact on the study marsh which was predominately at or above mean high water. In fact, the change in tide range was probably, in some respects, beneficial in that it actually increased the intertidal area within Cabin Point Creek.

Some significant changes in the vegetation did occur between the pre-construction and past construction years. Most of these appeared to be short-term changes associated with the extended period of construction. By the end of the study the only significant difference remaining was an increase in the percent "no cover" in the individual 0.25 m² quadrats. This appeared to result from cumulative small reductions in the percent cover of several species that were minor components of the marsh community. These
losses were offset to a limited extent by the appearance of two other species in these quadrats during the last year of the study.

The dominant species of the study marsh, *Spartina patens*, had approximately the same percent cover at the end of the study as it did at the beginning. The changes which occurred among the minor constituents of the wetland community, while not significant in the short term, may be indications of future changes.

**WATER QUALITY STUDIES**

The water quality within Cabin Point Creek is affected by two major sources of input, upland runoff and the Potomac River/Lower Machodoc Creek. Prior to and during construction Cabin Point Creek was relatively isolated from the influence of the Potomac River. In this situation the upland inputs dominated and given the low level of development during the study these inputs were generally small. The construction of the inlet has provided a more direct linkage with the nutrient enriched Potomac River which is currently probably the greater influence.

Inherent in this study as in most estuarine water quality studies are the natural daily cycles, seasonal trends and year-to-year differences in parameters which must be interpreted before any changes in water quality can be determined.

Temperature and salinity both inside and outside the creek showed the typical variation that would be expected in response to environmental conditions.

Total phosphorus varied greatly both inside and out with no apparent temporal or spatial patterns.
Suspended solids levels were somewhat elevated in the creek during the last phase of dredging and outside in Lower Machodoc Creek during periods of high wave action.

Dissolved oxygen levels showed strong seasonal variations and year-to-year differences both inside and outside Cabin Point Creek. The daily fluctuation of dissolved oxygen was generally greater inside the creek than outside.

In general, the differences between Lower Machodoc Creek and Cabin Point Creek decreased towards the end of the study. This indicates a greater influence of the nutrient enriched Potomac River on Cabin Point Creek as a result of the increased exchange through the inlet. Increased nutrient enrichment whether from the Potomac or from future upland sources could potentially lead to increased algal growth and more dramatic dissolved oxygen fluctuations.
APPENDICES

APPENDIX A - Environmental Effects of Inlet at Cabin Point, Virginia.


APPENDIX C - Slackwater Survey Results - by Sampling Date.

APPENDIX D - Temporal Variation of Water Quality Inside and Outside Cabin Point Creek

APPENDIX E - Intensive Survey Results - by Sampling Time and Date.
The purpose of this report is to provide guidance to the Baltimore District that will assist in their decision on issuance of permits for dredging an inlet and associated interior channels at Cabin Point, Westmoreland County, Virginia (Figure 1-1) which were approved by Cabin Point Inlet Committee dated 23 September 1975 and amended on 7 August 1976.

Prepared for U.S. Army Engineer District, Baltimore

by

U.S. Army Coastal Engineering Research Center

Research Division

Coastal Structures and Ecology Branches

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Fort Belvoir, Virginia 22060
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6. CONCLUSIONS

References
STUDY OBJECTIVES

The purpose of this report is to provide guidance to the Baltimore District that will assist in their decision on issuance of a permit for dredging an inlet and associated interior channels at Cabin Point Creek, Westmoreland County, Virginia (Figure 1-1). The request for a permit was made by Cabin Point, Inc. of Mt. Holly, Virginia with a plan dated 28 September 1975 and amended on 7 April 1976 and 15 May 1976. Throughout the remainder of this report the applicant's plan with amendments is referred to as the "Hutt Plan" (Signed by J. Clifford Hutt). Specific information and guidance requested by the Baltimore District (SF 2544 dated 14 April 1976) are as follows:

a. "The effect the applicant's proposed works would have on shoreline processes in Cabin Point Creek and the Lower Machodoc River."

b. "An estimate of the natural changes expected in the tidal creek should it remain undisturbed."

c. "If the applicant's proposed work would result in an adverse effect on shoreline processes and if natural changes expected would tend to place a high maintenance requirement on the applicant, what changes to the applicant's plans would decrease this conflict? Specific items to be investigated should
include the following: 1) the effect of the jetties on littoral drift, 2) the expected southward movement of the creek's mouth, 3) the need for maintenance dredging in the entrance channel and side channels, 4) the increase in the tide range within the creek, 5) the destruction of vegetation by the deposition of dredged material, 6) possible alternate disposal areas, including beach nourishment sites, 7) the possible location of drift nodes in the vicinity, and 8) the effect on nearby shell fish beds."

d. "In general, what waterway improvement may be made by the applicant without undue disruption to natural processes within Cabin Point Creek and the Lower Machodoc River?"

THE PROJECT

The project area is located on the south side of the lower Potomac River where Lower Machodoc Creek empties into the Potomac (Figure 1-1). A small bay called Cabin Point Creek is connected to the Potomac River by a natural tidal inlet approximately fifty feet wide, one to two feet deep and two thousand feet long. The present inlet is not navigable so the applicant would like to develop an entrance channel that will permit navigation by small pleasure boats between Cabin Point Creek and the river as well as improve navigation in Cabin Point Creek.

The Hutt plan consists of improving the channel by dredging an inlet near the present inlet, jettying the inlet entrance, and dredging channels throughout various parts of Cabin Point Creek (Figure 1-2).

The proposed inlet channel would be 60 to 100 feet wide and 4.9 feet deep below MNL (4.0 feet below MLW). The inlet entrance would be controlled by two, approximately 300-foot long, parallel, vertical wall, timber jetties oriented at an angle of 60° to the shoreline (Figure 1-2). Interior improvements in Cabin Point Creek would consist of 60-foot-wide channels with 1 on 2 side slopes 4.9 feet deep (below MNL). Dredge spoil would be placed on two marsh areas (Spoil Area Nos. 1 and 2, Figure 1-2).
FIGURE 1-2
THE HUTT PLAN

PROPOSED DREDGING AND
PROPOSED JETTY
IN LOWER MACHODOC CREEK
AT CABIN POINT
COUNTY OF WESTMORELAND
STATE OF VIRGINIA
APPLICATION BY CABIN POINT, INC.
MT. HOLLY, VIRGINIA

DATE: SEPTEMBER 23, 1975

SHEET 1 OF 2
GEOLOGY OF STUDY AREA

The state geology map shows that the project area is composed of alluvial sediments approximately 125 feet thick consisting of a variety of clays, sand, gravel and marl. Visual inspection of the area shows that immediately offshore of Cabin Point the bottom of the Potomac and Lower Machodoc Creek is composed of clay. At the -3' MLW contour the bottom sediments are bi-modal consisting of gravel and medium sand; at the breaker zone they are primarily gravel and coarse sand; and on the berm and back beach medium to fine sand (Table 1). The present Cabin Point Creek inlet bottom contains gravel and medium to fine sand. The Cabin Point Creek bottom consists of from several inches to several feet of very fine recent sediment and decaying vegetation overlying older sediments.

The beach adjacent to the project area varies in width from a few feet to approximately 60 feet (Figure 1-3). Land north and west of Cabin Point is older geologically and the surface elevation varies between 8 and 12 feet above MWL. South of Cabin Point and east of Cabin Point Creek the sediments were deposited more recently with a thin barrier beach and trees covering higher ground. Adjacent to the barrier and along the inlet are lowlands and marsh which range from MWL to approximately one foot above MWL.
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<td>0</td>
<td>7</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>Beach</td>
<td>Samples collected 25 May 1976</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 1-3. CABIN POINT CREEK

- Sand
- Lowland
- Marsh
- Woods

Cabin Point
Cabin Point Creek
8-12' M.W.
Lower Machope Creek

1000'

114
CHAPTER 2

SHORELINE PROCESSES

Observations during site visits, a study of aerial photographs and maps, and a wave hindcast from wind records give insight into the shoreline processes in the vicinity of Cabin Point Creek.

SHORELINE CHANGES

A study of aerial photographs of Cabin Point Creek and vicinity (Dept. of Agriculture aerial photos taken 10/2/53 and 6/12/72) shows that in general this area of coast is eroding. Measured net shoreline changes for the 19-year period from 1953 to 1972 are shown in Figure 2-1. They vary between a maximum of 5.6 feet of shoreline recession per year at Kingcopsico Point to a maximum shoreline advance of 7.7 feet per year immediately south of Cabin Point Creek Inlet. Of the 21 points at which shoreline changes were measured, 70% showed erosion, 20% showed no change and 10% (a small area adjacent to the inlet) showed accretion.

South or downdrift of Cabin Point Inlet there has been up to several feet per year of erosion in the past two decades; however, all but two lots in this area are now protected by bulkheads and/or groins so that the rate of shoreline change has been reduced.

In the early 1950's at a point 6,000 feet southeast of Cabin Point an inlet naturally broke through the spit adjacent to Glebe Creek (See Fig 1-1), and left an island in Lower Machodoc Creek. By 1961 a new spit began to develop into Weatherall Creek, and through 1975 the spit continued to grow while the Weatherall Creek inlet width increased (Figure 2-2).
FIGURE 2.1. SHORELINE CHANGE RATES (feet per year)
10/2/53 to 6/12/72
(reduced from 1" = 670')
(Department of Agriculture photos)
FIGURE 2-2. SHORELINE DEVELOPMENT SOUTH OF CABIN POINT CREEK
LONGSHORE TRANSPORT

The pattern of longshore transport in the area is reflected by the existing shoreline configuration and shoreline changes over the past 15 years. Figure 2-3 shows typical shoreline configurations that result from structures and inlets along a beach with longshore transport predominantly in one direction.

Using these longshore transport direction indicators, transport directions for the area of Cabin Point Creek can be determined (Figure 2-4). A node is present at Kingcopsico Point with transport in both directions away from the node. Transport is to the east and south for the study area east of Kingcopsico Point, and to the south for the area west of Kingcopsico Point (Figure 2-4). This transport direction is also indicated by the change in geometry of the spit and island near Glebe Creek.

LONGSHORE TRANSPORT PREDICTION

One method of estimating longshore transport rates is to hindcast wave conditions from wind measurements and use these wave hindcasts to predict longshore transport using the longshore energy flux method (SPM, US Army
Figure 2-4. Longshore Transport Direction
Interpreted from Shoreline Features
(from 6/12/72 Dept. of Agri. photo)
Coastal Engineering Research Center, 1975). Wind information was obtained at National Airport for 3-hour intervals during 1975 for a total of 2920 wind observations. (NOAA suggests that any differences between Cabin Creek and National Airport would be minor and should have little effect on this hindcast). The mean water depth of the Potomac River adjacent to Cabin Point Creek is approximately 25 feet and analysis shows that larger waves are fetch limited for the short fetch in the study area. Inspection of Chart 558 of the Potomac River shows that the fetch is approximately 32,000 feet at Cabin Point independent of the fetch direction (Figure 2-3), so SPM Figure 3-25 can be redrawn relating offshore wave height and period directly to wind speed (Figure 2-5).

Assuming that the direction of the waves is the same as the direction of the wind, the deepwater angle of the waves can be determined with reference to the shoreline (Figure 2-6). Given the wave conditions, waves can be refracted and shoaled into shore assuming parallel contours. Then the longshore energy flux factor, \( P_{ls} \), can be computed from SPM Equation 4-36 (pg 4-97):

\[
P_{ls} = 18.3 H_0^{5/2} \left( \cos \alpha_o \right)^{1/4} \sin(2 \alpha_o)
\]

where \( \alpha_o \) is the deepwater angle of the wave with respect to the shoreline, and \( H_0 \) is the deepwater significant wave height.

The potential longshore transport rate, \( Q \), in cubic feet per second is related to longshore energy by the relation:

\[
Q_l = \frac{k P_{ls}}{g (\rho_s - \rho_f) (1-P)}
\]

where \( k \) is taken as 0.4 for this case where sediment supply is very limited, \( P \) is a porosity coefficient, \( \rho_s \) is the sediment density, \( \rho_f \) is the density of water, and \( g \) is the acceleration due to gravity.
Figure 2-5 Predicted Wave Height for Wind Speeds (Fetch Limited, Depth Limited, Fetch = 6.1 Miles)
FIGURE 2-6  CABIN POINT CREEK WAVE HINDCAST GEOMETRY
This prediction scheme is used with one year of wind observations at three hour intervals to show that the predicted potential longshore transport rate is on the order of 7,000 cubic yards per year, but because sediment supply is very limited at this site the rate may be as low as 3000 yd$^3$/yr to the southeast. Essentially all of this material moves to the southeast (from left to right as seen looking from the beach offshore), so that net and gross longshore transport rates are considered equal at Cabin Point and to the southeast. Most transport is predicted to occur during the period September through January (Figure 2-7), and significant shore or river ice during this time will also reduce the actual transport below that predicted.

A cumulative distribution of transport is constructed by ranking the transport predictions (2920 predictions at three hour intervals for a year) in order from smallest to largest. The observations are then summed to obtain a cumulative distribution. This distribution curve (Figure 2-8) shows that for 80% of the time there is no appreciable longshore transport. Most transport occurs during 20% of the time, and approximately half of all transport occurs during the high wave conditions which occur 20% of the time.

The predicted potential transport of 3,000 to 7,000 cubic yards per year at Cabin Point decreases up Lower Machodoc Creek because sheltering by Coles Point lowers the wave height and resulting transport capacity. This decrease in transport further into Lower Machodoc Creek can be interpreted to mean that part of the sediment carried past Cabin Point is deposited at points in Lower Machodoc Creek.

The slow growth of the spit adjacent to Glebe Creek, the spit overlapping Cabin Point Creek Inlet, and the sand bar adjacent to Daiger Brothers Seafood confirms that transport rates are low.

The erosion of the shoreline from Kingcopsico Point to Cabin Point, about three miles, is probably the main source of sediment for longshore transport because the bluffs in this area contain sand and gravel. If this coast erodes at the present rate the supply of sediment will probably remain...
Figure 2-6. Predicted Cumulative Distribution of Longshore Sediment Transport for 1975

Figure 2-7. Predicted Monthly Sediment Transport Rates for 1975
the same. Shoreline structures such as groins and seawalls placed anywhere along the shoreline from Kingcopsico Point to Cabin Point will decrease the amount of available sediment in the beach zone as long as the structure traps sediment and prevents erosion. The present groins at Kingcopsico Point are near the drift node, so they probably have a negligible influence on shoreline processes at Cabin Point.
A field investigation of the project area was made on 24-25 May 1976. One phase of this field investigation included measurement of water levels for 25 hours in Lower Machodoc Creek and in Cabin Point Creek at a pier located towards the west end of the bay (Figure 3-1). Inlet water velocities and depths were measured at a representative cross-section approximately one third of the distance up the inlet from its mouth. During this field investigation Potomac River tide ranges were smaller than normal (about 1.5 feet) as compared with the mean range of 1.8 feet, and the measured bay tide amplitude was approximately one-fourth of the river amplitude (Figure 3-2). Maximum mean velocities across the channel were approximately one foot per second (Figure 3-3).

To gain an increased understanding of the hydraulics of the system a computer numerical finite difference model of the system, called a lumped parameter model, was used to simulate the 25-hour study period. This numerical model solves a form of the one-dimensional equation of motion of the water in the inlet, and combines this information with the continuity equation between the inlet and bay to estimate bay level and inlet velocities given the tide and system geometry. This model accounts for varying depth throughout the tide cycle, and considers the non-linear change in cross-sectional area with tide stage due to the sloping sides. The model is easy to use, inexpensive, and has been shown to give good results for both tidal and non-tidal inlet hydraulics (Seelig, Harris, Herchenroder, 1976). In spite of the complex geometry of the inlet channel and bay, the simple model does an acceptable job of predicting bay levels and inlet velocities for engineering purposes (Figure 3-4). This calibration gives confidence that the model can be used to simulate inlet-bay system hydraulics for various hypothetical inlet channel designs. Also, results should be more accurate for these designs since the inlet channel geometries will be less irregular.
FIGURE 3-1. FIELD MEASUREMENT LOCATIONS
(from USGS map, St. Clements Is, 1968)
**Figure 3-2.** Observed water levels during 24-25 May 1976 field investigation.
Ebb Velocities, fps
Head across inlet = -0.66 feet

Flood Velocities, fps
Head across inlet = +0.66 feet

Flood Velocities, fps
Head across inlet = 0.22

FIGURE 3-3. OBSERVED INLET VELOCITIES
FIGURE 3-4. OBSERVED AND PREDICTED WATER LEVELS AND INLET VELOCITIES OF CABIN POINT CREEK INLET

\[ m = 0.044 \]
The field inspection and aerial photography show that the present inlet is migrating southward in the direction of longshore transport and that it reorients as it migrates. Also the overlapping spit of the inlet is occasionally broken through. There also appear to be occasional storm washovers and/or periodic inlet breaks through the thin barrier island just south of Cabin Point adjacent to the tree line (Figure 1-3 shows this tree line at the steep transition between geologic types).

The bed material of the present inlet is medium sand and gravel, and during the inspection there was very little sediment motion in the inlet.
CHAPTER 4

PREDICTED INLET HYDRAULICS AND STABILITY FOR ALTERNATIVE INLET DESIGNS

INLET-BAY CONDITIONS

In the design of an inlet channel there are some variables which can be easily changed, such as inlet width, depth, and to a certain extent length, while other variables such as the tide amplitude and period are fixed in a given design.

At Cabin Point Creek Inlet the following parameters are taken as fixed:

1. The river tide amplitude and period are given by spring and mean tides with amplitudes of 0.9 and 1.0 feet (from tide tables for Coles Point) and with a period of 12.5 hours.

2. The Cabin Point Creek bay area (measured from the 6/12/72 aerial photo) is taken as \( A_{\text{bay}} = 3.5 \times 10^6 \text{ft}^2 \).

3. The inlet depth is taken as 4.9 feet MWL (as specified in the permit application) to allow for navigation.

Variables that can be easily changed at this stage of design are:

1. The inlet length. The Hutt plan has an inlet length \( L \) of approximately 2100 feet including jetties. This is the maximum inlet length considered feasible for this project. The minimum inlet length would be achieved by cutting through at the narrowest section of the barrier to give a length of 575 feet, including the 300 foot jetties of Hutt's plan.
(2) the inlet width. The Hutt plan specifies the width (B) of the inlet as 100 feet (Figure 4-1), but this could be varied.

SYSTEM HYDRAULICS

An analysis of Cabin Point Creek Inlet hydraulics (Hutt plan) shows that for most combinations of parameters this system has a high coefficient of repletion (Keulegan, 1967). This means that the tides in the bay will be approximately the same as the tide in the Potomac. In addition, the phase lag between the tide in the bay and the Potomac will be small (compared to Fig. 3.2 for the natural inlet).

Under these conditions the tidal prism in the inlet can be taken as the bay tide range, \( R_b \), times the bay area, \( A_{\text{bay}} \). However, the bay tide range is approximately equal to the Potomac tide range, \( R_o \), so the tidal prism is approximated as:

\[
P = R_o A_{\text{bay}}
\]

Or

\[
P = 7.0 \times 10^6 a_o^2 \text{ in ft}^3
\]

where \( a_o \) is the tidal amplitude \( (R_o/2) \).

The inlet cross-sectional area at mean water level, \( A_c \), for a rectangular channel of the Hutt Plan is given by:

\[
A_c = 4.9 B
\]
Figure 4-1. IDEALIZED HUTTON PLAN
(5/15/76)
The lumped parameter model is used to predict resulting currents and bay levels for various inlet conditions. An n of 0.035 is used to model bottom friction in this analysis, and this is the n corresponding to the mean inlet depth using the Masch et al (1973) relation between n and mean depth.

Given the inlet/bay system geometry and the tide conditions, the numerical model predicts bay tide levels and inlet velocities as functions of time. The predicted inlet velocities and bay levels for the Hutt Plan (Figure 4-1) for a sinusoidal spring tide are shown in Figure 4-2. Note that the bay tide has approximately the same amplitude as the outside tide with a slight phase lag. The inlet velocity is approximately sinusoidal with minor inertial effects near slack water. The maximum flood velocity is 1.0 feet per second, and the velocity is 0.95 feet per second at maximum ebb.

The numerical model has been run a number of times with different inlet widths and lengths for the given channel depth and bay area to yield the results shown in Figs 4-3 and 4-4.

The conclusions of this analysis are that inlet velocities are larger for those designs that have shorter and narrower inlets. A shorter inlet design of 575 feet has velocities approximately 20% higher than the Hutt Plan. For all designs the flood maximum velocity is slightly larger than the ebb velocity due to the changing depth with water level. For all plans investigated, the bay level fluctuation increases over the present condition. For the Hutt Plan the bay tide range is predicted to be four times larger than the present bay tide or approximately equal to the forcing tide. Figure 4-5 shows the measured bay levels on 24-25 May 1976 and the predicted bay levels for the Hutt Plan (lumped parameter prediction).

**Seiche Forcing**

Another possible type of long forcing that could influence Cabin Point Creek Inlet hydraulics can be transverse oscillations of the Potomac River adjacent to the inlet. (This type of forcing is important to small inlets on the Great Lakes, so it should be investigated in the design).
Figure 4-2. Predicted inlet velocities and bay levels for the Hutt plan (spring tide)
FIGURE 4-4. INLET VELOCITIES AS A FUNCTION OF INLET WIDTH (d=4.9' MWL)

FIGURE 4-3. TIDAL PRISM AS A FUNCTION OF INLET WIDTH (d=4.9' MWL) AND LENGTH
FIGURE 4-5. BAY LEVELS OBSERVED FOR THE NATURAL INLET AND PREDICTED FOR THE HUTT PLAN
A cross-section of the river (Figure 4-6) shows that the mean depth is 21 to 23 feet depending on the tide. The period of oscillation of the Potomac for this depth is 0.6 hours using Merian's formula (SPM, Eq. 3-42).

Transverse oscillations may be produced when storm winds push water up on one side of the river. When this surge is released the river oscillates under the influence of gravity. The one-dimensional surges on the Potomac are predicted using winds for 1975 measured at three-hour intervals at National Airport (assumed similar to the lower Potomac winds) (2920 observations) (Figure 4-7).

Note that these surges are generally small. The may be higher in Lower Machodoc Creek.

Based on this information the lumped parameter model is used with the transverse oscillation period of 0.6 hours and an upper limit amplitude of 0.1 foot to show that transverse oscillations produce maximum velocities of at most 0.5 feet per second for any inlet design.

**INLET STABILITY**

O'Brien (1969) and Jarrett (1976) have found that inlet cross-sectional area is related to tidal prism for stable tidal inlets. From Jarrett the relation between area and prism at spring tide for inlets with two jetties on the east coast is given by:

\[
A_c = 5.77 \times 10^{-5} P^{0.95}; \text{ in } \text{ft}^2
\]

(4-5)

The predicted cross-sectional area for an inlet dredged at Cabin Point is 184 square feet (Eq. 4-5) or an inlet 38 feet wide and 4.9 feet deep, MWL.

If the inlet cross-sectional area gets larger than the stable area, the inlet will tend to shoal; while if the inlet area is smaller than the stable area, the associated higher velocities will tend to scour out the channel.
Figure 4-6 Potomac River Cross-Section

Width $a = 28655 \text{ ft}$

Depth $21 \leq d \leq 23$'

Period of 1st transverse mode of oscillation, $T_1$:

$$T_m = \frac{2a}{n\sqrt{gd}} = \frac{2(28655)}{1.132 \cdot 21}$$

$$T_1 = \frac{21055\pi}{0.6 \text{ hrs}}$$
Figure 4-7

Transverse Surge Prediction
For THE POTOMAC RIVER
For 1975
Another stability indicator is that of Bruun defined as \((\text{Tidal prism at spring tide})/\text{(Annual longshore transport rate)}\) (Table 2). For Cabin Point the shoaling indicator parameter is at maximum 90, indicating that any inlet at this location will probably require maintenance dredging.
### Figure 4-8. Sediment Motion for Uniform Diameter Sediment

![Graph showing sediment motion for uniform diameter sediment]

### TABLE 2. Shoaling Indicator Parameter (Bruun, 1966)

<table>
<thead>
<tr>
<th>Value</th>
<th>Stability</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 100</td>
<td>Bad</td>
<td>Much shoaling</td>
</tr>
<tr>
<td>150</td>
<td>Fair</td>
<td>Some shoaling</td>
</tr>
<tr>
<td>Greater than 300</td>
<td>Good</td>
<td>Little shoaling and maintenance</td>
</tr>
</tbody>
</table>

(Tidal Prism/Annual Longshore Transport)
ANALYSIS OF ALTERNATIVES

There are three basic alternatives or some combination of these that will be considered:

(1) Do Nothing Plan. The development of this area will continue but no dredging of channels and inlets or inlet construction will be undertaken.

(2) The Hutt Plan. Build jetties, dredge an inlet and interior channels, and place dredged material on Spoil Area Nos. 1 and 2 (Figure 1-2).

(3) An Alternative Plan. Build jetties immediately south of Cabin Point, dredge a shorter inlet, dredge a channel offshore to the required depth, dredge interior channels, place some dredged material on upland areas, and place approved dredged sand and gravel directly on the beach face south of the inlet (Figure 5-1).

Each of these plans has advantages and disadvantages, and a summary of some of these factors is shown in Table 3. Discussion of the more important items in Table 3 follows.

(a) Erosion downdrift of jetties. No matter which plan is adopted, the erosion of the narrow beach south of Cabin Point is expected to encourage periodic breaks through the beach during storms. These breaks will probably be small and temporary. However, if an extreme event, such as a large storm with a high tide, is able to cut an inlet larger than the critical area of about 60 square feet, the inlet may tend to enlarge and remain open if the Do Nothing plan is adopted. This new inlet could predominate and tend to capture the present inlet.
TABLE 3. Analysis of Alternatives

<table>
<thead>
<tr>
<th>Factor</th>
<th>(1) No Action</th>
<th>(2) Butt Plan</th>
<th>(3) Alternative Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) down drift erosion</td>
<td>will continue at present rate</td>
<td>will increase</td>
<td>will increase</td>
</tr>
<tr>
<td>(b) spit growth at Vancouver Creek</td>
<td>will continue</td>
<td>will slow</td>
<td>will slow</td>
</tr>
<tr>
<td>(c) collection of sediment at inlet</td>
<td>some added growth, some bypassing</td>
<td>must longshore sediment trapped, additional bypassing by dredging</td>
<td>must longshore sediment trapped, additional bypassing by dredging</td>
</tr>
<tr>
<td>(d) flood tidal delta</td>
<td>small delta</td>
<td>small delta</td>
<td>larger delta</td>
</tr>
<tr>
<td>(e) dredging requirements</td>
<td></td>
<td></td>
<td>inlet will tend to be more self maintaining because of higher velocities and increased velocities as inlet shoals. However, self maintenance may be slow if large diameter sediment is deposited in the channel. Probably spring dredging required.</td>
</tr>
<tr>
<td>(f) navigation</td>
<td>none</td>
<td>more difficult to build due to orientation.</td>
<td>more difficult to build due to orientation.</td>
</tr>
<tr>
<td>(g) jetty construction</td>
<td>slow rate</td>
<td>increased erosion</td>
<td>increased erosion</td>
</tr>
<tr>
<td>(h) erosion of Cabin Point Creek</td>
<td>present rate, pollutants will be</td>
<td>increased erosion</td>
<td>increased erosion</td>
</tr>
<tr>
<td>(i) exchange of water</td>
<td>more concentrated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(j) movement of water from inlet</td>
<td>a significant portion will move up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(k) effect of water on oysters</td>
<td>Lower Naches Creek because it is on flood tide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(l) effect of high tide range on biota in Cabin Point Creek</td>
<td>more poor quality water on oysters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m) effect of initial dredging on Lower Naches Creek biota</td>
<td>poorer quality water, however biota accustomed to range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n) effect of maintenance dredging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(o) beach protection with dredged material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(p) dredged material effects on biota</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same as Butt Plan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Increased erosion is due to increased wave height and increased current velocity.
FIGURE 5-1   ALTERNATIVE PLAN

- **Beach Fill of Sand and Gravel to protect beach**
- **Inlet**: 40' wide, 4' deep MLW
- **Interior Channels**: 60' wide, side slope 1:2, 4' deep MLW
- **Cabin Point Creek**
- **Lowland Marsh**
- **Woods**
- **Sand**
- **1000'**

**Lower Machado Creek**
A disadvantage of the Alternative Plan is that it would cause accelerated erosion of the narrow beach just south of the new jetties.

(e) Dredging requirements. The Hutt Plan will probably require a good deal of maintenance dredging. The inlet velocities will be low, at a maximum of one foot per second (Figure 4-2). These velocities will not remove sediment from the inlet (Figure 4-8), so after storms causing high drift rates the inlet may not be navigable. The inlet area for the Hutt Plan is 2.6 times larger than the predicted stable area for an Atlantic coast inlet with two jetties and the shoaling indicator parameter of Bruun (tidal prism/longshore transport) has a value of at best 90. Both indicators show that the inlet will not clear itself of sediment that enters the inlet. Dredging will probably be required in late winter for the Hutt plan. For the first year most of the longshore transport will probably be trapped in a fillet just updrift of the jetties, and dredging may not be necessary.

At the proposed inlet site in the Hutt Plan the inlet width would have to be reduced to 20 feet with the 4.9 foot depth MWL to develop high enough velocities for the inlet to begin to maintain itself.

An advantage of the Hutt plan is that the inlet is located at a point where the water depths rapidly increase away from shore. Figure 3-1 shows that the 6 foot depth contour is closest to shore at this point. At the Alternate Plan location water depth increases more slowly with distance offshore, so that the 6 foot contour is three times further from shore.

In addition to the jetties, the Alternative Plan will require approximately a 500-foot channel to be dredged beyond the end of the jetties to provide a 4' deep MLW passage for navigation. This channel would probably shoal and require dredging every one to two years because sediment would be moved to the channel by currents in the Potomac River, tides and wind waves. This long outer channel is a disadvantage of the Alternative Plan.

The Alternative Plan uses a shorter and narrower inlet channel and shorter jetties (Figure 5-1, 5-2). This design is at the predicted stable inlet area determined from the prism vs area relationship (Equation 4-5) and produces higher
Figure 5-2. Cross-Section Survey of Alternative Plan Site
inlet velocities of about 2.5 feet per second maximum at spring tide (Figure 4-4). An additional advantage of this plan is that as the inlet shoals, the velocities will increase to about three feet per second at a depth of three feet MNL. These increased velocities then scour out the material so that the inlet will move back toward the hydraulically stable area (Figure 5-3). Note however, if a large amount of gravel should shoal the inlet, it is not known how long, if ever, it would take the inlet to naturally regain its predicted stable cross-sectional area. If the inlet is larger than the stable area, it will tend to shoal back to its stable area. In general the larger the inlet area, the more shoaling and dredging will be required to maintain the channel.

There is little guidance available on the effect of jetty orientation. Jetties perpendicular to the shore require less length to reach a given offshore depth than jetties positioned at an oblique angle to the shore. A west jetty longer than the east one will probably reduce wave heights at the entrance to the jettied channel and provide better protection to boats entering the inlet.

If jetties are constructed at Cabin Point the applicant should consider use of a sand eductor system to by-pass longshore transport. This system, currently being studied by the U.S. Army Waterways Experiment Station (principle investigator, Mr. Clark McNair, 601-636-3111), uses a small land-based centrifugal pumping system to transport sediment from the updrift to the downdrift side of jetties. The centrifugal pump drives a jet pump which is placed offshore at the desired dredging location, and pumps the sand-water mixture through a discharge line to the downcoast area. Mr. McNair calls Cabin Point an ideal location for an eductor because the longshore transport rate is small, the wave climate is mild, and longshore transport is predominantly in one direction. The advantages of this system are that the initial cost is low, it should significantly reduce dredging costs and the system is easy to use.

The centrifugal pumping system would be mounted on land near the base of the jetties, the jet pump intake anchored offshore west of the western
Figure 5-3. Stability Analysis for the Alternative Plan Inlet Design.
jetty where shoaling is expected and the discharge pipe laid so that the exit is located on the beach downdrift (south) of the jetties. When a shoal forms next to jetty, the system is turned on by the operator, perhaps for several days at a time, to by-pass the sediment. A funnel-shaped depression forms near the mouth of the jet pump which encourages sediment to move toward the intake of the jet pump.

By carefully dredging the shoal next to the base of the western jetty, little sediment will reach the end of the jetties, so shoaling in the inlet will be minor.

Two to three weeks of operation would be required each year to by-pass longshore transport. Operation in the winter is recommended to minimize harmful effects to biota. The system is portable and can be used at other locations.

Mr. McNair estimates that this installation could use off-the-shelf components including a jet pump with a 3" to 4" suction port ($1500), a centrifugal pump rated at 1000 to 1200 gallons per minute and 200 feet of head (electric power recommended) ($5000), 700 to 800 feet of heavy exit pipe ($600).

A disadvantage of the eductor system is that experience with this system is limited.

(i, j, k) For the Hutt and the Alternative Plans the flushing and dilution of water in Cabin Point Creek will be increased. In addition, this water will be discharged from the inlet earlier in the tidal cycle when Lower Machodoc Creek is ebbing so that more of this water will be carried directly into the Potomac. If Plan (1) (Do Nothing) is adopted polluted discharge from Cabin Point Creek will be more concentrated with pollutants and more of this water will be carried directly into Lower Machodoc Creek on the flood tidal cycle (Figure 5-4).

(m) All initial dredging operations and jetty construction should be carried out only in the winter months to minimize adverse effects on oysters and other biota in Lower Machodoc Creek. The old inlet should first be closed off using temporary sand bags (remove after dredging is complete).
Figure 5-4 predicted inlet discharge patterns for alternative inlet designs.
Dredging of interior channels and the back side of the inlet can be completed while the jetties are being built. Then Cabin Point Creek should be allowed to sit for sediment to settle out of suspension. The inlet then can be completely cut through and exterior channels dredged. When the dredger finishes the exterior channels, it can then eliminate any shoals that have formed in the inlet during adjustment. If Plans (1) or (2) or some combination are adopted, this dredging procedure should minimize effects on oysters in Lower Machodoc creek.

The amount of suspended sediment introduced into Lower Machodoc Creek by dredging will be similar to the amount stirred up by a storm.

(n,o) Some form of beach protection is recommended for the barrier beach south of Cabin Point. The most economical protection, if acceptable, would be placement of sand and gravel from dredging operations on the beach face.

(p) If at all possible the final plan should be designed to minimize destruction of wetlands. A walk-through inspection of the marsh just south of Cabin Point (Figure 1-3) showed that this area is very productive. An alternative disposal area could be the upland area west of Cabin Point Creek, although this disposal will be much more expensive. Acceptable sand and gravel should be placed directly on the beach face. Another suggestion is to place some dredged material within Cabin Point Creek (not on present marsh) in such a way as to encourage new marsh development. Garbisch et al (1975) and Johnson et al (1975) describe methods for creating marsh, which include examples in the Chesapeake Bay. (Contact your Soil Conservation Service representative for a list of contractors who could plant marsh grasses). Some dredged material could also be placed to fill the present inlet channel.
In specific response to questions by NAB shown on Page 1:

a. The Hutt and Alternative plans will increase the tidal range in the bay by a factor of three to four, or from a half foot to two feet for Spring tide. This increased range will initially encourage erosion to the bay shores of Cabin Point Creek. However, the increased fluctuation will encourage vegetation which will slow erosion. Marshes should adjust to the increased range with slow changes in the types of marsh grasses. The proposed 300-foot jetties will block all longshore transport north of the jetties, perhaps for a year or more. After that some shoaling in the inlet and adjacent portions of the bay and some by-passing will occur. Of the by-passed material some will form a small fillet south of the jetties. The decrease in sediment supply down-drift of the jetties will cause unprotected shores to erode at a faster rate.

b. If the "Do Nothing" plan is adopted the water quality in Cabin Point Creek will probably decrease as a result of runoff and other discharge from the housing development in the area (fertilizers, pesticides, pet wastes, construction materials, etc.). These chemicals will tend to build up in Cabin Point Creek and become concentrated with the present inlet because the exchange with Lower Machodoc Creek is relatively small and will decrease as the present inlet channel grows in length and become less efficient hydraulically. If the Do Nothing plan is adopted the water discharging from the inlet will be relatively, highly concentrated with pollutants and this water will tend to move up Lower Machodoc Creek (south) because the maximum inlet discharge occurs when the tide is on flood. With either the Hutt Plan or the Alternative Plan there will be almost four times as much mixing of water between Cabin Point Creek and Lower Machodoc Creeks, so pollutants will be less concentrated. In addition discharge from Cabin Point Creek will tend to move out into the Potomac River because maximum discharge from the inlet will occur on ebb tide.
The erosion to the narrow beach adjacent to Cabin Point will result in breaks through the barrier during extreme storms. For the Do Nothing Plan, if a large enough cross-sectional area is established at one of these break-throughs, the inlet may become established at this point and capture the present inlet. In any case navigation between Cabin Point Creek and Lower Machodoc Creek will probably be impossible due to the small size of natural inlets for the available tidal prism.

c. 1) The jetties in the Hutt Plan will cause a fillet to form updrift of the jetties, which will trap one to two years of longshore transport. After that time longshore transport will begin to move across the mouth of the inlet, and some of this material will be trapped in the inlet. The remainder of the material will be by-passed. Of the by-passed material, some sediment will form a fillet on the east side of the jetties. One method of by-passing longshore transport is to use an eductor system. Present indications are that such a system would be well suited to this project, (see Chapter 5).

2). If the Do Nothing plan is adopted the present creek mouth will migrate slightly to the southeast. Periodic breaks through the sand bar overlapping the inlet mouth should prevent the inlet from moving much further southeastward. There is a good possibility that a new inlet will be opened through the narrow barrier west of the existing inlet and that the new inlet will capture the bay tidal prism. In such a case, the existing inlet will close.

3). The Hutt Plan will probably require dredging annually, preferably in the late winter, once material begins to by-pass the inlet one to two years after the jetties are complete. Dredged material should be placed on the beach to the southeast. The eductor system discussed in Chapter 5 could be used to by-pass sediment and prevent most shoaling in the inlet. Interior channels will probably not need maintenance dredging except to dredge an occasional shoal near the inlet.

4). Tide range in the creek will increase approximately three to four times if the Hutt Plan is executed. The present inlet is long and small and has a high friction coefficient. As a result, there is a comparatively small
exchange of water between Lower Machodoc Creek and Cabin Point Creek. The Hutt Plan will allow the maximum exchange of water between Lower Machodoc Creek and Cabin Point Creek (Figure 4-3).

5). The Hutt Plan calls for placement of dredged material on Spoil Area Nos. 1 and 2. Placement on these presently productive marshes is not recommended because the fill will destroy most of the plant and animal life in these areas. The present marsh should adapt to the increased tidal range in Cabin Point Creek.

6). We recommend that some of the material be used to build additional marsh land. (see Garbisch et al, 1975 and Johnson et al 1975). That portion of dredged material which is clean sand and gravel should be placed directly on the beach south of Cabin Point to protect the beach. Additional dredged material could be placed on upland sites.

7). The only drift node in the vicinity is at Kingcosico Point.

8). The effect of the Hutt Plan on nearby shell fish will be minimized if the present inlet is closed off with temporary sand bags, interior channels dredged while jetties are built, and most of the inlet channel dredged from the interior outward. The system should then be allowed to sit for several weeks to allow suspended sediment in Cabin Point Creek to settle. The final cut could then be made at a low water stage of tide to connect Cabin Point Creek and Lower Machodoc Creek. The temporary sand bags closing the present inlet mouth should then be removed. All dredging operations should be conducted during the winter when shell fish are least active. The amount of suspended sediment introduced into Lower Machodoc Creek using this plan would be similar to the amount of sediment stirred up by a storm.

An advantage of the Hutt Plan is that water will be discharged from the inlet when Lower Machodoc Creek is on ebb tide, so that lower quality water from Cabin Point Creek will be directly carried out to mix with the Potomac River. With the present inlet, maximum discharge occurs when Lower Machodoc Creek is
on flood, so that Cabin Point Creek water will be carried up Lower Machodoc Creek.

d. Pros and cons of the various actions and alternatives are given in Chapter 5, and summarized in Table 3 and above.
REFERENCES


CABIN POINT CREEK PROFILE P-NA

FT.

0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340

50

40

30

20

10

0

-10

CABIN POINT CREEK PROFILES P-NA
CABIN POINT CREEK II SOUTH

PROFILE NO. 01

- OCT 1983
- JUN 1983
- JAN 1983
- AUG 1982

FEET (MSL)

0
-5
100
200
300
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FEET

CHOICE

MSL

OCT 1983
JUN 1983
JAN 1983
AUG 1982
CABIN POINT CREEK II SOUTH
PROFILE NO. 03

AUG0581
JUL0881
MAR1181
OCT3080
AUG2780

FEET (MSL)

FEET

0 100 200 300 400

CHOICE

MSL

0 2 5

-5
CABIN POINT CREEK & SOUTH
PROFILE NO. 03

- AUG 1382
- JUN 1182
- MAR 182
- DEC 881
- AUG 581

FEET

(MLLW)

M0

0

-5

0 100 200 300 400

385 375 365 355 345 335 325 315 305 300

CHOICE
AUGUST 1, 1980

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

TEMP (°C) AND SAL (ppt)

SUSPENDED SOLIDS

TOTAL PHOSPHATE

D.O. (mg/l) AND CHLA (μg/l)

LEGEND

- TEMP

- SAL

- DO

- CHLA

SUSPENDED SOLIDS (mg/l)

TOTAL PHOSPHATE (μg/l)

STATIONS

STATIONS

STATIONS

STATIONS
OCTOBER 5, 1980

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate

Legend
- X - Temp
- V - SAL
- A - D.O. (mg/l)
- O - CHL a
- A - TOTAL PHOSPHATE (mg/l)
NOVEMBER 20, 1980

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE
JANUARY 30, 1981

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate

Legend

- TEMP
- SAL

- DO
- CHLA
MARCH 17, 1981

TEMPERATURE AND SALINITY

DISTRIBUTION OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend
- TEMP
- SAL
APRIL 22, 1981

**TEMPERATURE AND SALINITY**

**DISSOLVED OXYGEN AND CHLOROPHYLL a**

**SUSPENDED SOLIDS**

**TOTAL PHOSPHATE**

Legend:

- **X** Temp
- **○** Sal
- **△** DO
- **○** CHLA

---

**TEMPERATURE AND SALINITY**

**DISSOLVED OXYGEN AND CHLOROPHYLL a**

**SUSPENDED SOLIDS**

**TOTAL PHOSPHATE**

Legend:

- **X** Temp
- **○** Sal
- **△** DO
- **○** CHLA

---
MAY 19, 1981

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphorus
JUNE 15, 1981

TEMPERATURE AND SALINITY

DISTRIBUTED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend
- TEMP
- SAL

Legend
- DO
- CHL a

SUSPENDED SOLIDS (mg/l)

TOTAL PHOSPHATE (mg/l)

STATIONS
AUGUST 5, 1981

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

X TEMP

v SAL

D.O.(mg/l) AND CHL-A (mg/l/10)

TOTAL PHOSPHATE (mg/l)

Legend

a DO

o CHL-A

STATIONS

STATIONS

STATIONS

STATIONS
FEBRUARY 19, 1982

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

TEMP

SAL

Legend

O2

U.S.A
MARCH 17, 1982

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

LEGEND

TURF

SAL

D.O. (mg/l) AND CHL.a (mg/l)

TOTAL PHOSPHATE (mg/l)
APRIL 19, 1982

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate
APRIL 29, 1982

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate

Legend

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<thead>
<tr>
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<th>Chla</th>
</tr>
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<tbody>
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<td>X</td>
<td>O</td>
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<tr>
<td>S</td>
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MAY 19, 1982

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

TEMP (deg. C) AND SAL (ppt)

D.O. (mg/l) AND CHL (ug/l)

SUSPENDED SOLIDS (mg/l)

TOTAL PHOSPHATE (mg/l)

Legend

× TEMP

○ SAL

△ D.O.

○ CHL a

Legend
JULY 28, 1982

TEMPERATURE AND SALINITY

DISTRIBUTED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

\( \times \) TEMP
\( \triangledown \) SAL
SEPTMBER 30, 1982

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL $a$

SUSPENDED SOLIDS

TOTAL PHOSPHATE
OCTOBER 27, 1982

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL \( \alpha \)

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

\( \times \) TEMP

\( \triangledown \) SAL

\( \Delta \) DO

\( \bigcirc \) CHL

SUSPENDED SOLIDS (mg/l)

TOTAL PHOSPHATE (mg/l)

STATIONS

STATIONS
NOVEMBER 26, 1982

TEMPERATURE AND SALINITY

Legend
X TEMP
V SAL

Dissolved Oxygen and Chlorophyll a

Legend
A DO
○ LA

Suspended Solids

Total Phosphate

Legend
A LA

205
DECEMBER 27, 1982

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

* TEMP

X SAL
JANUARY 26, 1983

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL \(\alpha\)

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend
- TEMPERATURE
- SALINITY

Legend
- DO
- ChLA
FEBRUARY 23, 1983

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate
MARCH 24, 1983

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

\[ \text{TEMPERATURE} \]

\[ \text{SALINITY} \]

\[ \text{D.O. (mg/l)} \]

\[ \text{and Chl-a (ug/l/10)} \]

\[ \text{TOTAL PHOSPHATE} \]

Legend

\[ \text{D.O. (mg/l)} \]

\[ \text{and Chl-a (ug/l/10)} \]
APRIL 21, 1983

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

Legend

D.O. (mg/l) AND CHL-a (kg/m^3)

SUSPENDED SOLIDS (mg/l)

TOTAL PHOSPHATE (mg/l)
MAY 20, 1983

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate
JUNE 20, 1983

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL "a"

SUSPENDED SOLIDS

TOTAL PHOSPHATE
AUGUST 26, 1983

TEMPERATURE AND SALINITY

SUSPENDED SOLIDS

DISSOLVED OXYGEN AND CHLOROPHYLL a

TOTAL PHOSPHATE

Legend
- TEMP
- SAL
MEAN MONTHLY SALINITY

Legend
△ Outside(1,8)
× Inside(4,5,6,7)

Outside=Mean for Stations 1,8
inside=Mean for Stations 4,5,6,7

STATIONS

MOVING TIME SERIES
MEAN(SAL) WITH MO BY YR

Legend
△ YR=80
● YR=81
▼ YR=82
◆ YR=83

MEAN OF STATIONS 4, 5, 6, 7
MEAN(SAL) WITH MO BY YR

MEAN OF STATIONS 1 and 8

Legend
△ YR=80
□ YR=81
▼ YR=82
◆ YR=83

SALINITY (ppt)

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

20
15
10
5
0
MEAN MONTHLY DISSOLVED OXYGEN

STATIONS

△ Outside(1,8)
× Inside(4,5,6,7)

Outside = Mean for Stations 1,8
Inside = Mean for Stations 4,5,6,7
MEAN(DO) WITH MO BY YR

MEAN OF STATIONS 4, 5, 6, 7

Legend

△ YR=80
□ YR=81
▼ YR=82
☒ YR=83
MEAN(DO) WITH MO BY YR

MEAN OF STATIONS 1 and 8

Legend

△ YR=80
■ YR=81
▼ YR=82
□ YR=83

DISSOLVED OXYGEN (mg/l)

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MEAN MONTHLY CHLOROPHYLL a

CHL. a (ug/l)

80

60

40

20

0

STATIONS

△ Outside(1,8)

× Inside(4,5,6,7)

Outside=Mean for Stations 1,8
inside=Mean for Stations 4,5,6,7
MEAN(CHLA) WITH MO BY YR

MEAN OF STATIONS 4, 5, 6, 7

Legend

△ YR=80
■ YR=81
▼ YR=82
□ YR=83
Mean Monthly Suspended Solids

Legend

- Δ Outside (1,8)
- × Inside (4,5,6,7)

Outside = Mean for Stations 1, 8
Inside = Mean for Stations 4, 5, 6, 7
MEAN MONTHLY SUSPENDED SOLIDS

STATIONS

Outside(1,8)
Inside(4,5,6,7)

Outside=Mean for Stations 1,8
Inside=Mean for Stations 4,5,6,7
MEAN MONTHLY TOTAL PHOSPHORUS

STATIONS

Outside(1,8)

Inside(4,5,6,7)

Outside=Mean for Stations 1,8

Inside=Mean for Stations 4,5,6,7
MEAN(SS) WITH MO BY YR

STATION 3

Legend

△ YR=80
× YR=81
□ YR=82
● YR=83

SUSPENDED SOLIDS (mg/l)
MEAN(TP) WITH MO BY YR

MEAN OF STATIONS 1 and 8

Legend
△ YR=80
■ YR=81
▼ YR=82
□ YR=83
INTENSIVE AUGUST 26, 1980 1150 TO 1305 HOURS

TEMPERATURE AND SALINITY

DISTRIBUTED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

X TEMP

v SAL


d O.T.P.(mg/l) AND CHL.a (ug/l/m)

Phosphate (umol/l)
INTENSIVE AUGUST 27, 1980 0545 TO 0650 HOURS

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate

Legend:

- TEMP
- SAL

- D.O. (mg/l) and Chl-a (ug/l)

- Total Phosphate (ug/l)
INTENSIVE SEPTEMBER 2, 1981 1800 TO 2400 HOURS

TEMPERATURE AND SALINITY

Suspended solids

Dissolved oxygen and chlorophyll a

Total phosphate
INTENSIVE SEPTEMBER 3, 1981 0600 TO 1000 HOURS

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll α

Suspended Solids

Total Phosphate
INTENSIVE AUGUST 12, 1982 0800 TO 1545 HOURS

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate
INTENSIVE AUGUST 12, 1982 1530 TO 2100 HOURS

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate
INTENSIVE AUGUST 13, 1982 0500 TO 0700 HOURS

TEMPERATURE AND SALINITY

DISTRIBUTED OXYGEN AND CHLOROPHYL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE
INTENSIVE  AUGUST 13, 1982  0900 TO 1200 HOURS

TEMPERATURE AND SALINITY

Dissolved Oxygen and Chlorophyll a

Suspended Solids

Total Phosphate

Legend

D.O. (g/l)

S.C.

Sal

Phosphate (g/l)

Legend

D.O.

S.C.

Phosphate (g/l)
INTENSIVE SEPTEMBER 15, 1983 0900 TO 1025 HOURS

TEMPERATURE AND SALINITY

DISSOLVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE
INTENSIVE SEPTEMBER 15, 1983 1200 TO 2000 HOURS

TEMPERATURE AND SALINITY

DISSLOVED OXYGEN AND CHLOROPHYLL a

SUSPENDED SOLIDS

TOTAL PHOSPHATE
INTENSIVE SEPTEMBER 16, 1983 0416 TO 0620 HOURS

TEMPERATURE AND SALINITY

Legend

D.O. (mg/l) AND CHL.a (µg/l/10)

SUSPENDED SOLIDS

TOTAL PHOSPHATE

Legend

TOTAL PHOSPHATE (mg/l)