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Present and historical environmental survey of Broad Creek, Norfolk, Virginia : with special reference to biotic communities and the effects of alum discharge

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PRESENT AND HISTORICAL ENVIRONMENTAL SURVEY OF BROAD CREEK, NORFOLK, VIRGINIA WITH SPECIAL REFERENCE TO BIOTIC COMMUNITIES AND THE EFFECTS OF ALUM DISCHARGE

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ABSTRACT

Sediment samples collected from 15 stations in Broad Creek, a tributary of the Eastern Branch Elizabith River (Norfolk, VA) were analyzed for various sedimentary and stratigraphic features to determine the distribution of alum sludge (aluminum as the hydroxide) resulting from discharge from the Moore's Bridge Water Treatment Plant. Enrichment of surface sediments with aluminum was evident at all stations, with decreasing concentration as one progresses downstream from the Moore's Bridge plant discharge. At the bottom of the cores, aluminum enrichment was not observed. With the exception of the aluminum enrichment in the surface layers, the sediments appear typical of tidal freshwater-estuarine transition zones.

The benthic invertebrate communities consisted of eurytopic and opportunistic species characteristic of freshwater-estuarine transition zones. While animal densities were low, they were within the range typical of this type of community, and no impact of the treatment plant was recognizable except perhaps at Stations 1 and 2. Diversity of the communities in the more saline downstream areas was similar to that found in the adjacent portions of the Eastern Branch Elizabeth River.

The marsh communities were also examined for possible effects of alum sludge discharge. The marshes around the upper half of Broad Creek are typical of freshwater-estuarine transition zones. No clear negative impacts were recognized either from the water treatment plant discharge or any other environmental factor.

The implications of several mitigation alternatives are discussed. It is concluded that elimination of alum sludge discharge would be appropriate to eliminate any possible effect of aluminum which may have been unrecognized. On the other hand, mitigation efforts involving removal of aluminum contaminated sediments are expected to have marked impacts on the marshes with little or no improvement in the benthic invertebrate communities, and are therefore not recommended.

INTRODUCTION

Broad Creek is a small tidal tributary of the Eastern Branch Elizabeth River. The shoreline of the creek is substantially urbanized with both residential and commercial development. Located at the head of Broad Creek is the Moores Bridge Water Filtration Plant of the City of Norfolk, in continuous operation since 1880. The by-products of water filtration have been discharged into the creek for the past 80 years. These by-products in recent times include alum sludge, activated charcoal, and particulates removed from the water being processed, mainly organic materials. Of particular concern is the discharge of alum sludge since aluminum like most heavy metals, can be toxic under certain circumstances.

Aluminum is a naturally occurring element in the matrix of clay minerals such as kaolinite which are characteristic of the sediments of the coastal plain of Virginia. The addition of alum sludge to a natural system such as Broad Creek can be expected to produce enrichment of the bottom sediments with aluminum. This enrichment can be quantitatively demonstrated by measuring aluminum as a ratio to another element in the substrate which will be conservative, an element such as silicon. By measuring the Al:Si ratio at varying distances downstream of the discharge point and at increasing depths in the sediment, one can then map the apparent extent of contamination resulting from the practice of discharging the alum sludge deposits from a water treatment plant such as the Moores Bridge Water Treatment Plant into the upper reaches of Broad Creek.

Alum sludge or more accurately aluminum hydroxide is relatively insoluble in water unless the solution is rather strongly acidic (pH 4 or less). When solubilized, aluminum is toxic like most other heavy metals, but as a solid such as aluminum hydroxide, it is quite non-toxic (Burrows, 1977; Driscoll, et al., 1980; Lamb and Bailey, 1981). Since water in Broad Creek is not strongly acidic (i.e., pH = 6.5 to 7.5), it is not expected that the aluminum would be in solution, and therefore, little or no toxicity is to be expected. However, there are two situations in which toxicity could develop: first, rainfall in the area is often acidic, sufficiently so to solubilize aluminum sulfate if the receiving water has a low buffering capacity (not considered likely in Broad Creek), and second, pH of pure water, especially under anaerobic conditions, could be low enough to solubilize alumimum hydroxides. An additional and more likely source of impact of alum sludge discharges on the benthic community would be mediated by changes in the substrate resulting from sedimentation. Considering the potential for impacts on the benthic fauna, it is important to evaluate the condition of the fauna associated with sediments in Broad Creek.

Submerged benthic communities have historically been useful in evaluating environmental impacts. The life history characteristics of the species inhabiting the benthos are such that they tend to be good long-term integrators of effects of natural physical parameters and pollutants (Boesch, 1977; Diaz, 1977). Low salinity environments like Broad Creek typically have communities which are naturally low in species. This makes an evaluation of changes resulting from pollutants more difficult to detect than in areas with more diverse communities (Roberts, et al., 1975). Nevertheless, pollutant effects on benthic communities are recognizable in low salinity habitats when of sufficient magnitude.

Benthic algal communities also may be negatively impacted by environmental pollutants, resulting perhaps in changes in community size. Changes in benthic algal communities can be examined in terms of chlorophyll a concentration in the sediment. While not an objective of the present study, a small amount of sedimentary chlorophyll a data was collected. The marsh communities adjacent to creeks may be affected by man's activities, resulting in changes in species composition, total marsh area, and plant production. It was a major objective to examine these communities.

OBJECTIVES

The objectives of this study were:

1. to determine the areal extent of discharged materials from Moores Bridge within Broad Creek using the aluminum:silicon ratio as an indicator;
2. to evaluate the benthic invertebrate communities within Broad Creek;
3. to evaluate the marsh communities near the filtration plant;
4. to review historical biological data for Broad Creek and the Elizabeth River and to relate the biological communities within the two systems;
5. to identify possible mitigation alternatives and evaluate their implications.

MATERIALS AND METHODS

Study Site Description

Broad Creek is a small tributary of the Eastern Branch Elizabeth River (Figure 1). It flows in a wide westward to southward curve from its origin at the confluence of the discharges from Lake Taylor and, to a lesser extent, from Lake Wright which contribute most of the freshwater entering this stream. There are several small streams entering Broad Creek at various downstream points, but these contribute little fresh water. Discharges from the two lakes are regulated, resulting in pulsed discharges of freshwater. The Moores Bridge Filtration Plant located at the head of Broad Creek seems to be the only major point source discharge into Broad Creek.

The shoreline of Broad Creek is a combination of undeveloped marsh, residential housing, and commercial development. From the discharge point of the water filtration plant downstream to the Military Highway bridge, the shoreline is exclusively undeveloped marsh. Between Military Highway and Virginia Beach Boulevard, the shoreline is extensively vegetated with isolated sections with residential and industrial development. Just upstream from Virginia Beach Boulevard is a public park on the western bank. Between Virginia Beach Boulevard and the Interstate 264 and railroad bridges at the mouth, the shoreline is today primarily residential with only a few undeveloped sections on the eastern bank, although there was a package sewage treatment plant serving one subdivision in the past. In

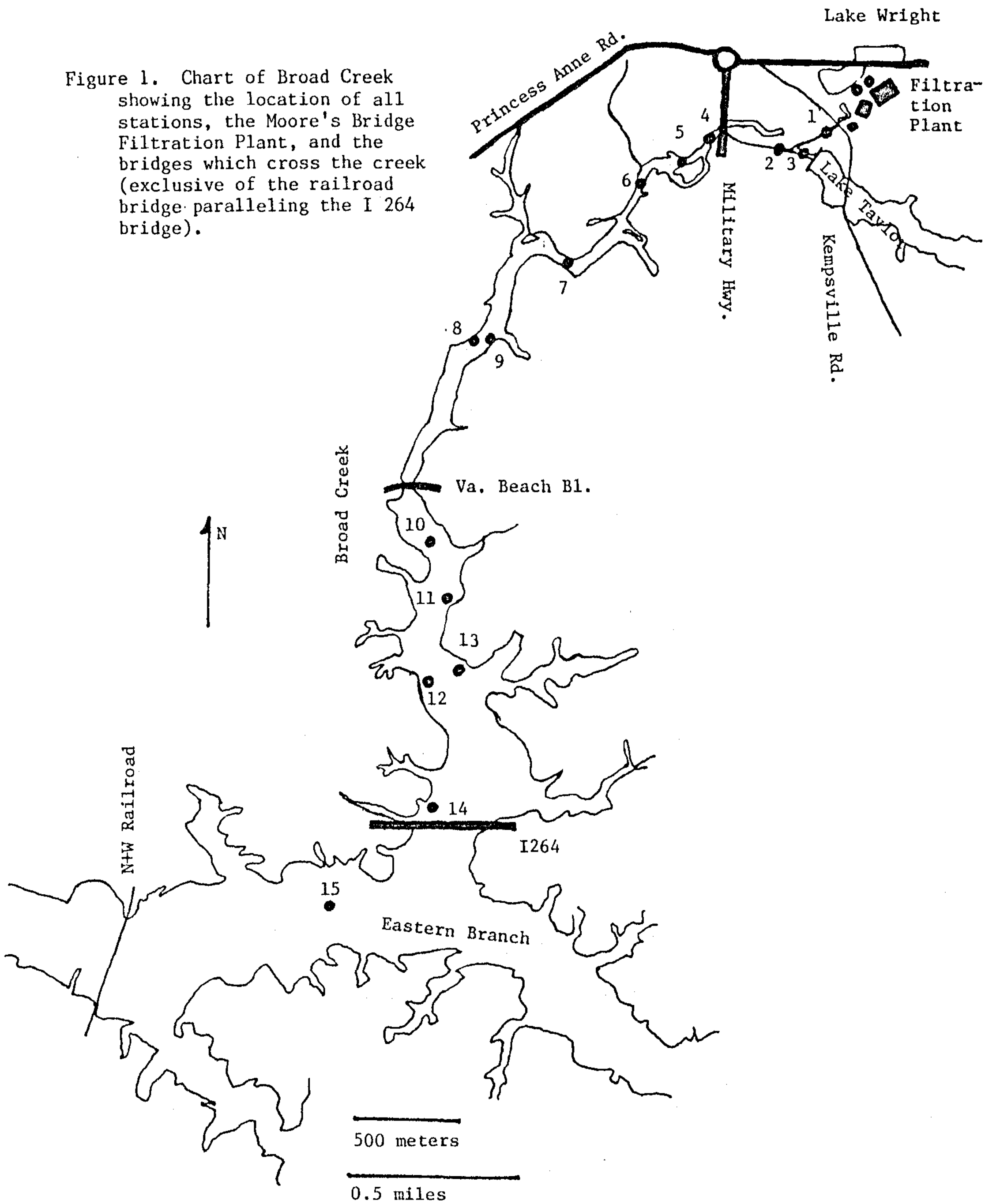

Figure 1. Chart of Broad Creek showing the location of all stations, the Moore's Bridge Filtration Plant, and the bridges which cross the creek (exclusive of the railroad bridge paralleling the I 264 bridge).

this section, many portions of the creek are bulkheaded.

The bottom of Broad Creek consists of moderately soft sediments in most locations. Wolfram (1979) reported the sediments to have a "'quick-sand-like' composition" both along the stream banks and in the channels. In our survey, sediments at most locations were found to be firm enough to support the field crew at all locations except a short stretch of the creek just upstream of the Virginia Beach Boulevard bridge. At that location, one sinks in the mud to chest level without detecting any firm underlying sediments, though the water depth is less than 1 foot (0.3 m).

Overall, Broad Creek is about 3 miles (4.8 km) in length and very shallow. Depths throughout the creek do not exceed 6-8 ft (1.8-2.4 m). The upper half of the creek is narrow ranging from 6 ft (1.8 m) wide at the head to about 75 ft (22.5 m) wide at the Virginia Beach Boulevard bridge. The lower half of the creek is broadens to about 1300 ft (390 m) before discharging into the Eastern Branch Elizabeth River.

Sampling Locations

Fifteen stations were established from the discharge point to the mouth of Broad Creek at the Eastern Branch Elizabeth River (Figure 1). Stations were placed close together near the head of the creek where the potential for impact of discharges from the filtration plant was greatest. These stations were sampled twice, once in March primarily for sedimentary characteristics including aluminum enrichment, and again in June to determine the condition of the benthic invertebrate community.

Station 1 was located in the stream carrying the discharge from Lake Wright and the filtration plant, and Station 3 was located in the discharge from Lake Taylor outside the major influence of the discharge from the filtration plant. Station 2 was located just downstream of the confluence of the discharges from Lake Wright and Lake Taylor. Stations 4 through 14 were spaced along the length of Broad Creek from the Military Highway Bridge to the Interstate 264 Bridge. Stations 8 and 9 and Stations 12 and 13 were located on opposite banks of the creek at about equal distance from the head to evaluate spatial replicability within the stream. Station 15 was located in the Eastern Branch Elizabeth River slightly downstream from the mouth of Broad Creek.

Stations 1, 2, and 3 were located in areas largely shaded by overhanging trees. Station 4, located just downstream of the Military Highway bridge, is partially shaded by high steep banks and bushes along the shoreline. All other stations are located in open water areas, unshaded throughout the day.

Physical Parameter Cores

On 23 March 1984, we sampled Stations 1 through 14 for Al:Si ratio analysis, sediment grain size analysis, and sediment stratigraphy. At each station, a 10 cm diameter core, ranging from 0.5 to 1.2 m in length, was collected. The core tube was inserted into the substrate manually until only a small portion remained above the sediment surface, hermetically plugged, and withdrawn by hand. Insertion of the core was accomplished as slowly as possible to minimize compaction of the core. Compaction of the sediment ranged from 5 to 10 cm and was greatest at stations with muddy substrates. Once withdrawn, the bottom end of the core was capped before withdrawal from the water. Cores were placed in as upright a position as possible during transport to the laboratory at Gloucester Point so as to minimize disturbance of the cores. The core from Station 12 was lost during transport back to the laboratory.

Analysis of Physical Cores

Each long core was cut into 33 cm sections and the ends capped. These sections were then placed on top of a sheet of 35.5 x 28.0 cm x-ray film and x-rayed with a Torr cabinet x-ray machine. Kodak AA Industrial X-ray film was used. The exposure time ranged from 3 to 4 minutes at 70 kV. After x-raying, the cores were extruded from the core tube and subsampled for Al:Si and grain size analyses. Samples were removed at centimeter intervals for the first 3 cm, and then at three centimeter intervals to the bottom of the cores.

Sediment samples from each station were analyzed for percent sand and silt-clay following the wet sieving procedures of Folk (1974). To present the grain-size data from the long cores, sediment descripters developed by Udden-Wentworth (Pettijohn, 1957) were used (Figure 2).

To analyze sediment subsamples for aluminum and silicon, each sample was mixed with a spatula, and 0.8-1.1 g of sediment (wet weight) was placed in a beaker. Larger subsamples were necessary for sections of core which contained a large proportion of sand or charcoal in order to obtain sufficient silt/clay. The sediment was suspended in 50 ml of a 1:15 Tween 20:distilled water solution. The Tween 20 was added not only as a dispersing agent but also to prevent cracking of the sediment cake as it dried on the filters. The sediment suspension was passed through a 100 um stainless steel sieve to remove all coarse sand and organic debris which would otherwise have prevented formation of a uniform sediment cake. The resulting suspension of fine particles was filtered onto preweighed 0.45 um

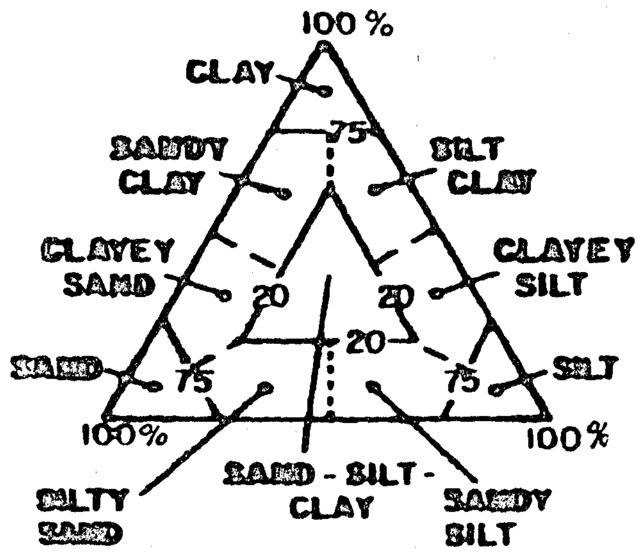

Figure 2. Sediment descripters used in the characterization of cores from Broad Creek, after Pettijohn (1957).

metricel filters an washed with 25 ml of the Tween 20 solution. The cake and filter were then dried and weighed.

The sample cake was analyzed by x-ray dispersive spectroscopy using a PGT Model 342 Spectroscope with a Si(Li) detector. The amplified signal at each wavelength is analyzed by a PGT System 4 computer. Samples were placed in the sample chamber, air was evacuated, and x-rays were passed through the sample. Each element absorbs and re-emits (fluoresces) x-rays at particular wavelengths. The x-ray energy emitted is measured and plotted against wavelength. The areas under peaks on the curve representing aluminum and silicon were determined by computer analysis of the spectrum and the ratio was calculated automatically.

At the same time that the long sediment cores were collected, a series of short 2.5 cm diameter cores were collected at all stations except 8, 12, and 15. The top 1 cm of these cores was analyzed for chlorophyll content as an indication of the condition of the benthic algal community. The top 1 cm from the 2.5 cm diameter cores was extruded into an Ehrlenmeyer flask. The sample was then extracted overnight at room temperature in the dark with a 50 ml portion of dimethyl sulfoxide in acetone, water and DEA (45:45:9:1). The extract was diluted as necessary and analyzed for chlorophyll a with a Turner Fluorometer. The chlorophyll content, uncorrected for phaeophytin, is expressed as mg/cm^2.

Biological Parameter Cores

On 15 June 1984 we sampled Stations 1-14 for the benthic invertebrate community. Station 15, located in the Elizabeth River in deeper water than the other stations, was sampled on 6 June 1984 from a larger vessel. At each Station, seven 5-cm diameter cores were collected to a depth of 10 cm for a total area sampled of 126 cm^2. Each core was subdivided into the top 5 cm and the bottom 5 cm to examine the vertical distribution of organisms. Each section of core was placed in a plastic bag and preserved with 10% formalin (stained with rose bengal). In the laboratory, samples were washed onto a 0.5 mm sieve and the residue sorted under a dissecting microscope to remove all organisms. So few organisms were obtained in the deep sediment fraction, that the samples were recombined with the top fraction of the core for analysis. All organisms were identified to the lowest possible taxonomic level. A sample of surface sediment was also examined to determine whether the grain size had changed since the March collection.

Evaluation of Tidal Marshes of Upper Broad Creek

On 28 August 1984, Dr. Eugene Silberhorn of the Virginia Institute of Marine Science examined the marshes adjacent to Broad Creek from the headwaters to the Virginia Beach Boulevard bridge. The principal marsh plants were identified and estimates were made of the area covered by various marsh plants.

RESULTS AND DISCUSSION

Physical Parameters

Sediment Characteristics

Surface sediments from the March and June collections were very similar. There was no indication that major changes in sediment distribution occurred during this period (Table 1 and 2). Most surface sediment (0-5 cm) in Broad Creek is muddy at the surface. Sand sized particles occurred at the surface only at Station 2, but were not mineral quartz, but rather charcoal particles ranging from 1-3 mm in diameter. Fine silt-size particles of charcoal were also detected at the surface of cores from Stations 1, 4, and 5.

Sand-size coal and charcoal particles occurred in the cores from Station 1 at 11-33 cm, Station 2 from 0-12 cm and Station 4 from 26 cm to the bottom of the core at 48 cm. Station 3, located in the channel draining from Lake Taylor and not in a direct line with Stations 1 and 2, did not show any sand-size coal-charcoal particles. The coal-charcoal layers at Stations 1, 2, and 4 consisted entirely of large particles with no fines, and probably resulted from episodic discharges from the filtration plant. While there were scattered occurrences of coal-charcoal particles in cores from Stations 6, 7, and 9, there were no layers of accumulation. Powdered activated charcoal was evident throughout much of the Broad Creek system.

The depth distribution of various sediment types differed from station

Table 1. Sediment type from Broad Creek Cores, March 1984. Sand (SA), Silty Sand (SISA), Clayey Sand (CLSA), Silt (SI), Sandy Silt (SASI), Clay (CL), and Sandy Clay (SACL), Sand size Charcoal (SA*).

Layer (cm)	1	2	3	4	5	6	7	8	9	10	11	13	14	15
0-1	SI	SA*	SISA	SI	SASI	SI	SI	SI	SI	SI	SI	SASI	SI	SI
1-2	SI	SA*	SASI	SI	SASI	SI	SI	SI	SI	SI	SI	SASI	SI	SASI
2-3	SI	SA*	SISA	SASI	SASI	SI	SI	SI	SI	SI	SI	SASI	SI	SASI
5-6	SI	SA*	SISA	SASI	SASI	SI	SI	SASI	SISA	SI	SI	SASI	SI	SASI
8-9	SI	SA*	SA	SA	SI	SI	SI	SISA	SI	SI	SI	SASI	SI	SASI
11-12	SA*SI	SA*	SA	SA	SI	SI	SI	SA	SI	SI	SI	SASI	SI	SASI
14-15	SI	SISA	SA	SISA	SI	SI	SI	SA	SASI	SI	SI	SASI	SI	SASI
17-18	CLSA*	SASI	SISA	SI	SI	SI	SI	SISA	SI	SASI	SASI	SASI	SI	
20-21	SA*	SASI	SA	SI	SI	SI	SI	SISA	SI	SI	SASI	SASI	SI	
23-24	SA*	SISA	SA	SI	SASI	SI	SI	SASI	SI	SASI	SI	SI	SI	
26-27	SA*	SISA	SA	SISA*	SASI	SI	SI	SASI	SI	SI	SI	SASI	SI	
29-30	SISA*	SISA	SI	SISA*	SASI	SI	SI	SISA	SI	SI	SI	SASI	SI	
32-33	SISA*	SISA	SISA	SISA*	SASI	SI	SI	SISA	SI	SI	SASI	SASI	SASI	
35-36	SISA	SA	SI	SISA*	SISA	SI	SASI	SISA	SACL	SI	SASI	SI	SASI	
38-39	SA	SA	SISA	SISA*	SISA	SI	SI	SISA	SACL	SASI	SASI	SASI	SASI	
41-42	SA	SA	SASI	SI	SISA	SI	SI	SI	SASI	SASI	SASI	SASI	SI	
44-45	SA	SISA	SISA	SISA*	SISA	SI	SI	SI	SI	SI	SISA	SI	SASI	
47-48	SA	SISA	SA	SA*	SASI	SI	SI	SI	SI	SI	SISA	SI	SASI	
50-51	SA	SA	SISA		SI	SI	SI	SI	SI	SI	SA	SASI	SASI	
53-54	SA	SA	SASI		SI	SASI	SASI	CL	SI	SI	SA	CL	SASI	
56-57	SA	SA	SASI		SI	SISA	SASI	CL	SI	SI	SA	CL	SASI	
59-60	SA	SA	SASI		SI	SA	SASI	CL	SI	SI		SI	SI	
62-63	SA	SA	SI		SASI	SASI	SASI	CL	SI	SI		SI	SI	
65-66	SA	SA	SA		SISA	SASI	SI	CL	SI	CL		SASI	CL	
68-69	SA	SA	SISA		CL	SI	SI	CL	CL	SI		SACL	CL	
71-72	SA	SA	SI		CL	SI	SI	CL	CL	SI		SACL	SI	
74-75	SA	SA	SI		CL	SASI	SI	CL	SI	SI		SACL	CL	
77-78	SA	SA	SI		CL	SI	SI	CL	CL	SI		SACL	SI	
80-81	SA	SA	SASI		CL	SI	SI	CL	SI	SI		SACL	SASI	
83-84	SA	SASI	SACL		CL	SI	SI		SI	SI		SACL	SI	

Table 1. (con't) Sediment type from Broad Creek Cores, March 1984. Sand (SA), Silty Sand (SISA), Clayey Sand (CLSA), Silt (SI), Sandy Silt (SASI), Clay (CL), and Sandy Clay (SACL), Sand size Charcoal (SA*).

Layer (cm)	1	2	3	4	5	6	7	8	9	10	11	13	14	15
86-87	SA	SI	CL		CL	SASI	SI		SASI	CL		SACL	SI	
89-90	SA	SI	SACL		CL	SASI	SI		SASI	CL		SI	SI	
92-93		SI	SACL		CL	SASI	SI		SASI	CL		CL	SI	
95-96		SI	CLSA		CL	SASI	SI		SI	CL		CL	SI	
98-99		SI	CLSA		CL	SASI	SI		SASI	CL		CL	SI	
101-102		SI	CLSA		CL	SASI	CL		SASI	SACL			SI	
104-105		SASI	CLSA			SASI	CL		SASI	CL			CL	
107-108		SASI	CLSA			SACL			SASI	SACL			CL	
110-111		SACL	CLSA			SACL			SI	SACL			CL	
113-114		SACL				SACL			SASI	SACL			CL	
116-117		SACL				SACL			SASI				CL	
122-123													CL	
125-126														

Table 2. Surface Sediment Type from the June Biological Collections

Station	% Sand	% Sand + Clay
1	2	98
2	95	5
3	16	84
4	10	90
5	30	70
6	1	99
7	2	98
8	2	98
9	2	98
10	0	100
11	0	100
12	15	85
13	19	81
14	1	99
15	15	85

to station (Table 1). Layers of mineral quartz sand occurred at Stations 1, 2, 3, 4, 8, and 11. It was predominantly coarse gravel sand (0.5-1.0 mm) mixed with some very coarse sand (1.0-2.0 mm). Layering of the sand in these cores, like that of the charcoal, was presumably created by episodic flow events except at Station 1 where sand occurred from 38 cm to the bottom of the core at 90 cm. The deep sandy layer at Station 1 may represent relic sand in the Broad Creek system, and may represent the interface between creek deposits and basement sediments.

Silty sediments, or muds, were the predominant sediment types found at most depths at all stations except Station 1. Layers of silt were interleafed with sandy silt or silty sand layers. Clayey sediments were found deep in cores from Station 3, 5, 6, 7, 8, 10, 13, and 14. These are thought to represent terrigenous deposits cut by the creek.

X-ray Stratigraphy

X-rays of the long cores revealed the dominance of physical processes over biological processes throughout Broad Creek (Fig. 3). Only in two cores was there evidence of biogenic structures. At the 90-95 cm depth in the core from Station 5, there were relic worm burrows in silty sediments that otherwise had little other structure. At the top (0-15 cm) of the core from Station 11 there were a few large burrows and several smaller burrows. There was also a shell lag layer at the 35-50 cm depth in the core from Station 14. This layer contained fragments of oysters, Macoma spp., and possibly other species. The uniform lack of biogenic structures except those found at Station 14 is an indication that the biotic communities present remain the same throughout the time period recorded in the cores.

The lack of biogenic structures in Broad Creek as evident from Figure 3

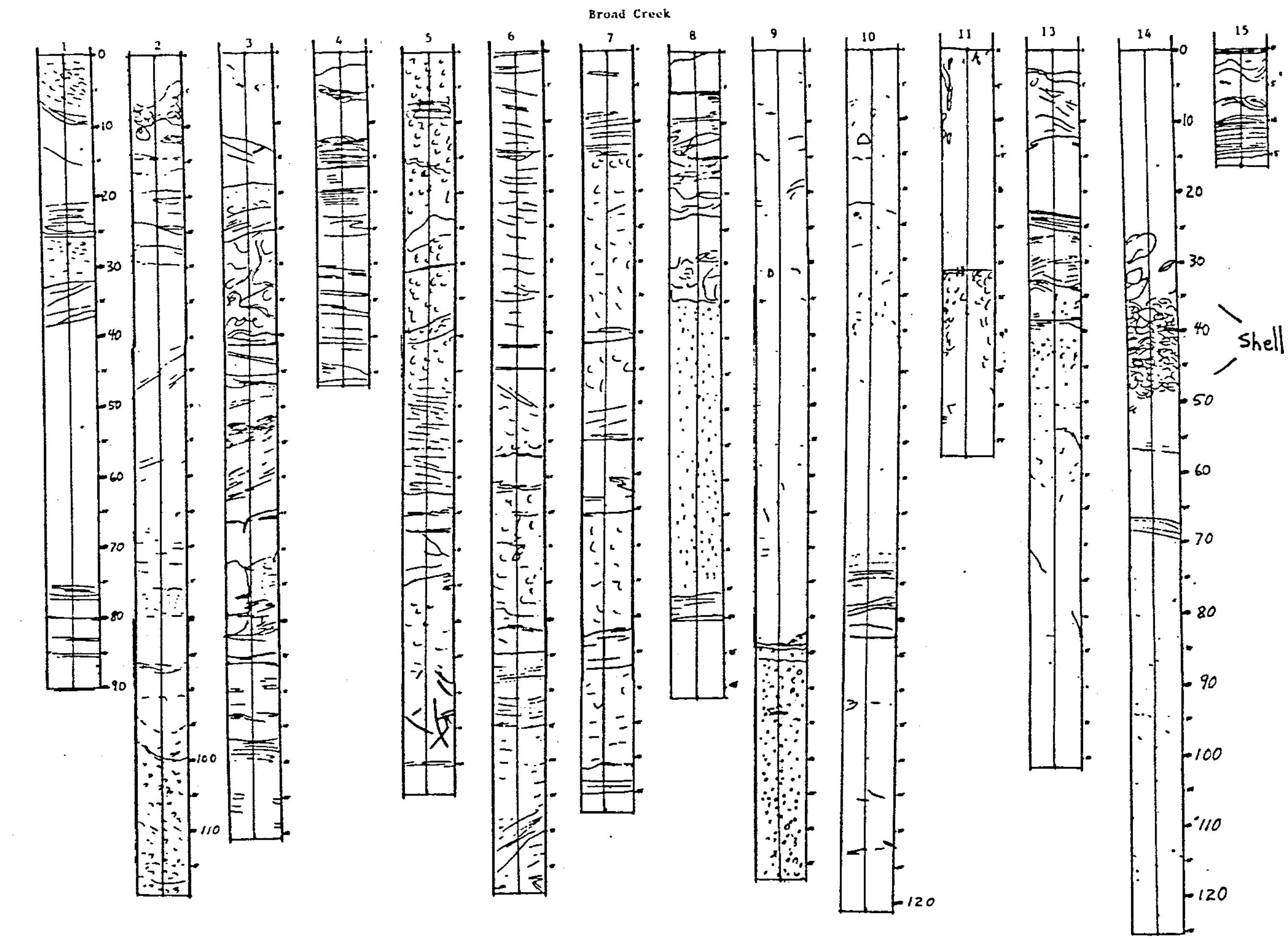

Figure 3. Schematic diagrams of x-ray cores from Broad Creek. Horizontal or tilted lines indicate physical lamination within cores resulting from sediment bedding. Areas that are dotted tended to have high detritus content. Featureless areas were uniform layers of one type of sediment.

is related to the transitional nature of the habitat from fresh to salt water and to episodic flow events. The eurytopic and opportunistic fauna of Broad Creek, described below in this report, characteristically are not major contributors to biogenic structure (Schaffner and Diaz, 1981). It is therefore very probable that a well developed advanced successional stage benthic community never existed in Broad Creek for as far back in time as is represented in the sample cores. The only possible exception may be the shell layer at Station 14. It is definitely a reworked shell layer with none of the shells in living position. This would indicate that the shell was either brought into the area from another source and not produced at the site, or if produced on the site, it was reworked so as to lose its original orientation. It is quite reasonable that at some point a shoreline property owner may have tried to establish a small oyster reef, a not uncommon practice in coastal waters of Virginia. If on the other hand, the shell lag is a relic of some past community, then at one time Station 14 had a more complex community than shared by the rest of Broad Creek.

Much of the lamination in the x-rays was due to layering of silts and sandy silts. When the sediment descripters in Figure 2 were compared to diagrams made from the x-rays (Figure 4), there was fair agreement between sediment changes and presence of laminations. For example the transition from silty sand to sand at Station 1 is particularly obvious. The presence of charcoal did not show up in the x-rays in any characteristic way which is not surprising since carbon is not a good absorber of x-rays.

Aluminum:Silicon Ratio Analyses

The Al:Si ratios ranged from 0.14 to 1.86 (Table 3). Background Al:Si ratios are taken to be ratios less than 0.2, based on analyses of kaolinite

Table 3. Aluminum:Silicon Ratios for sediments in cores collected in Broad Creek, VA in March 1984.

Depth of Sample (1)	Station 1	2	3	4	5	6	7	8	9
0-1	1.860	0.330	0.442	1.320	0.512	0.495	0.525	0.411	0.405
5-6	0.959	0.332	0.524	0.884	0.580	0.708	0.569	0.327	0.396
8-9									
11-12	1.526	0.357	0.343	0.753	0.706	0.531	0.552	0.256	0.391
17-18	0.240								
20-21		1.001	0.818	0.469	0.646	1.076	0.466	0.259	0.404
29-30	0.639	0.389	0.588	0.506	0.643	0.555	0.496	0.273	0.424
41-42	1.001		0.643	0.692	0.474	0.657	0.469	0.240	0.172
47-48		0.364							
50-51	0.389	0.266	0.380		0.525	0.567	0.466	0.253	0.160
59-60	0.364		0.303		0.507	0.259	0.382	0.216	0.165
62-63		0.363							
71-72	0.507	0.356	0.425		0.182	0.299	0.393	0.184	0.157
80-81	0.259	0.313	0.341		0.168	0.211	0.408	0.150	0.149
83-84									
89-90	0.269	0.612	0.226		0.151	0.182	0.529		0.137
98-99		0.380	0.211						0.138
99-100									
101-102					0.163				
104-105							0.143		
110-111			0.192						
113-114									
115-116						0.169			0.147
116-117		0.168							

(1) Sample depths are uncorrected for compaction

Table 3 (cont.). Aluminum:Silicon Ratios for sediments in cores collected in Broad Creek, VA in March 1984.

Sample (1)	10	11	12	13	14	15
0-1	0.277	0.420	ND	0.375	0.339	0.194
5-6	0.276			0.395	0.338	0.213
8-9		0.376				
11-12	0.274	0.375		0.367	0.363	0.194
14-15						0.190
20-21	0.265	0.359		0.388	0.335	
29-30	0.241	0.247		0.348	0.293	
41-42	0.223	0.208		0.399	0.304	
50-51	0.200	0.188		0.340	0.302	
56-57		0.179				
59-60	0.207			0.320	0.299	
71-72	0.213			0.269	0.308	
80-81				0.250	0.285	
83-84	0.285					
89-90	0.299			0.238	0.281	
98-99	0.289					
99-100				0.248	0.300	
101-102						
104-105						
110-111					0.294	
113-114	0.295					
115-116						
116-117						

and montmorillonite samples and bottom sediments obtained from the York River, VA. In general, the ratio declined with depth in the sediment column and with distance downstream. At the most upstream station, the ratio declined from 1.86 at the surface to 0.36 at 60 cm depth, with a lens of material at 18 cm with a ratio of 0.24. At Station 2 the surface sediment was predominantly coarse sand (filtering material). The ratios for subsamples above a depth of 20 cm are based on the very small fraction of silt-clay sized material in the samples. The Al:Si ratio could be biased toward higher values than would have been obtained had the sand-sized particles been ground to silt-clay sized particles for unclusion in the sample analyzed. At 20 cm, the ratio was 1.00, decreasing to 0.16 at 115 cm. At Station 4 located on the downstream side of the Military Highway bridge, the ratio at the surface was still high at 1.32, and declined only to 0.68 at 42 cm.

In general, at stations downstream from Station 4 the Al:Si ratio declined from 0.51 to 0.34 in the surface layer. At Station 10, located on the west bank just downstream of the Virginia Beach Boulevard bridge, the Al:Si ratio was only 0.28, only slightly above background. At this station, there was recent disturbance of the shore line where the property owner had planted a single row of <u>Spartina alterniflora</u> plugs and back-filled a concrete bulkhead. These disturbances may explain the low surface Al:Si ratios at this station which are distinctly lower than at Station 11 just downstream in Broad Creek. Some aluminum enrichment was observed even near the mouth of Broad Creek, 3.2 mi (5.1 km) from the discharge point.

Background Al:Si ratios were observed in the bottom subsamples of cores at depths below 115 cm at Station 2, and 30 to 100 cm at Stations 5 through 11. At Station 13 and 14, no non-enriched sediments were collected even at the bottom of the cores (100 and 125 cm respectively). through the degree of enrichment was uniformly low throughout the cores. At Station 15 in the Eastern Branch Elizabeth River, background ratios were observed even at the surface of the core. The depth of enrichment, especially at the downstream stations where the creek widens suggests physical reworking of sediments, since the range in the Al:Si ratio over the entire length of the cores is small.

Station 3, located in the discharge from Lake Taylor, is subjected to periodic inflows of water containing alum sludge and charcoal as during high tide or storm tides. The degree of aluminum enrichment at the surface at this station (Al:Si ratio = 0.44) was comparable to that at Station 6, some 0.7 mi downstream. There were buried strata, however, with ratios as high as 0.82 and 0.64 located at 20 and 41 cm. These correspond to high ratios at the same depths at Stations 1 and 2. Aluminum enrichment as Station 3 was evident to a depth of between 81 and 89 cm.

Sediments-Stratigraphy-Al:Si Ratios

When the sediment stratigraphy and Al:Si ratio data were compared, there were some clear relationships (Figure 4). When charcoal was visually evident as fine silt-size particles (surface of Stations 1 and 4 in particular), there tended to be high Al:Si ratios (>0.8). Only once was the Al:Si ratio high when the sediments were sand-size charcoal particles. However, high Al:Si ratios occurred when the sediment consisted of charcoal-sand particle mixtures. At distances sufficiently downstream from the source of alum sludge (below Station 7) there were only low ratios of Al:Si, regardless of sediment type.

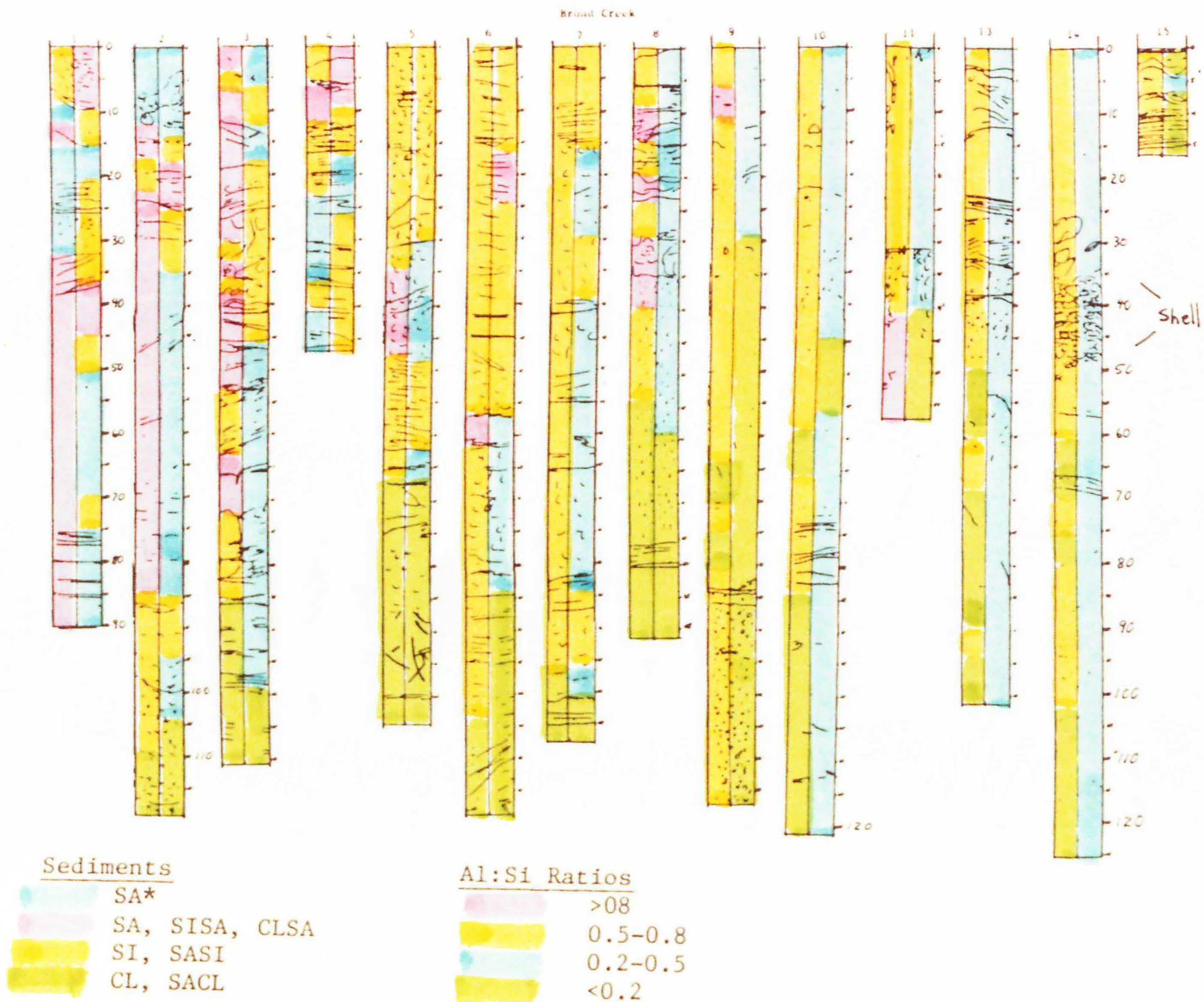

Figure 4. Comparison of sediments particle size, stratigraphy, and Al:Si ratios. Left side of the core diagram is colored to indicate the sediment particle type. The right side of the core diagram is colored to represent specific ranges of Al:Si ratio.

Progressing from Station 1 to 15 the stratigraphy and sediment grain size became less variable with depth in the cores. Below station 5, most of the sediments were silty. Lamination of cores was most pronounced at Stations 1, 2, 3, and 4, stations which also had the most variable depth distribution for the Al:Si ratios.

These data point to the episodic nature of alum sludge discharges. At Station 5 and further downstream, sediments tend to be more uniform with only small lenses of sand except at Station 8.

Background levels were observed near the bottom of cores from Station 2, 3, 5, 6, 7, 8, 9, 11, and 15. The clayey nature of sediments found to have these low Al:Si ratios tends to confirm this interpretation. These clays are representative of basement terrigenous sediments that would predate any filtration plant alum sludge discharges. Clay occurred at the bottom of cores at Stations 2, 3, 5, 6, 7, 8, 10, 13, and 14. At Stations 10, 13, and 14 the Al:Si ratios were slightly above the defined background value found in the other clayey sediments, but the values of Al:Si in all clay sediments were lower than in silty portions of the same cores, except at Station 10, for which the lowest Al:Si ratios occurred in the silty portions of the core.

Biological Parameters

Benthic Chlorophyll Concentrations

The benthic algal chlorophyll *a* concentration increased from Station 1 to Station 14 (Table 4). At Station 1 the chlorophyll concentration *a* was only 310 ug/cm^2, increasing to 874 ug/cm^2 at Station 4. At all downstream stations the chlorophyll *a* concentration ranged from 1000 to 2000 ug/cm^2 (with the exception of Station 13 with only 728 ug/cm^2). This distribution

Table 4. Sediment Chlorophyll concentrations observed in Broad Creek on 23 March 1984

Station	Chlor. a (ug/cm2)
1	309.52
2	436.97
3	699.16
4	873.95
5	1893.56
6	2039.22
7	1019.61
8	ns
9	1456.58
10	1729.69
11	1675.07
12	ns
13	728.29
14	1092.43
15	ns

with low sedimentary chlorophyll a concentrations at the four most upstream station corresponds with that for high aluminum enrichment in the surface sediment at the same four stations. However, these stations also are heavily shaded, and have low environmental salinity concentrations compared to the downstream stations.

Benthic Communities

A total of 17 benthic taxa were collected at the 15 stations (Table 5). The most abundant taxa were oligochaete worms, followed by polychaete worms. Faunal diversity was very low, with stations in the high salinity areas having the greatest number of species (Table 6). Very low diversity and species richness are characteristic of low salinity transitional habitats between fresh and estuarine waters. For example in the James River transition from freshwater to estuarine zone, the area between the Chickahominy River and Hogg Island, 14 taxa were reported (Diaz, 1977). In a more intensive study in the same reach of the James, Jordan et al. (1976) reported a total of 20 taxa.

The fauna from Broad Creek was composed of salt-tolerant freshwater species and estuarine endemic species of marine origin (Table 5). From the distribution of the fauna, it appears that Stations 2 and 3 were never exposed to salt water or exposed only for short intervals, since the fauna at these two stations is all of freshwater origin. The area from Station 4 to 10 is an area where salinities are thought to fluctuate widely, being fresh at some times, salty at others (Table 7). The fauna at these seven stations was a mixture of freshwater and marine species, with oligochaetes numerically dominant. Stations 11 to 15 were characterized solely by estuarine species of marine origin. This indicates that the salinity never

Table 5. Species List for Broad Creek Benthic Collections, May 1984

Annelida	
Oligochaeta	
Limnodrilus spp.	F*
Tubificoides spp.	M
Tubificoides heterochaetus	M
Polychaeta	
Streblospio benedicti	M
Polydora ligni	M
Podarke obscura	M
Capitellidae, immature specimens	M
Neries succinea	M
Heteromastus filiformis	M
Cistena gouldi	M
Arthropoda	
Copepoda	
Calanoid species	F
Harpacticoid species	M
Insecta	
Culicid species	F
Chironomid species	F
Plecopteran species	F
Dytiscid species	F
Mollusca	
Bivalvia	
Macoma balthica	M

* F = Freshwater species
M = Marine species

Table 6. Abundance data for benthic species collected from Broad Creek in May 1984.

Station	Species	1	2	3	4	5	6	7	Total
1	No animals in any core								
2	*Limnodrilus* spp.	0	2	2	3	0	1	0	8
3	*Limnodrilus* spp.	7	28	0	13	10	4	5	67
	Calanoids	0	0	1	0	0	0	2	3
	Culicid	0	0	1	0	0	0	0	1
	Chironomid	0	0	0	1	0	0	0	1
4	*Tubificoides heterochaetus*	0	2	2	3	0	2	0	9
	Capitellid immature	1	0	0	0	0	1	0	2
	Harpacticoids	3	4	0	0	0	4	2	13
5	*Tubificoides* spp.	78	33	67	14	2	3	93	290
6	*Tubificoides* spp.	1	2	0	2	1	0	1	7
	Streblospio benedicti	1	0	1	0	0	2	2	6
	Plecopteran	1	0	0	0	0	0	0	1
	Dytiscid	0	0	0	1	0	0	0	1
7	*Tubificoides* spp.	2	17	0	21	61	2	34	137
	Calanoids	0	0	2	1	0	0	0	3
	Harpacticoids	1	0	27	4	0	0	0	32
8	*Tubificoides* spp.	21	4	10	3	4	1	6	50
	Culicid	0	0	0	1	0	0	0	1
9	*Tubificoides* spp.	2	0	2	4	11	2	1	22
	Harpacticoids	2	0	1	0	0	3	1	7
10	*Tubificoides* spp.	0	1	0	0	1	0	0	2
	Streblospio benedicti	1	1	3	1	0	0	2	8
	Capitellid immature	1	0	6	0	0	0	0	7
	Harpacticoids	0	0	0	1	2	0	0	3
11	*Streblospio benedicti*	0	1	1	1	0	0	1	4
	Cistena gouldi	0	2	0	0	1	0	1	4
	Capitellid immature	1	0	3	0	4	3	0	11
	Polydora ligni	0	0	0	2	0	0	0	2
12	*Streblospio benedicti*	0	1	2	5	1	0	4	13
	Capitellid immature	2	1	0	0	0	2	0	5
	Polydora ligni	0	0	0	0	0	3	0	3
	Harpacticoids	0	0	0	0	1	0	0	1

Table 6. Abundance data for benthic species collected from Broad Creek in May 1984 (Con't.).

Station	Species	1	2	3	4	5	6	7	Total
13	*Streblospio benedicti*	0	0	0	0	2	0	0	2
	Capitellid immature	2	1	0	0	2	0	1	6
	Heteromastus filiformis	0	1	2	0	0	0	0	3
	Cistena gouldi	0	0	1	0	1	0	1	3
	Polydora ligni	0	0	1	0	0	1	0	2
	Tubificoides spp.	1	1	0	3	0	2	1	8
14	*Streblospio benedicti*	0	1	0	3	1	0	0	5
	Capitellid immature	1	0	0	1	0	1	0	3
	Heteromastus filiformis	0	1	0	0	1	0	1	3
	Podarke obscura	0	0	2	0	0	0	1	3
15	*Tubificoides* spp.	0	2	0	0	3	0	0	5
	Streblospio benedicti	0	0	5	0	42	36	1	84
	Nereis succinea	0	0	1	0	0	0	0	1
	Heteromastus filiformis	4	0	9	1	0	4	3	21
	Macoma balthica	2	1	0	0	0	0	0	3

Table 7. Salinity distribution at sampling sites in Broad Creek

Station No.	Salinity (o/oo) June	Salinity (o/oo) September
1	0	0
2	0	0
3	0	0
4	0	6
5	0	nd
6	1	nd
7	3	nd
8	6	nd
9	6	14
10	8	14
11	8	15
12	10	nd
13	10	15
14	13	nd
15	15	nd

nd = no data

drops below 5-8 o/oo in this reach of the creek.

A characteristic of the fauna that inhabits transitional and fluctuating low salinity habitats is that they are very eurytopic and tolerant of extreme environmental conditions. Conversely, more sensitive freshwater and marine species are excluded from these habitats. As a group, oligochaetes have the greatest ability to invade these transitional areas. In Broad Creek, the dominant taxa were, as expected, oligochaetes. The freshwater genus, *Limnodrilus*, was dominant at Stations 2 and 3. This genus is the most widely distributed and contains the most cosmopolitan oligochaete species in the world (Brinkhurst and Jamieson, 1971). *Limnodrilus* spp. have the broadest tolerances for organic enrichment, sediment type, water quality, and salinity of all oligochaetes (Brinkhurst and Cook, 1974; Diaz, 1980). The other dominant oligochaetes throughout Broad Creek were in the genus *Tubificoides*. They are also very hardy species that have an opportunistic life history similar to *Limnodrilus* spp., but are true estuarine endemics (Diaz, 1980).

Harpacticoid copepods were the only other taxa to have widespread occurrence at Stations 4-10. Other species that occurred at these stations were in low abundance and found at only one or two stations.

Polychaetes dominated the fauna at Stations 10-15. *Streblospio benedicti* was the most abundant species, followed by *Polydora ligni*. These are both species known to be tolerant of organic enrichment and very opportunistic in their life histories (Richardson, 1971; Boesch, et al., 1976; Grassle and Grassle, 1974). *Cistena gouldi* and *Podarke obscura* were the only two polychaetes to occur at these stations that are not considered to be opportunistic. These two species occurred at Stations 11, 13, and 14 giving some indication that environmental conditions at these stations have not fluctuated widely since these species became established. All individuals were small and probably recruited to the system early in the spring of 1984. Major recruitment periods for these species are April, May, and June.

In summary, the benthic communities were of low species diversity and abundance, but well within ranges reported for other low salinity fluctuating environments (Diaz, 1977; Tenore, 1972; Jordan, et al., 1976). These species have life histories which are consistent with the fluctuating conditions in Broad Creek. All the dominant species are opportunistic and very eurytopic. The physical harshness of the Broad Creek environment, especially with respect to salinity, is the major controlling factor in the development or lack of development of the benthic communities.

Tidal Marshes of Upper Broad Creek

There are approximately 70 acres of tidal marsh along the upper reach of Broad Creek between the discharge from Lake Taylor and the Virginia Beach Boulevard bridge (Figure 5). Four plant communities were recognized in the area (Table 8); a saltmarsh cordgrass (*Spartina alterniflora*) community, a saltbush community, a big cordgrass community, and mixed freshwater herbaceous community. The largest of these was the saltbush community covering an estimated 48 acres. The cordgrass communities each occupied an estimated 10 acres.

There is evidence of land and solid waste fill in several areas of this marsh complex. The marsh was formerly ditched for mosquito control. Neither of these facts bears on the potential for impact from alum sludge discharge except in so far as these represent disturbances to the system.

Figure 5. Map of Broad Creek showing the areal extent of all marsh types in the reach between the discharge point and the Virginia Beach Boulevard bridge.

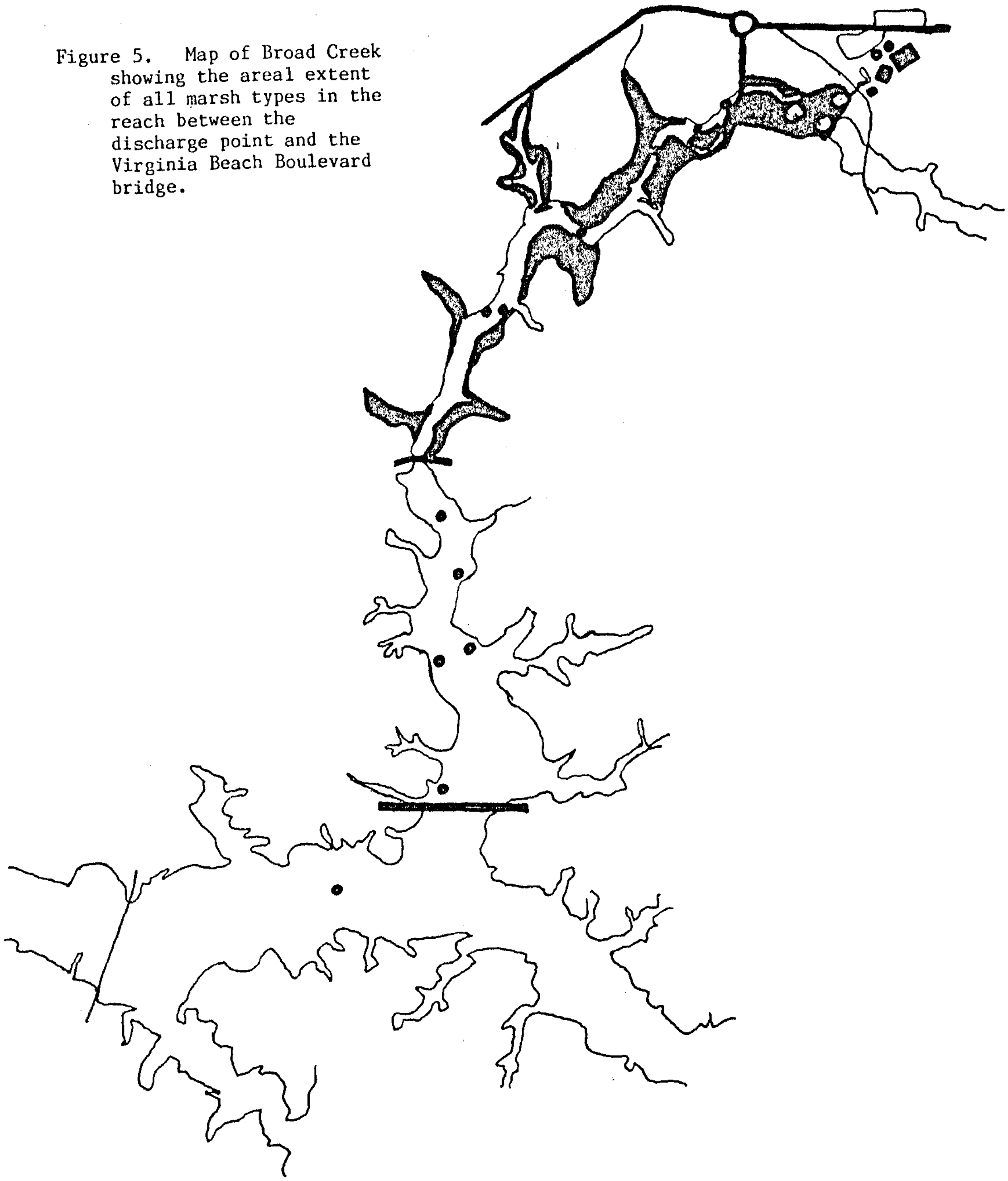

Table 8. Dominant marsh plants in tidal marshes of upper Broad Creek and area of coverage.

Community type	Plant Species	Area (acres)
Saltmash Cordgrass	*Spartina alterniflora*	10
Saltbush		48
Groundsel tree	*Baccharis halmifolia*	
Marsh Elder	*Iva fructescens*	
Saltmeadow Hay	*Spartina patens*	
Big Cordgrass	*Spartina cynosuroides*	10
Mixed Herbaceous		2
Giant Foxtail Grass		
Marsh Mallow	*Kosteletzkya virginica*	
Water Hemp	*Amaranthus cannabinus*	
Cattails	*Typha* spp.	
Marsh Hybiscus	*Hibiscus moscheutos*	

HISTORICAL DEPTH OF BROAD CREEK

In 1873, the U.S. Coast Survey made a bathymetric survey of the Eastern Branch Elizabeth River including Broad Creek. The survey was conducted by Robert Platt and recorded as Sheet Number 5, Section III of the Elizabeth River survey. The Boat Sheet of the survey is reproduced here as Figure 6. When a current navigational chart is compared to the 1873 survey, it appears that the depths used on the 1984 chart are the same as the 1873 depths.

According to anecdotal history, Broad Creek was at one time navigable, a notion also reported by Wolfram (1979). The depths as shown on Figure 6 give the lie to this notion, however. The depths are all corrected to mean low water. It can be seen that there are many zero depths at the upper end of Broad Creek. The deepest point in Broad Creek during the 1873 survey was 9 feet located a few hundred meters upstream from the present day Virginia Beach Boulevard bridge. Thus the Boat Sheet for 1873 does not in any way support the notion that Broad Creek was within memory of people living today deep enough to be considered navigable by other than a row boat or canoe.

HISTORICAL REVIEW OF BROAD CREEK

Because of its size and the overwhelming importance of the Elizabeth River proper, this system has been relatively well studied. There are very few data available regarding Broad Creek, however, which is only a minor tributary of the system. In reports prepared by the Virginia State Water

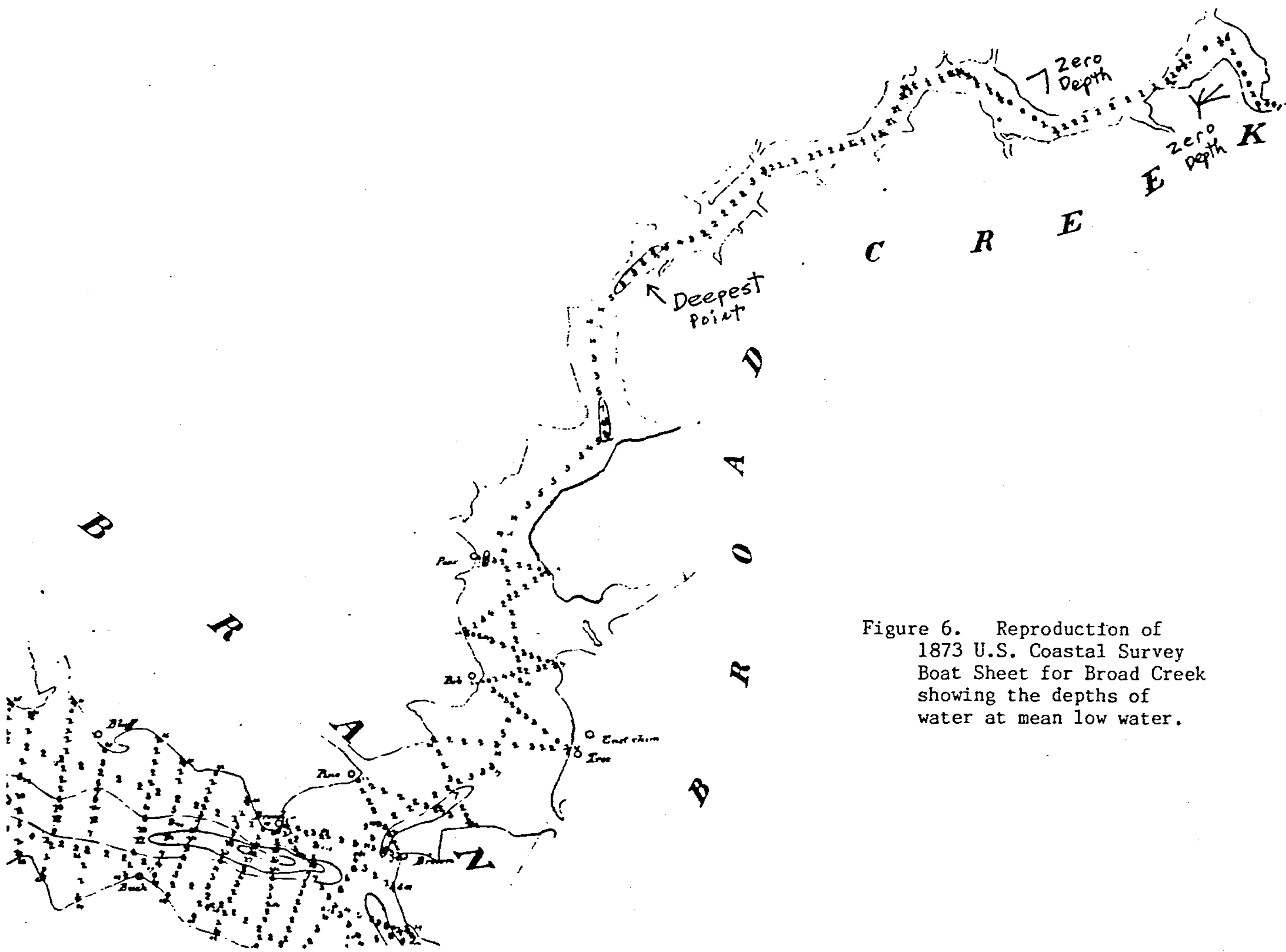

Figure 6. Reproduction of 1873 U.S. Coastal Survey Boat Sheet for Broad Creek showing the depths of water at mean low water.

Control Board (1983, 1984) summarizing background information regarding environmental problems in the Elizabeth River, there is no mention of Broad Creek. Near the mouth of Broad Creek are located two industrial discharges from Chevron Asphalt and Ecolochem (Virginia State Water Control Board, 1983). Their effects on Broad Creek are unknown but they may have contributed to impacts observed at nearby Eastern Branch stations (Schaffner and Diaz, 1981) Blair, et al. (1983) evaluated the discharge of the Moores Bridge Filtration Plant and reported that for 1983, the plant discharged a monthly average of 14,100 lbs total dry weight solids per day.

The only previous report dealing specifically with Broad Creek of which we are aware is that of Wolfram (1979). In that brief sampling related to citizen complaints about black floating material in the creek (charcoal?), the amount of aluminum in the water was determined among other water quality parameters. Measured concentrations of aluminum were alarmingly high, but it is not clear how the aluminum analyses were made. If the analysis included particulate aluminum as well as the dissolved fraction, as seems likely given the pH of the system, the measured levels cannot be interpreted in terms of toxic potential.

There are several reports that deal with the Eastern Branch Elizabeth River, but none have data collected at the mouth of Broad Creek. The work of Schaffner and Diaz (1982) come closest, with one station (No. 222) located in the Eastern Branch about a half mile downstream from the mouth of Broad Creek. The sediment type at this station was sandy-silt, similar to some areas of Broad Creek. X-rays of cores from Station 222 showed little biogenic structure. There were some buried oyster shells and physical laminations with traces of burrows in the top 5 cm of the core.

Compared to other stations in their study, Station 222 had lower species diversity, probably because of low salinity at this station. There may also have been an impact from pollutants released from the near-by Chevron Asphalt Plant or Ecolochem Corp. but with the interaction of salinity, they were not able to pinpoint any specific cause for low species diversity. The dominant species at Station 222 were opportunistic polychaetes, principally Streblospio benedicti.

A marsh inventory is being prepared for the Norfolk area including Broad Creek by Dr. Silberhorn. This report should be available within the next year.

CONCLUSIONS

1. The benthic communities observed in Broad Creek are typical of freshwater-estuarine transition zones. The fauna is characterized by eurytopic and opportunistic species. Though densities are low, they are typical of this community type, and we detected no impact of the treatment plant except at station 1 and 2.

2. Marshes around the upper half of Broad Creek are typical for freshwater-estuarine transition zone marshes. There are no obvious impacts on marsh flora attributable to the water filtration plant or any other environmental factor.

3. There was a distinct depression in the chlorophyll concentration in the sediment at Stations 1 to 4 indicating a depressed benthic algal population. However, there is no basis to distinguish clearly between effects of shading, sediment type, low salinity, and alum sludge.

4. There is little historical data on environmental conditions in Broad Creek. Therefore it is difficult to establish baseline conditions for benthic communities, depth and sediment, and algal communities.

5. Aluminum contamination is evident throughout Broad Creek, but medium to high levels of contamination are observed only at the upstream stations (Station 1 to 7) and generally in the upper portions of the cores.

6. Historical depth data for Broad Creek (1873) show it to be a shallow tributary of the Eastern Branch Elizabeth River even at that early date.

MITIGATION ALTERNATIVES

As indicated above, submersed bottom areas show some level of contamination from the point of discharge to mouth of the creek, but biological effects possibly attributable to the discharge are only recognizable at stations within about 0.5 to 0.7 mile of the discharge point. These are the only areas for which mitigation can really be argued. The only mitigation possible beyond the simple expedient of terminating discharges from the water filtration plant would be physical removal of the contaminated sediment. Differing degrees of removal which might be considered are:

1. dredging of those areas of Broad Creek with Al:Si ratios >0.2 (i.e. the entire creek) to a sediment depth of 1 m (3 miles (4.8 km) of creek);
2. dredging of those areas of Broad Creek with Al:Si ratios >0.5 (i.e. the areas with medium to high levels of contamination) to a depth of 1 m (1 mile (1.6 km) of creek);
3. dredging of those areas of Broad Creek with Al:Si ratios >0.8 (i.e. the areas with high levels of contamination) to a sediment depth of 1 m (0.4 miles (0.6 km) of creek).

Implications of mitigation

If removal of contaminated sediments to any of the extents suggested were accomplished, the nature of the environment is such that the communities would not change markedly. After the initial disturbance by dredging, the benthic community that redeveloped would remain in the pioneering stage of succession which is characteristic of all benthic communities in similar freshwater-estuarine transitional zones. The creek would gradually refill with sediments from land and street run-off, so no permanent gain in creek depth would accrue.

Since the marshes are unaffected by the discharges, no mitigation would be necessary for the marsh areas. Mitigation efforts in the creek proper would have significant near-term impacts on the marshes, especially if the creek were dredged by drag-line, the most likely method given the narrowness of the creek and the limitations to upstream navigation by dredging equipment imposed by the several bridges crossing the creek.

A serious implication of dredging the creek system would be potentially detrimental effects on downstream communities from siltation and mobilization of aluminum. It is not reasonable to expect that the effects of the resuspension of fine sediments during a dredging operation in the reach from Station 1 to 7 could be restricted to this reach.

Further, problems would also be encountered in finding a suitable disposal site for the dredged material. The dredged material could not be relocated within the confines of the creek which is simply too small to provide a suitable dumping site. It would also not be acceptable to place the sediment on the present marsh as this would elevate the marsh, thus changing the habitat value drastically. The only alternative dredge material disposal site would therefore be one outside the confines of Broad Creek, and probably outside the confines of the Elizabeth River, although it is beyond the scope of this report to evaluate all potential dredge material disposal sites.

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GLOSSARY

Bathymetric	pertaining to depth of a body of water.
Benthic	pertaining to the bottom of a water body; often used to describe organisms associated with the bottom.
Biogenic Structure	biologically produced structures in sediments which remain after an organism dies (e.g. tubes, shells, etc.) or biologically produced disturbances of sedimentary laminations.
Eurytopic	tolerant of a wide range of environmental conditions as defined by various parameters such as salinity, sediment type, temperature, etc.
Opportunistic	pertaining to organisms with a life style which allows rapid invasion of an environment with available resources (space, food, etc.).
Salinity (o/oo)	the salt content of the water in grams of salt/kilogram of water, expressed as parts/thousand.
Stratigraphy	description of the structure of a sediment column.
Terrigenous	refers to anything with a terrestrial origin; in the context of the present report, refers to sediments which have been exposed to air for extended periods, and not subject until recently if at all to aquatic erosion and redeposition.