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BERGEN COUNTY UTILITIES AUTHORITY

FINAL PROJECT REPORT

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APPENDIX A - PART II

NUTRIENT DYNAMICS OF THE TIDAL MARSHES AND MUDFLATS OF THE HACKENSACK RIVER ESTUARY

Submitted to

Clinton Bogert **Associates**

SEPTEMBER 1990

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SEPTEMBER 1990

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1. INTRODUCTION

The Hackensack River and its tributaries drain a 197-square mile watershed. The upper, freshwater portion contains a number of reservoirs which supply potable water to northern New Jersey. The Oradell Reservoir serves as the head of tide for the Hackensack River Estuary. The estuary extends about 22 miles from the Reservoir to Newark Bay, draining approximately 84 square miles. Figure 1.1 shows the Hackensack River watershed.

The water quality of the lower Hackensack River is effected by various point and non-point sources of pollutants. This study has provided an m-depth assessment of the major pollutant sources within the lower Hackensack River Watershed and has developed strategies for water quality enhancement of the river. The overall approach was the adaptation of appropriate hydrodynamic and water quality models to the River and its watershed. Details of the modeling effort are described in Appendix A, Part 1 of this study.

The dominant ecological feature of the tidal Hackensack River is the approximately 2,500 acres of tidal wetlands which occupy the Hackensack Meadowlands and surrounding areas. Based on studies of their ecological functions, tidal wetlands are thought to influence the nutrient dynamics of their flooding waters. The water quality in the lower Hackensack River may be affected by these extensive wetlands, particularly with regard to nutrient release or uptake. Therefore, an assessment of the nature and magnitude of the nutrient fluxes in these tidal wetlands was required as input to the water quality model for the estuary. However, the ecological research community is not in agreement as to the magnitude or direction of such fluxes and the important factors regulating nutrient exchange in estuaries are still under investigation.

Therefore, no data were available to estimate the magnitude of nutrient fluxes between the tidal wetlands and the estuarine Hackensack River. This study was conducted to assess the nutrient dynamics in the tidal wetlands of the Hackensack estuary and provide loading estimates for input to the water quality model of the estuary.

1.1 ECOLOGICAL HISTORY OF THE HACKENSACK MEADOWLANDS

The lower Hackensack River Basin is underlain by the sedimentary sandstones and shales of the Newark Group. The River valley was scoured by glaciers, and the retreat of the last glacier deposited a layer of glacial till which is composed of mixed sand, gravel and clay. Layers of peat and organic soils cover the glacial deposits in the tidal wetlands areas. Further details regarding the characteristics of the lower Hackensack River and its watershed are provided in Chapter 2 of Appendix A, Part 1 of this report

The tidal wetlands of the Hackensack Meadowlands have been affected by human activity for over three centuries. Historically, the basin was once the site of one of the largest Atlantic White Cedar (Chamaecyparis thyoides) bogs on the eastern seaboard. Early Dutch settlers harvested the cedar for building materials, diked and drained the wetlands, and used the land for agriculture. In the mid-nineteenth century, land companies drained the marshes to the north of the existing meadowlands, particularly in the areas surrounding Berry's Creek. Later, local mosquito control commissions tide-gated, diked and drained enormous areas of cedar bog and emergent marsh The subsequent dry soil conditions eliminated most of the remaining cedar stands. Increasing acreage of natural salt marsh was changed to freshwater marsh and to uplands. In the uplands, the peat eventually sank as it dried, leaving the elevation of the soil surface below sea level (State of New Jersey, 1984).

In 1922 the Oradell Dam was constructed to impound the upstream, fresh water portion of the Hackensack River at New Milford. This restricted much of the fresh water flow in the river and salt water intruded into the -estuary, completely altering the salinity regime of the system. The growth of coastal commerce required the dredging of the Hackensack River channel which changed the estuarine hydrodynamics. The once shallow estuary became a deeper, muddy tidal river fringed with marshland, in which fresh and tidal flows were controlled by human activity (State of New Jersey, 1984).

Phragmites australis, a pollution-resistant and somewhat salt water tolerant grass, invaded most of the diked and tidally flowed areas in the basin. The optimal location for Phragmites australis is at elevations above mean high water. A hurricane in 1950 broke many dikes and tidegates, reopening much of the reclaimed, but low-lying, land to tidal inundation. In particular, the Sawmill Creek subbasin was flooded regularly and vast mudflats formed in areas where the original peat had sunk below sea level. Over the four decades since the hurricane, salt marsh cordgrass (Spartina alterniflora) has become a significant component in the wetland community in the Sawmill Creek area, slowly invading the shallow mudflats. Spartina alterniflora has also colonized areas where stands of the once dominant Phragmites australis have died off due to prolonged inundation and higher salinities. However, Phragmites australis has survived in areas where it might not be able to colonize and has not been out competed by Spartina alterniflora in all portions of Sawmill Creek (Kraus and Smith, 1986).

The dynamic nature of the Sawmill Creek ecosystem is demonstrated by the change in vegetation observed in its wetlands over the past forty years. Table 1.1 summarizes data from Kraus and Smith (1986) for the Wildlife Refuge in Sawmill Creek. In 1989 Najarian Associates, L.P. calculated the acreage occupied by each ecological community within the entire Sawmill Creek system with cooperation from the Hackensack Meadowlands Development Commission (HMDC). At that time, mudflats occupied ± 780 acres; Spartina alterniflora, ± 131 acres; and Phragmites australis, ± 279.8 acres. Clearly, the 1989 analysis encompassed a larger area than that studies by Kraus and Smith and so the 1989 figures are not directly comparable to those provided in Table 1.1.

TABLE 1.1: Acreage Occupied by Three Ecological Communities over Time in The Sawmill Creek Basin

		MARSH	
YEAR	MUDFLAT	S. Alterniflora	P. Australis
1950	0.0,	0.0	589.0
1963	490.3	1.8	96.9
1972	410.0	68.8	1102
1985	402.2	74.4	212.1

Source: Kraus and Smith, 1986 and Najarian Associates, LP.

Another example of ongoing change in the Hackensack Estuary is a marsh renovation project in Mill Creek. The renovation consists of lowering the marsh surface elevation, removing Phragmites australis, and planting Spartina alterniflora. Clearly, through natural and human-influenced processes, the composition of the tidal wetland community in the estuary continues to evolve (Kraus and Smith, 1986).

In 1989 the Hackensack River estuary contained approximately ± 2,543 acres of tidally inundated wetlands of which ± 2,240 acres were Phragmites australis, ± 298 acres were Spartina alterniflora, ± 9 acres were other tidal wetland plants such as Spartina patens, Scirpus validus, Pluchea camphorata, and ± 780 acres were mudflats (in the Sawmill Creek basin). Figure 1.2 illustrates the distribution of tidal wetlands and mudflats in the Hackensack River estuary. Table 1.2 lists the acreage of tidally inundated wetlands (maximum elevation of 4.0 feet above mean sea level NGVD) and mudflats in the Hackensack River estuary listed by subcatchments used in the study (see Appendix A, Part 1 of this study for description of the Model segmentation).

TABLE 1.2: Area Occupied by Tidally Inundated Wetlands and **Mudflats** in the Hackensack Meadowlands by Species (in ACRES)

Model Drainage **Subbasin**	Phragmites	Spartina alterni-	Spartina	Scripus	Pluchea	Total
Berrys	225.1	5.4	**1.3**	-	-	231.8
Conrail	2925	4.9	0.9	-	3.7	298.3
Cromakil	331.6	118.7	-	-	-	450.3
Keamy	33	0.8	-	-	-	4.1
Losen	193.1	5.4	-	0.9	-	199.5
Moonachie	125.7	5.8	-	-	-	131.5
Penhom	23	0.0	-	-	-	2.3
Sawmill	285.7	131.8	0.8	-	-	4183
Secaucus	44.6	4.7	-	-	-	49.3
Secon	114.8	33	1.4	-	-	119.5
Teter	783	0.0	-	-	-	78.3
Walden	281.0	11.1	-	-	-	292.1
Wolmans	262.3	5.7	-		-	268.0
Total:	22402	297.6	4.4	0.9	**3.7**	2543.1

***Subcatchments** as defined for use in the DNM Model in Volume I of this Report.

13 NUTRIENT DYNAMICS AND PROCESSES IN TIDAL WETLAND ECOSYSTEMS

Tidal wetland systems have generally been assumed to be highly productive systems, providing nutrients that support' the productivity of estuarine and coastal waters. However, as described in Section 1.3, research into the nature and magnitude of such **exchanges** has provided more questions than it has answered. The following paragraphs summarize the current theory regarding nutrient dynamics in tidal wetlands.

Tidal marshes and **mudflats** are dynamic systems that, by their nature, must accrete at a rate greater than or **equal** to the rise in sea level in order to survive. Thus, over the long term, most tidal wetlands are sinks for suspended sediments. Younger coastal wetland systems expand rapidly, whereas older systems tend to be more stable and may eventually shrink in size if expansion is impossible, such as along the rocky coast of New England.

The Hackensack Meadowlands, particularly the Sawmill Creek **subbasin** is a young, evolving ecosystem. As described in the previous section, Spartina alterniflora is colonizing the vast **mudflats** and replacing Phragmites australis in many areas of the estuary. The northern section of the Meadowlands; dominated by Phragmites australis, **is** also accreting at a rapid rate (approximately 1 inch per year). As accreting systems, these marshes would tend to act as net sinks of suspended sediments to which nutrients may be adsorbed (HMDC, 1989): Marshes also accrete due to **build-up** of organic matter formed in situ. This organic matter may also be a sink for nutrients.

The movement of tidal waters over the marsh surface acts to physically aerate the water. It is reasonable to assume that this is the most important source of dissolved oxygen (DO) to the tidal waters flooding the marshes. In addition, photosynthetically active plants and associated algae uptake nutrients and produce oxygen during daylight hours of the growing season. This oxygen enters the water column as DO when the marsh **is** flooded. At night plants consume oxygen during photorespiration but this sink of DO is usually relatively small compared to the production of oxygen during the daytime. Thus, marshes often act to export DO, particularly during the growing season.

The nitrogen cycle in a marsh is complex and the nature and magnitude of each **component** is only partially understood. Bacterial nitrogen fixation **($N_2 \rightarrow$Organic-N)** in the rhizosphere ("root atmosphere") is the dominant process in the nitrogen cycle in marshes. When plants senesce in a marsh, the above-ground components become detritus which are a source of inorganic nitrogen to the estuary. The below-ground components decompose, are stored in the sediments and are recycled during the following growing season. Denitrification ($NO_3 \rightarrow N_2$) also occurs in marsh sediments and results in a loss of inorganic N from the marsh to the atmosphere. Some dissolved inorganic N, as NH_3-N or NO,-N, is periodically released from the marsh through porewater losses at low tide, leaching from leaves and stems during senescence, and surface runoff during storm events.

Dissolved organic N is also lost from senescing plants. The source of N-nutrients for the plants' exists in the pool of sediment N, accumulated from sedimentation (water column), decomposition (recycled plant material), and nitrogen fixation (atmosphere). Although some nutrient exchange with the water column does occur, marshes are predominantly closed systems acting as nitrogen transformers as the plants utilize remineralized nutrients year after year (Howes et al., 1986). In general, marsh vegetation tends to import inorganic nitrogen and export organic nitrogen (Whitney, 1989; Wolaver et al., 1983). In a nutrient-rich system like the Hackensack River estuary, the nutrient dynamics may be very different.

Mudflats, characterized by extensive, unvegetated sediments and associated algae and bacteria, have a different nutrient exchange regime than marshes. The large surface area exposed at low tide allows direct gas exchange to take place at the sediment surface for significant periods of time. Nitrogen fixation is a minor process in mudflats because of the lack of a rhizosphere habitat for the nitrogen-fixing bacteria. Denitrification is more important in mudflats because of the large resident population of bacteria in the anaerobic soils, and because it is not competing with plant uptake of inorganic N. Photosynthetic algae and bacteria may contribute significant amounts of DO to the water column. Additionally, sheet movement physically aerates the water column as the tides move across the large surface area of shallow mudflats (Seitzinger, 1987).

13 SUMMARY OF LITERATURE ON WETLAND-ESTUARINE AND MUDFLAT-ESTUARINE NUTRIENT EXCHANGE

Numerous researchers have measured nutrient exchange between estuaries and adjacent marshes and mudflats over the past thirty years. However, no consensus has been reached regarding the roles of marshes and mudflats in the nutrient dynamics of estuaries. One of the major reasons is that the estimation of these dynamics from direct measurements of wetland-estuarine nutrient exchange has proven to be extremely difficult. Problems encountered in long-term net flux measurements range from complex estuarine hydrodynamics to site specific marsh ecosystem dynamics. The most critical component of flux estimation is obtaining accurate water exchange measurements, since the calculation of net mass transport is based upon these data. Several different approaches have been used to obtain correct water flux measurements, including current meters, tide height and .hypsographic curves; bathymetry, or others. None have proven entirely satisfactory in all situations.

In addition to different flow measurement techniques, sampling intensity and duration vary widely in the literature. Sampling methods vary from measurements taken every half-hour over one tidal cycle to those taken every four-hours over four cycles. The interval between sampling events also varies from weeks to months. The vast differences in methodology used by researchers in water flux and nutrient flux estimates may explain some of the variation in the results from these studies and makes it very difficult, if not impossible, to compare results from different estuarine ecosystems. Site-specific hydrodynamic, biological and water quality conditions further complicate such comparisons.

Nixon (1980) has written an excellent summary of the results of flux research completed between 1963 and 1979. Since that time, approximately ten additional studies have been published. Tables 1.3 and 1.4 **summarize** the research to date on marsh-estuarine and mudflat-estuarine nutrient dynamics and provide the authors descriptions of seasonal and annual estimates of net import, export, or lack of exchange of nitrogen-series nutrients. Many of these studies included year-round data, however only the July, August and November, and Annual flux estimates of inorganic nitrogen are presented here for the purpose of comparison with the data obtained in this study.

The results from flux studies on marsh-estuarine interactions indicate that the dynamics of ammonia (NH,) and nitrate **(NO_3)** exchange in salt marshes are variable and do not appear to be correlated with salinity. Although most of the studies reported a net annual import of total inorganic nitrogen (which includes dissolved and particulate inorganic nitrogen), seasonal export of NH,, NO, or NO, often occurred. Welsh **(1980),** in Connecticut, and **Woodwell (1979),** in New York, found export of NH, in the summer and import in the winter, while Stevenson et al. (1976) and Heinle and Flemer **(1976),** both in Maryland, and Valiela et al. **(1978),** in Massachusetts; reported import of NH, in the summer and export in the winter. Whiting **(1989),** in South Carolina, reported import of NH, throughout the year. In general, when researchers found import of inorganic nitrogen, they found a **concomittant** export of organic nitrogen, particularly with the ebbing tide.

Research in the Hackensack River Estuary by Mattson and Vallario (1976) (not included in the summary tables because total nitrogen was not reported by nitrogen species) indicated that the estuary as a whole exported total nitrogen (inorganic and organic nitrogen) in the summer and in the winter. However, the upper section of the estuary near Mill Creek showed a net import of total nitrogen, while the Sawmill Basin showed a net export of total nitrogen. The net export in the lower section of the estuary was attributed to nutrient sources from sewage treatment plants, industrial overflow, and landfills. Marshes, in general, appear to act as nitrogen transformers, importing dissolved inorganic nitrogen and exporting dissolved and

TABLE 1.3: SUMMARY OF RESEARCH ON SEASONAL & ANNUAL NUTRIENT FLUX BETWEEN TIDAL MARSHES AND ESTUARINE WATERS
(E = EXPORT FROM MARSHES TO ESTUARY; I = IMPORT TO MARSHES FROM ESTUARY; 0 = NO MET EXCHANGE)

TIDAL MARSH AND ESTUARY STUDY			JULY			AUGUST			NOVEMBER			ANNUAL		
AUTHORS	LOCATION	SALINITY	NH4	NO2	NO3	NH4	NO2	NO3	NH4	NO2	NO3	NH4	NO2	NO3
1	MD	0-5	I	I	I	I	I	I	E	E	E	E	E	E
2	MD	0-9	I	I	I	I	E	E	E	E	E	E	E	E
3	VA	0-7										E	I	I
4	VA	0-12										I	I	I
5	VA	0-12	E	I	I	I	E	I	I	I	I	I	E	I
6	NH	0-31	I	I	E	I	E	E	I	I	E	I	I	I
7	MD	0-30			E			E			I			E
8	LA	0-30						E			E			E
9	DE	10-28										I	I	I
10	CT	15-25	E	E	I	E	I	E	I	I	I	E	I	I
11	GA	20-23										0	0	0
12	DENMARK	25-30	E		E	E		E	I		I	I		I
13	NY	26	E	E	E	E	I	E	E	I	I	E	I	I
14	MA	30-32	I		I	I		I	E		E	E		E
15	SC	30-34							E					
16	SC	30-34											I*	I*
17	SC	30-35	I	I*	I*	I	I*	I*	I	I*	I*	I	I*	I*

1. Stevenson et al. (1976)
2. Heinle and Flemer (1976)
3. Axelrad (1974) as presented in Nixon (1980)
4. Axalrad (1974) es presented in Nixon (1980)
5. Wolaver et al. (1983)
6. Daly and Mathieson (1981)
7. Correl (1981)
8. Stern et al. (1986)
9. Lotrich et al. (1977) as presented in Nixon (1980)
10. Welsh (1980)
11. Haines et al. (1976) as presented in Nixon (1980)
12. Jensen et al. (1985)
13. Woodwell et al. (1979)
14. Valiela et at. (1978)
15. Kjerfve et al. (1981)
16. Spurrier et al. (1988)
17. Whiting (1989)

* = NO3 + NO2

TABLE 1.4: SUMMARY OF RESEARCH ON SEASONAL AND ANNUAL NUTRIENT FLUX BETWEEN TIDAL HUDFLATB AND ESTUARINE WATERS
(E = EXPORT FROM MUDFLATS TO ESTUARY; I = IMPORT TO MUDFLATS FROM ESTUARY)

			JULY			AUGUST			NOVEMBER			ANNUAL		
AUTHORS	LOCATION	SALINITY	NH4	NO2	NO3	NH4	NO2	NO3	NH4	NO2	NO3	NH4	NO2	NO3
1	VA	0	E		I	E		I						
2	VA	0-10	E		I	E		I	E		I	E		I
3	LA	<1				E	I*	I*	E	I*	I*	E	I*	I*
4	CT	15-25	I	I	I	I	I	I	E	E	E	I	E	I
5	CANADA	20-28			I			E			E			E
6	LA	25				E	E*	E*	E	E*	E*	E	E*	E*
7	DENMARK	25-u)							E		E			

1. Cerco (1988)
2. Simon (1988)
3. Teague et al. (1988)
4. Welsh (1980)
5. Keizer et al. (1989)
6. Teague et al. (1988)
7. Jensen et al. (1985)

* = NO3 + NO2

particulate organic nitrogen. However, the dynamics of any particular system appear relatively unpredictable.

The results of most flux studies on mudflat-estuarine interactions indicate net import of NO, and export of NH, throughout the year. Teague et al. (1988) reported a net export of inorganic nitrogen both in August and November. However, Welsh (1980) found a distinct seasonal@ to inorganic nitrogen flux, with consistent import of NH, NO, and NO, during the July and August and export of those parameters in November. During the same time frame, she reported the opposite pattern in the adjacent marshes (export of inorganic nitrogen in the summer, import in the fall) and suggested that the mudflat was removing the pulses of nutrients released from the marsh.

Clearly, marsh-estuary, mudflat-estuary, and marsh-mudflat nutrient dynamics are complex. This complexity, along with the difficulties of measuring flows in an estuary and the inherent variability of estuarine water quality, make nutrient fluxes in these systems difficult to quantify. Continued efforts to refine flux measurements will provide further insight into the dynamics of estuarine ecosystems.

2. METHODS

This study was designed to explore the nutrient dynamics in the wetlands of the lower Hackensack River to determine their impacts on the water quality regime of the Estuary. In particular, this study was designed to examine the nutrient dynamics in three different ecosystems: wetlands dominated by Spartina altemiflora; wetlands dominated by Phragmites australis; and mudflats. The study 'included two scales of investigation: microscale experiments in small areas of marsh and mudflat; and macroscale experiments in the tidal creeks draining the wetlands. The microscale experiments were designed to provide estimates of the direct exchange between an isolated area of marsh or mudflat. The macroscale experiments were designed to analyze the dynamics of an entire wetland system which might contain more than one wetland ecosystem and other possible pollutant sources such as an STP on Mill Creek and two major landfills on Sawmill Creek. Thus, the macroscale experiments were designed to investigate the interaction between the wetlands and the other pollutant sources in the ecosystem

The sampling plan was also designed to provide data for the sediment nutrient and oxygen demand, and denitrification study conducted by Jay L. Taft, Ph.D. The benthic stations, described below, were sampled for those analyses. The results of that study are provided in Appendix A-2-3.

Possiile study areas were identified from United States Geological Survey (USGS) 7-1/2-minute topographic quadrangle maps, from 200-scale HMDC topographic maps, and from other HMDC data based on ecological communities, size, surrounding laud use and accessibility. The potential study areas were investigated during a river boat survey conducted by Najarian Associates, L.P. on September 7, 1988. The survey team included Jay L Taft, Ph.D. of Harvard University, one staff member from General Testing Corp. and four staff members from Najarian Associates, L.P. The tributaries considered were Moonachie Creek, Mill Creek, Sawmill Creek, and Berry's Creek Two of these, Mill Creek and Sawmill Creek, were targeted for the November 1988 study. **A** third tributary, Berry's Creek, was added **at a** later date for the July and August 1989 surveys.

2.1 MACROSCALE EXPERIMENTS-TRIBUTARY SAMPLING

2.1.1 Sawmill Creek

Sawmill Creek is the tributary with the greatest tidal exchange with the main Hackensack River. This basin contains extensive tidal marshes (±412 acres) and mudflats (±780 acres),. The marshes are dominated by Spartina alterniflora and Phragmites australis (see Figure 1.1). As shown in Table 1.1, above, the acreage of Phragmites australis is shrinking as that of Spartina alterniflora increases. The change in vegetation is the continuing result of the re-inundation of the system with saline water following the hurricane of 1950 and of increased sedimentation. The low salt marsh provides habitat for a variety of vertebrate and invertebrate fauna.

The mudflats dominating the system are large open areas which are flooded at every 'high tide, but become exposed mudflats during low tides. Homed pond weed and algae reside in the water column and on the mud surface while a host of invertebrates live in the upper few centimeters of the sediment. The mudflats are essential in the life cycle of many waterfowl, shore birds, fish and shellfish, providing them with food and habitat. The shallow waters allow photosynthesis to occur in the plants which occupy the water column and on the surface of the mudflat which adds oxygen to these waters (State of New Jersey, 1984).

The head of Sawmill Creek is flanked by the two largest active landfills (HMDC/MSLA 1C and HMDC Balefill Sanitary Landfills) in the Hackensack River watershed. These landfills have been suspected of being potentially large source of BOD and nutrients to Sawmill Creek and the Hackensack River (NJDEP, 1985). No data is available that accurately measures those loadings. HMDC monitors several wells to sample the **leachate** from these landfills. Some of this recent data was obtained for this study; no additional monitoring was conducted.

Four water quality stations (S1 - S4) and five benthic stations (S1 - S4 and S2A) were sampled. within Sawmill Creek; two water quality and benthic stations (M2 and M3) were sampled in the tidal marsh impoundment (see Section 2.2.2); and one water quality and benthic station (Ml) (see Section 2.2.1) and one denitrification station (N1) were sampled in the **mudflat** embayment within the Sawmill Creek subbasin. Figure 2.1 illustrates the location of these sampling stations. Each of these stations were sampled in November 1988, July 1989, and August 1989, except Ml which was not sampled in August 1989.

Station S3 is located in Sawmill Creek at the New Jersey Turnpike crossing. Approximately 498 acres of the Sawmill Creek basin drain to this station, almost all of it **mudflat.** The HMDC Landfills are located upstream of this station. Station S4 is located at the head of the Creek, adjacent to the landfills. Station S1 is located at the mouth of the Creek

2.13 Berry's Creek and Berry's Creek Canal

Berry's Creek drams a substantial tidal marsh system occupying ±219 acres. The system is dominated by Phragmites australis. The surrounding upland land use is predominantly industrial.

Two sampling stations were installed within Berry's Creek (S14 and S15) as shown on Figure 2.1. These stations were sampled in July 1989 and August 1989.

Berry's Creek Canal drains a large industrial/commercial watershed in its upstream end, ±128 acres of tidal marsh dominated by Phragmites australis in the central section, and dredge spoil fill in its lower end. Three benthic stations (S6, S7 and S8) were sampled within the **canal** reach as shown on Figure 2.1. Each of these **benthic** stations was sampled in November 1988 and August 1989.

2.13 Mill Creek

Mill Creek is the only tributary sampled that, enters the Hackensack River from the east. A sewage treatment plant discharges **±2.8 million** gallons per day (mgd) of secondary-treated effluent to the upper portion of the Creek Tidal marshes exist along the entire eastern side of the Creek. The lower section of the Creek is the site of an extensive marsh renovation project, which has involved lowering the marsh surface, removal of **Phragmites australis,** and subsequent planting of **Spartina alterniflora.**

Four sampling stations were installed within Mill Creek; three in the Creek **(S9, S9A** and **S11)** upstream of the mitigation site and one at the sewage treatment plant **(S10)** to monitor the quality of its effluent. These stations are shown on Figure 2.1. Stations **S9, S10,** and **S11** were sampled in November 1988, **July** and August **1989;** **S9A** was sampled in **July** and August 1989.

2.2 MICROSCALE EXPERIMENTS

In addition to the **instream** sampling stations, water quality and sediment samples were collected from a **mudflat** embayment and a tidal wetland impoundment in the **Sawmill** Creek basin Each of the macroscale experiments included more than one ecosystem or possible source of nutrient loading. The microscale experiments were designed to **evaluate** effects from the marsh and **mudflat** alone. It was anticipated that these results could be used in conjunction with the macroscale experiments to develop loading estimates that could be extrapolated to **all** of the **mudflats** and tidal wetlands within the Hackensack Estuary.

23.1 Tidal **Mudflats**

A representative tidal mudflat in the Sawmill Creek subbasin was chosen for the experiment (see Figure 2.2). The ±34.7 acre mudflat embayment was located adjacent to the HMDC Kingsland Landfill, bounded by HMDC access roads on the north, south and east, and the PSE&G powerline dike road on the west. Elevations ranged from -1 to +6 feet NGVD. The only source of water in the mudflat embayment was tidal exchange; a retaining wall forty feet deep separated the mudflat from the landfill, preventing potential contamination by leachate. One large channel (elevation -2.7 feet NGVD), one small channel (elevation + 0.9 feet NGVD), and one culvert (elevation -0.24 feet NGVD), drained the mudflat embayment. Since the large channel was the path for approximately 95% of the tidal volume, it was chosen as the site for representative sampling of tidal height and water quality (Station Ml). A 200-scale topographic map supplied by HMDC (1985) was used to estimate acreage and tidal volumes at 0.1 foot elevation intervals. This information was used to calibrate flow using measurements taken during the study.

2.23 Tidal Marsh

A representative tidal marsh in the Sawmill Creek subbasin was chosen for the experiment (see Figure 2.3). The tidally inundated portion of the ±3.5 acre marsh was dominated by Spartina alterniflora (67%) and Phragmites australis (33%). Phragmites australis and Panicum virgatum were dominant at elevations greater than mean high water (approximately elevation 3.7 feet NGVD). The tidal marsh impoundment topographic map and vegetation map are included as Figures 2.4 and 2.5. The marsh was located in an impoundment bordered on the north by Kingsland Ditch, on the south by Sawmill Ditch, on the east by the New Jersey Turnpike, and on the west by the Transco gas pipeline access road. Elevations ranged from -1 to +8 feet NGVD.

The impoundment was inundated and drained through one 48-inch corrugated aluminum pipe culvert with tidal waters from Sawmill Ditch; this pipe was selected as the monitoring location {Station M2). Because only one inlet/outlet linked the marsh impoundment with the Sawmill Creek basin, it was anticipated that accurate volume, flow, and water quality measurements would be possible. The entire impoundment was surveyed by Najarian Associates, LP. and a topographic map with a one-foot contour interval was generated. This map and tidal elevation measurements were used to calculate incremental tidal volumes, providing an additional check for flow measured during the study. The aerial extent of each plant species also was mapped.

2.3 SAMPLING METHODS

Sampling was conducted during November, 1988 and July and August 1989 at the instream "S" stations. The November surveys were conducted at a time when tidal wetland plants were senescing. The July and August surveys were selected as the period of greatest DO depletion in the River, and as a time when tidal wetland plants were growing rapidly. Water quality data were collected at each of the instream "S stations at two-hour intervals over four consecutive tidal cycles during the November sampling period and over two consecutive cycles in July and August. The water quality parameters sampled are listed in Tables 2.1 to 2.3. The data were collected during dry weather periods to avoid confounding effects of stormwater runoff.

The survey times and water quality parameters sampled at the tidal mudflat (Ml) and tidal marsh (M2, M3) stations were identical to those sampled in the tributaries, except that no sampling was done at Station Ml in August. During the November 1988 survey, Station Ml was sampled every 2 hours for approximately 48 hours, spanning four tidal cycles. Sampling at the marsh stations (M2, M3) in November occurred at a frequency of every hour only during the residence time of the tide on the marsh, a period of approximately 7 hours for each tidal cycle, for four tidal cycles. That is, sampling began when the tidal waters reached the marsh surface and ended when tidal waters dropped below the marsh surface. Plow was estimated using hand-held flow meters at each sampling time at Stations Ml and M2. In addition, staff

TABLE 2.1: SUMMARY OF PARAMETERS MEASURED DURING NOVEMBER 1988 SAMPLING PERIOD

PARAMETERS/STATION	M1	M2	M3	S1	S2	S2A	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13		N1	N2
TIDE/FLOW	X	X	X				X							X						
TEMPERATURE	X	X	X	X	X		X	X					X	X	X	X	X		X	X
TURBIDITY	X	X	X	X	X		X	X					X	X	X	X	X			
SALINITY	X	X	X	X	X		X	X					X	X	X	X	X		X	X
pH	X	X	X	X	X		X	X					X	X	X	X	X		X	X
CHLOROPHYLL-A	X	X	X	X	X		X	X					X	X	X	X	X			
DO	X	X	X	X	X		X	X					X	X	X	X	X		X	X
C-BOD5	X	X	X	X	X		X	X					X	X	X	X	X			
NH_3-N	X	X	X	X	X		X	X					X	X	X	X	X		X	X
NO_2-N	X	X	X	X	X		X	X					X	X	X	X	X		X	X
NO_3-N	X	X	X	X	X		X	X					X	X	X	X	X		X	X
TKN	X	X	X	X	X		X	X					X	X	X	X	X		X	X
TOTAL PHOSPHORUS	X	X	X	X	X		X	X					X	X	X	X	X			
ORGANIC PHOSPHORUS	X	X	X	X	X		X	X					X	X	X	X	X			
ORTHO-PHOSPHORUS	X	X	X	X	X		X	X					X	X	X	X	X			
TSS	X	X	X	X	X		X	X					X	X	X	X	X			
BENTHIC	X	X	X	X	X	X	X	X		X	X	X	X		X					
N_2																			X	X

LEGEND:

M1 MUDFLAT EMBAYMENT
M2 MARSH IMPOUNDMENT S
M3 MARSH IMPOUNDMENT N

N1 DENITRI MUDFLAT @ M1
N2 DENITRI RIVER @ W4

S1 SAWMILL BOUNDARY S
S2 SAWMILL BOUNDARY N
S2A SAWMILL MIDSTREAM
S3 SAWMILL TPKE
S4 SAWMILL LANDFILL
S5 N ARL STP

S6 BERRYS CANAL BOUNDARY
S7 BERRYS CANAL MID
S8 BERRYS CANAL UPPER
S9 MILL CREEK BOUNDARY
S10 SECAUCUS STP
S11 MILL CREEK UPPER

S12 PSE&G INTAKE
S13 PSE&G DISCHARGE

TABLE 2.2: SUMMARY OF PARAMETERS MEASURED DURING JULY 1989 SAMPLING PERIOD

PARAMETERS/STATION	M1	M2	M3	S1	S2	S2A	S3	S4	S6	S7	S8	S9	S9A	S10	S11	S14	S15		N1	N2
TIDE/FL[a]	X	X	X				X							X		X				
TEMPE[a] TURE	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
TURBIDITY																				
SALINITY	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
pH	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
CHLOROPHYLL-A	X	X	X	X	X		X	X				X	X	X	X	X	X			
DO	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
C-BOD5	X	X	X	X	X		X	X				X	X	X	X	X	X			
NH_3-N	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
NO_2-N	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
NO_3-N	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
TKN	X	X	X	X	X		X	X				X	X	X	X	X	X		X	X
TOTAL PHOSPHORUS	X	X	X	X	X		X	X				X	X	X	X	X	X			
ORGANIC PHOSPHORUS	X	X	X	X	X		X	X				X	X	X	X	X	X			
ORTHO-PHOSPHORUS	X	X	X	X	X		X	X				X	X	X	X	X	X			
TSS	X	X	X	X	X		X	X				X	X	X	X	X	X			
BENTHIC																				
N_2																			X	X

LEGEND:

- M1 MUDFLAT EMBAYMENT
- M2 MARSH IMPOUNDMENT S
- M3 MARSH IMPOUNDMENT N
- N1 DENITRI MUDFLAT @ M1
- N2 DENITRI RIVER @ W4
- S1 SAWMILL BOUNDARY S
- S2 SAWMILL BOUNDARY N
- S2A SAWMILL MIDSTREAM
- S3 SAWMILL TPKE
- S4 SAWMILL LANDFILL
- S6 BERRYS CANAL BOUNDARY
- S7 BERRYS CANAL MID
- S8 BERRYS CANAL UPPER
- S9 MILL CREEK BOUNDARY
- S9A MILL CREEK BELOW STP
- S10 SECAUCUS STP
- S11 MILL CREEK UPPER
- S14 BERRYS CREEK @ TPKE
- S15 BERRYS CREEK

TABLE 2.3: SUMMARY OF PARAMETERS MEASURED WRING AUGUST 1989 SAMPLING PERIOD

PARAMETERS/STATION	M1	M2	M3	S1	S2	S2A	S3	S4	S6	S7	S8	S9	S9A	S10	S11	S14	S15		N1	N2
TIDE/FLOW		X					X							X		X				
TEMPERATURE		X		x	x		X	x				x	x	x	x	x	x		x	x
TURBIDITY																				
SALINITY		X		x	x		x	x				x	x	x	x	x	x		x	x
pH		X		x	x		x	x				x	x	x	x	x	x		x	x
CHLOROPHYLL-A		X		x	x		x	x				x	x	x	x	x	x			
DO		X		x	x		x	x				x	x	x	x	x	x		x	x
C-BOD5		X		x	x		x	x				x	x	x	x	x	x			
NH_3-N		X		x	x		x	x				X	X	X	x	x	x		x	x
NO_2-N		X		x	x		x	x				x	x	x	x	x	x		X	x
NO_3-N		X		x	x		x	x				x	x	x	x	x	x		x	x
TKN		x		x	x		x	x				x	x	x	x	x	X		x	X
TOTAL PHOSPHORUS		X		x	x		x	x				x	x	x	x	x	x			
ORGANIC PHOSPHORUS		X		x	x		x	x				x	x	x	x	x	x			
ORTHO-PHOSPHORUS		X		x	x		X	x				x	x	x	x	x	x			
TSS		X		x	x		x	x				x	x	x	x	x	x			
BENTHIC	X	X	x	x	x	x	x	x	x	x	x	x	x		x	x	x			
N_2																			x	x

LEGEND:
M1 MUDFLAT EMBAYMENT
M2 MARSH IMPOUNDMENT S
M3 MARSH IMPOUNDMENT N
N1 DENITRI MUDFLAT @ M1
N2 DENITRI RIVER @ W4
S1 SAWMILL BOUNDARY S
S2 SAWMILL BOUNDARY N
S2A SAWMILL MIDSTREAM
S3 SAWMILL T P K E
S4 SAWMILL LANDFILL
S6 BERRYS CANAL BOUNDARY
S7 BERRYS CANAL MID
S8 BERRYS CANAL UPPER
S9 MILL CREEK BOUNDARY
S9A MILL CREEK BELOW STP
S10 SECAUCUS STP
S11 HILL CREEK UPPER
S14 BERRYS CREEK @ TPKE
S15 BERRYS CREEK

gauges were secured in place adjacent to the location at which flow was measured, and tidal elevation height was recorded at each sampling time.

During the July 1989 survey, samples at both the mudflat and marsh stations were collected at half-hour intervals. During low-flow periods, two half-hour samples were combined using flow-weighted compilation. This reduced the number of samples that needed to be analyzed during low flow periods when little change in mass flux was anticipated. Flow was estimated using hand flow meters at each sampling time. Staff gauges were used to record tidal elevations at the time of each sampling. A stilling well with an internal tide gauge was installed at Stations Ml and M2 with a continuous chart recorder as a check on manual recoding of observations on the staff gauges.

During the August 1989 survey, only Station M2 was sampled. Samples were taken every half hour and they were not composited. Flow and tidal elevation were recorded in the same manner as the July 1989 survey.

Tidal wetland acreage for the entire Hackensack Meadowlands was determined from available data, Topographic maps and aerial photographs, both at 200 scale, were obtained from HMDC. Tracings were made of the 0- and 4-foot elevation contours which were copied onto the aerial photographs. HMDC staff marked the limit of tidally inundated wetlands, the location of all tide gates, and the location and extent of Phragmites australis, Spartina alterniflora, Spartina patens, Scirpus validus, Pluchea camphorata on each map. Tibbet-Abbot-McCarthy & Staten Consultants, Inc. (TAMS) located the extent of each of the wetlands mitigation areas created by Hartz Mountain in the Belmans, Cromakill, and Mill Creek tributaries. TAMS also provided a written estimate of the acreage of newly created marsh dominated by Spartina alterniflora, upland islands, and open water for each mitigation site, e this information was recorded on the tracings, the areas of all tidally inundated wetlands and mudflats were digitized by Najarian Associates, L.P. staff. The acreage estimates were calculated for each tributary (see Table 2.4) and for each subcatchment basin defined for modeling purposes (see Table 1.2 and Appendix A, Part 1).

TABLE 2.4: Tidally Inundated Wetland Acreage by Tributary

TRIBUTARY	Phragmites australis	Spartina alternifl.	Spartina patens	Scripus validus	Total
Belmans	176.98	**3.69**	-	**0.92**	181.59
Cromakill	110.41	67.02	-	-	177.43
Mill	166.76	53.28	-	-	220.04
Doctors	259.20	5.82	-	-	265.02
Berrys Canal	128.63	0.14	-	-	128.77
Berrys Creek	212.25	5.41	**1.30**	-	218.96
Sawmill	279.79	131.54	-	-	41133
TOTAL	1334.02	266.90	130	0.92	1603.14

Benthic data were collected and analyzed at each sampling station during November 1988 and August 1989. The methodology for benthic sampling in the tributaries, **mudflat,** and marsh was identical to that used for the main-stem of the Hackensack River as **described** in Appendix A, Part 1.

Tidal elevation was monitored continuously at Station **H1** for the duration of each sampling period survey to provide a forcing function to drive the DNM model hydrodynamics (see Appendix A, Part 1 of this report).

2.4 PLOW CALCULATION

As noted above, an accurate time history of flow at a sampling site is essential for the accurate calculation of the mass transport through a system. The nature of the flow systems under study presented difficulties in direct measurement of flow. For example, in several instances the location of the sampling site did not provide a simple channel that could be used to generate an elevation to volume rating curve.

Based on the available data, two methods were used to calculate flows: 1) determination of flows through use of the DNM model; and 2) calculation of flows from elevation and flooded area data. The following paragraphs describe each method.

Method 1 employs the DNM hydrodynamic model to generate flow. The model is based on the one-dimensional continuity and momentum equations. Details regarding the model may be found in Appendix A, Part 1 of this study. The model was used to generate flows at Stations S9 and S9A in Mill Creek and Stations S14 and S15 in Berrys Creek. Water surface elevation data was collected at the mouth of the Hackensack River estuary (Station H1) for the relevant time period. The calibrated DNM Model was exercised for the appropriate sections of the estuary at half-hour increments from which flows at one-minute increments were determined.

The second method calculated flow from the rate of change of the volume of water inundating the marsh or flowing in the channel with respect to time:

$$Q_n = dV/dt$$

$$dV = V_{n+1} - V_n$$

$$dt = t_{n+1} - t_n$$

where: Q_n = Average Flow Rate between time t_n and time t_{n+1}

V_n = Volume at Time t_n

t_n = Time of n^{th} Observation

This technique was used at the Tidal Mudflat Embayment Station (Ml), the Tidal Marsh Impoundment Station (M2) and at Sawmill Creek at the New Jersey Turnpike Bridge (S3). The volume of water flooding the embayment, impoundment or marsh was based on the measured elevation and the associated volume at that elevation from a rating curve. The 'rating curve' was constructed by measuring the surface area of the embayment or impoundment between one .foot elevation contour intervals using an electronic digitizer on a 200-scale topographic map at Stations Ml and S3 (HMDC, 1985). Najarian Associates, L.P. surveyed the area surrounding Station M2 and produced a 30-scale topographic map with one-foot contours to supplement the 200-scale HMDC maps. The collected surface area data at l-foot intervals were interpolated- to O.l-foot intervals. The volume at a specific elevation was then calculated by multiplying the. surface area in each O.l-foot interval by the O.l-foot depth and summing those volumes up to the elevation in question,

Flows were then calculated by determining the difference in volume stored between two time periods and dividing that difference by the elapsed time. The elevation data were smoothed to eliminate discontinuities in the data. Several methods were used to smooth the data. For the November data at Station Ml, the August Data at Station M2, and all 'of the data at Station S3, a cubic polynomial was fitted independently to each rising and falling limb of the elevation curve. Separate curves were needed because asymmetry in the water surface elevation time series did not allow a good fit for a quartic polynomial over a complete tidal cycle. Linear interpolation was used to smooth the periods when the different polynomials joined, if needed At Station M2 in November, a quartic polynomial was independently fit to each complete tidal cycle. In addition, flows were assumed to be negligible at elevations below one (1) foot at Station M2 as the marsh surface is generally at elevations above one foot. A time series of water surface elevations was generated at one-minute intervals from these polynomials. Flows were calculated from these data as described, above.

For the July data at Stations Ml and M2, a polynomial or series of polynomials did not adequately fit the data. The data were corrected manually by drawing a smooth curve which was then electronically digitized. Based on that elevation data, flows were computed as described above. During July and August, flow data was available at Station M2. This data was compared to the calculated flows, with good results.

2.5 MASS FLUX CALCULATIONS

As discussed above, time series of flow data were generated at one-minute intervals for all applicable stations. Concentration data for water quality constituents were collected at approximately one-half hour to one hour intervals at each station. The water quality data were linearly interpolated to produce a water quality concentration time series at one-minute intervals.

The mass flux of each constituent was then calculated by integrating the product of the flow times the concentration at one-minute intervals for each half tidal cycle. The integration was conducted from slack tide to slack tide (zero flow). This integration may be represented by:

$$\text{Mass Flux} = \int_{t}^{t+T/2} (Q*C)*\delta t$$

Where: Q = Instantaneous Flow
C = Concentration
T = Tidal Cycle Period

The integration was carried out numerically. A mass flux time series was generated at one-minute increments by multiplying flow rate by concentration. These fluxes were multiplied by the time step, one minute) and summed over a half tidal cycle. This can be represented by:

$$\text{Mass Flux} = \sum_{i=t_1}^{i=t_2} (Q_i * C_i)\,\delta t$$

where:

Q_i = **Flow at time i**

C_i = Concentration at time i

δt = Elapsed time from i-l to i

t_1 = Time at the start of the half tidal cycle

t_2 = Time at the end of the half tidal cycle

This equation determines the mass transported into or out of the system over a half tidal cycle. The net mass for a tidal cycle was determined by subtracting the total mass leaving the system during an ebb tide from the total mass entering the system during the corresponding flood tide.

3. RESULTS AND DISCUSSION

The raw data collected for this study is presented in Appendix B, Part 1. The concentration data taken at each station during the surveys is summarized in tables within each section, below. The results of the mass flux analyses also are summarized in tables within each section, following. Appendix A-2-1 provides details regarding the net flux for several constituents for each station and each sampling period while Appendix A-2-2 provides graphs of the concentration, flow and flux data.

As described in Section 2.2, above, the net mass transported into (import) or out of (export) a system was calculated for each tidal cycle. These calculations provide an estimate of the pounds per tidal cycle transported by a system. However, the systems vary significantly in size and tidal exchange volume. Therefore, to provide some perspective as to the significance of the mass transport, the net mass transported was divided by the mass carried into the system during the flood portion of the tidal cycle. This provides an estimate of the percent import or export over a tidal cycle. If less than one percent of the incoming mass was transported over a tidal cycle, it was considered to be zero net transport.

During certain tidal cycles the flow volume entering the system during the flooding portion of the tidal cycle was roughly equivalent to that exiting the system under the ebbing portion of the cycle (less than 5% difference in total flow volume). Under these conditions any significant net mass transport of a constituent can be considered to be due to some process within the system and not simply to the unbalanced flow volumes. However, during other tidal cycles the flow volume transported during one portion of the tidal cycle was far greater than that transported during the other. In these cases, any significant mass transport noted may simply be due to the larger volume of water transported during one portion of the cycle and not to any processes in the system. To eliminate the flow imbalance, .a flow-weighted mass was calculated for each ebb and flood portion of each tidal cycle by dividing the total mass transported by the total volume of water transported. The flow-weighted mass for the flood and ebb portions of the cycle were compared to determine whether a net increase or decrease in concentration had occurred.

Total net transport was calculated for each sampling period. That is, the data over the entire two- or four-tidal cycle sampling period was combined to provide an estimate of net flow and mass transport. In certain cases, flow balanced over two to four tidal cycles, although it did not balance for each individual cycle. One example which occurred was that a larger flood volume in one tidal cycle was followed by a smaller flood volume and a larger ebb volume in the next cycle.

Data were also collected at Stations M3, S1, S2 and S4 in Sawmill Creek. For Stations M3, Sl and S2, the flow system in the marsh was such that the system did not empty or fill through a single point. It was not possible to relate the concentration at a given time and place to the volume of water that concentration represented. Therefore, it was not possible to determine the mass transport at those locations.

The experiments conducted for this project may be classified as three separate environments: microscale mudflat; microscale marsh; and macroscale wetland. The results are discussed under these headings for each station as follows.

3.1 MICROSCALE MUDFLAT • Station M-l

Concentration data for Station M-l is summarized in Table 3.1. A summary of the net import and export of mass is presented in Table 3.2, while more detailed tables and figures regarding results are provided in Appendices A-2-l and A-2-2.

November Data • Comparison of the total flood water volume to total ebb water volume for each tidal cycle during November revealed transport ranging from 2.4% (import) to -39% (export) of the total flood volume entering the system. During the

TABLE 3.1: Concentration Data **Summary** - Station Ml **(in mg/l)**

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
MONTH OF NOVEMBER						
CBOD5	26	2.91	0.70	1.80	4.93	24.05
NH3-N	23	3.68	050	252	454	13.72
NO,-N	25	1.04	0.33	0.00	1.36	31.38
NO,-N	23	037	0.04 .	0.29	0.43	9.86
Do	25	7.06	1.15	5.10	9.40	16.26
Salinity*	**26**	11.88	0.29	11.40	12.80	2.47
Chlorophyll-a	26	26.34	9.98	4.90	44.79	37.88
TKN	23	4.66	0.90	3.13	6.43	19.22
TPO4	22	0.27	0.07'	0.12	0.43	27.78
TSS	26	33.72	7.96	22.40	58.40	23.61
MONTH OF JULY						
CBOD5	49	3.62	0.67	2.00	4.95	18.43
NH,-N	49	130	033	0.88	2.02	25.48
NO,-N	49	0.27	**0.28**	0.01	1.14	103.26
NO,-N	49	0.64	0.07	0.48	0.74	1052
Do	51	**4.43**	1.69	2.00	8.50	38.20
Salinity*	48	7.86	0.46	7.07	8.51	5.91
Chlorophyll-a	47	26.78	11.87	3.10	58.90	44.33
TKN	**49**	2.83	0.76	1.11	5.03	26.73
TPO4	49	139	1.33	0.38	6.05	95.56
TSS	**50**	39.42	13.07	20.80	72.40	33.15

- Note: Salinity in PPT

Table 3.2: Summary of Import/Export Of Mass Flux in the Microscale Mudflat Experiment • Station M-1

STATION	DATE	T	CYCLE	FLOW	SALINITY	CBOD5	NH3	NO3	NO2	TKN	TOTAL N	TPO4	DO	CNL-A	TSS
M-1	11/88	D	CYCLE 1	I	I	I	I	I	E	I	I	I	I	E *	I
		N	CYCLE 2	E	E	E • *	E	E	E	E **	E	E	E	I	E
		D	CYCLE 3	I *	0	E	I	E	I *	I	I	E **	E	I	I
			NET 1+2	E *	E *	I	I	E **	E	I	I *	E *	I **	I *	0
			NET 1+2+3	0	E *	I • *	I	E	E	. I	I	E *	E *	I *	I **
M-1	07/89	D	CYCLE 1	0	E • *	E • *	I	E	E	E **	E	I	E	E **	E
		N	CYCLE 2	0	E *	I	I	E	E	I	I	E	E	I	E
			NET	0	E **	I *	I	E	E	I	I • *	I	E	I	E

* Less than 5% of the flood mass was transported

• * Less than 10% of the flood mass was transported first cycle, net flow import of 18% was recorded. During this cycle, over 18% of the incoming mass of **$CBOD_5$,** NH,-N, NO,-N, NO,-N, TKN, DO, salinity, TSS and **TPO_4** were imported. Clearly, some of this import is due simply to the large net flow import, although the percentage import of each **constituent** can not be directly related to the percentage import of flow. However, a greater percentage of each of these constituents was imported than the percentage import of flow suggests. This result suggests that processes in the system are contributing to their import, and that the import noted can not all be attributed to the flow imbalance.

Flow-weighted concentrations were calculated for all constituents. These **concentrations** were determined by dividing the total mass on the flood or ebb tide by the respective volume during that portion of the tide. For each constituent imported above, the flow-weighted concentration was higher during the flood tide than the ebb tide, which suggests the **mudflat** was a sink for these parameters.

Cycle 2 showed a net flow export of 39%. As expected, all parameters (except chlorophyll-a) were exported. However, less than 36% of the incoming mass of CBOD,, NH,-N, TKN, DO, **TPO_4,** and TSS were exported, and **$CBOD_5$** and TKN exhibited export of less than 10%. These results suggest that processes in the marsh may actually be contributing to the import of nutrients and that the overall net export may simply be attributable to the large net export of flow. Review of the **flow-**weighted concentration data revealed higher concentrations during the flood tide **than the ebb** tide for all constituents except for NO,-N and salinity. This suggests the **mudflat** is **acting** as **a sink** for all parameters except NO,-N and salinity. Salinity essentially balanced with **a** change in flow-weighted concentration between ebb and flood tide of -1.1%. NO,-N showed a large net export of about **185** pounds, which is 124% of the incoming mass. Even after consideration of the net flow export, this large value suggests **a** source of **NO_3-N** in the **mudflat** system during Cycle 2.

For Cycle 3, the incoming and outgoing flows approximately balanced with a net inflow of 139,395 cubic feet which is 2.4% of the total flood volume. The results for the net flux of water quality constituents were export of CBOD,, NO,-N, DO, and TPO_4 ranging from 7.5% to 21.5% of the incoming mass. This contradicts the results from Cycle 1 and Cycle 2 which suggest processes in the mudflat are resulting in import of $CBOD_5$, DO and TPO,, when the large flow export during Cycle 2 is considered. NH_3-N, TKN, and TSS were imported, with percentage import ranging from 17.9 to 24.2 percent. The results over the three cycles in November are consistent import for NH_3-N and TKN (when the large export of flow during Cycle 2 is taken into account), but are inconsistent for the other parameters.

November Net Analysis - A net analysis of all three complete tidal cycles in November was done in which the flood volume and the flood mass for each constituent were summed over all three cycles and compared to the respective ebb totals. The net analysis revealed a flow balance of 0.4%, indicating no net transport of flow. Cycle 2, which showed the greatest percentage flow imbalance also had the smallest flow volume. The ebb dominance in Cycle 2 was balanced in volume by the flood dominance during Cycle 1. The net analysis revealed import of CBOD,, NH_3-N, TKN, Total N, chlorophyll-a and TSS and export of NO,-N, NO,-N, and TPO_4. Very slight export of DO and salinity (less than 2%) were noted.

July Data - For Cycle 1, flows essentially balanced (0.3% import). NH_3-N and TPO_4 were imported at 35.2% and 47.3% of their incoming mass, respectively. Export of $CBOD_5$, NO_3-N, NO_2-N, TKN, DO, TSS, and chlorophyll-a was noted which varied from 52% to 113.4% of the flooding mass.

Flow also essentially balanced during Cycle 2 (0.2% import). During that cycle, import of $CBOD_5$, NH,-N, TKN, and TSS was observed, ranging from 11.9 to 35 percent of the flooding mass. However, NO_3-N, NO,-N, DO, salinity, TPO_4, and tidal cycles in November. This amounts to roughly 377 pounds per day or 10.8 pounds of NH,-N per acre of **mudflat** per day. In July, approximately 353 pounds of **NH_3-N** were transported over two tidal cycles which translates to roughly 10.2 pounds per acre per day. **Thus,** the results of NH,-N transport for November and July were remarkably consistent and did not show any seasonal differences. Individual cycles conformed to these transport directions, with a few **exceptions.** Based on the noted import of **NH_3-N** and export of NO,-N and NO,-N, the **mudflat** may have been importing **NH_3-N** from the flooding waters 'of Sawmill Creek and transforming the NH,-N to NO,-N and NO,-N.

Total Inorganic Nitrogen (NH,-N + NO,-N + NO,-N) was exported during November (119.49 lbs.) but imported during July (-181.1 lbs.). The July results are dominated by export of NO,-N (-435.4 lbs.). As discussed elsewhere in the report, the mass of NO,-N is unexpectedly large.

The pattern of nutrient transport observed. in the Sawmill Creek **mudflat** is not reflected in the few available papers discussing **mudflat/estuarine** nutrient dynamics. In Connecticut, Welsh (1980) found that the **mudflat** she studied was a source of DO. She **also** found it was was a sink for NH,-N, **NO_3-N** and **NO_2-N** in July and August, and a source of these nutrients in late October. In the other studies **NH_3-N** typically was exported while NO,-N and NO,-N were imported at lower salinities and exported at higher salinities. The lack of literature in systems with similar hydrodynamic and chemical conditions as the Hackesnsack River, as well as the difficulties noted in Section 13, preclude a complete comparison of these results to other studies.

Again, it must be remembered that the results presented in this section represent one short-term study and certainly can not be considered definitive. Additional data would be needed to determine if the conclusions reached herein are truely representative of the Sawmill Creek **mudflat.**

33 MICROSCALE MARSH • STATION M-2

Concentration data for Station M2 are summarized in Table 3.3 and a summary of the import or export of mass in the system is provided in Table 3.4. Appendices A-2-l and A-2-2 contain more detailed tables and figures regarding net transport at this station.

November Data • During Cycle 1, flows balanced (-0.2%). Import occurred for $CBOD_5$, NH_3-N, and TKN and export occurred for NO,-N, DO, salinity, TPO_4, and TSS. The largest net percentage transport was TPO_4 and NO,-N at 36.7% and 15. 1 %, respectively.

During Cycle 2, a flow balance of 0.7% (import) was found. Export of NO,-N, salinity, TPO_4, chlorophyll-a, and TSS and import of $CBOD_5$, NH,-N, TKN and DO was observed. TPO_4 and chlorophyll-a demonstrated export of more than 50% of the incoming mass; DO showed import of about 34% of the incoming mass.

During Cycle 3, flow balanced. During this cycle $CBOD_5$, NH,-N, TKN, TPO_4 and TSS were imported, while NO,-N, DO, salinity, and chlorophyll-a were exported. The most significant imports were 30.7% of the incoming mass of CBOD,, 18.9% of NH_3-N, 30.5% of TSS and 16.8% of TKN.

Cycle 4 showed slight export of flow of -1.5%. DO, salinity, TPO_4 and TSS were exported while the other constituents were imported. The constituents demonstrating the largest transport, based on percentage of the incoming mass, were DO at 23.7%, TPO_4 at 33.7% and chlorophyll-a at 53.9%.

Overall, for the November sampling period, consistent import over all four tidal cycles was observed for $CBOD_5$, NH,-N, and TKN. Salinity showed consistent export over all four tidal cycles while DO, TPO, and NO_3-N demonstrated export during three out of four cycles.

TABLE 3.3: Concentration Data **Summary** • Station M2 (in **mg/l**)

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
			MONTH OF NOVEMBER			
$CBOD_5$	32	2.07	0.66	0.80	435	32.16
NH,-N	33	251	0.55	1.70	4.41	22.11
NO,-N	33	1.17	0.11	1.02	1.48	9.56
NO,-N	3 3	0.40	030	0.31	0.46	8.33
DO	34	5.97	120	3.60	9.10	20.01
Salinity*	34	12.44	0.87	9.79	14.40	7.01
Chlorophyll-a	34	15.87	8.37	1.42	32.71	52.75
TKN	33	3.56	0.76	2.69	6.14	21.41
TPO_4	33	0.26	0.09	0.10	0.44	34.70
TSS	34	46.92	14.91	22.30	76.00	31.78
			MONTH OF JULY			
$CBOD_5$	54	232	0.83	0.80	4.85	35.83
NH,-N	53	0.99	0.29	0.13	1.46	29.80
NO,-N	53	0.25	031	0.00	1.81	123.62
NO,-N	53	0.47	0.28	0.06	0.90	5931
Do	53	239	0.76	1.20	4.10	31.85
Salinity*	52	8.46	1.32	7.07	16.10	15.64
Chlorophyll-a	47	15.81	10.65	2.94	51.60	67.35
TKN	53	2.69	0.86	1.48	4.48	31.83
TPO_4	53	0.92	0.60	**0.22**	2.32	65.85
TSS	54	**96.27**	96.86	2320	427.00	100.62
			MONTH OF AUGUST			
$CBOD_5$	46	2.80	0.72	1.60	5.10	25.82
NH,-N	46	0.90	0.42	035	1.89	46.97
NO,-N	46	0.46	0.32	0.03	1.00	68.45
NO,-N	46	0.43	0.31	0.04	0.90	72.02
Do	46	3.18	1.45	1.20	6.70	45.77
Salinity*	**46**	11.99	1.08	9.96	14.65	9.02
Chlorophyll-a	46	14.11	10.86	2.35	55.50	76.97
TKN	46	2.01	0.94	1.00	7.11	46.66
TPO_4	46	0.89	0.56	0.40	3.58	6235
TSS	46	62.97	71.80	14.00	517.00	114.01

* Note: Salinity in PPT

Table 3.4: Summary of Import/Export Of Mass Flux in the Microscale Marsh Experiment • Stetion H-2

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	No2	TKN	TOTAL N	TPO4	Do	CHL-A	TSS
M-2	11/88	D	CYCLE 1	O	E *	I	I **	E	I *	I	I *	E	E *	0	E **
		N	CYCLE 2	O	E *	I	I	E	E **	I	I	E	I	E	E *
		D	CYCLE 3	O	E *	I	1	E	E *	I	I **	I	E *	E	I
		N	CYCLE 4	O	E *	I	I	I *	0	I	I **	E	E	I	E
			NET	O	E *	I	I	E	E *	I	I	E	I *	E **	I **
H-2	07/89	D	CYCLE 1	0	E *	E **	I	E	I	I	I	E	E	I	E *
		N	CYCLE 2	0	E	I -	I	I	1	I	I	E	E *	O	I
			NET	0	E	0	I	E	I	I	I	E	E	I	I
M-2	08/89	D	CYCLE 1	0	E **	E	I	I	I • *	E *	I *	I	E	E	I
		N	CYCLE 2	0	E *	I	E	I -	I	I	I	E *	I	I	I **
			NET	O	E .	E .	E .	I	I • *	I	I	I *	E	E • *	I • *

M1 = TIDAL MUDFLAT EMBAYMENT STATION
M2 = TIDAL MARSH IMPOUNDMENT STATION

0 = CHANGE IN MASS ≤ 1.0%
* = CHANGE IN MASS ≤ 5.0%
** = CHANGE IN MASS ≤ 10.0%

D = DAYTIME
N = NIGHTTIME

Net Analysis for November - A net analysis of the entire sampling period was conducted which compared the total flood mass for all four cycles to the total ebb masss. This analysis revealed import of CBOD,, **NH_3-N, TKN,** Total N and TSS. **Surprisingly,** DO also showed net import even though it demonstrated export on three of four individual cycles. Export of salinity, NO,-N, NO,-N, TPO,, and chlorophyll-a were noted, although the salinity export was generally less than 5%.

July Data - Comparison of flood and ebb flows for the first tidal cycle showed export of 0.6% of the incoming flow. Import occurred for **NH_3-N,** NO,-N, and TKN. Export was noted for the other variables with 101.1% of the incoming **NO_3-N** mass flowing out of the system. DO showed net export of about 72.2% of the incoming mass or about 19 pounds. With the exception of **$CBOD_5$** (6.4%) and salinity and TSS (approximately **3%),** the other constituents showed net transport in the range of 20% to 35% of the incoming mass:

Flows also balanced for Cycle 2. During that cycle **$CBOD_5$** was imported as were **NH_3-N, NO_3-N, NO_2-N,** TKN, and TSS. The other constituents were exported. Thus, over the two cycles consistent import was seen for NH,-N, NO,-N, and TKN and consistent export for **DO, TPO_4,** and salinity. It should be noted that the net mass of DO exported during Cycle 1 was about 19 pounds or about 71% of the incoming mass while during Cycle 2 less than 1 pound (1.8%) of DO, was exported.

Net Analysis for July - **A** net analysis was conducted for the July data, comparing the sum of the mass transported during the flood tide in both cycles to that transported during the ebb tide for each constituent. The results showed export of salinity of more than **10%,** as well as export of NO,-N, **TPO_4,** and DO and import of NH,-N, NO,-N, **TKN,** total N, chlorophyll-a, and TSS. These results generally were consistent with the results for the individual tidal cycles.

August Data • The flow balanced within 69 cubic feet for each cycle in August. During the first cycle, NH,-N, NO,-N, NO,-N, TPO,, and TSS were imported. During the second cycle, CBOD,, NO,-N, NO,-N, TKN, DO, and TSS were imported; the constituents not listed were exported. Thus, only NO,-N, NO,-N, salinity and TSS showed a consistent transport pattern during the two cycles.

Net Analysis for August • A net analysis comparing total flood mass over both August cycles to total ebb mass revealed export of salinity, CBOD,, NH,-N, DO and chlorophyll-a and import of the other parameters. The net transport of salinity, $CBOD_5$, NH_3-N, and TPO_4 represented less than 5% of the incoming mass.

Comparison of Sampling Periods • Comparing the July and August data, import of NO,-N and Total N and export of salinity were the only consistencies in transport direction over all four tidal cycles. However, comparison of the net analyses (combining both tidal cycles for each month) revealed consistent import of TKN, TSS, NO,-N and Total N and consistent export of .DO and salinity. The other parameters showed export during one sampling period and import during the other.

Comparison of all three sampling periods revealed that flow was balanced and salinity exported in each of the eight tidal cycles. During most of the cycles, export of salinity accounted for less than 5% of the incoming mass. For all other parameters, transport direction was inconsistent in at least one tidal cycle. However, comparison of the net results (combining two tidal cycles in July and August and all four in November) among the sampling periods revealed net import. of TKN, Total N and TSS for all three periods. As shown in Table 3.2, the other parameters showed inconsistent results with no discernible seasonal pattern across all parameters. NH_3-N, NO_3-N, and TPO, showed the same transport direction for November and July but the opposite for August, while NO_2-N and DO showed the same pattern for July and August with the opposite result in November. Thus, no clear seasonal pattern was revealed.

An unusual pattern was noted in the data, in that a larger net mass of NO,-N than NO,-N was transported on both the ebb and flood tides in July and August. This was caused by the higher concentrations of NO,-N measured in the system over much of the July and August sampling periods. The typical relationship between NO,-N and NO,-N in natural waters is that NO,-N concentrations are higher than NO,-N concentrations because NO_2-N is usually oxidized quickly to NO_3-N. The reason for the unusual pattern at Station M2 can not be determined from the available data.

In reviewing the seasonal data, it is important to recall that slightly different methods were used to sample the marsh during the November, 1988 sampling period than during July and August, 1989. As discussed in Section 2.3, above, during November, sampling occurred only when the marsh surface was covered with water. The methods were refined in July and August so that sampling occurred throughout the tidal cycle. As expected, flows did not balance as well for the November sampling period as they did for the summer sampling. Thus, the July and August data should be considered more reliable than the November data.

Based on the net results for each sampling period described above, the marsh is a source of DO in the summer months and a slight sink in November, although in three of the four indiviual cycles in November the marsh was a source of DO. The marsh is also a sink for ammonia in two of three periods (July and November) and a slight source in the other; a source of nitrate in those same two periods and a sink in the other; and a sink for TKN and Total N in all three periods. Salinity shows a small, but consistent, export.

The DO results suggest reaeration of flooding waters under summer conditions. This is likely the result of both physical and biochemical processes, with physical processes more important. The export of DO during the summer months amounts to about 19.9 pounds over two tidal cycles or approximately 6.2 pounds per acre per day in

July and about 10.9 pounds over two tidal cycles in August or approximately 3.4 pounds per acre per day.

The import of NH,-N and export of NO,-N in November and July suggests that nitrification may have occurred in the marsh. The opposite pattern was noted in August, when NO,-N was imported and **NH_3-N** was-exported. However, NH,-N was imported during Cycle 1 in August which is consistent with the July and November results. Cycle 2 showed the opposite pattern, as did the net analysis for August. During Cycle 2 in August, a much smaller total mass of ammonia was imported on the flood tide than in any other summer cycle (approximately 8 pounds compared to an average of 12.9 pounds for the other three summer cycles). The mass exported in the ebb flow was 112 pounds, larger than the' average ebb mass of 10.1 pounds for the other three cycles but still smaller than the average inflow of 12.9 pounds.

As noted above, the **NO_3-N/NO_2-N** concentrations for the summer months had an unusual pattern In the **first** three summer cycles, NO,-N concentrations were larger than NO,-N concentrations under both flood and ebb conditions. In five of the six half-tidal cycles during that period, the total mass of NO,-N transported was more than double the **total** mass of NO,-N. However, during Cycle 2 in August the expected pattern occurred with the total mass of NO,-N transported two to three times **the** total mass of NO,-N. The total mass of NO,-N plus NO,-N transported in August was in the same range as that in July. Thus, Cycle 2 in August differs from the other three summer cycles in transport dynamics of NH,-N and NO,-N/NO,-N. That cycle **also** indicated an import of DO of almost **40%,** compared to consistent export of DO during the other three summer cycles. Although flow balanced during Cycle 2 in August, the total volume flooding the system was 12.5% less than during Cycle 1 in August and about 17.6% less than the average flood volume in July.

Clearly, the hydrodynamics and chemistry of Cycle 2 in August were vastly different from those in Cycle 1 in August and in both cycles in July, which were all quite similar. The fact that these differences occured for flow and for several quality parameters suggest some actual phenomenom, as opposed to error in measurement of some specific data. However, without additional data, it is not possible to even speculate on the reason for this variation.

Ignoring Cycle 2 in August for the moment, then, NH,-N was imported by the marsh. **A** total of about 8.3 pounds of NH,-N was imported to the marsh over the three summer cycles, which is about **5.5** pounds per day or about 1.7 pounds per acre of marsh per day. The NO,-N results are less consistent, although net export occurred in July, import occurred in Cycle 1 during August. The same pattern of NH,-N and NO,-N transport was observed in November when about a total of about 16 pounds of **NH_3-N** was transported over 4 cycles. This is roughly equivalent to 8 pounds per day or 2.5 pounds per acre per day. These results must be considered preliminary estimates, particularly because of the inconsistent data in August.

Total N was imported over all tidal cycles in the marsh. This is primarily because **TKN** was imported and **TKN** dominates the Total N calculations. Total Inorganic N (NH,-N + NO,-N + NO,-N) was imported during November (10.3 lbs.), July (7.7 **lbs.)** and August (3.53 lbs.).

33 MESOSCALE EXPERIMENTS

33.1 Sawmill Creek - Station S3

Table 3.5 summarizes the concentration data at Station S3 while Table 3.6 **summarizes** the mass transport results. Appendices A-2-l and A-2-2 provide further detailed tables and figures regarding these results.

November Data - For Cycle 1, comparison of the total volume of flow during the flood tide to that during the ebb tide revealed a net export of **0.1%,** that is flows **essentially** balanced. **Export** of CBOD,, NH,-N, NO,-N, TKN, Total N, DO, TPO,

TABLE 3.5: Concentration Data Summary • Station S3 (in mg/l)

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
			MONTHOFNOVEMBER			
$CBOD_5$	24	229	1.06	1.10	5.58	45.21
NH_3-N	24	2.83	0.90	1.25	4.49	3 1.63
NO,-N	24	1.47	1.92	0.95	10.47	130.19
NO,-N	24	0.40	0.05	0.22	0.44	13.01
Do	24	5.31	1.52	3.00	9.30	28.56
Salinity*	24	12.73	1.19	11.60	17.10	9.39
Chlorophyll-a	24	1230	6.72	1.10	27.84	54.64
TKN	24	3.90	1.28	2.03	6.90	32.92
TPO_4	24	0.27	0.08	0.10	039	31.42
TSS	24	43.93	15.51	2720	84.00	3531
			MONTH OF JULY			
$CBOD_5$	13	1.94	0.79	0.85	3.25	40.55
NH_3-N	13	0.13	0.51	027	2.12	45.2 1
NO,-N	13	0.26	0.16	0.02	0.48	60.99
NO,-N	13	0.67	0.07	0.58	0.81	10.61
Do	13	2.66	1.71	130	6.50	64.30
Salinity*	13	8.97	0.88	7.61	10.50	9.80
Chlorophyll-a	13	4.38	5.20	1.47	20.10	118.71
TKN	13	2.09	0.86	0.98	3.65	41.17
TPO_4	13	0.69	0:15	0.48	1.00	21.28
TSS	13	65.07	55.84	21.20	210.00	85.82
			MONTH OF AUGUST			
$CBOD_5$	12	3.10	0.87	1.95	4.50	27.92
NH,-N	12	1.05	0.49	0.07	1.85	46.84
NO_3-N	12	0.79	0.15	0.58	1.08	19.42
NO_2-N	12	036	0.03	0.33	0.42	7.59
Do	12	4.40	2.60	1.80	1130	59.15
Salinity*	12	11.66	139	8.15	13.75	11.96
Chlorophyll-a	12	16.16	10.02	7.89	36.40	62.04
TKN	12	2.10	0.64	1.23	324	30.53
TPO_4	12	0.67	0.22	0.40	1.19	33.27
TSS	12	73.28	28.57	38.40	116.00	38.99

• Note: Salinity in PPT

Table 3.6: Summary of Import/Export of Mass Flux in the Sawmill Creek System - Station S-3

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	NO2	TKN	TOTAL N	TPO4	DO	CHL-A	TSS
S-3	11/88	D	CYCLE 1	O	I **	E	E	E *	E	E	E	E	E	E	E
		N	CYCLE 2	O	I *	E	E **	E	O	E **	E	E	E *	E	E
		D	CYCLE 3	O	O	E	E	O	I *	E *	I	I	E	E	I
			NET 1+2	O	[illegible]	E	E	E	E	E	E	E	E	E	E
			NET 1+2+3	O	I *	E	E	E	E **	E. *	E **	E *	E	E	E *
S-3	07/89	D	CYCLE 1	O	E *	E	I **	O	I	E. *	O	I	E	E	E
		N	CYCLE 2	E *	E **	I	E	E	[illegible]	E	E	[illegible]	[illegible]	O	I
			NET	O	E **	E	E. *	E	[illegible]	E **	E **	I	E	E	E
S-3	08/89	D	CYCLE 1	O	E	I *	[illegible]	[illegible]	[illegible]	E	I	E	E	E	[illegible]
		N	CYCLE 2	E *	I *	I	E. *	I	O	I	I	I	I	[illegible]	I. [illegible]
			NET	E *	E *	I	I	[illegible]	I. [illegible]	I. [illegible]	I	E. [illegible]	I *	E *	[illegible]

S3 = SAWMILL CREEK AT NJ TPKE

O = CHANGE IN MASS ≤ 1.0%
. = CHANGE IN MASS ≤ 5.0%
. * = CHANGE IN MASS ≤ 10.0%

D = DAYTIME
N = NIGHTTIME

chlorophyll-a, TSS and, to a limited extent, NO,-N (1.7%) were noted. Salinity was imported.

For Cycle 2, flow showed an import of **0.2%,** with the same pattern of export of all parameters except salinity. During Cycle 2, export of NO,-N was 127.8% of the incoming mass compared to 1.7% export during Cycle 1.

Flows balanced in Cycle 3 (-0.2%). **$CBOD_5$, NH_3-N,** DO, chlorophyll-a, and, to a lesser extent, **TKN** were exported. NO,-N and Total N showed essentially no net transport, while NO,-N was slightly imported (3%). Sufficient data were not **available** for a complete analysis of Cycle 4.

Net Analysis for November - Calculation of net flow for the entire November sampling period (total flood volume over all three cycles compared to total ebb volume over those cycles) showed essentially total balance. The net analysis revealed export of **$CBOD_5$ (18%),** NH,-N **(20%),** NO,-N **(32%),** NO,-N **(6.9%), TKN** (6.9%); , Total N **(12.7%),** DO **(34%), TPO_4 (2.2%),** chlorophyll-a (88.3%) and TSS (3.6%); salinity was imported (3.5%).

July Data - For Cycle 1 in July, flow balanced within 0.2%. BOD,, TKN, DO, salinity, chlorophyll-a, and TSS were exported, NH,-N, NO,-N, and **TPO_4** were imported, and NO,-N and Total N showed essentially no net transport.

During Cycle **2,** flow balanced at -1.3%. NH,-N, NO,-N, **TKN,** Total N, and salinity were exported while **$CBOD_5$,** NO,-N, DO, **TPO_4** and TSS were imported. Thus, only NO,-N, **TKN,** and **TPO_4** showed consistent results over both cycles in July.

Net Analysis for July - The net analysis comparing the sum of the flood data over both cycles to the ebb tide data revealed that total flow essentially balanced. Net export was calculated for $CBOD_5$, NH_3-N, NO,-N, TKN, Total N, DO, salinity, and chlorophyll-a and net import for NO,-N, TPO_4, and TSS.

August Data - During Cycle 1 in August, flows essentially balanced (0.9%). $CBOD_5$, N&-N, NO,-N, Total N, and TSS were imported and the other parameters were exported, except for NO,-N which showed essentially no net transport.

During Cycle 2, export of flow occurred (-4.0%). $CBOD_5$, NO,-N, TKN, Total N, DO, salinity, TPO_4, chlorophyll-a and TSS were imported. NH,-N was exported while NO,-N showed no net transport. Thus, consistent transport directions occurred during both cycles for $CBOD_5$, Total N, and TSS only.

Net Analysis for August - The net analysis combining data for both tidal cycles in August revealed net flow export of -1.5%. Review of total mass transport indicated net import of CBOD,, N&-N, NO,-N, NO,-N, TKN, Total N, DO and TSS and export of salinity, chlorophyll-a and TPO_4.

Comparisan of Sampling Periods - The net analyses for each sampling period were compared; that is the volume and mass of each constituent transported during the flood portions of each tidal cycle was summed for each sampling period and compared to the total ebb volume and mass. Review of these net analyses revealed no net flow transport, except for slight (<2%) export in August. Only chlorophyll-a showed consistent transport results (export) for all three months. Differences in the results among the sampling period would not be surprising if a consistent seasonal pattern had been found. That is, July and August data, taken only two weeks apart, would be expected to be more similar than either of those would be to the November data. However, the November and July data showed the same net transport direction for $CBOD_5$, NH,-N, NO,-N, TKN, Total N, DO, and chlorophyll-a. The July and August data were the same only for salinity, NO,-N and TSS. Thus, there did not seem to be a consistent seasonal pattern to the results, although August was consistently different.

Station S3 is located in a portion of Sawmill Creek in which mudflats are the predominant ecological system, although some marsh areas do exist particularly adjacent to the Creek. Thus, the results of the-microscale marsh and mudflat experiments, also located in Sawmill Creek, were analyzed in relation to the results obtained at Station S3. DO was exported at Station S3 during November and July but imported in August based on the net transport analyses. The November and July data are consistent with the results of the marsh and mudflat studies. The net results from August are inconsistent with those at Stations Ml and M2, as are results from one tidal cycle in July. Station S3 showed the same change in net transport direction between the July and August sampling periods as Station M2 (the microscale marsh) for both NH,-N and NO,-N. No data were available at Station Ml (the microscale mudflat) in August. During November and July, the mudflat showed net import of NH,-N, TKN and Total N and export of NO_2-N and NO,-N. The same pattern occurred at S3 for NO,-N, but the opposite pattern occurred at Station S3 for NH,-N, TKN and Total N.

The lack of consistency in the nitrogen results and the DO results in August between Station S3 and Stations Ml and M2 may suggest that some other factor is affecting the transport dynamics at Station S3. Two large HMDC sanitary landfills are located on Sawmill Creek upstream of Station S3. Thus, if leachate from these landfills is entering Sawmill Creek it may be affecting the DO and nutrient exchange dynamics at Station S3. Therefore, in a digression from the experimental results, the following paragraphs summarize the data regarding water quality in the leachate from the HMDC landfills.

Landfill Data - Two sanitary landfills operated by HMDC are located at the head of Sawmill Creek. These are called the 1C and the Balefill Landfills. No data were available that measured the rate of flow or quality of any leachate that directly entered the Creek. However, several wells monitor the leachate at the perimeter of these landfills. Figure 3.1 shows the location of these wells in relation to Sawmill Creek. In order to examine the possible affect of the landfill complex on water quality of the Sawmill Creek system and consequently the Hackensack Estuary, data from these wells were examined. Tables 3.7 and 3.8 summarize the water quality from these results for the past three years.

Data were collected quarterly, however an analysis of Variance (ANOVA) statistical test on quarterly data revealed no seasonal patterns in the data for BOD,, NH,, pH, COD, TDS, lead, TOC, or zinc at Well 1C-1. Significantly higher NO, concentrations were noted in April at Well 1C-1 for the two 'measurements taken at that time. At Well 1C-2, NH, and NO, concentrations were, higher during April (based on two measurements in each season) at the 5% and 1% test levels, respectively. No other constituents showed seasonal patterns. At Well 1C-3, NO, concentrations again were significantly greater in April than in the other four seasons but no seasonal patter& were noted for the other parameters. Review of all the data revealed that NO, concentrations from April at all wells was consistently an order of magnitude greater than that measured in ether months. It must be noted, however, that the April data generally was taken only two times during the 1987 to 1989 study period, while data were taken three times in the other seasons.

Review of Table 3.7 reveals that ammonia concentrations varied from a minimum of 24.5 mg/l at Well 1C-1 to a maximum of 2,616.6 mg/l at Well 1C-3 and averaged 530.4 mg/l, 636.9 mg/l and 1064.2 mg/l at Wells 1C-1, 1C-2 and 1C-3, respectively. These concentrations contrast dramatically with concentrations in the range of 0.4 mg/l to 10.1 mg/l in Sawmill Creek at Station S4 at the head of Creek adjacent to the landfills and 0.07 to 4.49 mg/l at Station S3 in Sawmill Creek at the crossing of the New Jersey Turnpike. The instream concentrations seem to suggest that NH,-N levels were higher at Station S4. Because of difficulties in calculating flow at Station

Table 3.7: **Summary** *of Water* **Quality Data** from **HMDC/MSLA 1C Sanitary** Landfill 1987-1989

Well No.	STAT	BOD_5 mg/L	COD mgN/L	NH_4 mgN/L	NO_3 mgN/L	pH su	TDS mg/l	TOC ppm	Pb ug/L	an ug/L
1C-1	MEAN	75.4	12982.2	530.4	33.4	7.5	7119.7	995.2	131.4	222.5
	STDEV	34.8	34613.4"'	440.9	49.7	0.4	847	579.1	150	116
	HIN	10.0	479.9	24.5	5.5	6.8	5625	8	10	128
	MAX	138.0	111458.0	1016.4	143.0	8.3	8878	2160	500	492
	N	10	10	10	10	10	10	9	10	10
1C-2	MEAN	90.0	4430.8	636.9	45.5	7.5	9397.5	1463.6	239.6	352.7
	STDEV	54.1	2736.1	497.7	60.8	0.4	713.0	1003.1	131.6	170.4
	HIN	10.0	465.4	44.8	7.9	7.0	8424.0	146.0	10.0	192.0
	MAX	168.8	8055.0	1337.8	162.9	8.2	10447.0	3360.0	460.0	644.0
	N	9	8	8	9	9	9	8	9.	9
1C-3	MEAN	123.1	3693.9	'1064.2	41	7.5	19997.7	1362.8	194.2	561.3
	STDEV	3 4 . 8	2272.3	766.9	57.4	0.4	32019.3	754	140.5	613.7
	MIN	10	472.6	35	6.7	7	8742	763	10	149
	MAX	138	8103	2616.6	154.4	8.4	111086	3264	430	2203
	N	10	9	10	10	10	10	9	10	10

Source: HMDC Data

TABLE 3.8: Summary of Water Quality Data from HMDC Balefill Sanitary Landfill 1987-1989

Well No.	STAT	BOD_5 mg/L	COD mgN/L	NH_4 mgN/L	NO_3 mgN/L	pH su	TDS mg/l	TOC ppm	Pb ug/L	Zn ug/L
BP-2	MEAN	28.2	958.9	425.4	10.8	7.0	7558.7	554.9	132.0	149.0
	STDBV	8.7	625.2	138.7	9.4	0.4	12832.5	443.3	122.2	121.9
	HIN	10.0	8.5	40.3	2.1	6.5	2819.0	2.9	10.0	42.5
	MAX	37.5	2121.0	544.6	31.2	8.0	46228.0	1621.0	370.0	415.0
	N	11	11	11	11	11	1 1	9	11	11

Source: HMDC Data

S4, it was not possible to directly compare the loading of NH,-N at these two stations. Differences in concentrations may be the result of actual loading differences or of different flow volumes at each station However, salinity is a conservative substance and analysis of the data at the two stations does not reveal differences in salinity great enough to suggest that the volume of flow at one station is significantly greater than at the other. The variation in in-stream concentrations, however, preclude any statistical comparison of data between Stations S3 and S4.

Nitrate concentrations range from 5.5 to 162.9 mg/l in the leachate, compared to ranges of 0.05 to 1.19 mg/l at Station S4 and 0.02 to 10.5 mg/l at Station S3 in the Creek

The high concentrations of these constituents in the leachate reveal the potential for a significant source of these constituentsto Sawmill Creek and thus, the main stem of the Hackensack River. However, lack of knowledge of the hydraulics of the ground water - surface water interaction at the landfills precludes a analysis of specific loading rates. The possible impact of the landfills on Sawmill Creek is discussed in further detail, below.

Overall Analysis of **the Sawmill Creek System** - As noted above, the Sawmill Creek system results were not entirely consistent. In November, 1988 and July, 1989, the net analyses for each sampling period revealed consistent export of the nitrogen series parameters (except NO,-N which was imported in July), as well as CBOD,. During August, all nitrogen series parameters were imported. The data are not sufficient to explain the transport reversal in August. Do was imported during the summer sampling periods.

Considering the July and November data for NH,-N, net export occurred at Station S3. As noted above, the portion of the Sawmill Creek tidal system above Station S3, which would affect its water quality on the ebbing tide, consists of mudflat with some marsh along the'banks of the Creek During July and November, Station Ml, the microscale **mudflat** station, showed net import of **$CBOD_5$,** NH,-N, TKN, and Total N while **S3** showed export of these constituents. Station Ml also showed export of DO in both months while Station S3 showed export in November, but **import** in July. At the microscale marsh **station (M2),** CBOD, **was** imported in July and not transported in November, DO was imported in November, and the transport pattern for the other parameters was as described for Station Ml. Therefore, based on data for marsh and **mudflat** alone, import of NH,-N and **$CBOD_5$,** and export of DO would be expected at Station S3. This is not the pattern found.

Constituent Transport as Station S3 - The inconsistencies in parameter **transport** between Station S3 and Stations Ml and M2 suggest that **instream** processes or other sources and sinks are contributing to the nutrient dynamics at Station S3. Likely sources and sinks would be sediments within the channel or the landfills. The high concentrations of ammonia noted in the landfill **leachate** support the landfills as a likely source of this nutrient. Results of the sediment exchange experiments are 'inconclusive with both uptake **and** release of nutrients occurring (see Appendix A-2-3).

The available data are **not** sufficient to explain these findings. The consistent export of DO from the wetlands appears to masked by processes in the channel during certain cycles in the summer, resulting in net import of DO at Station S3. Welsh (1980) noted **a** similar pattern with import in the marsh and **mudflat** and export in the channel. Her system was quite different, however, with a large channel originating upstream. She attributed the export from the channel to upstream sources or other intervening marsh-mudflat systems with different dynamics. In this system, DO may be being consumed during the oxidation of NH,-N and **BOD_5** contributed by the landfill **leachate** or other sources.

The August reversal in transport direction for many parameters can not be explained. If the landfills are indeed sources of NH,-N and BOD, for Sawmill Creek, perhaps the **leachate** discharge during that period is less than in the other months, possibly the result of lower water tables. This would not explain the import of DO found during August, however.

Clearly, further data is needed to define the nutrient dynamics of the Sawmill Creek system. Data is needed to determine if the July and November data are truely representative and August is unusual, or if the system is highly variable.

To provide some notion of the magnitude of the exports of the system, loading estimates for BOD,, NH,-N and DO are provided even though these cannot be considered conclusive. Approximately 4,053 pounds of BOD_5 and 5,725 pounds of NH_3-N were exported at Station S3 over three tidal cycles in November or roughly 2,702 and 3,820 pounds per day of BOD, and NH,-N, respectively. During July, **approvimately** 2,345 of BOD, and 536 pounds of NH_3-N were exported over two tidal cycles which is equivalent to one day. In August, however, approximately 4,135 pounds of BOD_5 and 2,678 pounds of NH,-N were imported over two tidal cycles, or approximately one **day**.

For DO, about 171 pounds per day were exported in November, about 4,997 pounds were exported in July, and roughly 1,178 pounds per day were imported in August.

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3.3.2.1 Statidn S9

Table 3.9 summarizes the concentration data for Station S9 and Table 3.10 summarizes the import/export of mass for various constituents. Appendices A-2-l and A-2-2 provide further detail regarding mass transport in the system.

TABLE 33: Concentration Data Summary • Station S9 (in mg/l)

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
			MONTH OF NOVEMBER			
$CBOD_5$	23	3.47	1.27	2.10	7.80	36.64
NH_3-N	23	5.13	0.91	4.12	7.01	17.77
NO,-N	23	0.68	0.11	0.41	0.96	16.15
NO,-N	23	0.27	0.10	0.05	0.40	35.37
Do	23	3.09	1.23	0.60	5.15	39.76
Salinity*	23	7.18	1.32	4.33	9.51	18.39
Chlorophyll-a	23	17.26	7.83	2.18	2937	45.35
TKN	23	757	335	5.06	21.68	44.24
TPO_4	23	057	0.39,	0.20	1.80	69.88
TSS	23	27.70	9.16	12.00	53.20	33.07
$CBOD_5$	12	5.02	0.85	3.85	6.70	17.01
NH_3-N	12	1.79	039	0.94	2.42	21.61
NO,-N	12	0.85	0.79	0.25	2.93	9337
NO,-N	12	1.05	0.27	0.44	1.34	25.30
Do	12	3.38	1.41	1.10	5.70	41.69
Salinity*	12	4.03	0.97	2.56	5.63.	24.11
Chlorophyll-a	10	40.56	14.61	8.87	55.70	36.03
TKN	12	3.21	0.75	1.85	4.31	23.45
TPO_4	12	0.80	0.41	052	2.03	50.51
TSS	12	36.67	8.38	21.80	47.00	22.85
			MONTH OF AUGUST			
$CBOD_5$	11	3.63	1.57	2.40	8.20	43.19
NH_3-N	11	2.91	0.58	1.60	3.62	20.05
NO,-N	11	1.17	0.62	0.68	2.31	52.93
NO,-N	11	0.70	0.06	0.58	0.79	9.10
Do	11	2.60	1.01	0.40	4.00	38.84
salinity*	10	5.86	1.19	3.64	7.79	20.29
Chlorophyll-a	11	10.78	6.50	3.12	24.70	60.35
TKN	11	4.90	2.13	3.56	10.90	43.42
TPO_4	11	0.98	0.19	0.70	1.37	19.23
TSS	11	33.74	5.57	24.40	40.20	16.50

• Note: Salinity in PPT

Station S9 is located downstream of a sewage treatment plant (STP). Therefore, the quantity and quality of flows in Mill Creek are affected by the discharge from the STP during the ebb portion of the tide. Calculations of flow and mass loading at Station S9 were done both with and without consideration of the STP.

That is, the raw data were analyzed to determine the overall nutrient transport at Station S9. Then, treatment plant effluent volume and quality were reviewed to explain the overall findings and to determine how the system might function without the STP effluent. For example, if Station S9 showed a net export of flow during one cycle, the exported volume would be compared to the STP flow to determine if the export could be attributed to the STP alone. Similar analyses would be done for the export of water quality constituents. If import occurs for the system, consideration of STP inputs would reveal even greater import by the wetlands. Flows from the STP were prorated for each ebb and flood tide from the daily average flow for that day provided by the treatment plant authority. As a part of this study, the quality of the STP effluent was sampled (Station S10).

November Data - Three complete tidal cycles were sampled during November; Cycle 1 was not completely sampled. Comparison of flood flow volume to ebb flow volume at Station S9 indicated that flood volume was 1.3% greater than ebb volume during Cycle 2. When the STP flow was removed, the difference in volume based on tidal flow alone was greater: about 2.4% import. Net export of all constituents occurred except for salinity, chlorophyll-a, and total suspended solids which were imported. The largest percentage transport was TKN for which the ebbing mass was about 68% greater than the flooding mass; about 6% of this could be attributed to STP loading. In genral, the STP loadings accounted for between 0.1% and 7.5% of the net transport of water quality parameters to or from Mill Creek.

For Cycle 3, flow export of 1.9% occurred; with consideration of the STP flows this dropped to 1.2% export of tidal flow alone. $CBOD_5$, TKN, TPO_4, chlorophyll-a, and

TABLE 3.10: Summary of Import/Export of Mass in the Mill Creek System - Station S-9

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	ND2	TKN	TOTAL N	TPO4	DO	CHL-A	TSS
s 9	11/88	N	CYCLE 2	I *	I **	E	E *	0	I	E	E	E	E	I *	I
		O	CYCLE 3	E *	E *	I [illegible]	E *	E **	E **	I	I	I	E	I	I
		N	CYCLE 4	I *	I *	E	I *	I "	I *	I *	E *	I	E	I	I
			NET 2+3+4	0	0	E *	E *	0	I *	0	0	I • *	E	I	I
			NET 3+4	0	0	0	0	0	E *	I	I	I	E	I	I
S-9	07/89	D	CYCLE 1	E *	E	I *	E *	1	E *	I	I	1	E *	E	I
		N	CYCLE 2	0	I '	0	I *	0	I **	E	E	E • *	I	I	I
			NET	0	E	I •			O	O	I *	I *	I *	E	I
s-9	08/89	D	CYCLE 1	0	E	•	I **	E *	I *	I	I	I • *	I	I •	I
		N	CYCLE 2	E	E	I	E **	E	E	E *	E **	E **	I	I	I **
			NET	E *	E	I	I *	E **	E *	I	I	I *	I	I	I

TSS were imported while NH,-N, NO,-N, DO and salinity were exported. For Cycle 4, the flow balance was 4.8% (import); with the STP flows considered the balance was 5.7% import. Import occurred for all parameters except $CBOD_5$ and DO, which were exported. Thus, over the three tidal cycles analyzed, DO showed a consistent pattern of export, chlorophyll-a of import, and the other parameters showed no consistent transport pattern

Net **Analysis for November** - A net analysis was done which compared total flood volume and mass over the three tidal cycles to the total ebb volume and mass over those cycles for the raw data at Station S9. Analysis over three tidal cycles in November revealed no net transport of flow, salinity, NO,-N, TKN, or Total N. Export of 5% or less occurred for $CBOD_5$ and NH,-N along with import of less than 5% of NO,-N. Additionally, TPO_4, chlorophyll-a and TSS were imported while DO was exported at more than 5% of the incoming mass. Analysis of the STP loadings revealed that the export of these parameters could be explained by STP inputs with the exception of DO. That is, the marsh appears to uptake these constituents, including at least a portion of the STP loadings. For parameters that were imported, such as TPO_4, the marsh appears to uptake more of the nutrient that the STP supplies.

July Data - The net comparison of flow volume between the ebb and flood portions of the tide revealed 1.3% export during the first tidal cycle. $CBOD_5$, NO,-N, TKN, Total N, TPO, and TSS were imported. The largest percentage import was of NO,-N, of which about 153 pounds were imported over the tidal cycle, or about **30.3%** of the incoming mass.

During the second cycle the flow showed 0.8% import. Comparison of net mass transported revealed import of NH,-N, NO,-N, DO, chlorophyll-a, and TSS and no net transport of $CBOD_5$ and NO,-N. The percentage imports of NH,-N and NO,-N were about 4% and 6% of the flooding mass, respectively, and were over 20% of the flooding mass for the other imported parameters. TKN, Total N, and TPO_4 were exported, with about 31% more TPO_4 exiting the system than entered it.

Net Analysis for July - Import of TSS was the only consistent trend in transport over both tidal cycles during the July sampling period. A net analysis was conducted which compared the sum of the flooding volume and mass for each constituent for both tidal cycles to the sum of the ebbing volume and mass for those cycles. This analysis revealed no net transport of flow, NH_3-N, NO,-N, and TKN; export of salinity and chlorophyll-a; and import of the other parameters although the percentage import of $CBOD_5$, Total N, TPO_4, and DO amounted to less than 5% of the incoming mass. With consideration of the loading from the STP, flow and all water quality parameters except salinity and chlorophyll-a were imported.

August Data - During the first tidal cycle, flow balanced at 1.3% export. $CBOD_5$, N&-N, TKN, Total N, TPO, chlorophyll-a, TSS, and to a slight degree NO,-N (1.3%) were imported. NO,-N, DO, and salinity were exported. Transport direction was the same after consideration of STP flows for all parameters except NO,-N.

During the second tidal cycle, the percentage difference in flow between the flood and ebb tide was -11.9%, indicating export. With consideration of the STP flows, the percentage of flow exported drops to 6.5%. CBOD, (40%), DO (8%), chlorophyll-a (56%) and TSS (6.5%) were imported. NH,-N (5.7%), NO,-N (20.5%), NO,-N (15.2%), TKN (2.3%), Total N (6.2%), salinity (11.6%) and TPO, (8.7%) were exported. With consideration of the STP flows and loadings, all parameters except salinity were actually imported. Thus, except for salinity, the exported parameters during Cycle 2 may all be attributed to STP loadings to the system.

Net Analysis for August - Combining all flood and all ebb data for both tidal cycles in August revealed net export of flow of less than 5%; import of CBOD,, NH,-N (<5%), TKN, Total N, TPO, (<5%), chlorophyll-a and TSS; and export of NO,-N,

NO_3-N **(<5%),** and DO. With consideration of the STP flows, the net export percentage for flow dropped to 1.1% and all parameters except salinity were imported.

Comparison of Sampling Periods - The only parameter to display consistent transport results over all seven sampling periods was TSS (import). Comparing the net analysis for the three sampling periods, Total N, TPO_4 and TSS were imported. The other parameters revealed mixed results. The comparison of July data to August data showed consistent export of salinity, and import of $CBOD_5$, with mixed results for other parameters. No clear seasonal pattern to the data was revealed.

3.3.2.2 Station S9A

Station **S9A** is located upstream of **S9** and is designed to measure the loads in Mill Creek from the **Secaucus** STP and other upstream sources. The combined analysis of **S9** and **S9A** should allow determination of how much loading is attributable to the STP and other sources and how much is attributable to the surrounding marshes: Data for **S9A** was only collected during July and August, 1989. Table 3.11 summarizes the concentration data for that station, while Table 3.12 provides a summary of the mass transport results. See Appendices A-2-l and A-2-2 for detailed tables and figures regarding the mass transport results.

July Data - During **July,** for **Cycle** 1, the net flow balance was 8.2% export. However, essentially all of the imbalance was attributable to the Seacaucus STP so that export of **0.8%, or no** net transport, was achieved when the STP flow was taken into account. **$CBOD_5$, NH_3-N, TKN,** and Total N were imported. Since the STP was adding these constituents to the Mill Creek system under ebbing tide, the net import due to processes other than the STP was even larger than indicated simply by comparing the flow and ebb masses. If the STP is taken into account, import of NO,-N, NO,-N, TPO,, DO and TSS occurred in addition to import of CBOD,, NH,-N, **TKN** and Total N.

TABLE 3.11: Concentration Data Summary • Station S9A (in mg/l)

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
			M O N T H			
$CBOD_5$	12	6.05	2.33	3.80	13.00	38.54
NH,-N	12	1.99	039	1.57	2.56	19.39
NO_3-N	12	132	0.98	0.21	3.13	74.43
NO,-N	12	0.91	033	0.51	1.33	36.39
Do	12	3.62	1.83	120	7.20	50.60
Salinity*	12	3.47	1.05	2.20	5.40	30.16
Chlorophyll-a	10	56.40	24.62.	2.93	87.20	43.65
TKN	12	3.56	1.66	2.30	8.29	46.62
TPO_4	12	1.08	0.52	0.55	1.95	47.88
TSS	12	27.28	5.84	16.80	35.20	21.40
			MONTH OF AUGUST			
$CBOD_5$	11	422	055	3.25	5.10	13.06
NH,-N	11	2.16	0.86	135	4.02.	39.60
NO,-N	11	2.22	0.81	0.84	3.40	36.46
NO,-N	11	0.66	0.07	0.59	0.84	10.63
Do	11	2.38	1.60	0.00	4.50	67.30
Salinity*	11	3.92	1.07	2.74	6.17	27.18
Chlorophyll-a	10	7.48	3.99	2.86	16.40	53.38
TKN	11	4.32	0.71	3.54	5.67	16.41
TPO_4	11	2.00	0.71	0.92	3.02	35.51
TSS	11	29.18	7.33	18.40	38.80	25.13

* Note: Salinity in PPT

TABLE 3.12: Summary of Import/Export of Mass in the Mill Creek System • Station S-9A

STATION	DATE	TCYCLE		Flow	SALINITY	BOD5	NH3	NO3	NO2	TKN	TOTAL N	TPO4	DO	CHL-A	TSS
S-9A	07/89	D	CYCLE 1	E • *	E	I **	[illegible]	E	E	I	I	E	E *	E	O
		N	CYCLE 2	E	E	E	E	I	E	E	E	E	I	E	E **
			NET	E	E	I *	E **	I *	E	I	I	E	I *	E	E *
S-9A	08/89	D	CYCLE 1	E	E	E	E	E	E	E • *	E	I	E	E	E
		N	CYCLE 2	E	E	E	E	E	E	E	E	E	E	E	E
			YET	E	E	E	E	E	E	E	E	E • *	E	E	E

S9 = MILL CREEK BOUNDARY STATION
S9A = HILL CREEK MIDDLE BELOW STP

0 = CHANGE IN MASS ≤ 1.0 %
• = CHANGE IN MASS ≤ 5.0 %
• * = CHANGE IN MASS ≤ 10.0%

D = DAYTIME
N = NIGHTTIME

For Cycle 2, the flood and ebb flows showed a net export of 26.6% without consideration of the STP flow and a 12.8% export with consideration of that flow. During this Cycle, **BOD_5, NH_3-N,** NO,-N, TKN, Total N, salinity, **TPO_4,** chlorophyll-a and TSS were exported. With the STP loadings accounted for, **BOD_5,** NO,-N, TKN, Total N, DO, **TPO_4,** and chlorophyll-a **were** imported, while the other parameters were exported.

Net Analysis for July - A net analysis was conducted which combined the two tidal cycles. Over the two tidal cycles in July, net flow export was **14.5%.** With the STP flow considered, the export percentage dropped to 4.8%. Over this period there was net import of **BOD_5 (1.5%),** NO,-N **(2.6%), TKN,** Total N, and DO (4.6%) and net export of the other parameters. In addition, 'there was net import of BOD,, NH,-N, NO,-N, **TKN,** Total N, DO, TPO,, and TSS after consideration of **STP** loadings on the ebb tide. Analysis of **the** flow-weighted concentrations indicated net export of NO,-N, salinity and chlorophyll-a and net import of other constituents.

August Data - During August, for Cycle 1, net export of flow of 19.9% occurred; consideration of STP flows adjusted this value to 6.6% export. Without the consideration **ofSTP input,** net export of all constituents except TPO, occurred. With consideration of **STP** input on the ebb tide, net import of **$CBOD_5$,** NH,-N, NO,-N, NO,-N, TKN, Total **N,** and TPO, was observed. Analysis of the flow-weighted concentrations showed net export of CBOD,, NO,-N, NO,-N, DO, salinity, and **chlorophyll-a.**

During Cycle 2, flow export of 35.2% was observed without consideration of STP flow and export of 8.9% occurred with consideration of STP flow. Net export was observed for all parameters. However, consideration of the STP loadings reversed this trend for BOD,, **NH_3-N,** NO,-N, NO,-N, **TKN,** and Total N. The flow-weighted concentrations, without consideration of the STP loadings, showed export of **NH_3-N,** NO,-N, **NO_2-N, TKN,** Total N, DO, and TPO, and import of the other parameters.

Net Analysis for August - Analysis of net transport combining the two tidal cycles in August revealed export of flow **(24.7%),** and of all water quality parameter, without consideration of STP flows. With the STP flows considered on the ebb tide, the results were net export of flow (7.3%) and of DO, salinity, chlorophyll-a, and TSS. The other parameters were imported. The net- flow-weighted concentrations revealed export of NO;-N, NO,-N, Total N, DO, and salinity.

Comparison of Sampling Periods - Overall, without consideration of the source, net export or no net transport occurred on all four cycles for flow, salinity, NO,-N, chlorophyll-a, and TSS. Net export occurred over three of four cycles for BOD,, NH,-N, TKN, Total N, and DO. However; because of the net export of flow over three of the four cycles, much of that net export may be simply attributable to the flow imbalance and not to processes operating in the system. Much of the flow imbalance, and thus the mass loading to the system, is attributable to the **STP.**

Even with consideration of the flows from the Seacaucus STP, the net analyses for both sampling periods revealed flow export at Station S9A. This is the net export that would be expected in the STP were not in operation. However, it must be recalled that STP flows at this station were determined based on the average flows reported by the **STP.** It is possible that variations from that average occurred during some cycles. With consideration of the loadings from the **STP,** net import of CBOD,, NH,-N, NO,-N, TKN, Total N, and TPO, and net export of DO, salinity and chlorophyll-a occurred during both sampling periods. NO,-N and TSS were imported in one month and exported in the other. Thus, as expected, the STP plays a significant role in the nature and magnitude of pollutants flux at Station S9A.

Review of the flow-weighted concentration results, without accounting for STP effects, revealed net import of **BOD_5, TKN,** Total N, **TPO_4,** and **TSS** for at least three of four cycles. Net transport for the two sampling periods based on flow-weighted concentrations revealed import of CBOD,, NH,-N, TKN, and TSS in both months, and import of TPO_4 in July but no net transport of TPO_4 in August. Results for the transport of NO,-N indicated **import** in July and export in August, with the opposite result for Total N. Thus, it appears that imbalance in the flow volumes influence the net transport of constituents.

33923 **Comparsion of S9 and S9A**

Because of the discharge from the Seacaucus STP into Mill Creek, it is not possible to accurately assess the impact of the surrounding marsh on water quality based on the results at Stations S9 or S9A alone.

The discussion of STP loadings in the results section for Stations S9 and S9A are necessarily general. The flows from the STP were based on average daily flows reported by the plant. This flow rate was assumed to occur uniformly throughout the day which is actually highly unlikely. Thus, the loadings of each constituent attributed to the STP flow may be suspect. Therefore, another method was needed to isolate the effect of the marsh. The difference in net loadings between the two stations was calculated. Since S9A is located downstream of the STP but upstream of S9, the total loading at that station included treatment plant effects. Mill Creek includes extensive marsh area between S9 and S9A. Therefore, subtracting the mass transported at Station S9A from the mass transported at Station S9 should eliminate any effects of the STP. Table 3.13 summarizes the net transport between Station S9 and Station S9A.

For July, Cycle 1, net uptake of BOD_5, NO,-N, TPO,, and TSS was observed between Station S9 and S9A with net release of the other constituents. For Cycle 2, net uptake occurred for BOD,, NO_3-N, NH,-N, NO,-N, DO, salinity, chlorophyll-a and TSS. Over both cycles, net uptake was observed for CBOD,, NH,-N, NO,-N, NO,-N, DO, TPO_4, and TSS.

TABLE 3.13: Summary of Import/Export of Mess Flux in Mill Creek - Wet Transport Between Station S9 and S9A

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	NO2	TKN	TOTAL N	TPO4	DO	CHL-A	TSS
S-9 - S-9A	07/89	D	CYCLE 1	I	E	I	E	I	E	E	E	I	I	E	I
		N	CYCLE 2	I	E	I	I	E	I	E	E	E	I	I	I
			NET	I	E	I	I	I	I	E	E	I	I	E	I
S-9 - S-9A	08/89	D	CYCLE 1	I	E	I	I	I	I	I	I	I	E	I	I
		N	CYCLE 2	E	E	I	E	I	E	I	I	I	I	I	I
			NET	I	E	I	I	I	I	I	I	I	I	I	I

S9 = MILL CREEK BOUNDARY STATION
S9A = MILL CREEK MIDDLE BELOW STP
S9-S9A = NET DIFFERENCE (IMPACT OF MARSH)

0 = CHANGE IN MASS ≤ 1.0%
* = CHANGE IN MASS ≤ 5.0%
** = CHANGE IN MASS ≤ 10.0%

D = DAYTIME
N = NIGHTTIME

For August, Cycle 1, subtracting the loadings at S9A from those at S9 revealed uptake of all parameters except DO and salinity between Station S9 and S9A. For Cycle 2, net uptake of BOD,, NO_3-N, TKN, Total N, DO, TPO,, chlorophyll-a and TSS was observed. Comparing the total flow and mass transport for August revealed uptake of all parameters except salinity between Station S9A and Station S9.

The analysis of marsh impacts by subtracting mass transported at Station S9A from that transported at Station S9, is based on the assumption that flows for each station essentially were balanced over each tidal cycle. Any import or export of mass at each station would then depend only on processes within the system and any differences in loading between the two stations could be attributed to effects from the intervening marsh and any instream processes. However, because flows did not balance during all of the cycles at Stations S9 and S9A noted above, some of the mass transport may be attributable to the unbalanced flows. The analysis was then repeated using the flow-weighted concentrations to eliminate effects of flow imbalance. The net transport using this method revealed release of BOD_5, NH_3-N, NO,-N, TKN, Total N, DO, and chlorophyll-a and net uptake for NO,-N, salinity, TPO, and TSS for Cycle' 1 in July. This is consistent with the simple mass loading analysis for all' parameters except BOD_5 which showed net uptake using mass loading. For Cycle 2 in July, net release occurred for BOD_5, NO,-N, TKN, Total N, DO and TPO_4 and uptake for the' others. These results are consistent with the net mass results for all parameters except BOD_5 and DO.

For the August data, the flow-weighted concentration results indicate uptake of all parameters except salinity and TPO_4 for Cycle 1. Again, this is consistent with the net mass results for all parameters except DO and TPO_4. For Cycle 2, net uptake is observed for all parameters except salinity using the flow-weighted concentration. These results are consistent with the simple net mass loading results for all parameters except NH,-N, and NO,-N. Thus, for many parameters the results are consistent using both methods.

Conclusions based on these results must be drawn with caution. As noted, even after consideration of the addition of the STP flows on the ebb tide, acceptable flow balance did not result for all tidal cycles at Station **S9A.** Therefore, the net transport at that station may be due to the uneven tidal patterns rather than system processes. With that caution in mind, the results indicate that the marsh in Mill Creek imported **NH_3-N,** NO,-N, **NO_2-N,** DO, and CBOD, based on the overall net analyses for both months. When the direction of transport is determined from the flow-weighted concentration data, the results are less consistent. Using these data, NO,-N and Total N were exported, while NO,-N wasimported. All other parameters suggested mixed transport direction. Therefore, no definitive statement regarding the impact of the marsh on nutrient flux can be made.

It is interesting to note, however, that even with the upstream treatment plant, consistent export of nutrients did not occur at Station **S9.** This seems to suggest that processes in the system, including the marsh, are acting to consume the excess nutrients in the system. In fact, Total N and **TPO_4** are both imported into Mill Creek from the Hackensack Estuary, based on the results at Station S9 for all three sampling periods. This supports the conclusions reached above.

333 Berry's Creek

333.1 Station S-14

Summaries of concentration and mass transport data are presented in Tables 3.14 and 3.15, respectively. Appendices A-2-l and A-2-2 provide more detailed tables and graphs of these results.

July Data - During Cycle 1 in July, the flow balance indicated export of 5.8%. Mass transport analyses indicated export of BOD,, NH,-N, TKN, Total N, salinity, **TPO_4** and TSS and import of other parameters. During Cycle 2, flow was imported at 4.4%. Net import was observed for BOD,, NH,-N, NO,-N, **TKN,** Total N, salinity,

TABLE 3.14: Concentration Data Summary • Station S14 (in mg/l)

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
			MONTH OF JULY			
$CBOD_5$	12	3.34	1.73	1.60	6.90	51.83
NH_3-N	12	0.96	0.13	0.76	1.19	14.66
NO,-N	12	0.47	0.40	0.17	1.68	86.97
NO,-N	12	0.77	0.14	0.59	0.96	17.53
DO	12	3.10	1.15	1.90	5.40	37.14
Salinity*	12	7.34	1.24	5.81	9.42	16.83
Chlorophyll-a	12	26.94	13.71	3.52	51.40	50.89
TKN	12	2.00	0.69	1.12	3.15	34.55
TPO_4	12	0.50	0.08	0.38	0.61	15.44
TSS	12	43.83	19.62	21.60	90.00.	43.94
			MONTH OF AUGUST			
$CBOD_5$	12	252	0.70	1.62	4.05	27.68
NH_3-N	12	0.97	0.27	0.62	150	28.04
NO,-N	12	1.03	0.42	0.67	2.28	41.35
NO,-N	12	0.44	0.06	037	0.56	12.89
Do	12	3.64	0.85	2.50	4.95	23.26
Salinity*	12	10.11	1.69	7.43	13:03	16.72
Chlorophyll-a	12	19.41	10.78	7.15	41.20	55.55
TKN	12	2.38	1.17	1.12	5.46	49.18
TPO_4	12	0.61	0.17	0.42	0.90	27.28
TSS	11	37.64	14.39	1720	60.00	38.24

* Note: Salinity in PPT

DO, TPO, and TSS. Thus, flow and all water quality parameters, except NO,-N and DO, reversed transport direction from the first to the second tidal cycle.

Net Analysis for July - Combining the two tidal cycles releaved a net difference between total tide flood **and** total ebb flow volume of 0.1%. Combining total mass transport during the flood tide and ebb tide for both tidal cycles revealed export of salinity, **NH_3-N,** TKN, Total N, and TSS and import of all other parameters except for TPO, which showed no net transport. The net transport of BOD,, salinity, NH,-N, and Total N was less than 5% of the flooding mass.

August Data - For August, Cycle 1, analysis of flow showed net import of 712%. Import of BOD,, NH,-N, **NO_2-N,** TKN, Total N, TPO,, and chlorophyll-a was observed. For Cycle 2, net export of flow (9.8%) occurred along with import of BOD,, NH,-N, TKN, Total N, DO and chlorophyll-a. Thus, **BOD_5,** NH,-N, TKN, Total N, and chlorophyll-a demonstrated net import during both cycles. Salinity, NO,-N, and TSS were exported over both cycles. The other parameters showed mixed transport results.

Net Analysis for August - Combining the August data for both flood half-tidal cycles and both ebb half-tidal cycles revealed that flows essentially balanced (0.3% import). **BOD_5,** NH,-N, NO,-N, **TKN,** Total N, **TPO_4,** and chlorophyll-a were imported while NO,-N, DO, salinity and TSS were exported.

Comparison of Sampling Periods - For both months, BOD,, NO,-N and **chlorophyll-**a were imported in 3 of 4 cycles and in both net analyses. DO demonstrated mixed import and export during the individual cycles, but showed net export for both July and August. The other parameters showed inconsistent transport results.

TABLE 3.15: **Summary** of Import/Export of **Mass** In the **Berry's** Creek System - Station S14

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	NO2	TKN	TOTAL N	TPO4	Do	CHL-A	TSS
S-14	07/89	N	CYCLE 1	E **	E	E	E	I	I **	E	E	E **	I	I	E
		D	CYCLE 2	I *	I *	I	I ,**	E *	I **	I *	I *	I **	E	E	I
			NET	0	E *	I *	E *	I	I **	E	E *	0	E	I **	E
S-14	08/89	D	CYCLE 1	I **	E	I	I	E **	I	I	I	I	E	I *	E
		N	CYCLE 2	E **	E *	I *	I	E	E ii	I	I "	E **	I	I	E
			NET	0	E	I	I	E	I **	I	I	I	E *	I **	E

33392 Station S15

Summaries of concentration and mass transport data are presented in Tables 3.16 and 3.17, respectively. Appendices A-2-l and A-2-2 provide more detailed results.

July Data • During July, analysis of the total volume of ebb and flood tidal flow during Cycle 1 indicated export of 6.1%. **$CBOD_5$,** NH,-N, TKN, Total N, salinity, TPO,, chlorophyll-a and TSS were exported and NO,-N, NO,-N and DO were imported. During Cycle 2, flow import of 4.7% was calculated. Import of CBOD,, NO,-N, NO,-N, **TKN,** Total N, **TPO_4** and chlorophyll-a was observed along with export of NH,-N, DO and TSS. Combining all flood and all ebb data in a net analysis for July revealed net flow balance, export of salinity, BOD,, NH,-N, TPO,, DO, and TSS and import of the other water quality parameters.

August Data • The analysis of flows for Cycle 1 in August showed import of 6.7%. Import of over 10% of the flooding mass of BOD,, **NH_3-N,** NO,-N, salinity, and **TPO_4** occurred. For Cycle 2, the flow analysis revealed 9.5% export. **$CBOD_5$,** NO,-N, DO; chlorophyll-a, and TSS were imported while NH,-N, NO,-N, Total N, salinity and **TPO_4** were exported; there was no net transport of **TKN.**

Only CBOD, and Total N were consistent in transport direction over both tidal cycles. **A** net analysis was conducted for the August data which combined the flood and ebb data for both tidal cycles. That analysis showed net flow balance, import of **BOD_5,** NO,-N, DO, salinity, **TPO_4,** and TSS and export of the other parameters.

Comparison of Sampling Periods • For both July and August, no parameter showed a consistent pattern of import or export over all four tidal cycles. When the net analyses for each month were compared, flow balanced but only NH,-N showed a consistent pattern over the two months (net export). The other water quality parameters were exported during one month and imported during the other.

TABLE 3.16: Concentration Data Summary - Station S15 (in mg/l)

Variable	Number of Samples	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
MONTH OF JULY						
$CBOD_5$	12	3.72	0.99	238	5.92	26.56
NH_3-N	12	1.00	0.15	0.69	121	14.87
NO,-N	12	0.27	0.11	0.12	0.44	39.79
NO,-N	12	0.75	0.18	0.49	0.97	23.42
DO	12	3.46	0.99	1.90	5.10	28.53
salinity*	12	6.58	0.74	5.63	7.97	11.19
Chlorophyll-a	8	37.95	1157	2530	56.10	30.49
TKN	12	2.67	0.85'	1.43	4.67	31.80
TPO_4	12	0.57	0.11	0.42	0.71	18.65
TSS	12	81.18	4635	2520	152.00	57.09
MONTH OF AUGUST						
$CBOD_5$	12	2.98	0.56	2.22	3.85	18.74
NH_3-N	12	0.91	0.21	0.66	1.22	23.00
NO_3-N	12	0.80	0.24	0.37	1.18	29.52
NO,-N	12	0.43	0.08	033	0.52	17.76
Do	12	3.63	1.01	2.10	520	27.79
Salinity*	12	8.95	1.27	7.61	12.48	14.17
Chlorophyll-a	12	34.70	11.10	17.60	57.90	31.99
TKN	12	2.46	0.77	1.27	3.83	31.10
TPO_4	12	0.66	0.16	0.48	0.99	23.79
TSS	12	51.12	24.65	19.20	98.80	48.22

- Note: Salinity in PPT

3333 **Comparison of Stations S14 and S15**

Station S14 is located at the mouth of Berrys Creek while Station S15 is located upstream on that Creek In order to evaluate the effect of the wetlands in Berrys Creek on the loading of various parameters to the Hackensack River, it was necessary to eliminate the possible effects of other sources. This was accomplished by subtracting the net mass calculated at Station S15 from that calculated at Station S14. The area between the two stations is essentially all marsh. This technique would be acceptable if the flows balanced well for each cycle at each station. However, as noted above, both stations had uneven flows which did not balance well for the individual tidal cycles, but did balance when total flood flow and total ebb flow were calculated over two tidal cycles. Thus, the most relevant conclusions regarding the impact of the marsh on the water quality of Berrys Creek rests on the use of the net analyses for each month. That is, combining data from the two tidal cycles sampled in each month. Table 3.18 summarizes these results.

For July, subtracting net mass at Station S15 from net mass at Station S14 revealed import of **BOD_5,** NO,-N, NH,-N, NO,-N, TPO,, chlorophyll-a and TSS. NH,-N demonstrated essentially no net transport, while export of TKN, Total N, DO, and salinity was noted. The August data showed net import of **BOD_5,** NH,-N, NO,-N, TKN, Total N, **TPO_4,** and chlorophyll-a and net export of NO,-N, DO, salinity, and TSS. For both months, consistent results were obtained for **BOD_5,** salinity, NH,-N, NO,-N, **TPO_4,** DO, **and** chlorophyll-a.

To compensate for the imbalance in the transported flows, the net change in flow-weighted concentrations between Station S14 and S15 were calculated. In contrast to the Mill Creek results, noted above, the flow-weighted concentrations and mass flux analyses were in general agreement, with few exceptions.

The net transport direction results determined from the comparison of Station S14 with Station S15 also agree in most cases with the results at Station S14. Based on

TABLE 3.17: Summary of Import/Export of Mass in the Berry's Creek System • Station S15

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	NO2	TKN	TOTAL N	TP04	Do	CHL-A	TSS
S-15	07/89	N	CYCLE1	E **	E **	E	E *	I	I **	E	E	E	I	E	E
		D	CYCLE 2	I *	E *	I **	E **	[illegible] • [illegible]	I -	I	I	I • *	E	I	E
			NET	0	E *	E *	E **	[illegible]	I -	I	I	E • *	E **	I • [illegible]	E
S-15	08/89	D	CYCLE 1	I **	I	I	I	I	E *	E	E • *	I	E	E	E
		N	CYCLE 2	E **	E	I	E	E	I	0	E **	E	I	I	I
			NET	0	I •	I	E	E	I • *	E **	E • *	I	I *	E **	I

S-14 = BERRYS CREEK BOUNDARY STATION
S-15 = RERRYS CREEK UPPER STATION

0 = CHANGE IN MASS ≤ 1.0%
* = CHANGE IN MASS ≤ 5.0%
• * = CHANGE IN MASS ≤ 10.0%

D = DAYTIME
N = NIGHTTIME

TABLE 3.18: Summary of Import/Export of Mass Flux in Berry's Creek - Net Transport Between Station S14 and S15

STATION	DATE	T	CYCLE	FLOW	SALINITY	BOD5	NH3	NO3	NO2	TKN	TOTAL N	TPO4	DO	CHL-A	TSS
S-14 - S-15	07/89	D	CYCLE 1	E	E	E	E	I	I	E	E	I	I	I	I
		N	CYCLE 2	I	I	I	I	E	I	E	E	I	E	E	I
			NET	E	E	I	I	I	I	E	E	I	E	I	I
S-14 - S-15	08/89	D	CYCLE 1	I	E	I	I	E	I	I	I	I	I	I	E
		N	CYCLE 2	E	I	E	I	I	E	I	I	I	E	I	E
			NET	I	E	I	I	E	I	I	I	I	E	I	E

S-14 = BERRYS CREEK BOUNDARY STATION
S-15 = BERRYS CREEK UPPER STATION
S-14 - S-15 = NET DIFFERENCE (IMPACT OF MARSH)

O =CHANGE IN MASS ≤ 1.0%
* =CHANGE IN MASS ≤ 5.0%
** =CHANGE IN MASS ≤ 10.0%

D = DAYTIME
N = NIGHTTIME

both sets of results, the Berry's Creek marsh system appeared to import $CBOD_5$, NO_3-N, and chlorophyll-a and to export salinity and DO. The results for the other parameters were inconsistent,

4. SUMMARY AND CONCLUSIONS

This study investigated the dynamics and transport of pollutants in three tidal tributaries of the Hackensack Estuary: namely, Sawmill Creek, Mill Creek and Berry's Creek. The study also investigated microscale transport dynamics at a marsh impoundment site and a mudflat impoundment site in the Sawmill Creek sub-basin. Tidal elevation, flow and water quality data were collected at these sites during the periods November 1988, July 1989 and August 1989. Mass flux was calculated for nutrients, $CBOD_5$, DO, chlorophyll-a, TSS and salinity at each station for the ebb and flood portion of each tidal cycle. The mass of these constituents transported during the ebb portion of the tidal cycle was subtracted from the mass transported during the flood portion of the tidal cycle to determine the net import (flood mass > ebb mass) or-export (ebb mass > flood mass) of each constituent over a tidal cycle.

In addition, a net analysis was conducted for each sampling period which compared the pollutant load transported over the flood portions of the tidal cycles in a sampling period to that transported during the ebb portions of the same cycles. This provided an estimate of the total net transport for each sampling period. In many instances, the net analysis seemed to provide the best estimate of mass transport at each site due to better hydraulic flow balancing over the total duration of the tidal cycles in each sampling period than for each individual cycle. It is essential to achieve good hydraulic flow balance in order to differentiate the mass transport due to flow imbalance from that due to exchange between the wetlands and the estuary.

A major goal of this study was to investigate the impact of transport dynamics of $CBOD_5$, nutrients and dissolved oxygen on the water quality in the lower Hackensack River. Table 4.1 summarizes the results regarding transport of selected parameters between each tributary and the lower Hackensack River for the different sampling periods.

TABLE 4.1: Summary of Net Transport for Selected Parameters

EXPERIMENT	$CBOD_5$ N	J	A	NH_3-N N	J	A	NO_3-N N	J	A	Total N N	J	A	DO N	J	A
Sawmill Cr.- S3	E	E	I	E	E	I	E	E	I	E	E	I	E	E	I*
Mill Cr.- **S9**	E	I*	I	**E***	0	I*	0	1	E	0	**I***	I	•	**I***	**I**
Berrys Cr.- S14	•	**I***	**I**	•	E*	I	•	I	E	•	E*	I	•	E	E*

N= November 1988 I= Import A= August 1989
J= July 1989 **E=** Export
* = Less than 5% of Flood Mass transported

Review of Table 4.1 reveals that transport direction was not consistent for any parameter at any tidal tributary during the three sampling periods. Additional long-term data would be required to determine whether the variations are due to natural conditions within each tributary.

In Sawmill Creek, which has the largest tidal exchange with the lower Hackensack River, all parameters listed in Table 4.1 were exported during the November, 1988 and July, 1989 sampling periods, but were imported during the August, 1989 sampling period. The July and August 1989 sampling events were conducted within a period of two weeks apart and so were expected to serve as replicate sampling events. Clearly, the inconsistent results obtained during these two periods indicate the need for additional data to determine the reasons that the tidal tributaries behave as both sources and sinks of pollutants.

$CBOD_5$ and the nitrogen-series parameters were exported at Station S3 in Sawmill Creek during the November and July sampling events. Station S3 drains a large expanse of mudflat and a smaller area of tidal marsh. In addition, two active HMDC sanitary landfills are located at the head of the Creek. The flux of water quality parameters at Station S3 would be influenced by a combination of processes in the tidal marshes, mudflats, and ,possibly, by leachate from the landfills.

Two microscale experiments were conducted in the Sawmill Creek system: (a) at a mudflat embayment (Station Ml), and (b) at a marsh impoundment (Station M2). Station Ml was sampled during the November, 1988 and July, 1989 sampling periods. Consistent results were obtained when all data for each sampling period was combined into a net analysis, although results for individual tidal cycles varied to some extent. Based on these results, the mudflat appeared to import NH,-N, TKN, Total N, and $CBOD_5$ and to export NO,-N, NO,-N, and DO.

The microscale marsh station, M2, was sampled in November, 1988 and July and August, 1989, respectively. At Station S3, the transport results for the nitrogen-series parameters obtained from the July sampling period were similar to those from the November sampling period, and less so to the August results. 'The marsh consistently imported TKN and Total N during the three periods. NH,-N was imported during . November and July and exported in August, while NO,-N showed the opposite pattern. DO, on the other hand, was imported in November, and exported during July and August.

Thus, the export of CBOD,, NH,-N, and Total N at Station S3 during the November and July sampling periods can not be explained by the results of the microscale studies. A source of NH_3-N to the lower Hackensack River in the vicinity of Sawmill Creek was also noted in the data taken for the modeling study of the main stem of the River, described in Appendix A, Part I of this report. The results of this study do not indicate that the mudflats or marshes within Sawmill Creek are the source of the NH_3-N. A possible source could be the two HMDC sanitary landfills located at the head of Sawmill Creek. Analysis of leachate data taken from wells at the perimeter of these landfills revealed very high concentrations of NH,-N and other nitrogen-series parameters. However, data was not available to calculate actual loading rates from the landfills to the Creek. Therefore, the conclusion that the landfills are the source of excess NH_3-N must be regarded as speculative at this time.

In Berry's Creek and Mill Creek, two stations were sampled in each Creek to separate the impact of the wetlands on mass transport from the effect of other sources or sinks in the system These systems were sampled completely-in July and August, 1989, while an additional sampling was conducted in Mill Creek in November, 1988. Mill Creek is also affected by discharge from the Secaucus STP about 1,5 miles upstream from its mouth. As shown in Table 4.1, the results from Stations at the mouths of both Creeks revealed very inconsistent results.

The results for Mill Creek do not show the consistent export of CBOD, and nutrients that might be expected given the discharge of secondary-treated effluent from the Secaucus STP. These data suggest that the marsh acts as a sink for these parameters. During the July 1989 sampling period, all parameters listed in Table 4.1 were imported into Mill Creek from the Hackensack River, except NH,-N which had no net transport. During the August sampling period, only NO,-N and DO were exported, while the other parameters listed in Table 4.1 were imported. During the growing season, the marshes within the Mill Creek basin appear to have consumed the excess nutrients and CBOD, input to the system from the STP. In November, however, during the end of the growing season, when marsh plants stop growing and begin to senesce and die, $CBOD_5$ and NH,-N were exported from Mill Creek. Thus, the plants are no longer capable of removing the excess $CBOD_5$ and NH,-N from the system. Clearly, additional long-term data would be needed to confirm these conclusions.

There is no consensus in the scientific literature regarding the direction or magnitude of mass flux between tidal wetlands and estuaries. The complex chemistry and hydrodynamics of these systems create a high degree of natural variability as well as making it difficult to accurately measure flows and representative concentrations.

Methods used by researchers to sample the systems and to calculate net flux also vary widely. In addition, site specific conditions may make generalizations regarding estuarine-wetlands nutrient exchange unreliable. In particular, the Hackensack River estuary is a highly enriched system in which nutrient dynamics may be very different than those in less enriched systems. Another possible confounding factor was that each tributary studied contained other possible sources and sinks of nutrients, including an STP and two landfills. Most research in the literature' have analyzed systems with less human influences. For these reasons it is difficult to compare the results of this study to the results of other such analyses reported in the literature.

The wetlands of the Hackensack Estuary play an important role in the nutrient dynamics of its ecosystem. The system is complex and appears to be inherently variable in the nature and direction of nutrient exchange. This variability was also reflected in the sediment studies (see Appendix A-3-3) in which consistent results were not obtained. This study has been a critical first step in exploring the nature of nutrient and dissolved oxygen exchange between the tidal wetlands and the lower Hackensack River. Due to the variability in mass transport results, the conclusions reached herein must be considered somewhat speculative until additional data becomes available to further explore this system.

However, the results of this study have provided valuable insights into the nutrient and dissolved oxygen dynamics in the complex tidal wetland ecosystem of the lower Hackensack River. **The study also revealed that nutrient loads for the wetlands assumed in most previous studies of the lower Hackensack River were not appropriate.** The results of the comprehensive Marsh study were used to generate pollutant contributions from the extensive tidal marshes, mudflats and landfills of the lower Hackensack River Basin for use in the River Modeling phase of the study.

These results are summarized as follows:

1. The overall Nutrient Transport results do not indicate a clear and consistent pollutant loading pattern to the tidal Hackensack River. Thus, the extrapolation of these results to the remaining tidal marshes and mudflats within the lower Hackensack River Basin could not be justified.

2. The review of the net DO transport results revealed export from the tidal tributaries in almost all instances. These results were incorporated into the River Model by increasing the Dissolved Oxygen Reaeration coefficients in the relevant reaches of the River.

3. The review of the Net Pollutant transport results in the vicinity of the extensive HMDC Landfills indicate a source of both BOD and NH,-N to the river. Although the data were not consistent during the three monitoring periods, high pollutant concentrations present in the wells adjoining the landfills and the current literature, justify the extrapolation of these data to the remaining landfills within the watershed. ,

The results of this Tidal Marsh Study were incorporated into the River Modeling Phase of the lower Hackensack River Study (Appendix A, Part 1) to determine viable alternatives for water quality enhancement within the lower Hackensack River Basin.

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