STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Harmon W. Shields, *Executive Director*

DIVISION OF INTERIOR RESOURCES
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BUREAU OF GEOLOGY
C. W. Hendry, Jr., *Chief*

REPORT OF INVESTIGATIONS NO. 70

INDICATORS OF ORGANIC CONTAMINATION IN PLANTATION CANAL, BROWARD COUNTY, FLORIDA, 1971 - 72

By
Thomas N. Russo

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES,
CENTRAL AND SOUTHERN FLORIDA FLOOD CONTROL DISTRICT,
and
BROWARD COUNTY AIR AND WATER POLLUTION CONTROL BOARD

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Bureau of Geology
Tallahassee
March 29, 1974

Honorable Reubin O'D. Askew, *Chairman*
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

The Department of Natural Resources, Bureau of Geology, is publishing as its Report of Investigation No. 70 the report entitled, "Indicators of Organic Contamination in Plantation Canal, Broward County, Florida, 1971 - 72," by Thomas N. Russo, of the U. S. Geological Survey.

The purpose of this report is to document the water-quality characteristics of a contaminated controlled canal. The report demonstrates the value of the physical, chemical and biological properties of the bottom sediments in providing an overall picture of the long-term effects of contamination.

Respectfully yours,

Charles W. Hendry, Jr., *Chief*
Bureau of Geology

Completed manuscript received
February 13, 1974
Printed for the
Florida Department of Natural Resources
Division of Interior Resources
Bureau of Geology
By
Ambrose the Printer, Inc.
Jacksonville, Florida

Tallahassee
1974

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INDICATORS OF ORGANIC CONTAMINATION IN PLANTATION CANAL, BROWARD COUNTY, FLORIDA, 1971 - 72

By
Thomas N. Russo

INTRODUCTION

Plantation Canal is a fresh water canal of the FCD (Central and Southern Florida Flood Control District) in the heavily populated Fort Lauderdale area (fig. 1). It is about 2½ miles long. Its water levels are regulated by a salinity control structure S-33 (fig. 2), one half mile east of U. S. Highway 441. During the wet season, excess water is discharged into the tidal waters of the North Fork of New River which meanders 4 miles through the city of Fort Lauderdale, Florida. During the dry season fresh water is retained in Plantation Canal and there is little or no flow into the New River. Principal inflow to Plantation Canal during this period is composed of ground water and waste water from adjacent sewage treatment plants (fig. 2). The quality of water in the canal is largely related to the quality and quantity of waste waters entering it.

The quality of water in streams is usually determined by chemical, physical, and biological tests. Each test represents the water quality in the stream at a specific point in time. Changes in water quality over a long time may be detected only by recurrent sampling and analyses.

The abundance and distribution of benthic (bottom dwelling) organisms are influenced in a water body. When an organism is confronted with an adverse environmental condition it must adapt to that condition or eventually die and be replaced by more tolerant organisms.

Plantation Canal was selected for detailed study because water quality analyses indicated that the canal was the most contaminated canal in Broward County. Stream conditions are adverse to most forms of bottom life; only the most tolerant organisms are able to survive. South New River Canal above S-13A was selected as a control site because it is relatively uncontaminated.

PURPOSE AND SCOPE

The purpose of this report is to document the water-quality characteristics of a contaminated controlled canal. The report demonstrates the value of the physical, chemical and biological properties of the bottom sediments in providing an overall picture of the long-term effects of contamination.

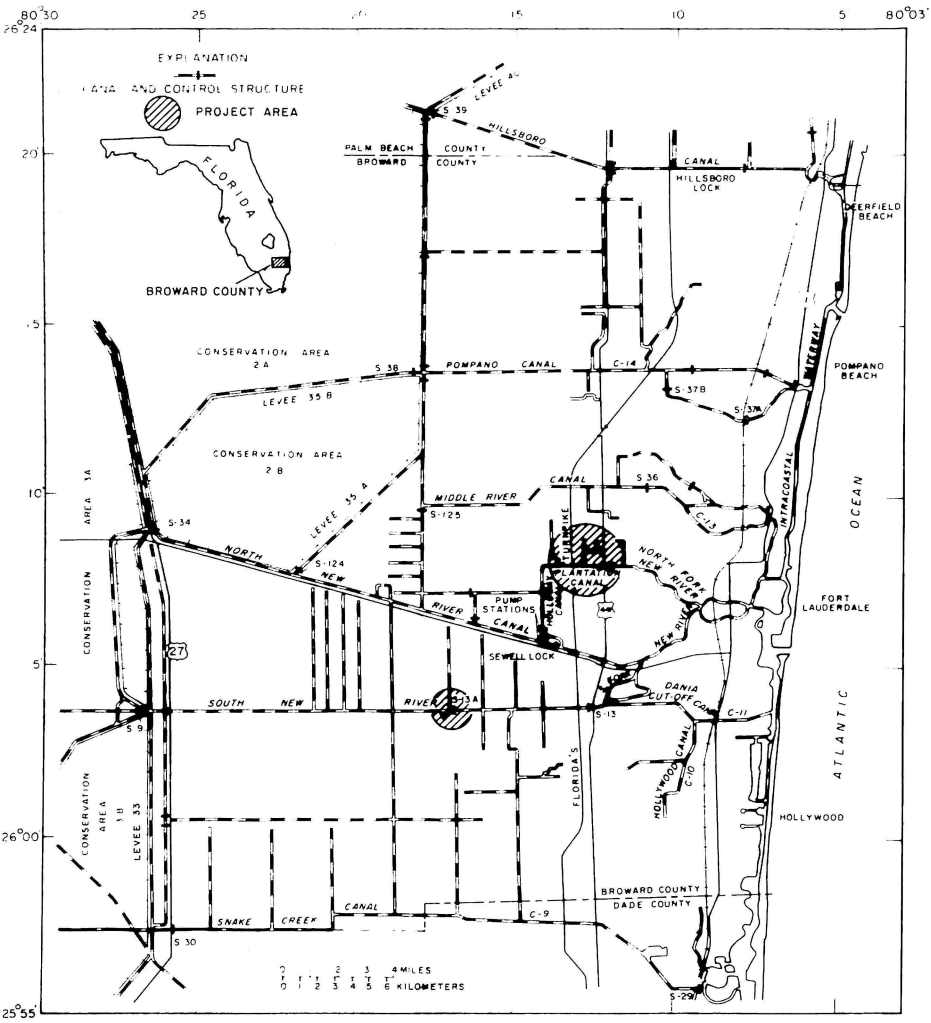


Figure 1 **Map showing the Broward County canal system and the canal reaches investigated.**

DATA COLLECTION

Water-quality samples were collected monthly at five sites on Plantation Canal (fig. 2) over a 15-month period and at the control site on the South New River Canal (fig. 1) for a 9-month period. The five sites established at Plantation Canal are spaced approximately at 0.6-mile intervals. Detailed descriptions of the sites are shown in table 1.

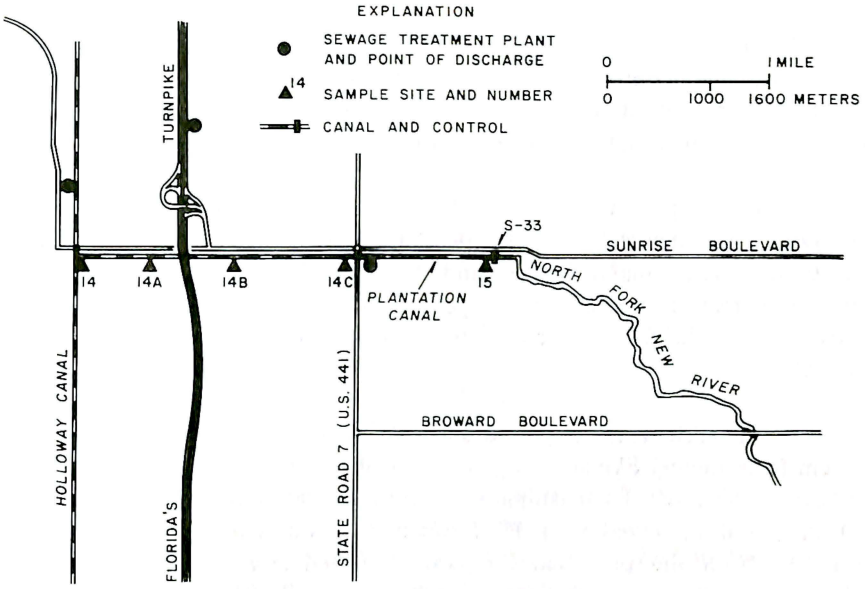


Figure 2 Location of sewage treatment plants, sample sites, and the salinity control structure on the Plantation Canal.

TABLE 1
SAMPLING SITES IN PLANTATION AND SOUTH NEW RIVER CANALS

Site	Identification Number	Location and Description
14	260807NO801402	Plantation Canal at N. W. 65 Avenue Bridge, south bank about 25 yards east of Earthen Bridge in Plantation.
14A	260807NO801328	Plantation Canal at Sunrise Blvd. opposite City of Lauderhill Entrance.
14B	260808NO801247	Plantation Canal at N. W. 47 Avenue Bridge, east side of bridge.
14C	260807NO801214	Plantation Canal at Highway 441, west side of bridge.
15	2832.00	Plantation Canal, nr. Ft. Lauderdale, Fla., above S-33.
Above S-13A	2859.00	South New River Canal, nr. Davie, Fla., above S-13A.

Water-quality parameters measured at the sites include temperature, dissolved oxygen content, specific conductance, pH, alkalinity, and free carbon dioxide. These field determinations were made near the surface and just above the bottom of the canals to detect stratification.

Water samples were also collected quarterly from selected sites and analyzed for chemical constituents. Chemical analyses normally included determinations for major nitrogen and phosphorus species, organic carbon, trace and heavy metals, biochemical oxygen demand, and pesticides. Bacteriological tests were made for total coliform, fecal coliform, and fecal streptococcus bacteria.

During each sampling period biological samples were collected with a 15 x 15 cm (centimeter) Ekman dredge near the shore, at quarter section, and in the middle of the canal. Each sample was sieved separately in a U. S. Standard No. 30 sieve and preserved in a 4% formalin solution. The organisms were then removed from the preserved samples, identified and counted. Counts were expressed as the number of organisms per square meter (Welch 1948).

Bottom sediments were collected at several sites with a core sampler and Ekman dredge. Particle size and core length were determined from the cores. The bottom sediments collected with an Ekman dredge were analyzed for organic and total carbon, organic nitrogen, exchangeable ammonium, phosphate, manganese, iron, aluminum, lead, mercury, and pesticides.

All field and biological tests were made by the writer. Chemical analyses of water and bottom sediments were made by U. S. Geological Survey, laboratories in Ocala, Florida, Washington, D. C., Denver, Colorado, and Harrisburg, Pennsylvania.

INDICATORS OF ORGANIC CONTAMINATION IN WATER

The principal cause of the poor quality of the water in Plantation Canal is liquid waste from adjacent sewage treatment plants. This waste contains large quantities of oxygen demanding materials and plant nutrients. These depress the dissolved oxygen content and increase the biochemical oxygen demand. Nutrients stimulate plant growth and the decaying vegetation produces the noxious odors associated with anaerobic decomposition. In contrast, the control site on the South New River Canal receives a smaller load of organic matter and nutrients. Dissolved oxygen levels at this site are usually high. There is no luxuriant growth of aquatic plants at the control site and no odors are discernible because decomposition is by aerobic rather than by anaerobic processes.

OXYGEN RELATED PARAMETERS

The introduction of organic materials into a body of water greatly influences both the use and production of oxygen, thus the oxygen related parameters, DO (dissolved oxygen), BOD (biochemical oxygen demand), CO_2 (carbon dioxide) and organic carbon are indicators of contamination. Dissolved oxygen levels in Plantation Canal were very low during the investigation; they may not be low perennially. The DO near the surface averaged 3.1 mg/l (milligrams per liter) (37 percent saturation) over a period of 15 months (fig. 3). The average DO above the bottom was 0.85 mg/l (10 percent saturation). Conditions above the bottom are probably anoxic at night or when oxygen production is low. DO levels are higher in the western reach of the stream (14-14B) than in the eastern reach (14B-15).

Ingram and others (1960) defined four arbitrary stream zones based on percent oxygen saturation. The descriptive names are **clean water** (70% saturation or greater), **degraduation** (less than 70%), **active decomposition** (less than 40% saturation) and a **recovery zone** whereby oxygen saturation increases greater than 40% saturation. Plantation Canal exhibits zones of degradation and active decomposition, however the length of the canal and the spatial distribution of the effluent prevents the development of a clearly defined recovery zone.

In South New River Canal above S-13A, (the control site) DO concentrations were high during the study period. The average DO at the control site was 5.9 mg/l (71 percent saturation) near the surface and 3.7 mg/l (44 percent saturation) above the bottom. The DO concentrations above the bottom at the control site were generally higher than near the surface in Plantation Canal.

Oxygen may be introduced into streams by atmospheric diffusion and by photosynthesis. The primary producers of oxygen in Plantation Canal are submersed aquatic plants and algae. The submersed plant community is made up of Florida elodea *(Hydrilla verticillate)*{*Pithophora* sp. and coontail, *(Ceratophyllum demersum).* Even though the mean depth is 6 feet, these plants are found only near the shore line. This may be due to unsuitable substrata, toxic substances in the waters and sediments or lack of available light at deeper depths.

Another aquatic plant community is composed of a blue green alga, *Anacystis* sp., and benthic algae *Pithophora* sp. and *Cladophora* sp. During an

algal bloom, DO concentrations reached 20.0 mg/l (254 percent saturation) during the day and decreased to 0.5 mg/l (5 percent saturation) by the next morning.

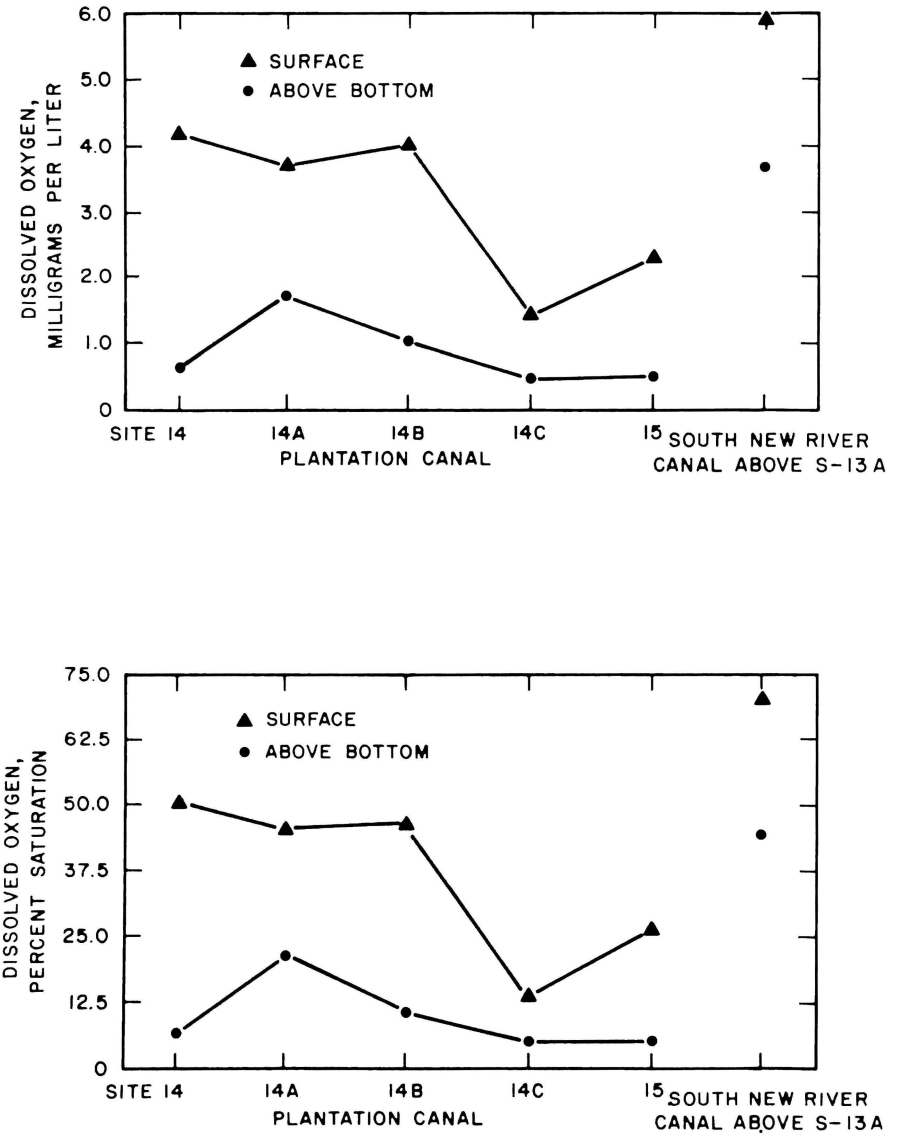


Figure 3 Average dissolved oxygen concentrations and percent saturation in Plantation Canal and South New River Canal above S-13A.

The remainder of the aquatic plant community are floating plants. These plants probably contribute little oxygen to the waters of Plantation Canal. However, dense concentrations of the plants may prevent sunlight from reaching submersed plants and algae and inhibit oxygen production. Light penetration is also inhibited by the high color (65 color units) and turbidity (55 Jackson Units) of the waters.

In contrast to Plantation Canal, the control site at the South New River Canal has an extensive littoral zone. Large communities of southern naiad (*Najas guadalupensis*), Florida elodea, *Chara* sp. and *Cladophora* sp. have colonized the area, whose waters are very clear. DO levels are usually high and the site is free of floating aquatic plants most of the time. Wide variations in DO are not characteristic of the control site.

The DO content in a canal is affected, in part, by the BOD (biochemical oxygen demand) content. BOD is a measure of the oxygen used in respiratory and chemical oxidation processes and indicates organic load. The average BOD at the control site on the South New River Canal was 1.9 mg/l (fig. 4), a characteristic of a relatively uncontaminated body of water. The average BOD in Plantation Canal, 6.4 mg/l, represents an organic concentration three times greater than at the control site. This higher BOD is largely responsible for the low DO levels which characterize Plantation Canal.

TABLE 2.
AQUATIC PLANTS FOUND IN PLANTATION CANAL AND SOUTH NEW RIVER CANAL ABOVE S-13A

Plantation Canal

Common Duckweed	*Lemna minor*
Water Lettuce	*Pistia stratioties*
Water Hyacinth	*Eichhornia crassipes*
Florida Elodea	*Hydrilla verticillata*
Coontail	*Ceratophyllum demersum*
Green alga	*Pithophora* sp.
Green alga	*Cladophora* sp.
Blue-Green alga	*Anacystis* sp.

South New River Canal Above S-13A

Southern Naiad	*Najas guadalupensis*
Florida Elodea	*Hydrilla verticillata*
Chladophora	*Chladophora* sp.
Stonewort	*Chara* sp.

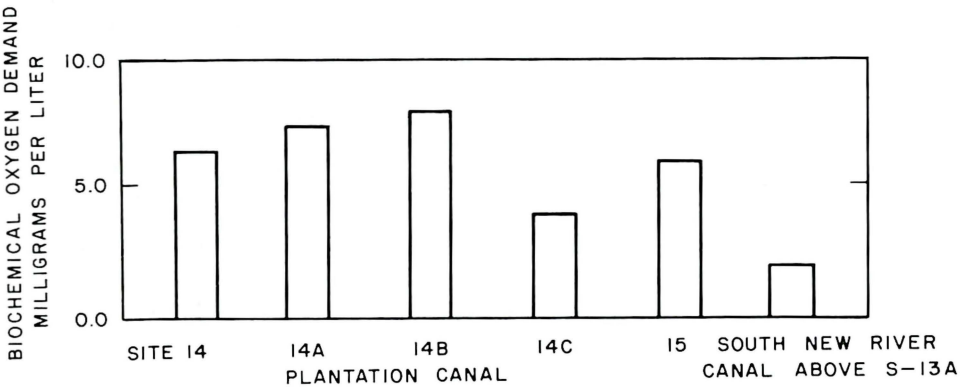


Figure 4 Average biochemical oxygen demand concentrations in Plantation Canal and South New River Canal above 13-A.

The high BOD and resulting low DO concentrations dictate the type of decomposition that takes place in Plantation Canal. When dissolved oxygen is available, aerobic decomposition converts organic matter into carbon dioxide, water, and other elemental substances. This occurs in both Plantation Canal and at the control site. At times, dissolved oxygen is not available in Plantation Canal. Then, decomposition still proceeds but by anaerobic means during which foul-smelling substances are produced (residual hydrogen, skatole, indole, mercaptans and hydrogen sulfide).

Organic carbon concentrations in Plantation Canal averaged 24 mg/l (fig. 5). East of Highway 441, organic carbon increased from 22 mg/l at site 14C to 32 mg/l at site 15. The organic carbon in Plantation Canal is mainly in the form of dissolved and particulate matter from sewage effluent and the biota living in the water. The organic carbon at the control site is composed chiefly of dissolved organic matter which leaches out of organic debris and the biota in the canal water, but which is resistant to biodegradation.

High carbon dioxide concentrations in water may also indicate a high degree of organic material. Average carbon dioxide concentrations in Plantation Canal were high, 14 mg/l near the surface and 20 mg/l above the bottom. Concentrations were highest near the surface in the eastern reach between sites 14C and 15 (fig. 6). Carbon dioxide concentrations at the control site in South New River Canal averaged 9 mg/l near the surface and 16 mg/l above the bottom. The higher concentrations in Plantation Canal indicate greater decomposition rates in the water and sediments.

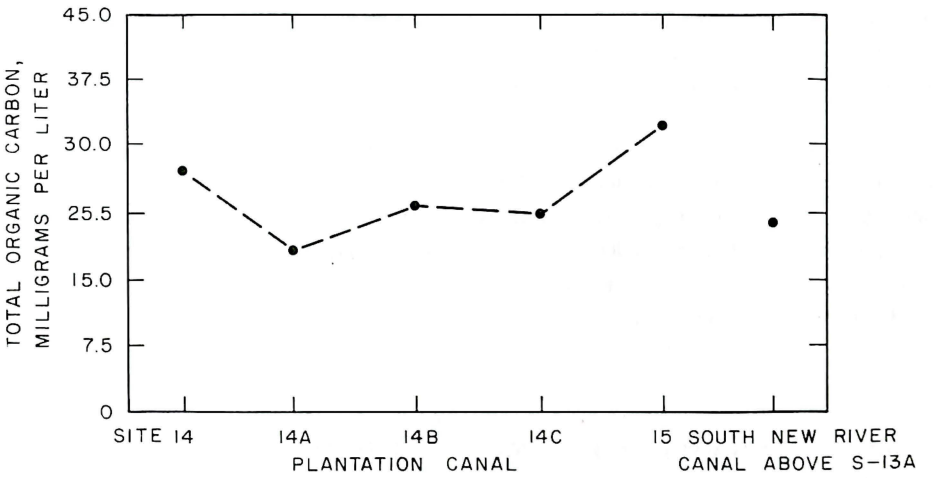


Figure 5 Average concentrations of total organic carbon in Plantation Canal and South New River Canal above S-13A.

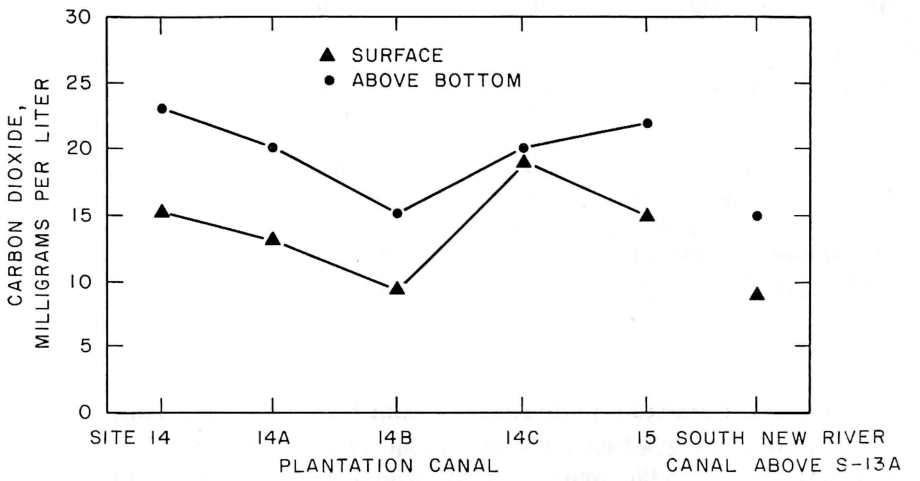


Figure 6 Average concentrations of carbon dioxide in Plantation Canal and South New River Canal above S-13A.

COLIFORM BACTERIA

The presence of coliform bacteria in water is usually considered an indicator of fecal contamination. The coliform group include *Escherichia coli, Aerobacter aerogenes,* and sixteen other species (Millipore, 1971). In general, these bacteria are considered non-pathogenic, but some *E. coli* strains can cause

enteritis and genitourinary infections. The presence of these organisms in a water sample is an indicator of the possible presence of pathogens, such as *Salmonella* (typhoid fever) and *Shigella* (shigellosis).

Total coliform bacteria concentrations in both Plantation Canal and at the control site (table 3) exceeded the state criteria (2,400 per 100 ml) for Class III waters (Recreation Propagation and Management of Fish and Wildlife) and federal criteria (200 per 100 ml) for surface waters. However, fecal coliform concentrations at the control site are below permissible limits set by federal authorities for surface waters.

TABLE 3.
SUMMARY OF BACTERIOLOGICAL DATA 1971 - 72

Site	Total Coliform*	Fecal Coliform	Fecal Strep	Fecal Coliform/ Fecal Strep Ratio
14	113,000 (9)+	363 (8)	140 (2)	1.0-9.0
15	108,000 (8)	3,550 (7)	540 (2)	0.12-1.0
Above 13A	8,200 (9)	390 (8)	1,070 (2)	0.24-0.70

* All counts are mean values expressed as colonies per 100 milliliters.
\+ number of samples.

Smith and Twedt (1971) developed a ratio between fecal coliform and fecal streptococci (FC/FS) bacteria. Under certain defined conditons, the FC/FS ratio is used to indicate the probable source of fecal waste. In general at FC/FS ratio greater than 4 indicates waste from human sources; a ratio less than 0.7 indicates waste from animal sources. The ratio between 0.7 and 4 indicates waste from both sources.

FC/FS ratios at sites 14 and 15 in Plantation Canal were greater than 4 and indicative of wastes from human sources. The FC/FS ratio at the control site ranged between 0.24 and 0.7 and are indicative of animal waste sources. According to Millipore (1971) duck-generated waste has a ratio of 0.6. Muscovy ducks are present at the site and are a likely source of waste materials.

MAJOR NITROGEN AND PHOSPHORUS SPECIES

Sewage treatment outfalls located near sites 14, 14B, and 14C, (fig. 2) introduce about 2.5 - 4 million gallons of sewage effluent into Plantation Canal daily. Even though sewage treatment plants are capable of removing much of the organic carbon from sewage, the sewage plant effluents still contain appreciable quantities of nutrients, including ammonium, nitrite, nitrate and phosphorus (table 4). The nutrient load (phosphorus and nitrogen compounds) entering the 2½-mile-long canal was calculated at almost 500 pounds per day (table 5). Some of the highest nutrient levels in south Florida have been measured in Plantation Canal, for example concentrations of phosphorus and ammonium have been as high as 13.5 mg/l PO_4 - P and 32 mg/l NH_4 - N (Sherwood 1970, written communication). Average values for the nutrient species ammonium, nitrite, nitrate, organic nitrogen, and phosphorus are listed in figures 7 and 8. High concentrations of ammonium, organic nitrogen and phosphorus generally occurred at sites 14 and 15. These sites are downstream from sewage outfalls (fig. 2) Concentrations of these constituents are reduced between sites 14A and 14C, possible because of nutrient uptake by aquatic plants or sedimentation of particulate material eastward from the source of contamination (figs. 7 and 8).

Ammonium concentrations are extremely high at site 14 (13 mg/l NH_4 - N) and site 15 (8 mg/l NH_4 - N). At the control site on the South New River Canal, the average was 0.15 mg/l NH_4 - N (fig. 7).

Changes in nitrite concentrations along Plantation Canal were inverse to changes in ammonium concentrations. Nitrite increased between sites 14 and 14A and then decreased in the remainder of the canal (fig. 8). The nitrite concentrations of the control site on the South New River Canal were below concentrations in Plantation Canal.

TABLE 4.
CHEMICAL CONSTITUENTS OF SECONDARY TREATED SEWAGE EFFLUENT
(after Environmental Protection Agency 1972)

Phosphorus as P	10[1/]
Ammonia Nitrogen as N	11.3
Organic Nitrogen as N	4.7
Nitrate and Nitrite Nitrogen as N	4.1
Biochemical Oxygen Demand range	=7-66*

1/ All values are milligrams per liter.

* Dependent upon operating efficiency of sewage treatment plant.

TABLE 5. CHEMICAL LOADS ENTERING PLANTATION CANAL
(loads are in pounds per day)

Source	Capacity (MGD)	Flow (MGD)	Receiving Site	Ammonium-N	Phosphorus-P	Nitrate-Nitrite	Organic N	BOD 5 days
Broward Estates Plant of Broward County Utilities	1.15	2.2	Below 14C	209	185	75	86	733
East Holloway Canal		.08	14	6	3.5	1.1		5
Turnpike		.08	14	6	3.5	1.1		5

From site 14A to site 15, nitrate concentrations showed a similar trend to nitrite in Plantation Canal (fig. 8). The average concentration in Plantation Canal and the control site was 0.2 mg/l NO_3 - N.

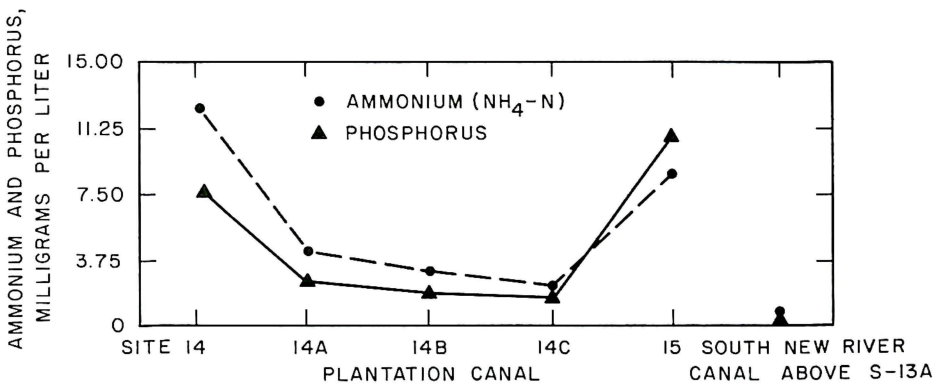


Figure 7 Average concentrations of ammonium (NH_4 - N) and phosphorus in Plantation Canal and South New River Canal above S-13A.

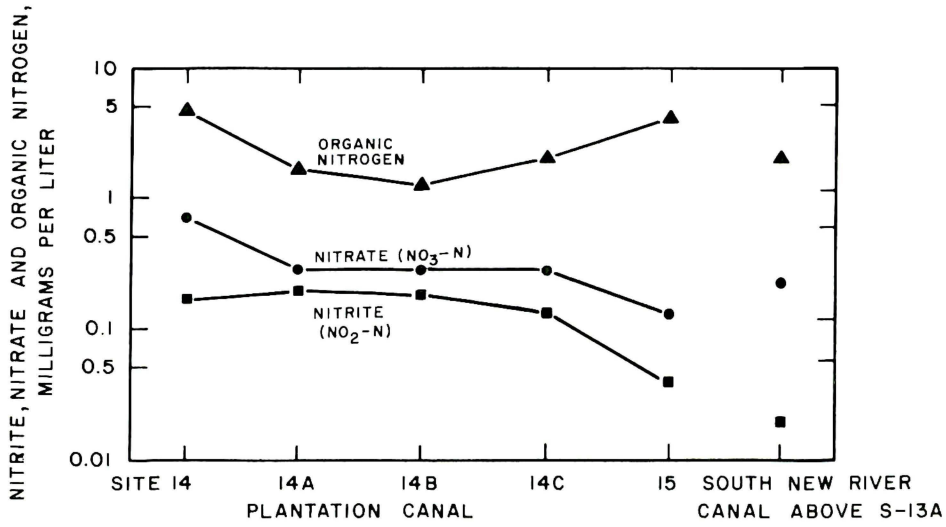


Figure 8 Average concentrations of nitrite, (NO_2 - N), nitrate (NO_3 - N), and organic nitrogen in Plantation Canal and South New River Canal above S-13A.

The highest concentrations of organic nitrogen (3-4 mg/l) were recorded at sites 14 and 15 (fig. 8). Concentrations at the remaining sites were less than 2 mg/l.

Changes in phosphorus and ammonium concentrations in Plantation Canal were similar (fig. 7). Average concentrations were high (7.5 mg/l PO_4 - P) at sites 14 and 15 and low at sites 14A - C. The control site on South New River Canal had the lowest concentration, 0.02 mg/l PO_4 - P.

The concentrations of ammonium, phosphorus and biochemical oxygen demand in Plantation Canal decreased appreciably from January 1971 to August 1972, due to increased flow beginning in October 1971. Percent oxygen saturation showed no change except at sites 14A and 14B (figs. 9 and 10).

Nutrients are found only in minute quantities at the control site. The ammonium present in Plantation Canal is 44 times the amount found at the control site. Other constituents such as phosphorus, nitrite and nitrate are found in concentrations which were 225, 6, and 2 times respectively the amount present at the control site.

Another aspect of the nutrient problem in Plantation Canal is aquatic plants. High concentrations of nutrients cause algal blooms and luxuriant growth of floating aquatic plants. When these plants die, they usually settle to the bottom with the particulates of sewage effluents. On the bottom, both the plants and particulates undergo decomposition and exert an oxygen demand upon the overlying waters. Materials produced from the decomposition of these plants become part of the sediments and may be a future source of nutrients.

Additional water-quality data collected were water temperature, specific conductance and alkalinity. Water temperature ranged from 18°C to 33°C near the surface in Plantation Canal. During such times the temperature difference between the surface and bottom was as much as 3°C when there was no flow in the canal.

The specific conductance of water in Plantation Canal ranged from 500 to 800 umhos (micromhos). Specific conductance was higher during the first 7 months of the study coincidental with a severe drought in south Florida. The average alkalinity (as bicarbonate) at all sites was 262 mg/l. The water was very hard.

Although the pH of the water varied considerably, in general it indicated that the water was alkaline. Near the bottom, pH was usually lower than near the surface, chiefly because of higher concentrations of carbon dioxide near the

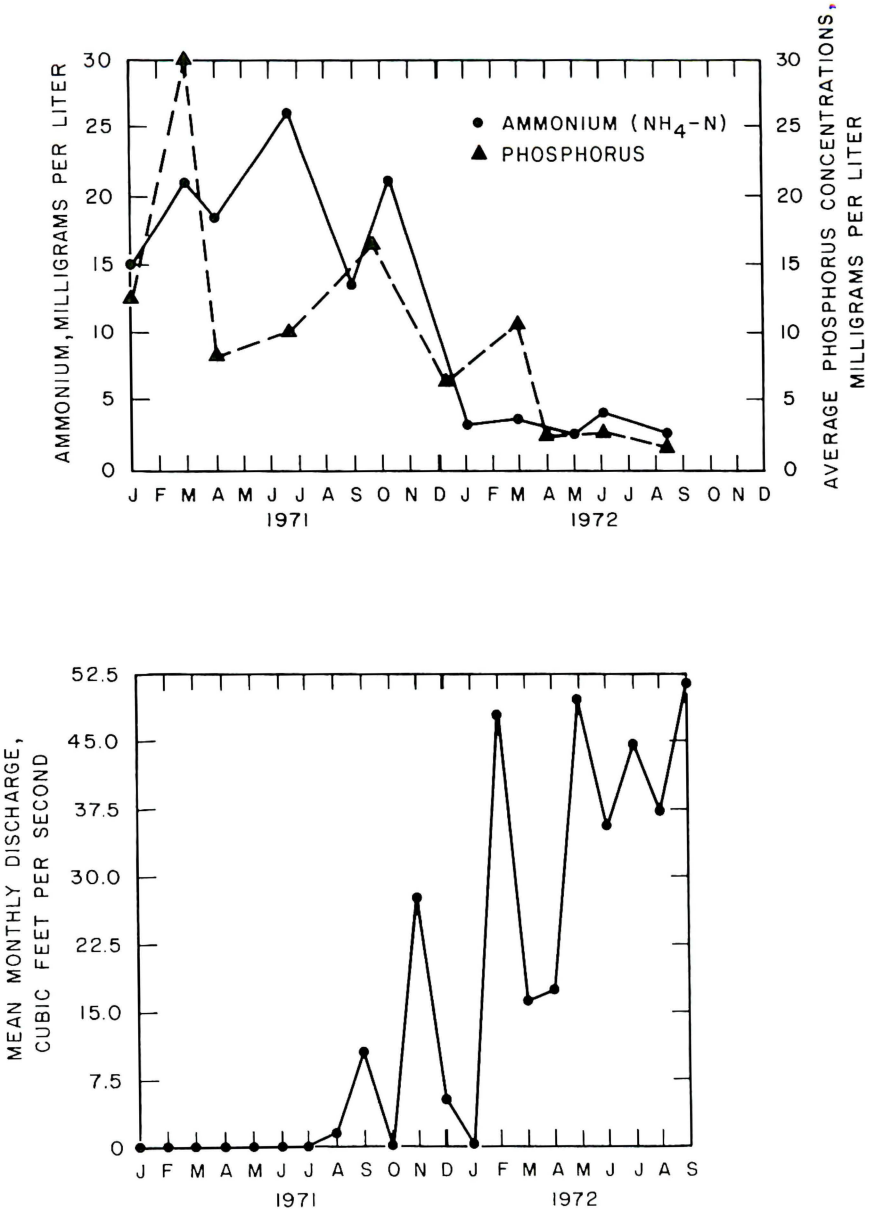
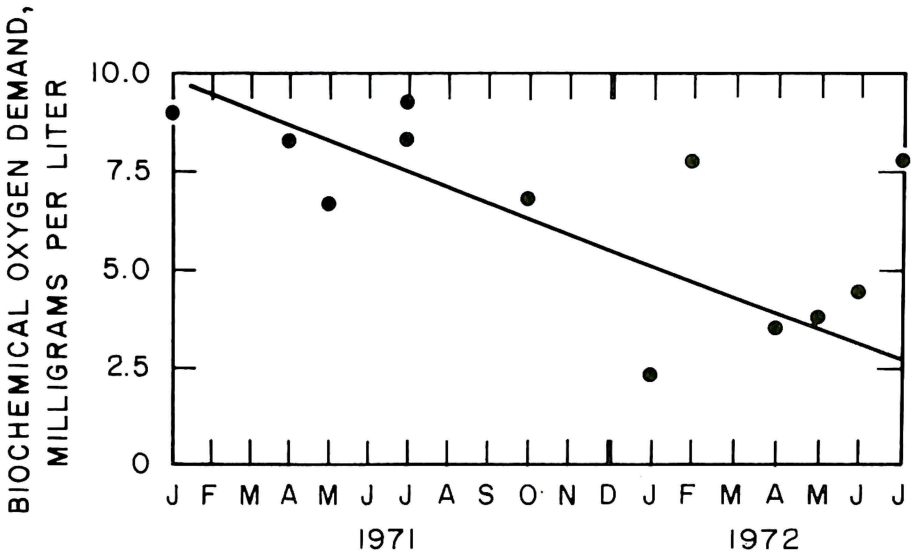


Figure 9 Discharge and concentrations of ammonium (NH_4 - N) and phosphorus in Plantation Canal 1971-72.



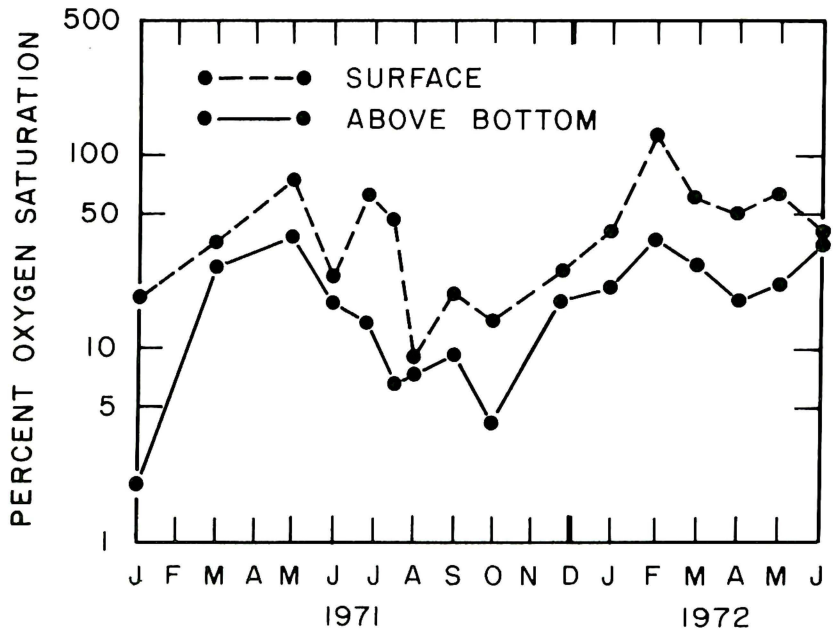


Figure 10 Relationship between biochemical oxygen demand concentrations in Plantation Canal and average percent oxygen saturation at sites 14A and 14B 1971-72.

bottom which forms carbonic acid in water. A pH as high as 8.4 near the surface was common during algal blooms and near submersed plants because of high uptake of carbon dioxide.

AQUATIC PLANTS AND ANIMALS

The plant communities in Plantation Canal consisted chiefly of floating aquatic plants, whereas those at the control site was chiefly submersed.

Plantation Canal is characterized by luxuriant growth of common duckweed, *Lemna minor*, water lettuce, *Pistia stratioites*, and water hyacinths, *Eichhornia crassipes.* The luxuriant growth is the result of an abundant supply of nutrients. The control site had a small population of water hyacinths during 1 month of the study period.

The submersed aquatic plant community in Plantation Canal is composed chiefly of coontail, *Ceratophyllum demersum*, and smaller populations of Florida elodea, *Hydrilla verticillata,* stonewort, *Chara* sp., *Pithophora* ap., and *Chladophora* sp. These plants were found only near the shore line. The submerged plant community at the control site extends farther from the shore due to a large littoral zone. Here, large populations of southern naiad, *Najas guadalupensis,* and Florida elodea are found, indicating better water quality.

The plantonic blue-green alga, *Anacystis* sp. may reach high concentrations and color the water a light green in Plantation Canal.

The frequency of luxuriant growths of floating aquatic vegetation in Plantation Canal seemed to decrease from February 1972 to June 1972. Its littoral zone increased in size and was composed of submersed aquatic plants and the benthic alga, *Chladophora* sp. which covered the bottom to the quarter section. The mosquito fish, *Gambusia affinis,* was present throughout the study and was greatest in number during March - June 1972. These fish, apparently tolerate the toxic substances in water, and have the ability to obtain sufficient oxygen in the thin film of water at the surface. Larger fish seen by the author were confirmed by local fishermen to be tarpon, *Megalops atlantica.* These fish apparently enter the canal when DO is high and flee into tributary canals and ponds when DO is low.

BOTTOM SEDIMENTS

The bottom sediments of a body of water reflect the physical and chemical nature of the overlying waters. Bottom sediments from a clean body of water resemble the soils of the surrounding area, while those of a polluted body

of water assume the characteristics of the contaminants entering the water (McKee and others, 1970).

Bottom sediment samples were collected at selected sites in Plantation Canal and the control site on South New River Canal. Particle size determinations were made from the top stratum of core samples. Samples collected by Ekman dredge were analyzed chemically. Care was taken to include only the upper 3 inches of bottom sediment. The average length of the cores obtained from Plantation Canal was 5 inches. Each core had an upper stratum of black organic sediment, and a lower stratum composed chiefly of sand. Thirty-two percent of the upper stratum of all bottom sediment samples in Plantation Canal and fifty-six percent of the control site were composed of silt and clay particle size materials. In general, sediments from station 14B, 14C, and 15 in Plantation Canal were characterized by noxious odors, dark black color and a fine texture.

TABLE 6
PERCENTAGE OF SELECTED PARTICLE SIZES OF BOTTOM SEDIMENTS IN PLANTATION CANAL AND SOUTH NEW RIVER CANAL ABOVE S-13A

Location	Percentage of Particle Size			
	gravel >2	sand 0.062-2.0	silt 0.062-0.004 (Millimeters)	clay (>0.004)
Plantation Canal	2	56	28.6	3.4
South New River Canal above 13-A	1.1	42.9	43.2	12.8

CHEMICAL CHARACTERISTICS

The chemical constituents analyzed in the bottom sediments were organic carbon, organic nitrogen, exchangeable ammonium and total phosphorus (fig. 11). The percentage of organic carbon and nitrogen in Plantation Canal ranges from 0.03 to 13 percent and 0.02 to 0.95 percent, respectively. Percentage of organic carbon and nitrogen were slightly higher than at the control site on the South New River Canal.

The sample from site 14 had the highest average concentration of organic carbon and nitrogen in Plantation Canal. The bottom sediment at this site is

composed of decaying organic detritus from floating aquatic plants. The aquatic plants are wind driven into this section of the canal where they eventually die and sink to the bottom. The concentration of organic carbon and nitrogen at site 14 was higher than at site 14A during the June sampling, but was the opposite during the August 1972 sampling (fig. 11).

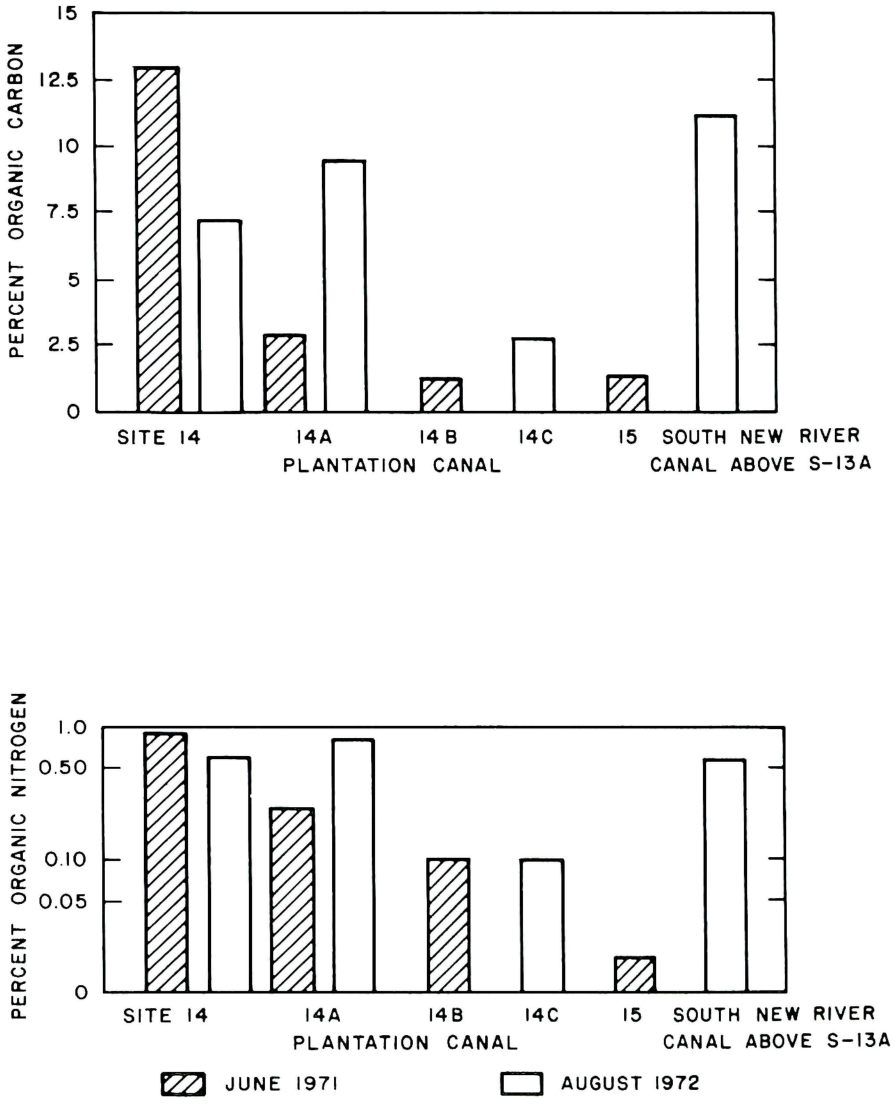


Figure 11 Percentage of organic carbon and nitrogen in bottom sediments of Plantation Canal and South New River Canal above S-13A.

Although the bottom sediments at the control site contain considerable amounts of exchangeable ammonium, nitrogen and phosphorus (fig. 12), the highest concentrations of both were at sites 14 and 14A in Plantation Canal. These high concentrations were due to the proximity of these sites to higher sewage effluent and organic plant detritus.

Additional constituents analyzed in the bottom sediments included iron, aluminum, manganese, mercury, lead, copper and volatile solids (table 7).

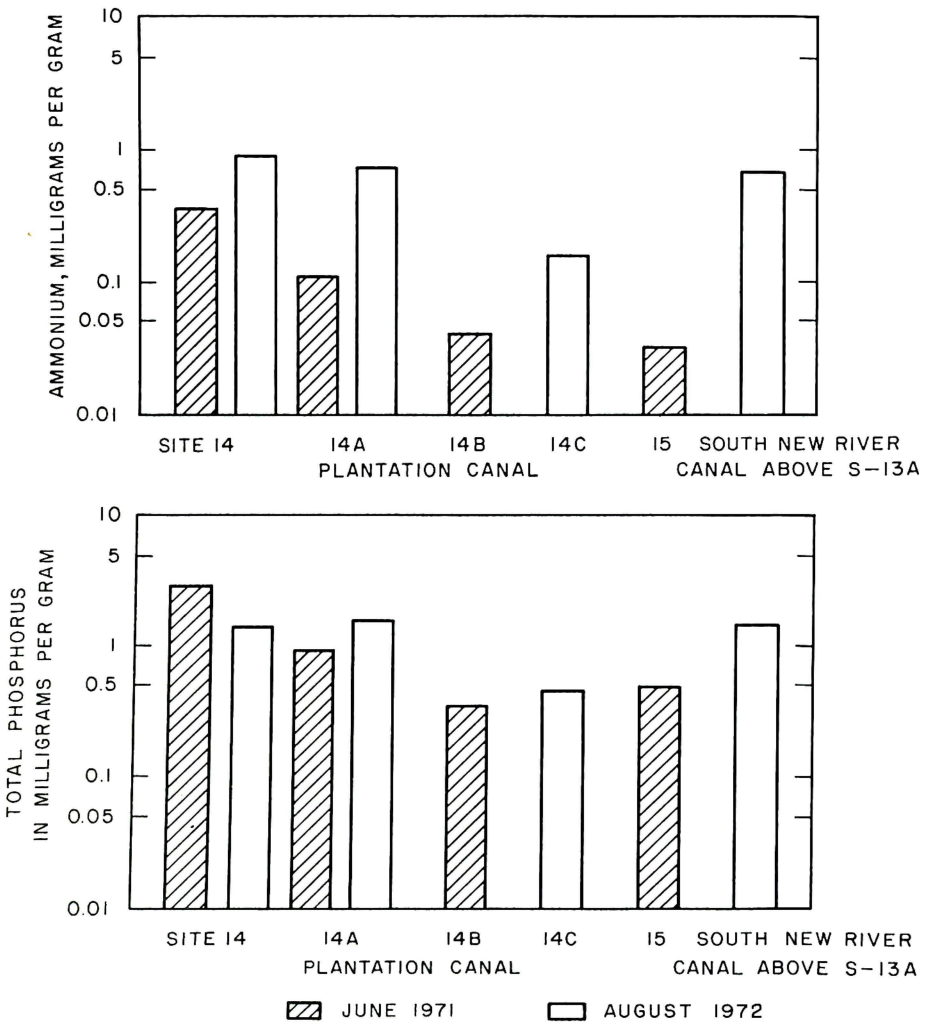


Figure 12 Ammonium and phosphorus concentrations in the bottom sediments of Plantation Canal and South New River Canal above S-13A.

TABLE 7. CONCENTRATIONS OF METALS IN THE BOTTOM SEDIMENTS OF PLANTATION CANAL AND SOUTH NEW RIVER CANAL ABOVE S-13A

Site	Date	Aluminum (ug/g)	Manganese (ug/g)	Iron (ug/g)	Copper (ug/g)	Mercury (ug/g)	Lead (ug/g)	Zinc (ug/g)	Chromium ug/g)	Volatile Solids (mg/g)
14	6-13-71	480	0.0	1,500	-	0.11	-	-	-	-
	8-27-72	190	18.	8,120	55	.00	130	210	29	135
14A	6-13-71	440	8	1,900	-	1.4	-	-	-	-
	8-29-72	3,190	28	11,100	81	.16	160	360	37	27
14B	6-13-71	160	4	760	-	-	-	-	-	-
14C	8-29-72	370	9	2,070	24	.08	1,110	200	180	44
15	6-13-71	8	12	1,500	-	1.3	-	-	-	-
Above 13A	8-29-72	1,800	86	15,800	38	.08	44	90	11	216

NUTRIENT RELEASE

Since the bottom sediments contain considerable amounts of nitrogen and phosphorus they are a potential source of plant nutrients. Phosphorus can exist in the sediment as calcium phosphate (apatite), organic phosphorus and in complex forms with metals such as iron, manganese, and aluminum (Serruya, 1971). Correlation coefficients (r) of phosphorus with inorganic carbon (as calcium carbonate) and with organic carbon were very good (r = 0.97 and 0.89) and suggest that the occurrence of phosphorus is clearly related to the occurrence of carbon compounds, (fig. 13). Additional correlations between phosphorus and the metals, iron, manganese, and aluminum (r = 0.92, 0.82, 0.89, respectively) indicate a similar occurrence-association with these metals, (fig. 14).

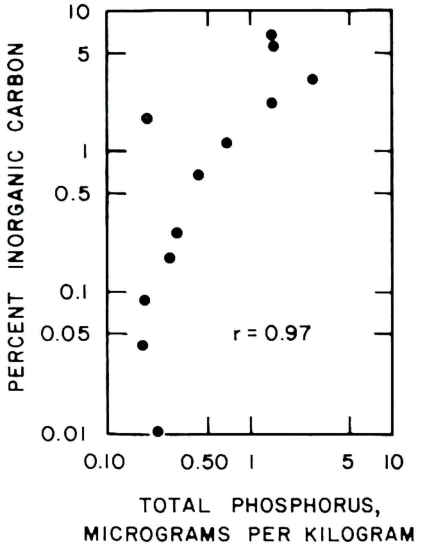
When the dissolved oxygen concentration decreases to less than 1.0 mg/l at the mud-water interface, iron and manganese are released into the water (Mortimer, 1971). Since phosphorus is held in a complex form with these constituents, all three are released into the overlying water in soluble form and may become available to aquatic plants (Mortimer, 1971). The low DO levels in Plantation Canal at the mud-water interface imply that phosphorus could be released into the over-lying canal waters. On the other hand, the bottom sediments at the control site probably contribute little phosphorus to the canal water by the mechanism, because dissolved oxygen concentrations are rarely less than 3 mg/l at the mud-water interface.

Brezonik and others (1969) placed bottom sediments from Anderson-Cue Lake in bottles and monitored ammonium and orthophosphate concentrations in the water. They found that considerably greater amounts of ammonium and orthophosphate were released under anoxic conditions than oxygenated conditions. Mixing or stirring the sediments with the water allowed still more ammonium and orthophosphate to leach into the water. During periods of high flow in Plantation Canal the bottom sediments may become mixed and thus contribute considerable quantities of nutrients to the canal waters. Mechanical operations used to remove aquatic plants also disturb the bottom and accelerate nutrient release.

PESTICIDES

Pesticides enter bodies of water with runoff, waste discharges, by direct application to control unwanted plant and animal pests, rainfall and dustfall, (Willrich and Smith, 1970).

Typically only trace amounts of pesticides were found in the waters of Plantation and South New River Canals because pesticides are virtually in living



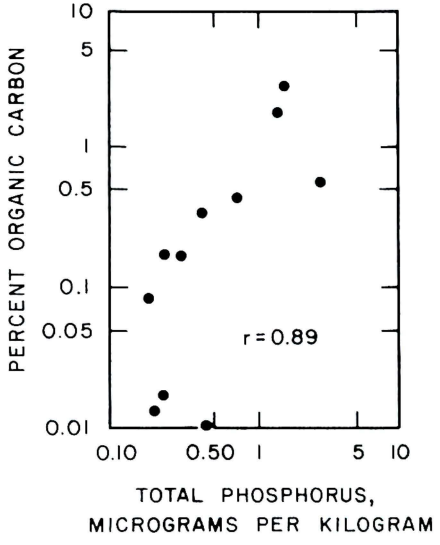
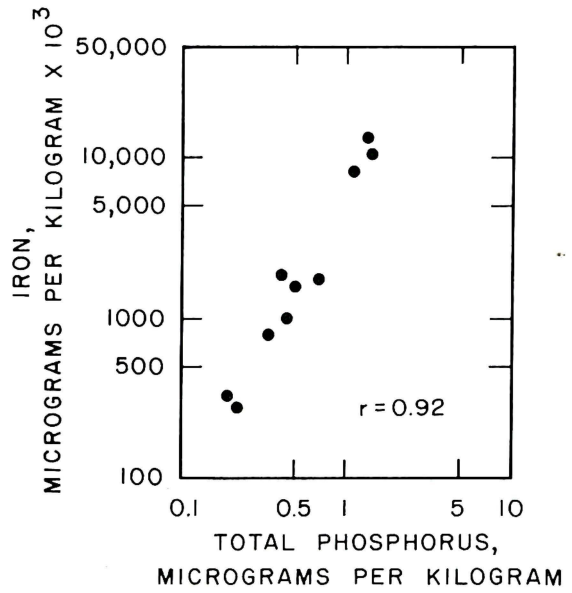


Figure 13 Inorganic and organic carbon versus phosphorus in the bottom sediments of Plantation Canal and South New River Canal above S-13A.



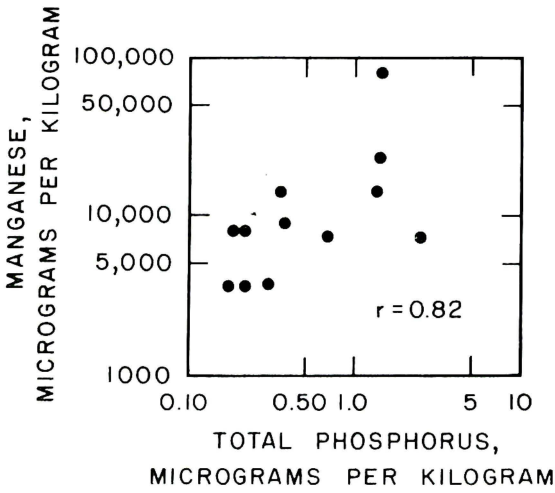


Figure 14 Iron and manganese versus phosphorus concentrations in the bottom sediments of Plantation Canal and South New River Canal above S-13A.

organisms (Klein and others, 1970). The average concentration of the DDT family (DDT, DDE, DDD) in the bottom sediments in Plantation Canal was 15.7 ug/kg (micrograms per kilogram) for 10 samples, compared to 0.86 ug/kg for 6 samples at the control site in South New River Canal. Samples in Plantation Canal were obtained by Ekman dredge from the middle of the canal; samples at the control site were usually obtained near shore.

The average dieldrin concentration in 10 water samples from Plantation Canal was 0.033 ug/l (micrograms per liter); its average concentration in 10 samples of bottom sediment was 27.9 ug/kg. In each of six samples of water from the control site, only a trace of dieldrin was found.

The principal herbicides found in the water and bottom sediments in the study area are 2, 4-D, and silvex. Diquat (2, 4-D; 6, 7-dihydrodipyrido 1, 2-a; '1' - c pyrazinediium salts) and 2, 4-D amine, are used to control aquatic weeds in the canals; 2, 4, 5-T is not used in the area (Browning 1972, written communication).

The herbicides not only enter the water directly from the spray but also from the dying plants that sink to the bottom of the canal.

Polychlorinated biphenyls (PCB's) are used to manufacture plastics, resins, and are also used with pesticides to extend the kill life of the formulation. PCBs are more resistant to degradation than DDT and its derivatives; their biological effects are unknown. Hammon (1972) indicated that industrial dumps and sewage effleunts are sources of these materials.

PCBs were not detected in the waters of Plantation Canal but were found in the bottom sediments; their concentrations ranged from 0 to 568 ug/kg in 8 samples. PCBs and the DDT family of compounds are also concentrated in food chains as indicated by Meyer and Wimberly (1971) (fig. 15).

CLASSIFICATION OF BOTTOM SEDIMENTS

Ballinger and McKee (1971) developed an OSI (Organic Sediment Index) to characterize the bottom sediments. The OSI is the product of the percent organic carbon and nitrogen in the bottom sediments. The OSI was calculated for each site each time a sample was taken (fig. 16).

The highest OSIs were found at sites 14, 14A, 14C and the control site. These bottom sediments are in a state of active decomposition and are composed of organic detritus and sludges. The bottom sediments also exhibit a very high chemical oxygen demand (table 8) and a potential for high nutrient release. The

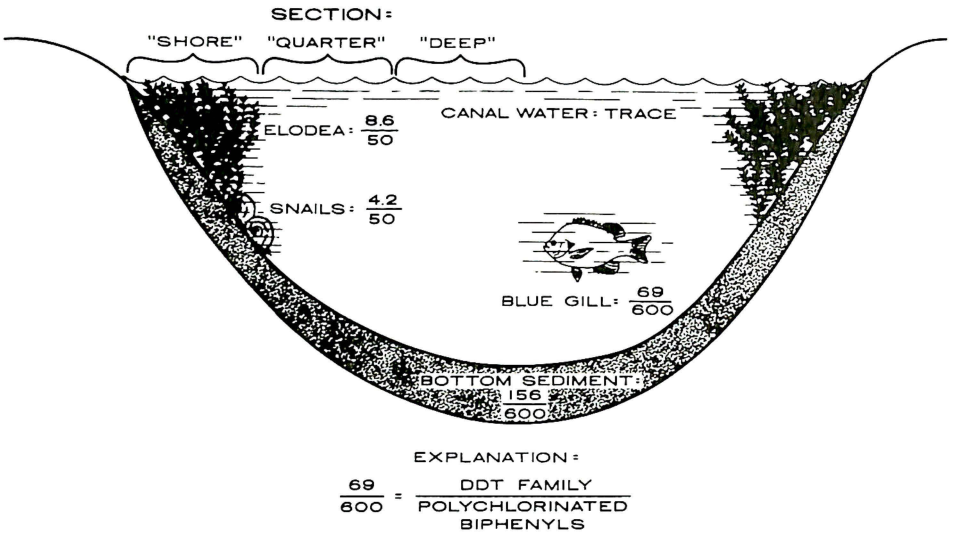


Figure 15 Biological magnification of the DDT family (DDT + DDE + DDD) and Polychlorinated Biphenyls in the Miami Canal. Values for water are given in micrograms per liter and for biota and bottom sediments in micrograms per kilogram (after Meyer and Wimberly, 1971).

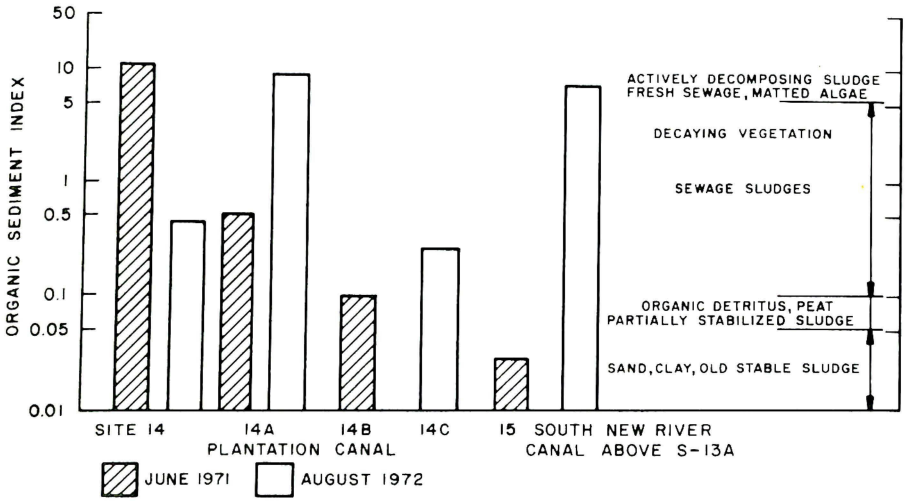


Figure 16 Organic sediment index in Plantation Canal and South New River Canal above S-13A.

bottom sediments at sites 14B and 15 in Plantation Canal are made up of stabilized sludges and inorganic matter. They exert a chemical oxygen demand and have a potential for nutrient release, but on a smaller scale (table 8).

TABLE 8.
CHEMICAL OXYGEN DEMAND IN THE BOTTOM SEDIMENTS IN PLANTATION CANAL AND SOUTH NEW RIVER CANAL ABOVE S-13A

Canal	Site	Chemical oxygen demand (micrograms per kilograms)
Plantation Canal	14	120,000
	14A	187,000
	14C	53,000
South New River Canal	above S-13A	250,000

The OSIs in figure 16 are helpful in locating the primary sources of contamination in the canal. One source is the East Holloway Canal which runs perpendicular to site 14 (fig. 2). Waste water from a sewage plant is discharged into this canal. The discharge flows into Plantation Canal through a culvert. During June 1971, the OSIs between sites 14 and 14A decreased from 10.1 to 0.5. The OSI was high at site 14 because the sediments were composed of decaying organic detritus. The decrease between these sites was due to the sedimentation of sewage particulates and green plants between the sites. Farther downstream at site 14B, the OSI decreased slightly due to the distance from a source of detritus. The OSI at site 15 was the lowest in the canal due to the proximity of the site to the salinity control structure S-33. During discharge the bottom sediments at this site are probably flushed into the North Fork New River. In August 1972, the OSI values between sites 14 and 14A did just the opposite; they increased from 0.48 to 9.0. This may be due to greater stabilization of the organic detritus at site 14 and increased productivity in the overlying waters at site 14A. The OSI at site 14C was 0.30; sewage effluent is discharged immediately downstream from the site.

Bottom sediment at the control site on the South New River Canal exhibited a high OSI value of 6.8 similar to site 14A. The OSI at the control site is high because of great productivity in the water and leaf litter contributed by terrestrial plants.

BENTHIC ORGANISMS

Just as the bottom sediments reflect the quality of the overlying waters, the composition of benthic organisms is an indicator of the physical and chemical characteristics of both the bottom sediments and the overlying water.

In general the benthic animals in Plantation Canal are tolerant of moderate to gross organic contamination (Beck, 1969). The most common animals found were the sludgeworm, *Tubifex tubifex,* and bloodworms, (Chiromonid larvae). These animals comprise 92 percent of the bottom community in Plantation Canal and are found in concentrations as high as 4,000 per M^2 (square meter). The pollution tolerant forms in Plantation Canal are adept at surviving at DOs as low as 0.85 mg/l for extended periods of time. According to Pennak (1953), a small percentage of a sludgeworm population survived 120 days under anoxic conditions. In the deep section samples in Plantation Canal sludgeworms were more abundant than bloodworms. Both are able to remain above the bottom sediment and avoid suffocation because of their wormlike form; a characteristic of pullution tolerant organisms and those living in muddy sediments. The life cycle of the bloodworm is generally on the order of 32 days (Hall and others, 1970) and the life cycle of sludgeworms may be even less. These short life cycles enable the animals to reproduce rapidly when stream conditions improve temporarily.

Phantom midge larvae, *Chaoborus* sp. were found only in the deep section samples. They tolerate moderate contamination. These animals migrate to the water surface at night and return to the bottom sediments during the day (Pennak 1953). Thus, they are not subjected continuously to adverse bottom conditions.

The majority of animals collected near the shore cannot tolerate the low DO and the muddy substrate found in the deeper sections of the canals. Scuds (amphipods) were found near the shore and were closely associated with submersed vegetation. DO ranged from 2 to 5 mg/l near the shore and the bottom sediments were composed chiefly of sand and rock. In addition, leeches, mayflies, damsel fly nymphs and dragon fly nymphs were also found near the shore during March - June 1972. Sludgeworms and bloodworms were also found near the shore. The population of bloodworms was greater than the sludgeworms. The larvae of the flower fly, *Tubifera* sp., called "rat-tailed

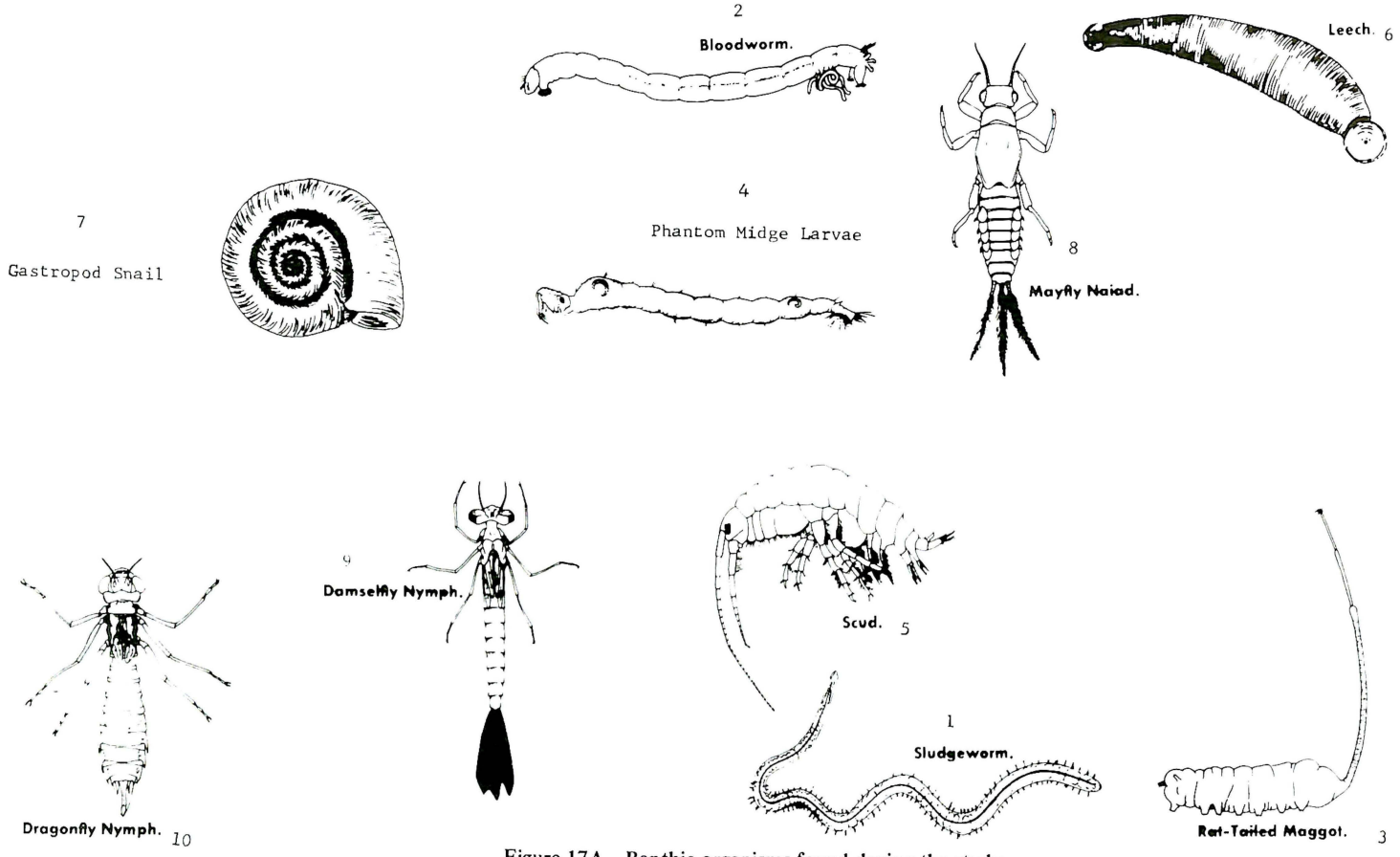


Figure 17A. Benthic organisms found during the study.

maggots" were collected at sites 14C and 15 from October 1971 to January 1972. These larvae are often found in septic water near the shore line where they feed on organic matter in the sediments and project their respiratory tubes (tails) above the surface. These animals made up 100 percent of the bottom community at each site at the time of sampling when DO near the surface and above the bottom was 0.2 mg/l and 0.0 mg/l, respectively. The rat-tail maggots are able to survive adverse conditions because they obtain oxygen from the atomosphere. They were not present at the control site on South New River Canal.

Most of the animals at the control site on South New River Canal were bloodworms and sludgeworms, collected chiefly from the deep and quarter section samples. They constituted 65 percent of the bottom community; numbers rarely exceeded 1,800 per M^2. The bottom zones are composed of fine sands and silts which constitute 75 percent of the bottom area. The animals are able to tolerate both of soft substrate and organic contamination.

Other aquatic insects collected from the deep section were the dipteran larvae *Chaoborus* sp. and *Ceratopogon* sp. The dipteran larvae comprised 8 percent of the benthic community, and tolerate a moderate amount of organic

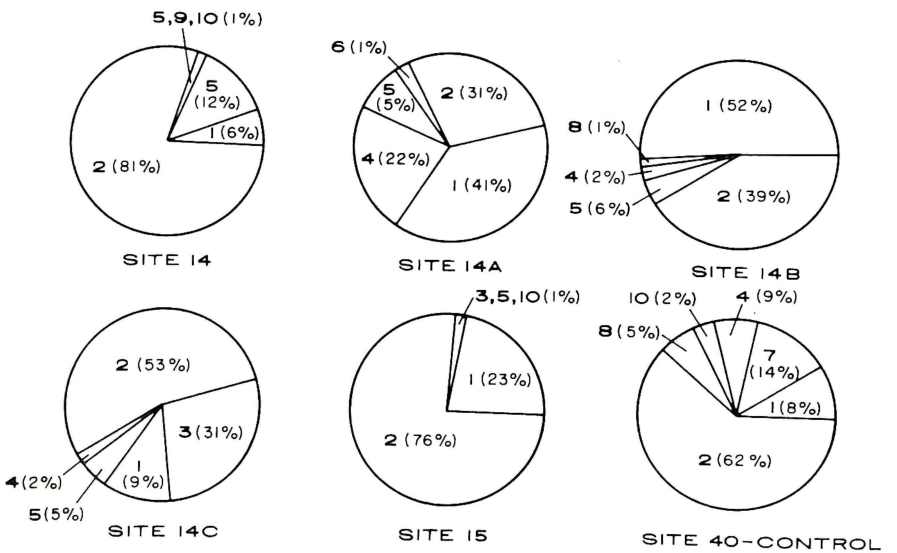


Figure 17B. Percentage composition of benthic organisms present at each site in Plantation Canal and South New River Canal above S-13A.

pollution. The mayfly naiad (207 animals per M^2) was collected during March - June 1972.

In the shore section, the snail *Marisa cornuelatus* was collected only during May and June 1972; the snail *Melanoides tuberculata* was collected during the entire sampling program (Russo 1973). Scuds (amphipods), with submersed vegetation were restricted to the shore samples.

Rat-tailed maggots were not found at the control site. They are probably limited by the amount of organic matter in the sediments and competition with other bottom organisms.

In Plantation Canal benthic communities contain large numbers of organisms represented by a few genera, which are able to tolerate moderate to gross organic contamination for extended periods of time. At the control site on the South New River Canal the benthic community contained 7 different genera but smaller populations of animals. The control site supports pollution tolerant forms found in Plantation Canal and, some that do not tolerate any appreciable organic contamination. The non-tolerant animals have relatively long life cycles, require a suitable substrate, and adequate supplies of food and oxygen.

The control site provides non-tolerant benthic organisms with the materials necessary to sustain life. The DO levels above the bottom at this site are high, averaging 3.3 mg/l. The bottom sediments in this area, chiefly fine sand, provide a suitable substrate for these animals to live in or on. Food is also abundant in the form of plant detritus and algae. The absence of these non-tolerant benthic organisms in Plantation Canal during most of the study indicates that DO levels, averaging 0.85 mg/l above the bottom are too low to sustain them. The bottom sediments in Plantation Canal are finely divided clay sized particles and most animals would sink in them and suffocate. Finally, the toxicity of high concentrations of ammonium-nitrogen and carbon dioxide would make living on or in the bottom sediments impossible.

Marisa cornuelatus and *Melanoides tuberculata* were present in the shore section at the control site but absent in Plantation Canal due chiefly to the low DO levels above the bottom and the unsuitable substrate.

BIOTIC INDICES

To relate the distribution and variety of the biota to the chemical and physical characteristics of the body of water being studied, a Biotic Index was computed from the biological data. This index, a numerical rating of the cleanliness of a body of water with respect to organic contamination, was devised by Beck (1969).

He categorized species of organisms that tolerate no appreciable organic contamination as Class 1 and the species that tolerate moderate organic contamination but cannot exist under near anaerobic conditions as Class 2. The index is computed as follows:

$$\text{Biotic Index} = 2\,(\text{n Class 1}) + (\text{n Class 2})$$

where n equals the number of different species present.

The hypothetical range of the Biotic Index may vary from zero to 40 and is broken down into three classifications. A biotic index of 10 or more is indicative of a clean stream; a moderately contaminated stream will have an index of 1 to 10 and a grossly contaminated stream will have an index less than 1. The following organisms were rated by the author as Class 2 indicators, *Melanoides tuberculata, Marisa cornuelatus,* the phantom midge *Chaoborus* sp., and leeches.

A Diversity Index was also determined, using a method of Patten (1962):

$$\text{Diversity Index} = (S\text{-}1)\ 1n\ N$$

where S is the number of different species in the sample and N is the total number of animals present. The diversity index is based upon two postulates: (1) clean water communities are composed of many different species which are not found in great numbers (high diversity), and (2) a contaminated body of water is characterized by a community composed of a few different species which are very abundant (low diversity).

The Biotic Index is a numerical rating based on the qualitative composition of the community while the Diversity Index is strictly a quantitative measurement.

Both the diversity index and the biotic index are dependent on a representative sample of the benthic populations present at each site. Since only 3 Echman dredge samples were collected at each site, important animals may be missed in sampling and populations of these animals in the samples may not have been representative. Therefore, both indices must be used with caution.

The biotic index values in Plantation Canal averaged 1 and ranged from 0 to 5 over the study period (fig. 18). The average biotic index value at the control site on South New River Canal was 5 and ranged between 1 and 7. Plantation Canal exhibits a biological zonation, according to the index values (fig. 18). The biotic indices for sites 14, 14C and 15 were all zero.

The diversity indices at sites 14, 14C and 15 ranged from 0 and 0.20. Sites 14A and 14B were characterized by higher indices ranging from 0.10 to 0.33. The diversity index at the control site on South New River Canal were higher,

0.2 on the average, and ranged from 0.10 to 0.60. The diversity indices at the study sites are low compared to 1.5 obtained from a canal in the conservation areas (Waller 1973 oral communication). These diversity indices are in accord with the biotic index values and reaffirm the zonation of the Plantation Canal.

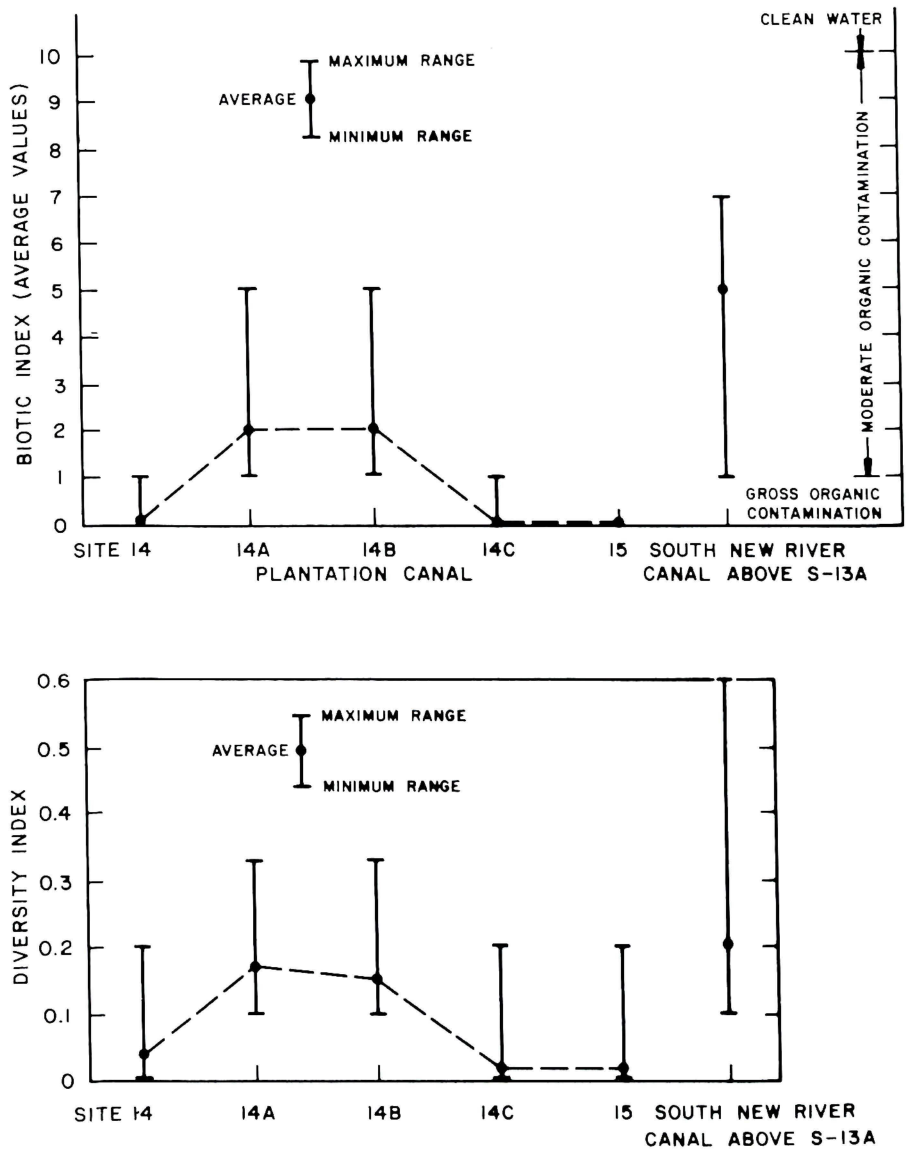


Figure 18 Biotic and diversity index values in Plantation Canal and South New River Canal above S-13A.

Plantation Canal improved slightly during the last 5 months of the study because of increased discharge from January 1972 to June 1972. In regards to water quality, the nutrient and BOD concentrations decreased and DO levels at sites 14A and 14B increased slightly (fig. 10). During this time the biotic and diversity indices reached peak values of 5 and 0.33 respectively, at these sites (fig. 18).

SUMMARY AND CONCLUSIONS

The principal source of the organic materials in Plantation Canal is effluent from sewage treatment plants. As a consequence the waters of Plantation Canal contain large quantities of oxygen demanding wastes and plant nutrients. During the first 10 months of the study these wastes accumulated in the canal because the canal did not flow.

The DO content of the water in Plantation Canal is extremely low because of high BOD and high nutrient concentrations and probably reach zero just above the bottom sediments. When conditions are anoxic, anerobic decomposition produces objectionable odors.

The high concentrations of nutrients result in luxuriant growth of algae and floating aquatic plants. These plants may discolor the water, inhibit flow and exert an oxygen demand when respiring and undergoing decomposition.

FC/FS ratios indicate the existence of human waste in Plantation Canal, and, hence the possible presence of pathogenic bacteria.

The bottom sediments in both Plantation Canal and South New River Canal above S-13A exert an oxygen demand upon the overlying waters. They also contain high levels of plant nutrients, metals and pesticides that may be released into the overlying waters.

Nutrients may also be released in both canals when the DO content falls below 1.0 mg/l at the mud-water interface. This probably occurs frequently in Plantation Canal and rarely at the control site in South New River Canal.

The bottom sediments in Plantation Canal are composed of highly decomposed and stabilized sludges. On the basis of the OSI the bottom sediments at sites 14, 14A, 14C and at the control site have a potential for high nutrient release and high oxygen demand.

The composition of the benthic communities reflected the quality of the bottom sediments and overlying waters. The communities in Plantation Canal

were composed of a few genera represented by large numbers of organisms (low biotic and diversity index values). The communities at the control site on South New River Canal had a greater number of different genera represented by a smaller number of organisms (greater biotic and diversity index values). The biotic and diversity indices indicated that Plantation Canal experienced moderate to gross contamination during the entire study particularly the stream reach east of Highway 441 and at site 14. A slight increase in the biotic and diversity indices at sites 14A and 14B was noted during the last few months of the study presumably because of an increase in flow. The increased flow tended to reduce BOD and nutrient content and to increase DO resulting in an improvement in the overall water quality of the canal.

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