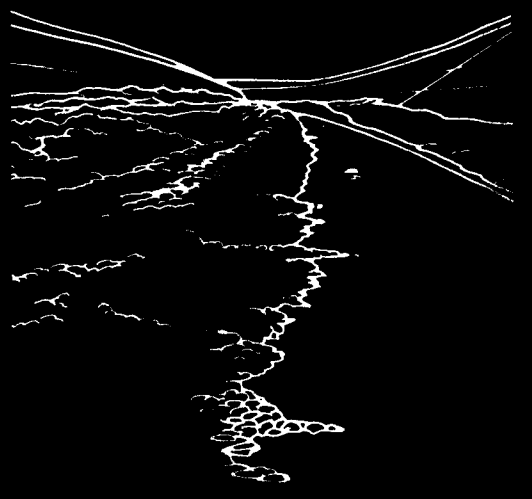

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A Water Resources Technical Publication

RESEARCH REPORT NO. 20

United States Department of the

INTERIOR

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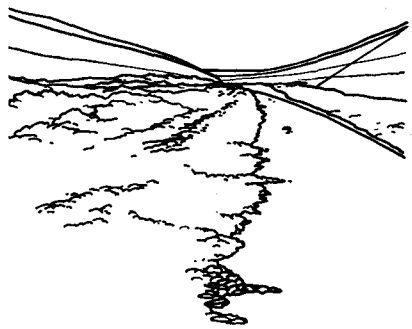

Biogeochemistry of Delta-Mendota Canal, Central Valley Project, California

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PREFACE

The Delta-Mendota Canal of the Federal Bureau of Reclamation is one of the larger concrete-lined canals in California. Periodic dewaterings of the canal and several capacity tests have revealed an extremely abundant benthos and related widespread sedimentation, which combine to significantly decrease canal capacity. Periodic mapping and sampling of sediments and benthos during several dewaterings were conducted in order to provide a better understanding of canal siltation and biota and to create a proper foundation for more systematic future studies.

Because of the large impact of organic life—such as clams, amphipods, and sponges—on sedimentation, a biogeochemical study of the sediments and organisms was initiated during the 1965–66 dewatering. The results of this study are reported herein. The information could be of value in deciding on methods for best controlling the organic growths.

Studies of this type are not common in engineering practice, and this report might serve as a prototype. It is hoped particularly that the findings would contribute to an improved understanding of any present or future water resource development related to the Sacramento-San Joaquin River Delta, such as the joint Federal-State San Luis Canal, the proposed Peripheral and East Side Canals, the California State Aqueduct, and others.

Included in this publication is an informative abstract and list of descriptors, or keywords, and identifiers. The abstract was prepared as part of the Bureau of Reclamation's program of indexing and retrieving the literature of water resources development. The descriptors were selected from the *Thesaurus of Descriptors,* which is the Bureau's standard for listings of keywords.

Other recently published Water Resources Technical publications are listed on the inside back cover of this research report.

ACKNOWLEDGMENTS

The work was done under U.S. Bureau of Reclamation Contract 14–06–200–2596A at the University of Minnesota. Gunta V. Pakalns prepared most of the canal samples for study and analyzed the samples for amino acids and carbohydrates. Inara Porietis carried out most of the hydocarbon analyses and Shirley A. Kraemer prepared the pigment analyses. Judy M. Bratt, George A. Sellers, and James R. Neihaus assisted in various phases of the laboratory work. Donald J. Hebert and others of the Bureau of Reclamation provided assistance and advice. The writers express appreciation and thanks to all these organizations and individuals.

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SUMMARY

During the winter dewatering period of the canal in 1965, bottom sediments and canal organisms were collected at 17 stations between mile posts 4.7 and 79.1. Field readings were made of hydrogen-ion concentration, oxidation-reduction potential, and oxygen content of the sediments, water, and canal organisms.

The oxygen content of the water shows that it was well aerated (10–13 mg/L), that of the upper part of the sediment and of accumulations of *Corbicula fluminea* was variable but generally low (1–7 mg/L) showing poor aeration. The lower values of 1–3 mg/L are accompanied by low positive or negative oxidation-reduction potentials (Eh), which show that reducing conditions and oxygen-depletion caused by bacterial activity prevail in these sediments. The hydrogen-ion concentration (pH) values of the water show that they are neutral to somewhat alkaline (7 to 8.45). The pH values of the sediments are generally slightly alkaline (7 to 8.05).

The hydrocarbons and other lipids of the canal organisms and sediments were extracted with benzene and methanol and were separated by column chromatography and gas chromatography. The saturated hydrocarbon fractions of both sediments and organisms are generally very small in amount, ranging from 0 to 18 percent of the extract, which itself is .04 to 5.15 percent of the wet sample. The aromatic hydrocarbons range from 0 to 18.51 percent of the extract.

The carbon and nitrogen contents of various canal materials range as follows:

	C percent	N percent
Corophium	30. 91	7. 52
Corbicula (soft body)	45. 07–48. 28	7. 50–11. 78
Sponge	23. 98	4. 73
Gnorimosphaeroma	30. 45	6. 10
Bottom sediments	1. 23–4. 18	>0. 02–0. 53

These values are more or less normal for both animals and sediments.

Gas chromatographic analyses of the saturated hydrocarbon fraction of *Corbicula fluminea* (Asiatic clam) showed the probable presence of small amounts of these hydrocarbons in the range C_{16}–C_{28}. The saturated hydrocarbons of a sample of sponge (*Spongilla sp.*) from the canal possibly included those in the range C_{16} to C_{32} or C_{33}, in addition to which there are other components, possibly including branched alkanes and cycloalkanes that could not be specifically identified. The saturated hydrocarbon contents of the bryozoans *Plumatella sp.* are low, including possibly some C_{16}–C_{18} compounds. The sediments associated with *Corbicula* seem to have little or no separable aliphatic hydrocarbons in most of the samples; one bottom sediment sample, however, yielded a large fraction of possible C_{26} and smaller portions of C_{21} to C_{28} compounds. Aromatic hydrocarbon fractions of both organisms and sediments yielded little or no additional fractions by gas chromatography.

The asphaltic and polar compound fractions of the benzene-methanol extracts, consisting mainly of chlorophyll-derived pigments, make up 80–98 percent of the extracts. The data emphasize the high organic productivity of the canal waters.

The chlorinoid pigment content of the sediments obtained by 90 percent acetone extraction is high (12–52 sedimentary chlorophyll degradation units per gram of sediment) and remains at high levels or increases down the canal. This points to the good preservative conditions for the organic debris in the canal bottom.

The carbohydrate content of the canal organisms extracted with sulfuric acid range from about 3×10^{-4} g/g to 28×10^{-4} g/g, and is about 24×10^{-4} g/g in the associated sediments. These relatively low levels of concentration show that the carbohydrate content of the organisms is low, and that much of it is being preserved in the sediments. Glucose and galactose are the main monosaccharides in *Corbicula*. The sediments contain galactose, glucose, mannose, arabinose, xylose, ribose, and mannose from sources other than *Corbicula*. These supply small but perhaps essential food supplies for organisms living in the sediments.

Protein compounds are plentifully represented in the canal waters by diatoms, other algae, copepods, cladocerans, and other organisms and in the canal sediments by *Corbicula*. The protein amino acids of

canal material were extracted with hydrochloric acid and separated in an amino acid analyzer. All the common protein amino acids are present in *Corbicula, Plumatella, Corophium, Spongilla,* and in *Gnorimosphaeroma.* Cystine is rare or absent in *Corophium* in the upper canal, but increases in amount farther down the canal, probably owing to changing food supplies. As far as can be determined there are few other significant changes in amino acid suites down the canal, except for a slight buildup in glycine.

Infrared absorption spectra were made of the benzene-methanol extracts of canal materials. While analyses of these spectra cannot be made completely at this time, they indicate that the organic acid contents of the organisms and sediments are very large in total amounts. Together with the protein content the organic acids represent a large nutritional source, considering the canal as a whole, that would best be transferred to irrigation areas rather than deposited in the canal.

GENERAL DATA

The Delta-Mendota Canal is one of the larger canals of the Federal Bureau of Reclamation's Central Valley Project in California (figure 2). It is located on the western side of the northern half of the semiarid San Joaquin Valley and extends from the Sacramento-San Joaquin River Delta near Tracy to the Mendota Pool on the San Joaquin River. In past years, during the winter and spring months, the canal was virtually idle. Since 1967, however, this excess capacity has been used to supply water for the San Luis Unit (figure 2).

The Delta-Mendota conveyance system consists of the Delta Cross Channel and associated deltaic channels, the intake channel with a fish collecting facility, the Tracy Pumping Plant with three discharge tubes, and the Delta-Mendota Canal. The canal (figure 1) is 113 miles (181.9 kilometers) long and mostly (95 miles or 152.9 kilometers) concrete lined. The downstream 18 miles are earth lined.

The concrete-lined section is about 100 feet (30.5 meters) wide at the top and 48 feet (14.6 meters) wide at the bottom, with water depth ranging from 16.5 feet (5.0 meters) at the upstream end to 14.03 feet (4.3 meters) at the downstream end. Designed capacity of the canal is 4,600 cubic feet per second (130.3 meter 3/sec.) or 2 million gallons per minute (126,180 liters per second) with an average velocity of 3.8 feet (1.2 meters) per second. The canal has four wasteways and is subdivided into pools by 21 check structures (figure 1).

The system was completed in June 1951. Since that time a steadily increasing water demand has led to a progressive increase of pumpage, particularly during irrigation peak in summer. Several partial dewaterings of the concrete section of the canal in the winters of 1952–53, 1953–54, 1960–61, 1962–63 and 1964–65, revealed highly abundant benthic life and numerous deposits of clam-bearing sediments on the canal bottom.

Regional geology of the canal alignment is uncomplicated. Near-surface deposits in which the canal was dug consist mostly of clayey-sandy oxidized Coast Range piedmont alluvium. The Sacramento-San Joaquin Delta, which serves as the immediate source area for canal water, has been reclaimed from a tidal marsh and has extensive deposits of peat and peaty sediments.

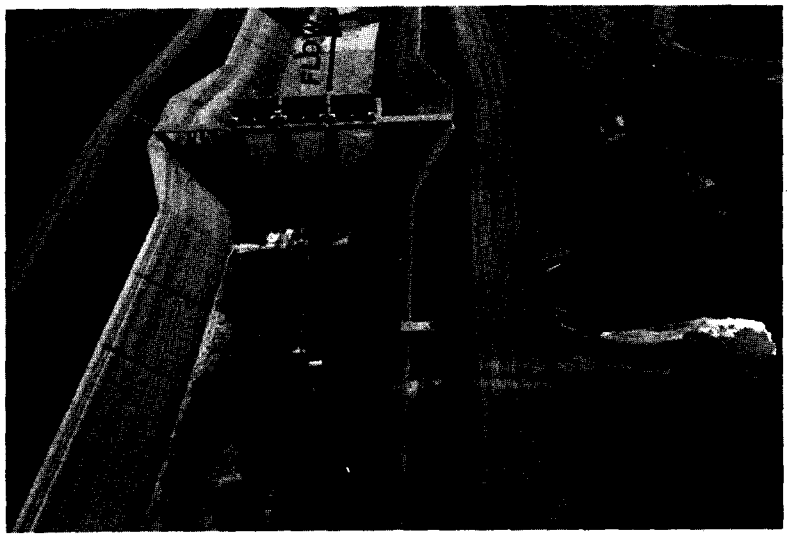

***Figure 1.*—General aerial view of the dewatered Delta-Mendota Canal and a typical check (Check No. 4, M.P. 24.4), with open gates and transition widening at the check. A concrete box drain with a settling basin are on the right canal bank upstream from the check. A bar of clam-bearing sediments on the invert was modified by a trench made by a front-end loader in order to drain shallow water pools behind bars. Concrete bridge (Koste Road, M.P. 24.5) is in the background. January 1963.**

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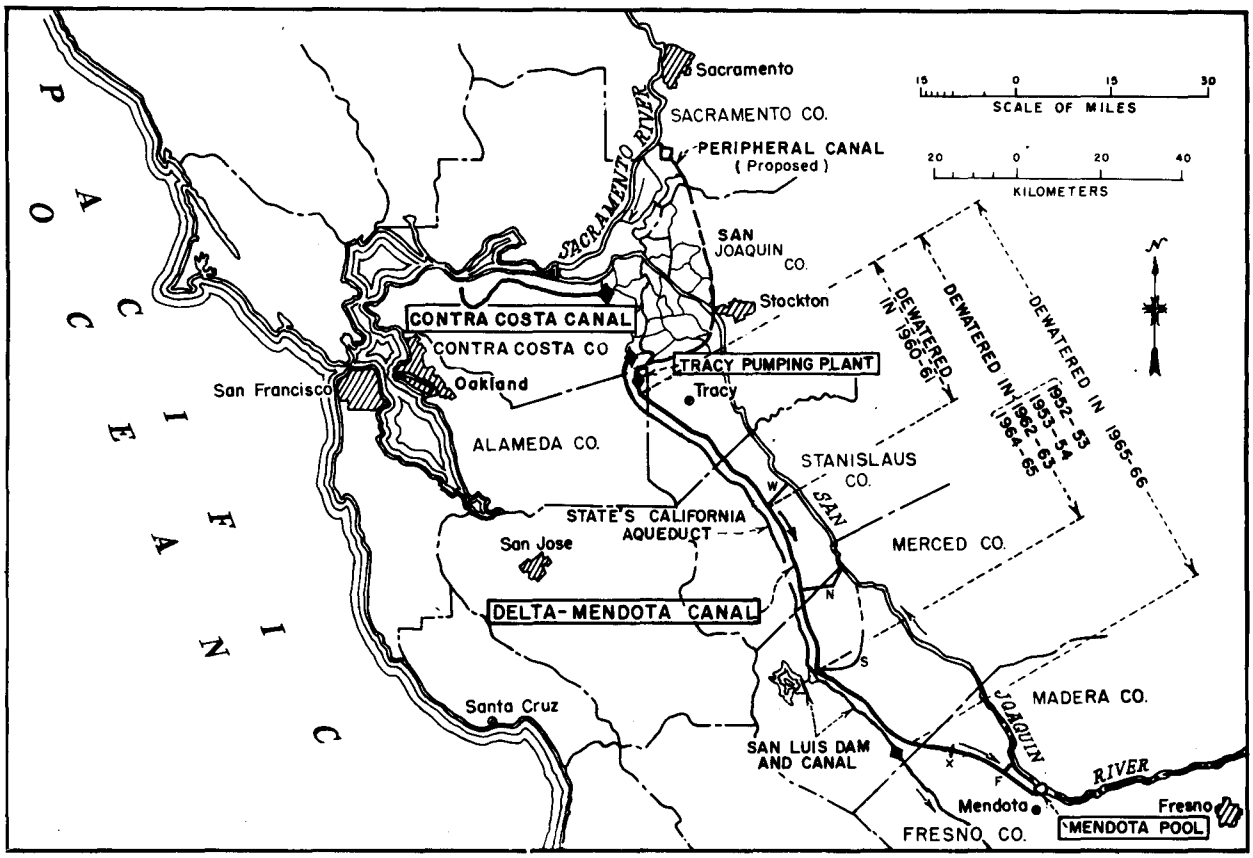


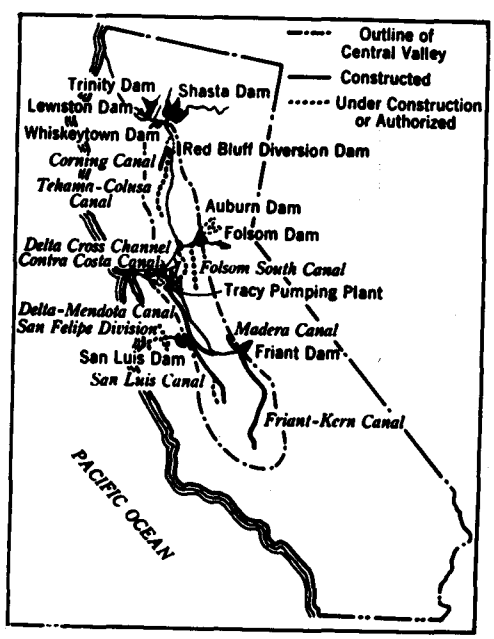


Figure 2.—Central Valley Project, Delta-Mendota Canal, and extent of dewaterings of the canal.

W=Westley Wasteway, M.P. 34.32.
N=Newman Wasteway, M.P. 54.38.
S=San Luis Wasteway, M.P. 69.99.
F=Firebaugh Wasteway, M.P. 111.22.
X=End of concrete-lined section of Delta-Mendota Canal, M.P. 98.64.

CANAL WATER

The primary sources of the canal water are releases from the northern California reservoirs and surplus Sacramento and San Joaquin River flows. The immediate source of the water is the Sacramento-San Joaquin Delta. The slow-moving waters of the Delta, as in most deltas and estuaries, are organically productive. In general, the canal water is of the sodium chloride type. Concentrations (weighted average) of total dissolved solids have been below 450 parts per million. Typical pH values of water are slightly basic (7.1–8.0). Amounts of major chemical constituents (Na^+, Ca^{++}, Mg^{++}, Cl', SO_4'') showed similar cyclic annual variations (figure 3).

Water temperature usually is 45 to 75° F. at the head and slightly higher (up to 80° F.) toward the Mendota Pool. No ice cover ever has been developed on the canal surface.

One of the prominent features of the Delta-Mendota Canal water is its high turbidity, which is related both to erosion of extensive peat deposits in the Delta and to suspended inorganic particles.

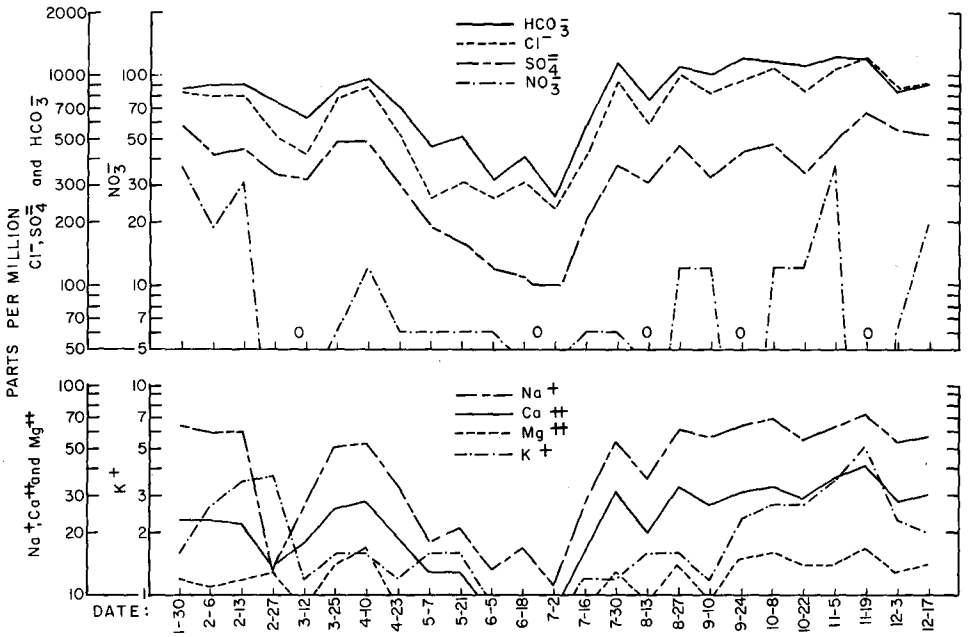


Figure 3.—**Annual changes of chemical composition of the Delta-Mendota Canal water during 1956 near beginning of the canal at M.P. 3.5.**

CANAL BIOTA

Enormous biologic productivity and associated siltation in the canal far exceed anything observed in other Bureau of Reclamation canals. The canal benthos is characterized by a small number of species, which are present in very large populations. Particularly notable is the abundance of "filter feeding" species (Prokopovich and Hebert, 1965).

The most notable benthonic species is the Asiatic clam—*Corbicula fluminea* Müller (figure 4). The mollusk was accidentally introduced into the United States from its native Asia, probably in the mid-1930's, and heavily infested the canal during the first few years of operation. The species has been found on side lining, in trashracks, screens, etc., but was most common in the patches of clam-bearing sediments on the invert (figure 5). Live clams occurred in unbelievably large amounts but only in the aerobic, uppermost 1 to 2 inches of sediments (figure 6, A). No less impressive were biomasses of *Corbicula* (figure 6, B and C).

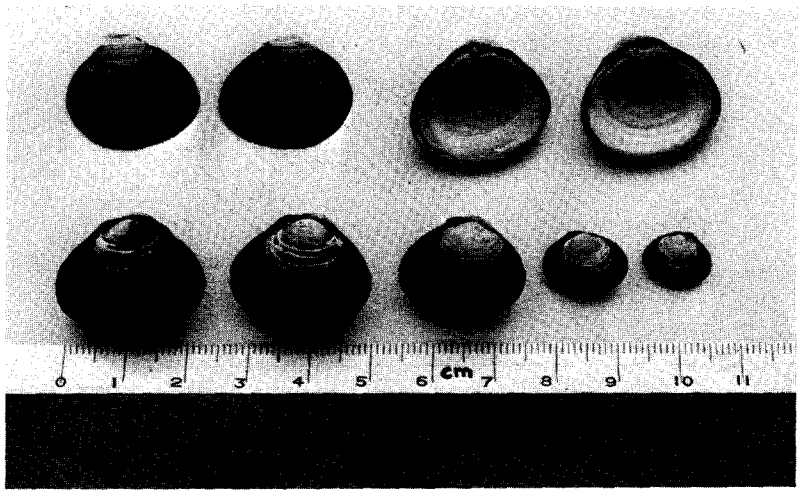


Figure 4.—Corbicula fluminea, **Müller, (Asiatic clam). 1965–66 dewatering at M.P. 54.73. Maximum shell length in the canal up to 6 centimeters, the most common shell length is about 1 centimeter.**

***Figure 5.*—Close-up view of a large, about 3′ thick, bar of clam-bearing sediments on the invert of the Delta-Mendota Canal at M.P. 18.9. Gravelly appearance is caused by abundance of *Corbicula.* A channel at the right was cut by a front-end loader to drain water dammed by the bar. Winter, 1960–61.**

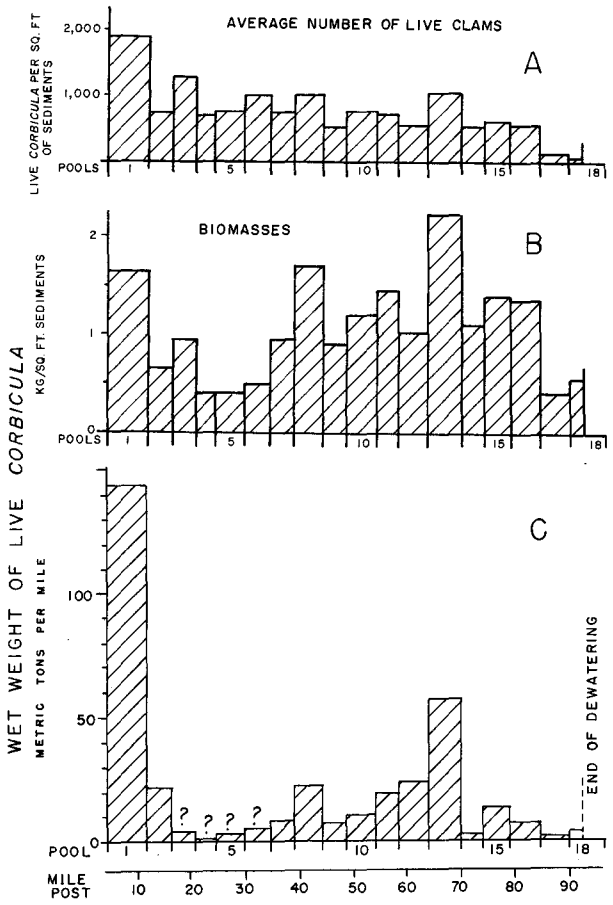


Figure 6.—**Distribution of *Corbicula* in individual pools during 1965–66 dewatering.**

A. Average number of live clams per square foot of bottom sediments.

B. and C. Biomasses (wet weight) of live *Corbicula*.

B. Data expressed as average weight of clams (in kilograms) per square foot of bottom sediments.

C. Data expressed as calculated weight of clams (in metric tons) per linear mile of a pool.

The second prominent benthonic species is a minute amphipod—*Corophium spinicorne* Stimpson. The species was noted mostly on the side lining along the entire canal, and was more abundant in the upstream 7 to 10 miles. In this reach, *Corophium* creates a peculiar "amphipod-mud coating," up to ½-inch thick, additionally fortified by colonies of bryozoa (figures 7 and 8). The species in some crust samples occurred in incredibly large numbers of 2,000 to 10,000 individuals per square foot of crust.

During several past dewaterings no less spectacular was the infestation by fresh-water sponges (figure 9). The infestation was particularly heavy in the central reaches of the canal, downstream of the main *Corophium* infestation. During the 1965–66 dewatering, sponge infestation showed marked reduction, probably related to the 1965–66 construction activity which raised the canal lining and caused more turbid water conditions.

The periphyton algae which have caused serious operational problems in many Bureau canals have been insignificant in the Delta-Mendota Canal and are limited to a 3- or 4-foot strip just below the water surface. Poor development of algal growth is explained by the turbidity of canal water, which inhibits photosynthesis. Distribution of algae on the concrete canal side lining during the 1965–66 dewatering is shown in table 1. Some of the diatoms in the list could be planktonic forms splashed on the lining by wave action.

Only a few species of other benthonic organisms were noted in the canal. The distribution and abundance of benthos during the 1965–66 dewatering are summarized in table 2.

The extremely abundant plankton (table 1) is represented mostly by diatoms, but no detailed systematic

Figure 7.—**Upstream view of the Delta-Mendota Canal from the Mountain House Siphon (M.P. 4.4), 1962–63 dewatering. Shows amphipod-mud coating on canal side lining and dead fish on the canal invert.**

TABLE 1.—*Distribution of algae on concrete canal side lining, sampled November 30–December 6, 1965*

Divisions			Pool No.	1 [1]		2 [1,2]		3 [1,2]		4 [1]	5		6	7	8 [2]		9 [1,2]		10	11	14	15 [1]		17		18 [1]	
			Genus \ M. P.	3.5	5.6	11.4	15.5	16.2	19.4	23.4	26.2	29.2	32.6	36.5	38.7	40.6	44.7	47.9	51.4	56.5	70.6	76.8	78.0	85.1	85.7	90.5	92.2
Chlorophyta			Spirogyra		×		×		×	×		×	×	×	×	×	×	×	×	×	×	×	×		×		
			Cladophora		×	×		×	×	×				×	×	×	×					×	×	×		×	×
			Sirogonium								×	×	×				×				×						
			Ulothrix							×			×	×								×					
			Volvox														×										
			Others										×	×		×	×		×						×		
Chrysophyta	Diatoms	Filamentous	Vaucheria									×						×	×	×					×		
			Terpsinoe	×	×						×	×	×	×		×									×	×	
			Melosira	×	×							×	×				×		×	×	×				×	×	
		Unicellular	Cymbella																								×
			Novicula										×														×
			Diatoma										×		×		×		×		×			×			×
			Gomphonema	×	×							×		×	×		×					×	×	×	×		×
			Synedra																								×
			Pinnularia																	×	×						×
Rhodophyta			Compsopogon						×													×					
Cyanophyta			Lyngbya	×																×	×			×			

[1] Short filaments. [2] Filamen ts mostly ≥ 1-ft. long.

studies of the plankton have been conducted to date. Fifteen plankton-net grab samples collected in March 1967 contained Bacillariophyceae (diatoms), Chlorophyceae (green algae), Cladocera, Copepoda, Bryozoa, Amphipoda, and Porifera. Specimens of the last three groups probably were detached from the wall of the canal. About 30 species of fish, some of which are very abundant, live in the canal.

***Figure 8.*—Close-up view of *Corophium* honeycomb with round colonies of dead bryozoa on the concrete canal side lining. Left canal bank below the Mt. House Siphon (about M.P. 4.7). December 1965.**

TABLE 2.—*Benthic organisms and their abundance in 77 samples of bottom sediments collected in pools 1 through 18 during the 1965–66 dewatering*

Organism	Present in		
	Number of pools	Percent of samples	Maximum population organisms, square feet
Corbicula fluminea Müller	18	100	3,847
Corophium spinicorne Stimpson	10	26	1,876
Gnorimosphaeroma lutea Menzies	14	40	489
Neomysis mercedis Helmes	0	0	0
Hirudinea	8	12	41
Oligochaeta	15	47	765
Polychaeta	10	16	80

In general, biomasses of *Corbicula* and infestations by other species decline in the downstream direction (figure 6). This apparently reflects a decrease in food supply in downstream pools, and indicates that the Delta is the main source of nutrients in the canal water.

The primary supply of food in the canal is the abundant plankton and suspended "peaty" particles that support the large population of filter-feeders. High biologic productivity of the canal has been caused by a sustained conveyance of eutrophic deltaic waters. Although only a few deltaic species were able to survive the artificial dynamic environment, the survivors proliferated in unbelievable amounts.

***Figure 9.*—Close-up view of highly abundant sponges on concrete canal side lining downstream from Check No. 5 at M.P. 29.8. Right canal bank near invert. Individual concrete panels are 12 feet. December 20, 1962.**

SEDIMENTATION IN THE CANAL

The most prominent feature noted during every dewatering of the canal was the profusion of clam-bearing sediments on its bottom. Sediments consistently appeared not as a continuous blanket but as more or less isolated patches or "bars," located mostly on the inside of bends in the canal (figures 10–12). During the past dewaterings, the thickness of sediments was observed to range from a few tenths of a foot to over 3 feet (figure 5). Lengths of the bars varied from less than 100 to over 1,000 feet. Most of the bars were up to 15–25 feet wide, but some of the bars extended across the entire 48-foot-wide invert. Unfortunately, during the 1965–66 dewatering the normal pattern of sedimentation in the canal was disrupted and enhanced by clayey soils introduced by construction work along the upstream 70 miles of the canal.

Canal sediments generally showed some horizontal stratification, had neutral or slightly basic reactions (pH 6.9–8.1), and were light to medium gray in their uppermost aerobic 2 to 4 inches. Below this upper aerobic zone, sediments became dark gray to olive black, anaerobic, and contained numerous shells of dead *Corbicula*. No live clams were observed in this lower zone. (A few brown, oxidized layers composed of spillage material were noted only during the 1965–66 dewatering.)

Some 200 samples of clam-bearing sediments were obtained and analyzed during four canal dewaterings between 1960 and 1966. Composition of all samples and character of their cumulative curves were notably consistent.

All cumulative curves were composed of two or three phases (figure 13) which reflect changes of composition of different fractions.

Superficially, the sediments appeared to be composed exclusively of shells of dead and live *Corbicula fluminea* (figures 4 and 5). The true composition of sediments, however, was more complex and shells amounted usually to only 20–35 percent of the total dry weight (figure 13). Practically all particles larger than 2.5 millimeters are shells. Inorganic sand with some admixtures of shell fragments and organic, peaty debris amounted to 30–60 percent of the dry weight of sediments and inorganic silt and clay, to 15–40 percent.

During the 1952–53 (and/or 1953–54), 1960–61, 1962–63, and 1965–66 dewaterings, sediments on the invert were removed by heavy equipment. New sediments, however, rapidly accumulated on the invert after each cleaning. Rates of sedimentation varied with location and time but in general appeared to diminish in the downstream direction. Particularly significant were the small amounts of sediments and low rates of sedimentation in the downstream pools; data on the amount and distribution of sediments during the 1965–66 dewatering are summarized on figure 14.

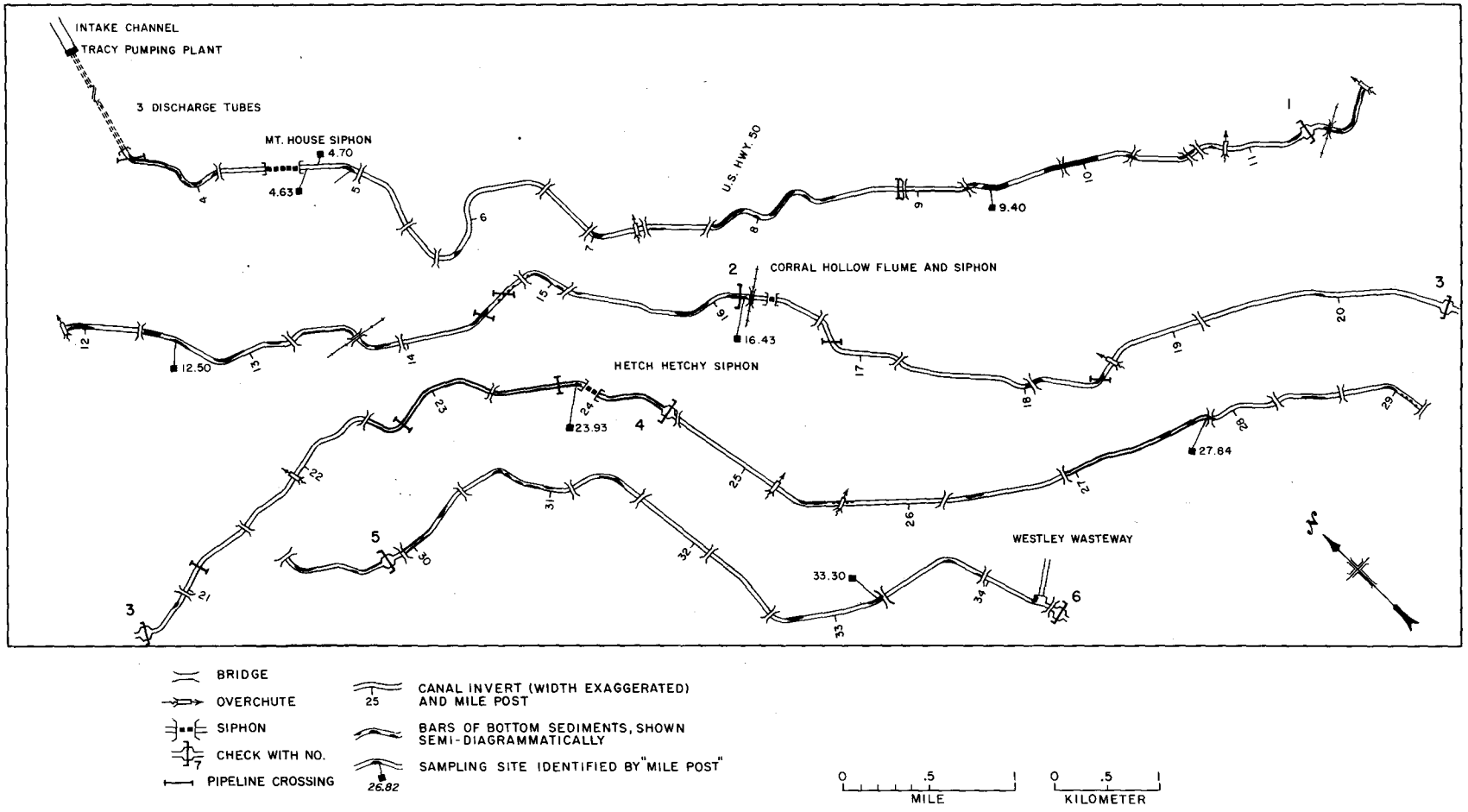


Figure 10.—1965–66 dewatering, pools 1 to 6. Distribution of bottom sediments and sampling sites.

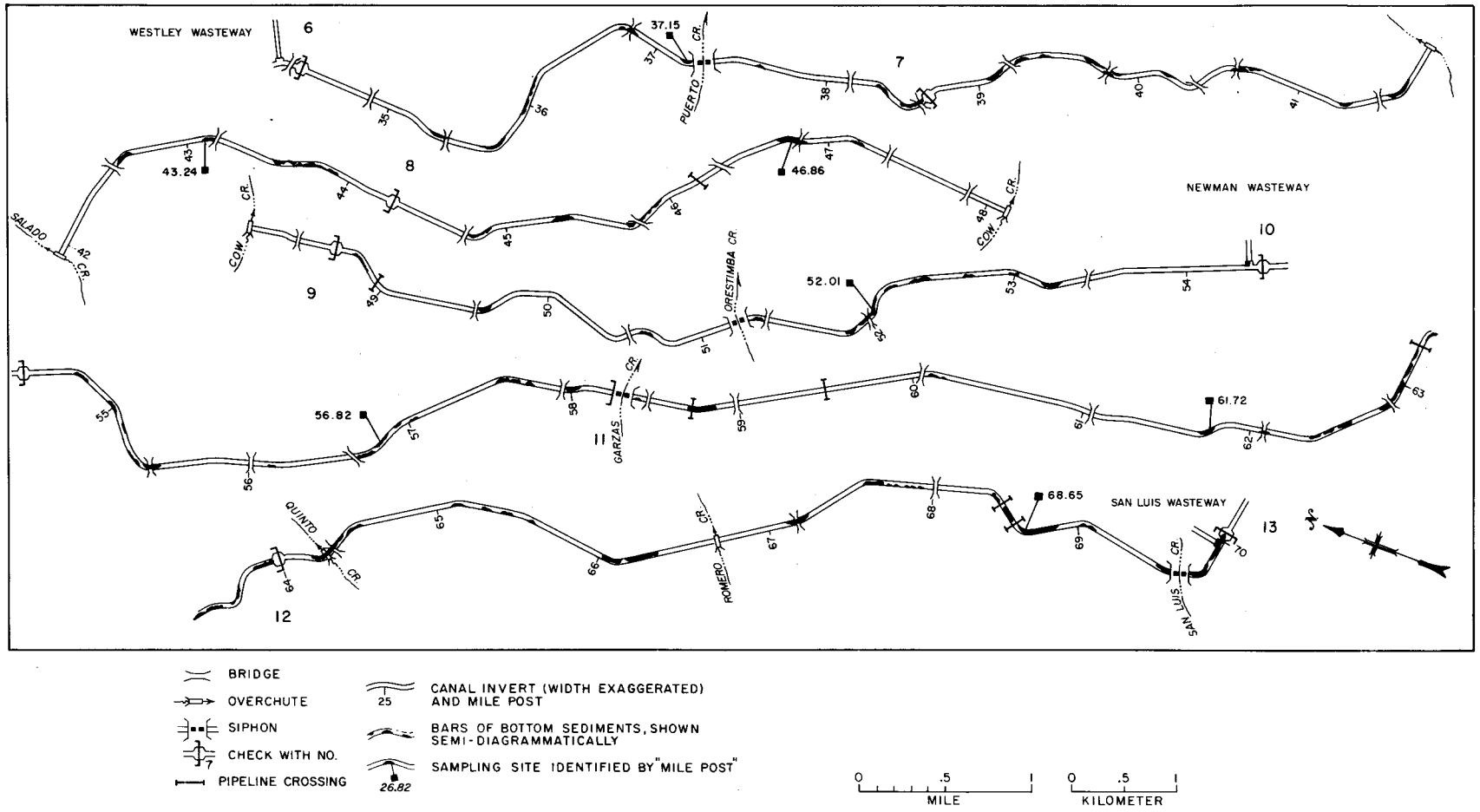


Figure 11.—**1965–66 dewatering, pools 7 to 13. Distribution of bottom sediments and sampling sites.**

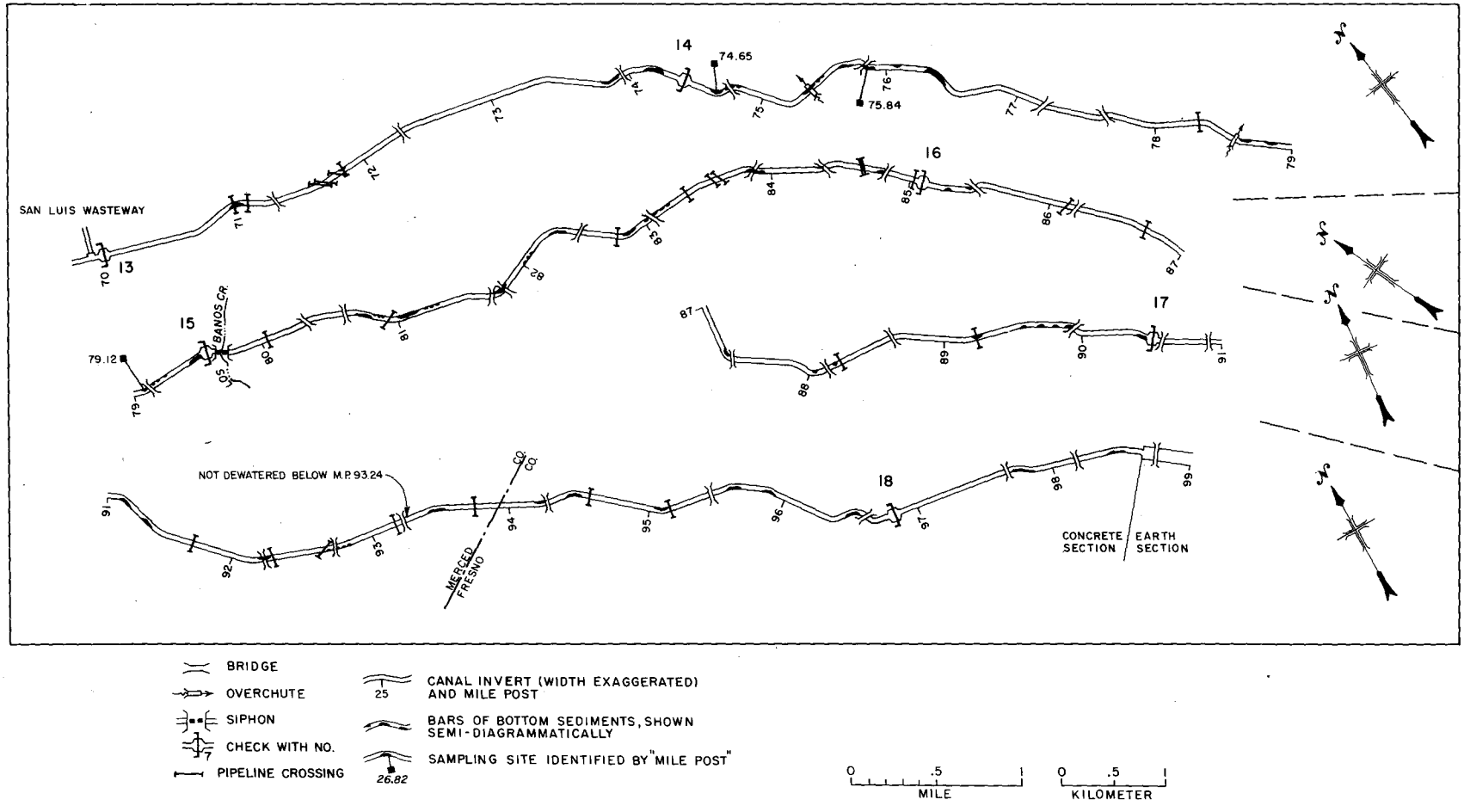


Figure 12.—1965–66 dewatering, pool 14 to M.P. 99. Distribution of bottom sediments and sampling sites.

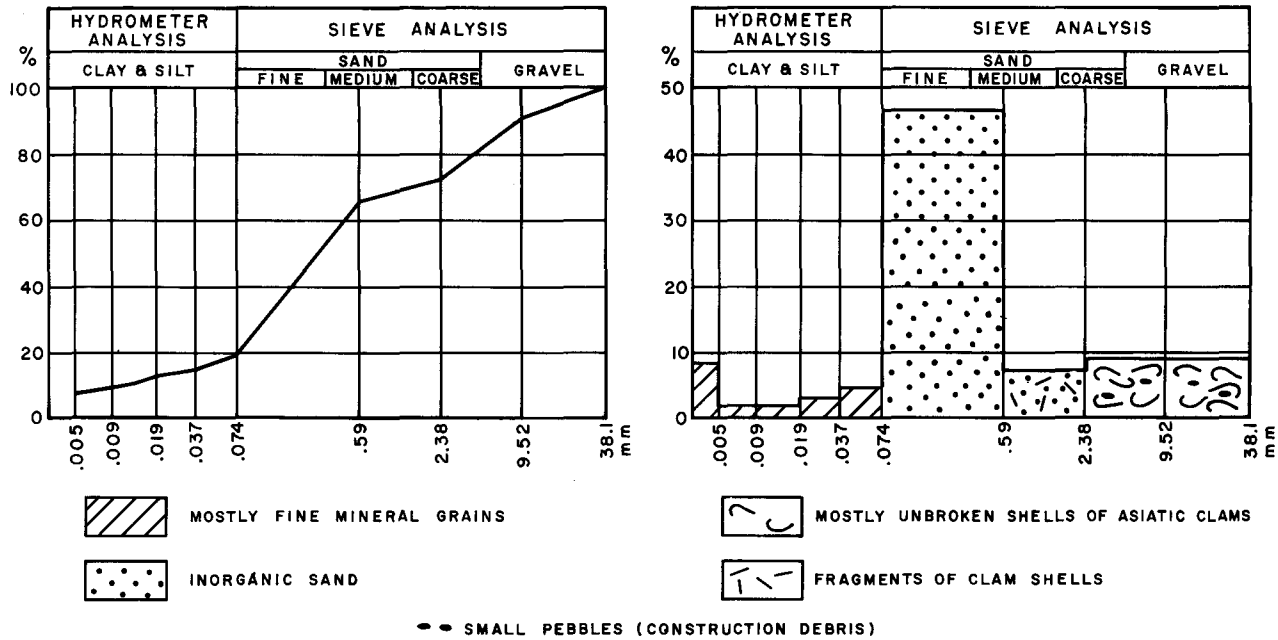


Figure 13.—Average cumulative curve and composition of canal bottom sediments, pools 1 to 6, 1965–66 dewatering.

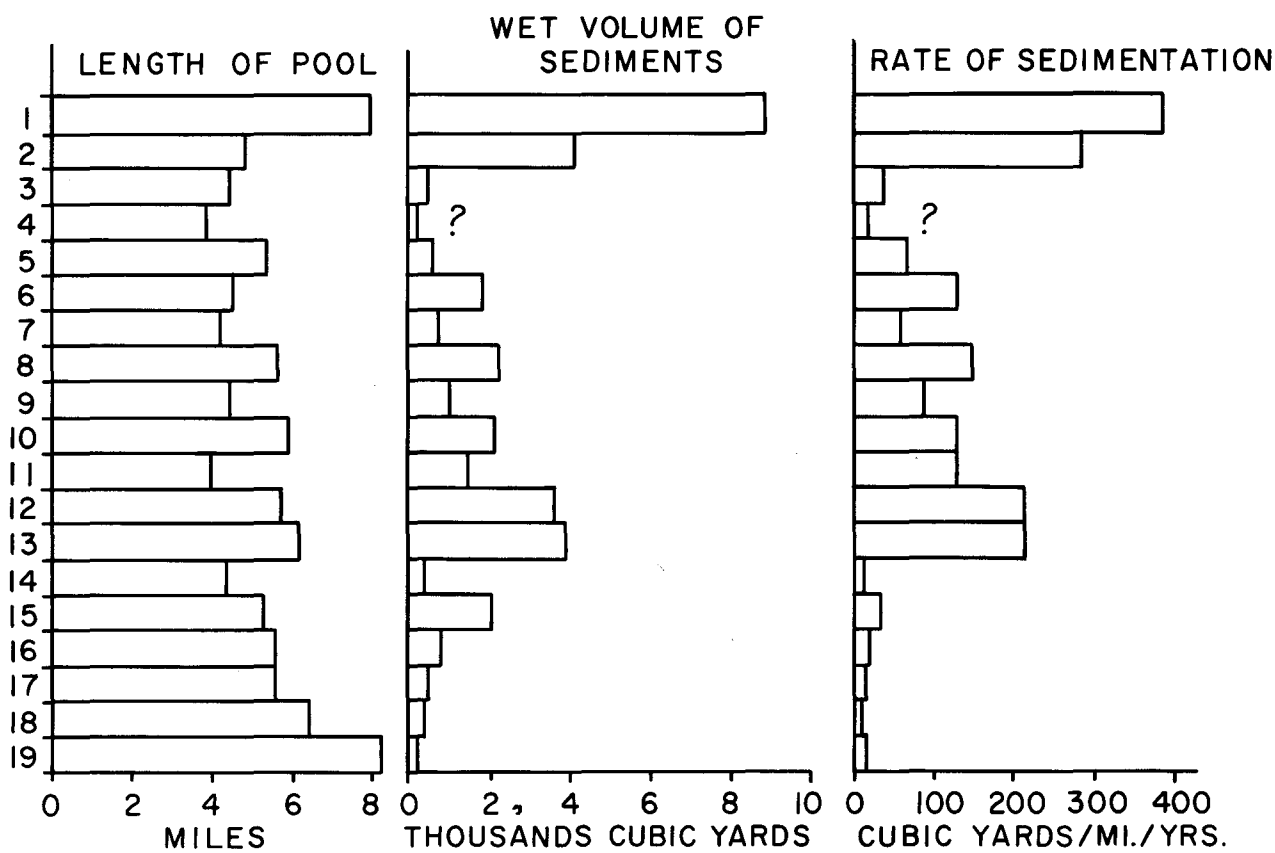


Figure 14.—Amount of bottom sediments and rates of sedimentation during 1965–66 dewatering.

FIELD AND LABORATORY PROCEDURES

On December 14 and 15, 1965, during the 1965–66 winter dewatering period, 37 samples, several of which were in duplicate, were collected at 17 stations in the canal between M.P. 4.7 and M.P. 79.12.[1] Following field readings of dissolved oxygen, pH and Eh of the water samples and the masses of canal organisms, the samples were frozen and shipped for laboratory studies to the University of Minnesota. Oxygen was determined electrometrically, and the pH–Eh readings were made with a Beckman battery-operated pH meter.

In March 1967, plankton-net samples were obtained at 15 stations along the canal. These were frozen and shipped to the University of Minnesota for additional studies.

Determinations of carbon and nitrogen in nine samples of canal materials were made by a Feigl combustion-train absorption process in the Microanalytical Laboratory, School of Chemistry, University of Minnesota. Measurements of loss on ignition and ash content were made by igniting the samples in a platinum crucible.

The lipid or bitumen content of the canal materials was analyzed in the following way: (1) extract 2–5 grams of wet sample with 80 percent benzene plus 20 percent methyl alcohol for 8 hours in Soxhlet extractors; (2) separate water from extract in separatory funnel; (3) dry extract to constant weight in vacuum dessicator under flow of nitrogen to prevent oxidation; (4) weigh and record nature, color, texture, fluorescence and odor of extract; (5) run infrared absorption spectrum of extract (figures 15–17); (6) separate extract in a 1 centimeter times 10 centimeters column of activated alumina (Alcoa A–20) into three eluted fractions: the first eluted with n-heptane (10 milliliters), followed by benzene (10 milliliters), followed by pyridine (8 milliliters), and by methanol (8 milliliters); the last two elutions are combined.

The *heptane-eluted* fraction is dried, described under microscope, and taken to represent the saturated hydrocarbon fraction. Its nature is ascertained by ob-

[1] Here and in the following text M.P.=Mile Post, i.e., distances from the head of the intake channel.

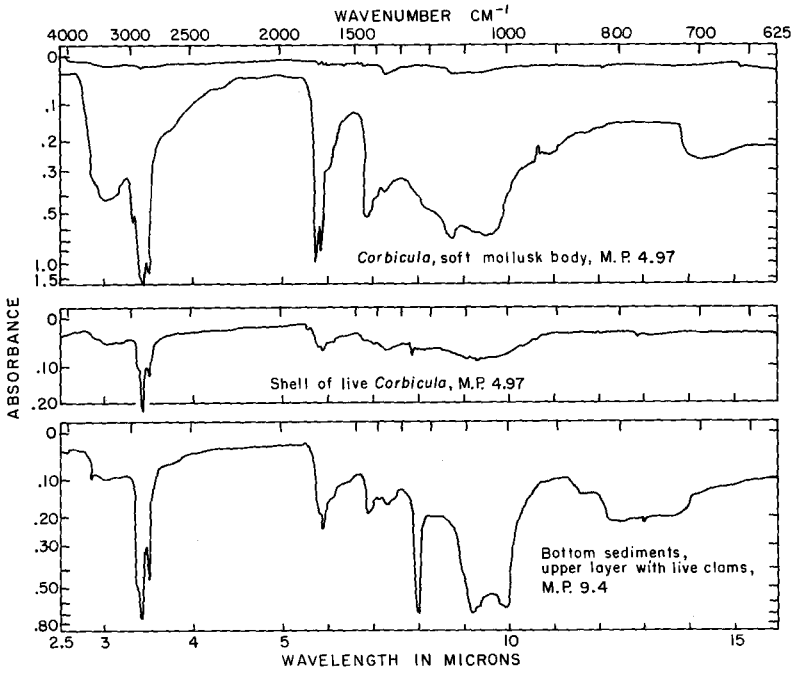


Figure 15.—**Infrared absorption spectra of benzene + methanol extracts of Delta-Mendota Canal materials—"a".**

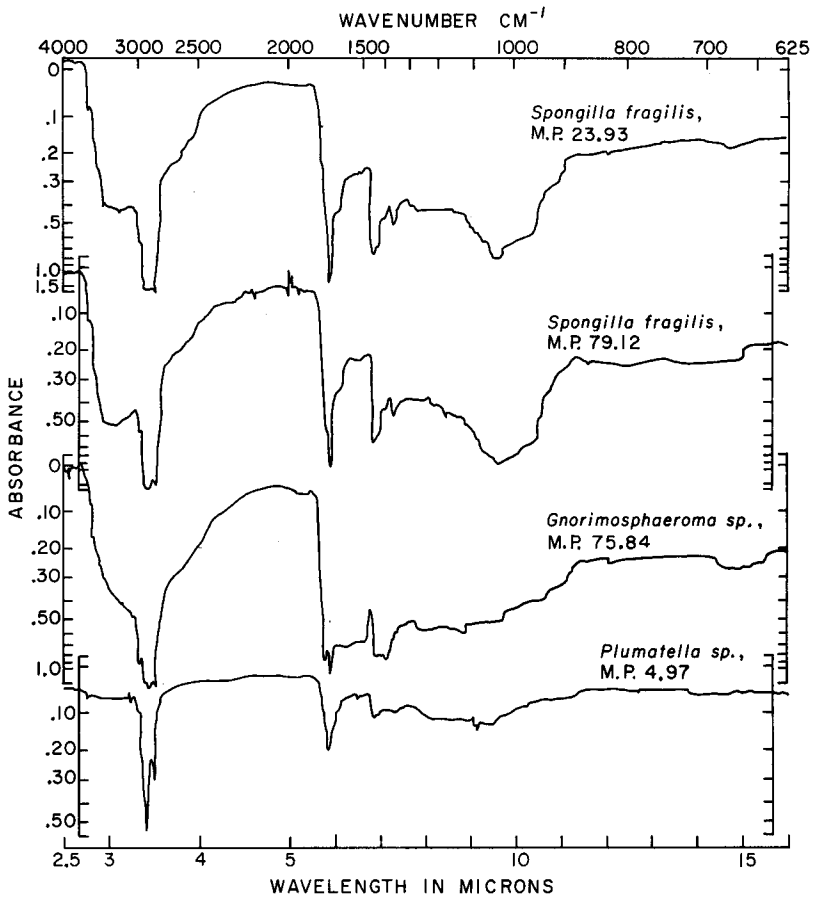


Figure 16.—Infrared absorption spectra of benzene + methanol extracts of Delta-Mendota Canal materials—"b".

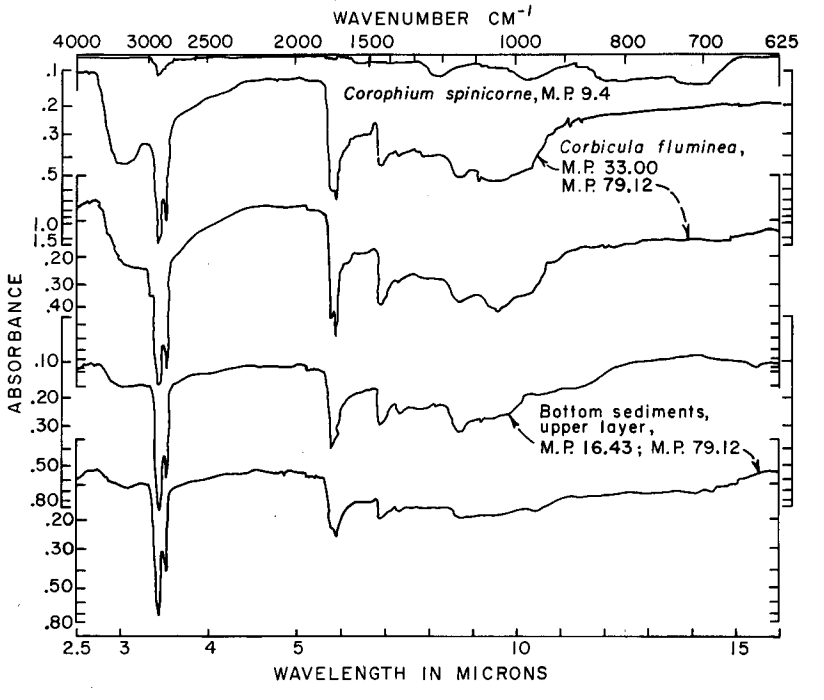


Figure 17.—Infrared absorption spectra of benzene + methanol extracts of Delta-Mendota Canal materials—"c".

taining a UV-visible absorption spectrum (figures 18–20) which should show no absorption peaks. As a further check, the sample is taken up in benzene and allowed to come in contact with a 5Å molecular sieve which should absorb all the unbranched normal alkane hydrocarbons. Branched alkanes, cycloalkanes, and other materials in the fraction remain unabsorbed. These subfractions may be separated further by gas chromatography.

The *benzene-eluted* fraction, treated in the same way, is taken to represent the aromatic hydrocarbons but other substances may also be present. A UV spectrum should show presence of aromatic nuclei if any occur. This fraction frequently contains carotenoid pigments, and a visible absorption spectrum will determine if any are present.

The *pyridine + methanol-eluted* fraction is taken as the asphaltic material of the sample and consists of tars and resins as well as the chlorinoid pigments (chlorophyll, pheophytin, and others) in modern materials; the pigments can be detected by means of a visible absorption spectrum.

A fourth, non-eluted fraction is polar material retained on the alumina column; it may contain resins, carbohydrates, some pigments, and other higher-molecular-weight substances.

Some of the individual fractions eluted from the alumina columns or after molecular sieving as noted above, after drying and weighing were taken up in about 50 microliters (μl) of n-heptane and 1–2 μl of the solution was injected on a gas chromatographic column: Varian-Aerograph Model 204, SE–30 column; temperatures both isothermal and programmed, carrier gas helium; flame ionization detectors. This process provided further separation of the column chromatographic extracts.

The organic pigmenting substances in the canal materials were found to consist mainly of chlorophyll-derived pheophytin pigments. This was learned from inspection of the visible absorption spectra of the pyridine + methanol-eluted column chromatographic fractions referred to above. Small quantities of probable carotene pigments may be present in the acetone extracts, but they would not be included in the measurements for pheophytin, as they do not absorb in the 665–667 mμ range.

The chlorinoid pigments were extracted in the following way. Samples ranging from 0.2 gram to 1.7 grams of the canal deposits were extracted in the dark in ultrasonic tanks with 90 percent aqueous acetone until no additional color could be obtained with addition of fresh solvent. A visible spectrum in the 660–670 mμ range was obtained with a Beckman DU Spectrophotometer, and a spectrum in the range 280 mμ to 700 mμ was obtained in a Bausch and Lomb 505 Spectrophotometer. Chlorophyll *a* and pheophytin *a*

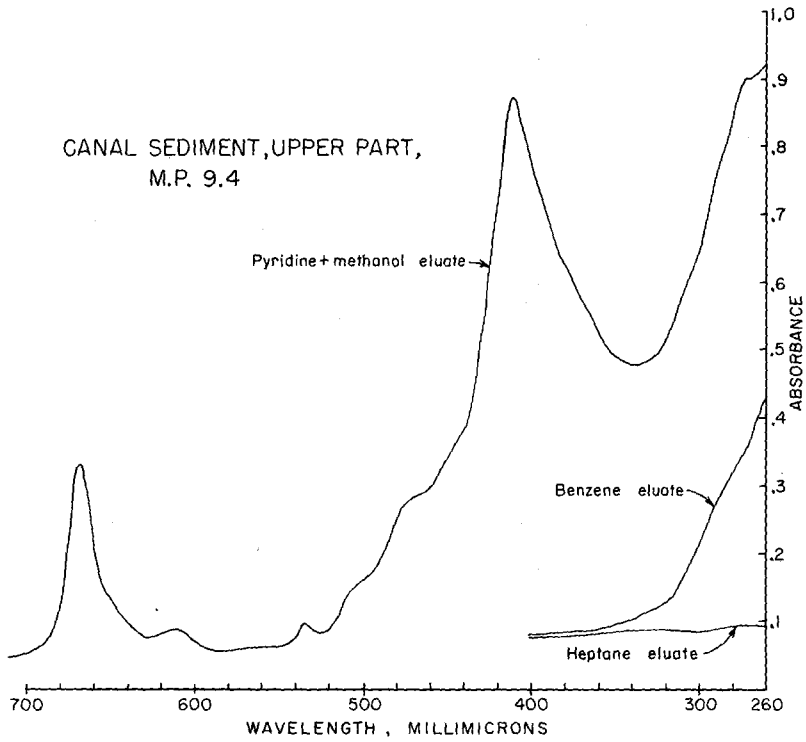


***Figure 18.*—Ultraviolet and visible absorption spectra of hydrocarbon fractions of Delta-Mendota Canal materials—"a".**

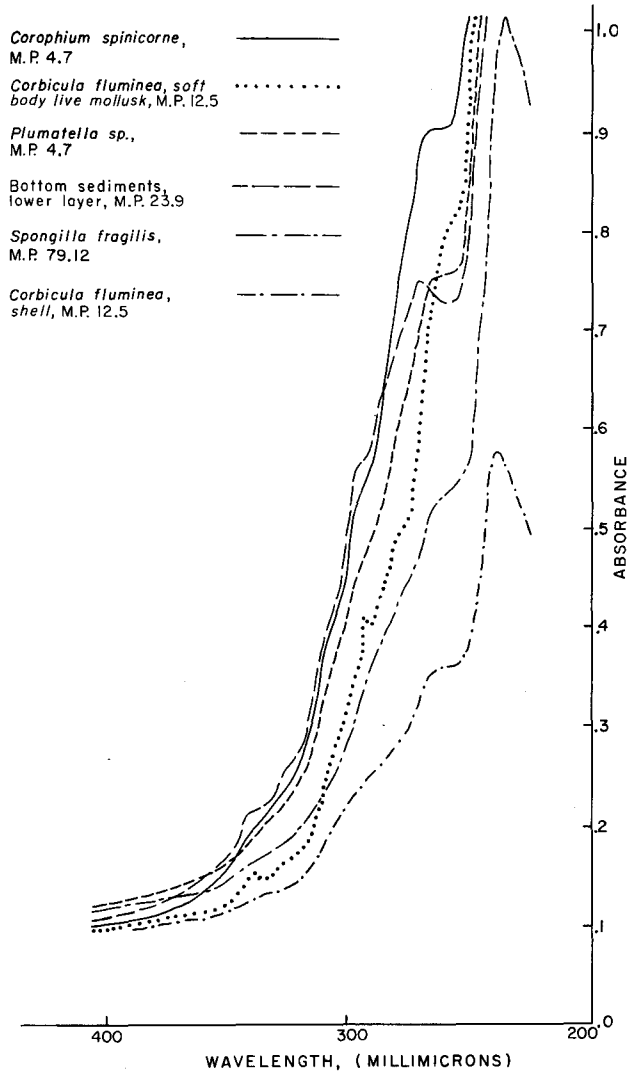


***Figure 19.*—Ultraviolet and visible absorption spectra of hydrocarbon fractions of Delta-Mendota Canal materials—"b".**

both have absorption maxima at 661–667 mμ. Chlorophyll *a* has another λ max at 432 mμ, while the comparable λ max of pheophytin *a* is at 409–412 mμ.

Similar extractions and absorption spectra were obtained of fresh spinach, in which all the chlorinoid pigment occurs as chlorophyll *a*. A portion of the spinach extract was allowed to degrade to pheophytin *a* and a generally quantitative relationship was established. The chlorinoid pigments are tabulated as SCDP (sedimentary chlorophyll degradation product) using the method of Vallentyne where:

$$\text{SCDP}=\frac{(\text{absorbance at } 665\ \text{m}\mu)\ (\text{volume of extract})}{\text{dry weight of sample}}$$

The carbohydrate contents of canal materials were studied by means of acid extraction, chromatography, and enzymatic preparations.

The monosaccharides were separated from the canal materials in the following way. The quantity of sulfuric acid necessary to neutralize the alkaline constituents of the sample was determined by preliminary acid extraction and subsequent back-titration with NaOH in presence of phenolphthalein. This amount of 0.5 *N* H_2SO_4 was added in excess of that needed to treat 1–20 grams of sample. Pretreatment of the sample with cold 70 percent H_2SO_4 for 8 hours may aid in extraction of humified samples. The sample and 0.5 *N* acid mixture was centrifuged and the solutions neutralized with $BaCO_3$. Desalting was done first by ethanolic precipitation, reduction to 25–50 milliliters in a flash evaporator, followed by passage through ion-exchange resins in three superposed columns: (1) Dowex 50 cation resin 8 percent cross-linked 50–100 mesh, (2) Duolite A–4 weak anion resin, and (3) Dowex 50 or Amberlite IR–120 (H^+) cation resin. The lower col-

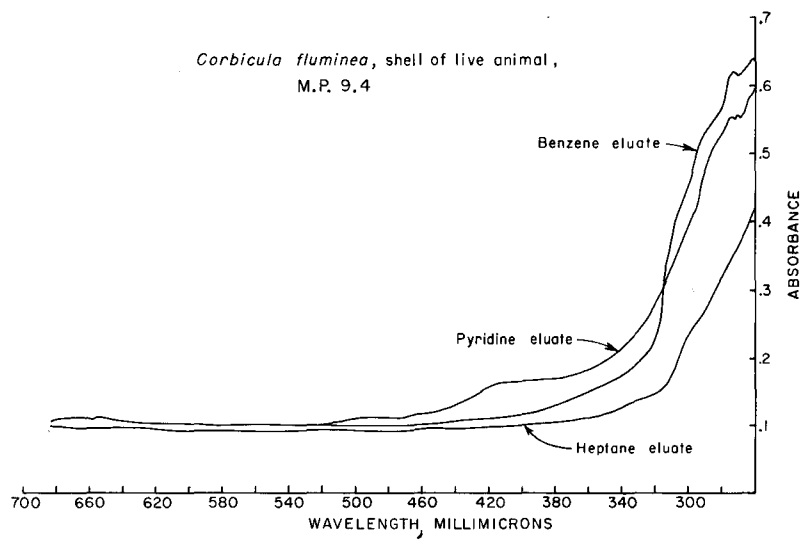


***Figure 20.*—Ultraviolet and visible absorption spectra of hydrocarbon fractions of Delta-Mendota Canal materials—"c".**

umn is used to insure that the effluent from the anion column was neutral or at least not alkaline. Capacity of resins should be at least 5 times the anticipated volume of salts.

Prior to use the ion-exchange resins are regenerated as follows. The cation resin is converted to the Na^+ form with 2 *N* NaOH, followed by rinsing with distilled water and is then converted to the H^+ form with 2 *N* HCl, again followed by thorough rinsing with distilled water. The anion resin is similarly regenerated with HCl and NaOH. In the deionization of the carbohydrate solution, 25 to 50 milliliters of solution were passed through the successive columns; the columns were flushed with 10 volumes of distilled water. The effluent from the columns was reduced to dryness in a flash evaporator and taken up in 10 milliliters of distilled water. Desalting may be done in an electric desalter but the process is more time consuming.

The carbohydrates in the samples were then separated by one-dimensional paper chromatography. The chromatograms were developed in a solvent system of butanol: acetic acid: water (4:1:5) or pyridine: ethyl acetate: water (11:45:6); from 1 to 80 μl. of sample was spotted on the chromatogram and development time was 24–48 hours. The spray used to detect the monosaccharides was aniline: phthalic acid: water-saturated butanol (0.9 gram: 1.6 milliliters: 100 milliliters). After development the chromatograms are air-dried in a hood for 2–3 hours; then are sprayed quickly and evenly and placed in an oven at 85–95° C for 4–5 minutes.

The unknown monosaccharides are identified by comparing the developed spots with those of a mixture of known monosaccharides placed on the chromatogram and by observing their color reactions; the hexoses (galactose, glucose, mannose) stain grayish brown with this spray, while the pentoses (arabinose, xylose, ribose, rhamnose) stain reddish brown. Semiquantitative determinations of monosaccharides were made by scanning the chromatograms in a recording densitometer (Photovolt Corp., N.Y.).

Enzymatic analysis of D-glucose and D-galactose is made by use of enzyme-oxidase preparations. These are available from Worthington Biochemical Corp., Freehold, N.J. The glucose-oxidase technique is a coupled enzyme system based on the following scheme of reactions:

$$\text{D-glucose} + O_2 + H_2O \xrightarrow{\text{glucose oxidase}} H_2O_2 + \text{gluconic acid}$$

$$H_2O_2 + \text{reduced chromogen} \xrightarrow{\text{peroxidase}} \text{oxidized chromogen.}$$

The absorbance of the oxidized chromogen solution at 400 mμ is read and compared to a standard curve for quantitative determination. The method is specific for D-glucose except that 2-deoxy-D-glucose is oxidized at 12 percent of the rate for glucose. The galactose-oxidase determinations are based on the following schematic reactions:

$$\text{D-galactose} + O_2 \xrightarrow{\text{galactose oxidase}} \text{D-galactohexodialdose} + H_2O_2$$

$$H_2O_2 + \text{reduced chromogen} \xrightarrow{\text{peroxidase}} \text{oxidized chromogen.}$$

The method is less specific than the glucose-oxidase reaction, since the galactose-oxidase system also attacks D-galactosamine and other monosaccharides, galactosides and oligosaccharides.

Another method for separation and identification of monosaccharides involves the preparation of alditol acetates of monosaccharide mixtures and their separation by gas chromatography. The glycose mixture is reduced with sodium borohydride for 3 hours; the excess borohydride is neutralized with acetic acid and the solution evaporated to dryness. The dry mixture is refluxed for 4 hours with a mixture of equal amounts of acetic anhydride and pyridine (ca 1cc/100 mg. of sugars). The solution is cooled and injected directly in a gas chromatograph equipped with a flame ionization detector.

The analyses of protein amino acids from canal materials involve their extraction and following paper chromatography or use of automatic amino acid analyzer.

Extraction: Free amino acids are extracted with water; protein amino acids are extracted with acid, generally 6 *N* HCl, to break the peptide bonds of the protein and liberate the individual amino acids. A 1- to 25-gram sample of organism or sediment is treated with concentrated HCl to neutralize the carbonates in the sample, 6 *N* NCl is added, and hydrolysis under reflux is carried on for 24 hours. The mixture is centrifuged, the supernatant decanted and saved, the precipitate is washed twice with distilled water, and the washings combined with the supernatant. The combined solution is nearly dried in a flash evaporator, then is transferred to a porcelain dish in a vacuum dessicator over silica gel "Tel Tale" dessicant. The precipitate is dissolved in 10–30 milliliters of distilled water, centrifuged, poured off, and supernatant saved;

the precipitate is further washed with distilled water, which is added to supernatant and is then dried to eliminate any remaining HCl. The residue is taken up in distilled water and passed through a column of Dowex 50 ion-exchange resin. Water is added until effluent pH is neutral and a test for iron is negative (amino acids are now absorbed on column and inorganic salts have been washed off column); 2 *N* NH_4OH is added to column to elute amino acids using 4–5 times as much ammonia solution as column is high. The eluate is reduced to dryness at 50° C, the residue is taken up in exactly 5 milliliters of 10 percent isopropyl alcohol and placed in a labeled bottle. Alternatively, for automatic amino acid analyzer the residue is taken up in 5 milliliters of pH 3.28 sodium citrate buffer solution.

Paper chromatography: A known amount of solution containing a mixture of amino acids as standards, and known amounts of the unknown solutions are spotted on a sheet of Whatman No. 1 filter paper; typically a total of 1–5 microliters (λ) of each solution is spotted in successive 1-microgram quantities and allowed to dry to avoid spreading of the spot. The chromatogram is placed in a chromatographic chamber with a suitable solvent such as butanol: acetic acid: water (4:1:5) for 24 hours, after which it is air dried. The chromatogram is stained by dipping it in a solution of 0.25 percent ninhydrin in acetone, dried in an oven for 2 minutes at 50° C, and stored in the dark. The colors come out fully in several hours. For semi-quantitative estimation the chromatogram is cut into strips and scanned in a recording densitometer.

Automatic amino acid analyzer: For more quantitative determination and better separation the amino acid hydrolyzates are analyzed in an automatic analyzer such as the Phoenix Model K–1000 used here: From .05 to .2 millimeter of solution is analyzed. The apparatus consists of ion-exchange resin columns in which circulate buffers of differing pH. The amino acids placed on the columns are continuously eluted and the effluent is mixed with a ninhydrin solution. The resulting colored solution is monitored photoelectrically and the effluent peaks representing individual amino acids are recorded on a chart.

HYDROGEN-ION CONCENTRATION, OXIDATION-REDUCTION POTENTIALS, AND OXYGEN CONTENT OF CANAL MATERIALS

Hydrogen Ion Concentration. The pH values of the canal waters during the 1965 sampling range from 7.0 to 8.45, indicating neutral to somewhat alkaline conditions. The instability of meter readings in the field suggests that the waters are poorly buffered. The pH value of the sediments are mostly somewhat alkaline (table 3).

Oxidation-Reduction Potentials. The Eh values of the canal waters during the sampling vary from null to moderately positive (table 3), indicating that an only weakly oxidizing environment prevails in the canal waters despite the high dissolved oxygen content. The Eh values of the canal sediments vary from slightly positive to negative and show generally reducing conditions in the sediments (table 3). No very strongly reducing conditions were noted and no H_2S accumulations were detected in the canal. The state of oxidation of the iron as a function of the activity of aerobic vs. anaerobic bacteria is suggested to exert an important if not the principal influence on the oxidation-reduction conditions in the canal sediments.

Under oxidizing conditions the organic matter will tend to be destroyed by bacterial action rather rapidly. Under reducing and anaerobic conditions the organic matter will be preserved for much longer periods of time.

Oxygen Content. The oxidizing conditions in the water and the reducing conditions in the sediments of the canal are further demonstrated by the content of oxygen as measured electrometrically with a silver electrode in the field (table 3). The oxygen content of the water samples is high in most of these samples and shows they are well aerated. The oxygen content of the upper part of the typical clam-bearing sediment (clam beds) is variable, low to moderate in amount. The low values of around 1 to 3 mg/L are accompanied by negative or low positive Eh values and indicate reducing conditions and oxygen depletion due to bacterial activity. Oxygen values occurring in the lower part of the sediments tend to be lower and more reducing than in the upper part of sediments. Bacterial decay in these sediments is incomplete due to development of anaerobic conditions.

TABLE 3.—*Field data on pH, Eh, and O_2 values of canal water, sediments, and organisms, December 14–15, 1965*

M.P.		pH	Eh(mv)	O_2mg/l	Temperature, C°
4. 70	Shallow water	7. 7	+290(ox)	(1)	10
	Amphipod-mud coating on side lining	7. 8	+209(red)	7. 2	10
	Silty bottom sediments	8. 2	+287(ox)	1. 78	10
4. 97	Shallow water	7. 6	+308(ox)	11. 8	10
	Upper part of clam bed [2]	6. 85	+137(red)	1. 1	10
	Blue clay, 6″ below surface	7. 0	+77(red)	(1)	(1)
	Sand at base of sediments	7. 8	+71(red)	(1)	(1)
9. 40	Shallow water	7. 5	+287(ox)	11. 7	9
	Amphipod-mud coating on side lining	7. 4	+275(ox)		
	Clam bed	7. 5	+149(red)	1. 37	9
12. 50	Shallow water	7. 95	+293(ox)	13. 9	9
	Clam bed, near surface	7. 9	+152(red)	1. 16	9
	Clay beneath surface	7. 95	+29(red)	1. 39	9
	Clam bed at 1-foot depth	7. 35	+95(red)	2. 56	9
16. 43	Shallow water	7. 75	+233(red)	(1)	(1)
	Top of clam bed	7. 6	+64(red)	(1)	(1)
	Bottom of clam bed	7. 0	+61(red)	(1)	(1)
23. 93	Shallow water	8. 0	+335(ox)	12. 91	12
	Live sponges from side lining	7. 5			
	Top of clam bed	7. 4	+149(red)	6. 18	12
	Bottom of clam bed	6. 8	+101(red)	7. 63	12
27. 84	Shallow water	7. 5	+173(red)	13. 17	9. 5
	Top of clam bed	7. 1	+158(red)	2. 19	9. 5
	Bottom of clam bed	7. 05	+59(red)	(1)	(1)
33. 30	Shallow water	7. 2	+275(ox)	13. 46	9. 5
	Top of clam bed	7. 3	+145(red)	1. 42	9. 5
	Bottom of clam bed	7. 2	+113(red)	1. 02	9. 5
37. 15	Shallow water	7. 0	+245(null)	12. 11	9. 5
	Top of clam bed	7. 3	+101(red)	1. 34	9. 5
	Bottom of clam bed	7. 4	+145(red)	0. 96	9. 5
68. 65	Shallow water	7. 7	+281(ox)	10. 88	15. 5
	Top of clam bed	7. 4	+125(red)	1. 91	15. 5
	Bottom of clam bed	7. 0	+83(red)	0. 88	15. 5
74. 65	Shallow water	8. 45	+287(ox)	10. 92	11. 5
	Veneer of mud on bare concrete invert	8. 05	+305(ox)	13. 55(?)	11. 5
75. 84	Shallow water	8. 1	+359(ox)	10. 17	11. 5
	Live sponges from side lining	7. 3	+209(red)	(1)	(1)
	Top of clam bed	7. 9	+245(null)	(1)	(1)
	Bottom of clam bed	7. 3	+113(red)	(1)	(1)
79. 12	Shallow water	8. 5	+281(ox)	8. 57	6
	Live sponges from side lining	7. 6	+317(ox)	(1)	(1)
	Top of clam bed	8. 05	+227(red)	3. 11	6
	Bottom of clam bed	7. 9	+125(red)	2. 59	6

(ox) = oxidized conditions.
(red) = reduced conditions.
[1] = not determined:
[2] = here and below : clam bed : a deposit of clam-bearing sediments on the canal invert.

CARBON, HYDROGEN, NITROGEN, ORGANIC MATTER, AND ASH CONTENTS OF CANAL MATERIALS

The organic carbon, hydrogen, and nitrogen contents of nine samples of canal organisms and sediments are shown in table 4. The ignition loss, representing an approximation of the total organic matter, and the ash content of canal samples are given in table 5.

The results indicate that the sediments of the canal, in addition to the organisms themselves, contain significantly large amounts of nutrients and organic matter which may serve as food supplies for other organisms in the canal, ranging from bacteria to fish.

TABLE 4.—*Organic carbon, hydrogen, nitrogen, and ash contents of canal materials in percent of dry weight*

Location, M.P.	Sample	C	H	N	Ash
4. 7	Exoskeletons of *Corophium spinicorne*, side lining	30. 91	4. 76	7. 52	2. 69
75. 84	*Spongilla fragilis* (live), side lining	23. 98	4. 07	4. 73	6. 05
4. 97	*Corbicula fluminea*, soft body of live mollusk, from invert	46. 67	7. 25	7. 50	(1)
33. 00	.....do	45. 07	6. 83	7. 58	.43
75. 84	.....do	48. 28	7. 36	11. 78	. 57
75. 84	*Gnorimosphaeroma lutea*, from invert	30. 45	4. 55	6. 10	2. 24
4. 97	Top of clam-bearing sediments	4. 18	. 99	. 53	30. 28
33. 00	.....do	1. 23	. 58	. 2	48. 60
75. 84	.....do	2. 64	. 84	. 5	37. 65

[1] = Not determined.

TABLE 5.—*Ash content and ignition loss of Delta-Mendota Canal materials*

Location, M.P.	Sample	Ash, percent	Ignition loss, percent
4. 7	Amphipod-mud coating, side lining.	91. 74	8. 26
4. 7	*Corophium*, >0.84 mm. fraction	89. 20	10. 80
4. 7	*Corophium*, 0.18–0.84 mm. Ø	92. 25	7. 75
9. 4	*Corophium*, >0.84 mm. Ø	89. 54	10. 46
9. 4	*Corophium*, 0.18–0.84 mm. Ø	91. 52	8. 48
4. 7	Dead Bryozoa colony, side lining	93. 61	6. 39
4. 97	Dead Bryozoa colony, >0.84 mm. Ø	92. 63	7. 37
4. 97	Dead Bryozoa colony, 0.18–0.84 mm. Ø	93. 87	6. 13
4. 97	*Corbicula*, soft body of live mollusk	4. 34(?)	95. 66
9. 4	.....do	14. 56	85. 44
12. 5	.....do	10. 29	89. 71
4. 7	*Corbicula*, shells of live mollusk	89. 19	10. 81
4. 97	.....do	76. 02	23. 98
9. 94	.....do	83. 39	16. 61
12. 5	.....do	54. 58	45. 42
12. 5	*Corbicula*, empty shell of dead mollusk	54. 74	45. 26
12. 5	*Corbicula*, dead shells at bottom of clam-bearing sediments	65. 04	34. 96
4. 7	Bottom sediments, top layer with live *Corbicula*	90. 59	9. 41
4. 97	.....do	87. 06	12. 94
4. 97	Gray mud, beneath clam layer >0.84 mm. Ø	90. 01	9. 99
4. 99	Gray mud, beneath clam layer 0.18–0.84 mm. Ø	92. 30	7. 70
4. 97	Brown mud at base of clam bed >0.84 mm. Ø	97. 92	2. 08
4. 97	Brown mud at base of clam bed 0.18–0.84 mm. Ø	95. 66	4. 34
9. 4	Bottom sediments, top layer with live *Corbicula* >0.84 mm. Ø	87. 41	12. 59
4. 97	Bottom sediments, top layer with live *Corbicula* 0.18–0.84 mm. Ø	90. 47	9. 53
12. 5	Bottom sediment top layer with live *Corbicula*	89. 24	10. 76
12. 5	Gray mud beneath clam layer	90. 40	9. 60
12. 5	Bottom sediments with shells of dead *Corbicula*	94. 86	5. 14

LIPIDS AND BITUMENS

The lipid materials of the canal samples (table 6) suggest a buildup in total lipids, and in relative amounts of aromatic hydrocarbons, tarry substances, and pigments in the *Corbicula fluminea* animal from 4.7 to 16.43 miles in the canal (figure 21). This buildup may be an indication that food is being stored in *Corbicula* because it is becoming scarcer in the canal water with progressive distance down the canal. The sediments show considerable amounts of hydrocarbons and other bitumens far down the canal as related to their organic content. The buildup of aromatic hydrocarbon and asphaltic fractions in the *Corbicula* animal noted in the upper part of the canal (figure 21) seems to level off or decrease farther down the canal, perhaps as a result of a changing food supply.

Gas chromatographic analyses of some of the hydrocarbon fractions of canal organisms and sediments were obtained, with the following results:

The saturated hydrocarbon fraction of the soft body of live *Corbicula fluminea* showed the presence in small amount of several components that are tentatively characterized as lying in the range C_{16} to C_{28}.

It is not known whether the hydrocarbons are natural to the clams or whether they may have accumulated in the clam body from its diet or from the water. This problem might be resolved by study of *Corbicula* from other areas.

The saturated hydrocarbons of *Spongilla fragilis* included those in the range C_{16} to C_{33} and were generally more numerous and more abundant than in *Corbicula*. In addition to these, there are several other components that may include branched aliphatics not yet identified.

The saturated hydrocarbons of the bryozoans (*Plumatella*) are low in amount, possibly including a little of C_{16}-C_{18} compounds.

The sedimentary accumulations associated with *Corbicula* had very low hydrocarbon content in the range C_{21} to C_{28}.

Neither the organisms nor sediments had much aromatic hydrocarbons separable by gas chromatography. One bryozoan sample contained a small amount of possible phenanthrene, $C_{14}H_{10}$.

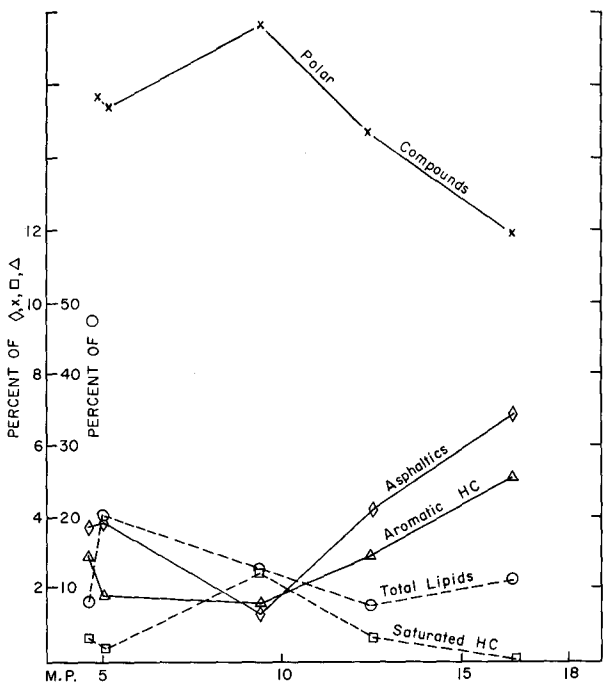


***Figure 21.*—Lipid extracts of soft body of live *Corbicula fluminea*.**

TABLE 6.—*Lipoid extracts of Delta-Mendota Canal samples*

[Solvent benzene-methanol 80: 20; eluting agents h-heptane, benzene, pyridine+methanol]

Location, M.P.	Sample	Wt. spl., g	Wt. ext., g	Extract, % spl.	Heptane, Ø % ext.	Benzene, Ø % ext.	Pyr. & MeOH, Ø % ext.	Polar, Ø % ext.
4. 7	*Corophium spinicorne*, exoskeletons, side lining	0. 98	0. 0171	1. 7	0	0. 58	4. 67	94. 73
9. 4	.....do	. 18	. 0046	. 025	15. 21	6. 52	13. 04	65. 21
4. 7	Amphipod-mud coating, side lining.	20	. 0164	. 082	4. 26	4. 26	28. 65	62. 8
4. 7	*Plumatella sp.* (bryozoa) from side lining	20	. 0204	. 012	0	. 98	43. 13	55. 88
4. 7	Sediments associated with *Plumatella*, side lining	20	. 0084	. 042	0	0	15. 4	84. 5
4. 7	.....do	25	. 0369	. 147	. 81	2. 71	22. 8	69. 1
23. 93	*Spongilla fragilis*, side lining	20. 0	. 1115	. 557	. 53	6. 09	32. 19	59. 37
4. 7	*Corbicula fluminea*, soft body of live mollusk	1. 7	. 0303	1. 7	. 66	2. 97	18. 15	78. 31
4. 97	.....do	4. 7	. 1472	3. 13	. 27	2. 31	13. 79	83. 64
4. 97	.....do	2. 6	1339	5. 15	. 40	1. 50	26. 7	71. 3
9. 4	.....do	1. 72	. 0451	2. 62	2. 5	1. 6	6. 9	88. 9
12. 5	.....do	3. 2	. 0510	1. 59	. 59	2. 94	21. 37	74. 9
16. 43	.....do	4. 0	. 0916	2. 29	0	5. 02	34. 93	60. 04
37. 15	.....do	10. 0	. 2717	2. 71	. 11	5. 26	14. 24	80. 38
68. 65	.....do	3. 4	. 0647	1. 90	. 15	0	11. 28	88. 55
4. 7	*Corbicula fluminea*, shell of live mollusk	2. 1	. 0019	. 09	0	31. 5	57. 8	10. 5
4. 97	.....do	7. 18	. 0051	. 07	7. 8	9. 5	21. 5	60. 7
9. 4	.....do	4. 8	. 0060	. 125	18. 3	8. 3	33. 3	40. 0
12. 5	.....do	6. 3	. 0044	. 69	6. 81	2. 27	27. 27	63. 63
16. 43	.....do	9. 8	. 0027	. 027	14. 81	18. 51	51. 85	14. 81
33. 0	*Corbicula fluminea*, shell of live animal	8. 8	. 0029	. 032	3. 44	0	31. 03	0
12. 5	*Corbicula fluminea*, dead empty shell	2. 9	. 0025	. 08	4. 0	8. 0	40. 0	48. 0
23. 93	.....do	9. 4	. 0015	1. 015	0	6. 66	33. 33	60. 00
33. 0	.....do	7. 4	. 0021	. 02	19. 04	9. 37	23. 81	47. 61
4. 7	Bottom sediments, top layer with live *Corbicula*	20. 0	. 0215	. 17	5. 11	10. 69	24. 65	59. 53
4. 97	.....do	10. 0	. 0374	. 37	. 8	3. 74	13. 63	82. 03
4. 97	Blue-gray mud below layer with live clams	20. 0	. 123	(1)	. 80	. 80	4. 12	94. 98
9. 4	Bottom sediments, top layer with live *Corbicula*	26. 4	. 0338	1. 28	1. 5	4. 7	23. 4	70. 4
12. 5	.....do	5. 0	. 0363	. 73	3. 31	4. 95	8. 26	83. 47
16. 43	.....do	20. 0	. 0631	. 315	1. 74	4. 75	14. 10	79. 39
33. 0	.....do	20. 0	. 0281	. 140	4. 26	3. 91	10. 32	81. 49
33. 0	Sediment at base of clam-bearing bed	20. 0	. 0114	. 057	13. 15	7. 89	16. 56	61. 22
37. 15	Bottom sediments, top layer with live *Corbicula*	20. 0	. 0570	. 28	2. 80	1. 57	8. 57	87. 36
68. 65	.....do	10. 0	. 0322	. 32	15. 52	2. 48	5. 89	76. 08
79. 12	Clam-bearing bottom sediments	20. 0	. 0515	. 257	1. 47	. 97	4. 66	92. 81

[1]=not determined.

CHLORINOID PIGMENTS

Three kinds of organic pigments are most likely to be found in aquatic plants, animals, and sediments: (1) chlorinoid pigments, including chlorophylls and prophyrins; (2) carotenoids, including the orange pigments carotene and xanthophylls; and (3) flavoproteins, the yellow pigments and related N-heterocyclic substances (Swain, Paulsen, and Ting, 1964).

Several other natural organic pigments may be present in small amounts in aquatic materials: (1) flavonoids or anthoxanthins and anthocyanins, the coloring matter of flowers and fruits; (2) napthoquinones and anthroquinones, the coloring matter of tree bark and echinoids; (3) bile pigments; and (4) pterins, the yellow pigments of insects, fish scales, and animal urine. The present work has dealt with the chlorinoid pigments as these are the most abundant in the canal organisms and sediments.

In the canal samples studied, only pheophytin *a* from chlorophyll *a* has been found (figure 22). The source of the chlorophyll *a* is believed to be planktonic algae, especially diatoms, which enter the canal from San Joaquin River. Chlorophyll *c*, which also occurs in diatoms, has not been found in the samples examined.

The results for samples so far studied are shown in table 7. No trends can be seen on the basis of the present analyses, but it is obvious that pheophytin is accumulating in the sediments faster than it can be used as a food by other organisms in the canal.

The principal source of the pheophytin of the sediments associated with the clams probably is the waste products (excreta) of the clams. Protozoans, diatoms, and other algae eaten by the clams have in turn supplied the chlorophyll which gave rise to the pheophytin in the digestive tracts of the clams. Some additional pigment is probably contributed also from the periostracum layer of the clams.

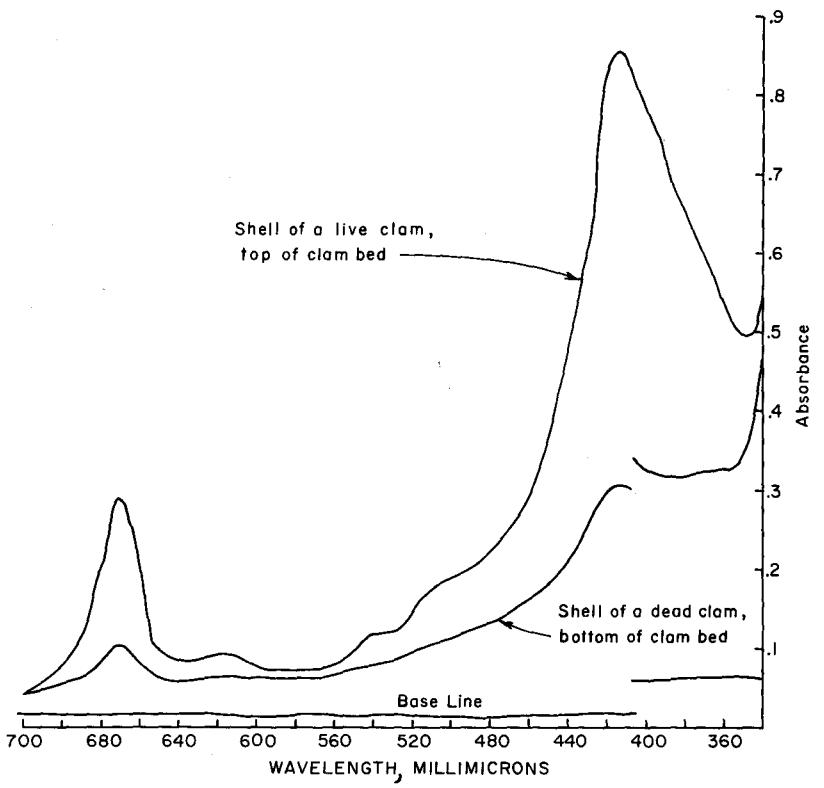


***Figure* 22.—Visible absorption spectra of 90 percent of acetone extracts of *Corbicula* shells collected at M.P. 79.12.**

TABLE 7.—*Chlorinoid pigment contents of typical canal benthos and sediments*

Location, M.P.	Sample	Dry weight, g	Sedimentary chlorophyll units, per gram
4. 63	*Corophium spinicorne* exoskeletons, side lining	0. 0922	2. 28
4. 7	.....do	. 0750	. 853
4. 7	Dead *Corophium* and amphipod-mud coating, from side lining	1. 0850	8. 479
4. 7	.....do	1. 0479	6. 905
4. 7	.....do	1. 023	15. 047
4. 7	*Plumatella sp.*, from side lining	. 1387	6. 26
4. 7	Mud coating associated with *Plumatella*	. 9463	7. 63
4. 7	.....do	1. 0397	6. 49
4. 97	.....do	. 9318	5. 47
75. 84	*Spongilla*, animal and skeleton, side lining	. 2602	14. 758
79. 12	.....do	. 2889	6. 854
75. 84	*Gnorimosphaeroma*, animal and exoskeleton	. 2437	. 628
4. 7	*Corbicula*, soft body of live mollusk	. 2154	9. 71
4. 97	.....do	. 1856	2. 20
9. 4	.....do	. 2238	2. 98
12. 5	.....do	. 1230	5. 27
16. 43	.....do	. 1813	3. 44
23. 9	.....do	. 1265	2. 93
27. 84	.....do	. 1607	4. 26
4. 7	*Corbicula*, shell of live mollusk	1. 2748	. 109
4. 97	.....do	1. 1538	. 062
9. 4	.....do	1. 1092	. 097
12. 5	.....do	1. 0196	. 035
16. 43	.....do	. 8560	0
23. 9	.....do	. 6152	. 093
27. 84	.....do	. 7732	. 098
12. 5	*Corbicula*, dead empty shell from the base of deposit	1. 0846	. 050
12. 5	.....do	. 9228	. 120
16. 43	.....do	. 8261	. 305
23. 9	.....do	. 8560	. 021
27. 84	.....do	. 5816	0
4. 97	Bottom sediments, blue-gray mud in middle of clam bed	1. 1740	43. 044
4. 97	Bottom sediments, brown mud beneath gray mud	. 9333	15. 560
4. 7	Bottom sediments, top layer with live *Corbicula*	1. 1678	38. 22
4. 97	.....do	1. 0010	27. 093
9. 4	.....do	. 7649	17. 680
12. 5	.....do	. 7358	47. 544
12. 5	.....do	. 6726	34. 438
16. 43	.....do	. 7211	31. 091
23. 9	.....do	. 4267	15. 503
27. 84	.....do	. 7713	12. 637
33. 0	.....do	. 5505	12. 817
37. 15	.....do	. 5783	35. 68
43. 24	.....do	. 6274	24. 60
46. 83	.....do	. 5354	31. 22
52. 01	.....do	. 5506	21. 18
56. 82	.....do	. 5383	41. 79
61. 72	.....do	. 5518	52. 328
68. 65	.....do	. 5526	40. 658
75. 84	.....do	. 6010	38. 692
79. 12	.....do	. 5008	62. 388
12. 5	Bottom sediments, with empty clam shells at the base of deposits	. 7520	7. 648
16. 43	.....do	. 7280	22. 85
23. 9	.....do	. 7935	1. 406
27. 84	.....do	. 5457	27. 408
33. 0	.....do	. 5424	18. 241
37. 15	.....do	. 5465	29. 336
43. 24	.....do	. 5728	31. 110
46. 83	.....do	. 5466	33. 69
52. 01	.....do	. 5398	41. 04
56. 82	.....do	. 5443	52. 21
61. 72	.....do	. 2844	50. 295
68. 65	.....do	. 5143	2. 275
74. 65	Bottom sediments, with empty dead shells at the base of deposits	. 3177	39. 814
75. 84	.....do	. 2622	36. 163
79. 12	.....do	. 5133	21. 353

CARBOHYDRATES

The analyses for total carbohydrates and for individual sugars are given in tables 8 and 9. The total carbohydrates of the sediments are relatively small in amount, but not enough analyses have been run for any trends to be recognized. As in the case of the pigments, there is an indication that more organic matter is being produced in the canal than can be used by existing organisms.

The monosaccharide contents of the samples so far studied indicate that the sediments associated with the canal organisms have a variety of the common monosaccharides that occur in aquatic plants. The monosaccharide content of *Corbicula fluminea* is principally glucose and galactose, but these and other sugars have not been separated satisfactorily from the clams.

The monosaccharide contents of several of the canal organisms range from about 3 x 10^{-4}g/g in the *Corbicula* shell to about 20 x 10^{-4}g/g in sediments associated with *Corbicula* and about 28 x 10^{-4}g/g in *Corophium*.

The carbohydrate contents of various recent lake sediments were shown by Rogers (1965) to range from 1.6 to 13.5 mg/g. Thus the Delta-Mendota Canal sediments are considerably lower in available carbohydrates than is typical of other organic sediments, and probably do not contribute appreciably to the food supplies in the canal.

Most of the common monosaccharides are present in the canal organic materials and include galactose, glucose, mannose, arabinose, xylose, ribose, and rhamnose.

TABLE 8.—*Total carbohydrate contents of samples from Delta-Mendota Canal*

Location, M.P.	Sample	Total carbohydrate, mg/g
4. 7	*Corophium*, exoskeletons from side lining, >0.84 mm. fraction	22. 8
4. 7	*Corophium* honeycomb, side lining, >0.84 mm. ø	19. 3
4. 7	*Corophium*, exoskeletons and associated sediments, side lining, >0.84 mm. ø	5. 6
4. 7	*Corophium*, exoskeletons and associated sediments, side lining, 0.18–0.84 mm. ø	6. 8
4. 7	.....do	17. 1
4. 97	*Plumatella sp.* and associated sediments, side lining, >0.84 ø	6. 0
4. 97	*Plumatella sp.* and associated sediments, side lining, 0.18–0.84 mm. ø	6. 4
4. 97	*Corbicula*, soft mollusk body	400. 0
4. 7	*Corbicula*, shell of live mollusk	4. 6
4. 97	.....do	2. 7
4. 7	Bottom sediments, upper layer with live *Corbicula*, 0.84 mm. ø	2. 7
4. 7	Bottom sediments, upper layer with live *Corbicula*, 0.18–0.84 mm. ø	7. 6
4. 97	Bottom sediments, upper layer with live *Corbicula*, >0.84 mm. ø	11. 8
4. 97	Gray mud at the base of clam layer, >0.84 mm. ø	6. 4
4. 97	Gray mud at the base of clam layer, 0.18–0.84 mm. ø	6. 9
4. 97	Brown mud with dead clams, >0.84 mm. ø	3. 6
4. 97	Brown mud with dead clams, 0.18–0.84 mm. ø	1. 8

TABLE 9.—*Monosaccharide contents of samples from Delta-Mendota Canal in 10^{-4} g/g of dry sample*

Location, M.P.	Sample	Galactose	Glucose	Mannose and arabinose [1]	Xylose	Ribose	Rhamnose	Total
4. 7	*Corophium spinicorne*, exoskeletons side lining	0	0	0	0	0	0	0
4. 7	Amphipod-mud coating, >0.84 mm. fraction	11. 14	6. 80	5. 06	1. 95	. 72	2. 45	28. 12
4. 7	Amphipod-mud coating, 0.18–0.84 mm. Ø	1. 51	1. 78	2. 58	2. 06	. 72	1. 36	10. 01
4. 7	*Plumatella sp.* and associated amphipod-mud coating, >0.84 mm. Ø	3. 27	3. 87	2. 95	1. 19	. 48	1. 61	13. 37
4. 7	*Plumatella sp.* and associated amphipod-mud coating, 0.18–0.84 mm. Ø	2. 23	1. 70	2. 34	. 87	. 55	. 54	8. 23
4. 7	*Corbicula fluminea*, soft mollusk body	[2]	[2]	(Good separation of monosaccharides not obtained)				
4. 7	*Corbicula fluminea*, shell of live mollusk	. 52	1. 00	1. 59	0	0	0	3. 11
4. 7	Bottom sediments, upper layer with live *Corbicula* >0.84 mm. Ø	3. 86	3. 83	6. 71	2. 28	1. 49	1. 96	20. 13
4. 7	Bottom sediments, upper layer with live *Corbicula* 0.18–0.84 mm. Ø	3. 95	6. 02	5. 54	1. 19	. 24	. 67	17. 61

[1] Both mannose and arabinose are present in the samples examined, but were not separated in the solvent system used for these analyses.
[2] Present.

PROTEIN AMINO ACIDS

The protein amino acids have been found to be preserved as residues in many different deposits of Recent sediment. The amino acids are preserved either as nitrogen-bonded peptides or are complexed with humic materials in the sediments (Swain, et al., 1959, 1964). The amino acids differ measurably in their thermal stability, as shown by Abelson (1957), by Jones and Vallentyne (1960), and by Vallentyne (1964). The individual acids also differ in their relative abundance and stability in aquatic sediments (Swain, 1961; Swain, et al., 1964). There is fair agreement between the thermal studies of Vallentyne and the data from natural materials.

The protein amino acids separated from canal materials are shown in tables 10A and 10B (figure 23). The amino acid cystine is low in amount or almost absent in the live clam specimens (figure 24) to a distance of about 25 miles. Farther down the canal, cystine occurs in increasing amounts. Cystine ($SCH_2CH(NH_2)COOH)_2$ is a major constituent of animal keratin. Much of the cystine in acid hydrolyzates, however, is in the form of the monosulfide cysteine $HSCH_2CHNH_2COOH$ as a result of hydrolytic degradation. The buildup of cystine and/or cysteine in the clam samples is at present unexplained, but may be due to a change in the food supply of the clams down the canal.

Four simplified representative examples of amino-acid chromatographs of canal organisms and sediments are shown on figure 23.

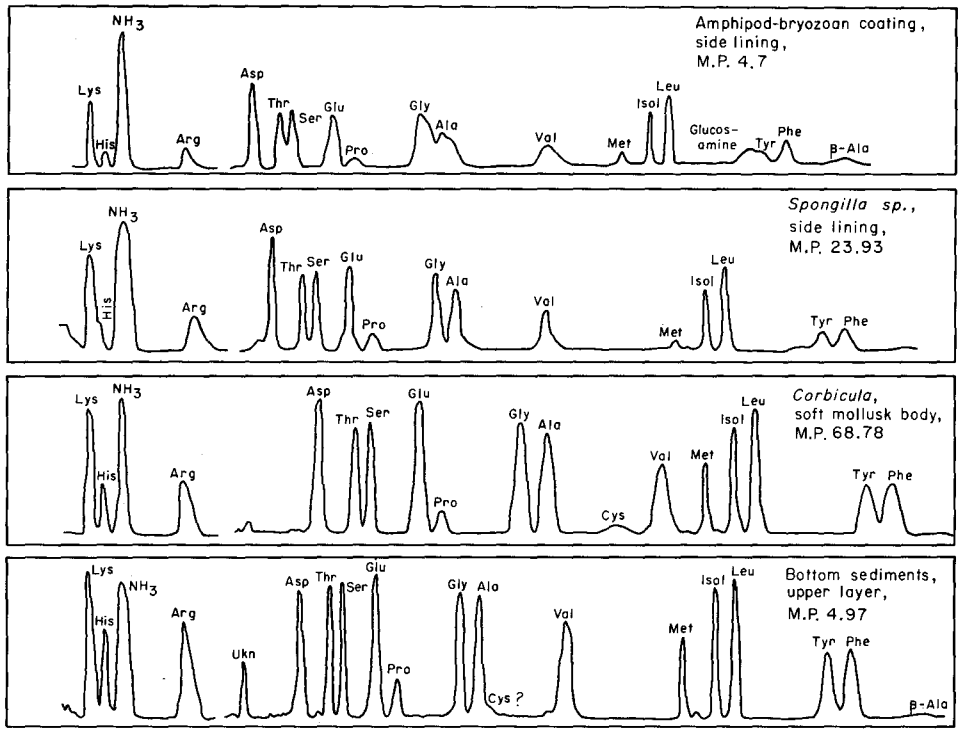


***Figure 23.*—Representative simplified amino acid chromatograms of samples from Delta-Mendota Canal.**

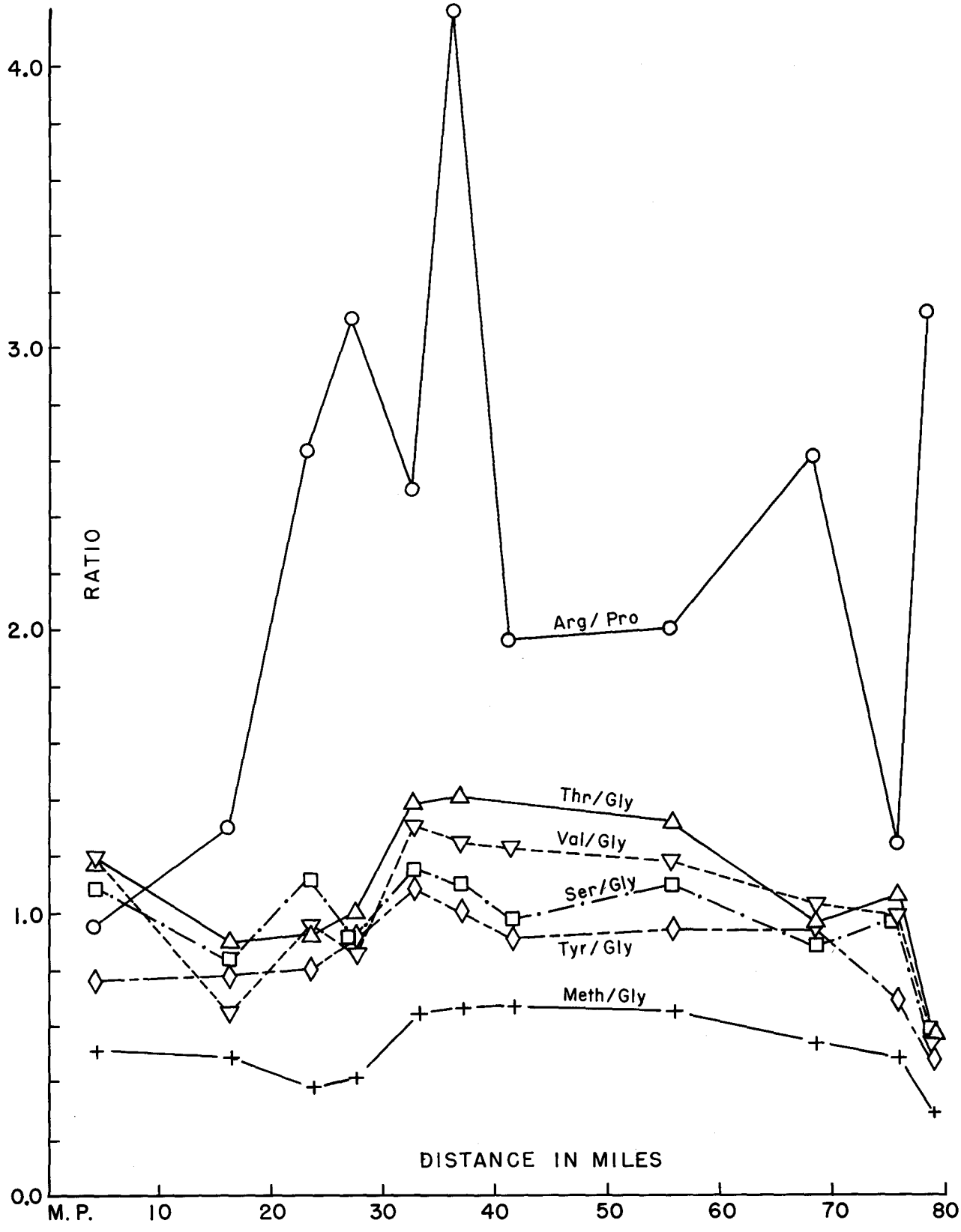


Figure 24.—Amino acid ratios in soft body of live *Corbicula* from Delta-Mendota Canal.

TABLE 10A.—*Amino acid analyses of samples from Delta-Mendota Canal*

[A. Neutral and acidic amino acids. Quantities are as 10^{-4} g/g of dry sample.]

Location, M.P.	Sample	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Cys	Val	Meth	Isol	Leu	Tyr	Phe	Total
4.7	*Corophium*, side lining	12.15	8.69	8.15	11.07	6.01	11.78	8.68	0	7.42	1.55	5.20	8.61	3.55	5.78	98.62
4.7	*Corophium*, >0.84 fraction	27.72	11.66	12.04	22.06	11.03	17.06	12.63	0	11.22	1.27	7.65	13.78	10.20	8.60	166.92
4.7	*Corophium*, 0.18–0.84 mm. ø	12.72	7.08	6.80	11.69	7.35	9.93	7.28	0	6.38	0	4.77	8.78	7.24	5.27	95.29
4.7	*Corophium*, wet, >0.84 mm	17.64	9.29	9.46	13.24	5.18	14.27	10.47	0	9.37	1.91	6.23	11.81	5.43	6.60	120.90
4.7	*Corophium*, wet, 0.18–0.84 mm. ø	11.19	7.57	6.81	9.44	8.24	10.93	8.51	0	6.99	.25	4.40	7.75	5.18	5.66	92.92
4.7	Amphipod-mud coating, side lining, >0.84 mm. ø	28.16	12.83	12.53	23.48	12.40	17.33	12.85	0	11.48	.14	8.07	14.38	8.36	9.52	171.53
4.7	Amphipod-mud coating, side lining, 0.18–0.84 mm. ø	14.31	6.88	6.36	12.98	6.59	9.43	6.82	0	6.15	0	4.36	7.64	6.20	5.12	92.84
4.7	*Plumatella sp.*, side lining	206.04	106.24	89.55	183.58	100.83	157.41	119.39	0	95.09	0	60.88	106.53	150.68	71.32	1,447.54
4.7	*Plumatella* and associated sediments, side lining, >0.84 mm. ø	14.65	10.44	10.29	13.00	6.96	14.40	11.94	Trace	12.19	2.13	6.56	11.73	5.93	7.45	127.13
4.7	*Plumatella* and associated sediments, side lining, 0.18–0.84 mm. ø	13.78	8.23	8.31	12.81	5.78	12.24	11.23	0	9.34	1.49	5.18	9.13	3.50	7.42	108.34
4.7	.....do	8.33	5.96	5.47	7.07	5.06	8.03	13.89	0	5.73	1.04	5.43	7.50	1.68	4.09	79.34

23. 93	Fresh water sponge, side lining	201. 65	105. 02	97. 31	188. 29	95. 21	85. 16	85. 51	0	83. 18	13. 37	6. 41	115. 18	59. 73	62. 82	1, 198. 84
4. 7	*Corbicula*, soft mollusk body	502. 14	253. 08	229. 30	568. 33	175. 26	209. 93	223. 25	0	252. 83	111. 04	231. 08	329. 48	162. 57	129. 15	3, 427. 51
4. 7	.....do	519. 09	265. 99	213. 70	588. 40	185. 12	186. 50	225. 72	0	257. 62	120. 11	216. 04	330. 19	175. 06	196. 19	3, 479. 73
16. 43	.....do	583. 64	269. 76	247. 51	779. 92	282. 34	302. 05	275. 94	0	294. 38	149. 20	285. 18	393. 86	236. 52	222. 39	4, 322. 69
23. 93	.....do	629. 96	279. 53	331. 80	764. 92	266. 34	299. 65	274. 07	0	284. 32	114. 29	269. 22	424. 17	240. 50	240. 55	4, 419. 32
27. 84	.....do	383. 16	176. 84	161. 78	468. 04	185. 55	179. 32	125. 27	0	154. 71	74. 14	159. 82	248. 88	161. 34	152. 04	2, 630. 94
33. 00	.....do	789. 42	406. 86	334. 62	984. 39	349. 80	293. 84	325. 68	194. 54	385. 22	190. 70	371. 28	579. 09	316. 40	334. 75	4, 969. 90
37. 15	.....do	664. 47	335. 77	260. 53	746. 53	183. 93	239. 89	199. 79	102. 10	297. 25	159. 24	289. 90	424. 63	237. 50	243. 21	4, 334. 19
43. 34	.....do	606. 54	278. 69	221. 55	651. 65	241. 71	231. 08	228. 27	112. 98	282. 21	155. 17	259. 78	383. 10	219. 13	227. 01	4, 098. 87
56. 82	.....do	798. 60	442. 77	365. 38	957. 88	348. 25	339. 72	545. 08	180. 00	392. 97	215. 02	344. 59	584. 23	296. 14	456. 43	6, 267. 16
68. 75	.....do	739. 02	347. 09	326. 31	914. 12	285. 56	377. 65	386. 10	52. 66	377. 51	196. 09	359. 86	571. 66	333. 20	401. 66	5, 668. 49
75. 84	.....do	891. 80	440. 67	408. 52	1, 176. 80	345. 30	427. 09	590. 29	219. 38	414. 24	201. 43	334. 56	615. 00	276. 16	429. 24	6, 780. 48
79. 12	.....do	560. 71	267. 97	262. 75	760. 75	226. 77	541. 67	287. 25	237. 24	276. 15	243. 63	690. 43	395. 56	250. 69	267. 35	5, 068. 92
4. 97	*Corbicula*, shell of live mollusk	26. 07	4. 07	5. 69	7. 97	9. 59	40. 37	4. 08	1. 70	6. 34	2. 74	3. 94	5. 74	14. 56	12. 73	145. 59
16. 43	*Corbicula*, shell of dead mollusk	13. 87	1. 57	2. 13	2. 79	5. 57	24. 62	1. 17	. 93	2. 49	21. 25	1. 27	1. 82	6. 88	3. 68	90. 04
4. 97	Bottom sediments, upper layer with live clams >0.84 mm. Ø	16. 99	8. 09	7. 57	14. 67	5. 92	11. 11	7. 81	0	6. 89	0	4. 51	8. 06	5. 49	6. 02	103. 13
27. 84	Clam bearing bottom sediments	7. 29	3. 16	3. 38	6. 66	4. 18	3. 63	3. 09	(Incomplete analysis due to failure of buffer change)							
37. 15	.....do	8. 78	3. 39	4. 01	7. 62	4. 59	8. 85	3. 60	0	3. 71	1. 26	5. 48	4. 75	3. 46	2. 08	61. 58
43. 24	.....do	3. 76	1. 75	1. 50	2. 87	1. 66	5. 91	1. 34	0	1. 66	. 63	1. 15	1. 95	2. 14	1. 32	27. 64
75. 84	.....do	12. 04	6. 68	5. 30	6. 38	9. 06	14. 42	2. 13	0	3. 82	1. 30	2. 40	3. 76	2. 94	2. 94	73. 17
95. 1	.....do	13. 37	6. 68	7. 79	11. 26	5. 67	10. 36	7. 73	Trace	6. 62	. 58	5. 69	8. 51	5. 12	6. 12	95. 50
4. 97	Brown mud, bottom sediment	. 24	. 12	. 14	1. 96	Trace	. 16	. 16	0	Trace	0	0	0	0	0	0

TABLE 10B.—*Amino acid analyses of samples from Delta-Mendota Canal*

[B. Basic amino acids. Quantities are as 10^{-4}g/g of dry sample]

Location, M.P.	Sample	Lys	His	NH_3	Arg	Glucose-amine	Basic aa	Total aa
4. 7	*Corophium*, side lining	13. 54	3. 79	8. 83	10. 35	Present	36. 51	135. 13
4. 7	*Corophium*, >0.84 fraction	20. 18	5. 25	9. 92	15. 07	(?)	50. 42	217. 34
4. 7	*Corophium*, 0.18–0.84 mm. Ø	10. 96	3. 15	10. 06	8. 23	0	32. 40	127. 69
4. 7	*Corophium*, wet, >0.84 mm	16. 23	4. 66	9. 79	13. 29	(?)	43. 97	164. 87
4. 7	*Corophium*, wet, 0.18–0.84 mm. Ø	11. 21	3. 14	14. 39	9. 04	(?)	37. 78	130. 70
4. 7	Amphipod-mud coating, side lining, >0.84 mm. Ø	21. 09	5. 67	7. 03	16. 18	Present	49. 87	221. 40
4. 7	Amphipod-mud coating, side lining, 0.18–0.84 mm. Ø	11. 33	. 31	6. 38	8. 71	0	26. 73	119. 57
4. 7	*Plumatella sp.*, side lining	26. 08	6. 33	35. 08	23. 13	0	90. 62	1, 538. 16
4. 7	*Plumatella* and associated sediments, side lining, >0.84 mm. Ø	16. 50	3. 81	8. 50	13. 97	Present	42. 79	169. 92
4. 7	*Plumatella* and associated sediments, side lining, 0.18–0.84 mm. Ø	12. 63	3. 25	6. 89	9. 89	Present	332. 69	141. 00
4. 7	.....do	8. 85	2. 25	7. 37	5. 90	Present	24. 42	103. 76
23. 93	Fresh water sponge, side lining	129. 50	42. 67	49. 18	90. 38	0	311. 73	1, 510. 57
4. 7	*Corbicula*, soft mollusk body	440. 91	144. 29	159. 39	170. 12	0	914. 71	4, 342. 22
4. 7	.....do	445. 91	137. 09	50. 72	348. 40	0	982. 12	4, 461. 85
16. 43	.....do	420. 92	213. 59	77. 74	366. 44	0	1, 078. 19	5, 400. 88
23. 93	.....do	894. 98	327. 67	253. 64	728. 19	0	2, 204. 84	6, 624. 16
27. 84	.....do	665. 78	213. 17	192. 12	575. 06	0	1, 646. 13	4, 277. 07
33. 00	.....do	994. 56	270. 53	127. 58	878. 19	0	2, 270. 86	7, 240. 76
37. 15	.....do	772. 58	205. 34	95. 13	768. 50	0	1, 841. 55	6, 175. 74
43. 34	.....do	275. 94	128. 85	52. 87	473. 28	0	930. 74	5, 029. 61
56. 82	.....do	438. 60	251. 92	138. 46	693. 78	0	1, 522. 76	7, 789. 92
68. 75	.....do	1, 006. 18	482. 53	122. 77	744. 31	0	2, 355. 79	8, 024. 28
75. 84	.....do	866. 23	399. 65	241. 83	840. 53	0	2, 348. 24	9, 128. 72
79. 12	.....do	762. 64	413. 48	69. 27	704. 60	0	1, 949. 99	7, 018. 91
4. 97	*Corbicula*, shell of live mollusk	12. 43	7. 76	7. 93	7. 26	0	35. 38	180. 97
16. 43	*Corbicula*, shell of dead mollusk	2. 53	2. 39	26. 08	3. 08	0	34. 08	124. 12
4. 97	Bottom sediments, upper layer with live clams (>0.84 mm. Ø)	13. 24	4. 02	10. 30	9. 48	Trace	37. 04	140. 17
27. 84	Clam-bearing bottom sediments	8. 09	2. 25	8. 04	6. 33	0	24. 70	(1)
37. 15	.....do	14. 90	6. 21	9. 74	10. 57	0	41. 42	103. 00
43. 24	.....do	4. 13	1. 49	5. 03	3. 96	0	14. 61	42. 25
75. 84	.....do	15. 87	5. 57	38. 58	11. 02	0	71. 04	144. 21
95. 1	.....do	6. 99	3. 10	5. 30	4. 24	0	19. 63	115. 13
4. 97	Brown mud, bottom sediment	8. 04	2. 22	6. 06	6. 16	0	22. 48	0

[1] Incomplete analysis.

AMINO ACID RATIOS IN CANAL MATERIALS

In a study of the thermal stability of protein amino acids, Vallentyne (1964) showed that several amino acids degrade to other common amino acids as follows:

Valine	>glycine.
Serine	>glycine, alanine, and ethanolamine.
Threonine	>glycine.
Methionine	>glycine, alanine, amino-butyric acid.
Tyrosine	>glycine.
Arginine–HCL	>proline, near ornithine.

The ratios of these amino acids in the canal samples of *Corbicula fluminea* and in a few of the associated sediments are shown in figures 24 and 25 and table 11. The rather irregular nature of the ratios val/gly, ser/gly, and arg/pro in *Corbicula* in the upper 30 miles of the canal may be due to the heterogeneous nature of the other organic matter of the canal that contributes to the food supply of *Corbicula*. The relative uniformity of the ratios, other than arg/pro, between 30 and 75 miles perhaps indicates a constancy of food supply of the clams in that part of the canal. The striking increase at 79 miles in glycine relative to threonine, valine, serine, tyrosine, and methionine suggests that protein degradation may be taking place in some of the clams in the lower part of the canal. Whether this is the result of some change in the food supply or of another environmental factor cannot be determined at present.

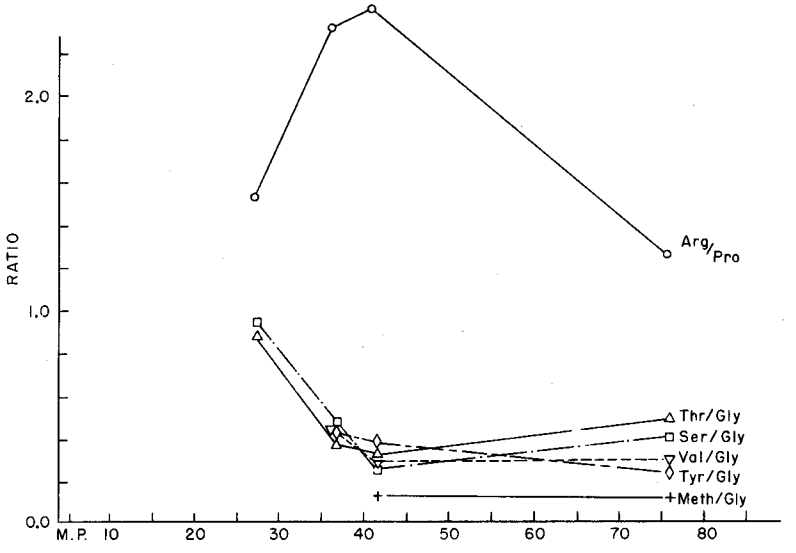


***Figure 25.*—Amino acid ratios in clam-bearing sediments from the invert of Delta-Mendota Canal.**

TABLE 11.—*Amino acid ratios in Delta-Mendota Canal materials*

Location, M.P.	Sample	Val/Gly	Ser/Gly	Thr/Gly	Meth/Gly	Tyr/Gly	Arg/Pro
4. 7	*Corophium spinicorne*, side lining	0. 63	0. 69	0. 74	0. 13	0. 30	1. 72
4. 7	*Plumatella sp.* and assoc. sed., >0.84 mm. fraction, side lining	. 85	. 71	. 73	. 15	. 41	2. 01
4. 7	.....do	. 76	. 68	. 67	. 12	. 29	1. 71
4. 7	.....do	. 71	. 68	. 74	1. 3	. 21	1. 17
23. 93	*Spongilla fragilis*, side lining	. 98	1. 14	1. 23	. 16	. 70	. 95
16. 43	*Corbicula fluminea*, shell of dead mollusk	. 10	. 09	. 06	. 86	. 28	. 55

PLANKTON SAMPLES

In March 1967, plankton net samples were obtained from 15 stations along the canal at the time of the spring plankton bloom. They were frozen and used for determinations of ash content, loss on ignition, and chlorophyll pigment (table 12). Protein amino acids were obtained for two samples (table 13A and 13B). The values for ignition loss clearly show the highly organic and nutritive nature of the plankton, and its potential as a source of food for *Corbicula* and other canal organisms.

The plankton samples (actually seston) consist of the following organisms as tentatively identified:

(1) Diatomaceae, many types.
(2) Chlorophyceae (green algae).
(3) Cladocera.
(4) Cyclopoida.
(5) Seeds.
(6) Large plant fragments.
(7) Egg cases and other spheroidal organic bodies.
(8) Bryozoans.
(9) *Corophium.*
(10) Sponges.
(11) Insect parts.

In addition to which, mica flakes and other mineral grains are present in more or less abundance.

The chlorophyll-bearing planktonic organisms occurred throughout the entire canal during the March sampling.

The amino acid contents of the two plankton samples analyzed differ by more than an order of magnitude and may indicate a marked reduction in available protein content of the plankton down the canal. More samples should be run on plankton organic matter.

TABLE 12.—*Chlorophyll content, ash, and ignition loss of plankton net samples from the Delta-Mendota Canal*

Location, M.P.	Ash, percent	Ignition loss, percent	"Sedimentary Chlorophyll" (ash-free)	Chlorophyll, mg/g
1. 42	77. 03	22. 97	108. 1	46. 7
4. 41	79. 44	20. 56	205. 5	88. 8
14. 80	87. 86	17. 14	525. 1	226. 8
24. 48	63. 59	36. 41	141. 2	61. 0
34. 39	83. 87	16. 13	334. 2	144. 4
42. 53	68. 57	31. 43	121. 6	52. 5
51. 40	83. 61	16. 39	433. 9	187. 4
61. 06	61. 18	38. 82	152. 2	65. 7
68. 03	76. 39	23. 61	283. 5	122. 5
75. 84	81. 33	18. 67	290. 7	125. 6
84. 38	72. 29	27. 71	99. 2	42. 9
92. 73	70. 40	29. 60	169. 1	73. 1
98. 82	86. 84	13. 16	237. 8	102. 7
106. 58	81. 92	19. 08	280. 9	121. 3
111. 51	85. 84	14. 16	321. 6	138. 9

TABLE 13A.—*Amino acid analyses of plankton net samples from Delta-Mendota Canal*

[A. Neutral and acidic amino acids. Quantities are as 10^{-4} g/g of dry sample.]

Location, M.P.	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Cys
14. 80	439. 55	189. 55	207. 69	468. 22	213. 71	286. 86	232. 80	0
84. 38	19. 10	9. 52	10. 15	16. 65	8. 61	15. 29	11. 94	0

Location, M.P.	Val	Meth	Isol	Leu	Tyr	Phe	Total
14. 80	209. 67	27. 71	172. 67	261. 01	353. 08	254. 01	3, 316. 53
84. 38	9. 36	. 93	6. 54	11. 17	8. 27	7. 71	135. 24

TABLE 13B.—*Amino acid analyses of plankton net samples from Delta-Mendota Canal*

[B. Basic amino acids. Quantities are as 10^{-4} g/g of dry sample.]

Location, M.P.	Lys	His	NH_3	Arg	Glucose-amine	Basic aa	Total aa	Ignition loss
14. 80	112. 47	228. 47	190. 97	140. 93	0	672. 84	3, 989. 37	17. 14
84. 38	4. 71	8. 38	8. 61	3. 80	0	25. 50	160. 74	27. 71

RELATIONSHIP OF ALGAL AND OTHER ORGANIC GROWTH CONTROL PROBLEMS IN DELTA-MENDOTA CANAL TO THOSE OF OTHER AREAS

Algal cells in the water of the canal form the basic food supply for other organisms.

The control of algal growth in waters by the use of copper sulfate has been studied for many years (Moore and Kellerman, 1905). For example, sewage effluent from Madison, Wis., into Lake Monona was treated with copper sulfate as early as 1918 (Frey, 1963; Domogalla, 1935). Although the long-term effects of copper sulfate accumulation in sediments has been of concern, studies by Mackenthun and Cooley (1952) showed that the present levels of copper sulfate in Lake Monona are not toxic to any extent even to the clam *Pisidium,* over a 60-day observation period.

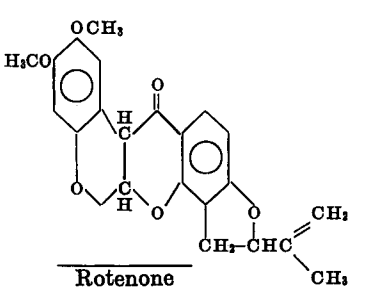
Of the various elements in lake waters essential to the growth of the alga *Microcystis aeruginosa,* only nitrogen, phosphorus, and iron were found to be likely limiting factors (Gerloff and Skoog, 1954). The critical minimum cellular concentration of nitrogen in *Microcytis* (necessary for maximum growth) was determined to be about 4 percent and of phosphorus, 0.12 percent. It was found experimentally that variation in the carbohydrate contents of the cells affected the critical level of nitrogen and that values below 4 percent pertained with certain increased carbohydrate contents. Nitrogen, in many natural waters, is present in considerably less abundance relative to need than are phosphorus and iron. Reduction of the nitrogen supply is regarded as the best means for algal control in many natural waters.

Fitzgerald and Skoog (1954) screened about 300 organic compounds for selective toxicity to bloom-producing blue-green algae. They found 2, 3-dichloronaphthoquinone to be most effective in reducing blooms of blue-green algae, with no observable harmful effects on other organisms.

The biological effects of copper sulfate treatment and of other uses of algicides and herbicides have been discussed by Nichols, *et al,* (1947) and Mackenthun and Cooley (1952). According to Tarzwell (1963), copper sulfate is the most widely used material for the prevention of control of algal blooms in water supplies. Of the other algicides now on the market, some are more expensive and all have drawbacks of broad-spectrum chemical toxicants to some degree. Besides being costly, use of chemical algicides may act to reduce the effectiveness of other biological controls such as predators, competitors, and parasites. Species resistant to the algicide may develop, requiring increased dosages to the point where concentrations lethal to fish or other organisms may be reached. In water below pH 7, copper sulfate can be toxic to fish in concentration of 0.04 part per million.

Studies of anti-algal species of actinomycetes, fungi, and bacteria have shown some promise. Two such species were found (Tarzwell, 1963) which produce anti-metabolite substances specific for blue-green algae, but they have so far been difficult to isolate and recover.

One of the chemical substances used rather widely as an insect and fish poison is the hydrocarbon rotenone,



Rotenone

which is obtained from ground derris roots. According to Fukami, *et al* (1967), the chemical is effective as follows: the enzyme system involved in the coupled oxidation of reduced nicotinamide-adenine-dinucleotide ($NADH_2$) and the reduction of cytochrome *b* is inhibited by very low concentrations of rotenone. The effect is apparently true whether the enzyme system is derived from species that are highly susceptible or

are resistant to rotenone (Fukami, 1956; Fukami and Tomizawa, 1956; Lindahl and Oberg, 1961; and Ernster, Dallner, and Azzone, 1963). Species differences apparently account for effectiveness of rotenone rather than differences in $NADH_2$ oxidation systems in susceptible and resistant species (Fukami, 1961; O'Brien, 1966).

Experimentation with application of rotenone-6-C^{14} to the enzyme system consisting of the microsome fraction and reduced nicotinamide-adenine-dinucleotide phosphate ($NADPH_2$) and to living mice and house flies gave the following results. The products of hydroxylation were identified as: rotenolone I, rotenolone II, 8″-hydroxyrotenone, 6′, 7′dihydro-6′, 7′-dihydroxyrotenone; two rotenolones of each of the last-mentioned compounds, and uncharacterized polar materials. Several of these metabolites exhibit approximately the same toxicity to mice as does rotenone.

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ABSTRACT

Numerous deposits of unusual clam-bearing sediments and an extremely abundant benthos of amphipods and fresh-water sponges on the canal lining were observed during each of several dewaterings of the Delta-Mendota Canal.

A biogeochemical study of sediments and some organisms from the canal showed a relationship of organic materials to nutritive condition of the water, pH, Eh, and oxygen content. The canal waters are well aerated (10–13 mg/L). The invert (canal-bottom) sediments are generally poorly aerated (1–7 mg/L), have negative oxidation-reduction potentials, and show reducing conditions. Small amounts of saturated and aromatic hydrocarbons occur in benzene-methanol extracts of sediments and organisms. Relatively large amounts of chlorophyll-derived pigments throughout canal sediments indicate good preservative conditions for organic matter. Carbohydrates are low throughout the canal. Protein amino acids and organic acids are plentifully entrapped in the sediments and represent a large nutritive source that tends to be lost by decay in the canal rather than to be transferred to irrigation waters.

Benthonic biomasses as well as sediment masses of the canal decrease downstream, perhaps as interrelated phenomena.

DESCRIPTORS—amino acids/amphipods/aquatic animals/benthos/biogeochemistry/California/canals/carbohydrates/Central Valley Project/chlorophyll/clams/diatoms/dissolved oxygen/food chain/hydrogen-ion concentration/lipids/nutrients/organic matter/oxidation-reduction potential/plankton/proteins.
IDENTIFIERS—Delta-Mendota Canal.

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