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Land Treatment of Menhaden Waste Water by Overland Flow

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Land Treatment of Menhaden Waste Water by Overland Flow

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ABSTRACT

From April through August, 1974, menhaden processing waste water from an industrial plant near Dulac, Louisiana was partially reclaimed using land treatment by overland flow. The waste was pumped from a primary treatment pond after screening, and was spray-discharged at a rate of 5.08 cm (2 in) per week onto a naturally vegetated spoil bank of clay soil material (6 percent slope, 30 m long). The effluent flowed unevenly through the plant cover and litter layer. The effluent, with total organic carbon, nitrogen, and phosphorus concentrations of 800, 600, and 50 mg/l, respectively, was purified by the action of the soil-plant system, reducing the waste nutrient load an average of 58, 51, and 53 percent for C, N, and P, respectively. The soil-plant system removed an average of 814, 581, and 47 kilograms per hectare of carbon, nitrogen, and phosphorus, respectively, over the five month period. Roseau cane, *Phragmites communis*, the dominant plant on the slope, increased in live standing crop by 55 percent and in nitrogen and phosphorus by 47 and 13 percent, respectively. Levels of groundwater nitrogen just exceeded 10 mg/l at a depth of 30 cm after five months. Waste total coliform MPN was diminished by 66 percent over the slope. Regression analysis indicates that higher levels of C, N, and P may be removed from the waste if the slope length were increased. Uneven flow of the waste over the spoil bank indicated that mechanical grading and sloping would be necessary to allow greater

reclamation of the waste. Because of the suitability of overland flow techniques for waste water treatment, dredge spoil disposal sites in South Louisiana are recommended for advanced waste water treatment where favorable waste effluent composition, climate, and soil-plant systems are available.

INTRODUCTION

Soil methods for treating and disposing of liquid wastes from food related industries are widely used. By 1973, 1,300 industrial plants including more than 300 canneries were using some form of land treatment (Godfrey, 1973).

Bendixon (1969) describes the factors governing the attractiveness to food processing industries of soil methods for treating and disposing of wastes: (1) food wastes have a high organic content and are difficult to handle by conventional methods; (2) plant operation is often seasonal with all or a large part of the waste water concentrated into a period of a few months; (3) plants often are located in small towns or rural areas where municipal treatment facilities are not adequate to handle extreme seasonal loads; and (4) land treatment offers a high degree of flexibility, and in most cases, costs are favorable compared to alternatives.

Land treatment of waste water and sewage is a natural recycling process that combines the soil and plant ecosystems with the applied effluent. Purification of the waste water is carried on by the microbiota, the plant community, and the chemical and the mechanical action of the soil. Land treatment processes as opposed to disposal techniques are designed to effect the best possible benefits to the environment while producing a renovated water resource.

Soil is the most important parameter in planning land treatment programs. Three designs of land treatment are commonly

used depending upon the soil composition, porosity, and drainage qualities: rapid infiltration, spray irrigation, and overland flow (Pound and Crites, 1973; Reed et al., 1972). Rapid infiltration is commonly used in arid areas with well drained gravel or sandy soils. Purification takes place by microbial and mechanical action as the effluent percolates through the soil column. An important side benefit is ground water recharge. Spray irrigation methods purify waste mainly by infiltration and percolation of effluent through the soil column and incorporation of the waste into the vegetative growth cycle. At Pennsylvania State University successful renovation of waste water by spray irrigation has been continuously practiced since 1963. The combined action of the living and nonliving components of the soil column where purification occurs has been termed the "living filter" because of its natural recycling character (Kardos, 1967, 1970; Parizek et al., 1967; Pennypacker et al., 1967).

Overland flow is the most recent and least studied of the three methods. Poorly drained and impermeable soils with vegetative cover have been found to provide satisfactory treatment of effluent wastes when these wastes are allowed to flow slowly over an evenly sloped surface. This "grass filtration" has been used predominantly for the disposal of cannery wastes (Gilde, 1967, 1970). In addition, low-lying areas such as deltaic plains built from alluvial clays over high water tables, provide opportunities for land treatment by overland flow where other modes requiring unsaturated well-drained soils are impractical.

The most investigated and successful overland flow operation is the Campbell's Soup cannery in Paris, Texas where waste water is applied along the top of carefully prepared terraced slopes (C.W. Thornthwaite Associates, 1969). Eroded land formally used for cotton fields was graded into terraced watersheds between 2 to 10 acres in area from 200 to 300 feet in length, and at inclines between 2 and 12 percent. At the end of each watershed, a receiving stream collected the runoff from spray application after flowing slowly through water-tolerant grasses. The planted grass serves several purposes: (1) it protects the soil surface from erosion by retarding the flow of water across the slope; (2) it provides a protected habitat for microorganisms and a vast surface area for the absorption of impurities contained in the water; and (3) when cut for hay, it is a valuable cash crop that provides an effective means for reclaiming plant nutrients from the organic waste (Gilde, 1970). The runoff from the slope accounted for 60 percent of the effluent applied, while evapotranspiration and infiltration accounted for 20 percent each. Microbial and soil activity removed over 90 percent of the nitrogen, phosphorus, and organic carbon from the cannery waste. Uptake of N and P by reed canary grass (*Phalaris arundinacea*) was 62 and 10 pounds, respectively, per ton of grass.

Objectives

Land treatment seemed a promising method of waste water reclamation and recycling for trial use in the coastal zone of Louisiana because of the lack of water treatment facilities,

saturated soils, the high costs of water pollution, the imminent requirement for "zero discharge", and the desire to preserve and improve the quality of the coastal wetlands. Hence, from April through August, 1974, the author under auspecies of the Department of Marine Sciences and the Office of Sea Grant Development of Louisiana State University in cooperation with Zapata Haynie Corporation and the Stream Control Commission conducted a study to determine the general feasibility of using overland flow on naturally vegetated dredged spoil banks by measuring: (1) the effluent quality at distances down slope from the point of discharge; (2) the ground water quality at distances down slope from the point of discharge; (3) the efficacy of the plant cover in removing plant nutrients from the applied waste and its response to the treatment in live standing crop; (4) the microbial activity of the soil surface in the treated site; (5) any change in soil chemistry; and (6) the effect of treatment runoff on receiving marsh areas.

DESCRIPTION OF THE AREA

The Zapata Haynie Corporation is located on the eastern bank of the Houma Navigation Canal proximal to Bayou Grand Caillou, south of Dulac, Louisiana (Figure 1). The company processes Gulf menhaden (Brevoortia patronus) into commercial fish meal, solubles, and oils. Full time fishing and plant operations continue throughout the legal fishing season from mid April to mid October each year. The menhaden caught in the Gulf of Mexico are ferried to the shore plant in Dulac by way of the Houma Navigation Canal. Canal water is pumped into the fish laden holds of the ships at dockside to aid in the transferral of menhaden from the ship to the plant.

There are two main waste water components from the plant process (Figure 1A). Stickwater, a fairly high protein liquid, when not used in solubles production makes up a considerable portion of the industrial waste stream (Rao and Pike, 1972). From pumping of the fish in ship-to-shore transport, high organic waste water results from shredded portions of menhaden entering the transfer or bail water. The plant formerly pumped both waste effluents into a settling pond adjacent to the canal where gravitational flow separated out most of the particulate matter. The pond effluent was subsequently discharged into the canal. However, because of recent pollution and treatment requirements, advanced treatment facilities were constructed and the settling pond operation terminated. The impounded waste water was deemed suitable for the experimental purposes.

In 1972, the dredged levee of the settling pond facing the enclosed marsh broke open and waste water flowed into the marsh, polluting the area as far north as station 4 (Figure 1). Levels of nitrogen and phosphorus in the marsh water prior to the experiment are listed in Table 1.

The most acceptable natural slope for overland flow is located on the eastern bank of the canal 300 m (1,000 ft.) north of the settling pond (Figure 1). The canal bank averages 2.5 m (6 ft.) in height above water level and extends over 30 m (100 ft.) into an enclosed fresh water marsh with variable slopes due to uneven compaction and erosion. The average slope is about 6 percent.

The canal bank, deposited during the dredging of the navigation canal in 1962, is heterogeneous in character, composed of irregular distributions of silt and clay. Analysis of selected chemical properties of the spoil material is presented in Table 2. Brupbacher (personal communication) classifies the canal bank as mineral soil material. The canal bank vegetation was sampled and identified by J. Monte and M. Carroll of the Geography and Botany departments, respectively, at LSU (Table 3). There is dense hetergeneous plant cover on the bank, but patterns of growth are discernable. Phragmites communis, the dominant species, is observed throughout the length of the slope and in the marsh. Trees and shrubs on the slope are: Ilex decidua, Ilex vomitoria, Melia azedarach, Myrica cerifera, Rubis sp., Salix nigra, and Sambucus canadensis. Downslope Baccharis halimifolia increases in numbers. Figure 2 presents the distribution of the vegetation in the experimental and surrounding area.

The enclosed marsh is classified by its salinity range and vegetation as a fresh water marsh (Chabreck, 1972). Major species are: Alternanthera philoxeroides, Lemna minor, Phragmites communis, Sagittaria falcata, Scirpus validus, and Spartina patens (Table 3). Extensive open water covers over half of the enclosed marsh. No salinity was detectable by refractometer. Flushing of the marsh is poor with the only flow occurring through a 1 m (3 ft.) diameter culvert in the northeast corner of the marsh. The marsh floor is up to 3 feet below the free surface. The marsh soil material near Dulac is a mucky peat with 79.13 percent organic matter (Brupbacher et al., 1973) (Table 3).

DeMont (1974) sampled aquatic fauna in the spray runoff and culvert areas (Table 4). In areas not covered by living Lemna minor, the marsh floor near the runoff zone was dominated by the tubificid worm, Limnodrilus profundicola. In areas where L. profundicola was present, the worm comprised more than 85 percent of the biomass.

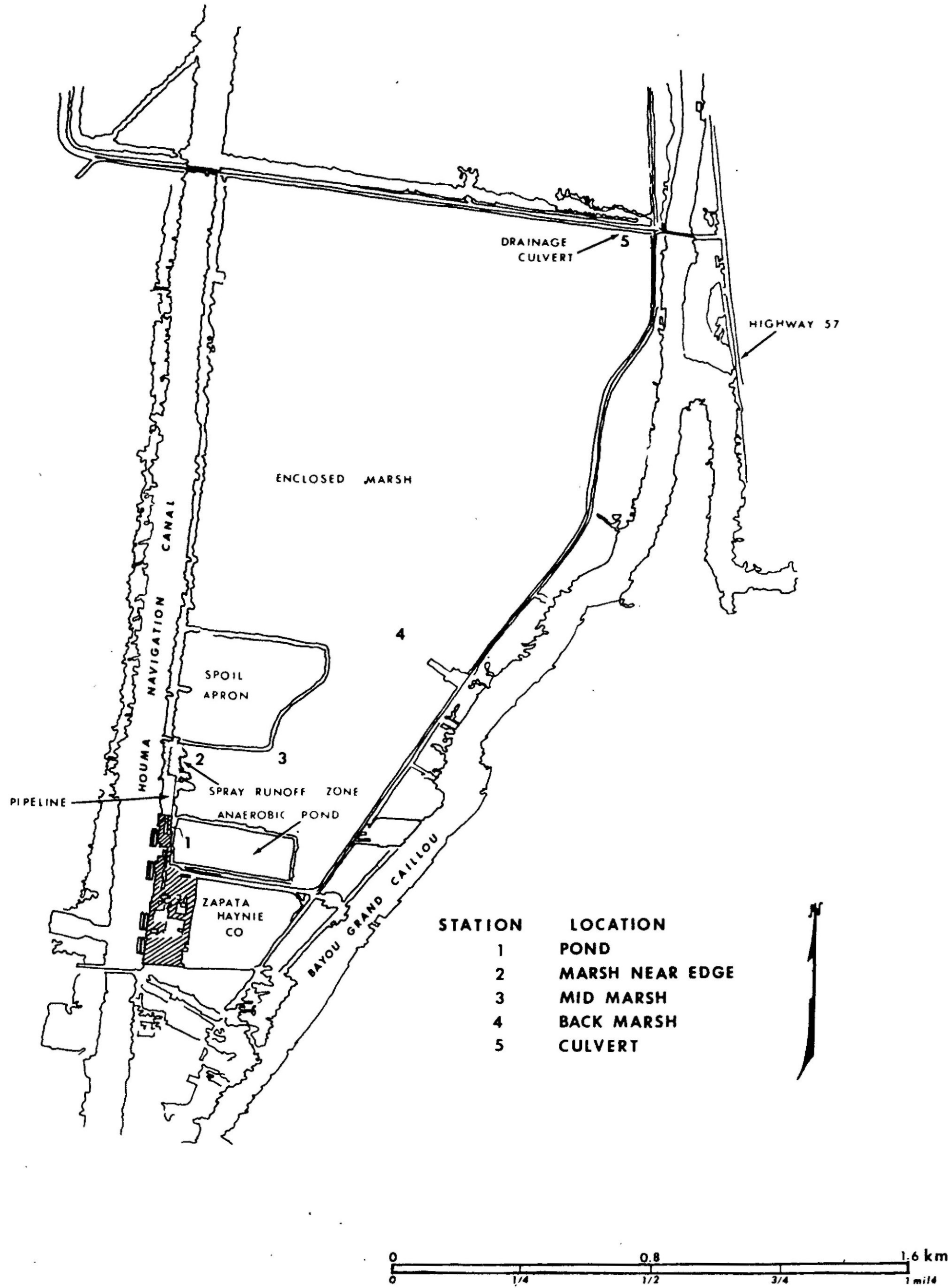

Figure 1. Location of the Zapata Haynie Menhaden Plant, the Experimental Area, and the Enclosed Marsh.

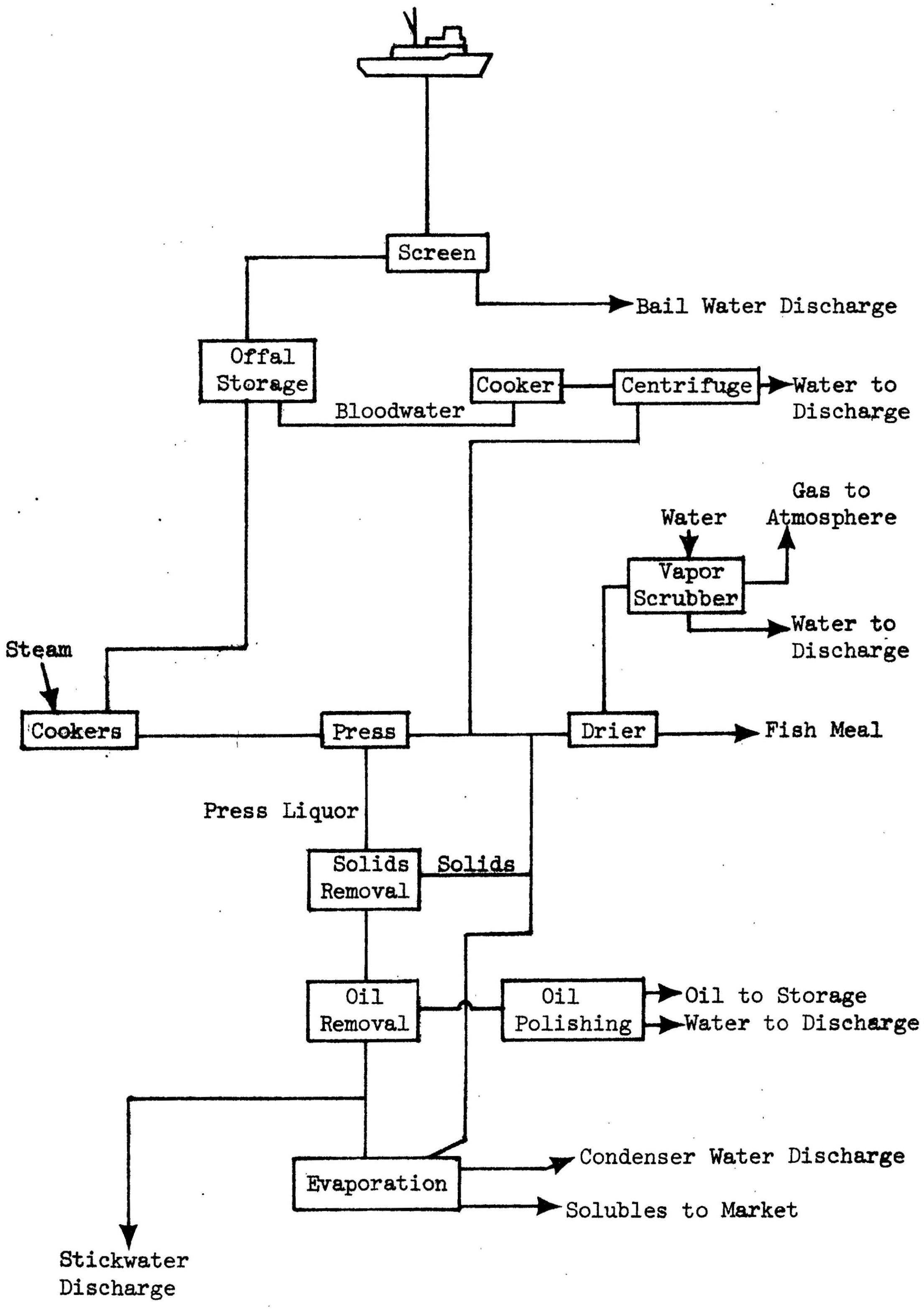

Figure 1A. Flow Diagram for Fish Meal Production

Table 1. Water Chemistries at Selected Stations in the Enclosed Marsh Prior to the Project

Date	Sampling Station	NH_4^+-N	$(NO_3^-+NO_2^-)$-N	Organic N	Total N	Available PO_4^{-3}-P	Organic PO_4^{-3}-P	Total PO_4^{-3}-P
	2	0.755	0.410	7.850	8.602	4.290	0.596	4.886
April 4, 1974	3	2.133	0.422	3.416	5.550	0.930	1.115	2.045
	4	0.109	0.446	4.812	4.922	0.421	0.282	0.704
	5	0.236	0.193	0.753	1.532	0.115	0.136	0.251

units are in mg/l

Table 2. Chemical Properties of Soil Materials

Location	Extractable Elements					Organic Matter	Organic C	Organic N	pH
	P	K	Ca	Mg	Na				
	ppm					%	%	%	
Canal Bank	219	392	2470	908	289	2.03	n.a.	n.a.	7.4
Enclosed Marsh	48	706	5240	6400	19400	79.13	45.90	2.50	5.5

Table 3. Canal Bank and Enclosed Marsh Vegetation

A) Canal Bank

Trees and Shrubs:

	Common Name
Baccharis halimifolia	sea myrtle or groundsel tree
Ilex decidua	possum haw
Ilex vomitoria	yaupon
Myrica cerifera	wax myrtle
Melia azedarach	China tree or Chinaball tree
Rubis sp.	blackberry, dewberry
Sabel minor	dwarf palmetto
Salix nigra	black willow
Sambucus canadensis	elderberry

Weeds and Grasses:

Cersium spinosissinus	thistle
Eleocharis sp.	marsh spike grass
Erigeron philedelphicus	
Geranium carolinianum	wild geranium
Hydrocotyl sp.	
Hydrocotyl ranunculoides	pennywort
Ipomea sagitta	morning glory
Iris sp.	iris
Melilotus indica	sour clover
Mikania scandens	climbing hempweed
Oxalis sp.	lady's sorrel
Phragmites communis	common reed or roseau cane
Phytolacca americana	polk weed
Pilea sp.	richweed
Polygonum sp.	smartweed
Polynigon sp.	
Ptilimnium sp.	mock bishop's weed
Rannunculus sp.	
Senecio glabellus	butterweed
Solidago sp.	goldenrod
Sonchus aspera	sow thistle
Thelypteris sp.	marsh fern
Urtica chamaedryoides	nettle
Verbena sp.	wild verbena

Table 3. (Continued)

B) Enclosed Marsh

Species	Common Name
Alternanthera philoxeroides	alligator weed
Bacopa monnieri	waterhyssop
Juncus effusus	soft rush
Lemna minor	duckweed
Phragmites communis	common reed or roseau cane
Sagittaria falcata	arrowhead
Scirpus validus	leafy three-square
Spartina patens	cordgrass or wiregrass
Zizaniopsis mileacae	cutgrass

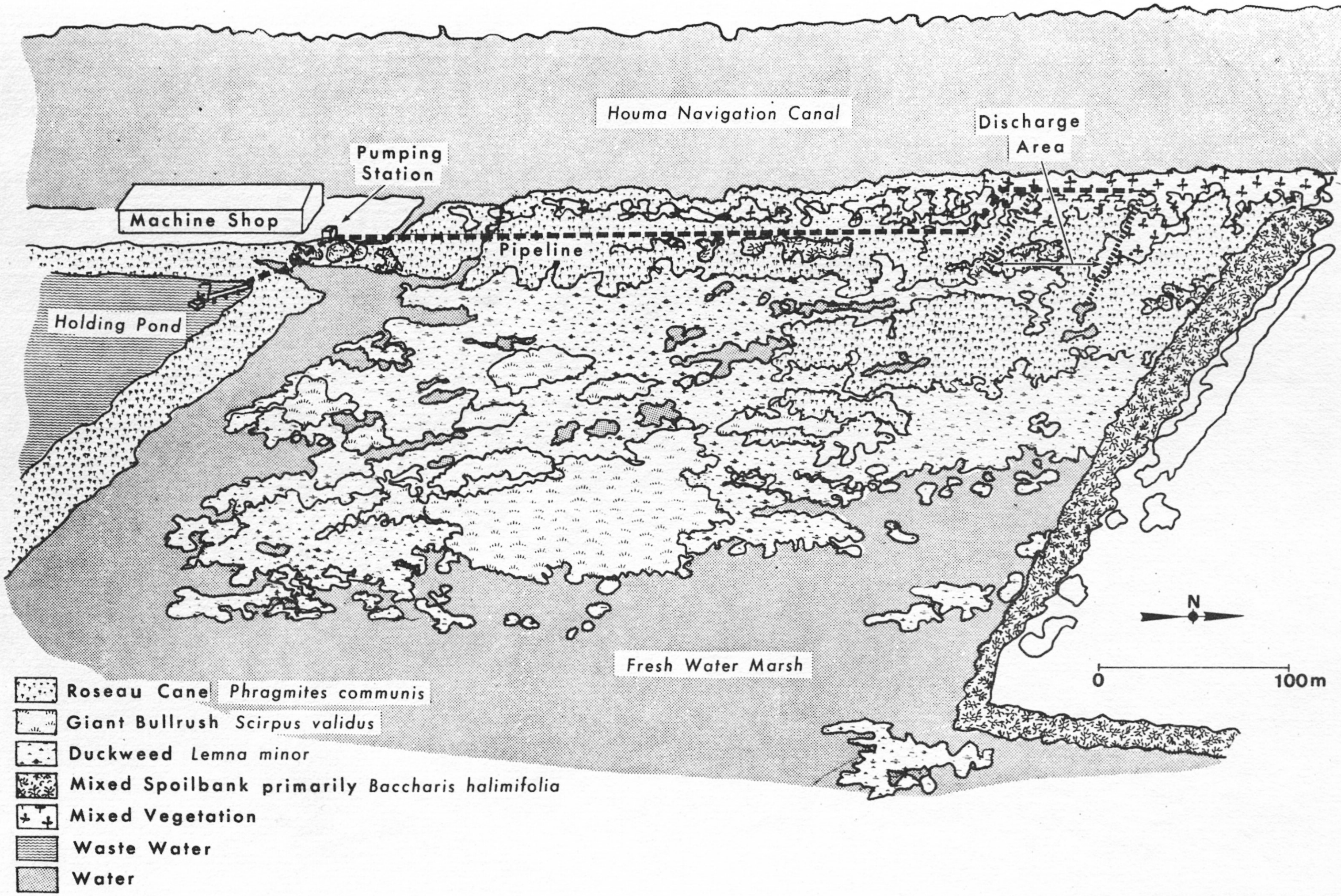

Figure 2. Vegetation Map of the Experimental and Surrounding Area.

Table 4. Aquatic Invertebrates and Fish Collected in the Enclosed Marsh

	Location	
	Spray Runoff Zone (Station 2)	Culvert (Station 5)
Annelida		
Tubificidae		
Limnodrilus profundicola	X	
Arthropoda		
Crustacea		
Mysidacea		
Taphromysis louisianae	X	
Amphipoda		
Talitridae		
Hyalella azteca	X	
Decapoda		
Palaemonidae		
Palaemonetes pugio	X	X
Macrobrachium ohione	X	
Insecta		
Hemiptera		
Corixidae (Water boatmen)	X	
Nepidae (Water scorpions)		X
Ranatra sp.		X
Diptera		
Chironomidae (Midges)		
Chironomus sp.	X	
Tanypodinae	X	
Mollusca		
Gastropoda		
Physidae		
Physa sp.	X	
Limnaeidae	X	
Limnaea sp.		
Chordata		
Vertebrata		
Osteichthyes		
Clupeidae		
Brevoortia patronus	X	X

Table 4. (Continued)

	Location	
	Spray Runoff Zone (Station 2)	Culvert (Station 5)
Cyprinodontidae		
Lucania parva		X
Poecilidae		
Gambusia affinus		X
Heterandria formosa		X

METHODS AND MATERIALS

Field Engineering

The main objectives in the construction of the overland flow system were: (1) to provide a continuous flow of solid-free waste from the settling pond, (2) to pump the filtered waste 300 m north along the canal bank to the experimental area, and (3) to apply the waste in an evenly distributed sheet flow from the top of the slope to provide maximum contact of the soil and plant systems with the waste runoff.

Pumping station (Figures 3A and 4)

A pumping station containing a 20 horsepower, electric centrifugal pump and motor secured to the cement foundation was constructed near the settling pond close to the menhaden plant machine shop. Inside the station a switch and starter were connected to an automatic clock timer and manual on-off button for convenient operation of the pump (Figure 5). Specifications for the pump and electrical assembly are listed in Table 5.

Input apparatus (Figure 3B)

A catwalk pier was built from the northeast corner of the settling pond to a point where the pond was deep enough to provide ample unrestricted flow of waste water free of floating solids. An H-frame suction apparatus equipped with two 60 cm long cylindrical 1/4 in. (0.63 cm) hardware cloth filters was built from 3 in. (7.62 cm) polyvinyl chloride (PVC) pipe (Figure

6). The suction apparatus was threaded onto a 2 in. (5.08 cm) verticle brass foot valve and joined to a 90 degree 3 in. PVC elbow fitted with a bleeder valve. The suction apparatus was lowered 60 cm into the pond by a support crane at the pier terminus. A 120 cm square baffle was installed in the pond at the pier terminus to prevent floating solids from clogging the suction apparatus. The PVC elbow was connected to a 1.8 m section of pressurized rubber hose to allow normal maintenance removal of the filters for cleaning. Two wooden aqueducts 13.6 m and 6 m in length conveyed the 3 in. suction pipe from the settling pond, over a portion of the marsh, to the pump.

Spray discharge apparatus (Figures 3C and 7)

From the pump 300 m (1,000 ft) of 3 in. PVC pipe was laid in a trail paralleling the canal through dense vegetation. At the experimental site, the pipeline was routed west to reach the zenith of the spoil bank. At this turn, a 3 in. gate valve was installed for flow control. At the top of the slope the pipeline turned and paralled the canal for 24.2 m (80 ft). Three 90 degree "T" joints bifurcated the pipeline and were connected to similar "T" joints increasing the number of discharge outlets to 12 evenly spaced over 16.7 m (55 ft).

Each outlet was fitted with a 91 cm (3 ft) upright pipe of 1 in. (2.54 cm) diameter. The top of the upright pipe was connected to a 90 degree elbow fitted with a length of 1 in. pipe 3 in. long and compressed at the end. The end was ground into a parabolic curve to guide the discharged waste in a thin fan shape that resulted in small droplets with minimal erosion impact (Figure 8).

The design for this type of discharge is advantageous for several reasons: (1) it has no moving parts or holes that will suffer wear or clogging; (2) maintenance requirements are small due to the ease of cleaning; (3) the effluent is evenly sprayed in a thin sheet to cover the slope as evenly as possible; (4) it permits aeration of the effluent; and (5) horizontal discharge under low pressure minimizes aerosol formation that could transmit pathogenic bacteria and viral organisms (Sorber and Guter, 1972).

Application rate

The discharge rate was adjusted to 2 in. (5.08 cm) per week according to recommended loading rates on clay soils (Pound and Crites, 1973) and past research (Gilde, 1970). Flow was controlled through two 3 in. gate valves one situated near the treated area and the other in a triangular by-pass that completed a flow circuit around the pump (Figure 3A). Waste was applied 3 hours a day 9 a.m. to 12 noon, for four days Monday through Thursday each week. The next three days provided a dry-up period for any ponding that was likely to occur (Reed, 1972). Operation of the pump was automatically activated and terminated by the adjustable clock timer in the pumping station.

Priming the pump was achieved by hose through a sampling spigot at the discharge end of the pump. Air was flushed out of the 24.2 m (80 ft) intake pipeline by three bleeder valves. Because the pump could not be easily placed below the free surface of the pond, priming had to be repeated at the start of each weekly pumping period.

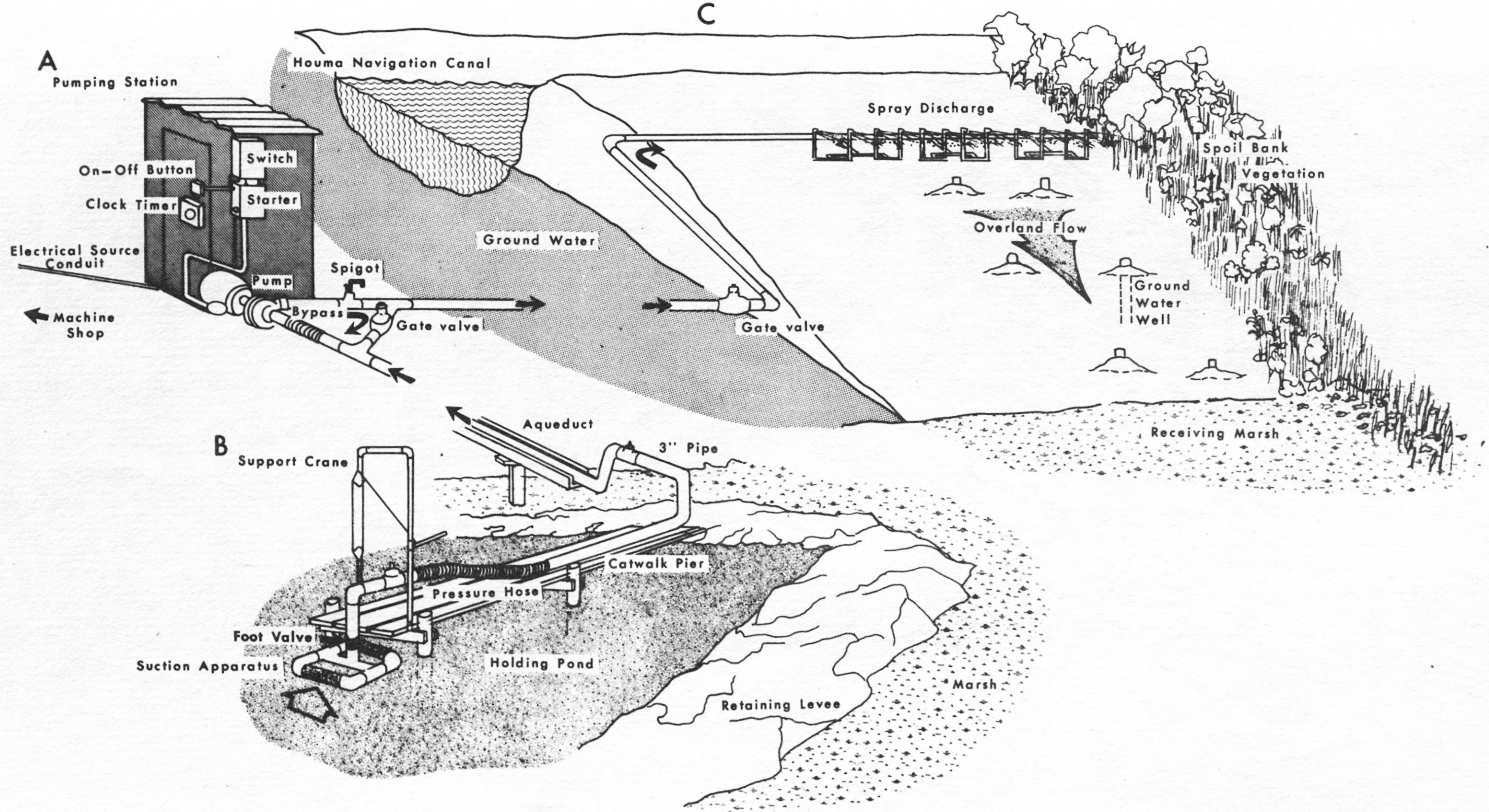

Figure 3. Schematic Diagram of the Overland Flow System Showing the (A) Pumping Station, (B) Input Apparatus, and the (C) Discharge Apparatus on the Canal Bank.

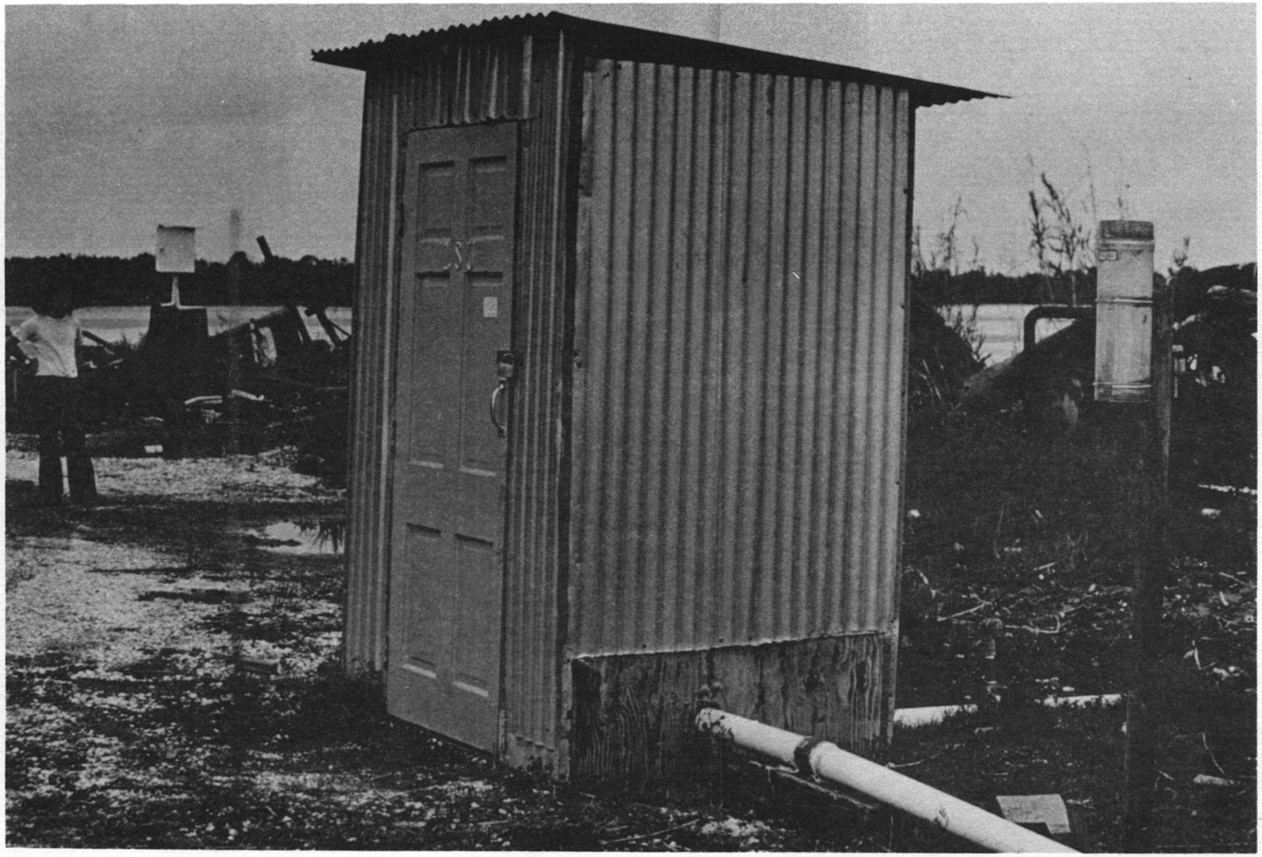

Figure 4. Pumping Station

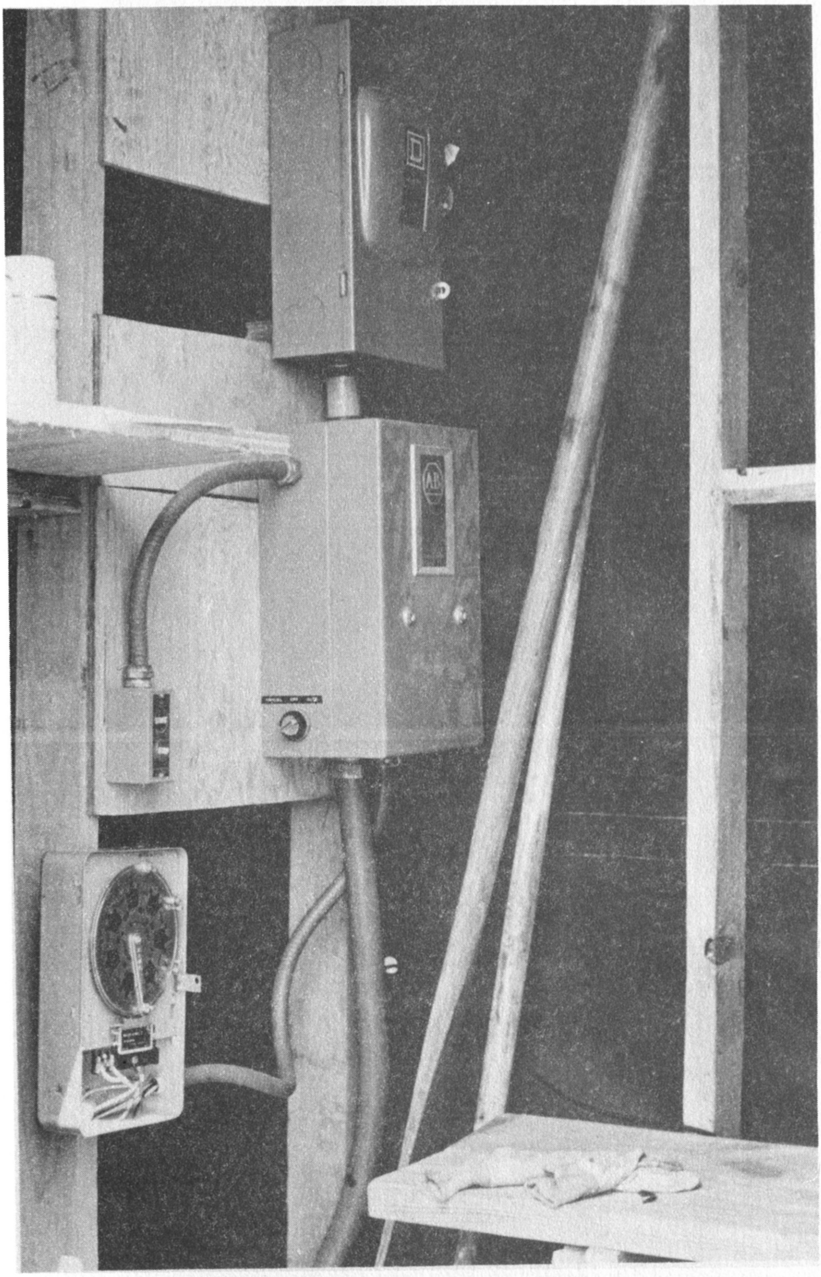

Figure 5. Interior of Pumping Station Showing the Switch, Starter, Clock Timer, and On-Off Button.

Table 5. Specifications for Pumping Assembly

1) Pump: Pacific Type L end suction centrifugal pump with integral h.p. frame construction code 10-25705-130001-1851 with a mechanical seal fitted with a 6.9 in. impeller

GPM 360	Head 152	
HP 20	Cycles 60	Phase 3
RPM 3500	Volts 230/460	Amps 46/23
Service Factor 1.15	Form MCA	
BRG Drive End 310	BRG Opp Drive End 207	
Time cont	40 camb	

2) Switch: Square D 100 amp D-323 N DC switch

3) Starter: Allen and Bradley 709-DAA starter with 3 N71 Allen and Bradley heater elements connected to a 800 S 25 amp Allen and Bradley on-off button

4) Pump Station: Wood frame construction measuring 1.2 X 1.5 X 1.8 m with a 10 cm thick cement foundation, tar paper insulation, and 0.28 mm corrugated tin roofing and siding

Figure 6. Suction Apparatus

Figure 7. Spray Discharge Apparatus

Figure 8. Closeup View of Spray Discharge Nozzle

Field Techniques

Several methodological techniques were executed in the field in order to gain sufficient information about the general and specific land system responses to the waste water application. The measurements included monthly sampling of: (1) the overland flow stream; (2) groundwater; (3) cover vegetation; (4) soil and aquatic microorganisms; (5) soil; and (6) surface water in the receiving marsh.

Overland flow

Two parallel sampling transects 1 m wide and 3 m apart were cut through the length of the vegetated slope. The medially placed transects ran from the spray discharge line at the top of the slope to the marsh edge. Spray runoff flowed over the slope and into the marsh in about 1.5 hours from the start of pumping. Two hours after pumping ceased the runoff area was free of noticeable surface flow. After the three day drying period, any ponding formed from the uneven surface flow had normally dried up.

Overland flow was sampled monthly on Thursdays, the last day of spray discharge, two hours after pumping began when steady flow over the slope was attained. Replicate samples were taken in half liter glass bottles containing 5 ml chloroform at distances of 7.5 m (25 ft), 15 m (50 ft), and 24.2 m (80 ft) downslope. Single samples were also taken at 36.4 m (120 ft) downslope, in the marsh 3 m from the edge, in the settling pond, and at the culvert (station 5). The latter served as a control. Samples were stored on ice and taken to the laboatory for analysis.

Groundwater

Groundwater wells were made from 4 ft (1.2 m) lengths of 3 in. PVC pipe by cutting double rows of 3.2 mm (0.12 in.) slits along the pipe (Figure 9). Well holes were bored in both transects at distances of 7.5, 15, and 22.5 m (75 ft) downslope from the discharge line with a 3 in. manually operated bucket auger. The six slitted tubes were inserted into the cored holes and driven down with a rubber mallet. The uppermost row of slits was adjusted down 81.3 cm (32 in.), 43.2 cm (17 in.), and 30.5 cm (12 in.) below the surface at the 7.5, 15, and 22.5 m distances, respectively, to enable capture of the water percolating through the soil column at varied depths. The wells were installed a month before discharge began to allow the pipe-soil interface to seal. Between measurements the tops were kept covered. During the spray period samples were taken monthly in half liter glass bottles containing 5 ml of chloroform. They were stored on ice and brought to the laboratory for analysis.

Vegetation

Nutrients

Roseau cane, *Phragmites communis*, is distributed in clumps over the length of the slope in varying stages of growth. *Phragmites* thrives in brackish and fresh water marshes (Chapman, 1960; Bird, 1969) and is a water tolerant plant that is well suited as a cover plant for overland flow. Although not in commercial demand in the United States, *Phragmites* is used for numerous purposes in other lands including antibiotics, paper, and baskets (Coleman, 1974).

Live *Phragmites* stems were clipped monthly just above the soil

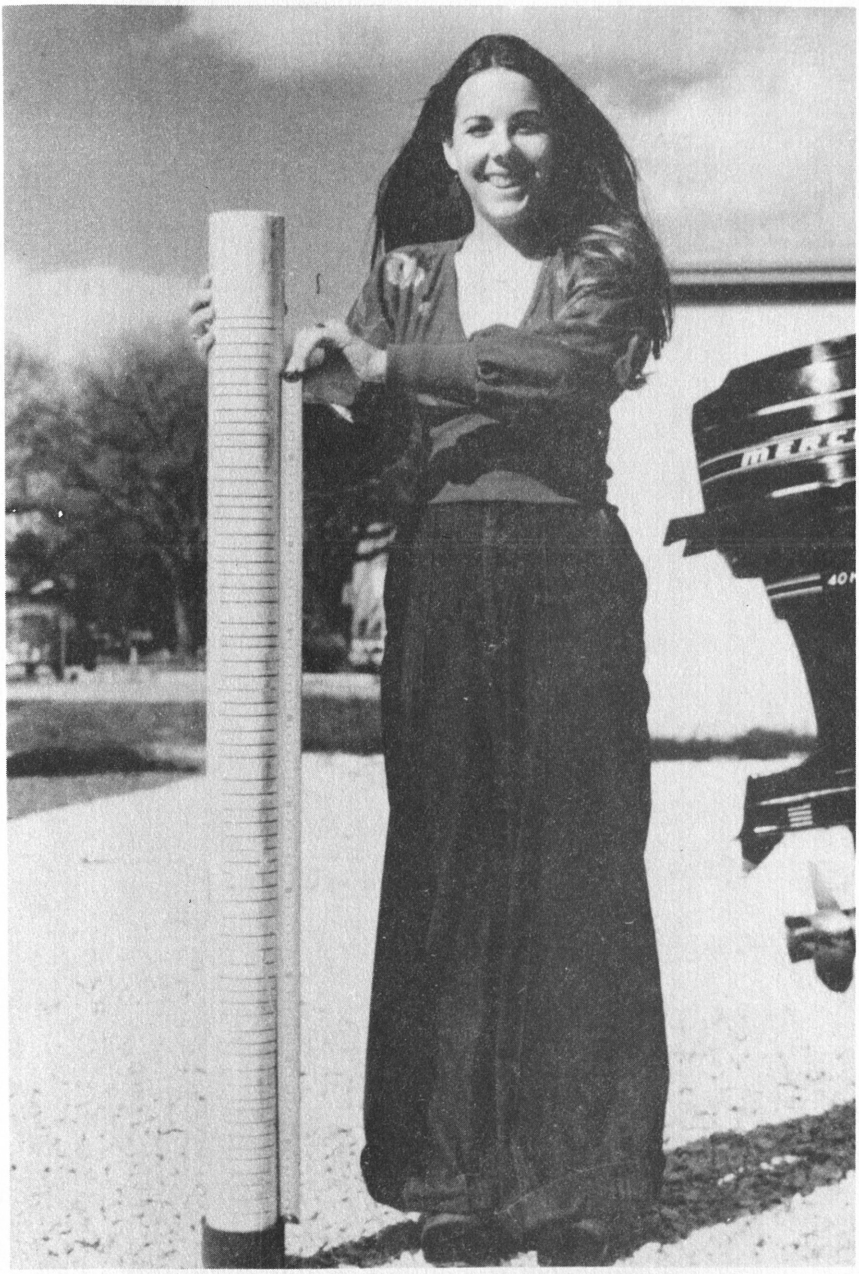

Figure 9. Groundwater Well

surface at distances of 7.5, 15, and 22.5 m from the line of discharge. Thirty samples were taken randomly across the slope at each distance in addition to the same number from a control plot. Sampling for plant nutrients was carried out during the months of June, July, and August.

Live standing crop

Phragmites was harvested after the experiment was concluded on October 5 to determine the effect of the treatment on the live standing crop. Twenty replicate quadrats (1 m^2) were taken at random at intervals of 4.5 m (15 ft) downslope from the line of discharge in the treated and control areas.

Microbiology

Soil microbiology

Surface soil was sampled monthly at distances of 7.5 and 22.5 m downslope from the line of discharge, at the marsh edge, and beside the slope as a control. Samples were taken in triplicate with sterile standard 100 x 15 mm Petri plates. The Petri plate was taken from a sterile bag at the site, turned concave downward, and gently pressed into the ground. The cover was inserted under the plate and both were removed, sealed with tape, labelled, and stored on ice until analyzed.

Aquatic microbiology

Water was sampled in July only for the measurement of total coliforms. Replicate samples were taken in sterile 160 ml prescription bottles at the following locations: (1) the settling pond: (2) the groundwater 7.5 m from the line of discharge; (3) the groundwater 22.5 m from the line of discharge; (4) the marsh edge; (5) mid marsh (station 4); (6) the culvert (station 5); and (7) the Houma Navigation

Canal, 3 km from the menhaden plant.

Soils

Cores were taken monthly at distances of 7.5, 15, and 22.5 m from the line of discharge with a manually operated 3 in. bucket auger. Samples were taken from each core at the following depths: (1) 0 to 10 cm; (2) 25 to 36 cm; (3) 51 to 61 cm; and (4) 76 to 86 cm. Samples were placed in plastic bags, stored on ice, and brought to the laboratory for analysis.

Laboratory Techniques

Overland flow

Runoff and pond waste collected in the field was analyzed for carbon, nitrogen, and phosphorus. Carbon samples, collected separately in 250 ml plastic bottles, were kept frozen until analyzed, while nitrogen and phosphorus samples were analyzed within one week after sampling. Carbon was analyzed as total organic carbon (TOC) and dissolved organic carbon (DOC) after the wet oxidation method of Menzel and Vaccaro (1964) using an Oceanography International total carbon analysis system. Particulate organic carbon (POC) was determined from the difference between TOC and DOC. Nitrogen was analyzed as total-N (Kjeldahl N), ammonium-N, and nitrate and nitrite-N after Bremner (1965) modified by Ho (1974). Organic-N was determined from the difference between total-N and ammonium-N. Phosphorus was analyzed as available phosphate-P and total phosphate-P after a method modified from Strickland and Parsons (1965). Organic phosphate-P was determined from the difference between total phosphate-P and available phosphate-P. In addition, pond waste was measured regularly for pH with a Sar-

gent PB S-30007 pH meter. Concentrations of metals in the pond waste were measured in July only by J. Mayer of the Dept. of Marine Sciences at LSU.

Groundwater

Samples drawn from the field wells were analyzed within one week for nitrogen as total-N (Kjeldahl N), ammonium-N, nitrate and nitrite-N, and for phosphorus as available phosphate-P and total phosphate-P. Organic-N and organic phosphate-P were determined by difference as described above. Because of the lower ammonium-N concentrations, NH_4^+-N was analyzed using a procedure after Strickland and Parsons (1965) modified by Ho (1974).

Vegetation

Nutrients

Phragmites samples were dried in a hot air oven at 80°C for 72 hours and finely ground in a Wiley mill. After thorough mixing of each ground sample, a subsample was analyzed for total-N and total-P at the Feed and Fertilizer Laboratory at LSU. Techniques of analysis follow Official Methods of Analysis of the A.O.A.C. (1970).

Live standing crop

Samples from the October harvest were stripped of any dead plant material, individual stems counted, dried in a hot air oven at 80°C for 72 hours, and weighed to the nearest gram.

Microbiology

Soil microbiology

Soil samples were plated on selective media for enumeration of colony growth of general aerobic heterotrophic and protein metabolizing or proteolytic microorganisms. Nutrient agar (Difco) was used for gen-

eral heterotrophic media. Proteolytic media was prepared after Hood (1974) as follows: 1,000 ml distilled water, 1,000 ml skimmed milk, 40 g of Difco Bacto Agar, and 2 g of Difco Yeast Extract, and adjusted to pH 7.6. Both media were sterilized under steam and poured into 216 sterile 100 x 15 mm Petri plates for each bacterial test two days before the test. One day after field sampling, samples were serially diluted and spread plated on the prepared plates as described by Parkinson et al.(1971). Plates were inverted, stored at 23°C, and counted two and three days after plating. Only counts between 30 and 300 per plate were recorded. To correct for dry weight soil, subsamples were oven dried at 100°C for 24 hours.

Aquatic microbiology

Water samples were tested for total coliforms by presumptive and confirmed tests according to Standard Methods (1965).

Soils

Prior to analysis samples were air dried at room temperature for one month. Next they were ground mechanically in a Bico pulverizer so that particles passed through a U.S. Standard Sieve No. 10 with 2 mm openings. The ground samples were analyzed by the Louisiana Soils Testing Laboratory at LSU. Tests included in the analysis were those for soil reaction (pH), phosphorus, potassium, calcium, magnesium, and organic matter. Analytical methods used are described by Brupbacher et al. (1968).

RESULTS AND DISCUSSION

Overland Flow

Carbon, nitrogen, and phosphorus concentrations of the menhaden waste in the settling pond were widely variable over the experimental period (Tables 6, 7, and 8). The stored waste water pumped from the pond had very high and variable ammonium-N levels that accounted for more than half of the total-N of the waste. The residence of the menhaden bail water and stickwater in the pond over a period of almost a year appears to have changed the composition of the original proteinaceous effluent through anerobic decomposition and nitrogen mineralization. Aided by the warm near subtropical climate, evaporation of the superjacent pond water may have created a nitrogen gradient with depth. The pond waste may have remained poorly mixed during rainy periods due to the overlying cover of surface solids.

Waste water applied to the slope lost a highly significant percentage of C, N, and P to the soil-plant system. For the experimental period, carbon averaged 57.8 percent removal, nitrogen 51.4 percent and phosphorus 52.7 percent. Although these percentages are not as high as those reported elsewhere (C.W. Thornthwaite and Associates, 1969; Hoeppel et al., 1974) differences in performance can be explained by the composition of the waste and its level of treatment, the heterogeneity and variable density of the plant cover, and the length, surface roughness, and irregular slope of the canal bank.

The impounded menhaden waste had a mean total-N concentration of 600 mg/l whereas comparable overland flow systems purified effluent containing about 20 mg total-N/l. The difference in nitrogen levels, a factor of 30 times, is in part a result of the menhaden waste receiving only primary treatment while the great majority of land treatment operations employ secondary treated effluent and use the land as tertiary treatment (see Glossary).

During the study period, caustic washdown water used for cleaning the plant sedimentation tanks was continuously added to the stored waste water in the settling pond. At regular intervals, pH was measured to determine if the spray-discharged waste would be too alkaline for plant and microbial growth. Because menhaden are primary herbivores, their capture and processing by the plant constituted a second concentration of the trace metals in the Gulf of Mexico previously concentrated by the phytoplankton on which they fed. Metals in the waste water therefore might have been too concentrated for successful land treatment. Measurement of pH and metals (Table 9) indicates that the waste water was never too alkaline for direct spray discharge onto the land. Contamination of the soil and receiving marsh by lead, nickel, and chromium was not a problem since these elements were either absent or present in insignificant concentrations.

The vegetation in the study site was a natural plant community that showed varying growth patterns as a result of height above groundwater and the effect of the unnatural fresh water marsh enclosed by man-made structures. Trees and shrubs not well adapted for growth in saturated soils showed poor growth. Shrubs such as <u>Rubis</u>

died in the treated area. At Paris, Texas graded slopes were sown with reed canary grass (Phalaris arundinacea) which was removed by periodic harvest, thus removing the N and P taken up by vegetative growth. Where harvests occur through natural senescence, death, and microbial degradation, a litter layer accumulates on the soil surface that may be subsequently removed by runoff or incorporated into the soil humus. The litter at Dulac minimized spray droplet splash and retarded the downslope flow as well as providing increased surface area for bacterial growth. The low organic matter content of the soil surface (2 percent) indicates that runoff from the heavy rain in the area (averaging 60 in/yr) was effective in removing organic detritus from the vegetated canal bank, permitting the kinetics of microbial mineralization and immobilization to be concentrated on the applied waste.

The runoff from the spray discharge did not flow in an evenly distributed sheet flow. Irregularities in the soil surface caused the runoff to channel in rivulets over the slope. The stationary discharge nozzles kept the daily discharge from flowing in new patterns and excluded areas in the treated site from waste coverage. Although removal of C, N, and P from the waste was near 50 percent, a longer slope would have increased the amount of nutrient removal. At Paris, Texas, slope lengths of 175 ft (58 m) were sufficient to remove over 90 percent of the applied nutrients. The effectiveness of the canal bank to renovate the waste may have been substantially increased by mechanical grading and sloping.

To determine the statistical significance of the vegetated canal bank as a treatment system, the percent removal of C, N, and P was

regressed on distance downslope from the line of discharge both as linear and quadratic functions (Table 10). In all cases quadratic regression improved the intercept and R-square value (the percent variance due to regression) over linear regression, but the curves retained a high degree of linearity suggesting that greater removal of nutrients may have been possible over longer slopes.

Groundwater

Groundwater analyses for N and P (tables 11 and 12) were conducted to measure the nutrient percolation, biological degradation, and mechanical effects in the soil at several depths. To evaluate the level of nutrient accumulation and oxidation in the capped wells, these were pumped dry after the July sampling and allowed to recharge for the August sampling. The August results show that the saturated soils released about 10 mg NH_4^+-N/1 to the groundwater, probably due to the high nitrogen levels in the waste, especially the ammonium-N fraction. In the 81.3 cm wells, nitrate and nitrite-N levels appeared higher than in the shallower wells sampled in August, possibly as a result of *in situ* oxidation. Organic-N results for August show the effects of flushing the wells of accumulated water. The reduction in organic-N from 17.36 mg/1 in July to 0.93 mg/1 in August at the shallow 30.5 cm depth strongly influenced the total-N level at that depth for August. The 11.33 mg total-N/1 concentration, the highest for the three depths, exceeds the 10 mg/1 USPHS drinking water standard after 5 months of treatment. Phosphorus results for August indicate higher levels of available phosphate-P and total phosphate-P in the 15 and 22.5 m wells. Similarly, flushing the wells removed accumulated P and revealed the lower levels of P in the groundwater. Groundwater

contamination from both organic-N and organic-P from the applied waste is not expected after 5 months.

Vegetation

Analysis of Phragmites for N (Table 13) showed a highly significant increase in stem and leaf tissue N, almost doubling in plants sampled at the top of the slope (7.5 m from discharges). The summer average for N in the treated Phragmites sampled over the slope was 1.84 percent compared with 1.25 percent for the control. Treated Phragmites P concentrations (Table 13) showed no differences compared to the control, but a highly significant difference was observed between the top (7.5 m) and the bottom (22.5 m) slope. The summer average for P in the treated Phragmites sampled on the slope was 0.18 percent compared to 0.16 percent for the control. N and P in the plant tissue increased an average of 47 percent and 13 percent respectively in the treated area.

From live standing crop results (Table 14), an average biomass of 1,128.1 g/m^2 of Phragmites was harvested in the treated area compared to 726 g/m^2 for the control. This increase of 55 percent is not statistically significant, however, because of the wide variation in plant density and distribution over the canal bank.

Microbiology

Soil microbial activity was measured at the top and bottom slope, at the receiving marsh floor, and beside the slope (control) (Table 15). Because of the unlevel surface of the canal bank, runoff flowed unevenly over the soil. To compare this effect, samples were taken in soils saturated by the waste and in sites adjacent to them. Aerobic heterotrophic microbial growth in the saturated sites

experienced a highly significant increase compared to the unsaturated and control areas. Proteolytic activity was highly significant in the waste-saturated soils only at 7.5 m. The increase of heterotrophic microbial biomass indicates an active transformation of menhaden waste into bacterial cells; however, three days after cessation of flow, heterotrophic and proteolytic numbers in the saturated soils had fallen back to control levels.

Total coliform MPN's (Table 16) in July revealed little danger of water pollution from spray runoff after four months of treatment. Coliforms treated by the slope were diminished in number by 66 percent and were found in lower concentrations in the marsh environment at stations sequentially distant from the receiving marsh edge. Levels of coliforms in canal water upstream of the treated area coincided with the MPN of the culvert water. The latter was within the total coliform MPN criteria of 230/100 ml set by the Louisiana Stream Control Commission. Below the treated soil surface, however, coliform MPN exceeded this criteria in the shallow depth well (30.5 cm) where the soil was saturated for extensive periods. In the deep well (81.3 cm), coliform MPN was the same as background numbers.

Soils

Chemical analyses of the soil profile (Table 17) reflect the heterogeneity of the dredged soil material. Differences of Ca, K, and P were highly significant from month to month. Organic matter in the soil surface (top 10 cm) ranged from 1.7 to 4.4 percent from May through August. Although this increase suggests a trend of buildup over time, a steady decline of organic matter downslope was

detected each month, reflecting the rapid rate of bacterial degradation and immobilization of the organic waste compounds.

Receiving Marsh

Water chemistries in the receiving marsh taken after 5 months of treatment (Table 18) present the effect of waste runoff on the marsh. Levels of N and P were higher than background levels as far away as station 3, but no changes beyond this point were detected.

On September 8, Hurricane Carmen passed west of Dulac with flood tides and winds up to 70 mph passing over the enclosed marsh. The buffering effect of the marsh in retarding drainage was reflected by the nutrient levels in the marsh water after the storm (Table 18). Levels of N as ammonium-N increased at station 2 from the movement of the waste runoff which had accumulated at the receiving marsh and slope junction. In the remainder of the marsh, where vegetation is less dense, N levels decreased from storm rain and tidal dilution. After the storm, phosphate-P was concentrated at stations 2 and 3, having been displaced away from the marsh edge but poorly mixed. Nutrients at the culvert (station 5) remained fairly uniform throughout the experimental period indicating that containment and reclamation of the waste water was achieved.

Nutrient Balance

Nutrients removed by the soil-plant system were calculated on an area basis to determine the volume of nitrogen and phosphorus removed from the waste water over the experimental period. The

volume of nutrients removed by the vegetated canal bank may be used as a guide for planning more efficient land treatment systems in similar environments.

Menhaden waste water was applied at a rate of 2 inches per week, a volume of 54,300 gal/acre/week spray-discharged over 6,500 sq. ft. Because of pumping problems, inoperative time accounted for 25 percent of the total pumping time resulting in 121,540 gal or 515,330 liters of waste discharged over 5 months. The volume of N and P removed by the vegetation and the soil column and the loss to the groundwater (Table 19) was calculated from the averaged data of each component.

The losses of nutrients by vegetative uptake and percolation to groundwater were rather small, 4.6 percent of the total volume retained by the slope. In other studies, cover vegetation played a dominant role in nutrient removal from the applied waste, accounting for as much as 42 percent of the waste nitrogen. The differences may be a result of the plant density, root depth, growing cycle, and controlling climatic factors for the separate plants. At Dulac, Phragmites was neither dense nor uniform over the slope, and other plants not sampled may have removed a considerable portion of the nutrient load. The nitrogen and phosphorus uptake by Phragmites averaged 2.5 and 0.1 pounds of N and P per ton, respectively. Differences between the Dulac and Paris, Texas (62 lbs N and 10 lbs P/ton) removal levels can be partially explained by several reasons.

1) The surface runoff did not flow evenly over the slope. This is supported by the average decrease in Phragmites percent N downslope from 2.1 to 1.7 percent (Table 13). Comparison of the percent of N and P in the treated cover vegetation at Dulac and Paris, Texas

shows closer agreement: 2.1 percent N and 0.21 percent P for upslope *Phragmites* (Dulac) compared to 3.1 percent N and 0.44 percent P for *Phalaris* (Paris, Texas) (C.W. Thornthwaite Associates, 1969).

2) The terraced slopes at Paris, Texas provided an even, thin, sheet-flow with a longer (6 hr) spray period. At Dulac the natural slopes did not cause comparable residence periods over the slope.

3) The waste compositions for each treatment were not similar because of the storage period of the menhaden waste. The cannery waste at Paris, Texas was treated on the land almost immediately after primary screening and gravity separation to remove cooking grease (Stevens, 1972).

The clay soil material of the canal bank provided a good barrier against nutrient percolation through the saturated soil profile. At the Paris, Texas overland flow site, where the clay soils infiltrated water at the rate of 0.1 in. (0.25 cm) per day, less than 1 percent of the total-N and 2 percent of the total-P percolated into the groundwater at a depth of 100 cm. At Dulac, however, less than 0.5 percent of the total-N and 0.7 percent of the total-P entered the groundwater. Although the nutrient load was heavier at Dulac, the differences in treatment ages of the two systems may have been a factor affecting the soil retention capacities. At the 30.5 cm depth, which was within a saturated zone near the receiving marsh edge, less than 1.5 percent total-N and 4 percent total-P entered the groundwater. Because of the impermeability of the clay soil, this shallow depth proved to be as adequate a barrier against nutrient contamination as the 7 foot (2.1 m) depth required for spray irrigation in

well drained porous soils (Parizek et al., 1967).

Overland Flow Theory

The greater fraction of the nitrogen and phosphorus in the waste applied to the vegetated slope was retained by the soil. Although the fraction removed by the cover vegetation may have been underestimated for the reasons previously discussed, it probably would not have accounted for more than 30 percent of the nutrient removal. The biological and chemical tranformations undergone by the cannery waste nitrogen and phosphorus were not well understood at Paris, Texas and a comprehensive laboratory study conducted by the U.S. Army Corps of Engineers was begun to determine what the actual tranformations were (Carlson et al., 1974; Hoeppel et al., 1974).

Nitrogen in the waste water was present either as ammonium-N or organic-N; no nitrate-N was detected. Adsorption is one of the most important yet poorly understood processes by which chemicals are removed from waste water applied to the soil (Murrmann and Koutz, 1972). In the soil, the ammonium ion participates in ion exchange and competes with other actions for exchange sites on organic and mineral fractions of the soil. However, in the presence of clay minerals and certain organic soil fractions, ammonium ions are preferentially adsorped (Pound and Crites, 1973). Adsorption is a fairly rapid process, but many types of adsorbed chemicals are slowly converted to more insoluble forms. During this time, the adsorbed phase provides a labile source of chemicals for vegetative uptake or removal by slow precipitation processes (Murrmann and Koutz, 1972). Volatilization of ammonium-N may occur to some extent, but

high pH and considerable air-water contact are necessary to account for significant amounts (Pound and Crites, 1973). Ammonium-N retained on the aerobic soil surface is nitrified to nitrite and nitrate by Nitrosomas and Nitrobacter, respectively. In anaerobic sites nitrate is denitrified and lost as gas.

Phosphorus applied to soils may precipitate as calcium, aluminum, or iron phosphate compounds. In addition, phosphorus may be removed by vegetative uptake and anion exchange with kaolinite clays (Pound and Crites, 1973). Other forms of phosphorus in clay soils occur as occluded or reductant soluble phosphorus and in organic phosphates.

Waste is applied in overland flow treatment in alternating periods of wetting and drying. Because the wetted surface extends only through the top few inches of soil, the active biodegradation of the waste takes place in this zone. In June the increasing aerobic heterotrophic microbial population was about 200 X 10^6/g soil (Table 15) in the waste-saturated zone. At Paris, Texas, this level of growth was attained during the month of August (C.W. Thornthwaite Associates, 1969). These high microbial populations demonstrate that active biodegradation of the waste compounds was occurring in the surface zone at both treatment sites.

When the soil surface is flooded, oxygen penetration to the soil surface is diminished and an anaerobic-aerobic double layer develops that is characterized by a decreasing oxidation reduction or redox potential with depth. Because the menhaden waste was anaerobic as it flowed over the slope, infiltration of the waste into the soil enhanced the formation of anaerobic microsites in the porous cavities

of the soil surface zone. As the redox potential decreases, transformations of chemical properties of the soil proceed in a manner similar to waterlogged soils such as rice paddies (Carlson et al., 1974; Hoeppel et al., 1974). Studies of the behavior of of soils subjected to submergence have been conducted by Patrick and Mahapatra (1968), Patrick and Mikkelsen (1971), and Ponnamperuma (1972).

A large fraction of nitrogen not accounted for in the nutrient balance at Dulac is believed to have been lost by vigorous nitrification of ammonium-N during the dry aerobic period followed by the subsequent denitrification of the nitrate during the wet anaerobic period. Hunt (1972) believes that nitrogen loss in the anaerobic-aerobic double layer microsites may be a primary mechanism for nitrogen removal from applied waste water.

Phosphorus compounds, especially iron phosphates, become more soluble upon their reduction from the ferric to the ferrous state. In flooded soils this occurs when the redox potential drops below +200 mv, and it induces the release of phosphate to the soil solution. Hydrated ferric oxide on clay particles is reduced in a similar manner and releases occluded phosphate compounds layered underneath. Upon drying, phosphorus reprecipitates, but calcium phosphates usually require a longer period to reprecipitate (Carlson et al., 1974). Studies by Patrick and Khalid (1974) stressed the importance of the sorption process in removing P from solution under reducing conditions. Reduced ferrous hydroxide and hydrated ferrous hydroxide gel sorbed orthophosphate from solutions containing over 5 mg P/l possibly as a result of their increased surface area. Thus phosphorus removal from waste water applied to soils over periods of wetting and drying is

believed to be accomplished by reduction, hydrolysis, fixation, sorption, and refixation of phosphorus compounds in the soil.

Costs

The costs of water treatment by overland flow are distributed between the capital costs of land, pretreatment, transmission, and distribution and the costs of operation and maintenance.

Recent reviews (Pound and Crites, 1973) list the typical costs of land as ranging from $225 to $500 per acre. Pretreatment of the waste including screening, primary and secondary trickling filter treatment, and chlorination totals 54¢/1,000 gal. Transmission and distribution costs for cannery waste varied from $200 to $2,300 per acre. In the overland flow system where terracing and grading of the slopes are important, costs can be approximated on an acre basis as $362 for cleaning the land, $108 for seeding to produce the vegetative cover, $348 for the piping system, and $188 for miscellaneous work.

At Paris, Texas, maintenance costs were 1 to 2¢/1,000 gal for the 3.5 mgd overland flow system. The annual operation cost was about 5¢/1,000 gal. This cost may be slightly reduced if the cover vegetation is sold for profit.

For the experimental work at Dulac, costs may be itemized in a similar manner. 1) The land for waste treatment was obtained free of any payment for use by obtaining permission to trespass for purposes of research. However, because land treatment is designed for multiple use benefits, no displacement of a prior use such as duck hunting or marsh conservation was effected. The cover crop, mostly removed by

microbial degradation and flushed out of the marsh as detritus benefits the overall productivity of areas removed from the treatment site. In areas where extensive dredging operations have created spoil disposal sites in marsh and estaurine areas, waste water treatment could beneficiate such an area into a multiple use system. 2) The pretreatment was provided by a preexisting settling pond, but if such a facility were not present, pretreatment could be accomplished at a cost of 20.6¢/1,000 gal. 3) Transmission and distribution costs totaled $2,500 for the pumping assembly, input apparatus, piping, and spray discharge apparatus. 4) Maintenance and operation costs were fairly low; part replacements and energy requirements averaged $200/yr with full time personnel costing $10,000/yr.

If the 24 acre spoil disposal site north of the menhaden plant were used for overland flow treatment of the plant waste water it could treat 150,000 gpd at a liquid loading rate of 2 in. per week. The capital and operating costs for the system (Table 20) do not include the cost of land as it may be used for the asking. However, this situation may change.

Table 6. Levels of Organic Carbon in the Overland Flow

	Total Organic Carbon				Dissolved Organic Carbon				Particulate Organic Carbon			
Sampling Site	May	June	July	Aug	May	June	July	Aug	May	June	July	Aug
Settling Pond	925.0	1088.0	459.0	728.0	709.0	676.0	135.0	403.0	216.0	236.5	48.0	325.0
7.5 m	685.5	935.0	228.5	390.0	563.0	529.0	157.5	193.0	122.5	396.0	71.0	197.0
15.0 m	660.0	750.0	414.5	251.5	570.5	562.5	204.5	186.0	89.5	187.5	210.0	65.5
24.2 m	451.0	879.0	225.5	271.5	293.0	463.5	192.0	206.5	158.0	415.5	33.5	65.0
36.4 m	237.0	587.0	266.0	260.0	176.0	518.0	180.0	217.0	61.0	69.0	86.0	43.0
Marsh Edge	81.0	83.0	151.0	229.0	71.0	65.0	130.0	215.0	10.0	18.0	21.0	14.0

units are in mg/l

Table 7. Levels of Nitrogen in the Overland Flow

	Ammonium-N					Organic-N				
Sampling Site	April	May	June	July	Aug	April	May	June	July	Aug
Settling Pond	206.50	440.62	840.40	600.00	650.00	106.00	71.88	94.97	52.00	153.57
7.5 m	185.76	383.06	787.15	559.16	506.25	58.65	91.94	33.66	54.02	74.10
15 0 m	198.36	366.93	744.65	435.00	356.25	39.38	95.57	39.72	31.15	75.29
24.2 m	217.38	219.75	718.07	177.50	468.75	16.97	111.49	40.23	16.11	59.52
36.4 m	176.01	90.72	lost	295.00	350.00	68.55	62.46	lost	32.62	36.90
Marsh Edge	9.56	14.11	9.57	35.00	120.00	16.68	3.31	16.59	5.19	75.24

Total-N

Sampling Site	April	May	June	July	Aug
Settling Pond	312.50	512.50	935.37	652.00	803.57
7.5 m	244.54	475.00	820.81	613.18	580.35
15.0 m	237.74	462.50	784.37	466.15	431.54
24.2 m	234.35	331.25	758.31	193.61	528.27
36.4 m	244.56	153.18	450.00	327.72	386.90
Marsh Edge	16.25	17.42	26.16	40.19	195.24

units are in mg/l

Table 8. Levels of Phosphorus in the Overland Flow

Sampling Site	Available PO_4^{-3}-P April	May	June	July	Aug	Organic PO_4^{-3}-P April	May	June	July	Aug
Settling Pond	24.71	25.62	38.81	26.66	27.50	30.95	49.06	9.26	6.45	17.85
7.5 m	20.87	25.00	8.21	16.18	8.50	33.00	11.85	8.05	4.22	3.35
15.0 m	17.40	18.43	11.83	17.32	7.75	29.40	5.59	5.07	4.29	5.14
24.2 m	20.88	19.37	8.48	22.14	7.25	14.73	12.99	4.97	6.57	5.30
36.4 m	20.35	17.50	4.53	28.57	8.87	28.23	4.93	0.46	3.86	4.18
Marsh Edge	3.10	2.25	7.56	15.47	11.25	7.76	6.08	4.48	4.12	8.47

Total PO_4^{-3}-P

Sampling Site	April	May	June	July	Aug
Settling Pond	55.66	74.68	48.07	33.11	45.35
7.5 m	53.88	36.85	16.28	17.02	11.85
15.0 m	46.81	24.03	16.92	21.61	12.89
24.2 m	35.61	32.37	13.45	28.71	12.55
36.4 m	48.58	22.43	5.00	32.43	13.05
Marsh Edge	10.86	8.33	12.05	19.59	19.72

units are in mg/l

Table 9. pH Values and Concentrations of Metals in the Menhaden Waste Water

A. pH Values

Date	May 18	June 20	July 15	July 25	August 26
pH	7.45	7.61	7.69	7.80	7.83

B. Concentrations of Metals (July only)

	Fe	Cu	Zn	Mn	Pb	Ni	Cr
Particulate Fraction	3230.0	34.7	850.0	34.7	0.0	7.4	0.0
Soluble Fraction	115.0	37.5	-----	trace	23.5	0.0	0.0

units are in ug/l

Table 10. Quadratic Regressions of Per Cent Removal of C,N,and P (Y) Regressed on Distance Downslope (X)

Chemical Property	Regression Equation	F	Significance	R-Square
TOC	$Y = 4.8143 + 0.8517X - 0.003727X^2$	13.49	* *	0.4498
DOC	$Y = 3.1613 + 0.3284X - 0.001054X^2$	0.36	N.S.	0.0590
POC	$Y = -9.6158 - 3.3244X + 0.03146X^2$	0.57	N.S.	0.0337
NH_4^+-N	$Y = 1.05711 + 0.3168X + 0.001235X^2$	18.09	* *	0.4628
Organic-N	$Y = -0.6719 + 2.6281X - 0.03706X^2$	3.20	*	0.1324
Total-N	$Y = 0.4323 + 0.5840X - 0.001627X^2$	30.01	* *	0.5883
PO_4^{-3}-P	$Y = 5.7206 + 1.2118X - 0.008186X^2$	7.78	* *	0.2705
Organic PO_4^{-3}-P	$Y = 5.7078 + 1.1124X - 0.005823X^2$	7.44	* *	0.2616
Total PO_4^{-3}-P	$Y = 6.9840 + 1.3437X - 0.008746X^2$	12.39	* *	0.3712

Table 11. Levels of Nitrogen in the Ground Water

		Ammonium-N				Nitrate+Nitrite-N			
Sampling Well	Depth	May	June	July	Aug	May	June	July	Aug
7.5 m	81.3 cm	2.48	1.94	4.70	9.03	0.51	0.16	0.48	2.07
15.0 m	43.2 cm	2.59	1.31	2.96	6.24	0.93	0.46	0.44	0.74
22.5 m	30.5 cm	3.77	3.16	4.96	10.40	0.41	0.18	0.11	0.52

units are in mg/l

		Organic-N				Total-N			
Sampling Well	Depth	May	June	July	Aug	May	June	July	Aug
7.5 m	81.3 cm	1.32	2.54	14.62	0.79	3.80	4.48	19.33	4.50
15.0 m	43.2 cm	0.31	1.08	10.86	1.75	2.91	2.39	13.83	8.00
22.5 m	30.5 cm	0.78	11.69	17.36	0.93	4.56	14.85	22.33	11.33

units are in mg/l

Note: Ground water wells were pumped dry after July sampling.

Table 12. Levels of Phosphorus in the Ground Water

Sampling Well	Depth	Available PO_4^{-3}-P				Organic PO_4^{-3}-P			
		May	June	July	Aug	May	June	July	Aug
7.5 m	81.3 cm	0.08	0.14	2.30	0.26	0.02	0.16	0.48	0.06
15.0 m	43.2 cm	0.36	0.03	4.72	1.71	0.16	0.04	2.70	0.53
22.5 m	30.5 cm	0.18	1.71	5.58	1.09	0.06	0.48	0.25	0.58

Sampling Well	Depth	Total PO_4^{-3}-P			
		May	June	July	Aug
7.5 m	81.3 cm	0.09	0.30	2.78	0.32
15.0 m	43.2 cm	0.52	0.07	7.14	2.25
22.5 m	30.5 cm	0.06	5.72	5.44	1.68

units are in mg/l

Note: Ground water wells were pumped dry after July sampling.

Table 13. Total N and Total P Percentages of *Phragmites communis* (dry weight) in the Treated and Control Areas

Month	Distance Down Slope: Top Slope (7.5 m)		Middle Slope (15.0 m)		Bottom Slope (22.5 m)		Control	
	%N	%P	%N	%P	%N	%P	%N	%P
June	2.30	0.20	1.80	0.15	1.60	0.14	1.30	0.15
July	2.03	0.22	1.62	0.19	1.78	0.16	1.40	0.19
August	1.95	0.19	1.68	0.17	1.83	0.15	1.04	0.13

Table 14. Comparison of Live Standing Crop of *Phragmites communis* (dry weight) in the Treated and Control Areas (October only)

	Distance Down Slope: Top Slope (7.5 m)	Middle Slope (15.0 m)	Bottom Slope (22.5 m)	Control
# Stems/m^2	25	21	26	17
Live Wt/m^2	1,172 g	1,032 g	1,102 g	726 g
Live Wt/Stem	46.52 g	50.73 g	44.06 g	43.0 g

Table 15. Numbers of General Heterotrophic and Proteolytic Soil Microorganisms in the Treated and Control Areas

Distance Down Slope		# Microbes in Soil Saturated by Overland Flow		# Microbes in Soil Not Saturated by Overland Flow		# Microbes in Soil 3 Days After Overland Flow	
		Gen Hetero	Proteo	Gen Hetero	Proteo	Gen Hetero	Proteo
Canal Bank	7.5 m	184.143	11.236	36.870	1.994	7.456	1.058
	22.5 m	216.720	3.899	44.266	2.620	5.060	0.708
	Control	8.270	3.664	8.920	1.809	3.453	0.566

		June		July		August	
		Gen Hetero	Proteo	Gen Hetero	Proteo	Gen Hetero	Proteo
Marsh	10.0 m from Slope	13.600	1.502	27.353	9.589	3.206	1.111

units are X 10^6/g dry weight

Table 16. Total Coliform MPN'S of Selected Samples Taken in the Experimental and Surrounding Area (July only)

Sampling Location	MPN
Settling Pond (Station 1)	1.7×10^6/100 ml
Receiving Marsh Edge	5.8×10^5/100 ml
Ground Water 81.3 cm From Treated Soil Surface	170/100 ml
Ground Water 30.5 cm From Treated Soil Surface	1.2×10^4/100 ml
Mid Marsh (Station 4)	2.4×10^3/100 ml
Culvert (Station 5)	170/100 ml
Navigation Canal 3 km Upstream From the Plant	170/100 ml

Table 17. Soil Chemistry Profile of the Canal Bank Prior to and During the Overland Flow Treatment

Date	Sample	Extractable Elements P	K	Ca	Mg	pH	Organic Matter (%)
		ppm					
March	1A	260	500	2755	1000+	7.0	2.83
	1B	181	258	2510	981	7.2	1.95
	1C	191	189	2390	862	7.6	1.40
	1D	223	215	1695	711	7.9	0.78
	2A	209	289	2150	930	7.6	1.95
	2B	216	233	1850	875	7.7	1.10
	2C	170	392	2600	989	7.4	2.18
	2D	123	218	2260	618	7.7	1.03
	3A	188	389	2505	796	7.6	1.33
	3B	172	281	2405	914	7.7	1.45
	3C	153	225	2490	719	8.0	0.71
	3D	219	237	2490	757	8.1	1.30
May	1A	261	481	2150	1000+	7.6	3.12
	1B	194	332	2550	799	7.4	1.17
	1C	166	260	2500	838	7.5	1.40
	1D	166	333	2370	841	7.9	0.91
	2A	---	---	----	---	---	----
	2B	190	248	1860	757	7.8	0.96
	2C	213	288	1980	964	7.9	0.99
	2D	228	397	1760	1000+	7.9	0.86
	3A	330+	500+	2840	1000+	7.6	2.00
	3B	213	328	2460	914	7.9	1.09
	3C	228	253	1680	626	7.9	0.65
	3D	232	297	1450	818	7.6	1.56
June	1A	156	500+	1600	892	6.7	4.37
	1B	38	500+	3180	820	7.8	1.14
	1C	57	337	2500	812	7.8	1.04
	1D	71	276	2030	761	7.9	1.09
	2A	133	500+	1920	918	7.0	4.21
	2B	81	500+	2130	980	7.5	1.30
	2C	71	467	1940	936	7.7	1.04
	2D	62	383	1960	903	7.7	1.92
	3A	185	500+	2600	1000+	7.2	4.68
	3B	85	429	1920	951	7.5	1.51
	3C	81	267	1620	718	8.1	0.78
	3D	85	297	1800	746	8.2	0.70
July	1A	194	500+	2860	822	6.7	4.47
	1B	223	290	2370	737	7.6	1.20
	1C	204	242	2750	798	8.1	0.83
	1D	133	330	4000+	815	8.0	1.01
	2A	213	456	3130	879	8.0	2.37

Table 17. (Continued)

Date	Sample	Extractable Elements P	K	Ca	Mg	pH	Organic Matter (%)
		------------ppm------------					
	2B	161	473	3450	1000+	8.0	1.25
	2C	152	424	2830	956	8.0	1.07
	2D	180	400	3050	864	8.3	0.88
	3A	213	500+	2570	730	7.9	2.16
	3B	166	500+	3900	828	8.0	1.53
	3C	194	377	2520	729	8.3	1.01
	3D	166	417	3540	906	8.1	0.86
August	1A	330+	500+	2770	1000+	7.2	3.12
	1B	218	413	3740	691	7.7	1.43
	1C	198	448	3360	894	7.7	1.95
	1D	184	459	4000+	956	7.8	1.14
	2A	300	500+	2640	872	7.6	2.55
	2B	223	254	2380	722	8.0	0.88
	2C	165	469	3870	1000+	7.7	1.07
	2D	73	434	4000+	826	8.0	1.04
	3A	300	500+	4000+	1000+	7.6	2.57
	3B	227	498	3340	1000+	8.0	1.30
	3C	237	273	2170	655	8.0	0.83
	3D	261	335	2260	707	8.1	0.88

Notes:

"1" is 7.5 m from the line of discharge.
"2" is 15 m from the line of discharge.
"3" is 22.5 m from the line of discharge.

"A" is at a depth of 0-10 cm.
"B" is at a depth of 25.4-35.6 cm.
"C" is at a depth of 50.8-60.9 cm.
"D" is at a depth of 76.2-86.4 cm.

Table 18. Water Chemistries at Selected Stations in the Enclosed Marsh After Five Months of Discharge

Date	Sampling Station	NH_4^+-N	$(NO_3^-+NO_2^-)$-N	Organic N	Total N	Available PO_4^{-3}-P	Organic PO_4^{-3}-P	Total PO_4^{-3}-P
Sept 5, 1974	2	1.480	0.340	9.723	11.203	0.825	0.490	1.315
	3	1.200	0.482	6.114	7.314	2.500	0.484	2.984
3 Days Before Hurricane Carmen	4	0.280	0.085	6.849	7.129	0.462	0.471	0.934
	5	0.335	0.519	1.131	1.466	0.165	0.051	0.217
Sept 16, 1974	2	10.344	0.173	0.173	10.517	2.918	1.675	4.594
	3	3.103	0.172	1.379	4.482	1.945	1.837	3.783
8 Days After Hurricane Carmen	4	0.431	0.069	1.534	1.965	0.540	0.581	1.121
	5	1.517	0.137	1.310	2.827	0.059	0.237	0.297

units are in mg/l

Table 19. Nutrient Balance for the Overland Flow Treatment for Five Months

Flow Pathway	Carbon		Nitrogen		Phosphorus	
	lbs	kg	lbs	kg	lbs	kg
Inputs (Spray Discharge)	187.4	412.3	150.6	331.4	12.0	26.5
Outputs (Runoff into Marsh)	79.1	173.9	73.3	161.3	5.7	12.5
Retained by Slope	108.3	238.3	77.3	170.1	6.3	13.9
Vegetative Uptake	--	--	1.8	4.0	.06	0.2
Percolation to Groundwater	--	--	1.6	3.5	0.4	0.8

	Carbon		Nitrogen		Phosphorus	
	lbs/acre	kg/ha	lbs/acre	kg/ha	lbs/acre	kg/ha
Amount Removed by Soil-Plant System	725.8	813.5	518.0	580.6	42.2	47.3

Table 20. Capital and Operating Costs for 150,000 gpd Overland Flow System on the Spoil Disposal Site North of the Zapata Haynie Menhaden Plant[a]

Cost item	Overland Flow
Land used, acres	20
Land required, acres[b]	24
Capital costs	
Land	free (if not, @ $500/acre)
Earthwork	$20,000
Pumping station	15,600
Transmission	41,250
Distribution	20,000
Collection	2,000
Total capital costs	$98,850
Capital cost per purchased acre	free (if not,$4,600)
Amortized cost[c]	$9,675
Capital cost, ¢/1000 gal.	1.4
Operating costs	
Labor	$10,000
Maintenance	3,750
Power	1,800
Total operating costs	$15,550
Operating cost, ¢/1,000 gal.	1.1
Total cost, ¢/1,000 gal.	2.5

a. Estimated for 1973 dollars, ENRCC index 1860 and STPCC index 192
b. 20% additional land required for buffer zone and additional capacity
c. 15-year life for capital items, excluding land; interest rate 7%
Source: Pound and Crites (1973)

RECOMMENDATIONS AND CONCLUSIONS

Recommendations

Overland flow appears to be an effective and efficient method for treating menhaden waste water. This project has shown that a highly significant nutrient load was removed from primary treated menhaden bail water and stickwater wastes pumped from an anaerobic settling pond by the physical, biological, and chemical properties of a naturally vegetated dredged canal bank. However, the extent of nutrient removal was restricted by the natural topographical relief, variability of the cover vegetation, soil depth to the water table, and slope length.

1) Leveled slopes for overland flow would permit better sheet-flow and longer retention of the spray-discharged waste.

2) Where saturation of the soil by waste may be detrimental to vegetation that requires well drained soils in which to grow, replacement by indiginous water tolerant plants such as *Phragmites* may be beneficial to the treatment system. If commercial sale of the cover vegetation is intended, a plant used for hay such as *Phalaris* may be sown.

3) The infiltration rate was not measured at Dulac, but nutrient percolation after 5 months just exceeded the permissable total-N level for drinking water at the 30 cm depth. Since the menhaden industry processes fish seasonally (7 mo/yr), the 30 cm depth may be a satisfactory minimum for the depth of the soil column in soils with a comparable distribution of clays.

4) Removal rates have indicated by direct measurement and statistical inference that slope lengths of 175 ft (53 m) may be the min-

imum distance to insure adequate soil-plant contact for waste water treatment comparable to tertiary treatment.

5) Discharge of the waste continued through the late spring and summer growing seasons because of the favorable environmental conditions for waste water treatment by the land. However, application of waste may be feasible at reduced rates in the fall and winter where climate and soil-plant systems are favorable.

6) The objectives of this study were to determine the general feasibility of using low-lying clay soil material as land treatment sites for purifying waste water from riverine food product industries. The data support the conclusion that multiple use management of already existing dredge spoil disposal sites with land treatment systems may benefit the overall environment of South Louisiana by conserving potential and renewable land and water resources.

7) The results of this research project by their very nature are limited, and can not be generalized or extrapolated to encompass any waste water in need of treatment or any soil-plant system that may seem amenable to overland flow treatment. Because of the specific physical, chemical, and biological composition of individual waste effluents, each must be evaluated accordingly as well as the land system that is intended to provide the waste water treatment.

Conclusions

Carbon, nitrogen, and phosphorus concentrations in the menhaden waste water showed a highly significant decrease when spray-discharged over a 100 ft (30 m) vegetated canal bank with an average slope of 6 percent. Quadratic regression analysis was highly significant for TOC,

total-N, and total PO_4^{-3}-P when percent removal was regressed on distance downslope.

Phragmites communis percent N and percent P concentrations showed a highly significant increase 7.5 m downslope from the spray discharge. Percent N and percent P concentrations decreased with distance downslope, possibly because of uneven waste coverage in the treated area.

Phragmites communis live standing crop showed an average 55 percent increase in biomass from the control areas, but the differences were not significant because of uneven distributions of plants on the canal bank.

Aerobic heterotrophic microbial growth showed a highly significant increase in numbers in the waste-saturated soils but not in adjacent soils within the treated area. Proteolytic microbial growth showed a highly significant increase in numbers in waste-saturated soils but not in adjacent soils within the treated area.

The vegetated slope for overland flow should be as level as possible, preferably less than 6 percent, to obtain greater purification of applied waste water by vegetative uptake, microbial degradation, and chemical and mechanical transformations in the soil.

A depth of 30 cm below the treated canal bank was not sufficient to maintain levels of total-N in the groundwater below the 10 mg N/1 USPHS drinking water standard. Depths of 43 and 81 cm were sufficient to maintain levels of total-N below 10 mg N/1.

Total coliform MPN levels after 4 months of discharge showed a decrease in MPN from the top of the slope into the marsh toward the

drainage culvert (station 5). At this time in July there was no danger of polluted water leaving the marsh as indicated by total coliforms.

Dredged clay and clay soil spoil disposal sites may be of value as water treatment sites for overland flow techniques. Proper multiple use of these areas may be of beneficial importance to the coastal marsh region for water quality maintenance and improvement.

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APPENDIX A

Table 1. Composition of Major Plant Effluent Streams

Parameter	Bail Water	Stickwater	Condenser Water
BOD-5 mg/L	5000	1500	22
COD mg/L	6000	2500	350
Dissolved Solids mg/L	30000	25000	26000
Suspended Solids mg/L	4000	6000	70
Temperature °F	70	150	85
1000 gallons per day	23	43.7	53.7
Chloride mg/L	12000	11000	11000

Source: Rao and Pike (1972).

GLOSSARY OF TERMS, ABBREVIATIONS, SYMBOLS AND CONVERSION FACTORS.

TERMS

Bail water: Water which is used to transport the menhaden by pumping them from the holds in the fishing vessel to the processing plant.

BOD-5 (Biochemical Oxygen Demand): A measure of the oxygen consumption by aerobic organisms over a 5-day test period at 20°C. It is an indirect measure of the concentration of biologically degradable material present in organic wastes contained in a waste stream.

COD (Chemical Oxygen Demand): A measure of the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in water.

Coliform: Relating to, resembling, or being the colon bacillus.

Fish meal: A ground, dried product made from fish or shellfish or parts thereof, generally produced by cooking raw fish or shellfish with steam and pressing the material to obtain the solids which are then dried.

Fish oil: An oil processed from the body (body oil) or liver (liver oil) of fish. Most fish oils are a by-product of the production of fish meal.

Fish solubles: A product extracted from the residual press liquor (called "stickwater") after the solids are removed for drying (fish meal) and the oil extracted by centrifuging. This residue is generally condensed to 50 percent solids and marketed as "condensed fish solubles".

Groundwater: The supply of freshwater under the earth's surface in an aquifer or soil that forms the natural reservoir for man's use.

Infiltration: The entrance of applied water into the soil through the soil-water interface.

Loading rates: The average amount of liquid or solids applied to the land over a fixed time period taking into account periodic resting.

Mineralization: The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Overland flow: Wastewater treatment by spray-runoff (also known as "grass filtration") in which wastewater is sprayed onto gently sloping, relatively impermeable soil which has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

pH: The pH value indicates the relative intensity of acidity or alkalinity of water, with the neutral point at 7.0. Values lower than 7.0 indicate the presence of acids; above 7.0 the presence of alkalies.

Press liquor: Stickwater resulting from the pressing of fish solids.

Primary treatment: Removes the material that floats or will settle in sewage. It is accomplished by using screens to catch the floating objects and tanks for the heavy matter to settle in.

Secondary treatment: The second step in most waste treatment systems in which bacteria consume the organic parts of the wastes. It is accomplished by bringing the sewage and bacteria together in trickling filters or in the activated sludge process.

Stickwater: Water and entrained organics that originate from the draining or pressing of steam cooked fish products.

Tertiary waste treatment: Waste treatment systems used to treat secondary treatment effluent and typically using physical-chemical technologies to effect waste reduction.

Zero discharge: The discharge of no pollutants in the wastewater stream of a plant that is discharging into a receiving body of water.

ABBREVIATIONS

ENRCC: Engineering News-Record construction cost

ft: foot

gal.: gallon

gpd: gallons per day

hr: hour

in: inch

lb: pound

m: meter

mgd: million gallons per day

mg/l: milligrams per liter

ml: milliliter

mm: millimeter

mo: month

MPN: most probable number

ppm: parts per million

STPCC: sewage treatment plant construction cost

yr: year

SYMBOLS

C: carbon

Ca: calcium

K: potassium

Mg: magnesium

N: nitrogen

P: phosphorus

u: micro

CONVERSION FACTORS

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles	1.609344	kilometers
square feet	0.092903	square meters
pounds	0.453592	kilograms
inches per hour	2.54	centimeters per hour
pounds per acre	1.1208	kilograms per hectare
million gallons	3.06	acre-feet
acre-inch	27,154	gallons
gallons	4.24	liters

APPENDIX B

Table 1. Analysis of Variance and Regression Coefficients for Dependent Variable TOC in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	10906.411	5453.205	13.493	0.0001	0.449	63.507
Error	33	13336.852	404.147		Std Dev	TOC Mean	
Corrected Total	35	24243.264			20.103	31.655	

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	9869.182	24.419	0.0001	3920.834	9.701	0.0038
Dist Sq	1	1o37.228	2.566	0.1187	1037.228	2.566	0.1187

Source	B Values	T for Ho=B	Prob T	Std Err B	Std B Values
Intecept	4.81438	0.735	0.465	6.5493	0.0
Dist	0.85177	3.114	0.003	0.2734	1.2429
Dist Sq	-0.00372	-1.602	0.118	0.0023	-0.6392

Table 2. Analysis of Variance and Regression Coefficients for Dependent Variable DOC in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	2384.676	1192.338	1.036	0.364	0.059	227.148
Error	33	37970.677	1150.626		Std Dev		DOC Mean
Corrected Total	35	40355.353					

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	2301.650	2.000	0.166	582.949	0.506	0.481
Dist Sq	1	83.026	0.072	0.789	83.026	0.072	0.789

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	3.16135	0.286	0.776	11.050	0.0
Dist	0.32843	0.711	0.481	0.461	0.371
Dist Sq	-0.26862	0.789	0.789	0.003	-0.140

Table 3. Analysis of Variance and Regression Coefficients for Dependent Variable POC in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	75494.019	37747.009	0.576	0.572	0.0337	496.895
Error	33	2160244.879	65461.966		Std Dev	POC Mean	
Corrected Total	35	2235738.898					

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	1578.963	0.024	0.877	59727.720	0.912	0.346
Dist Sq	1	73915.056	1.129	0.295	73915.056	1.129	0.295

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	-9.61587	-0.115	0.908	83.325	0.0
Dist	-3.32449	-0.955	0.346	3.480	-0.505
Dist Sq	0.03146	1.062	0.295	0.029	0.561

Table 4. Analysis of Variance and Regression Coefficients for Dependent Variable NH_4^+-N in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	13457.479	6728.739	18.097	0.0001	0.562	92.758
Error	42	15615.797	371.804		Std Dev	NH_4^+-N Mean	
Corrected Total	44	29073.276			19.282	20.787	

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	13314.985	35.811	0.0001	678.075	1.823	0.184
Dist Sq	1	142.493	0.383	0.5392	142.493	0.383	0.539

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	1.05711	0.188	0.851	5.618	0.472
Dist	0.31682	1.350	0.184	0.234	0.472
Dist Sq	0.00123	0.619	0.539	0.001	0.216

Table 5. Analysis of Variance and Regression Coefficients for Dependent Variable Organic-N in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	272073.928	136036.964	3.207	0.0492	0.132	1601.29
Error	42	1781451.267	42415.506		Std Dev		Organic-N Mean
Corrected Total	44	2053525.196			205.950		-12.861

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	143908.558	3.392	0.072	46658.048	1.100	0.300
Dist Sq	1	128165.370	3.021	0.089	128165.370	3.021	0.089

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	-0.67198	-0.011	0.991	60.0112	0.0
Dist	2.62812	1.048	0.300	2.5057	0.465
Dist Sq	-0.03706	-1.738	0.089	0.0213	-0.772

Table 6. Analysis of Variance and Regression Coefficients for Dependent Variable Total-N in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	10730.665	5365.332	30.011	0.0001	0.588	59.990
Error	42	7508.682	178.778		Std Dev		Total-N Mean
Corrected Total	44	18239.347			13.370		22.282

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	10483.486	58.639	0.0001	2304.420	12.889	0.0009
Dist Sq	1	247.178	1.382	0.2463	247.178	1.382	0.2463

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	0.43236	0.110	0.912	3.896	0.0
Dist	0.58406	3.590	0.0009	0.162	1.098
Dist Sq	-0.00162	-1.175	0.246	0.001	-0.359

Table 7. Analysis of Variance and Regression Coefficients for Dependent Variable Available PO_4^{-3}-P in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	12118.692	6059.346	7.785	0.0017	0.270	84.039
Error	42	32682.333	778.150		Std Dev	Available PO_4^{-3}-P Mean	
Corrected Total	44	44801.025			27.895	33.193	

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	5865.696	7.538	0.0089	9920.673	12.749	0.0009
Dist Sq	1	6252.995	8.035	0.0070	6252.995	8.035	0.0070

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	5.72068	0.703	0.485	8.128	0.0
Dist	1.21186	3.570	0.0009	0.339	1.454
Dist Sq	-0.00818	-2.834	0.0070	0.002	-1.154

Table 8. Analysis of Variance and Regression Coefficients for Dependent Variable Organic PO_4^{-3}-P in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	17108.757	8554.738	7.441	0.002	0.261	91.107
Error	42	48279.786	1149.518		Std Dev	Organic PO_4^{-3}-P Mean	
Corrected Total	44	65388.544			33.904	37.213	

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	13944.608	12.130	0.0012	8359.892	7.272	0.010
Dist Sq	1	3164.149	2.752	0.104	3164.149	2.752	0.104

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	5.70783	0.577	0.566	9.879	0.0
Dist	1.11245	2.696	0.010	0.412	1.105
Dist Sq	-0.00582	-1.659	0.104	0.003	-0.679

Table 9. Analysis of Variance and Regression Coefficients for Dependent Variable Total PO_4^{-3}-P in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	R-Square	C.V.
Regression	2	16028.364	8014.182	12.398	0.0002	0.371	65.729
Error	42	27148.200	646.385		Std Dev	Total PO_4^{-3}-P Mean	
Corrected Total	44	43176.565			25.424	38.679	

Source	d.f.	Sequential SS	F Value	Prob F	Partial SS	F Value	Prob F
Dist	1	8891.818	13.756	0.0006	12197.843	18.870	0.0001
Dist Sq	1	7136.546	11.040	0.0019	7136.546	11.040	0.0019

Source	B Values	T for Ho B=0	Prob T	Std Err B	Std B Values
Intercept	6.98403	0.942	0.351	7.408	0.0
Dist	1.34376	4.344	0.0001	0.309	1.642
Dist Sq	-0.00874	-3.322	0.0019	0.002	-1.256

Table 10. Analysis of Variance for TOC in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	3	1677153.75	559051.25	43.51	0.0001	* *
Dist	3	542295.00	180765.00	14.07	0.0002	* *
Mo X Dist	9	182070.25	20230.02	1.57	0.204	N.S.
Error	16	205549.00	12846.81			

Table 11. Analysis of Variance for DOC in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	3	928545.25	309515.08	143.12	0.0001	* *
Dist	3	150664.25	50221.41	23.22	0.0001	* *
Mo X Dist	9	149821.50	16646.83	7.69	0.0004	* *
Error	16	34601.00	2162.56			

Table 12. Analysis of Variance for POC in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	3	207792.84	69264.28	3.27	0.047	*
Dist	3	22719.84	7573.28	0.35	0.786	N.S.
Mo X Dist	9	205166.28	22796.25	1.07	0.429	N.S.
Error	16	338609.50	21163.09			

Table 13. Analysis of Variance for NH_4^+-N in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	1415765.29	353941.32	193.035	0.0001	* *
Dist	3	208162.36	69387.45	37.843	0.0001	* *
Mo X Dist	12	199705.23	16642.10	9.076	0.0001	* *
Error	20	36671.19	1833.55			

Table 14. Analysis of Variance for Organic-N in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	39359.34	9839.83	22.137	0.0001	* *
Dist	3	9601.17	3200.39	7.200	0.002	* *
Mo X Dist	12	16690.04	1390.83	3.129	0.011	*
Error	20	8889.69				

Table 15. Analysis of Variance for Total-N in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	1400312.45	350078.11	178.310	0.0001	* *
Dist	3	288916.80	96305.59	49.052	0.0001	* *
Mo X Dist	12	172348.22	14362.35	7.315	0.0002	* *
Error	20	39266.18	1963.39			

Table 16. Analysis of Variance for Available PO_4^{-3}-P in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	473.08	118.27	7.895	0.0008	* *
Dist	3	1345.43	448.47	29.938	0.0001	* *
Mo X Dist	12	815.59	67.96	4.537	0.0018	* *
Error	20	299.60	14.98			

Table 17. Analysis of Variance for Organic PO_4^{-3}-P in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	2918.71	729.67	121.321	0.0001	* *
Dist	3	1208.08	402.69	66.95	0.0001	* *
Mo X Dist	12	1848.44	154.03	25.611	0.0001	* *
Error	20	120.28	6.01			

Table 18. Analysis of Variance for Total PO_4^{-3}-P in the Overland Flow

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	4803.91	1200.97	88.637	0.0001	* *
Dist	3	5111.21	1703.73	125.743	0.0001	* *
Mo X Dist	12	1940.34	161.69	11.933	0.0001	* *
Error	20	270.98	13.54			

Table 19. Analysis of Variance for NH_4^+-N in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	179704926	44926231.4	9.682	0.0007	* *
Dist	2	17791287	8895643.7	1.917	0.180	N.S.
Mo X Dist	8	12024742	1503092.8	0.323	0.943	N.S.
Error	15	69597070	4639804.6			

Table 20. Analysis of Variance for $(NO_3^- + NO_2^-)$-N in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	2753639.6	688409.9	1.239	0.336	N.S.
Dist	2	690275.4	345137.7	0.621	0.554	N.S.
Mo X Dist	8	2886583.3	360822.9	0.649	0.727	N.S.
Error	15	8330299.8	555353.3			

Table 21. Analysis of Variance for Organic-N in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	845728736	211432184	27.482	0.0001	* *
Dist	2	58643726	29321863	3.811	0.044	*
Mo X Dist	8	118224267	14778033	1.920	0.131	N.S.
Error	15	115399073	7693272			

Table 22. Analysis of Variance for Total-N in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	1148671481	287167870	18.483	0.0001	* *
Dist	2	151602929	75801465	4.878	0.022	*
Mo X Dist	8	150206756	18775844	1.208	0.357	N.S.
Error	15	233051388	15536759			

Table 23. Analysis of Variance for Available PO_4^{-3}-P in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	65806371	16451592.9	14.280	0.0001	* *
Dist	2	7395970	3697984.9	3.209	0.068	N.S.
Mo X Dist	8	10184391	1273048.9	1.105	0.412	N.S.
Error	15	17280707	1152047.1			

Table 24. Analysis of Variance for Organic PO_4^{-3}-P in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	9709990.1	2427497.5	1.588	0.228	N.S.
Dist	2	3635318.5	1817659.2	1.189	0.332	N.S.
Mo X Dist	8	24386847.0	3048355.8	1.994	0.118	N.S.
Error	15	22925449.1	1548363.2			

Table 25. Analysis of Variance for Total PO_4^{-3}-P in the Groundwater

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	101887513	25471878.1	5.804	0.005	* *
Dist	2	18591165	9295582.6	2.116	0.153	N.S.
Mo X Dist	8	45856049	5732006.1	1.305	0.311	N.S.
Error	15	65870544	4391369.6			

Table 26. Analysis of Variance and Orthogonal Comparisons for % Total N in *Phragmites communis* (dry wt)

Source	d.f.	Sum of Squares	Mean Square	F Value	Significance
Mo	2	0.0323	0.0162	0.649	N.S.
Dist	3	1.0843	0.3614	14.484	* *
Error	6	0.1497	0.0249		

Comparison	F Value	Significance
Top,Middle,and Bottom Slope vs Control	31.105	* *
Top Slope vs Bottom Slope	7.647	*
Top and Bottom Slope vs Middle Slope	3.705	N.S.

Table 27. Analysis of Variance and Orthogonal Comparisons for % Total P in *Phragmites communis* (dry wt)

Source	d.f.	Sum of Squares	Mean Square	F Value	Significance
Mo	2	0.00236	0.00115	6.084	*
Dist	3	0.00496	0.00165	8.758	*
Error	6	0.00113	0.00018		

Comparison	F Value	Significance
Top, Middle, and Bottom Slope vs Control	3.762	N.S.
Top Slope vs Bottom Slope	22.574	* *
Top and Bottom Slope vs Middle Slope	0.469	N.S.

Table 28. Analysis of Variance and Chi Square Test for Live Standing Crop of *Phragmites communis* (dry wt)

Source	d.f.	Sum of Squares	Mean Square	F Value	Significance
Dist	4	581924	145481	0.504	N.S.
Treat	1	808020	808020	2.802	N.S.
Dist X Treat	4	606126	151531	0.525	N.S.
Error	9	2594638	288293		
Pooled Error	13	3200764	246212		

		Significance
Chi Square Test	$X^2 = 673.0$ with 4 d.f.	* *

Table 29. Orthogonal Comparisons of Numbers of Heterotrophic Soil Microorganisms (per g dry wt)

Comparison	Significance
1) Treated Soils vs Control	* *
2) Saturated Top Slope vs Saturated Bottom Slope	N.S.
3) Unsaturated Top Slope vs Unsaturated Bottom Slope	N.S.
4) 3 Day Dried Top Slope vs 3 Day Dried Bottom Slope	N.S.
5) Unsaturated Slope vs 3 Day Dried Slope	N.S.
6) Saturated Slope vs Unsaturated and 3 Day Dried Slope	* *

Table 30. Orthogonal Comparisons of Numbers of Proteolytic Soil Microorganisms (per g dry wt)

Comparison	Significance
1) Treated Soils vs Control	*
2) Saturated Top Slope vs Saturated Bottom Slope	* *
3) Unsaturated Top Slope vs Unsaturated Bottom Slope	N.S.
4) 3 Day Dried Top Slope vs 3 Day Dried Bottom Slope	N.S.
5) Unsaturated Slope vs 3 Day Dried Slope	N.S.
6) Saturated Slope vs Unsaturated and 3 Day Dried Slope	* *

Table 31. Analysis of Variance for P in the Soil Profile

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	126020.400	31505.100	11.997	0.0001	* *
Dist	2	15226.300	7613.150	2.899	0.073	N.S.
Mo X Dist	8	16099.700	2012.462	0.766	0.636	N.S.
Depth	3	31589.000	10529.666	4.009	0.018	*
Mo X Depth	12	24659.333	2054.944	0.782	0.663	N.S.
Dist X Depth	6	12017.700	2002.950	0.762	0.607	N.S.
Mo X Dist X Depth	24	63020.967	2625.873			

Table 32. Analysis of Variance for K in the Soil Profile

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	204017.900	51004.475	8.661	0.0003	* *
Dist	2	152.133	76.066	0.012	0.988	N.S.
Mo X Dist	8	86390.200	10798.775	1.833	0.119	N.S.
Depth	3	120815.250	40271.750	6.839	0.002	* *
Mo X Depth	12	64378.500	5364.875	0.911	0.550	N.S.
Dist X Depth	6	141320.600	5888.358	3.751	0.009	* *
Mo X Dist Depth	24	749608.983	12705.237			

Table 33. Analysis of Variance for Ca in the Soil Profile

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	15649983.3	3912495.83	10.789	0.0001	* *
Dist	2	1002880.0	501440.00	1.382	0.269	N.S.
Mo X Dist	8	2126386.7	265798.33	0.732	0.663	N.S.
Depth	3	500290.0	166763.33	0.459	0.716	N.S.
Mo X Depth	12	2251443.3	187620.28	0.517	0.882	N.S.
Dist X Depth	6	3811110.0	635185.00	1.751	0.151	N.S.
Mo X Dist X Depth	24	8703006.7	362625.23			

Table 34. Analysis of Variance for Mg in the Soil Profile

Source	d.f.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	38494.10	9623.525	0.394	0.811	N.S.
Dist	2	8226.03	4113.016	0.168	0.846	N.S.
Mo X Dist	8	167525.80	20940.725	0.859	0.563	N.S.
Depth	3	22487.78	7495.927	0.307	0.821	N.S.
Mo X Depth	12	239272.97	19939.413	0.818	0.631	N.S.
Dist X Depth	6	371440.37	61906.727	2.540	0.047	*
Mo X Dist X Depth	24	584789.13	24366.213			

Table 35. Analysis of Variance for pH in the Soil Profile

Source	d.s.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	4.782	1.195	1.052	0.401	N.S.
Dist	2	2.556	1.278	1.122	0.341	N.S.
Mo X Dist	8	7.233	0.904	0.796	0.612	N.S.
Depth	3	10.707	3.569	3.143	0.043	*
Mo X Depth	12	8.973	0.747	0.658	0.772	N.S.
Dist X Depth	6	4.346	0.724	0.637	0.700	N.S.
Mo X Dist X Depth	24	27.250	1.135			

Table 36. Analysis of Variance for Organic Matter (%) in the Soil Profile

Source	d.s.	Sum of Squares	Mean Square	F Value	Prob F	Significance
Mo	4	3.514	0.878	3.803	0.015	*
Dist	2	1.914	0.957	4.142	0.027	*
Mo X Dist	8	2.016	0.252	1.090	0.403	N.S.
Depth	3	30.004	10.001	43.288	0.0001	* *
Mo X Depth	12	10.838	0.903	3.909	0.002	* *
Dist X Depth	6	4.328	0.721	3.122	0.020	*
Mo X Dist X Depth	24	5.544	0.231			

VITA

Mark Meo was born on June 20, 1948, in Marblehead, Massachusetts where he graduated from Marblehead High School in 1966. In June, 1971, he received a B.A. degree in Biology from Northeastern University, Boston, Massachusetts. In January, 1972, he enrolled in the Graduate School of Louisiana State University in Baton Rouge.

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EXAMINATION AND THESIS REPORT

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Major Field: Marine Sciences

Title of Thesis: Land Treatment of Menhaden Waste Water by Overland Flow

Approved:

John W. Day

Major Professor and Chairman

James G. Traynham

Dean of the Graduate School

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Date of Examination:

November 22, 1974