TRACE CONTAMINANT REMOVAL FROM SECONDARY DOMESTIC EFLUENT BY VASCULAR AQUATIC PLANTS

DISSERTATION OF A STUDY UNDERTAKEN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE DEGREE OF

DOCTOR OF SCIENCE

BY

SAKSIT TRIDECH

Department of Environmental Health Sciences
School of Public Health and Tropical Medicine

Tulane University

New Orleans, Louisiana

March 7, 1980

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DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCES
SCHOOL OF PUBLIC HEALTH AND TROPICAL MEDICINE

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ABSTRACT

Biological methods for purification of wastewaters are generally considered more energy efficient and cost-effective than physical-chemical methods. Vascular aquatic plants employing solar energy as the principal energy source have been shown capable of absorption, translocation and/or metabolic breakdown of heavy metals and trace organics. Nutrient, heavy metal and trace organic removals, pathogen destruction and usable by-products (harvested plants) may be realized by stocking aquatic plants in polishing ponds subsequent to secondary biological treatment or the inclusion of such plants in stabilization basins. Such treatment systems may represent the ultimate in energy conservation and optimization.

This study was under taken to compare relative efficiency of organic, nutrient and trace contaminant removals from domestic waterwaste secondary effluent by selected vascular aquatic plants. The study was divided into three phases: 1) Field Survey; 2) Batch Screenings of nine aquatic plant species; and 3) Continuous Flow Studies. A field study was conducted to determine contaminant accumulation under natural conditions and selected plant species for the batch screening study. The objective of the batch screening study was to determine the removal capabilities for various plant species and selected the most efficient for further study. The continuous flow studies were undertaken to evaluate capability of trace contaminant removal by selected aquatic plant species (rooted, submersed and floating) under plug flow conditions.

During the field study, aquatic plant species were selected and collected from various areas in the New Orleans area. Plant, water and sediment samples were collected and analyzed for pertinent trace contaminant concentrations. Results indicated almost all of the aquatic plants exhibited very high concentration factors $\frac{\mu g/gm \text{ dry plant tissue}}{\mu g/gm \text{ water}}$ for most contaminants evaluated. This is of particular significance since some trace contaminants, i.e. selenium, phenol, boron, are perhaps the most difficult to remove by secondary and advanced treatment techniques. Another important finding was that the efficiency of trace contaminant removal is plant specific.

The results of the batch screening study indicated trace contaminant removals by vascular aquatic plants followed either a pseudo first order kinetic model or a composite exponential model. Accumulation of trace contaminant in plant tissue fit a first order exponential-one compartment uptake model, excepting that of arsenic uptake by coontail which followed a two compartment uptake model. Results indicated that bulrush and water hyacinth display an overall greater affinity for contaminants of concern. Hence, these were selected for the continuous flow studies.

Results of the continuous flow study indicated that recirculation enhanced pollutant removal efficiency. It was observed that trace contaminant removal rate coefficients resulted from recirculation were greater than nonrecirculation run (approximately twice as great). Both water hyacinth and bulrush systems were excellent in reducing organics (Biochemical Oxygen Demand and Total Organic Carbon) and solids to levels expected from a physical-chemical tertiary treatment system. Nitrogen removals were also very effective as was heavy metals and trace organics removal. Water hyacinths were more efficient in the removal of nitrogen; whereas, bulrush was much more effective in the removal of trace contaminants.

Overall results indicated that vascular aquatic plants can effectively reduce organic, nitrogen and trace contaminant content of secondary effluent to very low levels with essentially no energy requirements except solar radiation. Residue contaminant levels in most cases were less than those achievable from many tertiary physical-chemical treatment systems, particularly for organics, solids, and nitrogen. Obtained removals of heavy metals and trace organic compounds (except for arsenic and boron) were greater than 80-90%. With optimization of the system, even better results can be expected. The system proposed is of simple technology, cost effective with essentially minimal energy requirements. Consequent future consideration should be given to this system as a tertiary wastwater treatment alternative.

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CHAPTER I

INTRODUCTION

INTRODUCTION

Effective wastewater treatment is an important worldwide problem, especially in countries which are limited in water resources. Water reuse in such areas must be practical and optimized. Even in areas where water resources appear plentiful the indirect, unplanned reuse of wastewater for domestic purposes is widespread. Wastewater at times can represent a significant portion of the total flow in many receiving waters and affects the quality of the aquatic environment. Since the typical wastewater treatment plant is not designed to remove all contaminants from wastes, there is concern over a possible health risk to subsequent users of these water supplies.

Advanced wastewater treatment techniques which are employed for the tertiary treatment of domestic wastewaters are energy intensive, expensive and relatively ineffective for the removal of many trace contaminants. Experience has indicated that ammonia, nitrate and total nitrogen, specific heavy metals (including selenium, mercury and boron), and trace organics including phenol are all difficult to consistently remove to safe levels using present technology (1, 2, 3). Arsenic, cadmium and polychlorinated biphenyls (PCB) are other trace compounds which are of concern. More economical and efficient methods of trace contaminant removal will be necessary if the reuse potential of wastewaters is to be fully realized.

A preliminary literature evaluation indicated that certain vascular aquatic plants have the capability to enhance water quality generated by current treatment methods. Upgrading of stabilization ponds by the inclusion of aquatic plants, for example, may result in compliance to the Water Pollution Control Act of 1975 (PL 92-500) for small communities without additional treatment expense or added complexity of operation. Nutrient, heavy metal and trace organic removals, pathogen destruction and usable by-products (harvested plants) may be realized when such plants are stocked in polishing ponds subsequent to secondary biological treatment.

Scope

This study was designed to describe the relative capabilities of selected aquatic plants for trace contaminant removals under similar environmental conditions. Trace contaminants selected were those whose removal has been demonstrated to be expensive and/or relatively ineffective by conventional secondary and tertiary treatment processes. Heavy metals selected for the study were boron, cadmium, mercury, arsenic, and selenium. Trace organics included PCB and phenol. Nutrient removal efficiency (nitrogens and phosphorus) were assessed. Monitoring included physical-chemical, and biological parameters to allow for correlation of uptake so that some basis of design for full-scale systems might be realized. Approximately 10 species of aquatic plants were investigated. Selection of these plants was based on a preliminary literature evaluation and included floating, submersed, and rooted plants.

Objectives

1. To compare relative efficiency of organic, nutrient and trace contaminant removals from domestic wastewater secondary effluent by selected vascular aquatic plants.

2. To evaluate the potential enhancement of oxidation pond performance by inclusion of such plants.

3. To develop design considerations for pilot scale and full-scale follow-up studies.

4. To determine factors affecting the effectiveness of treatment; pH, temperature, oxidation reduction potential (ORP), light intensity, etc.

CHAPTER II

LITERATURE REVIEW

LITERATURE REVIEW

Trace Contaminant Removal by Conventional Wastewater Treatment Methods

Wastewater treatment techniques currently considered "State-of-the-Art" for trace contaminant removal are expensive, energy intensive physical-chemical processes. These methods include: chemical precipitation, carbon adsorption, ion exchange, electrodialysis, reverse osmosis, and ammonia stripping. Trace contaminants of concern which tends to persist through treatment are boron, cadmium, mercury, arsenic, and selenium. Phenol and polychlorinated biphenyls (PCB) are other trace organic compounds which are of concern. Removel efficiencies of advanced wastewater treatment methods for these trace contaminants will be described as follows.

Boron can be removed from wastewaters by evaporation, ion exchange and reverse osmosis. It is reported that at a pH of 5, reverse osmosis can achieve a 36 to 80% boron removal efficiency (4). A brackish ground water initially containing borate at 0.35 mg/l as boron treated by reverse osmosis yielded a boron level of 0.14 mg/l in the permeate and 0.4 mg/l in the concentrate. Ion exchange has achieved 90% boron removal (4). An influent boron concentration of 10 mg/l was reduced to 1 mg/l. It has been found that performance of reverse osmosis and ion exchange are independent of pH and ionic strength. One process of boron removal from water developed by R.W. Goeldner is distillation (5). It involves evaporation, and recondense the vapor. By this process, a waste containing 21,000-

22,000 mg/l of boron was reduced to 50 to 80 mg/l B in the recondensed vapor. The distillation process appeared ineffective in boron removal because of the high boron residual in the effluent. Even after passing this wastewater through a 6 ft. column containing ceramic Rashing contact rings, the condensed vapor still contained 2 to 3 mg/l of boron. Field observations and laboratory studies indicate the failure of conventional treatment processes in reducing boron content of wastewater to acceptable levels based on use.

Removal of trace metals including cadmium, mercury, arsenic, and selenium from wastewaters can be accomplished by ion exchange, reverse osmosis, electrodialysis, distillation, chemical precipitation and floatation processes (6, 7, 8, 9, 10). The most common method for removal of these contaminants as recommended by the U.S. Environmental Protection Agency (EPA) is chemical precipitation followed by settling, filtration, and carbon adsorption. One study employing this method and using raw wastewater from a residential suburb of Cincinnati, Ohio evaluated ferrous sulfate (45 mg/l Fe) at pH 6, ferrous sulfate (20 mg/l Fe) plus low lime (260 mg/l as $Ca\ CO_3$) at pH 10, and high lime (600 mg/l as $CaCO_3$) at pH 11.5. With an initial concentration of 5 mg/l Cd (soluble cadmium salt was added to the influent wastewater to produce initial concentration of 5 mg/l Cd), results showed a residual cadmium concentration of 0.05 mg/l for iron addition, 0.044 mg/l for low lime, and 0.014 mg/l for high lime (7). The investigator stated that while none of the above systems for cadmium removal yield effluent sufficient to meet the EPA water quality criteria for metals in potable water sources (10 µg/l), the high lime system yielded the lowest residual.

Some difficulties may occur during the chemical precipitation process. Increasing pH with lime or caustic soda will cause redissolution of certain amphoteric elements. It is difficult to precipitate cadmium ion in the presence of complexing agents such as cyanide and ammonia. Cadmium forms soluble complexes with ammonia and with cyanide, which may interfere with its removal by precipitation (4, 7).

The same physical-chemical treatment sequence as described above effectively removed mercury from wastewaters except at low (5 µg/l) residual concentrations. Results indicate that the high lime process will yield an effluent level of 54 µg/l at an initial concentration of 0.5 mg/l. EPA water quality criteria for mercury in potable water sources, however is limited to 2 µg/l. The proposed effluent standards permit 20 µg/l mercury when the receiving stream low flow equals or exceeds 10 times the waste flow (7). The concentration of mercury observed in the effluent is therefore higher than the set standard and problems with treatment efficiency is similar to that of cadmium removal.

Precipitation with sulfide addition has been suggested for mercury removal (4). But even with using a combination of sulfide precipitation, flocculation, settling, filtration, and activated carbon polishing, limitations of removal exist. Flocculation, settling, filtration or dissolved air floatation do not enhance the efficiency of precipitation of the soluble mercury. Formation of methyl mercury sulfide complexes may occur in the presence of sulfides causing solubilization of the mercury present.

In the preceding study (7), arsenic concentrations were reduced from 5 mg/l to 58 µg/l with iron addition. Concentrations of arsenic in the effluents were 915 µg/l and 770 µg/l with low lime and high lime systems, respectively. The limitations of using this method for arsenic removal are the same as with cadmium and mercury removal. Arsenic can form slightly soluble compounds with a number of metals, including iron. Insoluble arsenic trisulfide is precipitated by reaction with hydrogen sulfide in acid solution, but readily dissolves in basic solutions (7). Therefore, pH conditions greatly affect the treatment efficiency.

Selenium removal was also investigated in the preceding study (8, 10). It was found that none of the precipitants were effective in removing selenium by settling and filtration and activated carbon. Iron was the most effective precipitant, reducing selenium from 0.05 mg/l to 12 μg/l with adsorption on old carbon and to 13.0 μg/l with adsorption by new carbon. Activated carbon did not significantly increase cumulative removal of selenium. Initial concentration of 0.1 mg/l selenium were reduced to 22.0 μg/l and to 20.0 μg/l for old and new carbon adsorption, respectively. In water, selenium anions are relatively stable. Selenite ions form complexes with a number of metal ions. Results indicated that initial concentrations of selenium could not be removed to meet recommended standards.

Other studies of removal of trace metals by tertiary physical-chemical treatment were conducted at Dallas, Texas and Orange County, California (11). The results are shown in Table 1. At Dallas, removal of metals by biological treatment (activated sludge) was also studied. Results of this study are shown in Table 2. It has been shown that the removal efficiency of some metals by these methods is unsatisfactory because of high metal residuals in the effluents especially when significant industrial discharge into the municipal system is practiced.

TABLE 1. Removal of Selected Parameters by Tertiary Physical-Chemical Treatment (11).

	DALLAS			ORANGE COUNTY		
PARAMETER	Initial Concentration	Removal Per Cent	Residual Concentration	Initial Concentration	Removal Per Cent	Residual Concentration
TOC	12 mg/l	44.2	6.7 mg/l	-	-	6.7 mg/l
COD	50 mg/l	92.0	4.0 mg/l	142 mg/l	87.3	18 mg/l
NH_3-N	5 mg/l	28.0	3.6 mg/l	45 mg/l	93.0	3.1 mg/l
TKN	9 mg/l	50.0	4.5 mg/l	53 mg/l	91.0	4.8 mg/l
NO_2 & NO_3-N	5.1 mg/l	0	5.1 mg/l	-	-	-
TDS	479 mg/l	Inc.*	608 mg/l	1020 mg/l	-	-
Phenol	-	-	-	-	-	3.9 μg/l
Ag	2.6 μg/l	7.7	2.4 μg/l	5.5 μg/l	73.0	1.5 μg/l
As	17.0 μg/l	82.3	3.0 μg/l	3.3 μg/l	27.0	2.4 μg/l
B	300 μg/l	10.0	270 μg/l	1000 μg/l	16.0	840 μg/l
Ba	120 μg/l	Inc.*	140 μg/l	81 μg/l	62.0	31.0 μg/l
Cd	5 μg/l	60.0	2 μg/l	29 μg/l	94.0	1.7 μg/l
Cr	27 μg/l	25.9	20 μg/l	154 μg/l	83.0	26.0 μg/l
Cu	29 μg/l	Inc.*	46 μg/l	266 μg/l	88.0	32.0 μg/l
Fe	590 μg/l	83.0	100 μg/l	325 μg/l	80.0	66.0 μg/l
Hg	0.16 μg/l	Inc.*	0.51 μg/l	9 μg/l	26.0	6.7 μg/l
Mn	41 μg/l	73.1	11 μg/l	35 μg/l	86.0	4.9 μg/l
Pb	34 μg/l	Inc.*	35 μg/l	19 μg/l	72.0	5.3 μg/l
Se	2.9 μg/l	69.0	0.9 μg/l	1.8 μg/l	Inc.*	1.9 μg/l
Zn	63 μg/l	0	63 μg/l	412 μg/l	57.0	162 μg/l

*Inc. - Increase

TABLE 2. Removal of Selected Contaminants by Biological Treatment (11).

	Ranges of Removals as Reported by Cohen	LA Sanitary District Projected Removals		Activated Sludge Removal Dallas		EPA Study Removal	
	Per Cent	Per Cent	Residual Metal (µg/l)	Per Cent	Residual Parameter Concentration	Per Cent	Residual Parameter Concentration
TOC	-	-	-	70.7	12 mg/l	60.0	25 mg/l
COD	-	-	-	80.7	50 mg/l	73.0	110 mg/l
NH_3-N	-	-	-	67.3	5 mg/l	42.0	14 mg/l
TKN	-	-	-	61.3	9 mg/l	34.0	18 mg/l
NO_3 & NO_3-N	-	-	-	Inc.**	5.1 mg/l	-	-
Phenol	-	-	-	-	-	45.0	175 µg/l
Ag	-	69	5.3	Inc.**	2.6 µg/l	-	-
As	-	48	5.2	18.7	17.0 µg/l	-	-
B	-	-	-	Inc.**	300 µg/l	-	-
Ba	-	-	-	33.3	120 µg/l	-	-
Cd	20-45	73	5.7	58.3	5 µg/l	18	30 µg/l
Cr	40-80	77	240*	64.9	27 µg/l	42	218 µg/l
Cu	0-70	76	-	79.4	29 µg/l	56	113 µg/l
Fe	-	-	-	9.2	590 µg/l	57	1827 µg/l
Hg	20-75	84	0.19	44.8	0.16 µg/l	35	3.5 µg/l
Mn	-	-	-	42.3	41 µg/l	35	140 µg/l
Ni	-	-	-	-	-	21	182 µg/l
Pb	50-90	80	58	52.8	34 µg/l	38	92 µg/l
Se	-	-	-	34.1	2.9 µg/l	-	-
Zn	35-80	77	497*	44.2	63 µg/l	52	277 µg/l

*Source controls needed to meet ocean outfall criteria
**Inc. - Increase

Several methods including physical-chemical and biological are available for phenol removal (4). Phenol shows significant toxicity in biological processes at concentration exceeding 125 mg/l. The most effective treatment of phenolic wastes is by ozonization (12, 13, 14). Phenol can be reduced from 49.8 mg/l to 9.1 mg/l with a flow rate of ozone of 0.1 l/min. in 60 minutes of reaction time. At flow rate of ozone of 0.5 l/min. in 60 minutes of reaction time, phenol is reduced from 299 mg/l to 56 mg/l. This method is relatively expensive and complicated. Cost of ozonization is 4 to 7 times that of biological oxidation. Some ozone-consuming constituents such as solids, sulfides, cyanides, and thiocyanates have to be removed before ozone treatment. Changes in pH during operations will change the nature of the hydrated ozone species.

Since the technology requires for reduction of PCB's concentration in wastewaters is not greatly developed, the discussion herein is limited. PCB's are similar to compounds of chlorinated hydrocarbon and/or pesticides. Therefore, treatment techniques for chlorinated hydrocarbon and pesticide removals may be applied for PCB's removal. Reduction methods include: converting halogenated organic to hydrogen halide, incineration, steam distillation, and steam stripping processes (5). EPA recommends incineration and land disposal for PCB-containing wastes, but the environment impact of such disposal techniques are not known (15). These methods are expensive and therefore not generally considered feasible.

Overall pollutant removal efficiencies by biological and physical-chemical treatment processes are shown in Table 3. Pollutants include total dissolved solids, nitrogen, trace metals, phenol, and trace organics. General comments and evaluation on contaminant removal by each treatment

TABLE 3. Pollutant Removal by Wastewater Treatment Processes (11).

(Noted in Per Cent Removal)

CONSTITUENT	SECONDARY TREATMENT (BIOLOGICAL)	CHEMICAL PRECIPITATION			ACTIVATED CARBON ADSORPTION	COMMENTS ON ACTIVATED CARBON	RESIDUAL LEVEL (µg/l)	GENERAL COMMENTS ON REMOVAL
		LIME	FERRIC CHLORIDE	ALUM				
Total Dissolved Solids	P	P	-	-	P	-	-	Generally increase TDS with treatment. Reverse Osmosis effective in removal
Ammonia Nitrogen	VG	P	-	-	P	-	-	Bio nitrification most effective; Breakpoint Chlorination and Stripping lowers F to VG
Nitrate Nitrogen	VG	P	-	-	P to G	Depends on anerobic bioactivity	-	Bio denitrification most feasible
Phenol	P	P	-	-	P	Limited by driving force to about 1 mg/l	>1 µg/l	Treatment methods not effective in reducing Phenol to 1 µg/l limit
Trace Organics	G	G	-	-	G	Removal depends on specific organics	=5 mg/l TOC and COD	Chlorinated Organics may be increased with Break point Chlorination; Ammonia Stripping effective in Removing Volatile Refractory Organics
Arsenic (As)	P to F	P to G	G	-	P	Reacts with Sulfides	3 µg/l	Depends on influent level, pH, and Redox potential
Barium (Ba)	F	P to G	-	G	F to G	Due to highly soluble nature	>30 µg/l	Enhanced precipitation as Sulfate conc. increases
Boron (B)	P	P	-	-	P	-	>290 µg/l	Generally negligible
Cadmium (Cd)	P to G	F to VG	-	F	F to VG	Old Carbon better	2 µg/l	High removals due to precipitation of Sulfide and Hydroxide forms

Poor (P) - <30% Fair (F) - 30-60% Good (G) - 60-90% Very Good (VG) - >90%

TABLE 3 (cont.). Pollutant Removal by Wastewater Treatment Processes (11).

(Noted in Per Cent Removal)

CONSTITUENT	SECONDARY TREATMENT (BIOLOGICAL)	CHEMICAL PRECIPITATION			ACTIVATED CARBON ABSORPTION	COMMENTS ON ACTIVATED CARBON	RESIDUAL LEVEL (µg/l)	GENERAL COMMENTS ON REMOVAL
		LIME	FERRIC CHLORIDE	ALUM				
Chromium (Cr)	F to G	G	VG	G (Cr^{+6}) VG (Cr^{+3})	P to G (Cr^{+3}) VG (Cr^{+6})	Reduction with Bioactivity Cr^{+3} less soluble than Cr^{+6}	20 µg/l	Depends on influent level and oxidation state
Copper (Cu)	P to G	P to G	-	G	G to VG	Enhanced Sorption better with New Carbon	70 µg/l	Influenced by Influent Concentration
Iron (Fe)	P to F	P to VG	-	-	P to G	Sulfide complexes ppt. but anaerobic bioactivity causes reduction to soluble Fe^{+2}	>40 µg/l	Depends on influent level, pH, and Redox potential
Lead (Pb)	F to G	F to G	-	VG	P to G	-	<5 µg/l	Enhanced precipitation with higher Sulfate levels
Manganese (Mn)	F	G to VG	-	P	F	Bioactivity on the Carbon reduces Mn^{+4} to Mn^{+2} and release	5 µg/l	Depends on pH and Redox potential
Mercury (Hg)	P to G	P to G	VG	G	P to G	Variability due to biological activity	5 µg/l	Removal is a function of pH, initial conc., and degree of complexation
Selenium (Se)	F	P to G	G	F	P to G	Variability due to highly soluble characteristics	2 µg/l	Depends on influent concentration
Silver (Ag)	P to G	P to VG	VG	VG	P to G	High affinity for Sulfhydryl groups	2 µg/l	Depends on influent level
Zinc (Zn)	F to G	P to F	-	P	P to G	Zinc Sulfide ppt	>60 µg/l	Depends on influent and Sulfate levels

Poor (P) - <30% Fair (F) - 30-60% Good (G) - 60-90% Very Good (VG) - >90%

method were also discussed by Englande and Reimers (11).

Role of Aquatic Plants in Wastewater Treatment

The preceding methods for the purification of wastewaters are physical-chemical techniques which are generally considered more energy efficient and relatively expensive and complicated. Biological methods are generally considered more cost-effective than the physical-chemical methods for both secondary and tertiary treatment. One potential biological method for wastewater treatment is that of employing aquatic vascular plants for nutrient and trace contaminant removal.

The capacity of vascular aquatic plants to assimilate nutrients and remove excess nitrates and phosphates from sewage effluents has been noted (16, 17, 18, 19, 20). The use of the water hyacinth as a nutrient removal method from wastewater effluents had been suggested by Dymond as early as 1948 (21). He concluded that the water hyacinths yield nitrogen removal of 3,445.8 kg/ha/year (3,075 lb/acre/year) which represents the discharge of 220 persons over a 1 year period.

Clock used water hyacinths for nitrogen and phosphorus removal from wastewaters at the University of Florida (22). He reported high quantitative removals of nitrogen and substantial phosphorus removals during a five-day detention period. Nitrate nitrogen was reduced from 1.7 mg/l to 0.06 mg/l and organic nitrogen from 5.6 mg/l to 0.86 mg/l. Total phosphate-P was reduced from 3.9 mg/l to 1.2 mg/l.

Rush or reed ponds for wastewater treatment was investigated in Netherlands (23). Rush was found to remove nitrogen at a rate of 260 kg/ha/year (above ground) and 320 kg/ha/year (below ground) with total loading to the pond of 1,004 kg/ha/yr. Phosphorus was also removed at a rate of 50 kg/ha/yr (above ground) and 55 kg/ha/yr (below ground) at a total pond loading of 167 kg/ha/yr. Reed showed lower N and P removal ability than rush.

Culley and Epps (24) studied the use of greater duckweed for wastewater treatment and animal feed in Louisiana. The duckweed, species of Spirodela oligorrhiza was investigated. They observed removals by duckweed of 184.9 kg total nitrogen/ha/month (165 lb/acre/month) and 59.4 kg phosphorus/ha/month (53 lb/acre/month). The duckweed contained a high nutritive content, especially protein. Nutrient removal using common duckweed, Lemna minor, was conducted by Harvey and Fox (25). Effluent from the University of Florida treatment plant, Gainesville was used in their study. They observed Kjeldahl nitrogen reductions from 4.5 mg/l to 0.5 mg/l with a 10 day detention time (75-89% removal). At the same detention period, nitrite nitrogen was reduced 8.8 mg/l to 3.5 mg/l (21-60% removal) and total phosphorus was reduced from 15.4 mg/l to 2.6 mg/l.

Peterson et al (26) reported on the full-scale harvest of aquatic plants for nutrient removal from an eutrophic lake in Lake Sallie, Minnesota. Since types of aquatic plants were not described, nutrient removal potential of various plants was not defined. Aquatic plant harvesting removed 721.1 kg (1,590 lb) of nitrogen (3.5% of total nitrogen input) and 100.2 kg (221 lb) of phosphorus (1.37% of total phosphorus input to the lake) during the 1970 water year.

Boyt, Bayley and Zoltek studied the removal of nutrients from treated municipal wastewater by a wetland system at Wildwood, Florida (27). Several species of aquatic plants found naturally in swamps displayed nutrient and heavy metal removal capabilities. The plants studied included Lemna sp. (duckweed), Typha latifolia (cattail), Salix sp. (willow), etc. The results indicated a 98.1% reduction in total phosphorus and 89.5% in total nitrogen with initial concentrations of 6.4 mg/l total phosphorus and 15.3 mg/l total nitrogen. It was estimated that by using the swamp system as an alternative to tertiary treatment a savings of $79,500/yr (ENR 1974 cost base) for the residents of Wildwood would be realized.

Other species of plants investigated for wastewater treatment application as reported by Woodwell (28) are Phleum pratense (grass), Zea mays (corn), Pinus rigida (pine), etc. A reduction of total inorganic nitrogen of 91% and phosphorus as PO_4 of 98% was observed.

Vascular aquatic plants have also been shown capable of sorption, translocation and/or metabolic breakdown of heavy metals and trace organics. Wolverton concluded from lab scale wastewater investigations that water hyacinths can remove a maximum of 0.50 mg of nickel and 0.67 mg of cadmium per gram (dry weight) plant material over a 24-hour period (29). A maximum concentration of 0.176 mg lead and 0.150 mg of mercury per gram dry plant tissue by water hyacinths has also been reported by Wolverton and McDonald (30). During the same study alligator weeds removed a maximum of 0.101 mg of lead per gram of dry plant tissue over twenty-four hours and a minimum of 0.153 mg of mercury per gram over six hours. Wolverton has reported phenol removal potential by water hyacinths at a rate of 12 mg per gram dry plant weight per day (31).

The use of macrophytes for water purification was conducted by Kathe Seidel in West Germany (23). She investigated several macrophytes such as Scirpus lacustris, Carex stricta, Pragmites communis. These plants were found to remove trace contaminants from wastewaters. For example, Acorus calamus removed a concentration of 4.1 mg of copper per kilogram dry weight plant material. It also removed a concentration of 383 mg of manganese and 56.9 mg of boron per kilogram dry plant tissue.

The phenomenon involved in trace contaminant removal by aquatic plants is poorly understood. The literature is also lacking with respect to the trace pollutant uptake potential of various vascular aquatic plants (with the possible exception of water hyacinths). Optimization and system design techniques for the inclusion of such plants as a tertiary treatment method are also lacking.

Public Health Significance of Trace Contaminants

Wastewaters constitute a major route by which trace contaminants are distributed into the physical environment and potentially affect living organisms, including man. Wastes containing toxic contaminants are discharged into natural water bodies where they can contact and become concentrates in food chain organisms and plants. Trace contaminant accumulation in the environment therefore represents environmental insult and a potential threat to human health.

Public Health significance of trace contaminants warrants efficient removal by waste treatment facilities so that minimal emission to the environment will be realized. Many small communities and rural areas will require low cost, low energy and relatively simple techniques to realistically comply with these goals. With increasing demands for water reuse, larger municipalities find secondary and tertiary treatment method expensive and/or ineffective for nutrient and trace contaminant removals. The research was designed to evaluate a simple, cheap, and potentially effective method for efficient removal of these contaminants for small or large communities and industry alike.

Limits on effluent concentrations of heavy metals are based on criteria as related to water use (municipal water supply, irrigation water, fish and wildlife propagation, etc.). The environmental significances of the trace contaminants selected for study are discussed briefly in the following.

Boron concentrations less than 0.1 mg/l are considered innocuous for human consumption (32). Long term ingestion may result in a clinical syndrome known as borism (a central nervous system disorder). Although it is an essential element for plant growth, the amount of 750 µg/l in irrigation water is deleterious to certain plants.

Cadmium will accumulate with age in the human kidney and liver. It has particularly been shown to accumulate in mollusks, crustaceans, and plants (33). Mathis and Cummings had determined concentrations of cadmium in sediments, water and biota in the Illinois River (34). They observed concentrations of cadmium in bottom sediments are in the range of 0.2 to 12.1 ppm. Concentrations in clams are in the range of 0.15 to 1.41 ppm. Concentrations in fishes; omnovorous and carnivorous fishes, are in the range of 0.001 to 0.069 ppm, and 0.004 to 0.085 ppm, respectively. In the Illinois River water, cadmium concentrations were observed in the range of 0.0001 to 0.002 ppm. Average concentration of cadmium in other rivers is 0.08 ppm which was reported by Bowen (34). EPA suggests a limiting cadmium concentration of 10 µg/l for domestic water supply Concentrations of 0.4 to 1.2 µg/l Cd from soft to hard water are recommended for fresh water aquatic life and 5.0 µg/l Cd for marine aquatic life (35).

Inorganic mercury is relatively less toxic to humans than organic mercury, methyl mercury or mercury vapor (36). Mercury accumulation can cause gastroenteritis and severe kidney injury. Methyl mercury can accumulate in blood cells, brain and central nervous system which can lead to irreversible damage to the nervous system (37). The "Minimata Incident" is the most commonly referenced case of mercury poisoning of human subjects. In this case the individuals received extreme doses through contaminated fish and shellfish. Public water systems are protected by the maximum permissible level of 0.002 mg/l (38). Toxicity of mercury to fishes and aquatic insects has been reported. Mercury concentration of 0.01-0.02 mg/l is toxic to fishes. The 96-hr TL_m for aquatic insects; acroneuria, ephemerella, and hydropsyche, is 2.0 mg/l Hg (39). In Sweden, concentrations of methyl mercury in sediments sampled from a coastal area of the Bothnian Bay were as high as 14 to 525 ppb dry sediment (40). Mercury levels in bottom muds below some municipal and industrial outfalls in Michigan were usually below 1 mg/kg; however, in some areas a maximum range of 10-20 mg/kg dry weight was recorded (41). Levels of mercury in the flesh of fish in the St. Clair River, Lake St. Clair, some portions of the Detroit River, and some areas of Lake Erie were above 5 mg/kg. EPA recommends a limiting mercury concentration of 2.0 µg/l for domestic water supply. Concentration of 0.05 µg/l Hg is recommended for fresh water aquatic life and wildlife. Mercury concentration of 0.10 µg/l is recommended for marine aquatic life (35).

Arsenic has long been demonstrated toxic to human and aquatic life. Inorganic arsenicals (arsenites) are found to be more toxic than organic forms (arsenates). Exposure to arsenics causes skin irritation or possible dermatitis, hyperkeratosis, gastrointestinal disorders, peripheral neuropathy, mascular weakness, and skin cancer (37). Arsenic has been found to accumulate in soils and aquatic biota. Soils with no previous history of arsenical treatment may have arsenic concentrations of 2-20 µg/g. High arsenic levels of 1,270 µg/g have been found in deeper strata over sulfide deposits in the New Brunswick District, Canada. Arsenic concentrations of 0.02-2.48 µg/g in large mouth black bass in several southern states were reported (42). EPA suggests a limiting arsenic concentration of 50 µg/l for domestic water supply and 100 µg/l for irrigation of crops (35).

Selenium toxicity resembles that of arsenic which includes both acute and chronic symptoms, sometimes resulting in death. It has been reported that selenium affects the growth of wheat, rye, oats and barley grown in soil treated with sodium selenate at concentrations of 10 ppm selenium (43). Selenium-containing plants are also toxic to higher animals for consumption. Selenium poisoning occurs with live stock and is called "Alkali Disease" (44). Therefore, concentrations of selenium in irrigation water and live stock water supply must be limited to 20 µg/l for continuous use. Domestic water supply requires selenium levels less than 10.0 µg/l (35).

Phenol is an important toxic and/or taste and odor causing compound of concern. Certain phenolic materials are toxic to aquatic life and may pose a health hazard to humans. They cause strong tastes and odors in drinking water supply. Pure phenol of 0.079 mg/l is toxic to minnows within 30 minutes and 56.0 mg/l to mosquito fish in 96 hours. Phenolics cause damage to epithelial cells and reproductive systems of trout and also affect the taste of fish (44). Maximum concentration of phenol recommended for aquatic life and for domestic water supply is 1.0 µg/l (35).

Polychlorinated biphenyls (PCB's) are remarkably persistent in the environment and degrade very slowly. PCB causes skin disorders in humans and failures to reproduce in some animal species. Because of its ability to produce cancer in rats, it may also cause cancer in humans (45, 15). The estimated loss of PCB's to the water environment over the past 40-year period would approach 60,000 tons with remaining nondegraded residues estimated at 30,000 tons in water (37). Duke et al (46) has studied PCB (Aroclor 1254) in the water, sediment, and biota of Escambia Bay, Florida. Juvenile shrimps were observed to be sensitive to PCB's. These died when exposed to 5.0 ppb of Aroclor 1254 in flowing sea water. The Aroclor content in water contained less than 1 ppb produced a 2.5 ppm content in shrimp. Hansen et al (47) stated that juvenile pin-fish and another estuarine fish died in water containing 32 μg/l of Aroclor 1016, but survived at lower concentrations. The fish in New York's Hudson River have levels of PCB's in the range of 4 to 49 ppm with an average of over 15 ppm. This is three times the maximum concentration allowed in food by the Food and Drug Administration (45). Maximum concentrations of total PCB in unfiltered water (for fresh water and marine aquatic life) are set at 0.001 μg/l with residues in body tissues of aquatic organism less than 0.05 μg/g (35, 44).

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The study consisted of three phases: (1) Start Up and Field Survey; (2) Batch Screening Study; and (3) Continuous Flow Study The objective of the field study was to observe trace contaminant accumulation under natural conditions in an effort to determine plant species for the screening study. The objective of the batch screening was to determine removal capacity for various plant species and select the most efficient for further evaluation. The continuous flow study was designed to study selected species (rooted, submersed, and floating) in order to determine removal capacities of trace contaminant removal under continuous flow conditions. These phases will be further detailed as follows:

Phase I - Start Up and Field Survey:

This phase was performed during June, 1978 to November, 1978. It included equipment selection and purchase, equipment set-up, development of analytical methods, and plant species selection and collection.

The species were selected for study based on a high contaminant removal efficient potential as determined by a preliminary literature evaluation and the experiences of Drs. John T. Barber and Leonard B. Thien, Department of Biology, Tulane University. Plants were divided into floating, submersed, and rooted classifications (48, 49, 50, 51) and included:

Common Name	Scientific Name	Classification
Bulrush	Scirpus L.	Rooted plant
Rush	Juncus spp.	Rooted plant
Arrowhead	Sagittaria graminea	Rooted plant
Water hyacinths	Eichhornia crassipes	Floating plant
Duckweed	Lemna minor	Floating plant
Water-bonnet	Pistia stratiotes	Floating plant
Elodea	Elodea canadensis	Submersed plant
Coontail	Ceratophyllum demersum	Submersed plant
Alligator-weed	Alternanthera philoxeroides	Emersed plant

Pictures of the above plants are shown in Figures 1-9.

Plant, water, and sediment samples were collected from various water bodies surrounding the New Orleans area and analyzed for pertinent trace contaminant concentrations. Some of the collected plants were washed and stocked in a hydroponic solution for the subsequent batch screening study. Details of the procedure employing this hydroponic solution for plant acclimatization are included in Appendix A.

Phase II - Batch Screening Study:

Phase II started on December 22, 1978 and concluded in June, 1979. This phase consisted of screening the aquatic vascular plants previously listed for relative trace contaminant removal efficiency Ninety liter aquaria were filled with secondary effluent from the West Bank Sewage Treatment Plant (trickling filter waste treatment facility) and stocked with different species of selected acclimatized mature plant in each aquarium. These included bulrush, rush, arrowhead, water hyacinths, duckweed (two aquaria were used, #1 and #2), water-bonnet,

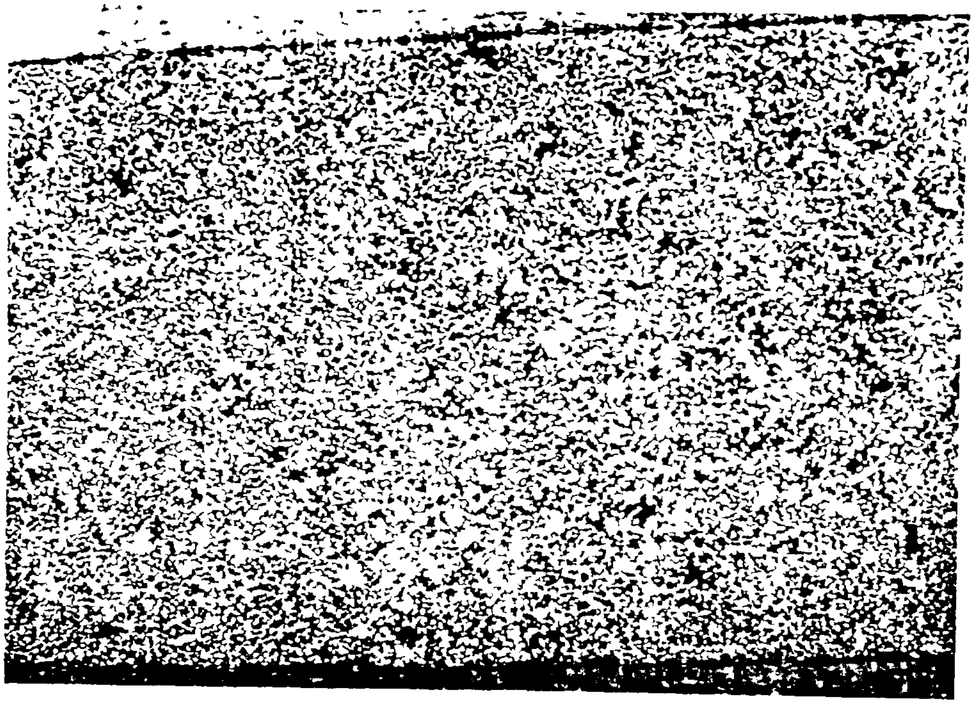


Figure 1. Lemna minor (Duckweed)

Figure 2. Ceratophyllum demersum (Coontail)

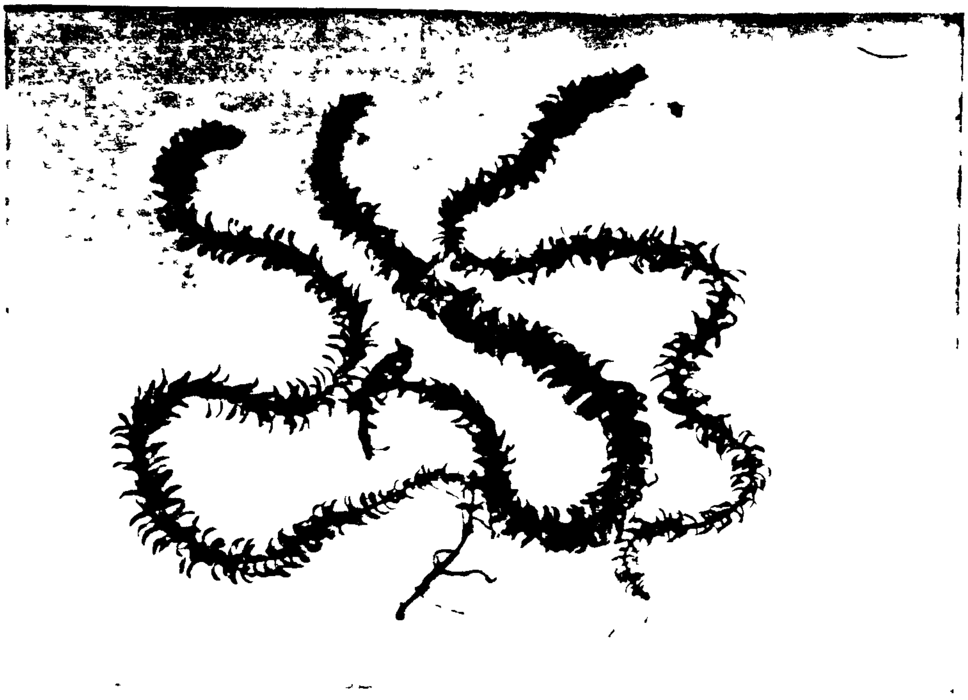


Figure 3. Elodea canadensis (Elodea)

Figure 4. Pistis stratiotes (Water-bonnet)

Figure 5. Alternanthera philoxeroides (Alligator-weed)

Figure 6. Sagittaria graminea (Arrowhead)

Figure 7. Eichhornia crassipes (Water hyacinths)

Figure 8. Scirpus L. (Bulrush)

Figure 9. Juncus spp. (Rush)

elodea, coontail, and alligator-weed. The effluent water was spiked with quantities of arsenic (As), boron (B), Cadmium (Cd), Mercury (Hg), Selenium (Se), phenol and polychlorinated biphenyls (PCB) to yield approximate concentrations of 1, 5, 1, 1, 1, 1 and 0.03 mg/l respectively. Types of chemicals used for spiking the secondary effluent (7, 8, 52) are shown in Table 4. Each aquarium was filled with eighty liters of spiked effuent prior to plant inclusion. All plants were weighed (wet-weight) before being stocked in the aquaria. For rooted plants (bulrush, rush and arrowhead), the root zones were supported by acid-washed gravel.

Each aquarium used for this phase was divided into 3 partitions by 2 glass baffles to minimize short circuiting of flow. The aquaria were equipped with Dynaflo magnetic pumps allowing circulation of flow of approximately 40 ml/min. This provided increased contact between the water and roots of the plants and reduced mass transfer resistance. A schematic of the aquaria used in this phase is illustrated in Figure 10.

A control aquarium with only spiked effluent (no plants) was employed. Another aquarium was stocked with algae in order to aid in assessing performance of selected plant species as compared to that occurring in an oxidation pond. Plants were grown in the Tulane Research Center greenhouse under constant temperature conditions of 25° C ± 5° C.

A pre-test of the Batch Screening Study aquaria was conducted during December 13-19, 1978, prior to commencing the experiment. Results of the pre-test are presented in Table D-1 of Appendix D. During the study, liquid volume losses in each aquarium due to evapotranspiration were controlled by the addition of nitrogen/phosphate-free distilled water. Samples were withdrawn over a four week period in accordance with the testing schedule outlined in Table 5. Productivity at the end of this period was assessed by analyzing the plant tissue increase of the standing crop (dry weight basis).

Table 4. Chemicals Used for Spiking the Secondary Effluent

Trace Contaminant	Chemical form added
Arsenic (As)	$NaAsO_2$
Boron (B)	H_3BO_3
Cadmium (Cd)	$CdCl_2 . 2\ H_2O$
Mercury (Hg)	$HgCl_2$
Selenium (Se)	SeO_2
Phenol	C_6H_5OH
Polychlorinated Biphenyls (PCB)	Arochlor 1254

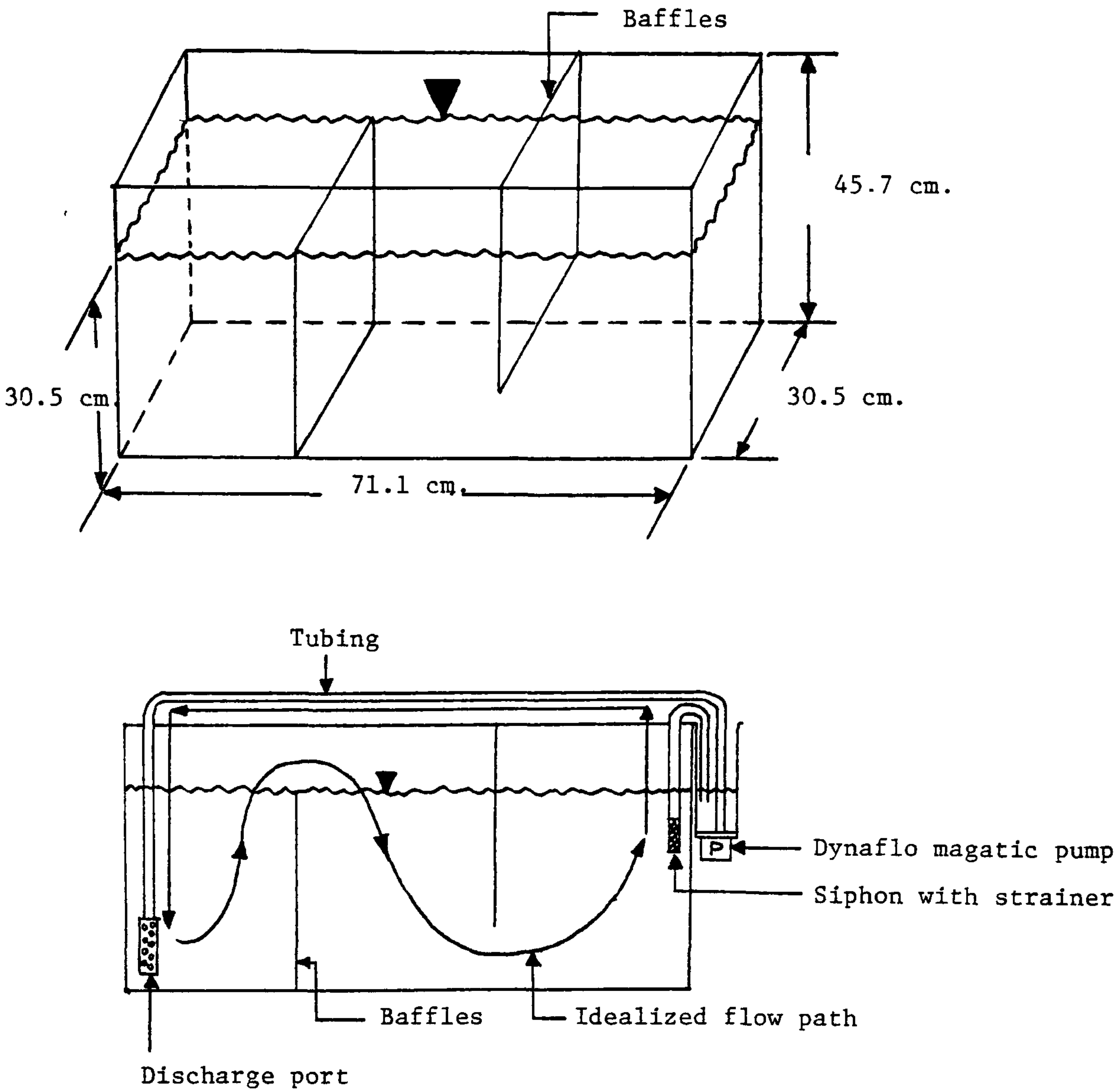


Figure 10. Schematic of Batch Screening Aquarium

Table 5. Testing Schedule-Screening Study

Parameters to be measured	Sampling location In Pond	 Plant Tissue (root, stem, leaves)
pH*	X	
Temperature*	X	
Evaporation	X	
Solar Radiation*	X	
Biochemical Oxygen Demand (BOD)	X	
Total Organic Carbon (TOC)	X	
Dissolved Oxygen* (DO)	X	
Oxidation Reduction Potential* (ORP)	X	
Phenol	X	X
Polychlorinated Biphenols (PCB)	X	X
Heavy Metals (B, Cd, Hg, As, Se)	X	X
Nitrogen (TKN, NH_3, NO_2, NO_3)	X	X
Phosphate	X	X
Fecal Coliform	X	

* Measurements made daily. Other parameters monitored three times for the first week, two times during the second, once during the third and the end of the fourth week.

Phase III - Continuous Flow Study:

Phase III was conducted during July to October, 1979. This phase consisted of two parts, a Continuous Flow - Nonrecirculation and a Continuous Flow - 1:1 Recirculation run.

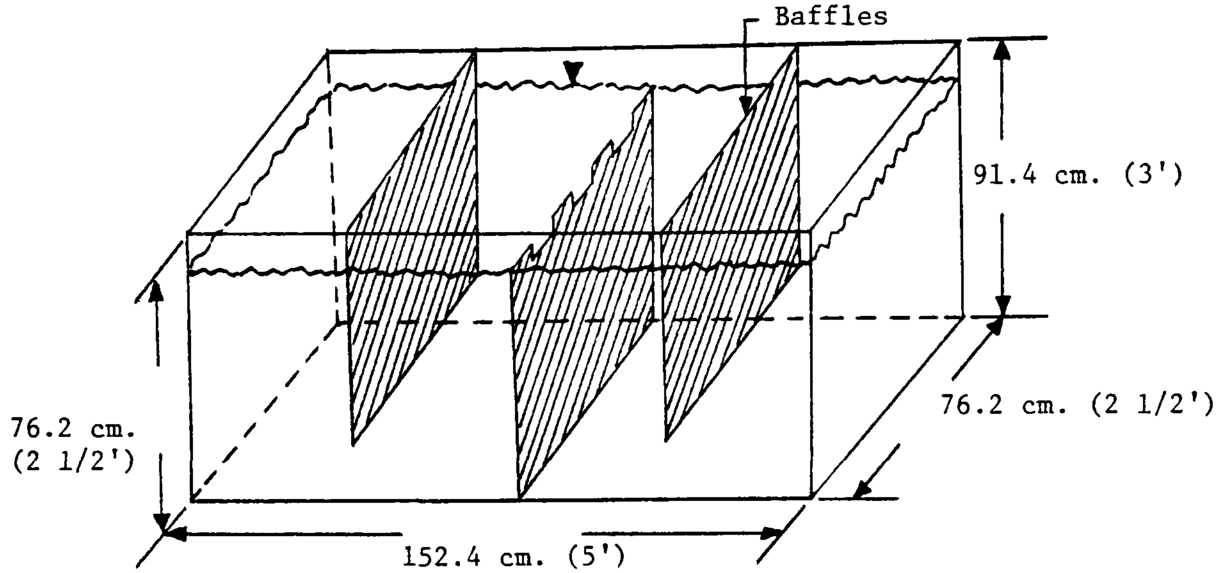
(1) Continuous Flow Study - Nonrecirculation:

Based on the results of the batch screening study, and practical considerations such as productivity of the plants, ease of harvesting etc., three different plant species were selected for the continuous flow studies. Due to high removal capacity for most contaminants, bulrush was chosen for further study. Elodea was also selected as the submersed plant and water hyacinths was picked as the floating plant for additional evaluation. Water hyacinths was also selected because of the literature base available for comparison of obtained data.

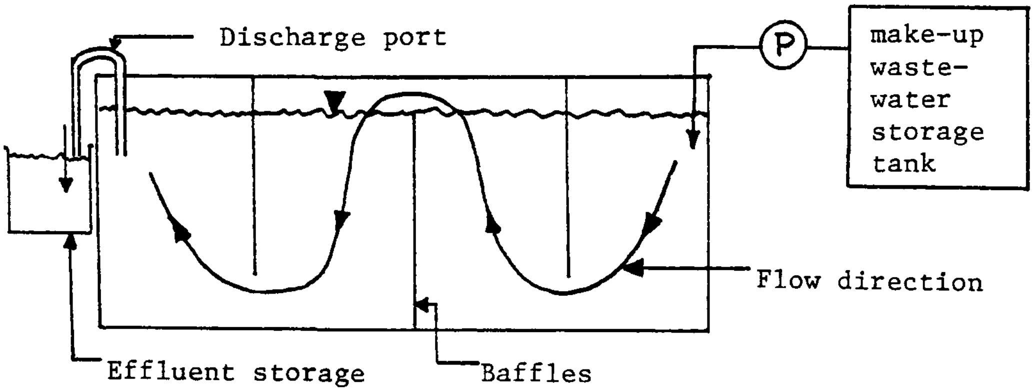
Baffled, epoxy coated wooden tanks of approximately 900 liter capacity were employed during the 58 day study. Tanks were divided into four partitions with baffles to minimize short circuiting. Figure 11 illustrates the tanks employed. Pre-test of the tank was performed during June 5-19, 1979. Results of the pre-test are shown in Table E-1 in Appendix E. Minimal loss of added chemicals to the tank surface was observed. Dye testing to insure that plug flow conditions predominated was also performed.

Plants were stocked in the tanks following the same procedure as employed in the batch screening study except that the tanks were initially filled with hydroponic solution. Spiked effluent was then pumped into each basin, and flow rates were adjusted to yield a 15 day retention time (40 ml/min). Spiking of the secondary effluent was similar to the batch screening study except that the boron concentration

a) Testing Chamber Schematic



b) Continuous Flow Study, Non-recirculation



c) Continuous Flow Study, 1:1 Recirculation

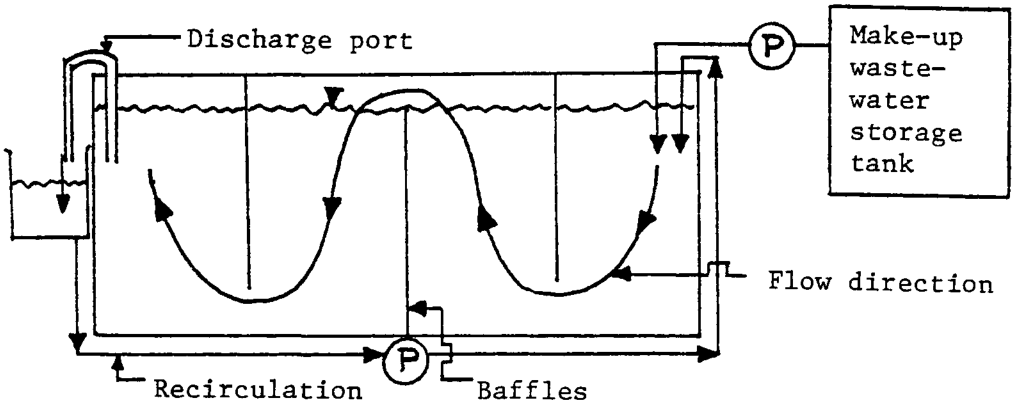


Figure 11. Continuous Flow Basin Schematics

was reduced to 1 mg/l. In this study ammonium hydroxide (NH_4OH) was also added to the secondary effluent to yield a concentration of approximately 25-30 mg/l N to approximate the concentration typical of raw domestic waste water. This study was also conducted in the greenhouse at a temperature of 25° C ± 5° C. After two retention periods, intensive sampling and analysis were effected over a four week period. Testing was conducted as per the schedule outline in Table 6.

(2) Continuous Flow Study, 1:1 Recirculation:

The procedure similar to that described above was repeated employing a 1:1 recirculation of effluent flow to feed flow. Flow rates were adjusted to yield a 7.5 day retention. Prior to run commencement the basins were stocked with new mature plants. Only bulrush and water hyacinths were selected for this run since elodea exhibited a significant decrease in productivity during the nonrecirculation run. Two test basins were set in series for bulrush with flow rates adjusted to yield a 7.5 day retention. This was necessary because the optimal water depth for bulrush growth is 0.5 meters; whereas for water hyacinth it is 1 meter. During this run water was added to make up for evapotranspiration.

A ninety liter aquarium was used as a control (no plants) in both nonrecirculation and 1:1 recirculation studies. Data were collected as described above to evaluate the effect of increased flow velocity and decreased retention time within the tanks. A schematic of the test basins is illustrated in Figure 11. Photographs of the experimental set-up are also shown in Figures 12-15.

Table 6. Testing Schedule-Continuous Flow Study

		Location in Sampling			
Parameter to be Measured	Frequency of Analysis	Influent	In Pond	Effluent	Plant Tissue (root, stem, leaves)
pH	daily	X	X		
Temperature	daily		X		
Flow	daily	X		X	
Evaporation	daily		X		
Solar Radiation	daily		X		
BOD	2/week	X		X	
TOC	daily	X		X	
Total and Volatile Suspended Solids	2/week	X		X	X
D.O.	daily		X		
ORP	daily		X		
PCB	2/week	X		X	X
Phenol	2/week	X		X	X
Heavy Metals, B, Cd, Hg, As, Se	2/week	X	X	X	X
Nitrogen, TKN, NH_3, NO_2, NO_3	2/week	X	X	X	X
Phosphate	2/week	X	X	X	X
Fecal Coliform	2/week	X		X	

Figure 12. Water hyacinths basin, Continuous Flow Study; 1:1 Recirculation Run.

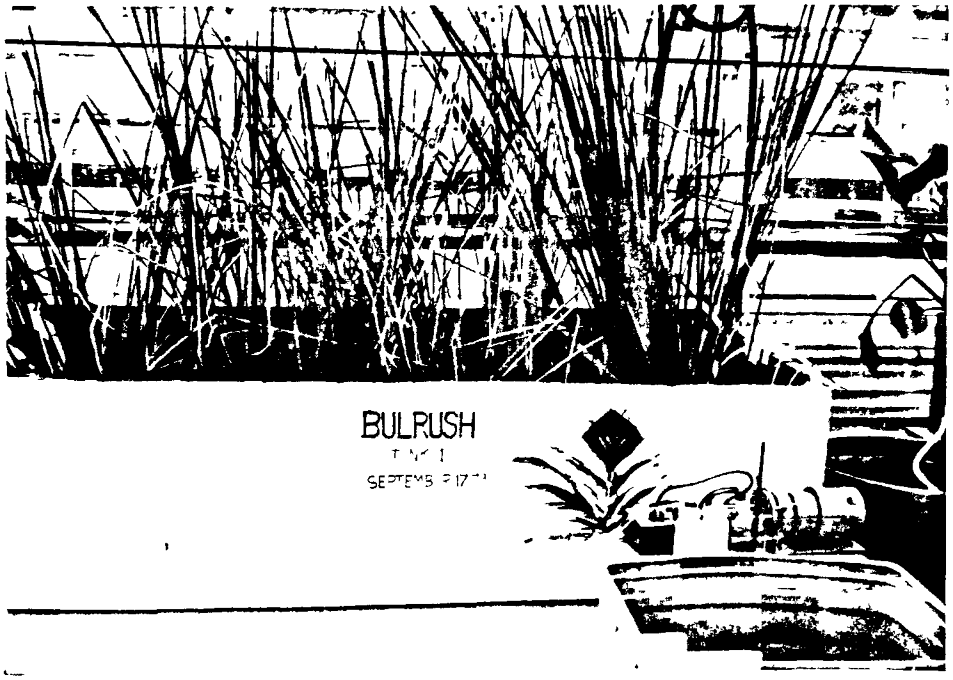


Figure 13. Bulrush Basin #1, Continuous Flow Study; 1:1 Recirculation Run.

Figure 14. Bulrush Basin #2, Continuous Flow Study; 1:1 Recirculation Run.

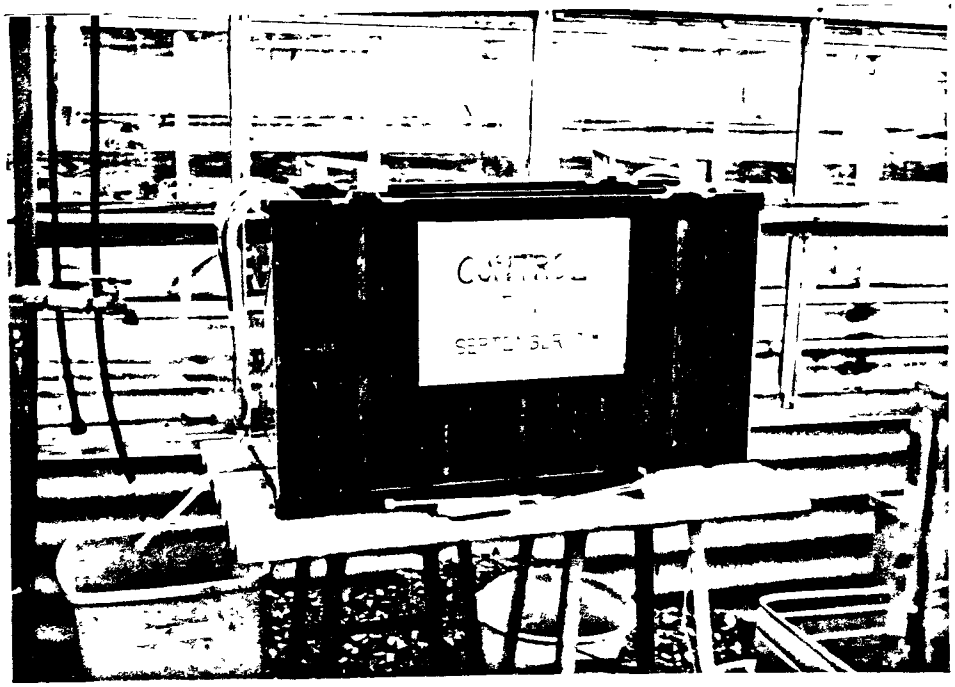


Figure 15. Control Basin, Continuous Flow Study; 1:1 Recirculation Run

Sampling Methods

During the field survey, aquatic plants were collected from different areas as previously described. Water and soil or sediment samples were also taken from the same location. Plant and water samples were withdrawn randomly during the Batch Screening Study. During the Continuous Flow Study, water samples including grab samples of influent, in-pond and effluent were collected throughout the study. The plant samples were taken from two locations from within a given test basin (Points A and B). Point A was located in the first partition of the test chamber or the first chamber (for bulrush in the continuous flow study - 1:1 recirculation run). Point B was located in the second partition (or the second chamber for bulrush in the recirculation run). The objective of this sampling order was to determine the effect (if any) of plant location on trace contaminant uptake.

(1) Water Samples: For water samples, pH and oxidation-reduction potential (ORP) were determined in situ. Biochemical oxygen demand (BOD_5) and fecal coliform analysis (membrane filter procedure) were performed immediately following the collection of samples. Remaining portion of water samples were stored in glass containers, preserved, and refrigerated at 4°C according to the procedures described in the Standard Methods and EPA Methods (53, 54) for trace contaminant analysis.

(2) Plant Samples: Plant samples were washed with tap water and rinsed with distilled water The total amount of plants removed from each aquarium for each sampling was weighed (wet-weight) and then separated into the roots, stem, and leaf portion. Wet plant samples were used for analysis of phenol and PCB's to prevent losses of phenol and PCB's by volatilization when drying the plant. When time did not

allow for immediate analysis the samples were frozen until analysis could be performed. Remaining plant samples were dried in an oven at 60°C for 2 days (29, 30, 55) to determine sample dry weight and then analyzed for other trace contaminant content.

(3) Soil or Sediment Samples: Soil or sediment samples were collected in glass containers and refrigerated at 4°C. Wet samples were used for determination of phenol and PCB's. Samples were also dried for dry weight determination following the method used for plant tissue. These dry samples were then analyzed for other trace contaminant content.

Analytical Methods

A. Water Sample Analysis

(1) pH. During the course of the investigation, water pH was measured by a Beckman Zeromatic pH Meter, Model SS-3, manufactured by Beckman Instruments, Fullerton, California.

(2) Temperature. Water temperatures were determined by a built-in temperature probe of a Dissolved Oxygen Meter, Hand Probe Type, Model 54 and/or Model 54A manufactured by Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio.

(3) Evaporation. Water evaporation was measured from both aquarium and an evaporation pan. The evaporation pan was 26 inches long, 20 inches in width, and 4 3/4 inches deep and evaporation was recorded throughout the experiment.

(4) Solar Radiation. Solar radiation intensity was monitored daily by employing a Weathertron Solar Radiation Unit, Model R401 - Mechanical Pyranograph, manufactured by Weather Measure Corporation, Sacramento, Calirofnia.

(5) Dissolved Oxygen (D.O.). Dissolved oxygen water concentration was determined by a YSI Hand Probe Dissolved Oxygen Meter as previously described.

(6) Biochemical Oxygen Demand (BOD_5). The BOD_5 was determined using the procedure outlined in Standard Methods (53).

(7) Total Organic Carbon (TOC). Total Organic Carbon of water samples were detected by Total Carbon Analyzer, Model DC-50, manufactured by Dohrmann Envirotech, Mountain Diew, California.

(8) Total and Volatile Suspended Solids (SS and VSS). Both SS and VSS of influent and effluent samples were determined in accordance with Standard Methods.

(9) Oxidation Reduction Potential (ORP). The ORP of water samples was monitored by an ORP probe connected to a pH meter, Model 701/digital . Both probe and pH meter were manufactured by Orion Research Incorporated, Cambridge, Massachusetts.

(10) Fecal Coliform Examination. The membrane filter procedure followed was as per Standard Methods.

(11) Determination of Arsenic (As), Cadmium (Cd), and Selenium (Se) in Water Samples. Arsenic, cadmium and selenium were determined by Flameless Atomic Absorption Spectroscopy (56, 57, 58, 59). An Atomic Absorption Perkin-Elmer Model 372 was used. Background correction was incorporated and the unit was equipped with a Graphite Furnance Model HGA 2200. This equipment was manufactured by Perkin-Elmer Corporation, Norwalk, Connecticut. The minimum detection limits of arsenic, cadmium and selenium by using the above method were 0.0002, 0.000003 and 0.0005 µg/ml, respectively (60).

For arsenic analysis, the standard conditions of the Atomic

Absorption were set at a wavelength of 193.4 nm, a drying temperature at 100°C for 30 seconds, a charing temperature at 250°C for 30 seconds, and an atomizing temperature at 2000°C for 7 seconds. A sample of 20 µl was employed and covered with 20 µl of 1000 mg/l Ni (as $Ni(NO_3)_2$) to prevent losses of arsenic by volatilization (61). Under these conditions, a standard aqueous solution of 0.100 mg/l As has a recovery efficiency of 98-105 percent.

For cadmium analysis, the standard conditions were set at a wavelength of 228.8 nm, a drying temperature at 125°C for 40 seconds, a charing temperature at 350° for 40 seconds, and an atomizing temperature at 2000°C for 12 seconds. Under these conditions, a standard aqueous solution of 0.100 mg/l Cd has a recovery efficiency of 98-107 percent.

The standard conditions for selenium analysis were set at a wavelength of 196.0 nm, a drying temperature at 100°C for 30 seconds, a charing temperature at 350°C for 30 seconds, and an atomizing temperature at 2200°C for 10 seconds. Sample injection was identical to that used for arsenic analysis i.e. by covering the top of the sample with 20 µl of 1000 mg/l Ni (61). A standard aqueous solution of 0.100 mg/l Se has a recovery efficiency of 95-104 percent.

(12) Determination of Boron (B) in Water. The Curcumin Method, a colorimetric technique, described in Standard Methods (53,54) was employed. Minimum detectable quantity of boron is 0.2 µg. A synthetic sample of 240 µg/l B analyzed by this method showed a relative error of 0%. A standardization curve for boron is shown in Figure B-1 of Appendix B.

(13) Determination of Mercury (Hg) in Water. Mercury concentration was determined by Cold Vapor Methods (54, 62, 63, 64), using a

Coleman Mercury Analyzer, Model MAS-50. Sensitivity of the instrument is equal to or better than 0.0001 μg/ml Hg. The standardization curve for mercury analysis is shown in Figure B-2 of Appendix B.

(14) Determination of Phenol in Water. In both the field and batch studies, water samples were analyzed for phenol concentration by using colorimetric method described in Standard Methods and EPA Methods (53, 54). The minimum detectable quantity of phenol by this method is 0.5 μg. The standardization curve for phenol analysis is shown in Figure B-3 of Appendix B.

During the continuous flow study phenol concentrations were analyzed by Gas Chromatographic Methods using a Free Fatty Acid Phase column. Gas chromatograph procedures were followed according to Standard Methods. A gas chromatograph Model 5830-A manufactured by Hewlett Packard (Avondale, Pennsylvania) was used. The precision of this method is the same as the colorimetric method. However, by testing in the laboratory with the gas chromatograph cited above, standard aqueous solutions of 1.0 mg/l and 0.025 mg/l phenol showed recovery efficiencies of 92-108 percent.

(15) Determination of Polychlorinated Biphenyls (PCB's) in Water. Water sample volumes of 400 ml were extracted twice with 50 ml of hexane. Anhydrous Sodium Sulfate (Na_2SO_4) was added to the extract to absorb trace water in the extract. The extract was then concentrated to about 1 ml by evaporation. The extract was cleaned by pouring through a 200 mm x 9 mm (I.D.) chromatographic column containing 3.0 gm of activated Florisil topped with 2.0 gm of anhydrous sodium sulfate and eluted with 40 ml of 5% ethyl alcohol in hexane (65, 66).

The extract was analyzed for PCB by electron capture gas chromatography (67, 68). A Microtek 220 gas chromatograph equipped with integrator was used throughout the study. By using the gas chromatographic method, the minimum detectable quantity of PCB (Aroclor 1016) as determined by the NIOSH analytical method was 32 picograms per injection (4 µl) (69). The gas chromatograph used in this study was also capable of detecting nanograms of PCB per injection (5µl).

(16) Determination of Total Kjeldahl Nitrogen TKN), Ammonia (NH_3), Nitrate (NO_3), Nitrite (NO_2), and Phosphate (PO_4) in Water. Determinations were made in accordance with Standard Methods and EPA Methods. For TKN and ammonia determination, the detectable range is optimal at 1.0 to 2.5 mg/l for the titrimetric procedure. For nitrate determination, the Brucine Method was used with the detectable range between 0.1 to 2 mg NO_3-N/l. The colorimetric method of nitrite determination has a detectable range of 0.01 to 1.0 mg NO_2-N/l. Stannous Chloride Method used for phosphate determination has an optimal detectable range between 0.01 to 0.5 mg P/l. Standardization curves for NO_3, NO_2, and PO_4 analyses are shown in Figure B-4 to Figure B-6 in Appendix B.

B. Plant Sample Analysis.

(1) Determination of Arsenic (As), Cadmium (Cd), Mercury (Hg), and Phosphate (PO_4) in Plant Tissues. A dry and ground plant sample of 0.25 grams was added with 5 ml conc. HNO_3, 1 ml conc. H_2SO_4 and 2 ml 70% $HClO_4$ and refluxed for 2 hours or until the solution became clear using a water condensor to prevent loss of arsenic and mercury (56, 70, 71, 72). Samples were then cooled to room temperature and diluted to 100 ml with deionized water and analyzed for trace contaminants by using the procedures previously outlined for water analyses.

(2) Determination of Boron (B) in Plant Tissue. Dry ashing was the only method used for boron analysis in plant tissue(71, 73). Dry and ground plant samples of 0.25 grams were moistened with saturated $Ba(OH)_2$ solution (addition of base to the sample before ignition to prevent boron loss), then dried at 150°C for one hour and ashed at 600°C for ten hours. Ten ml of 5N. HCl was added to the cooled sample and diluted to 100 ml with deionized water. The concentration of boron in the sample was then analyzed by the same procedure outlined for the water samples.

(3) Determination of Selenium (Se) in Plant Tissue. A 0.25 gram sample of dried and ground plant tissue was placed in a refluxing flask. Five ml conc. HNO_3, 1 ml conc. H_2SO_4 and 0.1 gm HgO were next added and the sample was refluxed as described above (74, 75, 76, 77). Selenium analysis by the flameless atomic absorption method was next effected using the technique previously described for water samples.

(4) Determination of Phenol in Plant Tissue. Approximately 8-10 grams of wet plant sample was pulverized with a polytron using 35-50 ml of chloroform for extraction. The plant tissue was then allowed to remain in contact with chloroform for at least 48 hours (31). The chloroform layer was analyzed for phenol content by the same methods employed for water.

(5) Determination of Polychlorinated Biphenyls (PCB) in Plant Tissue. The procedure of extracting PCB from biological samples was adapted for plant samples. Wet plant samples of about 8-10 grams were extracted with five ml of acetonitrile using a polytron for grinding. Twenty-five ml of 2% aqueus sodium sulfate was added to the combined extract. This solution was extracted by using five ml of hexane(65,66).

The hexane extract was concentrated and the PCB analysis procedure employed for water samples was followed.

(6) Determination of Nitrogen (N) in Plant Tissue. Kjeldahl digestion was used in the analysis of samples for total nitrogen. Dried and ground plant samples of 0.25 grams were added to a Kjeldahl flask containing 5 ml of digestion reagent (mixture of K_2SO_4, conc. H_2SO_4, and HgO). Samples were digested until the solution became clear. Samples were next cooled to room temperature and diluted to the appropriate volume for analysis. The sample was analyzed for nitrogen using the same procedure as that employed for water samples.

C. Sediment or Soil Sample Analysis

Most of the methods used for plant samples were used for sediment or soil samples except for PCB, nitrate and nitrite analysis.

(1) Determination of PCB in Sediment or Soil Samples. Approximately 10-20 grams of sediment or soil sample was added to an extraction thimble and placed in a soxlet apparatus. Three hundred mililiters of hexane was next added to the reservoir and the reservoir connected to the soxlet extractor. Extraction with refluxing was effected over a 24 hour period and the hexane extract was next concentrated to about 1 ml (65, 66). The extract was cleaned by the florisil procedure and analyzed for PCB as described for PCB water sample analysis.

(2) Determination of Nitrate (NO_3) and Nitrite (NO_2) in Sediment or Soil Samples. Extraction was performed by shaking 1 gram of sediment or soil sample with 5 ml saturated $CaSO_4$ solution for 10 minutes. The suspension was then allowed to settle or filtration was effected if necessary (78). The extract was analyzed for nitrate or

nitrite by the colorimetric method as described for nitrate and nitrite water sample analysis

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Results of Field Survey.

Results of the field survey are shown in Tables 7 and 8. In Table 7, concentration of trace contaminants in aquatic plant tissues collected during the field survey are illustrated. As indicated, all of the aquatic plants exhibited very high concentration factors (ratios) ($\frac{\mu\text{g/gm dry plant tissue}}{\mu\text{g/gm water}}$ and $\frac{\mu\text{g/gm dry plant tissue}}{\mu\text{g/gm dry soil}}$) for most contaminants evaluated. Selenium, phenol, and mercury generally exhibited the highest concentration factors in the plants observed (48,980 in coontail; 65,000 in elodea; and 20,330 in water-bonnet µg/gm dry weight per µg/ml water, respectively). This is of particular significance since these parameters are perhaps the most difficult to remove by secondary and advanced treatment techniques. Another important finding was that the efficiency of trace contaminant removal is plant specific. For example, duckweek exhibited a concentration for boron of over 7,000 compared to those of bulrush, rush, arrowhead, water hyacinth, coontail, and alligatorweed of approximately 600 to 800 (based on dry weight of plant tissues).

Table 8 shows the concentration of trace contaminants in water and sediments or soils analyzed during the field study located in the vicinity where the plant species were collected. Average, median and ranges of trace contaminant concentrations in both waters and sediments are illustrated. As exhibited by Table 8 most of trace contaminant concentrations in the natural environment exist at low levels. These values were employed in the accumulation or concentration factor calculations,

Table 7 Concentration of Trace Contaminants in Aquatic Plants Collected During Field Study

AQUATIC PLANT	TRACE CONTAMINANT	CONCENTRATION OF TRACE CONTAMINANTS IN PLANT TISSUE (mg/gm Dry Plant) Average	Range	ACCUMULATION FACTOR μg/gm dry wt. / μg/ml (water)	μg/gm dry wt. / μg/gm dry soil
1. Duckweed	As	0.0712	0.0604 - 0.0820	2,540	79
	B	1.2079	0.8450 - 1.5709	7,210	7,347
	Cd	0.0016	0.0008 - 0.0023	1,600	2,286
	Hg	0.0049	0.0038 - 0.0060	1,810	366
	Se	1.1270	1.0920 - 1.1620	37,570	1,365
	Phenol	0.0050	0.0019 - 0.0082	5,000	5,000
	Total Nitrogen	8.2810	5.5860 -10.9760	2,120	3,831
	Phosphate	4.352	4.080 - 4.624	7,290	61,643
2. Coontail	As	0.0596	0.0524 - 0.0669	2,130	66
	B	0.1200	0.0000 - 0.2400	720	730
	Cd	0.0010	0.0008 - 0.0013	1,000	1,428
	Hg	0.0053	0.0048 - 0.0058	1,960	395
	Se	1.4694	1.2273 - 1.7115	48,980	1,780
	Phenol	0.0262	0.0055 - 0.0469	26,200	26,200
	Total Nitrogen	13.7368	12.6336 -14.8400	3,510	6,355
	Phosphate	12.104	8.128 -16.080	20,270	171,445
3. Elodea	As	0.0648	-	2,310	72
	B	0.4050	-	2,420	2,463
	Cd	0.0008	-	800	1,143
	Hg	0.0297	-	11,000	2,216
	Se	1.2087	-	40,290	1,464
	Phenol	0.0650	-	65,000	65,000
	Total Nitrogen	17.6848	-	4,520	8,182
	Phosphate	5.760	-	9,650	81,586
4. Water-bonnet	As	0.0629	-	2,250	70
	B	0.3975	-	2,370	2,418
	Cd	0.0008	-	800	1,143
	Hg	0.0549	-	20,330	4,097
	Se	1.3300	-	44,330	1,611
	Phenol	0.0091	-	9,100	9,100
	Total Nitrogen	11.6256	-	2,970	5,379
	Phosphate	3.120	-	5,230	44,193
5. Alligator-weed	As	0.0644	0.0600 - 0.0698	2,300	72
	B	0.1028	0.0194 - 0.1863	610	625
	Cd	0.0040	0.0011 - 0.0069	4,000	5,714
	Hg	0.0219	0.0018 - 0.0420	8,110	1,634
	Se	1.1118	1.0990 - 1.1247	37,060	1,347
	Phenol	0.0236	0.0055 - 0.0418	23,600	23,600
	Total Nitrogen	12.3368	8.9488 -15.7248	3,150	5,708
	Phosphate	2.158	2.156 - 2.160	3,610	30,566

Table 7. Concentration of Trace Contaminants in Aquatic Plants Collected During Field Study (continued)

AQUATIC PLANT	TRACE CONTAMINANT	CONCENTRATION OF TRACE CONTAMINANTS IN PLANT TISSUE (mg/gm Dry Plant)		ACCUMULATION FACTOR	
		Average	Range	µg/gm dry wt. / µg/ml (water)	µg/gm dry wt. / µg/gm dry soil
6. Water Hyacinths	As	0.0657	0.0619 - 0.0696	2,350	73
	B	0.1406	0.0000 - 0.2813	840	855
	Cd	0.0008	-	800	1,143
	Hg	0.0058	0.0041 - 0.0075	2,150	433
	Se	1.2390	1.1153 - 1.3627	41,300	1,501
	Phenol	0.0226	0.0143 - 0.0309	22,600	22,000
	Total Nitrogen	11.5360	6.6080 -16.4640	2,950	5,337
	Phosphate	4.188	3.240 - 5.136	7,010	59,320
7.Arrowhead	As	0.0632	0.0528 - 0.0736	2,260	70
	B	0.1069	0.0000 - 0.2138	640	650
	Cd	0.0014	0.0008 - 0.0021	1,400	2,000
	Hg	0.0148	0.0137 - 0.0159	5,480	1,104
	Se	0.8540	0.7840 - 0.9240	28,470	1,035
	Phenol	0.0055	<0.0010 - 0.0110	5,500	5,500
	Total Nitrogen	10.0520	9.7440 -10.3600	2,570	4,651
	Phosphate	3.980	3.600 - 4.360	6,670	56,374
8.Bulrush (*Scirpus spp.*)	As	0.0611	-	2,180	68
	B	0.1163	-	690	707
	Cd	0.0019	-	1,900	2,714
	Hg	0.0052	-	1,930	388
	Se	0.8867	-	29,560	6,074
	Phenol	0.0025	-	2,500	2,500
	Total Nitrogen	8.9040	-	2,280	4,119
	Phosphate	1.164	-	1,950	16,487
9. Rush (*Juncus spp.*)	As	0.0599	0.0524 - 0.0675	2,140	67
	B	0.1025	0.0888 - 9.1163	610	623
	Cd	0.0009	0.0008 - 0.0011	900	1,286
	Hg	0.0041	0.0040 - 0.0042	1,520	306
	Se	1.1433	1.1387 - 1.1480	38,110	1,385
	Phenol	0.0035	0.0021 - 0.0050	3,500	3,500
	Total Nitrogen	5.8520	4.9840 - 6.7200	1,500	2,707
	Phosphate	1.412	0.856 - 1.968	2,360	20,000

Table 8. Concentration of Trace Contaminants in Waters and Sediments (Soils) During Field Survey

TRACE CONTAMINANT	CONCENTRATION IN WATER, mg/l			CONCENTRATION IN SEDIMENTS OR SOILS mg/gm dry soil		
	Average	Median	Range	Average	Median	Range
As	0.028	0.029	0.016 - 0.038	0.8984	0.8458	0.8012 - 1.1009
B	0.167	< 0.100	< 0.100 - 0.502	0.1644	0.1755	0.1290 - 0.1775
Cd	0.001	< 0.001	< 0.001 - 0.002	0.0007	0.0008	0.0003 - 0.0009
Hg	0.002	0.001	0.001 - 0.005	0.0134	0.0108	0.0069 - 0.0250
Se	0.030	0.030	0.025 - 0.034	0.8254	0.8182	0.7240 - 0.9411
Phenol	< 0.001	< 0.001	0.000 -<0.001	< 0.001	<0.001	0.000 -<0.001
Total Nitrogen (as N.)	3.91	2.52	2.30 - 6.90	2.1614	1.7439	0.5825 - 4.5754
Phosphate	0.59	0.56	0.36 - 0.87	0.0706	0.0631	0.0482 - 0.1080

the results of which are tabulated in Table 7. As previously illustrated plant tissue concentrations can be more than hundreds to thousands times that of the corresponding water or soil concentration (based on dry weight of plant tissues).

Results of Batch Screening Study

In Table 9, relative uptake efficiencies of trace contaminants observed during the batch screening study for the selected vascular aquatic plants is tabulated. For each aquatic plant, parameters are arranged in priority from highest to lowest removal efficiency with each final concentration (at the end of 28 days) being presented. Table 10 summarizes the results shown in Table 9, indicating plant species which exhibited highest percent removal of trace contaminants for rooted, floating, submersed and emersed plants during the batch study. Concentration of trace contaminants accumulated in plant tissue at 21 days or the end of experiment (28 days) is also given. The plant concentration at 21 days is shown for some species because of the inavailability of whole plant analysis. Plant mass remaining for sampling at the end of 28 days was not always sufficient to allow whole plant analysis necessitating that the 21 day value be employed. Plant trace contaminant concentration for root, stem, and leaves at 28 days for bulrush, rush, arrowhead, water hyacinth and alligatorweed are tabulated in detail in Tables D-26 through D-34 of Appendix D.

For most contaminants, bulrush was observed to be the most efficient rooted species. It exhibited highest removal for arsenic (82.1%), cadmium (98.9%), mercury (92.8%), selenium (94.9%), and phosphate (89.6%). Arrowhead and rush showed highest removals for boron (16.5%) and nitrogen (99.9%), respectively For polychlorinated biphenyls (PCB), these three rooted plants showed one hundred percent removal.

Table 9. Relative Uptake Efficiency of Waste Comtaminants by Aquatic Plant System in Batch Screening Study (28 Day-Run)

CONTAMINANTS IN WASTEWATER	PLANTS IN AQUARIUM	RELATIVE UPTAKE EFFICIENCY % REMOVAL	 CONCENTRATION OF CONTAMINANTS IN WATER AT COMPLETION OF EXPERIMENT (mg/1)
Arsenic	Bulrush	82.14	0.20
	Rush	54.22	0.52
	Elodea	20.75	1.01
	Coontail	15.82	1.06
	Water hyacinths	12.50	1.03
	Alligator-weed	11.80	1.02
	Arrowhead	10.53	1.09
	Duckweed # 1	10.26	1.12
	Duckweed # 2	4.16	1.18
	Water-bonnet	0.62	1.28
	Control (no plants)	4.35	1.06
Boron	Duckweed # 2	17.76	4.02
	Coontail	17.63	4.00
	Elodea	17.52	4.02
	Arrowhead	16.47	4.07
	Duckweed # 1	16.14	4.11
	Alligator-weed	14.62	4.13
	Bulrush	14.62	4.13
	Rush	12.64	4.24
	Water hyacinths	12.46	4.30
	Algae	10.91	4.34
	Water-bonnet	10.67	4.32
	Control (no plants)	1.49	4.76
Cadmium	Bulrush	98.85	0.02
	Rush	91.44	0.13
	Coontail	91.11	0.13
	Elodea	85.71	0.19
	Arrowhead	78.41	0.30
	Alligator-weed	76.30	0.33
	Duckweed # 2	75.72	0.34
	Water hyacinths	68.60	0.43
	Duckweed # 1	60.27	0.54
	Algae	46.17	0.75
	Water-bonnet	24.85	1.02
	Control (no plants)	22.75	1.03

Table 9. Relative Uptake Efficiency of Waste Contaminants by Aquatic Plant System in Batch Screening Study (28 Day-Run) Continued.

CONTAMINENTS IN WASTEWATER	PLANTS IN AQUARIUM	RELATIVE UPTAKE EFFICIENCY % REMOVAL	CONCENTRATION OF CONTAMINANTS IN WATER AT COMPLETION OF EXPERIMENT (mg/l)
Mercury	Bulrush	92.75	0.06
	Rush	79.13	0.18
	Elodea	79.19	0.19
	Alligator-weed	75.18	0.21
	Arrowhead	74.17	0.20
	Duckweed #2	70.53	0.24
	Water hyacinths	70.16	0.23
	Coontail	70.01	0.23
	Duckweed # 1	67.20	0.27
	Algae	62.20	0.32
	Water-bonnet	47.42	0.49
	Control (no plants)	60.39	0.34
Selenium	Bulrush	94.89	0.08
	Rush	61.80	0.54
	Arrowhead	29.77	1.00
	Coontail	28.89	1.02
	Duckweed #2	10.98	1.30
	Elodea	18.28	1.22
	Alligator-weed	10.52	1.30
	Water hyacinths	8.19	1.32
	Water-bonnet	6.11	1.35
	Duckweed # 1	0.00	1.49
	Algae	0.00	1.44
	Control (no plants)	0.00	1.44
Phenol (Method of determination is not sufficiently sensitive)	Duckweed # 1	100.00	0.00
	Duckweed # 2	100.00	0.00
	Coontail	100.00	0.00
	Elodea	100.00	0.00
	Water-bonnet	100.00	0.00
	Alligator-weed	100.00	0.00
	Water hyacinths	100.00	0.00
	Arrowhead	100.00	0.00
	Bulrush	100.00	0.00
	Rush	100.00	0.00
	Algae	100.00	0.00
	Control (no plants)	100.00	0.00

Table 9. Relative Uptake Efficiency of Waste Contaminants by Aquatic Plant System in Batch Screening Study (28 Day-Run) Continued.

		RELATIVE UPTAKE EFFICIENCY	
CONTAMINANTS IN WASTEWATER	PLANTS IN AQUARIUM	% REMOVAL	CONCENTRATION OF CONTAMINANTS IN WATER AT COMPLETION OF EXPERIMENT (mg/l)
Polychlorinated biphenyls (PCB)	Bulrush	100.00	0.00
	Rush	100.00	0.00
	Water hyacinths	100.00	0.00
	Alligator-weed	100.00	0.00
	Arrowhead	100.00	0.00
	Elodea	100.00	0.00
	Coontail	100.00	0.00
	Duckweed #2	100.00	0.00
	Duckweed #1	>87.50	<0.001
	Algae	>87.50	<0.001
	Water-bonnet	57.14	0.003
	Control (no plants)	66.67	0.002
Total Nitrogen (TKN, NO_3-N, and NO_2-N)	Rush	99.97	0.03
	Bulrush	99.62	0.05
	Alligator-weed	96.50	0.45
	Elodea	94.23	0.69
	Coontail	92.28	0.91
	Algae	72.23	3.66
	Arrowhead	62.73	4.74
	Water-bonnet	58.53	5.27
	Duckweed #2	55.22	5.49
	Duckweed #1	45.88	6.82
	Water hyacinths	41.70	7.26
	Control (no plants)	59.99	5.12
Phosphate	Bulrush	89.55	0.59
	Rush	65.41	1.92
	Alligator-weed	38.06	3.23
	Water-bonnet	20.59	4.70
	Duckweed #1	17 92	4.74
	Duckweed #2	17.42	4.57
	Water hyacinths	13.30	4.93
	Elodea	8.19	5.20
	Arrowhead	7.51	5.02
	Algae	-0.71	5.73
	Coontail	-4.64	6.04
	Control (no plants)	-0.91	5.34

Table 9. Relative Uptake Efficiency of Waste Contaminants by Aquatic Plant System in Batch Screening Study (28 Day-Run) Continued.

CONTAMINANTS IN WASTEWATER	PLANTS IN AQUARIUM	RELATIVE UPTAKE EFFICIENCY % REMOVAL	CONCENTRATION OF CONTAMINANTS IN WATER AT COMPLETION OF EXPERIMENT (mg/l)
BOD_5	Rush	92.66	0.7
	Bulrush	87.70	1.7
	Arrowhead	85.28	1.6
	Alligator-weed	82.57	1.5
	Elodea	49.28	6.4
	Duckweed # 2	44.17	5.4
	Algae	30.36	5.8
	Coontail	23.33	6.2
	Water hyacinths	21.76	10.1
	Duckweed # 1	13.99	10.8
	Water-bonnet	-5.00	10.7
	Control (no plants)	-7.55	7.5
TOC	Rush	70.15	4.0
	Arrowhead	61.15	5.4
	Bulrush	59.52	5.1
	Alligator-weed	57.60	5.3
	Elodea	54.05	6.8
	Duckweed # 2	47.59	7.6
	Coontail	18.94	10.7
	Duckweed # 1	18.84	11.2
	Water hyacinths	18.04	10.9
	Algae	6.15	12.2
	Water-bonnet	1.55	12.7
	Control (no plants)	1.75	11.2

Table 10. Plant Species Exhibiting Highest Percent Removal for Trace Contaminants of Concern

Trace Contaminant	Plant	% Removal	Concentration in Water After 28 days, mg/l	Concentration in Plant Tissue at Day 21 * (µg/gm dry plant tissue)
ROOTED				
As	Bulrush	82.1	0.20	138.60
B	Arrowhead	16.5	4.07	-
Cd	Bulrush	98.9	0.02	92.40
Hg	Bulrush	92.8	0.06	433.20
Se	Bulrush	94.9	0.08	357.00
Total N	Rush	99.9	0.03	11,013.30
Phosphate	Bulrush	89.6	0.59	384.00
PCB	Bulrush	100.0	0.00	0.3021
	Rush	100.0	0.00	1.0414
	Arrowhead	100.0	0.00	6.5655
FLOATING				
As	Water hyacinth	12.5	1.03	77.00
B	Duckweed	17.8	4.02	-
Cd	Water hyacinth	68.6	0.43	808.00
Hg	Duckweed	70.5	0.24	1,851.20*
Se	Duckweed	11.0	1.30	250.80*
Total N	Duckweed	55.2	5.99	27,626.70*
Phosphate	Duckweed	17.9	4.74	9,520.00*
PCB	Water hyacinth	100.0	0.00	3.6360
	Duckweed	100.0	0.00	22.9245
SUBMERSED				
As	Elodea	20.7	1.01	32.00
B	Elodea	17.5	4.02	68.96
Cd	Coontail	91.1	0.13	2,828.00*
Hg	Elodea	79.2	0.19	814.00
Se	Coontail	28.9	1.02	286.00*
Total N	Alligator-weed	96.5	0.45	9,034.70
Phosphate	Alligator-weed	38.1	3.23	3,904.00
PCB	Alligator-weed	100.0	0.00	0.8642*
	Elodea	100.0	0.00	1.8120
	Coontail	100.0	0.00	15.4613**

* Concentration in Plant Tissue at 28th day.

** Concentration in Plant Tissue at 7th day.

The water hyacinth and duckweed systems appeared the most effective floating species for trace contaminant reduction. Water hyacinth system showed highest removal of arsenic (12.5%), cadmium (68.5%), and polychlorinated biphenyls (100%) among the floating plants while duckweed system showed highest removals of boron (17.8%), mercury (70.5%), selenium (11.0%), nitrogen (55.2%), phosphate (17.9%) and also polychlorinated biphenyls (100%).

Results of the submersed and emersed plants were mixed with elodea and coontail displaying poor acclimation to the secondary effluent. Among these submersed plants elodea system showed highest removal of arsenic (20.7%), boron (17.5%), and mercury (79.2%) while coontail system showed highest removal of cadmium (91.1%) and selenium (28.9%). Alligatorweed adapted well but was only effective in removing nitrogen (96.5%) and phosphate (38.1%). All three plant systems exhibited one hundred percent removal of polychlorinated biphenyls.

Of the three selected grouping of plants, rooted plants showed the highest overall removal efficiencies. This was especially true for bulrush which was the most effective in reducing the content of all trace contaminants from the secondary effluent except for boron and nitrogen. As expected, the observed concentration of trace contaminants accumulated in plant tissue during this study was much higher as compared to the results of similar plants collected during the field survey since aqueous exposure concentrations were higher.

Applicable Mathematical Model for Batch Screening Study - Trace Contaminant Removal for Secondary Effluent.

Modeling of trace contaminant removal and plant uptake rates are very important in the determination of parameter removal efficiency projections and necessary for the optimization and scale up design for pilot and full scale wastewater treatment facility implementation. Trace contaminant removal from the batch screening study was compared to various removal models commonly employed for describing substrate removal rates i.e. zero order, first order, second order, etc. Usually substrate removal rates follow a pseudo first order relationship or a composite exponential form which represents a series of zero order reactions with removal of different components being effected at different rates. Experimental data collected was found to fit either the pseudo first order kinetic model or the composite exponential model. The equation for the first order kinetic model applied for the collected batch screening data is described as follows (79, 80, 81):

$$S = So\ e^{-Kt} \ldots\ldots\ldots\ldots (1)$$

Where:

S = trace contaminant concentration in water at time t, mg/l

So = initial concentration of trace contaminant in water, mg/l

K = trace contaminant removal rate coefficient, day^{-1}

t = time, days

The equation describing composite exponential removal kinetics for the batch screening study is (82):

$$S = S_1 e^{-k_1 t} + S_2 e^{-k_2 t} + \ldots\ldots + S_n e^{-k_n t} \ldots\ldots\ldots (2)$$

Where:

S = trace contaminant concentration in water at time t, mg/l

S_1= constant for k_1 term $S_1 e^{-k_1 t}$ which represents the initial concentration of components removed at rate k_1

S_2= constant for k_2 term $S_2 e^{-k_2 t}$ which represents the initial concentration of components removed at rate k_2

S_n= constant for k_n term $S_n e^{-k_n t}$ which represents the initial concentration of components removed at rate k_n

(So = initial concentration of trace contaminant in water, mg/l and So = $S_1 + S_2 + \ldots\ldots + S_n$).

k_1 = trace contaminant removal rate coefficient, day^{-1} (for term $S_1e^{-k_1t}$)

k_2 = trace contaminant removal rate coefficient, day^{-1} (for term $S_2e^{-k_2t}$)

k_n = trace contaminant removal rate coefficient, day^{-1} (for term $S_ne^{-k_nt}$)

t = time, days

By plotting ln S/So versus time, the trace contaminant removal rate coefficient(s) can be determined for both first order and composite exponential removal kinetics. Figures 16-a to 16-c show examples of the determination of removal rate coefficients (cadmium removal for rooted, floating and submersed and emersed plants, respectively). Techniques for mechanically obtaining the various coefficients can be found as presented by Englande (82). Removal rate coefficients estimated from the plots were recalculated by computer in order to confirm percent fitness (regression coefficient) to the proposed kinetic models. The computer control program and the equation used for calculation of regression for the batch screening data analysis are presented in Appendix G. Summary of trace contaminant kinetic modeling coefficients for the batch screening study are summarized in Table 11. As indicated, data was observed to fit pseudo first oder or two compartment exponential removal kinetics.

For arsenic removal, bulrush was found to follow pseudo first order kinetics among the rooted plant group; whereas rush and arrowhead followed the composite exponential model. Among floating plants, water hyacinth exhibited composite exponential kinetics; whereas duckweed followed the pseudo first order model. Water-bonnet data did not show any significant arsenic removal and consequently was characterized by a negligible correlation coefficient. Submersed plants, coontail and elodea followed pseudo first order kinetics; but an emersed plant, alligatorweed,

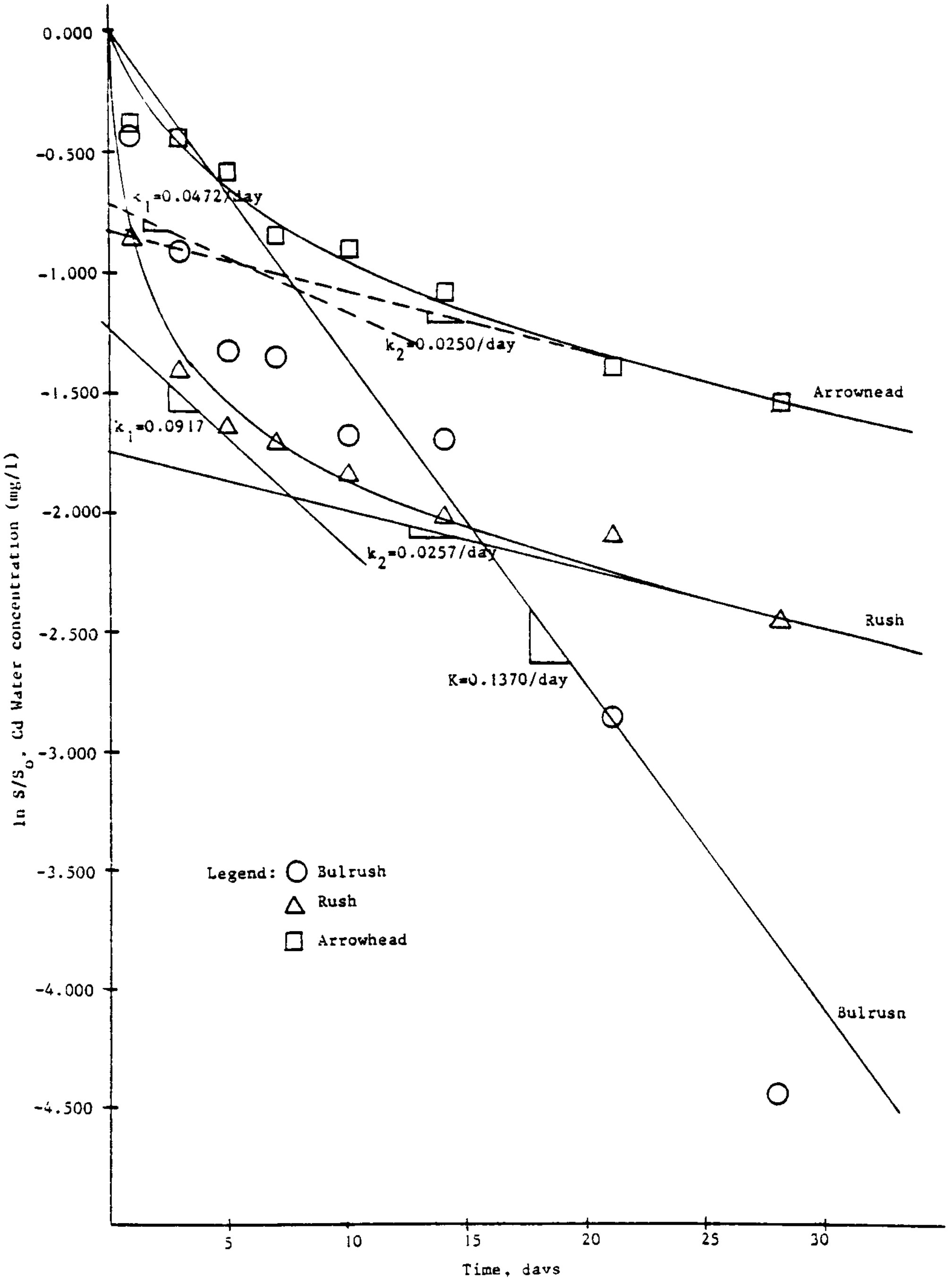


Figure 16-a. Determination of Cadmium Removal Rate Coefficient (K) for Rooted Plants, Batch Screening Study

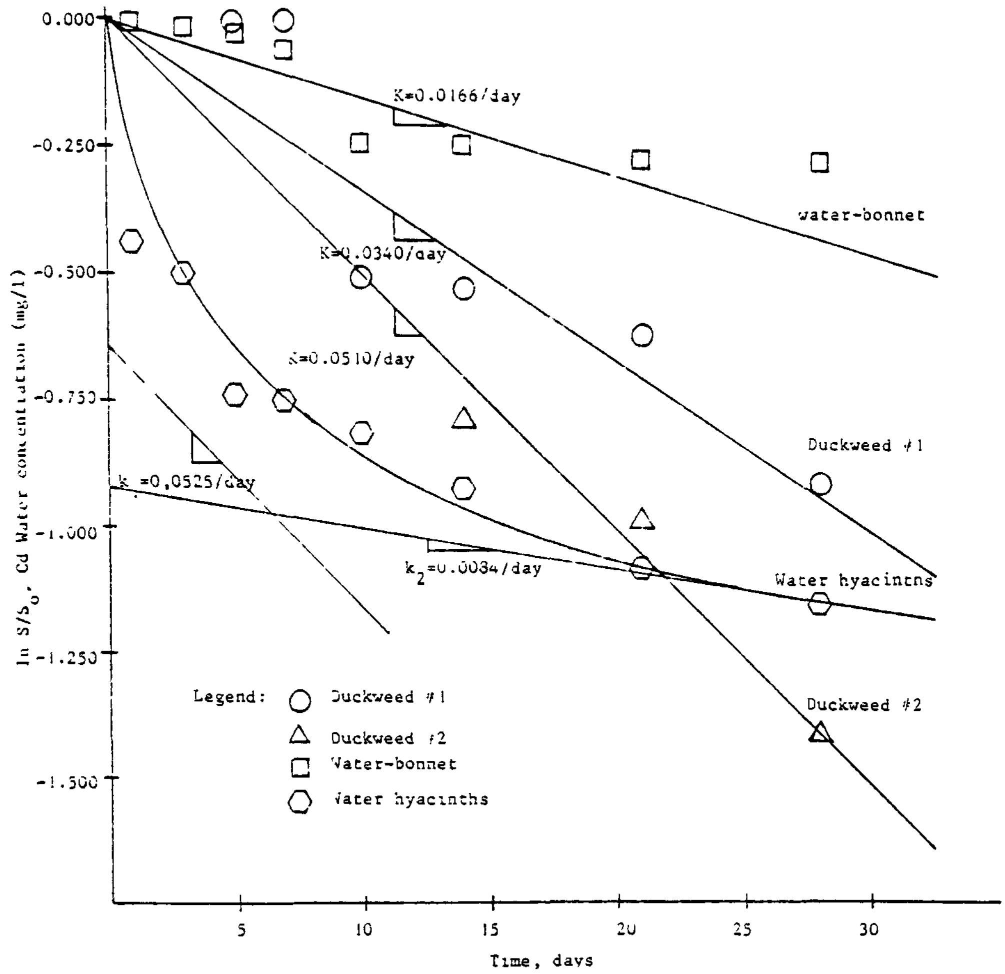


Figure 16-b. Determination of Cadmium Removal Rate Coefficient (K) for Floating Plants, Batch Screening Study

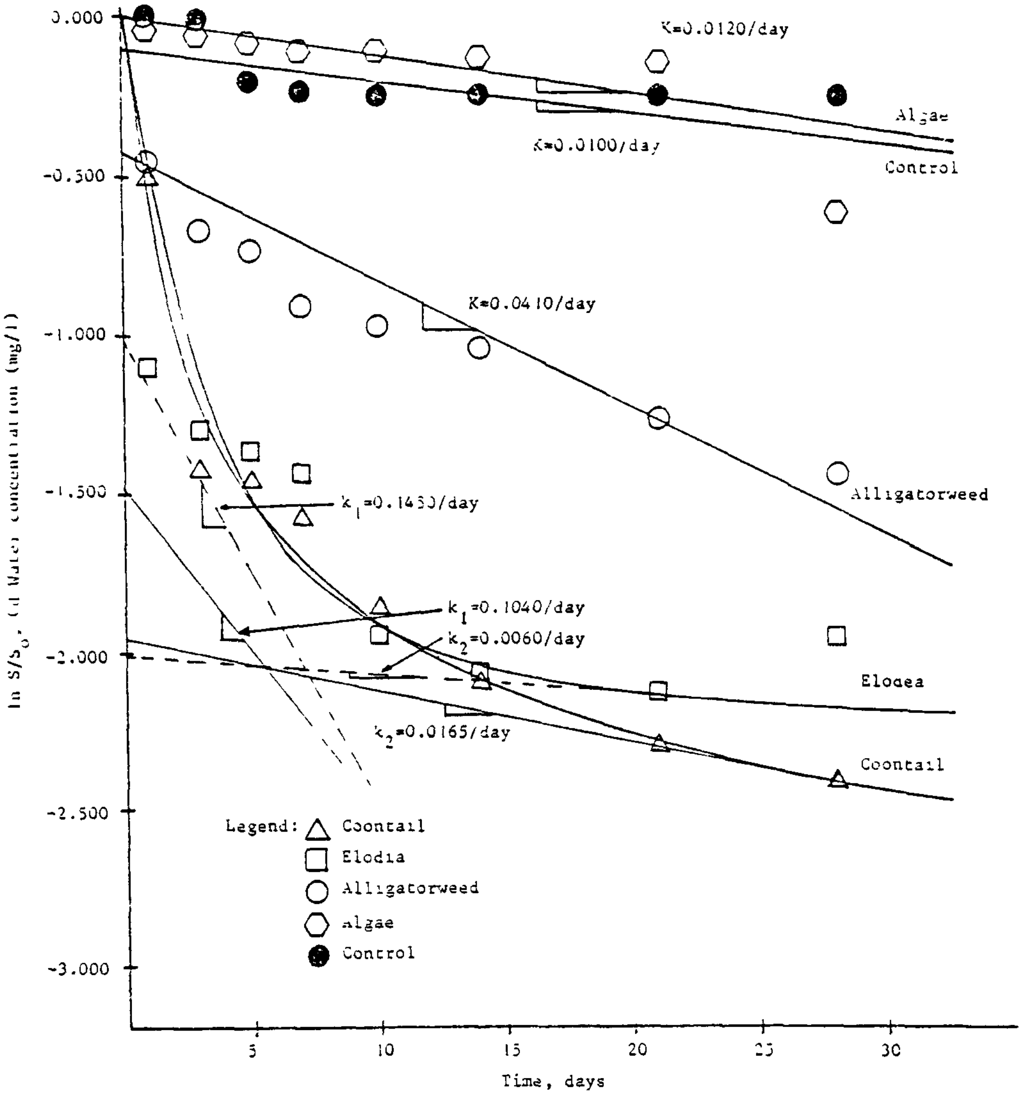


Figure 16-c. Determination of Cadmium Removal Rate Coefficient (K) for Submersed and Emersed Plants, Batch Screening Study

Table 11. Kinetic Description of Trace Contaminant Removal During Batch Screening Study.

Trace Contaminant	Plant	Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
		K (day-1)	S_o* (mg/l)	k_1 (day-1)	S1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	<u>Rooted</u>								
Arsenic	Bulrush	0.0643	1.136	-	-	-	-	9	98.8
	Rush	-	-	0.5917	0.391	0.0139	0.745	9	94.4
	Arrowhead	-	-	0.0025	1.174	1.2025	0.041	9	98.2
	<u>Floating</u>								
	Water hyacinths	-	-	2.1930	0.061	0.0010	1.115	9	38.1
	Duckweed #1	0.0053	1.271	-	-	-	-	5	75.7
	Duckweed #2	0.0016	1.218	-	-	-	-	4	77.7
	Water-bonnet	***	-	-	-	-	-	-	-
	<u>Submersed & Emersed</u>								
	Coontail	0.0075	1.263	-	-	-	-	9	88.7
	Elodea	0.0079	1.277	-	-	-	-	9	91.8
	Alligator-weed	-	-	0.0888	0.133	0.0005	1.017	9	96.7
	Algae	-	-	0.0007	1.126	0.1917	0.091	9	99.2
	Control (no plants)	-	-	0.0002	1.061	0.0450	0.243	9	89.8

* S_o = Initial concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination.

*** = No Significant Removal

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	Rooted								
Boron	Bulrush	0.0040	4.823	-	-	-	-	9	39.4
	Rush	0.0056	4.899	-	-	-	-	9	71.8
	Arrowhead	0.0062	4.876	-	-	-	-	9	70.6
	Floating								
	Water hyacinths	0.0056	5.142	-	-	-	-	9	56.4
	Duckweed # 1	0.0084	5.354	-	-	-	-	4	88.6
	Duckweed # 2	0.0073	5.062	-	-	-	-	4	62.9
	Water-bonnet	0.0038	4.910	-	-	-	-	9	73.3
	Submersed & Emersed								
	Coontail	***	-	-	-	-	-	-	-
	Elodea	***	-	-	-	-	-	-	-
	Alligator-weed	0.0039	4.805	-	-	-	-	9	48.9
	Algae	***	-	-	-	-	-	-	-
	Control (No plants)	0.0004	4.825	-	-	-	-	9	1.6

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination.

*** = No significant removal

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	Rooted								
Cadmium	Bulrush	0.2092	1.250	-	-	-	-	9	92.7
	Rush	-	-	0.0368	0.359	1.3633	1.136	9	99.9
	Arrowhead	-	-	0.1589	0.827	0.0256	0.435	9	92.2
	Floating								
	Water hyacinths	-	-	0.0252	0.800	1.7229	0.575	9	98.1
	Duckweed # 1	0.0356	1.447	-	-	-	-	9	86.2
	Duckweed # 2	0.0510	1.375	-	-	-	-	4	99.3
	Water-bonnet	0.0129	1.349	-	-	-	-	9	81.5
	Submersed & Emersed								
	Coontail	-	-	0.4730	1.374	1.6117	0.045	9	85.8
	Elodea	-	-	0.3194	-0.992	0.2936	2.089	9	68.1
	Alligatorweed	0.0625	1.052	-	-	-	-	9	74.3
	Algae	0.0142	1.403	-	-	-	-	9	73.7
	Control (No Plants)	0.0104	1.258	-	-	-	-	9	56.9

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 \ e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 \ e^{-k_2 t}$

** n = Sample Population for Removal Rate Coefficient Determination.

Table 11. (Continued)

Trace Contaminant	Plant	Kinetic Modeling Coefficients Pseudo First Order K (day-1)	 Pseudo First Order S_o* (mg/l)	 Composite Exponential k_1 (day-1)	 Composite Exponential S_1* (mg/l)	 Composite Exponential k_2 (day-1)	 Composite Exponential S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	<u>Rooted</u>								
Mercury	Bulrush	0.0717	0.636	-	-	-	-	9	79.9
	Rush	-	-	0.0176	0.288	0.3037	0.578	9	98.5
	Arrowhead	0.0562	0.626	-	-	-	-	9	75.0
	<u>Floating</u>								
	Water hyacinths	0.0264	0.702	-	-	-	-	9	78.3
	Duckweed # 1	0.0315	0.783	-	-	-	-	9	86.3
	Duckweed # 2	0.0260	0.876	-	-	-	-	4	66.2
	Water-bonnet	-	-	0.0225	0.788	3.8120	0.141	9	93.8
	<u>Submersed & Emersed</u>								
	Coontail	0.0323	0.698	-	-	-	-	9	90.3
	Elodea	0.1177	0.841	-	-	-	-	9	86.5
	Alligatorweed	-	-	0.0166	0.336	0.1857	0.513	9	97.8
	Algae	-	-	0.4696	0.393	0.0109	0.451	9	98.9
	Control (No plants)	0.0405	0.829	-	-	-	-	9	88.1

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

Table 11. (Continued)

Trace Contaminant	Plant	Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential				n**	Regression Coefficient, r^2 (%)
		K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)		
	Rooted								
Selenium	Bulrush	0.1373	1.544	-	-	-	-	7	99.4
	Rush	0.0348	1.383	-	-	-	-	7	95.7
	Arrowhead	0.0113	1.415	-	-	-	-	9	93.6
	Floating								
	Water hyacinths	***	-	-	-	-	-	-	-
	Duckweed # 1	***	-	-	-	-	-	-	-
	Duckweed # 2	***	-	-	-	-	-	-	-
	Water-bonnet	***	-	-	-	-	-	-	-
	Submersed & Emersed								
	Coontail	0.0231	2.028	-	-	-	-	3	93.1
	Elodea	0.0145	1.816	-	-	-	-	3	98.9
	Alligatorweed	0.0082	1.608	-	-	-	-	3	81.7
	Algae	***	-	-	-	-	-	-	-
	Control (No plants)	***	-	-	-	-	-	-	-

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

*** = No significant removal

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	<u>Rooted</u>								
Phenol	Bulrush	0.4802	0.619	-	-	-	-	3	73.2
	Rush	6.2860	0.537	-	-	-	-	2	100.0
	Arrowhead	1.8255	0.644	-	-	-	-	4	99.8
	<u>Floating</u>								
	Water hyacinths	1.4227	0.574	-	-	-	-	4	99.1
	Duckweed # 1	6.2634	0.525	-	-	-	-	2	100.0
	Duckweed # 2	-	-	-	-	-	-	-	-
	Water-bonnet	6.1377	0.463	-	-	-	-	4	100.0
	<u>Submersed & Emersed</u>								
	Coontail	2.8756	0.550	-	-	-	-	3	100.0
	Elodea	6.1377	0.463	-	-	-	-	2	100.0
	Alligatorweed	1.0136	0.543	-	-	-	-	4	96.3
	Algae	0.7357	0.608	-	-	-	-	3	96.3
	Control (No plants)	0.5004	0.563	-	-	-	-	4	96.4

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	<u>Rooted</u>								
Polychlorinated biphenyls (PCB)	Bulrush	2.0794	0.008	-	-	-	-	2	100.0
	Rush	2.1972	0.009	-	-	-	-	2	100.0
	Arrowhead	1.7917	0.006	-	-	-	-	2	100.0
	<u>Floating</u>								
	Water hyacinths	1.9459	0.007	-	-	-	-	2	100.00
	Duckweed # 1	1.2916	0.008	-	-	-	-	3	96.5
	Duckweed # 2	-	-	-	-	-	-	-	-
	Water-bonnet	0.2430	0.005	-	-	-	-	4	29.6
	<u>Submersed & Emersed</u>								
	Coontail	1.5391	0.006	-	-	-	-	4	70.6
	Elodea	1.7865	0.007	-	-	-	-	4	79.8
	Alligatorweed	1.9459	0.007	-	-	-	-	2	100.0
	Algae	0.6931	0.008	-	-	-	-	3	100.0
	Control (No plants)	1.5391	0.006	-	-	-	-	4	70.6

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1\ e^{-k_1t}$

S_2 = Constant for k_2 term $S_2\ e^{-k_2t}$

**n = Sample Population for Removal Rate Coefficient Determination

Table 11. (Continued)

Trace Contaminant	Plant	Kinetic Modeling Coefficients						n**	Regression Coefficient, r^2 (%)
		Pseudo First Order		Composite Exponential					
		K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)		
	Rooted								
Total Nitrogen	Bulrush	0.2402	10.8	(After 10 days)		-	-	4	98.9
	Rush	0.2278	8.1	(After 10 days)		-	-	4	99.6
	Arrowhead	0.0435	18.9	-	-	-	-	9	95.8
	Floating								
	Water hyacinths	0.0420	18.3	(After 10 days)				3	88.8
	Duckweed #1	0.0236	19.0	-	-	-	-	9	86.1
	Duckweed #2	0.0743	18.2	(After 10 days)		-	-	3	97.9
	Water-bonnet	0.0546	17.5	(After 10 days)		-	-	4	97.6
	Submersed & Emersed								
	Coontail	0.1955	16.9	(After 14 days)		-	-	3	94.4
	Elodea	0.1713	14.6	(After 10 days)		-	-	4	99.2
	Alligatorweed	0.1547	18.9	(After 7 days)		-	-	5	89.6
	Algae	0.0719	19.8	-	-	-	-	9	96.6
	Control (No plants)	0.0784	17.0	(After 14 days)		-	-	3	95.9

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	Rooted								
Phosphate	Bulrush	0.1210	3.54	(After 14 days)		-	-	2	100.0
	Rush	0.0299	5.37	-	-	-	-	9	92.5
	Arrowhead	0.0037	5.55	-	-	-	-	9	18.6
	Floating								
	Water hyacinths	-	-	0.4513	-0.23	0.0032	5.63	9	9.0
	Duckweed # 1	0.0044	6.11	-	-	-	-	9	12.7
	Duckweed # 2	***	-	-	-	-	-	-	-
	Water-bonnet	0.0073	6.00	-	-	-	-	9	20.4
	Submersed & Emersed								
	Coontail	***	-	-	-	-	-	-	-
	Elodea	0.0047	7.11	-	-	-	-	9	4.4
	Alligatorweed	0.0153	5.82	-	-	-	-	9	58.6
	Algae	***	-	-	-	-	-	-	-
	Control (No plants)	***	-	-	-	-	-	-	-

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1\,e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2\,e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

*** = No Significant Removal

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	Rooted								
BOD_5	Bulrush	0.1254	11.8	-	-	-	-	9	87.5
	Rush	0.0699	8.0	-	-	-	-	9	80.0
	Arrowhead	0.0626	9.0	-	-	-	-	9	86.8
	Floating								
	Water hyacinths	0.0857	11.1	-	-	-	-	9	87.2
	Duckweed # 1	0.0517	12.2	-	-	-	-	9	79.0
	Duckweed # 2	0.0509	10.0	-	-	-	-	4	81.5
	Water-bonnet	0.0685	11.4	-	-	-	-	9	82.3
	Submersed & Emersed								
	Coontail	0.0097	9.0	-	-	-	-	9	41.9
	Elodea	0.0295	12.5	-	-	-	-	9	83.1
	Alligatorweed	0.0473	6.8	-	-	-	-	9	64.2
	Algae	0.0117	6.9	-	-	-	-	9	37.2
	Control (No plants)	***	-	-	-	-	-	-	-

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

*** = No Significant Removal

Table 11. (Continued)

		Kinetic Modeling Coefficients							
		Pseudo First Order		Composite Exponential					
Trace Contaminant	Plant	K (day-1)	S_o* (mg/l)	k_1 (day-1)	S_1* (mg/l)	k_2 (day-1)	S_2* (mg/l)	n**	Regression Coefficient, r^2 (%)
	Rooted								
TOC	Bulrush	0.0313	12.6	-	-	-	-	4	99.8
	Rush	0.0486	13.3	-	-	-	-	4	98.9
	Arrowhead	0.0215	14.2	-	-	-	-	4	60.5
	Floating								
	Water hyacinths	-	-	0.0160	2.5	0.0004	10.8	4	25.6
	Duckweed # 1	0.0375	13.4	-	-	-	-	9	69.9
	Duckweed # 2	0.0232	15.2	-	-	-	-	4	74.2
	Water-bonnet	0.0375	14.4	-	-	-	-	4	56.1
	Submersed & Emersed								
	Coontail	0.0043	13.3	-	-	-	-	4	20.3
	Elodea	0.0238	14.6	-	-	-	-	4	85.3
	Alligatorweed	0.0269	12.7	-	-	-	-	4	97.0
	Algae	0.0009	12.3	-	-	-	-	4	0.9
	Control (No plants)	***	-	-	-	-	-	-	-

* S_o = Initial Concentration for K

S_1 = Constant for k_1 term $S_1 e^{-k_1 t}$

S_2 = Constant for k_2 term $S_2 e^{-k_2 t}$

**n = Sample Population for Removal Rate Coefficient Determination

*** = No Significant Removal

followed the composite exponential model as did algae and the control (no plants). The reader is referred to Table 11 for specific kinetic rate and correlation coefficients. In all cases except for water-bonnet and water hyacinth the correlation coefficients were very high ($>76\%$, most being breater than 90%). Personal observation indicates that plant acclimation may have accounted for the poor water hyacinth correlation.

Boron is an essential element for plants and it is toxic to plants when present in larger amounts in soil or water (70). In excess of 2.0 mg/l in irrigation water, boron is deleterious to certain plants (32). Therefore, plants will uptake boron only to their physiological requirement level. Therefore most of the plant systems exhibited very low boron removal rate coefficients during the batch screening study. Study design included an initial boron concentration of 5 mg/l which proved to be a surplus for the plants resulting in a low significance of its removal by the vascular aquatic plants studied. Boron kinetic modeling coefficients for different plants are summarized in Table 11. All plant systems followed the pseudo first order kinetic removal model, except coontail, elodea, and algae which eshibited no significant boron removal. Correlation coefficients were relatively low due to poor uptake characteristics of the plant investigated.

Cadmium kinetic modeling coefficients by vascular aquatic plants are also tabulated in Table 11. All plant systems showed very significant cadmium removal as compared to algae and control tanks with high correlation coefficients (generally $>85\%$). Among the rooted plant system group, only bulrush followed the pseudo first order kinetic removal model, rush and arrowhead obeyed the composite exponential model. Duckweed and water-bonnet followed pseudo first order kinetics among the floating plant system group; while water hyacinth data best fit the composite exponential model. For submersed and emersed plants, both coontail and elodea were observed to fit the composite exponential model; whereas alligator-weed followed pseudo first order kinetics. Both algae and control (no plants) followed the pseudo first order kinetics.

Mercury kinetic modeling coefficients are summarized in Table 11. As with cadmium, all plant systems showed very significant mercury percent removals and rates of removal. Both algae and control (no plants) also exhibited removal. Correlation coefficients were high in all cases (>55%) with most surpassing 85%. Bulrush and arrowhead followed pseudo first order kinetics; while rush best fit the composite exponential model. For floating specie systems both water hyacinth and duckweed followed the pseudo first order model; whereas water-bonnet followed the composite exponential fit. Among the submersed and emersed plant systems, coontail and elodea followed pseudo first order kinetics, while alligator-weed best fitted the composited exponential model. Algae also following these kinetics, but the control exhibited first order kinetics.

For selenium removal, kinetic modeling coefficients are summarized in Table 11. Only rooted, submersed and emersed plant systems showed significant selenium removal. Correlation coefficients are very high (82%) with most >93%. None of the floating plants, algae or control showed any significant removal. Pseudo first order removal was exhibited by all plants. Bulrush appeared best for selenium removal with alligator-weed exhibiting lowest potential for removal.

Phenol was removed to a significant extent by all vascular aquatic plants, algae and the control systems as shown by Table 11. Kinetic modeling coefficients are also tabulated in Table 11. Extremely high removal rates were observed since phenol was removed to its detectable limit within a four or five day period. An increase in phenol concentration in plant tissue during this batch screening experiment was observed indicating phenol was removed from the wastewater effluent by plant uptake. Wolverton has also indicated very significant phenol removals of 25-100 mg/1 to 0.1-0.5 mg/1 within 72 hours and accumulations of average 36 mg/gm dry plant tissue by water hyacinth (31). From the results of this batch screening study, all plants including algae and the control exhibited pseudo first order removal kinetics. Highest removal rates were shown by coontail and rush; the lowest were in the control and with bulrush.

Polychlorinated biphenyls (PCB) removal from the batch screening study paralleled phenol removal results. Kinetic modeling coefficients are summarized in Table 11. Correlation coefficients were always >70% (except for water-bonnet due to poor adaptability) with most > 95%. All aquatic plants and algae and control (no plants) exhibited pseudo first order removal kinetics as indicated by 100% reduction in PCB content following two ro four days exposure. As expected, a significant increase of PCB concentration in plant tissue was observed (see Table 10). The highest PCB removal rate coefficients were found for rush and bulrush with water-bonnet displaying the lowest.

Nutrient removal (nitrogen and phosphate), kinetic modeling coefficients are tabulated in Table 11. Most of nitrogen and phosphate removal by vascular aquatic plant system followed the pseudo first order kinetics, except for phosphate removal by water hyacinth which fitted the composite exponential model. Most plants required significant time for acclimatization given the nitrogen forms presented in effluent domestic sewage during the beginning of the experiment. After one to two weeks significant and constant rate of nitrogen removal was realized by the plant species. Only for bulrush was an acclimation period required for phosphate. Removal rates became constant following two weeks of exposure. Bulrush and rush exhibited the highest removal rates for both nitrogen and phosphate, whereas duckweed showed the lowest nitrogen removal rate. Algae and the control (no plants) did not show any significant phosphate removal.

In Table 11, kinetic model organic removal coefficients (BOD_5 and TOC) are also tabulated. As for nutrient removal, both BOD_5 and TOC removal rates followed the pseudo first order removal kinetics model. Only for TOC removal by water hyacinth did the rate appear to follow the composite exponential form. However, the k_2 term (0.0004 day^{-1}) is quite low as is the correlation coeffieient of 25.6%. The highest BOD_5 removal rate was observed from bulrush (0.1254 day^{-1}) and the lowest for coontail (0.0097 day^{-1}). For TOC removal, the highest removal rate was exhibited by rush (0.0486 day^{-1}) and the lowest by algae (0.0009 day^{-1}). Variation in control tank data precluded kinetic model determination or verification.

Applicable Mathematical Model for Batch Screening Study - Plant Accumulation of Trace Contaminants.

Exposure of plant species to trace contaminants spiked in secondary effluent wastewater during the batch screening study resulted in high accumulation of these trace contaminants in plant tissue. Figures 17-a to 17-c show examples of trace contaminant (cadmium) accumulation in rooted, floating, submersed and emersed plants as a function of time, respectively. As indicated, the concentration of trace contaminants in plant tissue increased rapidly until approximately 3 days and then this rate of increase slowed as exposure time continued to increase (as plotted on semilogarithmic paper). Wolverton and McDonald (83) also studied cadmium uptake by water hyacinth. Their results indicate

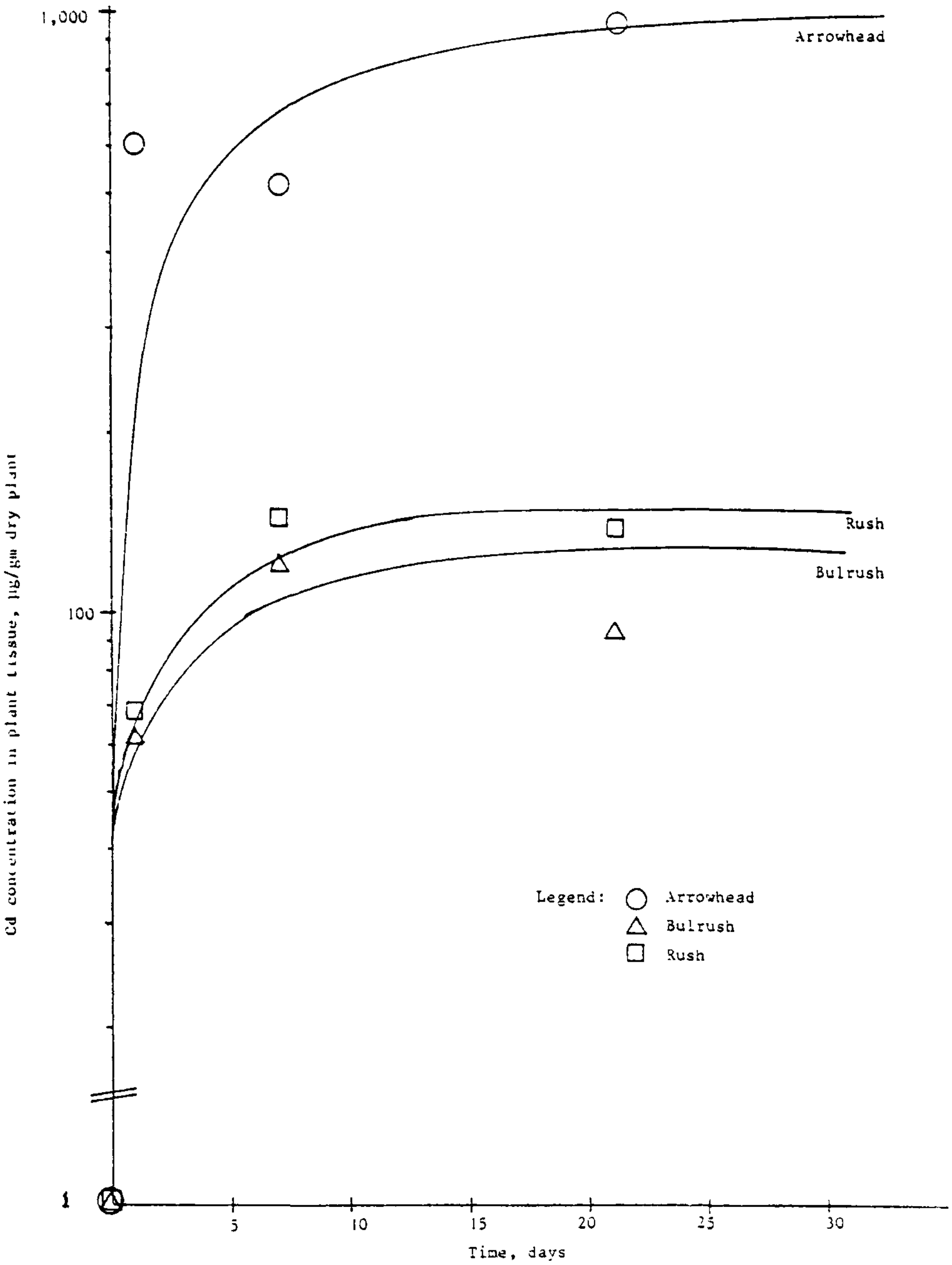


Figure 17-a. Accumulation of Cadmium in Rooted Plants as a function of time, Batch Screening Study

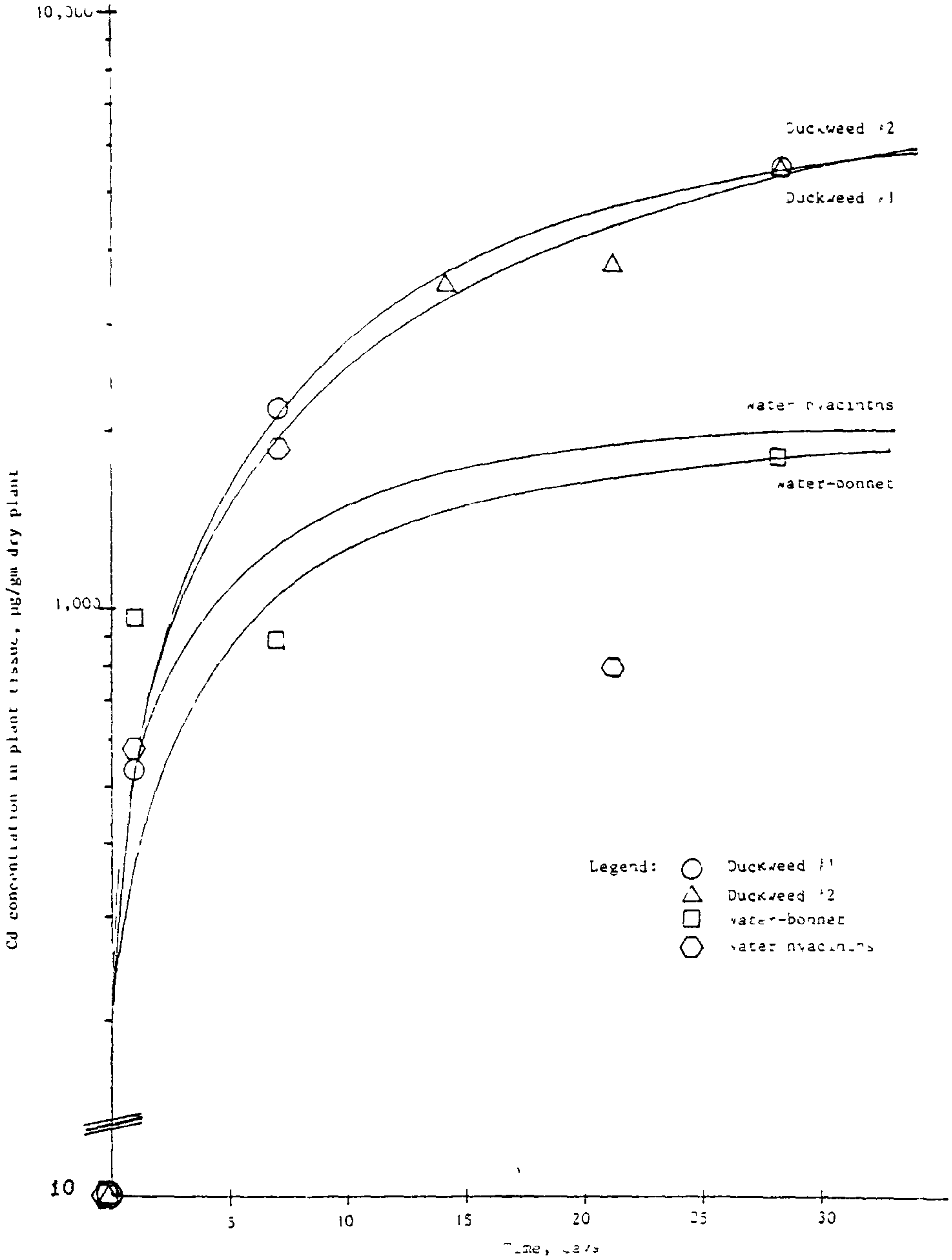


Figure -6. Accumulation of Cadmium in Floating Plants as a Function of Time, Batch Screening Study

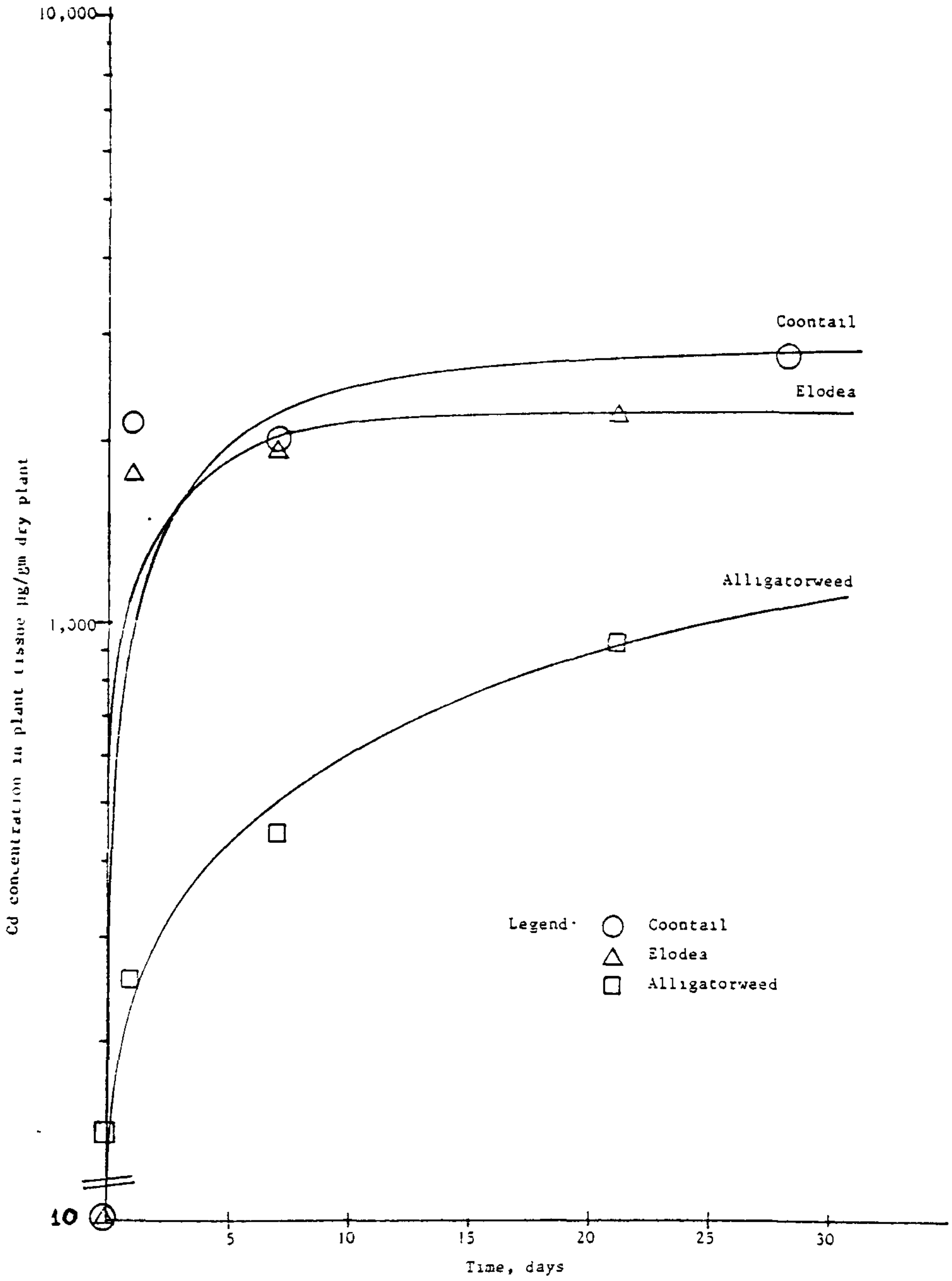


Figure 17-c. Accumulation of Cadmium in Submersed and Emersed Plants as a Function of Time, Batch Screening Study

that cadmium is sorbed by roots of water hyacinth under cadmium water concentration of 0.001 mg/l (river water) yielding accumulation of cadmium in the roots of water hyacinth at an average of 0.9, 1.4, and 3.0 µg/gm root dry weight after 24, 48, and 72 hours exposure periods, respectively. Cadmium concentration in plant tissue increased with time lineally, they concluded however long period of plant exposure should be evaluated. Results for the batch screening of this experiment indicate that the concentration of trace contaminants in plant tissues will increase until at some point they will become saturated or an equilibrium concentration will be attained. The time to saturation will be a function of the plant species, the concentration of contaminant, etc.

Absorption of trace contaminant in vascular aquatic plants (as shown by examples in Figures 17-a through 17-c) may be described by a first order exponential equation. A mathematical model describing tissue uptake kinetics was initially introduced by Ruzic who described radionuclide accumulation into marine organisms (84). An extension of this uptake model for monosodium methane arsonate (MSMA) by vascular aquatic plants was described by Anderson, et al. (85). This model also demonstrated the best fit of the plant accumulation data obtained during the batch screening study. The uptake model can be described as follows:

One compartment model;

$$C = M \frac{k_i}{k_o} (1-e^{-k_o t}) \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (3)$$

Two compartment model;

$$C_t = M \frac{k_{i_a}}{k_{o_a}} (1-e^{-k_{o_a} t}) + M k_{i_b} t \; . \; . \; (4)$$

where:

C = absorbed or tissue concentration (μg/gm)

M = trace contaminant water concentration (mg/l)

k_i = inward rate constant (day^{-1})

k_o = outward rate constant (day^{-1})

k_{i_a} = inward rate constant (day^{-1}) for $t<t_o$

k_{o_a} = outward rate constant (day^{-1}) for $t < t_o$

k_{i_b} = inward rate constant (day^{-1}) for $t > t_o$

t_o = time of opening of 2nd compartment

t = time, days

Most aquatic plants in the batch screening study followed the one compartment model for each trace contaminant considered. Only coontail data fit the two compartment model and only for arsenic uptake. Anderson, et al., (85) also observed that arsenic (MSMA) uptake by coontail followed the two compartment model. In the two compartment model, they explained that the first phase of uptake is reversible with exchange of trace contaminants to the water while the second is irreversible with trace contaminant retained permanently in plant tissues.

In order to determine constants for uptake equations, a plot of $\frac{\text{concentration of trace contaminant in plant tissue}}{\text{water concentration}}$ versus time is necessary. Figures 18-a to 18-c illustrate examples of determination of outward rate constants (k_o). The inward rate constants (k_i) is next calculated using the above two equations.

Table 12 cites inward and outward rate constants for trace contaminant uptake by vascular aquatic plants from the batch screening study.

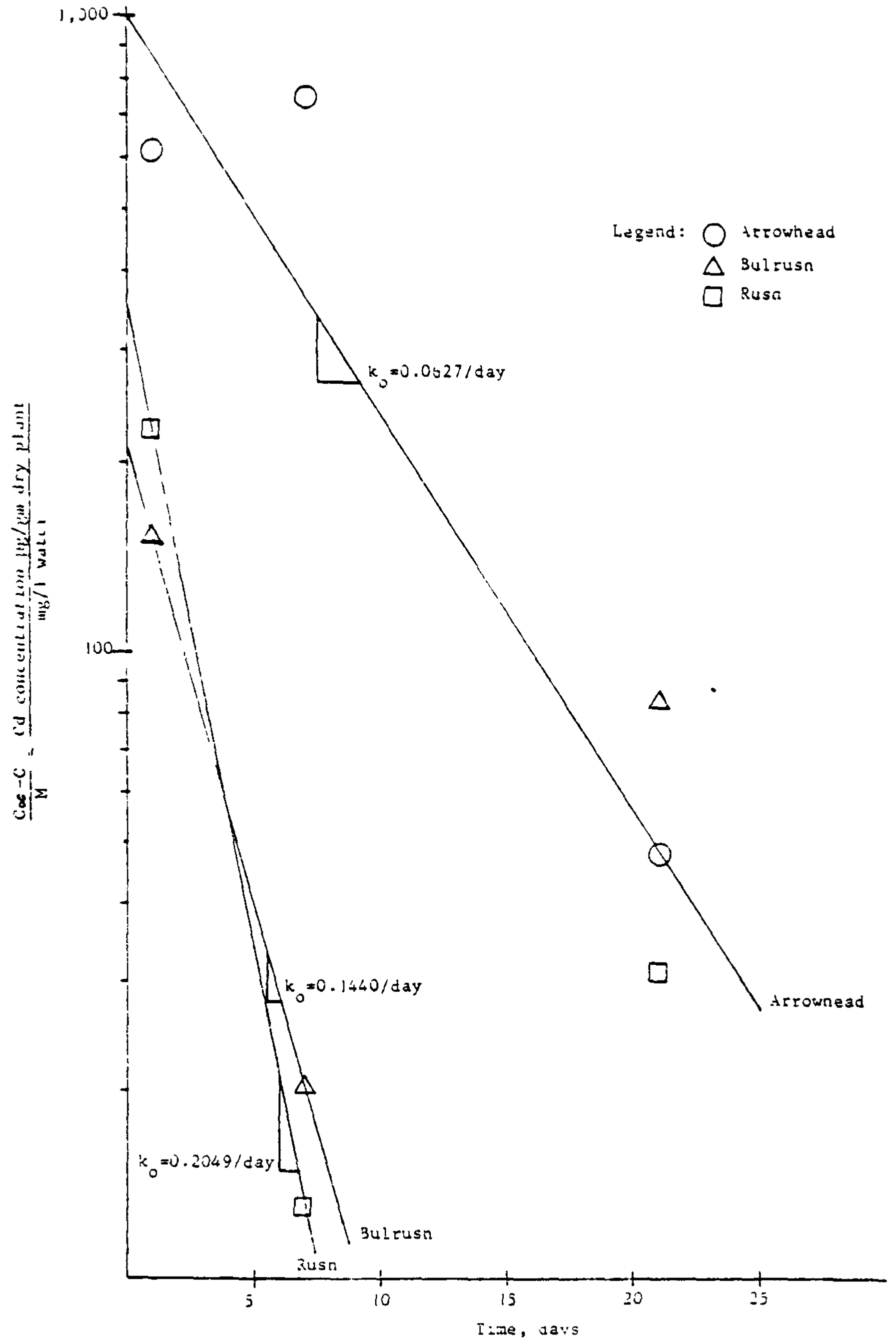


Figure 18-a. Determination of Outward Rate constant, k_o (per day) of Cadmium Uptake by Rooted Plants, Batch Screening Study

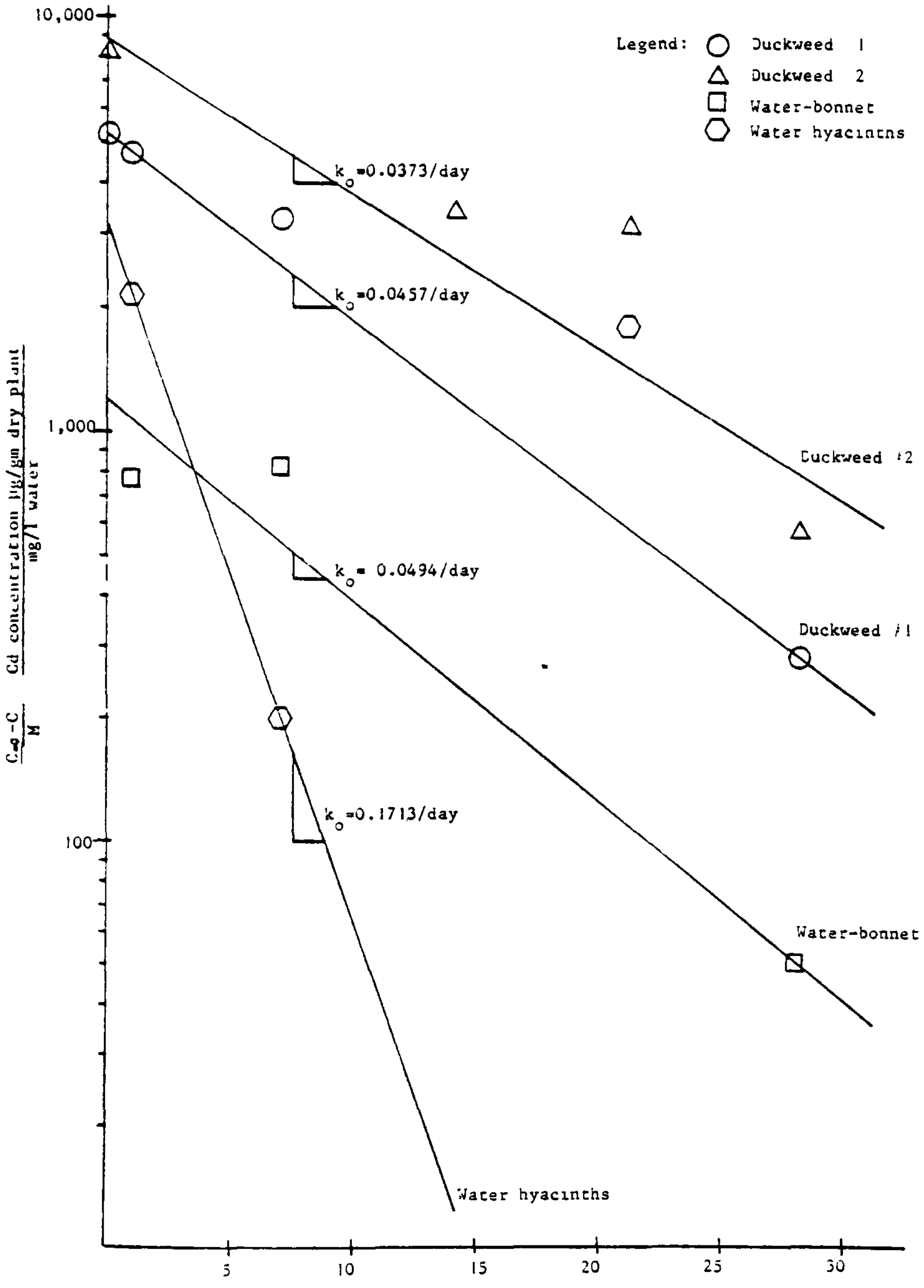


Figure 18-6. Determination of Outward Rate Constant, k_o (per day) of Cadmium Uptake by Floating Plants, Batch Screening Study.

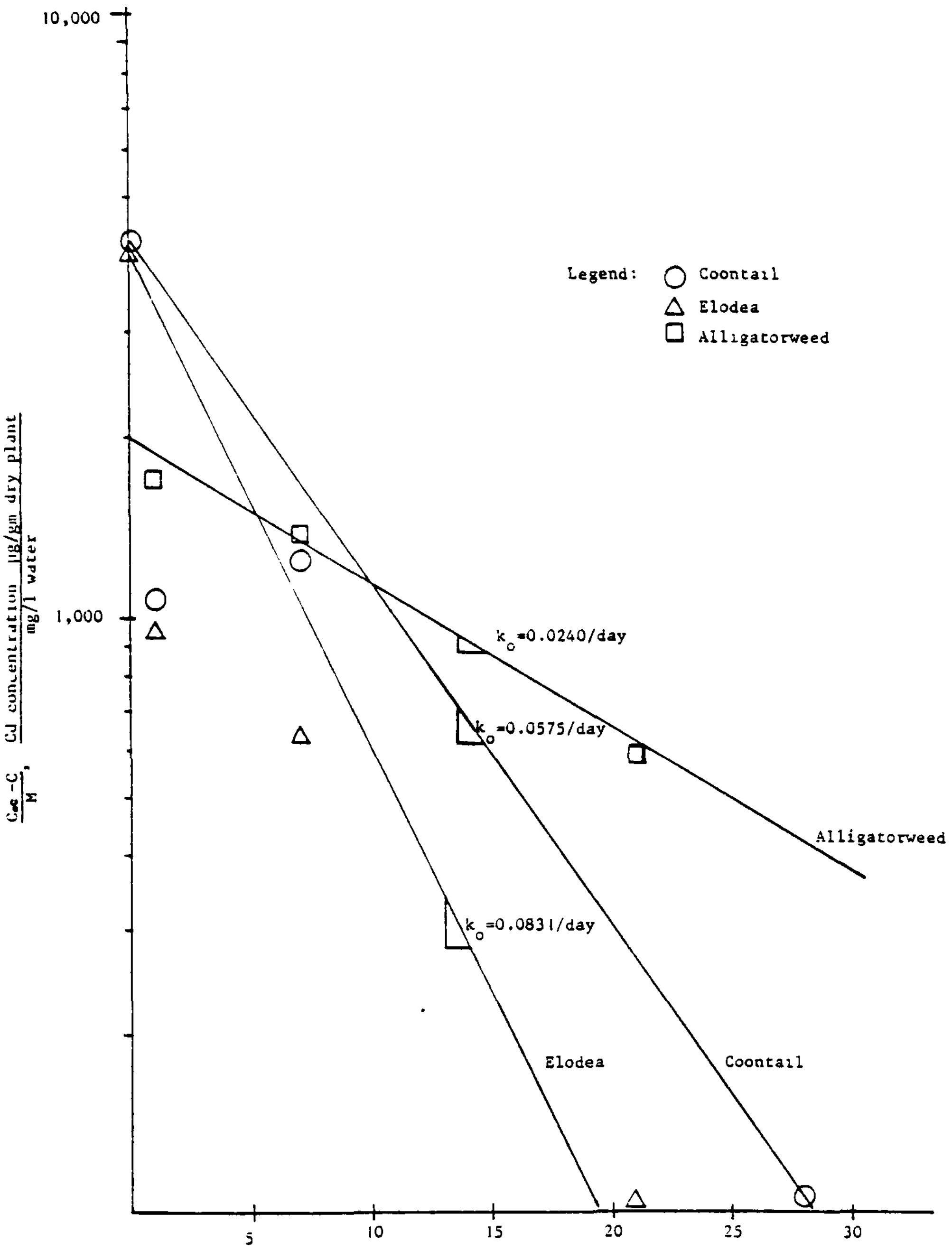


Figure 18-c. Determination of Outward Rate Constant, k_o (per day) of Cadmium Uptake by Submersed and Emersed Plants, Batch Screening Study

Table 12. Inward and Outward Rate Constants (k_i and k_o) for Trace Contaminant Uptake by Vascular Aquatic Plants, Batch Screening Study using the Model of Ruzic

Trace contaminant	Plant	k_i/day	k_o/day
Arsenic	Rooted		
	Bulrush	11.2022	0.0555
	Rush	0.3873	0.0296
	Arrowhead	1.4844	0.0456
	Floating		
	Duckweed #1	2.7356	0.1138
	Duckweed #2	0.4295	0.0183
	Water-bonnet	0.6244	0.0377
	Water hyacinths	4.0155	0.0577
	Submersed and Emersed		
	Coontail	1.6575(1st) 0.8437(2nd)*	0.1129
	Elodea	1.5191	0.535
	Alligatorweed	3.9382	0.0499
Boron	Bulrush	k_i=k_o**	
	Water hyacinths	k_i=k_o	
	Elodea	0.9526	0.0618
Cadmium	Rooted		
	Bulrush	42.0674	0.1440
	Rush	84.4368	0.2049
	Arrowhead	97.9687	0.0627
	Floating		
	Duckweed #1	235.6900	0.0457
	Duckweed #2	313.4454	0.0373
	Water-bonnet	77.5062	0.0494
	Water hyacinths	517.5226	0.1713
	Submersed and Emersed		
	Coontail	243.7865	0.0575
	Elodea	336.4965	0.0831
	Alligatorweed	51.0638	0.0240

Table 12. (continued)

Trace contaminant	Plant	k_i/day	k_o/day
Mercury	Rooted		
	Bulrush	56.9892	0.0424
	Rush	38.4057	0.0596
	Arrowhead	177.4112	0.0699
	Floating		
	Duckweed #1	84.8369	0.0537
	Duckweed #2	150.4750	0.0463
	Water-bonnet	106.3624	0.0769
	Water hyacinths	131.0017	0.0959
	Submersed and Emersed		
	Coontail	107.5601	0.0506
	Elodea	143.1088	0.0919
	Alligatorweed	81.5714	0.0571
Selenium	Rooted		
	Bulrush	147.0486	0.2507
	Rush	50.5338	0.2444
	Arrowhead	209.6049	0.2539
	Floating		
	Duckweed #1	$k_i=k_o$**	
	Duckweed #2	$k_i=k_o$	
	Water-bonnet	9.0600	0.0432
	Water hyacinths	7.4076	0.0446
	Submersed and Emersed		
	Coontail	9.3555	0.0431
	Elodea	156.7082	0.2370
	Alligatorweed	8.1492	0.0441
Phenol	Bulrush	2.3543	0.0760
	Water hyacinths	$k_i=k_o$	
	Elodea	$k_i=k_o$	

Table 12. (continued)

Trace contaminant	Plant	k_i/day	k_o/day
Polychlorinated biphenyls	Rooted		
	Bulrush	4.5382	0.0468
	Rush	29.1083	0.0998
	Arrowhead	114.3592	0.0401
	Floating		
	Duckweed	514.0000	0.0514
	Water-bonnet	311.9200	0.1114
	Water hyacinths	77.5200	0.0612
	Submersed and Emersed		
	Coontail	840.2727	0.1027
	Elodea	121.2121	0.2000
	Alligatorweed	10.0697	0.0433
Total Nitrogen	Rooted		
	Bulrush	$k_i=k_o$**	
	Rush	$k_i=k_o$	
	Arrowhead	145.3400	0.0507
	Floating		
	Duckweed #1	D/M***	
	Duckweed #2	D/M	
	Water-bonnet	94.4865	0.0368
	Water hyacinths	23.6395	0.0107
	Submersed and Emersed		
	Coontail	D/M	
	Elodea	316.9919	0.1114
	Alligatorweed	$k_i=k_o$	
Phosphate	Rooted		
	Bulrush	14.0697	0.0289
	Rush	$k_i=k_o$**	
	Arrowhead	$k_i=k_o$	
	Floating		
	Duckweed #1	124.8197	0.0846

Table 12. (continued)

Trace contaminant	Plant	k_i/day	k_o/day
Phosphate (continued)	Duckweed #2	76.9655	0.0465
	Water-bonnet	103.7862	0.0596
	Water hyacinths	$k_i=k_o$	
	<u>Submersed and Emersed</u>		
	Coontail	$k_i=k_o$	
	Elodea	59.2353	0.0212
	Alligatorweed	41.7358	0.0553

* k_i of 2nd compartment for coontail

** $k_i=k_o$ when the uptake process reaches equilibrium

*** D/M = Data does not fit proposed uptake model

It is observed that most of plants were able to concentrate all trace contaminants many times above the levels found in the wastewater. All of the rooted, floating, submersed and emersed plants exhibited uptake following the first order - one compartment model for every trace contaminant, except as indicated for coontail during arsenic uptake.

Productivity of Vascular Aquatic Plants During Batch Screening Study

Both total wet weight and dry weight of plant tissues at the beginning and the end of batch experiment are summarized in Table 13. All of rooted plants exhibited a significant productivity increasing both wet weight and dry weight. Bulrush yielded the highest productivity (18% and 27% wet weight and dry weight increase, respectively) among these rooted plants. An emersed plant, alligatorweed, showed the highest percent increase of productivity in this batch experiment (52% and 26% wet and dry weight increase, respectively). All of floating and submersed plants showed decrease in productivity except duckweed (tank #1), where there was a wet weight increase but a decrease in dry weight.

A decrease in productivity occured probably because of plant acclimatization to wastewater conditions. It is possible that some trace contaminants in the wastewater may have been present at concentration levels sufficient to cause toxicity or inhibition to the plant present. For example, boron concentration in wastewater was 5 mg/l which may have been toxic to some plants. As noted previously, boron concentration in irrigation water of 2.0 mg/l is deleterious to certain plants (32). Frequency of the sampling schedule probably also had some effect on plant growth since much plant tissue was required for analysis resulting in insufficient plant tissue remaining for optimal recovery and growth. The turbidity of the secondary effluent may also have

Table 13. Productivity of Vascular Aquatic Plants (gm), Batch Screening Study, 28 Day Run

Plant Species	Total Wet Weight		Percent Wet Weight Increase (%)	Total Dry Weight		Percent Dry Weight Increase (%)
	0 Day	28 Days*		0 Day	28 Days*	
Rooted						
Bulrush	3,200.50	3,772.94	17.89	612.26	777.72	27.02
Rush	3,421.90	3,660.02	6.96	631.34	724.74	14.79
Arrowhead	1,107.00	1,233.90	11.46	55.90	65.39	16.96
Floating						
Duckweed #1	389.00	418.69	7.63	25.25	14.79	-41.42
Duckweed #2	389.00	365.18	-6.12	25.25	10.27	-59.34
Water-bonnet	630.50	338.37	-46.33	29.63	19.03	-35.78
Water hyacinths	1,442.30	1,302.99	-9.66	89.57	73.79	-17.62
Submersed and Emersed						
Coontail	714.20	265.85	-62.78	48.21	14.40	-70.12
Elodea	734.60	543.18	-26.06	38.05	25.05	-34.18
Alligatorweed	1,146.00	1,744.33	52.21	251.20	315.71	25.68

* Includes weight of plant tissue removed during sampling

affected plant growth. Hart (86) observed coontail and elodea growing in Lake Bouef, Louisiana. He stated that both coontail and elodea grow very well in clean water, however, during heavy rain and storm run-off with resultant high solids content productivity is impaired for both plants.

Fecal Coliform Population During Batch Screening Study.

Figures 19-a through 19-c illustrate the relationship of fecal coliforms in water as a function of time for rooted, floating and submersed plant aquaria. It is observed that in every aquarium the number of fecal coliforms at the beginning of the experiment is low and at about 5-7 days the number of fecal coliforms present peak and then decrease after 7 to 10 days followed by a complete remission of fecal coliforms after 15 days or at the end of experiment. This trend of fecal coliform growth follows the general bacterial growth curve which includes lag, log growth, stationary and death phases (87).

Evapotranspiration, Solar Radiation, Water Temperature, Dissolved Oxygen Concentration (D.O.), pH and Oxidation Reduction Potential (ORP) during Batch Screening Study.

Evapotranspiration, evaporation, and solar radiation data are summarized in Table 14. It was observed that most plants exhibited good evapotranspiration except arrowhead, duckweed and coontail, compared to evaporation only from the control tank. Rush showed the highest evapotranspiration with an average of 8 mm/day. Solar radiation in the range of 0.141-0.805 cal/cm^2/min. was recorded and is sufficient for optimal plant growth.

Water temperature, dissolved oxygen concentration (D.O.), pH and oxidation reduction potential (ORP) data of batch screening study are summarized in Appendix H (Tables H-1 through H-4). Water temperature

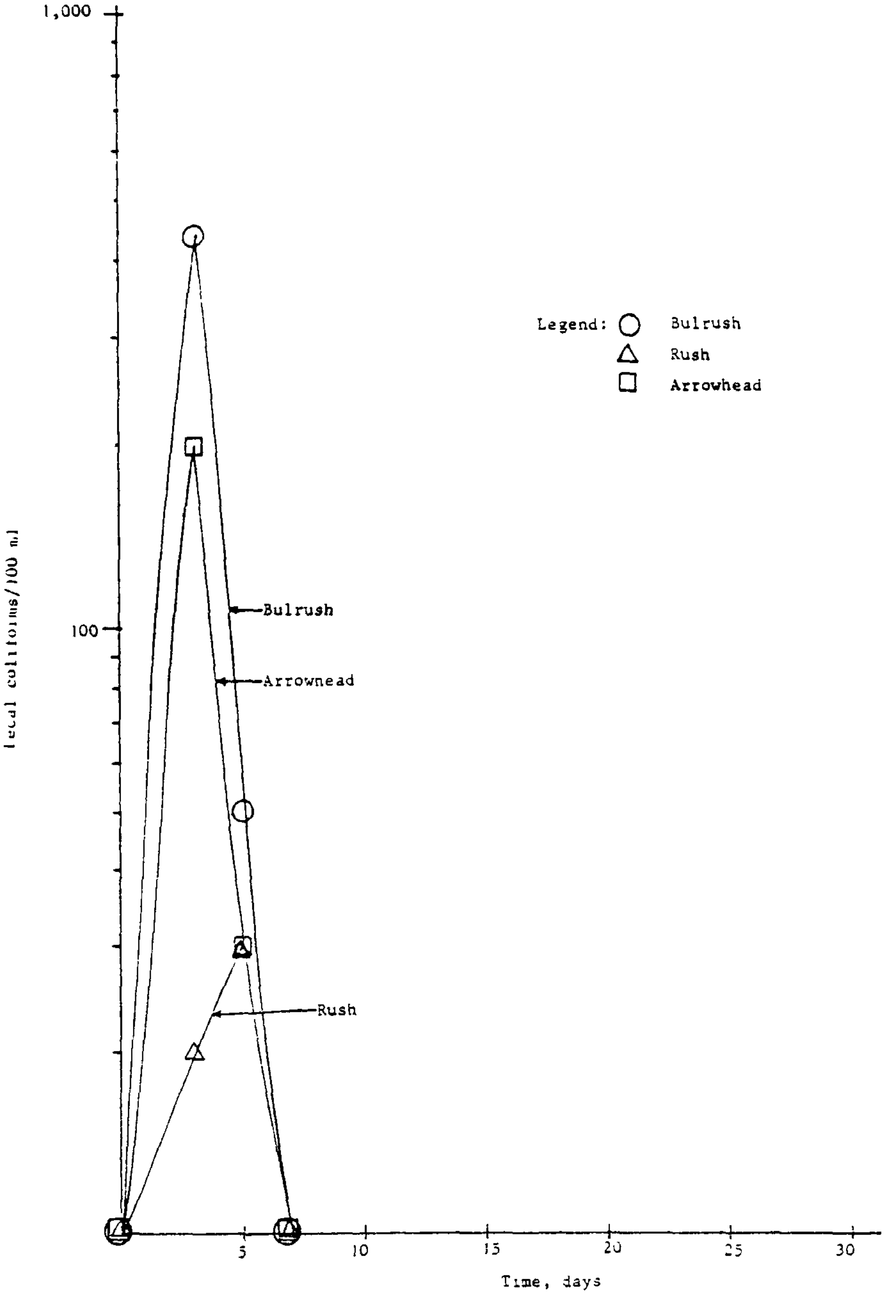


Figure 19-a. Fecal Coliforms in Rooted Plant Aquaria as a Function of Time, Batch Screening Study

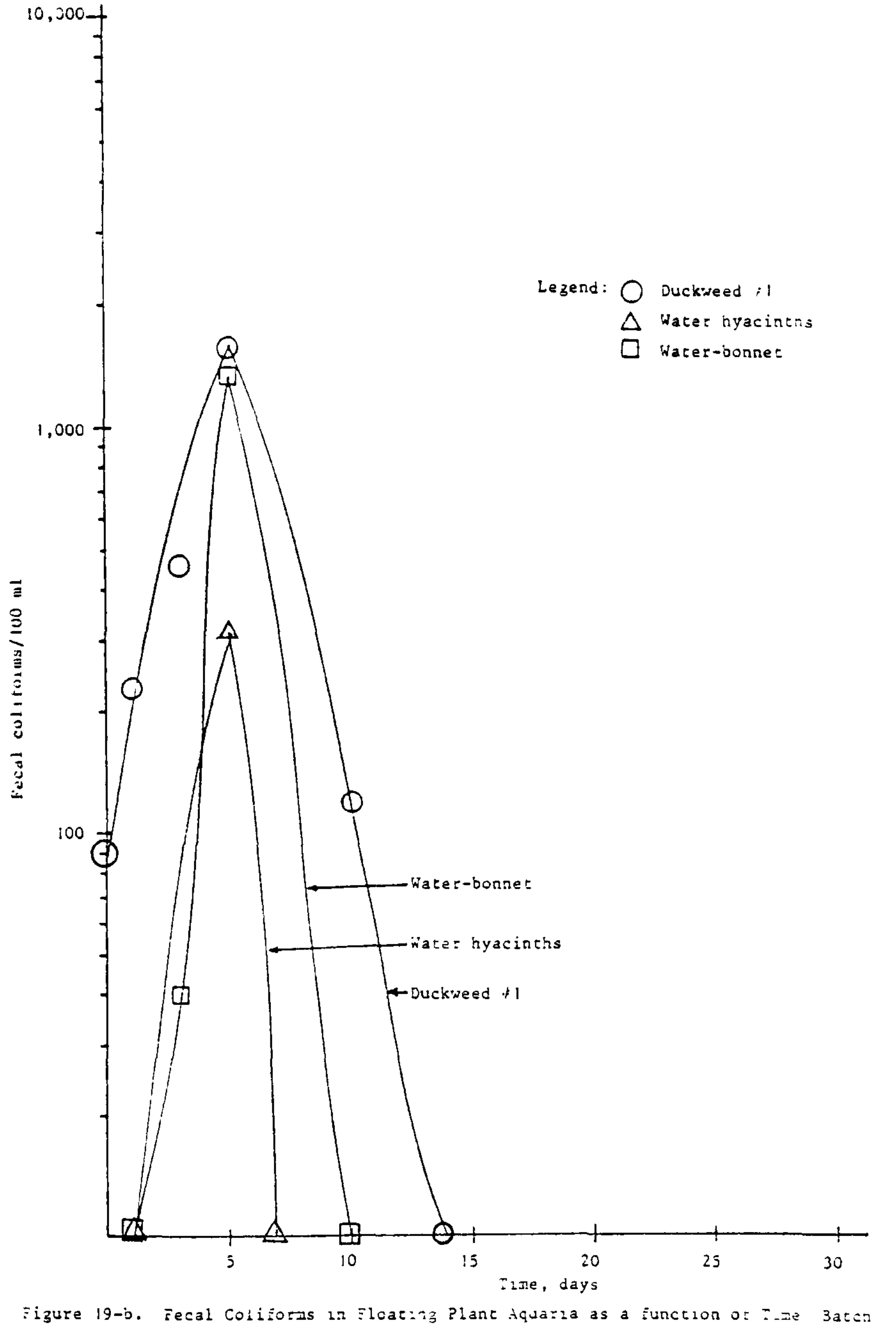


Figure 19-b. Fecal Coliforms in Floating Plant Aquaria as a Function of Time Batch Screening Study

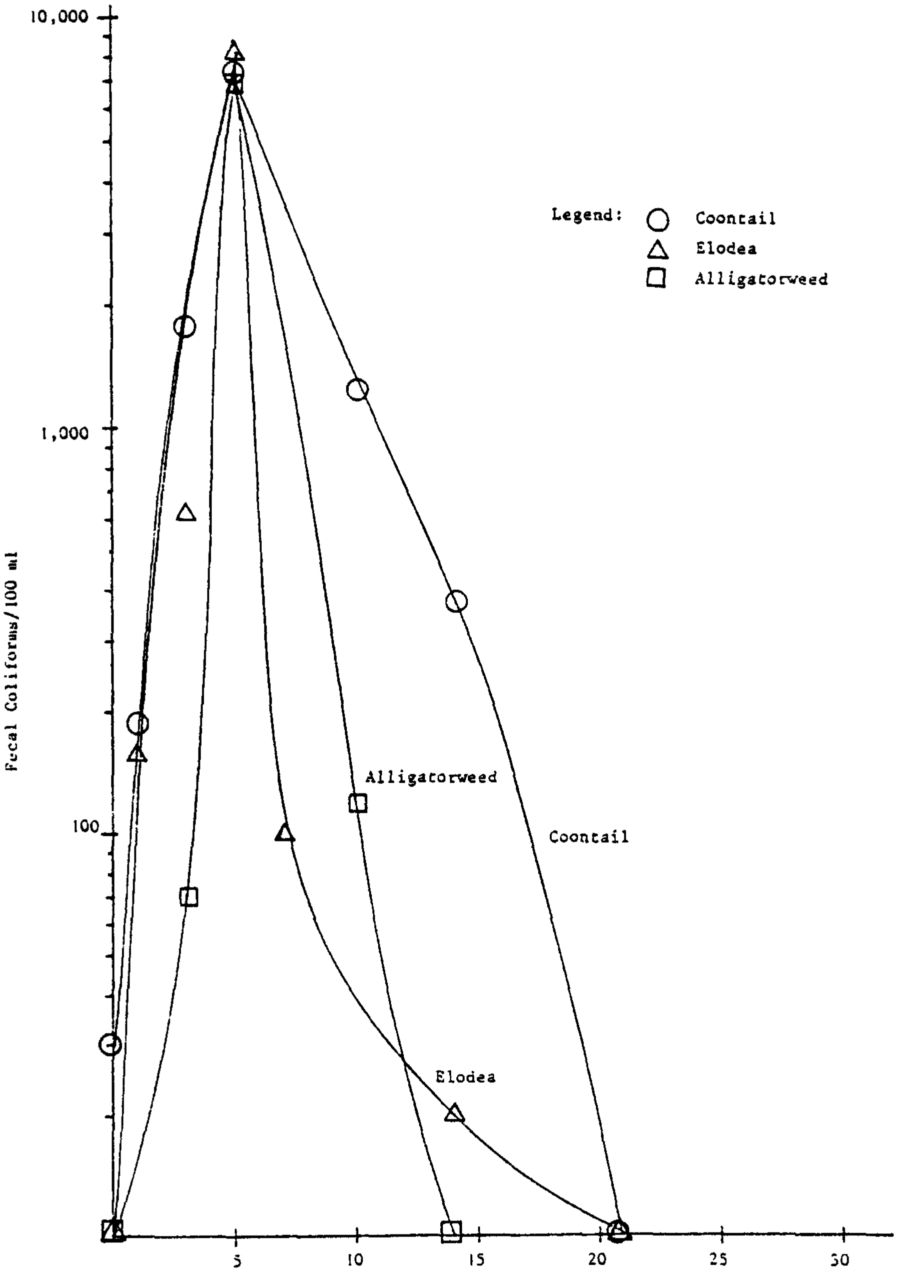


Figure 19-c. Fecal Coliforms in Submersed and Emersed Plant Aquaria as a function of Time, Batch Screening Study

Table 14. Summary of Evapotranspiration and Solar Radiation Data, Batch Screening Study

Parameter	Plant	Range	Mean	Median
Evapotranspiration, mm/day	Rooted			
	Bulrush	1.0-4.3	3.1	3.1
	Rush	1.8-10.5	8.0	8.1
	Arrowhead	0.4-2.7	1.5	1.4
	Floating			
	Duckweed #1	0.1-2.5	1.5	1.5
	Duckweed #2	1.2-3.3	2.0	2.0
	Water-bonnet	1.7-3.6	2.6	2.7
	Water hyacinths	1.5-3.6	2.3	2.3
	Submersed and Emersed			
	Coontail	0.4-2.8	1.5	1.5
	Elodea	1.0-4.0	2.8	2.9
	Alligatorweed	1.6-5.4	3.7	3.5
	Algae	1.3-5.9	4.3	4.5
	Control (no plant)	0.5-2.9	2.0	1.8
Solar Radiation, cal/cm^2/min.	All plants	0.141-0.805	0.457	0.456

of all plants was nearly constant with a range of 21-23°C. Dissolved oxygen concentration of water in each plant aquarium was also nearly constant with an average of 4.1 to 5.9 mg/l during daylight hours. Water pH for plant growth was observed almost constant in the range of 7-8. Oxidation reduction potential for all plants was also observed at levels above +130. Therefore, it could be concluded that these factors did not contribute significantly to differences in plant behaviors during the batch study.

Results of Continuous Flow Study, Nonrecirculation Run (15 day retention).

Based on the results of the batch screening study three plants were selected for studying trace contaminant removal efficiency under continuous plug flow conditions. Bulrush was selected for the rooted plant with water hyacinth and elodea being picked as the floating and submersed plants respectively. Under the conditions of the test, elodea died after 30 days of experiment initiation, consequently only water hyacinth and bulrush systems were evaluated for the duration of the testing.

Table 15 shows trace contaminant removal by water hyacinth and bulrush. Concentration of trace contaminants in both influent and effluent are shown. Also, results from control (no plants) are presented for comparison. Both water hyacinth and bulrush systems exhibited very effective removals for all trace contaminants evaluated. As indicated, the water hyacinth system was excellent in reducing organics (95% for BOD and 80% for TOC) and also nitrogen (85%) and phosphate (65%). Bulrush system showed excellent removals for cadmium (91%), mercury (93%), and selenium (95%). Both plant systems exhibited excellent reductions of phenol (95%) and polychlorinated biphenyls (95%). Only arsenic and boron were effectively

Table 15. Trace Contaminant Removal by Vascular Aquatic Plants, Continuous Flow Study, Non-recirculation, 58 Day Run (15 Day Retention)

Plant	Parameter	Influent Concentration, mg/l			Effluent Concentration,* mg/l			Percent Removal (%)
		Mean	Median	Range	Mean	Median	Range	
Water hyacinths	BOD_5	45.5	43.5	26.7 -73.8	2.3	1.9	<0.1 -4.8	94.95
	TOC	25.5	21.5	12.5-43.7	5.1	5.5	2.5-10.7	80.00
	Arsenic (As)	1.201	1.170	1.045-1.408	0.711	0.726	0.468-0.895	40.80
	Boron (B)	1.596	1.591	1.269-1.884	1.028	1.029	0.522-1.454	35.59
	Cadmium (cd)	1.497	1.551	1.089-1.749	0.224	0.189	0.084-0.443	85.04
	Mercury (Hg)	1.549	1.552	1.225-1.961	0.131	0.123	0.035-0.210	91.54
	Selenium (Se)	1.542	1.474	1.391-1.804	0.614	0.564	0.320-0.928	60.18
	Phenol	1.044	1.009	0.906-1.312	0.028	0.039	0.000-0.050	97.32
	Polychlorinated biphenyls (PCB)	0.055	0.047	0.012-0.121	<0.001	0.000	0.000-0.002	>98.18
	Total Nitrogen	21.84	23.23	8.98-39.16	3.31	3.63	2.38-4.67	84.84
	Phosphate	6.28	5.58	4.18-10.72	2.22	2.21	1.53-2.70	64.65
Bulrush	BOD_5	45.5	43.6	27.5 -71.2	11.0	8.9	3.5 -20.4	75.78
	TOC	25.9	21.9	12.8-43.8	8.8	8.2	3.9-14.5	66.02
	Arsenic	1.187	1.157	1.078-1.386	0.517	0.542	0.259-0.681	56.44
	Boron	1.655	1.676	1.141-2.180	1.058	1.178	0.381-1.610	36.07
	Cadmium	1.457	1.515	1.078-1.815	0.133	0.131	0.021-0.225	90.87
	Mercury	1.548	1.572	0.967-1.933	0.107	0.103	0.023-0.207	93.09
	Selenium	1.515	1.413	1.386-1.649	0.222	0.233	0.074-0.343	85.35

Table 15. (continued)

Plant	Parameter	Influent Concentration, mg/l			Effluent Concentration,* mg/l			Percent Removal (%)
		Mean	Median	Range	Mean	Median	Range	
Bulrush (cont.)	Phenol	1.025	0.996	0.921-1.312	0.040	0.034	0.021-0.073	96.10
	Polychlorinated biphenyls (PCB)	0.041	0.025	0.012-0.118	0.002	0.000	0.000-0.017	95.12
	Total Nitrogen	21.21	20.65	9.18-37.25	5.28	5.20	0.36-9.36	75.11
	Phosphate	6.11	5.76	4.42-9.99	2.96	2.35	0.90-5.22	51.55
Control (no plants)	BOD$_5$	36.6	32.2	26.0-60.0	11.0	9.7	5.3-20.0	69.92
	TOC	18.5	18.8	12.2-22.2	13.5	13.3	9.7-18.2	27.03
	Arsenic	1.125	1.113	1.056-1.292	1.041	1.045	0.968-1.093	7.47
	Boron	1.635	1.729	0.922-2.016	1.688	1.701	1.455-1.912	**
	Cadmium	1.249	1.259	0.759-1.617	0.242	0.214	0.144-0.404	80.62
	Mercury	1.237	1.171	0.950-1.722	0.228	0.224	0.171-0.271	81.57
	Selenium	1.461	1.441	1.331-1.578	0.804	0.796	0.745-0.862	44.97
	Phenol	0.958	0.924	0.764-1.275	0.270	0.295	0.081-0.391	71.82
	Polychlorinated biphenyls	0.034	0.037	0.010-.064	0.025	0.007	0.000-0.101	26.47
	Total Nitrogen	18.68	16.22	7.42-35.74	5.13	4.48	3.58-7.78	72.54
	Phosphate	5.67	5.74	3.73-7.74	4.40	4.55	3.02-5.22	22.40

* Concentration includes make-up for evapotranspiration

** No significant removal

removed with both plants exhibited the same low percent removal (41-56% for arsenic and 36% for boron).

Even with the poor quality of the secondary effluent feedwater, the water hyacinth system showed 95 and 80 percent removal of BOD_5 and TOC, respectively with an average effluent concentration of 2.3 and 5.1 mg/l respectively. Dinges (88, 89) and Cornwell, et al. (21) also observed high nutrient (nitrogen and phosphate) removal efficiency from using water hyacinth in stabilization ponds. Dinges observed 77-87% of BOD_5 removal with a corresponding effluent concentration of 5.2 - 5.7 mg/l from his pilot study in Texas. His study showed nitrogen removal of 63-69% with effluent concentrations of 2.47 - 3.59 mg/l. He also observed that water hyacinth could uptake some trace pollutants i.e., arsenic, mercury, polychlorinated biphenyls, etc., but he did not quantify percent of removals. He also noted these trace contaminants were concentrated in the plant tissues.

Villamil, et al. (90) used water hyacinths for the clarification of wastewaters and the production of energy in Puerto Rico. They observed very high percent removal of both total nitrogen and phosphorus from a clarifying pond stocked with water hyacinth. Total nitrogen was reduced 95% with an effluent concentration of 0.05 mg/l. A 25% reduction of phosphorus was observed with an effluent concentration of 0.84 mg/l. From the foregoing studies it can be concluded that the water hyacinth system is excellent in reduction of organics and nutrients and also has potential for other trace contaminant removal.

Studies employing bulrush for wastewater purification are much fewer than those evaluating water hyacinths with limits discussion. However, there are several studies which will be compared and discussed subsequently. From the continuous flow-nonrecirculation study, bulrush displayed a lower potential for removal of organics and nutrieints as compared to the water hyacinths system; however, it exhibited higher removals of other trace contaminants including cadmium, mercury, and selenium. Both bulrush and water hyacinth were very effective in phenol and PCB removal. Seidel, et al. (91) observed that bulrush showed a very high phenol and phenolic derivatives removal efficiency. Even highly toxic penta chlorophenol (PCP) could be effectively removed by bulrush.

The results from this continuous flow study indicated that by using the bulrush system the BOD_5 and TOC were reduced 76% and 66% with an effluent concentration of 11 and 9 mg/1, respectively (Table 15). Total nitrogen and phosphate removal indicated 75% and 51% reduction with the effluent concentrations of 5.28 and 2.96 mg/1, respectively. Jong (23) and Seidel (91) stated that BOD_5 of domestic wastewater (from recreation and camping sites) could be reduced from a concentration of 127-347 mg/1 to 7-18 mg/1 by a bulrush system. Pope, et al. (92) also conducted a pilot study of secondary and tertiary wastewater treatment in California by using bulrush and reed (Phragmites spp.). Their study was concerned primarily with organic and nutrient removal including cost analysis. They observed that BOD was removed 54-56% with an effluent concentration of 6-16 mg/1 for the tertiary treatment system. Ammonia nitrogen in the same system was reduced 40-67% with effluent concentrations of 3-15 mg/1.

To the author's knowledge no study on the use of bulrush for the removal of heavy metals and trace organics have been published. Comparison with the literature is therefore not possible. Results from this study indicate bulrush to have a very high trace contaminant removal potential exceeding in most cases that of water hyacinths.

Trace Contaminant Kinetic Removal Rate Coeffieicnts during Continuous Flow Study, Nonrecirculation Run.

Due to time limitations only one retention time (15 days) evaluation was conducted for each plant studied. Since a plug flow condition prevailed in the reactor (as determined by dye tracer testing) a kinetic evaluation was made using the equations verified during the batch screening study. Equation (1) in the section presenting batch screening results was used for calculation of kinetic removal rate coefficients in this run by employing the 15 day retention time. Table 16 shows removal rate coefficients of trace contaminants by water hyacinth, bulrush and control (no plants). As indicated, both bulrush and water hyacinth exhibited a much higher removal rate than the control.

Suspended Solid (SS) and Volatile Suspended Solid (VSS) Removal during Continuous Flow - Nonrecirculation Study.

Table 17 shows removal efficiency of suspended solid and volatile suspended solid during the continuous flow-nonrecirculation study. As indicated, both water hyacinth and bulrush exhibited excellent SS and VSS removal. The water hyacinth system removed 99.2% suspended solids and 98.8% volatile suspended solids with an effluent concentration of 0.8 mg/l for both SS and VSS. The bulrush system exhibited 94.2% and 90.7% for SS and VSS removal with an effluent concentration of 5.5 and 7.0 mg/l, respectively. Comparison of these results to the study of Dinges (88, 89) who used water hyacinth for upgrading stabilization pond effluent, indicate higher percent solids removal with effluent concentrations approximately the same. Dinges observed a hyacinth system to remove 84-93% total suspended solid (TSS) and 86-93% volatile suspended solid (VSS) with effluent concentration of 7.0-7.5 and 5-6 mg/l, respectively.

Table 16. Trace Contaminant Kinetic Removal Rate Coefficients (K), Continuous Flow Study, Non-recirculation Run (15 Day Retention)

Trace Contaminant	Removal Rate Constant (K), per day		
	Water hyacints	Bulrush	Control (no plants)
BOD_5	0.1990	0.0945	0.0801
TOC	0.1073	0.0720	0.0210
Arsenic (As)	0.0349	0.0554	0.0052
Boron (B)	0.0293	0.0298	*
Cadmium (Cd)	0.1266	0.1596	0.1094
Mercury (Hg)	0.1647	0.1781	0.1127
Selenium (Se)	0.0614	0.1280	0.0398
Phenol	0.2412	0.2162	0.0844
Polychlorinated biphenyls (PCB)	>0.2671	0.2014	0.0205
Total Nitrogen	0.1258	0.0927	0.0861
Phosphate	0.0693	0.0483	0.0169

* No significant removal

Table 17. Summary of Suspended Solid (S.S.) and Volatile Suspended Solid (VSS) Removal, Continuous Flow Study, Non-recirculation

Parameter	Plant	Mean	Median	Range	Percent Reduction
Suspended Solid, mg/l	Water hyacinths				
	Influent	105.2	98.5	16.0-257.0	>99.2
	Effluent	<0.8	<0.1	<0.1-3.0	
	Bulrush				
	Influent	110.7	79.0	15.0-342.0	94.2
	Effluent	6.4	5.5	<0.1-15.0	
	Control(no plants)				
	Influent	64.1	58.0	12.0-144.0	80.9
	Effluent	12.2	9.0	3.0-30.0	
Volatile Suspended Solid, mg/l	Water hyacinths				
	Influent	68.0	60.0	15.0-136.0	>98.8
	Effluent	<0.8	<0.1	<0.1-3.0	
	Bulrush				
	Influent	74.4	54.0	15.0-202.0	90.7
	Effluent	6.9	7.0	<0.1-13.0	
	Control(no plants)				
	Influent	46.1	43.5	12.0-96.0	72.6
	Effluent	12.6	10.5	3.0-30.0	

Villamil, et al., (90) also observed 90% removal of total suspended solids from a concentration of 43.3 mg/l to 0.5 mg/l by using water hyacinths for the clarification of wastewaters and the production of energy in Puerto Rico. Pope, et al., observed 53% removal of total suspended solid (TSS) and 60% volatile suspended solid (VSS) removal by using bulrush for tertiary wastewater treatment. The observed effluent concentrations of TSS and VSS were 6-18 and 4-11 mg/l, respectively (92).

Uptake of Trace Contaminants by Vascular Aquatic Plants during Continuous Flow-Nonrecirculation Run.

Table 18 shows trace contaminant concentration in plant tissue (μg/gm dry plant tissue). Accumulation of arsenic, boron, cadmium, mercury, selenium, phenol, polychlorinated biphenyls, total nitrogen and phosphate in root, stem, and leaves of both water hyacinth and bulrush during the 58 days of study are shown. Accumulation of these trace contaminants by both plants significantly increased with time. The water hyacinth system showed an accumulation of nutrients (nitrogen and phosphate), phenol and polychlorinated biphenyls (in terms of μg/gm dry plant) higher than bulrush. The bulrush system accumulated arsenic, cadmium, and mercury greater than the water hyacinth system. Both plants showed about the same accumulation of boron and selenium.

Cadmium was concentrated in the root tissue by water hyacinth with very little translocation experienced, compared to bulrush. The other metals and trace organics were significantly translocated to the stem and leaves. Wolverton and McDonald (93) also stated that cadmium concentrated in the roots of water hyacinth at much higher levels than in other parts. Mercury concentration in the root of bulrush at 58 days was observed to be lower than the concentration at 30 days. This occured probably because of analytical error. Wolverton and McDonald (93) also

Table 18. Trace Contaminant Concentration in Plant Tissue (µg/gm dry plant tissue), Continuous Flow Study, Non-recirculation Run

Parameter	Roots			Stems			Leaves		
	0 Days	30 Days	58 Days	0 Days	30 Days	58 Days	0 Days	30 Days	58 Days
Water hyacinths									
Arsenic	32.6	465.3	531.3	29.0	122.1	130.2	33.0	117.7	136.5
Boron	356.6	246.8	240.5	200.0	340.8	220.0	320.0	168.0	409.2
Cadmium	2.0	768.9	1,352.4	0.4	91.3	189.2	0.8	16.5	35.7
Mercury	1,120.0	4,754.8	12,236.7	768.8	4,508.0	7,740.4	240.0	4,472.8	5,079.9
Selenium	36.6	385.0	1,463.7	24.0	236.1	300.3	30.6	237.2	317.1
Phenol	12.7	26.7	60.9	12.3	26.1	57.7	9.5	21.6	44.0
Polychlorinated biphenyls	0.0	11.87	90.43	0.00	20.93	27.19	0.00	5.09	62.64
Total Nitrogen	15,596.0	2,908.0	21,798.0	16,688.0	27,020.0	34,916.0	16,968.0	16,422.00	22,078.0
Phosphate	6,240.0	5,624.0	10,320.0	4,384.0	4,120.0	8,976.0	4,512.0	5,240.0	8,744.0
Bulrush									
Arsenic	33.0	226.6	617.4	34.6	125.4	222.6	33.2	121.0	149.1
Boron	222.8	226.8	360.8	113.6	220.0	306.4	294.0	257.6	368.4
Cadmium	2.0	457.6	1,096.2	0.4	192.3	415.8	0.4	212.3	256.2
Mercury	231.2	4,319.7	1,965.6	724.0	3,403.4	1,610.7	884.0	2,710.4	1,644.3
Selenium	31.0	326.7	1,143.8	31.4	262.5	396.9	27.1	273.9	382.9
Phenol	5.9	6.9	9.7	2.9	3.8	7.9	2.6	3.4	7.0
Polychlorinated biphenyls	1.06	9.49	19.57	1.06	3.67	16.32	0.00	5.52	14.80
Total Nitrogen	6,412.0	13,622.0	19,446.0	3,668.0	19,880.0	15,246.0	8,372.0	14,490.0	19,250.0
Phosphate	672.0	4,016.0	7,208.0	1,200.0	5,424.0	6,464.0	2,192.0	3,880.0	6,456.0

noted the same problem. They indicated that results of mercury data from their study were extremely erratic because mercury is higher volatile surmising that much of this metal was lost during the digestion process. However, data of mercury concentration in the stem and leaves of bulrush in this continuous flow study showed a significant increase in concentration as a function of time.

Due to the vast number of parameters evaluated, plant uptake kinetics could not be aquately evaluated due to the small number of samples taken. However, preliminary analysis indicates that data appears to fit the first order exponential kinetic model which was followed during the batch screening study.

Productivity of Vascular Aquatic Plants during Continuous Flow-Nonrecirculation Run.

Total wet weight and dry weights of both water hyacinth and bulrush at the beginning and the end of the experiment during continuous flow nonrecirculation study are shown in Table 19. Results indicated a very high productivity increase of water hyacinth (118.8% wet and 122.9% dry weight increase). A comparison between the batch screening and the continuous flow study results show a great increase in productivity. Because run time of the continuous flow was 58 days, the water hyacinth system had more time for acclimitization to wastewater conditions with subsequent acclimation and growth yield.

Bulrush exhibited a 14.4% and 26.5% total wet and dry weight increase, respectively. It exhibited almost the same percent increase in productivity as during the batch screening study.

Table 19. Productivity of Vascular Aquatic Plants (gm), Continuous Flow Study, Non-recirculation, (58 Day Run)

Plant Species	Total Wet Weight		Percent Wet Weight Increase (%)	Total Dry Weight		Percent Dry Weight Increase (%)
	0 Day	58 Days*		0 Day	58 Days*	
Water hyacinths	18,865.5	41,285.5	118.84	1,111.2	2,476.8	122.89
Bulrush	28,797.2	32,932.5	14.36	5,140.3	6,503.2	26.51

* Includes weight of plant tissue removed during sampling

Fecal Coliforms, Water Temperature, Dissolved Oxygen Concentration (D.O.), Oxidation Reduction Potential (ORP), Evapotranspiration, Solar Radiation, pH and Flow Rates during Continuous Flow-Nonrecirculation Run.

The number of fecal coliforms in water of each test basin is shown in Table 20. The water hyacinth and bulrush systems exhibited very high percent fecal coliform reduction which were slightly higher than the control (no plants). Fecal coliforms in the effluent of hyacinth and bulrush systems were in the range of 0-2,300 and 0-8,750 fecal coliforms/100 ml, respectively (99 and 95% reduction). Dinges (88) observed 98% reduction of fecal coliforms with the effluent concentration of the range 3-1,400 fecal coliforms/100 ml from hyacinth system. Seidel (91) also indicated that the number of E. coli, total coliform, Salmonella and enterococci were reduced significantly in using bulrush and other higher plants for wastewater treatment.

Water temperature, D.O., ORP, evapotranspiration, and solar radiation data are summarized in Table 21. Temperature, D.O., and ORP data are similar as experienced during the batch screening study. Since plants grew very well during the nonrecirculation - continuous flow run, both water hyacinth and bulrush exhibited high evapotranspiration, compared to the control (no plants). For this phase of study, solar radiation averaged 1.021 and with a range of 0.624-1.389 cal/cm^2/min which was sufficient for optimal plant growth.

Water pH (influent, pond, and effluent) data is summarized in Table 22 and flow rates are summarized in Table 23. Both the water hyacinth and bulrush systems maintained nearly constant pH in the range of 7-9.

Table 20. Summary of Fecal Coliform (Fecal coliforms/100 ml) Continuous Flow Study, Nonrecirculation Run

Plant		Geometric Mean	Median	Range	Percent Reduction
Water hyacinths					
	Influent	10,965	41,900	600-103,200	99.5
	Effluent	56	250	0-2,300	
Bulrush					
	Influent	13,868	38,574	500-97,600	95.3
	Effluent	652	1,050	0-8,750	
Control (no plants)					
	Influent	9,795	24,240	450-96,700	94.5
	Effluent	541	1,175	0-3,750	

Table 21. Summary of Water Temperature, Dissolved Oxygen Concentration (D.O.), Oxidation Reduction Potential (ORP), Evapotranspiration, and Solar Radiation Data, Continuous Flow Study, Non-recirculation

Parameter	Plant	Mean	Median	Range
Temperature. °C	Water hyacinths	24.9	25.0	22.7-30.8
	Bulrush	23.8	23.3	20.5-29.3
	Control*	28.0	28.0	23.6-33.9
Dissolved Oxygen, mg/l	Water hyacinths	2.0	2.1	1.4-2.5
	Bulrush	1.1	1.1	0.2-2.6
	Control	2.0	1.6	0.9-9.4
ORP	Water hyacinths	177	177	170-183
	Bulrush	169	170	144-184
	Control	168	171	122-186
Evapotranspiration, mm/day	Water hyacinths	11.1	10.5	7.5-18.5
	Bulrush	18.9	18.3	8.0-25.0
	Control	4.1	4.0	2.2-10.0
Solar Radiation, cal/cm^2/min	All plants	1.021	0.993	0.624-1.389

* Control - No plants and water loss due to evaporation only

Table 22. Summary of pH Data, Continuous Flow Study, Non-recirculation

Plant	Parameter	Median	Range
Water hyacinths	Influent pH	8.3	7.1-9.2
	Pond pH	7.1	6.8-7.7
	Effluent pH	7.4	7.0-7.6
Bulrush	Influent pH	8.4	7.2-9.2
	Pond pH	7.2	7.0-7.6
	Effluent pH	7.6	7.2-7.7
Control (no plants)	Influent pH	8.4	7.3-9.3
	Pond pH	8.1	7.5-9.5
	Effluent pH	8.7	8.3-9.3

Table 23. Summary of Flow Rate (ml/min) Data, Continuous Flow Study, Non-recirculation

Plant		Mean	Median	Range
Water hyacinths				
	Influent	41.2	41.0	40.6-43.0
	Effluent	41.0	41.0	40.7-41.3
Bulrush				
	Influent	41.1	41.1	40.7-42.8
	Effluent	41.0	41.0	40.8-41.8
Control (no plants)				
	Influent	4.2	4.2	4.1-4.3
	Effluent	4.2	4.2	4.1-4.2

Results of Continuous Flow Study, 1:1 Recirculation Run (7.5 day Retention).

Results of overall trace contaminant removal of vascular aquatic plants during the continuous flow; 1:1 recirculation study, are shown in Table 24. As indicated, both the water hyacinth and bulrush systems exhibited very high removal efficiencies for most parameters evaluated. Comparison of results between the continuous flow-nonrecirculation (15 day tetention) and 1:1 recirculation runs indicate similar percent trace contaminant removal. The water hyacinth system exhibited slightly lower removal efficiencies in the recirculation run than in the nonrecirculation run and the bulrush system showed slightly higher removal efficiency in the recirculation than the nonrecirculation system. Since removal efficiency of both runs indicated similar results, it can be concluded that recirculation enhanced pollutant removals (7.5 days vs. 15 days retention).

A study of the effects of velocity or flow rate on cadmium absorption by water hyacinth was investigated at the Tulane University Riverside Research Laboratiry during the same time as the continuous flow study phase of this research by a group of Tulane University chemical engineering students (94). They concluded that influent flow rates affected cadmium absorption by the water hyacinth. As the velocity increased the uptake of cadmium increased proportionally. From their study employing different flow rates, 15, 30, and 60 ml/min, the highest plant concentration of cadmium occurred at the fastest influent flow rate (60 ml/min). Therefore, velocity of flows at about 40 and 80 ml/min. were used in design of the nonrecirculation (15 day retention) and recirculation (7.5 day retention) continuous flow employed in this study.

Table 24. Trace Contaminant Removal by Vascular Aquatic Plants, Continuous Flow Study, 1:1 Recireculation, 39 Day Run (7.5 Day Retention)

Plant	Parameter	Influent Concentration, mg/l			Effluent Concentration, mg/l			Percent Removal(%)
		Mean	Median	Range	Mean	Median	Range	
Water hyacinths	BOD_5	66.2	70.1	42.2-90.8	3.2	2.2	0.4-7.3	95.2
	TOC	21.4	19.7	18.8-26.2	6.5	6.2	5.6-7.8	69.6
	Arsenic (As)	1.091	1.094	0.990-1.188	0.523	0.506	0.473-0.643	52.1
	Boron (B)	1.057	1.073	0.807-1.299	0.938	0.926	0.475-1.499	11.3
	Cadmium (Cd)	1.387	1.408	1.182-1.529	0.543	0.583	0.368-0.594	60.8
	Mercury (Hg)	1.838	1.911	1.511-2.133	0.061	0.056	0.038-0.118	96.7
	Selenium (Se)	1.673	1.650	1.573-1.925	0.827	0.858	0.682-0.995	50.6
	Phenol	1.077	1.031	0.875-1.475	0.118	0.087	0.069-0.250	89.0
	Polychlorinated Biphenyls (PCB)	0.029	0.035	0.014-0.037	0.000	0.000	0.000-0.000	100.0
	Total Nitrogen	37.30	37.46	18.16-53.36	5.96	5.84	4.24-7.39	84.0
	Phosphate	5.42	5.59	3.04-6.59	4.41	3.96	2.20-7.95	18.6
Bulrush	BOD_5	67.6	71.7	42.2-92.4	3.2	2.4	0.4-7.1	95.3
	TOC	22.2	21.5	19.1-26.8	7.1	7.0	5.5-9.1	68.0
	Arsenic (As)	1.101	1.105	1.001-1.166	0.407	0.407	0.374-0.445	63.0
	Boron (B)	1.120	1.124	0.893-1.351	0.702	0.684	0.400-0.942	37.3
	Cadmium (Cd)	1.349	1.364	1.111-1.507	0.130	0.090	0.033-0.297	90.4
	Mercury (Hg)	1.847	1.943	1.350-2.133	0.041	0.036	0.031-0.060	97.8
	Selenium (Se)	1.673	1.644	1.567-1.925	0.159	0.129	0.055-0.352	90.5

Table 24. (continued)

Plant	Parameter	Influent Concentration, mg/l			Effluent Concentration, mg/l			Percent Removal (%)
		Mean	Median	Range	Mean	Median	Range	
Bulrush (cont.)	Phenol	1.067	0.990	0.837-1.687	0.151	0.128	0.081-0.275	85.8
	Polychlorinated biphenyls (PCB)	0.039	0.038	0.033-0.045	0.000	0.000	0.000-0.000	100.0
	Total Nitrogen	37.25	37.01	19.69-51.88	4.67	2.34	1.12-13.55	87.5
	Phosphate	5.16	4.91	3.92-6.67	4.28	3.54	1.87-8.00	17.0
Control (no plants)	BOD_5	62.8	66.9	34.2-90.6	11.9	10.3	8.1-21.5	81.0
	TOC	18.8	18.8	14.0-25.6	9.7	9.0	7.4-12.5	48.4
	Arsenic (As)	1.042	1.061	0.979-1.089	0.808	0.836	0.616-1.023	22.5
	Boron (B)	1.057	1.000	0.817-1.458	1.176	1.168	0.787-1.624	Inc.*
	Cadmium (Cd)	1.202	1.243	0.940-1.402	0.728	0.748	0.638-0.814	39.4
	Mercury (Hg)	1.505	1.552	1.233-1.634	0.109	0.118	0.083-0.126	92.8
	Selenium (Se)	1.666	1.644	1.562-1.892	1.320	1.336	1.116-1.503	20.8
	Phenol	0.963	0.947	0.687-1.412	0.221	0.215	0.087-0.406	77.0
	Polychlorinated biphenyls (PCB)	0.023	0.021	0.010-0.037	0.000	0.000	0.000-0.000	100.0
	Total Nitrogen	34.90	35.10	17.82-46.07	8.23	8.26	5.84-10.32	76.4
	Phosphate	4.59	4.50	3.04-6.12	5.76	5.52	2.69-9.61	Inc.*

* Inc. = Increase

Trace Contaminant Removal Rate Coefficients during Continuous Flow Study, 1:1 Recirculation Run.

Kinetic removal rate coefficients for this run were also estimated in the same manner as for the continuous flow-nonrecirculation study and as illustrated in Table 25. Since trace contaminant percent removals from nonrecirculation and recirculation runs are similar, most of removal rate coefficients of the recirculation run are greater than the nonrecirculation because of difference in retention time (nonrecirculation detention time was approximately twice as great).

Suspended Solid (SS) and Volatile Suspended Solid (VSS) Removal during Continuous Flow, 1:1 Recirculation Run.

Table 26 shows removal efficiency of suspended solid and volatile suspended solid. Both water hyacinth and bulrush systems exhibited very high removal efficiency surpassing that obtained during the nonrecirculation run. The water hyacinth system removed 97.8% SS and 96.7% VSS with an effluent concentration of 1.6 mg/l for both SS and VSS. The bulrush system exhibited 98.5% and 97.7% for SS and VSS removal with an effluent concentration of 1.1 mg/l for both SS and VSS.

Uptake of Trace Contaminants by Vascular Aquatic Plants During Continuous Flow, 1:1 Recirculation Run.

Table 27 illustrates trace contaminant concentration in plant tissue (μg/gm dry plant tissue). Accumulation of trace contaminants in roots, stem, and leaves of both water hyacinth and bulrush during the 39 days of study are presented. Accumulation of the trace contaminants by both plants significantly increased with time following the same pattern as for the nonrecirculation run. Although the concentration of trace contaminants within the plant tissue increased as a function of time accumulation in plant tissue was less than for the nonrecirculation run.

Table 25. Trace Contaminant Kinetic Removal Rate Coefficient (K), Continuous Flow Study, 1:1 Recirculation Run, 7.5 Day Retention

Contaminant	Removal Rate Constant (K), per day		
	Water hyacinths	Bulrush	Control (no plants)
BOD_5	0.4039	0.4067	0.2218
TOC	0.1589	0.1520	0.0882
Arsenic (As)	0.0980	0.1327	0.0339
Boron (B)	0.0159	0.0623	**
Cadmium (Cd)	0.1250	0.3119	0.0668
Mercury (Hg)	0.4541	0.5077	0.3500
Selenium (Se)	0.0939	0.3138	0.0310
Phenol	0.2948	0.2607	0.1962
Polychlorinated* biphenyls (PCB)	>0.4490	>0.4885	>0.4181
Total Nitrogen	0.2445	0.2777	0.1926
Phosphate	0.0275	0.0249	**

* Use concentration of 0.001 mg/l as minimum detection limit for calculation

** No significant removal

Table 26. Summary of Suspended Solid (S.S.) and Volatile Suspended Solid (VSS) Removal, Continuous Flow Study, 1:1 Recirculation Run

Parameter	Plant		Mean	Median	Range	Percent Reduction
Suspended Solid, mg/l	Water hyacinths					
		Influent	73.2	76.0	35.0-107.0	97.8
		Effluent	1.6	1.0	0.0-7.0	
	Bulrush					
		Influent	73.4	82.5	26.0-104.0	98.5
		Effluent	1.1	0.0	0.0-4.0	
	Control(no plants)					
		Influent	58.1	65.0	19.0-89.0	88.8
		Effluent	6.5	6.0	3.0-14.0	
Volatile Suspended Solid, mg/l	Water hyacinths					
		Influent	48.2	49.5	21.0-75.0	96.7
		Effluent	1.6	1.0	0.0-7.0	
	Bulrush					
		Influent	49.0	55.5	17.0-73.0	97.7
		Effluent	1.1	0.0	0.0-4.0	
	Control(no plants)					
		Influent	39.6	44.0	6.0-64.0	85.9
		Effluent	5.6	4.0	2.0-14.0	

Table 27. Trace Contaminant Concentration in Plant Tissue (µg/gm dry plant tissue), Continuous Flow Study, 1:1 Recirculation Run

Parameter	Roots			Stems			Leaves		
	0 Days	15 Days	39 Days	0 Days	15 Days	39 Days	0 Days	15 Days	39 Days
Water hyacinths									
Arsenic	17.8	95.3	239.4	12.6	75.9	77.0	14.0	59.4	66.0
Boron	328.2	260.7	263.3	210.3	240.2	213.6	320.4	330.4	340.5
Cadmium	0.4	326.7	1,138.3	0.4	24.2	70.4	0.4	6.6	11.0
Mercury	384.0	1,631.3	3,078.6	528.8	787.6	495.0	460.0	782.1	453.2
Selenium	32.2	255.2	585.9	32.2	266.2	271.7	28.4	253.0	281.6
Phenol	14.9	23.6	38.2	12.9	19.4	33.2	10.7	12.9	28.4
Polychlorinated biphenyls	0.00	29.99	48.52	0.00	0.00	15.27	0.00	0.00	7.84
Total Nitrogen	13,720.0	13,524.0	20,608.0	13,160.0	20,930.0	23,508.0	13,776.0	19,824.0	22,694.0
Phosphate	4,224.0	8,613.0	10,936.0	7,056.0	7,072.0	10,000.0	7,712.0	9,336.0	9,480.0
Bulrush									
Arsenic	23.4	73.7	169.4	13.6	72.6	73.7	12.7	75.9	85.8
Boron	218.9	221.4	343.9	192.6	240.7	298.8	286.6	245.2	350.1
Cadmium	1.2	102.3	451.0	0.4	34.1	121.0	0.4	57.0	137.5
Mercury	897.6	608.3	711.7	1,206.4	577.2	425.7	1,177.6	607.2	595.1
Selenium	31.6	271.7	279.4	28.2	258.5	291.5	28.4	270.6	284.9
Phenol	6.3	7.2	8.3	4.1	5.5	6.9	2.9	3.6	5.7
Polychlorinated biphenyls	0.00	9.63	16.43	4.07	0.00	17.33	0.00	10.15	12.41
Total Nitrogen	8,624.0	9,772.0	13,398.0	11,200.0	11,928.0	10,360.0	12,040.0	9,254.0	16,016.0
Phosphate	2,304.0	7,792.0	9,136.0	6,368.0	6,480.0	6,200.0	3,760.0	3,988.0	4,984.0

As with the nonrecirculation run, due to the small number of plant samples, plant uptake kinetics could not be evaluated. However, preliminary analysis indicates that data appeared to follow the first order exponential kinetic model described by the batch screening study data.

Productivity of Vascular Aquatic Plants during Continuous Flow, 1:1 Recirculation Run.

Total wet weight and dry weight of both water hyacinth and bulrush at the beginning and the end of experiment during the recirculation run are shown in Table 28. Results indicated a high productivity increase of both water hyacinth and bulrush. (70.19% wet and 46.53% dry weight increase for water hyacinth, with 12.82% wet and 11.00% dry weight increase for bulrush). A comparison between the nonrecirculation and recirculation runs indicates both plant productivities in the recirculation run were less than in the nonrecirculation primarily because of difference in time of exposure.

Fecal Coliforms, Water Temperature, Dissolved Oxygen Concentration (D.O.), Oxidation Reduction Potential (ORP), Evapotranspiration, Solar Radiation, pH and Flow Rates during Continuous Flow, 1:1 Recirculation Run.

Table 29 shows fecal coliforms in the influent and effluent from the continuous flow - 1:1 recirculation run. Both water hyacinth and bulrush systems indicated very high percent removals (99.9%). The number of fecal coliforms in the effluent were in the range of 0-6,250 and 0-350 fecal coliforms/100 ml for water hyacinth and bulrush systems, respectively. Bulrush exhibited better fecal coliform reduction, compared to the bulrush system during the nonrecirculation run. (99.9% VS. 95.3%).

Temperature, D.O., ORP, evapotranspiration and solar radiation are summarized in Table 30. Dissolved oxygen concentration in this run for

Table 28. Productivity of Vascular Aquatic Plants (gm), Continuous Flow Study, 1:1 Recirculation (39 Day Run)

Plant Species	Total Wet Weight		Percent Wet Weight Increase (%)	Total Dry Weight		Percent Dry Weight Increase (%)
	0 Day	39 Days*		0 Day	39 Days*	
Water hyacinths	20,861.0	35,503.9	70.19	1,483.2	2,173.3	46.53
Bulrush	49,567.5	55,923.7	12.82	7,221.9	8,016.3	11.00

* Includes weight of palnt tissue removed during sampling

Table 29. Summary of Fecal Coliform (Fecal coliforms/100 ml) Continuous Flow Study, 1:1 Recirculation Run

Plant		Geometric Mean	Median	Range	Percent Reduction
Water hyacinths					
	Influent	16,673	7,675	2,550-150,000	99.9
	Effluent	19	22	0-6,250	
Bulrush					
	Influent	16,983	8,775	3,000-162,000	99.9
	Effluent	12	25	0-350	
Control (no plants)					
	Influent	13,932	7,000	2,400-144,000	98.3
	Effluent	233	415	0-4,900	

Table 30. Summary of Water Temperature, Dissolved Oxygen Concentration (D.O.), Oxidation Reduction Potential (ORP), Evapotranspiration, and Solar Radiation Data, Continuous Flow Study, 1:1 Recirculation Run

Parameter	Plant	Mean	Median	Range
Temperature, °C	Water hyacinths	23.1	22.8	21.0-25.2
	Bulrush	22.4	22.0	20.8-25.0
	Control*	24.7	24.8	22.8-27.2
Dissolved Oxygen, mg/l	Water hyacinths	3.8	3.8	3.0-4.3
	Bulrush	3.8	3.7	3.0-4.7
	Control	1.5	1.5	1.1-2.4
ORP	Water hyacinths	197	198	175-212
	Bulrush	199	197	182-213
	Control	186	186	167-205
Evapotranspiration, mm/day	Water hyacinths	28.0	28.5	20.0-35.0
	Bulrush**	9.3	9.0	8.0-11.0
	Control	3.5	3.4	2.2-5.5
Solar Radiation, cal/cm^2/min	All plants	0.938	0.986	0.275-1.188

* Control = no plants and water loss due to evaporation only

** Measured from 1 of 2 test chambers

both water hyacinth and bulrush systems were greater than in the nonrecirculation run (average of 3.8 mg/l for both water hyacinth and bulrush systems). Water temperature was maintained in approximately the same range as for the nonrecirculation run.

Both water hyacinth and bulrush showed very high evapotranspiration rates, compared to the nonrecirculation, especially for water hyacinth (average of 28.0 and 9.3 mm/day for water hyacinth and bulrush, respectively). This occurred probably because of an increase in flow rate and plant absorption rate increase as previously mentioned. Solar radiation exhibited an average intensity of 0.938 with a range of 0.275-1.188 Cal/em^2/min which is sufficnet for optimal plant growth.

Water pH data (influent, pond, and effluent) is summarized in Table 31 and flow rates are summarized in Table 32. The pH for both the water hyacinth and bulrush systems ranged from 7-9 similar to that of the nonrecirculation continuous flow study.

Table 31. Summary of pH Data, Continuous Flow Study, 1:1 Recirculation Run

Plant		Median	Range
Water hyacinths			
	Influent	8.4	7.5-9.1
	Pond	7.1	6.7-7.7
	Effluent	7.0	6.9-7.7
Bulrush			
	Influent	8.4	7.6-8.9
	Pond	7.3	7.0-7.9
	Effluent	7.3	7.2-7.8
Control (no plants)			
	Influent	8.6	7.7-9.8
	Pond	7.6	7.2-7.8
	Effluent	8.0	7.9-8.3

Table 32. Summary of Flow Rate (ml/min) Data, Continuous Flow Study, 1:1 Recirculation Run

Plant		Mean	Median	Range
Water hyacinths				
	Influent*	41.1	41.0	40.8-42.0
	Effluent	81.9	82.0	80.5-82.3
Bulrush				
	Influent*	41.4	41.2	40.9-43.0
	Effluent	82.0	82.0	81.9-82.2
Control (no plants)				
	Influent*	4.2	4.2	4.2-4.3
	Effluent	8.4	8.4	8.3-8.6

* Does not include recirculation flow

CHAPTER V

CONCLUSIONS, RECOMMENDATIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Vascular aquatic plants in the natural environment exhibited very high concentration accumulation factors ($\frac{\mu g/gm\ dry\ plant}{\mu g/ml\ water}$ or $\frac{\mu g/gm\ dry\ plant}{\mu g/gm\ dry\ soil}$) for most contaminants evaluated. This is of particular significance since some trace contaminants i.e., selenium, phenol, boron, are perhaps the most difficult to remove from wastewater by secondary and advanced treatment techniques. Another important finding was that the efficiency of trace contaminant removal is plant specific. For examples, duckweed exhibited a concentration for boron of over 7,000 accumulation factor compared to those of bulrush, rush, arrowhead, water hyacinth, coontail and alligatorweed of approximately 600 to 800 (dry weight basis).

Vascular aquatic plants also exhibited high percent trace contaminant removal from secondary effluent during the batch screening study Bulrush was observed to be the most efficient rooted species for removal of most trace contaminants. Water hyacinth and duckweed appeared the most effective floating species for trace contaminant reduction. Results of the submersed plants were mixed with elodea and coontail displaying poor acclimation to the secondary effluent. Alligatorweed adapted well to the wastewater but was only effective in removing nitrogen and polychlorinated biphenyls (PCB).

All rooted plants, bulrush, rush and arrowhead adapted well to the secondary effluent and exhibited an increase in productivity. Floating and submersed plants did not show any significant increase in productivity except for alligator weed (emersed plant).

Kinetic removal of trace contaminants was found to follow either a pseudo first order removal model or a composite exponential model. Uptake of trace contaminants by vascular aquatic plants resulted in an increase of contaminant concentration in plant tissue as a function of time. All plant uptake data followed a one compartment mathematical model except for arsenic uptake by coontail which best fit a two compartment model.

Very high percent reductions of fecal coliforms were found for all plants during the batch screening study (89-100%) following a two week contact period.

Results of the continuous flow study indicated that recirculation enhanced pollutant removal efficiency. It was observed that trace contaminant removal rate coefficients obtained from the recirculation run were greater than from the nonrecirculation experiment (approximately twice as great). Both water hyacinth and bulrush systems were excellent in reducing organics (BOD and TOC) and solids to levels expected from a physical-chemical tertiary treatment system. Nitrogen removals were also very effective as was heavy metals removal. Water hyacinths were more efficient for the removal of nitrogen than bulrush; whereas, bulrush was much more effective in the removal of trace contaminants (cadmium, mercury, selenium, phenol and polychlorinated biphenyls).

Overall results indicated vascular aquatic plants can effectively reduce the organic, nitrogen and trace contaminant content of secondary effluent to very low levels with essentially no energy requirements except solar radiation. Residue levels in many cases are less than those achievable from most tertiary physical-chemical treatment processes, particularly for organics, solids, and nitrogen. Removals of heavy metals and trace organics (except for arsenic and boron) obtained generally was greater than 80-90% with most $>$ 90%. With optimization of the vascular aquatic plant-lagoon system, even better results can be expected. The system proposed is of simple technology, cost effective with essentially minimal energy requirements. Consequently future consideration should be given to this system as a tertiary wastewater treatment alternative.

Results obtained from this study based on plant growing under temperatures of 20 ± 5°C and other environmental conditions. Temperature constraint for each plant may limit application. For example, optimum temperature for water hyacinth growth is 5 - 35°C. For future performance another temperature condition should be evaluated.

RECOMMENDATIONS AND SUGGESTED RESEARCH

Based on the results of the research reported herein the following recommendations for follow-up research are made.

1. Toxicity of specific trace contaminants to specific aquatic plants should be evaluated and threshold limits determined.

2. Longer periods of plant exposure to trace contaminants should be conducted to establish the time at which plants become saturated with specific trace contaminants resulting in uptake cessation. Such information will provide useful data for system design and harvesting schedules.

3. The effect of influent turbidity on plant yield and contaminant uptake should be evaluated especially for submersed and rooted species.

4. Addition detention times should be employed for continuous flow of both nonrecirculation and recirculation conditions. This will allow for a more accurate assessment of the kinetic removal coefficient for contaminants of concern.

5. Additional vascular aquatic plants and the uptake of other trace contaminants should be investigated.

6. Pilot scale testing should be implemented so that full scale design criteria can be developed. Optimal detention time, pond configuration, velocity of flow, etc. should be evaluated.

7. The reuse potential of generated effluent and harvested crop should be investigated.

8. Efficiency performance and cost analysis should be studied in greater detail based on pilot testing and compared to other advanced wastewater treatment systems.

9. Application of using aquatic plants for other purposes, such as for sludge treatment and stabilization should be investigated.

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APPENDICES

APPENDIX A

Plant Acclimatization

Plant Acclimatization

After field collection, aquatic plants were washed with tap water and stocked in glass aquarium which were filled with hydroponic solution for acclimatization. The plants were grown in the greenhouse located at the Tulane Hebert Center Riverside Research Laboratory under constant temperature conditions of 25°C ± 5°C. The hydroponics (nutrient water or solution culture) consists of essential mineral nutrients required for healthy plant growth. Acclimatized in the hydroponic solution was effected at least 2 weeks prior to commencing the experiment.

The hydroponic solution employed is composed of 2 portions, Stock Concentrate #1 and Stock Concentrate #2. Preparation of each is shown in Table A-1 (95). Stock Concentrates #1 and #2 were diluted with tap water in the ratio of 1:200. For example, 100 ml of Stock #1 and 100 ml of Stock #2 would be used to make 20 liters of nutrient water.

Table A-1. Hydroponic Solution Preparation

Stock Concentrate #1

Chemical	Amount/liter
Potassium Nitrate (KNO_3)	50.5 gm.
Potassium Phosphate (KH_2PO_4)	27.2 gm.
Magnesium Sulfate ($MgSO_4.7H_2O$)	49.3 gm.
Sodium Chloride (NaCl)	5.8 gm.
Micronutrient concentrate	100.0 ml.

Micronutrient Concentrate

	gm./liter
Boric Acid (H_3BO_3 85%)	2.85
Manganese Sulfate ($MnSO_4.H_2O$)	1.54
Zinc Sulfate ($ZnSO_4.7H_2O$)	0.22
Copper Sulfate ($CuSO_4.5H_2O$)	0.08
Molybdic Acid ($MoO_3.2H_2O$ 85%)	0.02
Ferric Chloride ($FeCl_3$)	0.15

Stock Concentrate #2

	gm./liter
Calcium Nitrate ($Ca(NO_3)_2.4H_2O$)	118.1
Sequestrene 300 Fe	5.0

Note - make up in proportion 1 part Stock Concentrate #1, 1 part Stock Concentrate #2, to two hundred parts dechlorinated tap water.

APPENDIX B

Standard Curves for Analytical Analysis

Table B-1. Standard Curve Data for Boron (B).

Determination

μg B	% Transmission	Absorbance
0.00	100.0	0.000
0.25	94.1	0.026
0.50	89.6	0.047
0.75	84.5	0.073
1.00	80.6	0.093

Table B-2. Standard Curve Data for Mercury (Hg).

μg Hg	% Transmission	Absorbance
0.00	100.0	0.000
0.10	94.2	0.026
0.30	86.2	0.064
0.50	78.3	0.106
0.70	72.3	0.140
1.00	60.6	0.217
2.00	38.3	0.416
3.00	23.2	0.634

Figure B-1. Boron Standardization Curve

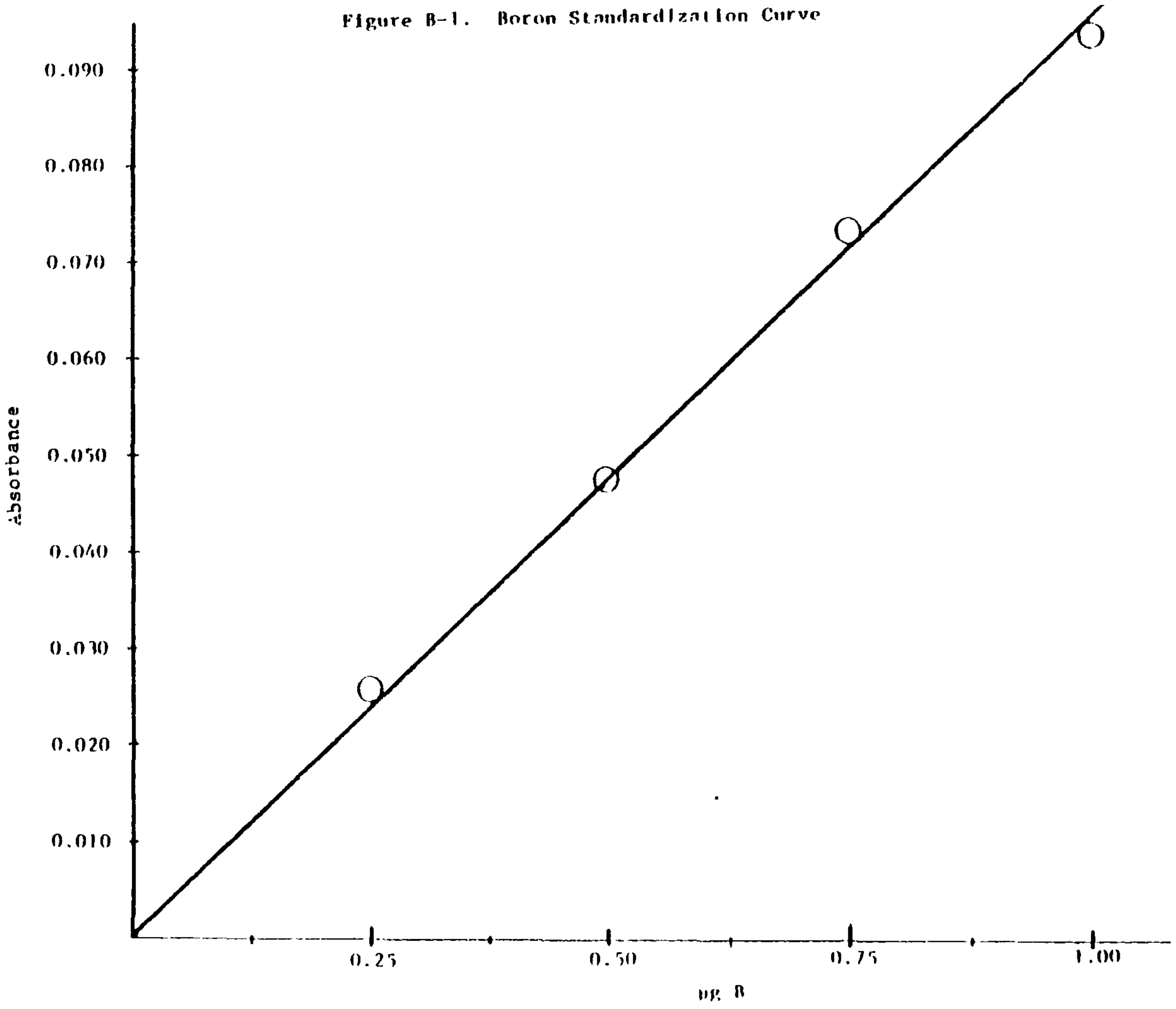


Figure B-2. Mercury Standardization Curve.

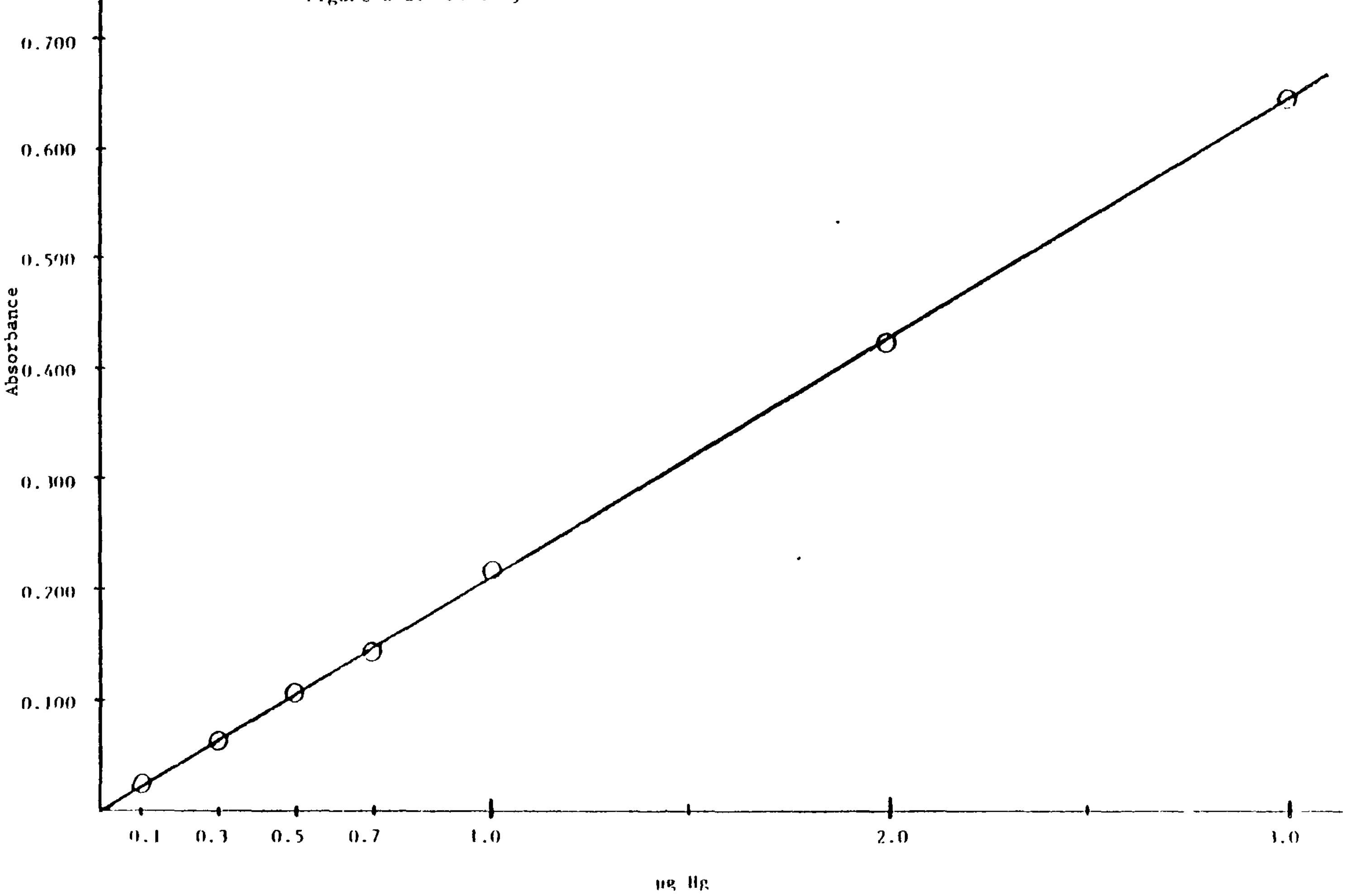


Table B-3. Standard Curve Data for Phenol.

Concentration, mg/1	% Transmission	Absorbance
0.00	100.0	0.000
1.00	71.0	0.149
2.00	51.8	0.286
3.00	37.9	0.421
4.00	27.0	0.569
5.00	20.1	0.697

Table B-4. Standard Curve Data for Nitrate (NO_3).

μg NO_3-N	% Transmission	Absorbance
0.00	100.0	0.000
1.00	91.0	0.041
2.00	84.6	0.073
4.00	73.0	0.137
7.00	50.6	0.296
10.00	38.5	0.414

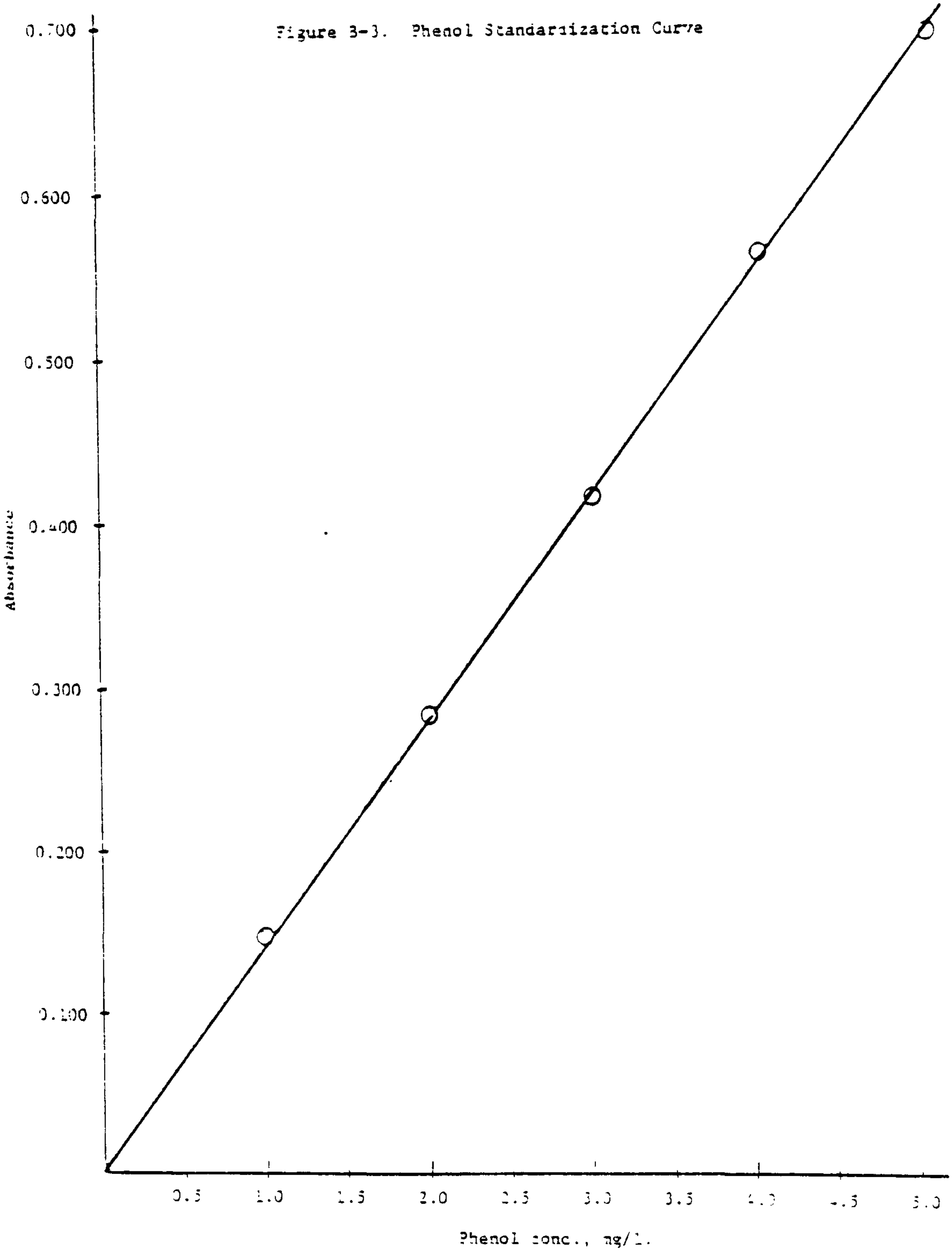


Figure 3-3. Phenol Standardization Curve

Figure B-4. Nitrate Standardization Curve

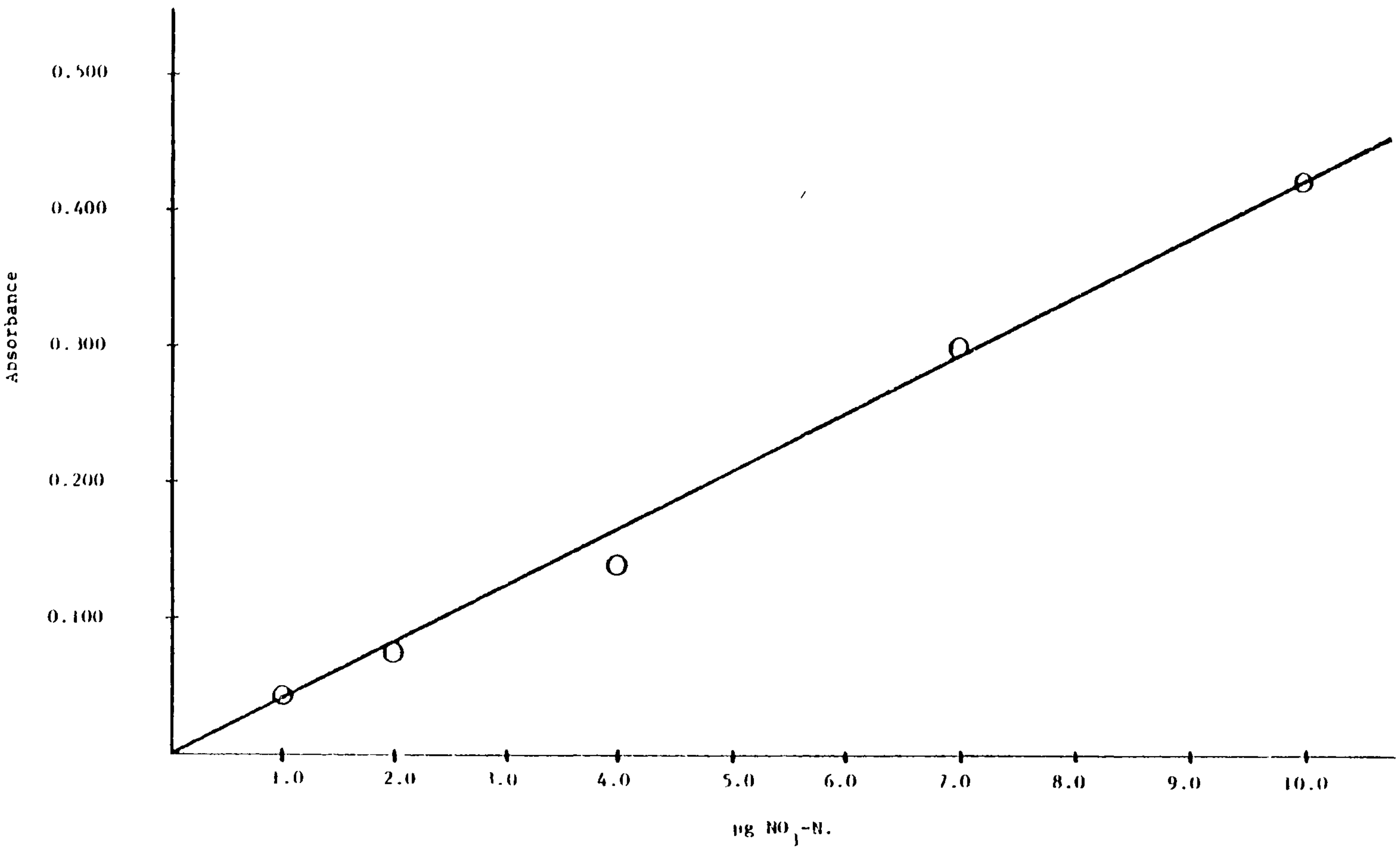


Table B-5. Standard Curve Data for Nitrite (NO_2).

µg NO_2-N	% Transmission	Absorbance
0.00	100.0	0.000
0.50	96.2	0.016
1.00	91.5	0.038
1.50	87.1	0.060
2.00	82.6	0.083
3.00	73.9	0.131
4.00	65.7	0.182
5.00	58.0	0.237
10.00	34.0	0.468

Table B-6. Standard Curve Data for Phosphate ($PO_4^{\equiv}$).

µg $PO_4^{\equiv}$	% Transmission	Absorbance
0.0	100.0	0.000
10.0	85.3	0.069
25.0	72.8	0.138
50.0	57.9	0.237
75.0	45.9	0.338
100.0	36.2	0.441
150.0	26.0	0.585
200.0	14.5	0.839

Figure B-5. Nitrite Standardization Curve

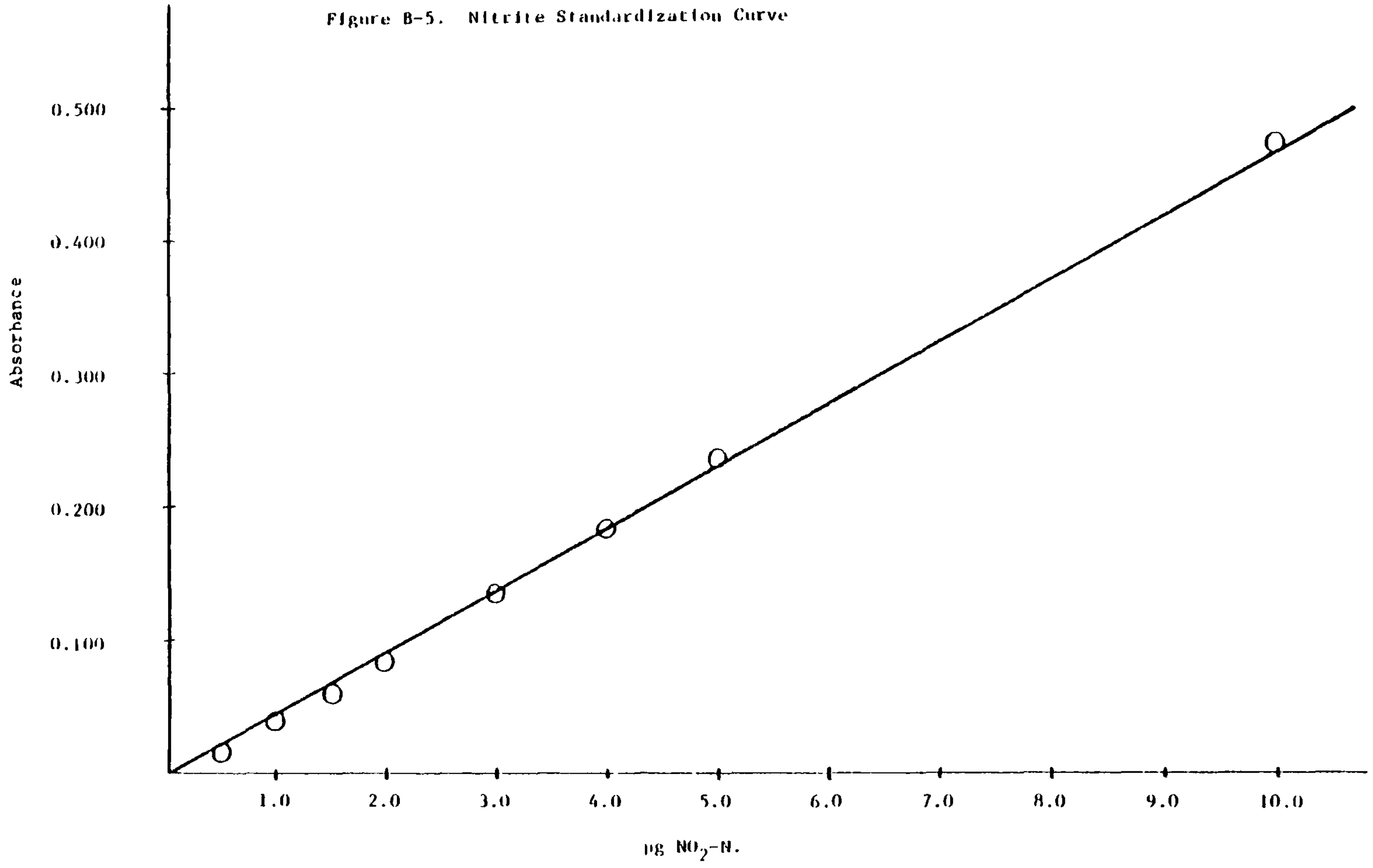
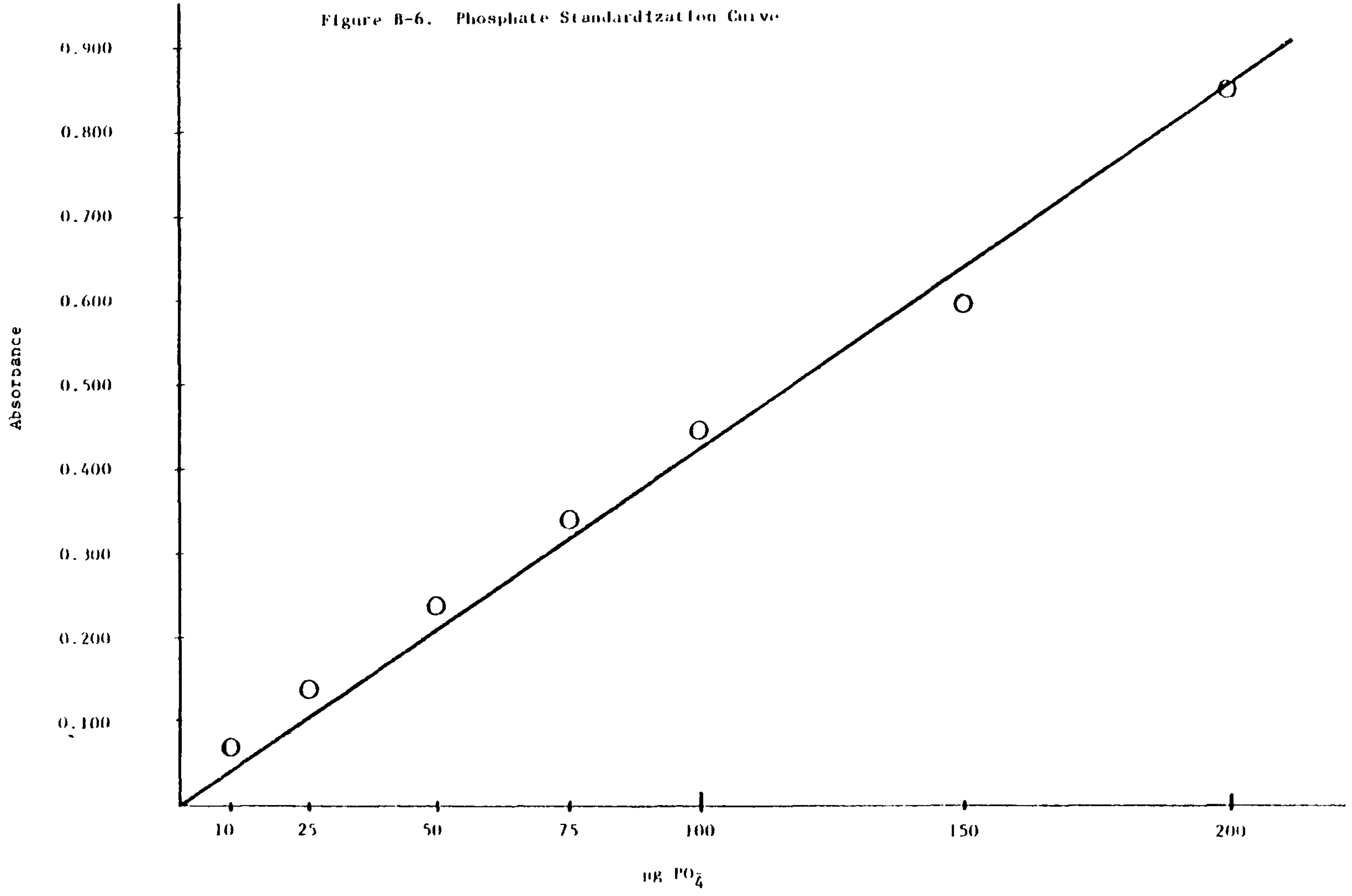


Figure B-6. Phosphate Standardization Curve



APPENDIX C

Field Study Data

Table C-1. Arsenic Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg AS /gm Dry Plant Tissue	Sampling Location	Date Collected	mg As /gm Dry Plant Tissue
Duckweed	Lake Bouef	9-20-78	0.0820	N.O. East	9-24-78	0.0604
Coontail	Lake Bouef	9-20-78	0.0069	N.O. East	9-24-78	0.0524
Elodea	Lake Bouef	9-20-78	0.0648	-	-	-
Water-bonnet (Pistia Spp.)	Lake Bouef	9-20-78	0.0629	-	-	-
Water Hyacinth	Lake Bouef	9-20-78	0.0696	N.O. East	9-24-78	0.0619
Arrowhead (Sagittaria Spp.)	Riverside	10-3-78	0.0736	N.O. East	9-24-78	0.0528
Alligator-weed	Riverside	9-25-78	0.0688	N.O. East	9-24-78	0.0600
Rush (Juncus Spp.)	Belle Chasse	9-25-78	0.0675	N.O. East	9-22-78	0.0524
Bulrush (Scirpus Spp.)	-	-	-	N.O. East	9-24-78	0.0611

Table C-2. Boron Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg B/gm Dry Plant Tissue	Sampling Location	Date Collected	mg B/gm Dry Plant Tissue
Duckweed	Lake Bouef	10-27-78	0.8450	N.O. East	9-22-78	1.5709
Coontail	Lake Bouef	10-9-78	0.2400	N.O. East	9-22-78	<0.0001
Elodea	Lake Bouef	10-9-78	0.4050	-	-	-
Water-bonnet (Pistia spp.)	Lake Bouef	10-9-78	0.3975	-	-	-
Water Hyacinths	Lake Bouef	10-9-78	0.2813	N.O. East	9-22-78	<0.0001
Arrowhead (Sagittaria spp.)	Riverside	10-9-78	0.2138	N.O. East	10-9-78	<0.0001
Alligator-weed	Riverside	9-25-78	0.1863	N.O. East	9-22-78	0.0194
Rush (Juncus spp.)	Belle Chasse	9-25-78	0.0888	N.O. East	10-9-78	2.6331
Bulrush (Scirpus spp.)	-	-	-	N.O. East	9-22-78	0.1163

Table C-3. Cadmium Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg Cd/gm Dry Plant Tissue	Sampling Location	Date Collected	mg/gm Dry Plant Tissue
Duckweed	Lake Bouef	9-20-78	0.0023	N.O. East	9-24-78	0.0008
Coontail	Lake Bouef	9-20-78	0.0008	N.O. East	9-24-78	0.0013
Elodea	Lake Bouef	9-20-78	0.0008	-	-	-
Water-bonnet (Pistia spp.)	Lake Bouef	9-20-78	0.0008	-	-	-
Water Hyacinth	Lake Bouef	9-20-78	0.0008	N.O. East	9-24-79	0.0008
Arrowhead (Sagittaria spp.)	Riverside	10-3-78	0.0021	N.O. East	9-24-78	0.0008
Alligator-weed	Riverside	9-25-78	0.0011	N.O. East	9-24-78	0.0069
Rush (Juncus spp.)	Belle Chasse	9-25-78	0.0011	N.O. East	9-24-78	0.0008
Bulrush (Scirpus spp.)	-	-	-	N.O. East	9-24-78	0.0019

Table C-4. Mercury Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg Hg/gm Dry Plant Tissue	Sampling Location	Date Collected	mg Hg/gm Dry Plant Tissue
Duckweed	Lake Bouef	9-20-78	0.0038	N.O. East	9-24-78	0.0060
Coontail	Lake Bouef	9-20-78	0.0058	N.O. East	9-24-78	0.0048
Elodea	Lake Bouef	9-20-78	0.0297	-	-	-
Water-bonnet	Lake Bouef	9-20-78	0.0549	-	-	-
Water Hyacinth	Lake Bouef	9-20-78	0.0041	N.O. East	9-24-78	0.0075
Arrowhead	Riverside	10-3-78	0.0137	N.O. East	9-24-78	0.0159
Alligator-weed	Riverside	9-24-78	0.0420	N.O. East	9-24-78	0.0018
Rush	Belle Chasse	9-25-78	0.0042	N.O. East	9-22-78	0.0040
Bulrush	-	-	-	N.O. East	9-24-78	0.0052

Table C-5. Selenium Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg Se/gm Dry Plant Tissue	Sampling Location	Date Collected	mg Se/gm Dry Plant Tissue
Duckweed	Lake Bouef	10-9-78	1.0920	N.O. East	9-22-78	1.1620
Coontail	Lake Bouef	10-9-78	1.7115	N.O. East	9-22-78	1.2273
Elodea	Lake Bouef	9-20-78	1.2087	-	-	-
Water-bonnet	Lake Bouef	9-20-78	1.3300	-	-	-
Water Hyacinth	Lake Bouef	9-20-78	1.3627	N.O. East	9-22-78	1.1153
Arrowhead	Riverside	10-3-78	0.9240	N.O. East	9-22-78	0.7840
Alligator-weed	Riverside	9-24-78	1.0990	N.O. East	9-22-78	1.1247
Rush	Belle Chasse	9-25-78	1.1480	N.O. East	9-22-78	1.1387
Bulrush	-	-	-	N.O. East	9-22-78	0.8867

Table C-6. Phenol Concentration in Plant Tissue, Field Study *

PLANT	Sampling Location	Date Collected	mg Phenol/gm Dry Plant Tissue	Sampling Location	Date Collected	mg Phenol/gm Dry Plant Tissue
Duckweed	Lake Bouef	10-9-78	0.0019	N.O. East	10-9-78	0.0082
Coontail	Lake Bouef	10-9-78	0.0055	N.O. East	10-9-78	0.0469
Elodea	Lake Bouef	10-9-78	0.0650	-	-	-
Water-bonnet	Lake Bouef	10-9-78	0.0091	-	-	-
Water Hyacinth	Lake Bouef	10-9-78	0.0143	N.O. East	10-9-78	0.0309
Arrowhead	Riverside	10-9-78	0.0110	N.O. East	10-9-78	0.0000
Alligator-weed	Riverside	10-9-78	0.0055	N.O. East	10-9-78	0.0418
Rush	Belle Chasse	10-9-78	0.0050	N.O. East	10-9-78	0.0021
Bulrush	-	-	-	N.O. East	10-9-78	0.0025

* Colorimetric Method Analysis

Table C-7. Total Nitrogen Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg N/gm Dry Plant Tissue	Sampling Location	Date Collected	mg N/gm Dry Plant Tissue
Duckweed	Lake Bouef	10-9-78	5.5860	N.O. East	9-22-78	10.9760
Coontail	Lake Bouef	10-20-78	12.6336	N.O. East	9-22-78	14.8400
Elodea	Lake Bouef	10-9-78	17.6848	-	-	-
Water-bonnet	Lake Bouef	10-9-78	11.6256	-	-	-
Water Hyacinth	Lake Bouef	10-9-78	6.6080	N.O. East	9-22-78	16.4640
Arrowhead	Riverside	10-9-78	9.7440	N.O. East	10-9-78	10.3600
Alligator-weed	Riverside	9-25-78	15.7248	N.O. East	9-22-78	8.9488
Rush	Belle Chasse	9-25-78	4.9840	N.O. East	9-22-78	6.7200
Bulrush	-	-	-	N.O. East	10-9-78	8.9040

Table C-8. Total Phosphorus Concentration in Plant Tissue, Field Study

PLANT	Sampling Location	Date Collected	mg P /gm Dry Plant Tissue	Sampling Location	Date Collected	mg P/gm Dry Plant Tissue
Duckweed	Lake Bouef	10-9-78	4.6240	N.O. East	9-22-78	4.0800
Coontail	Lake Bouef	10-21-78	16.0800	N.O. East	9-22-78	8.1280
Elodea	Lake Bouef	10-9-78	5.7600	-	-	-
Water-bonnet	Lake Bouef	10-9-78	3.1200	-	-	-
Water Hyacinth	Lake Bouef	10-9-78	3.2400	N.O. East	9-22-78	5.1360
Arrowhead	Riverside	10-9-78	4.3600	N.O. East	10-9-78	3.6000
Alligator-weed	Riverside	9-25-78	2.1600	N.O. East	9-22-78	2.1560
Rush	Belle Chasse	9-25-78	1.9680	N.O. East	10-22-78	9.8560
Bulrush	-	-	-	N.O. East	10-9-78	1.1640

Table C-9. Water Concentration of Trace Contaminants, Field Study (mg/1)

Trace Contaminant	Area Collected		
	New Orleans East	New Orleans	Lake Bouef
Arsenic (As)	0.029	0.038	0.016
Boron (B)	0.000	0.000	0.502
Cadmium (Cd)	<0.001	<0.001	0.002
Mercury (Hg)	0.002	0.001	0.005
Selenium (Se)	0.025	0.030	0.034
Phenol	<0.001	<0.001	<0.001
Total Kjeldahl Nitrogen (TKN)	2.3	6.6	2.2
Ammonia (NH_3-N)	0.0	0.6	0.0
Nitrate (as NO_3-N)	0.2	0.3	<0.1
Nitrite (as NO_2-N)	<0.1	<0.1	<0.1
Phosphate ($PO_4^{\equiv}$)	0.6	0.9	0.4

Table C-10. Sediment Concentration of Trace Contaminants, Field Study (mg/gm dry sediment)

Trace Contaminants	Area Collected			
	New Orleans East	New Orleans	Belle Chasse	Riverside
As	0.801	0.831	0.861	1.101
B	0.175	0.176	0.177	0.129
Cd	0.001	<0.001	0.001	0.001
Hg	0.025	0.012	0.007	0.009
Se	0.858	0.779	0.724	0.941
Phenol	<0.001	<0.001	<0.001	0.001
TKN	2.895	4.569	0.585	0.574
NO_3-N (as NO_3-N)	0.003	0.007	0.005	0.008
NO_2-N (as NO_2-N)	0.000	0.000	0.000	0.000
$PO_4^{\equiv}$	0.048	0.067	0.059	0.108

APPENDIX D

Batch Screening Study Data

Table D-1. Pre-Test of Glass Aquarium (Used for Batch Screening)
December 13 - 19, 1978

Days Test Parameters	0 (12-13-78)	1 (12-14-78)	2 (12-15-78)	4 (12-17-78)	6 (12-19-78)	% loss in Aquarium
Temp, °C	18.9	17.8	17.8	17.9	19.0	-
pH	7.8	7.9	7.9	7.8	7.9	-
D.O., mg/l	7.8	7.6	5.4	5.0	4.5	-
BOD_5, mg/l	15.6	13.0	12.8	10.1	7.4	52.56
Evaporation, mm/day	0.0	1.5	0.8	1.0	1.2	-
As, mg/l	1.043	1.049	1.046	1.055	1.035	0.77
B, mg/l	4.933	4.794	5.160	4.200	4.130	16.28
Cd, mg/l	1.105	1.133	1.056	0.951	1.001	9.41
Hg, mg/l	0.974	0.911	0.967	0.567	0.769	21.05
Se, mg/l	1.012	0.996	0.924	1.155	0.918	9.24
Phenol, mg/l	0.750	0.660	0.050	0.050	0.075	90.00
PCB, mg/l	0.003	0.003	0.003	<0.001	0.005	0.00

Table D-2. BOD_5 Water Concentration, Batch Study (mg/1)
December 22, 1978-January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Removal
Duckweed # 1	12.5	12.1	8.4	10.4	8.6	7.4	5.4	7.3	10.8	13.99
Duckweed # 2	9.6	-	-	-	-	-	6.5	4.2	5.4	44.17
Coontail	8.1	7.4	9.6	9.1	9.4	9.0	7.6	7.2	6.2	23.33
Elodea	12.6	11.5	13.6	10.0	8.9	10.0	8.2	5.9	6.4	49.28
Water-bonnet	10.2	10.2	9.1	8.9	8.7	8.4	5.7	8.8	10.7	-5.00
Alligator-weed	8.5	5.5	4.2	4.1	6.8	5.5	3.9	1.7	1.5	82.57
Water hyacinths	12.9	9.9	6.5	6.4	6.8	4.5	3.7	3.9	10.1	21.76
Arrowhead	10.8	7.0	6.6	5.9	6.1	5.9	4.1	1.8	1.6	85.28
Bulrush	13.5	9.4	7.4	5.9	3.3	3.4	3.7	2.6	1.7	87.70
Rush	9.9	5.1	5.8	6.0	5.6	5.3	2.6	1.3	0.7	92.66
Algae	8.4	6.9	6.6	5.7	5.7	5.7	4.9	5.7	5.8	30.36
Control (no plants)	7.2	5.4	3.6	4.5	5.1	4.9	2.8	8.0	7.5	-7.55

Table D-3. TOC Water Concentration, Batch Study (mg/l)
December 22, 1978- January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Reduction
Duckweed # 1	13.8	11.6	10.9	11.2	11.0	10.2	9.7	8.7	11.2	18.84
Duckweed # 2	14.5	-	-	-	-	-	13.7	7.6	7.6	47.59
Coontail	13.2	11.2	10.8	11.0	12.4	11.9	11.8	14.0	10.7	18.94
Elodea	14.8	12.8	9.8	9.0	14.9	12.8	9.3	10.6	6.8	54.05
Water-bonnet	12.9	12.8	9.5	9.4	11.7	11.0	13.0	7.8	12.7	1.55
Alligator-weed	12.5	10.7	9.1	8.3	10.8	9.6	9.0	7.7	5.3	57.60
Water hyacinths	13.3	11.1	16.3	11.7	11.4	11.0	12.1	12.7	10.9	18.04
Arrowhead	13.9	10.8	9.5	9.4	9.6	9.4	9.9	12.2	5.4	61.15
Bulrush	12.6	10.9	9.6	9.0	8.8	8.3	8.3	6.6	5.1	59.52
Rush	13.4	9.4	9.0	8.8	8.7	8.2	6.7	4.3	4.0	70.15
Algae	13.0	11.2	9.2	9.2	12.3	12.3	10.2	13.1	12.2	6.15
Control (no plants)	11.4	10.4	9.0	9.7	9.8	9.6	6.9	10.9	11.2	1.75

Table D-4. As Water Concentration, Batch Study (mg/l)
December 22, 1978-January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Removal
Duckweed # 1	1.248	1.248	1.248	1.136	1.248	1.216	1.136	1.120	1.120	10.26
Duckweed # 2	1.227	-	-	-	-	-	1.176	1.176	1.176	4.16
Coontail	1.264	1.264	1.264	1.229	1.176	1.168	1.080	1.068	1.064	15.82
Elodea	1.272	1.269	1.254	1.236	1.168	1.168	1.200	1.077	1.008	20.75
Water-bonnet	1.288	1.288	1.288	1.288	1.280	1.280	1.280	1.280	1.280	0.62
Alligator-weed	1.152	1.136	1.112	1.109	1.080	1.056	1.064	1.016	1.016	11.80
Water hyacinths	1.176	1.120	1.115	1.110	1.096	1.104	1.045	1.168	1.032	12.50
Arrowhead	1.216	1.184	1.168	1.152	1.152	1.152	1.136	1.120	1.088	10.53
Bulrush	1.120	1.109	0.896	0.864	0.712	0.536	0.501	0.296	0.200	82.14
Rush	1.136	0.952	0.776	0.720	0.683	0.672	0.584	0.544	0.520	54.22
Algae	1.216	1.200	1.176	1.160	1.136	1.136	1.120	1.112	1.104	9.21
Control (no plants)	1.104	1.104	1.072	1.080	1.072	1.056	1.064	1.056	1.056	4.35

Table D-5. B Water Concentration, Batch Study (mg/1)
December 22, 1978-January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Removal
Duckweed # 1	4.900	4.896	5.062	4.962	4.285	4.834	4.787	4.611	4.109	16.14
Duckweed # 2	4.894	-	-	-	-	-	5.036	4.153	4.025	17.76
Coontail	4.869	4.864	5.012	4.997	4.445	4.766	4.766	4.049	4.008	17.63
Elodea	4.869	4.869	4.962	4.787	4.252	4.252	4.718	4.698	4.016	17.52
Water-bonnet	4.837	4.837	4.750	4.907	4.849	4.752	4.856	4.475	4.321	10.67
Alligator-Weed	4.837	4.896	4.425	4.718	4.830	4.611	4.513	4.682	4.130	14.62
Water hyacinths	4.912	4.971	5.387	4.712	5.238	4.929	4.927	4.473	4.300	12.46
Arrowhead	4.869	4.919	4.456	4.663	4.846	4.766	4.629	4.113	4.001	16.47
Bulrush	4.837	4.719	4.406	5.079	4.805	4.682	4.422	4.666	4.130	14.62
Rush	4.850	4.879	4.739	5.079	4.671	4.629	4.273	4.426	4.237	12.64
Algae	4.875	4.787	5.069	4.987	4.398	5.026	4.837	4.867	4.343	10.91
Control (no plants)	4.837	4.837	4.594	4.845	5.087	4.716	4.828	4.762	4.765	1.49

Table D-6. Cd Water Concentration, Batch Study (mg/l)
December 22, 1978-January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Removal
Duckweed # 1	1.349	1.349	1.349	1.344	1.344	0.808	0.792	0.720	0.536	60.27
Duckweed # 2	1.384	-	-	-	-	-	0.624	0.512	0.336	75.72
Coontail	1.440	0.872	0.344	0.336	0.297	0.224	0.176	0.144	0.128	91.11
Elodea	1.344	0.448	0.368	0.344	0.320	0.192	0.165	0.160	0.192	85.71
Water-bonnet	1.352	1.344	1.328	1.312	1.272	1.056	1.056	1.024	1.016	24.85
Alligator-weed	1.384	0.880	0.712	0.664	0.560	0.528	0.488	0.392	0.328	76.30
Water hyacinths	1.376	0.875	0.832	0.656	0.648	0.608	0.544	0.464	0.432	68.60
Arrowhead	1.408	0.960	0.904	0.792	0.608	0.576	0.480	0.352	0.304	78.41
Bulrush	1.392	0.896	0.552	0.368	0.360	0.261	0.256	0.080	0.016	98.85
Rush	1.496	0.632	0.368	0.288	0.272	0.240	0.200	0.187	0.128	91.44
Algae	1.397	1.349	1.328	1.280	1.252	1.252	1.232	1.208	0.752	46.17
Control (no plants)	1.336	1.328	1.312	1.088	1.048	1.040	1.040	1.035	1.032	22.75

Table D-7. Hg Water Concentration, Batch Study (mg/l)
December 22, 1978 - January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Reduction
Duckweed #1	0.814	0.739	0.786	0.625	0.561	0.525	0.522	0.517	0.267	67.20
Duckweed #2	0.811	----	----	----	----	-----	0.761	0.589	0.239	70.53
Coontail	0.767	0.617	0.611	0.603	0.550	0.494	0.440	0.433	0.230	70.01
Elodea	0.894	0.756	0.622	0.342	0.272	0.252	0.229	0.211	0.186	79.19
Water-bonnet	0.930	0.774	0.767	0.711	0.700	0.583	0.527	0.458	0.489	47.42
Alligator-weed	0.850	0.742	0.625	0.561	0.383	0.336	0.350	0.239	0.211	75.18
Water hyacinths	0.764	0.650	0.625	0.597	0.539	0.533	0.533	0.525	0.228	70.16
Arrowhead	0.786	0.595	0.447	0.400	0.306	0.333	0.314	0.280	0.203	74.17
Bulrush	0.800	0.550	0.417	0.336	0.336	0.329	0.322	0.230	0.058	92.75
Rush	0.877	0.703	0.461	0.440	0.355	0.229	0.230	0.200	0.183	79.13
Algae	0.836	0.706	0.539	0.433	0.430	0.430	0.383	0.378	0.316	62.20
Control (no plants)	0.856	0.850	0.778	0.620	0.597	0.433	0.428	0.433	0.339	60.39

Table D-8. Se Water Concentration, Batch Study (mg/1)
December 22, 1978- January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Removal
Duckweed # 1	1.488	1.488	1.488	1.488	1.488	1.488	1.488	1.488	1.488	00.00
Duckweed # 2	1.456	-	-	-	-	-	1.456	1.424	1.296	10.98
Coontail	1.440	1.440	1.440	1.440	1.440	1.440	1.440	1.312	1.024	28.89
Elodea	1.488	1.488	1.488	1.488	1.488	1.488	1.488	1.320	1.216	18.28
Water-bonnet	1.440	1.440	1.440	1.440	1.440	1.440	1.440	1.440	1.352	6.11
Alligator weed	1.454	1.454	1.454	-	1.454	-	1.454	1.312	1.301	10.52
Water hyacinths	1.440	1.440	1.440	-	1.440	-	1.440	1.456	1.322	8.19
Arrowhead	1.424	1.368	1.360	1.376	1.336	1.216	1.200	1.168	1.000	29.77
Bulrush	1.488	1.400	1.040	-	0.608	-	0.149	0.088	0.076	94.89
Rush	1.424	1.424	1.112	-	1.064	-	0.824	0.704	0.544	61.80
Algae	1.440	1.440	1.432	1.424	1.424	1.440	1.440	1.440	1.440	00.00
Control (no plants)	1.440	1.440	1.440	-	1.440	-	1.440	1.480	1.440	00.00

Table D-9. Phenol Water Concentration, Batch Study (mg/l) *
December 22, 1978 - January 19, 1979

Plant	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	% Removal
Duckweed # 1	0.525	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Duckweed # 2	0.537	-	-	-	-	-	0.000	0.000	0.000	100.00
Coontail	0.550	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Elodea	0.463	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Water-bonnet	0.550	0.168	0.100	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Alligator-weed	0.575	0.131	0.050	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Water hyacinths	0.537	0.087	0.025	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Arrowhead	0.644	0.102	0.025	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Bulrush	0.550	0.550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Rush	0.537	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Algae	0.594	0.337	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.00
Control (no plants)	0.537	0.400	0.100	0.000	0.000	0.000	0.000	0.000	0.000	100.00

*Colorimetric Method Analysis

Table D-10. PCB's Water Concentration, Batch Study (mg/1)
December 22, 1978-January 19, 1979

Time, Days Plant	0Day	1 Days	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28Days	% Reduction
Duckweed # 1	0.008	0.002	<0.001	<0.002	0.002	<0.001	0.002	0.002	<0.001	>87.50
Duckweed # 2	0.006	-	-	-	-	-	0.001	<0.001	0.000	100.00
Coontail	0.006	<0.001	0.002	<0.001	<0.001	<0.001	0.001	<0.001	0.000	100.00
Elodea	0.007	0.001	0.002	0.001	0.003	<0.001	<0.001	<0.001	0.000	100.00
Water-bonnet	0.007	0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	57.14
Alligator-weed	0.007	0.001	0.001	<0.001	0.005	0.001	<0.001	0.000	0.000	100.00
Water hyacinths	0.007	<0.001	0.001	<0.001	<0.001	<0.001	0.003	0.000	0.000	100.00
Arrowheads	0.006	<0.001	0.001	0.005	<0.001	<0.001	<0.001	<0.001	0.000	100.00
Bulrush	0.008	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.000	100.00
Rush	0.009	<0.001	0.001	<0.001	<0.001	0.001	0.002	<0.001	0.000	100.00
Algae	0.008	0.004	<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	>87.50
Control (no plants)	0.006	<0.001	0.002	<0.001	<0.001	0.001	0.001	<0.001	0.002	66.67

Table D-11. Total Nitrogen Water Concentration (Includes TKN, NH_3, NO_3, NO_2), Batch Study (mg/l)
December 22, 1978 - January 19, 1979

Plant	Time, days 0	1	3	5	7	10	14	21	28	% Reduction
Duckweed # 1	19.8	17.3	17.9	16.9	15.3	15.1	15.4	13.2	7.6	61.62
Duckweed # 2	18.7	-	-	-	-	-	16.7	12.0	5.9	68.45
Coontail	17.7	16.7	18.6	18.5	18.6	16.9	13.9	8.1	0.9	94.91
Elodea	19.7	15.6	14.8	14.7	12.3	11.4	7.7	1.8	0.7	96.45
Water-bonnet	18.6	16.8	16.0	18.2	17.9	16.5	13.4	10.8	5.9	68.28
Alligator-weed	18.9	18.6	19.2	17.3	15.4	8.1	1.3	0.5	0.4	97.88
Water hyacinths	18.3	16.5	19.3	19.7	18.5	18.5	16.2	15.7	9.0	50.82
Arrowhead	19.8	16.1	17.5	15.7	14.5	13.5	11.5	9.7	4.7	76.26
Bulrush	18.7	16.9	16.4	14.1	12.1	9.1	3.0	1.0	<0.1	>99.46
Rush	18.6	17.7	14.3	12.1	9.5	6.3	2.8	0.7	<0.1	>99.46
Algae	19.8	20.3	19.3	17.0	16.4	12.7	8.8	3.4	3.7	81.31
Control (no plants)	17.9	20.6	20.6	18.2	17.6	15.9	15.3	11.7	5.1	71.51

Table D -12. TKN Water Concentration, Batch Study (mg/l)
December 22, 1978 - January 19, 1979

Plant	Time, days								
	0	1	3	5	7	10	14	21	28
Duckweed # 1	11.9	10.3	9.7	9.4	8.3	8.3	7.8	7.2	3.0
Duckweed # 2	11.5	-	-	-	-	-	9.4	6.7	2.6
Coontail	11.4	8.6	9.7	10.3	10.0	9.1	8.3	4.7	0.6
Elodea	11.5	8.5	8.4	7.8	6.7	6.2	4.5	0.8	0.7
Water-bonnet	12.0	10.7	6.7	8.8	8.1	7.8	6.9	5.5	2.8
Alligator-weed	11.5	9.3	9.0	8.1	7.6	4.4	1.1	0.5	0.4
Water hyacinths	11.4	10.1	9.6	9.4	9.1	9.6	9.4	8.1	3.4
Arrowhead	11.9	9.7	9.1	7.8	7.3	6.9	6.5	4.8	0.6
Bulrush	11.4	10.0	9.0	7.2	6.5	4.9	1.8	1.0	0.0
Rush	12.0	10.0	6.3	5.4	4.9	3.0	1.3	0.0	0.0
Algae	11.4	11.2	10.1	8.6	7.9	6.7	5.3	0.4	0.2
Control (no plants)	11.4	11.3	10.3	9.3	8.8	8.4	7.4	5.5	0.3

Table D-13. NH_3 Water Concentration, Batch Study (mg/l)
December 22, 1978-January 19, 1979

Plant	Time, Days								
	0	1	3	5	7	10	14	21	28
Duckweed # 1	7.2	6.5	7.9	7.2	6.9	6.6	6.5	6.0	0.8
Duckweed # 2	6.6	-	-	-	-	-	6.8	5.0	0.4
Coontail	5.8	7.6	8.8	8.2	8.6	7.8	5.6	3.4	0.0
Elodea	7.7	6.7	6.4	6.8	5.6	5.3	3.1	0.0	0.0
Water-bonnet	5.9	5.4	8.2	7.9	7.9	6.5	4.7	3.5	0.7
Alligator-weed	6.0	7.8	8.2	7.5	6.5	3.5	0.0	0.0	0.0
Water hyacinths	5.8	5.4	8.5	9.1	8.8	7.9	6.3	6.2	1.8
Arrowhead	7.1	5.6	7.9	7.4	6.6	5.7	4.5	4.0	0.0
Bulrush	6.4	5.8	7.2	6.7	5.5	4.1	1.2	0.0	0.0
Rush	5.6	6.3	6.7	5.4	3.6	2.8	0.4	0.0	0.0
Algae	6.6	7.7	8.4	6.8	6.6	4.6	2.9	0.0	0.0
Control (no plants)	5.1	7.8	9.1	7.7	6.9	5.6	5.8	4.0	0.0

Table D-14. Nitrate Nitrogen (NO_3-N) Water Concentration, Batch Study (mg/l)
December 22, 1978 - January 19, 1979

Plant	Time, days								
	0	1	3	5	7	10	14	21	28
Duckweed # 1	0.7	0.5	0.3	0.3	0.1	0.2	0.1	0.0	3.7
Duckweed # 2	0.7	-	-	-	-	-	0.4	0.3	2.9
Coontail	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Elodea	0.5	0.3	0.0	0.1	0.0	0.0	0.0	0.9	0.0
Water-bonnet	0.7	0.6	1.1	1.4	1.9	2.2	1.8	1.8	2.3
Alligator-weed	1.3	1.4	2.0	1.7	1.3	0.3	0.2	0.0	0.0
Water hyacinths	1.0	1.0	1.2	1.2	0.6	0.9	0.5	1.4	3.8
Arrowhead	0.8	0.6	0.5	0.5	0.6	0.8	0.5	0.8	4.1
Bulrush	0.9	1.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0
Rush	1.0	1.4	1.3	1.3	1.0	0.5	1.0	0.7	0.0
Algae	1.7	1.3	0.7	1.5	1.7	1.4	0.6	2.9	3.3
Control (no plants)	1.3	1.4	1.1	1.1	1.8	1.9	2.0	2.1	4.6

Table D-15. Nitrite Nitrogen (NO_2-N) Water Concentration, Batch Study (mg/l)
December 22, 1978 - January 19, 1979

Plant	Time, days								
	0	1	3	5	7	10	14	21	28
Duckweed #1	0.02	0.02	0.05	0.04	0.02	<0.01	0.04	<0.01	0.05
Duckweed #2	0.01	-	-	-	-	-	0.02	<0.01	0.02
Coontail	0.02	0.02	0.03	0.02	0.02	<0.01	0.02	<0.01	0.07
Elodea	0.02	0.03	0.03	0.02	0.02	0.02	0.04	0.07	0.02
Water-bonnet	0.02	0.03	0.05	<0.01	0.01	0.03	0.03	0.05	0.14
Alligator-weed	0.02	0.04	0.04	0.04	0.05	0.01	0.02	0.02	0.00
Water hyacinths	0.03	0.04	0.04	0.03	0.02	0.01	0.02	0.04	0.13
Arrowhead	0.04	0.02	<0.01	0.02	0.01	<0.01	0.03	0.02	0.04
Bulrush	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.05
Rush	0.03	<0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03
Algae	0.04	0.02	0.07	0.03	0.10	0.02	0.03	0.07	0.16
Control (no plants)	0.04	0.02	0.07	0.01	0.03	<0.01	0.02	0.04	0.13

Table D-16. Phosphate ($PO_4^{\equiv}$) Water Concentration, Batch Study (mg/1)
December 22, 1978 - January 19, 1979

Plant	Time, days									% Reduction
	0	1	3	5	7	10	14	21	28	
Duckweed # 1	5.8	5.7	5.7	6.7	6.5	6.0	5.0	6.6	4.7	18.96
Duckweed # 2	5.5	-	-	-	-	-	6.4	6.6	4.6	16.36
Coontail	5.8	6.1	8.7	9.7	9.7	9.7	5.7	7.3	6.0	-3.45
Elodea	5.7	5.6	7.2	8.3	8.5	8.5	4.8	7.3	5.2	8.77
Water-bonnet	5.9	5.2	5.7	6.6	6.5	6.1	4.0	5.7	4.7	20.34
Alligator-weed	5.2	5.0	5.7	6.2	5.3	6.0	4.7	4.1	3.2	38.46
Water hyacinths	5.6	5.0	5.9	5.7	5.2	5.6	4.9	5.9	4.9	12.50
Arrowhead	5.4	5.2	5.7	6.0	5.4	5.6	4.5	5.4	5.0	7.41
Bulrush	5.7	4.8	4.7	5.0	4.0	3.8	3.5	1.4	0.6	89.47
Rush	5.6	4.7	4.7	4.7	4.7	4.1	3.8	2.9	1.9	66.07
Algae	5.7	5.9	5.7	5.7	5.6	5.7	5.3	5.7	5.7	0.00
Control (no plants)	5.3	5.1	5.5	5.4	5.8	5.8	4.8	6.2	5.3	0.00

Table D-17. Water Temperature, Batch Study (°C) December 22, 1978 - January 19, 1979

Plant	Days																												
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	19.0	22.4	22.3	21.3	20.7	21.0	21.3	21.7	22.5	23.3	20.3	18.1	18.4	19.3	21.5	23.7	21.1	19.3	18.3	19.6	18.2	20.2	23.7	20.2	20.2	23.2	25.0	25.7	24.9
Duckweed # 2	19.6	-	-	21.0	20.7	20.8	21.3	21.7	22.7	23.2	21.3	18.5	18.9	19.7	22.3	24.4	21.8	20.4	19.3	21.3	18.7	20.2	23.9	20.8	20.7	23.7	24.8	26.1	25.2
Coontail	20.3	22.8	22.3	21.5	21.3	21.3	21.8	21.8	22.8	23.3	21.4	18.3	19.2	20.0	22.3	24.2	21.3	20.0	19.1	20.0	18.7	20.7	23.8	20.6	21.6	23.6	24.4	26.1	25.2
Elodea	20.1	23.2	22.2	21.3	21.2	21.2	21.9	22.0	23.1	23.4	21.6	18.9	20.0	20.8	23.1	24.9	22.0	21.2	20.4	21.3	19.5	21.2	24.9	21.0	21.3	23.9	24.7	26.4	25.4
Water-bonnet	20.5	24.0	23.0	22.1	20.7	21.6	22.3	22.0	22.8	23.2	21.7	18.7	19.6	21.0	22.8	24.8	22.1	21.0	20.0	20.7	19.9	21.0	23.4	21.3	20.6	23.8	25.0	26.7	25.7
Alligator-weed	20.4	23.5	22.3	21.5	21.3	21.4	21.9	22.1	23.0	23.3	22.0	18.8	19.8	20.6	23.1	24.8	22.6	21.1	21.0	21.2	20.3	21.3	24.8	21.0	21.2	24.1	25.7	25.3	25.4
Water hyacinths	20.7	23.5	22.1	21.8	21.6	21.5	22.2	22.2	23.4	24.7	22.4	19.2	20.3	22.0	23.3	25.0	22.8	21.3	21.7	21.4	20.2	21.4	25.0	21.5	21.5	24.6	25.9	25.9	25.8
Arrowhead	19.6	22.3	22.3	21.6	21.3	21.2	21.7	21.8	22.8	23.0	21.3	17.8	18.5	19.8	21.8	24.0	21.0	19.6	19.0	21.6	18.0	20.0	23.2	20.1	19.4	24.0	24.8	25.8	24.7
Bulrush	18.7	22.7	22.1	22.0	21.2	21.4	21.8	21.6	23.0	23.2	21.4	18.0	18.6	19.3	21.6	23.6	21.2	19.5	18.8	20.3	17.9	19.3	22.8	19.7	19.2	23.6	24.0	26.0	24.7
Rush	20.0	24.2	23.6	23.3	23.2	22.3	23.6	24.2	24.4	24.3	23.0	19.6	20.7	21.6	24.0	24.9	24.0	21.6	21.2	22.1	20.0	22.7	25.3	21.9	21.3	25.8	26.3	27.0	25.6
Algae	19.5	25.0	24.6	24.7	24.1	23.8	24.8	23.3	25.7	26.2	24.2	21.4	22.7	23.0	25.3	27.0	24.5	23.1	23.2	23.6	22.0	24.6	26.3	23.6	23.5	26.7	27.7	29.0	28.2
Control (no plants)	20.0	23.8	24.6	23.0	23.1	22.2	23.6	22.6	23.7	23.8	22.6	19.5	20.4	21.1	23.9	24.8	22.9	21.6	21.2	21.8	20.0	22.4	25.1	22.0	21.2	25.1	26.2	26.9	25.3

Table D-18. Dissolved Oxygen Concentration, Batch Study (mg/l)
December 22, 1978 - January 19, 1979

Plant	Time, days																												
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	8.2	4.3	3.4	3.3	3.3	2.7	2.1	1.9	2.2	2.0	2.6	3.3	4.1	4.7	4.8	4.4	3.8	5.0	5.7	6.2	6.3	6.5	6.2	5.8	5.7	4.9	2.3	2.1	2.4
Duckweed # 2	7.6	-	-	3.7	3.2	2.2	0.9	0.4	0.5	0.4	1.1	1.2	1.6	1.7	1.6	2.2	1.8	4.6	6.7	8.7	7.8	7.3	8.4	9.7	9.9	9.4	7.4	4.3	2.9
Coontail	7.7	2.6	0.4	0.3	0.8	1.1	1.7	1.2	1.7	1.6	2.1	3.8	5.5	6.3	6.9	5.2	2.5	7.4	9.4	10.0	7.6	6.8	8.5	9.7	10.7	9.2	6.8	5.6	4.5
Elodea	8.5	3.8	0.4	0.9	1.4	0.9	2.1	0.9	1.5	0.6	1.3	3.1	5.1	5.3	5.8	3.9	0.6	6.1	9.1	9.4	5.8	3.8	8.4	12.5	13.8	11.7	10.5	9.4	7.9
Water-bonnet	8.0	7.2	5.2	5.3	5.4	4.8	4.8	4.7	5.0	4.6	4.5	5.4	6.0	6.0	6.3	5.7	5.1	6.4	7.0	7.1	7.1	7.1	6.8	7.0	6.9	6.8	6.5	4.7	4.0
Alligator-weed	7.3	5.3	3.2	3.9	4.3	4.1	4.6	4.0	4.2	3.6	3.5	4.9	5.8	5.0	4.4	2.6	2.0	4.5	6.0	5.8	5.3	4.8	4.5	5.9	6.3	5.6	4.8	4.1	4.2
Water hyacinths	7.5	6.2	2.7	4.4	4.5	4.2	4.8	4.6	4.4	4.0	4.2	5.0	5.5	5.2	5.1	4.3	3.9	5.2	5.8	5.6	5.2	4.3	2.8	2.8	2.7	1.8	1.0	1.2	1.1
Arrowhead	8.2	6.8	4.3	5.8	6.4	6.0	6.2	4.6	4.0	2.6	2.5	4.4	5.4	5.5	5.4	4.4	2.7	4.6	6.0	6.5	5.9	5.3	5.0	5.6	6.3	5.3	3.1	2.7	3.8
Bulrush	8.3	7.0	2.3	2.8	2.3	2.8	3.1	2.5	2.9	2.7	2.5	3.6	4.3	4.1	4.1	2.9	1.5	4.6	6.0	6.8	4.5	4.3	4.9	7.0	8.3	7.2	4.9	3.7	2.9
Rush	7.5	6.2	3.4	4.3	4.2	4.4	4.6	5.4	4.5	4.1	4.2	5.3	5.6	5.2	4.6	3.7	3.3	4.3	4.7	4.3	4.2	4.0	3.7	5.1	5.9	5.0	4.2	4.1	4.1
Algae	8.0	7.8	5.6	5.7	5.7	6.0	5.8	4.3	5.6	5.4	5.5	6.2	6.3	6.7	6.4	5.9	5.1	4.4	3.1	2.3	4.3	5.7	6.0	6.7	7.6	7.3	6.5	5.9	5.5
Control (no plants)	5.9	4.9	5.2	5.2	5.5	5.9	6.0	6.0	6.1	6.1	6.3	7.0	6.8	7.4	7.3	7.0	7.0	7.2	7.5	7.7	7.5	7.3	5.8	4.1	2.3	0.6	2.9	4.4	5.3

Table D-19. pH, Batch Study (Measured at 8 cm. below Water Surface)
December 22, 1978 - January 19, 1979

Plant	Time, days																												
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	7.9	8.0	7.8	7.8	8.0	7.7	7.5	7.5	7.8	7.7	7.6	7.9	8.0	8.0	7.9	8.0	8.0	8.0	8.0	8.0	8.1	8.1	8.1	8.3	8.0	8.0	7.9	7.8	7.7
Duckweed # 2	8.0	-	-	-	8.0	-	7.6	-	7.7	7.7	-	7.9	8.0	8.0	7.9	8.1	8.0	8.2	8.2	8.3	8.3	8.4	8.4	8.3	8.4	8.6	8.5	8.4	8.2
Coontail	7.9	8.0	7.9	7.7	7.9	7.8	7.8	7.6	7.9	7.9	7.8	8.1	8.2	8.2	8.3	8.3	8.1	8.3	8.2	8.4	8.4	8.3	8.3	8.3	8.5	8.4	8.3	8.4	8.3
Elodea	8.1	7.9	8.0	7.8	8.0	7.9	7.8	7.6	7.9	7.8	7.8	8.1	8.2	8.2	8.2	8.2	8.1	8.2	8.3	8.2	8.1	8.1	8.2	8.5	8.6	8.7	8.7	8.8	8.7
Water-bonnet	8.1	8.1	8.1	8.0	8.2	8.0	7.9	7.7	8.0	7.9	7.9	8.0	8.2	8.2	8.2	8.3	8.3	8.3	8.2	8.3	8.2	8.4	8.2	8.3	8.3	8.3	8.4	8.3	8.1
Alligator-weed	8.0	7.9	8.0	7.6	7.9	7.7	7.7	7.4	7.6	7.6	7.4	7.6	7.8	7.8	7.5	7.8	7.7	7.8	7.7	7.8	7.8	7.6	7.8	7.9	7.9	7.9	7.9	7.9	7.7
Water hyacinths	8.1	7.9	7.9	7.6	8.0	7.7	7.8	7.6	7.8	7.9	7.7	8.0	8.1	8.2	8.0	8.1	8.0	8.1	8.1	8.1	8.0	8.0	7.9	7.9	7.9	7.9	8.0	7.9	7.7
Arrowhead	8.1	7.9	8.0	7.8	8.0	7.9	7.9	7.6	7.9	7.9	7.7	8.0	8.1	8.3	8.1	8.1	8.0	8.1	8.1	8.1	8.1	8.1	8.0	8.3	8.1	8.0	8.0	7.9	7.9
Bulrush	8.1	8.1	7.8	7.5	7.9	7.5	7.6	7.2	7.6	7.6	7.3	7.6	7.7	7.8	7.4	7.7	7.5	7.7	7.7	7.7	7.6	7.4	8.0	7.8	7.9	7.8	7.6	7.5	7.4
Rush	8.0	7.8	7.7	7.4	7.6	7.4	7.4	7.2	7.5	7.5	7.3	7.6	7.7	7.8	7.4	7.7	7.6	7.8	7.6	7.6	7.5	7.4	7.7	7.8	7.8	7.8	7.7	7.6	7.3
Algae	8.2	8.2	8.2	8.1	8.2	8.2	8.0	7.9	8.1	8.2	8.1	8.3	8.3	8.4	8.3	8.3	8.3	8.2	7.9	7.8	8.0	8.0	8.2	8.2	8.3	8.4	8.4	8.3	8.3
Control (no plants)	8.0	8.0	8.0	8.0	8.2	8.2	8.0	7.9	8.1	8.2	8.2	8.3	8.3	8.5	8.4	8.4	8.3	8.4	8.4	8.3	8.3	8.4	8.3	8.2	7.8	7.9	7.9	8.0	8.0

Table D-20. pH, Batch Study (Measured at 8 cm. Above the Bottom of Aquarium) December 22, 1978 - January 19, 1979

Plant	Time, days																												
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	7.9	8.0	8.0	7.8	8.0	7.7	7.7	7.5	7.8	7.8	7.7	7.9	8.1	8.1	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.1	8.1	8.3	8.1	8.0	7.9	7.8	7.7
Duckweed # 2	8.0	-	-	-	8.0	-	7.7	-	7.8	7.7	-	7.9	8.0	8.0	7.9	8.1	8.0	8.2	8.2	8.3	8.3	8.4	8.4	8.4	8.5	8.6	8.6	8.5	8.3
Coontail	7.9	8.0	7.9	7.7	7.9	7.8	7.8	7.6	7.9	7.9	7.8	8.0	8.1	8.2	8.2	8.3	8.1	8.2	8.2	8.4	8.4	8.4	8.3	8.4	8.5	8.4	8.3	8.4	8.3
Elodea	8.1	7.9	8.0	7.8	8.0	7.9	7.8	7.6	7.9	7.9	7.9	8.1	8.2	8.2	8.2	8.2	8.1	8.2	8.3	8.2	8.1	8.1	8.3	8.6	8.7	8.7	8.7	8.8	8.8
Water-bonnet	8.1	8.1	8.1	8.0	8.1	8.0	7.9	7.8	8.0	8.0	7.9	8.1	8.2	8.2	8.2	8.2	8.3	8.3	8.2	8.3	8.2	8.4	8.3	8.3	8.3	8.3	8.4	8.3	8.1
Alligator-weed	8.0	7.9	8.0	7.6	7.9	7.6	7.7	7.3	7.6	7.6	7.3	7.6	7.8	7.8	7.5	7.8	7.6	7.8	7.7	7.8	7.8	7.6	7.8	7.9	7.9	7.9	7.9	7.9	7.7
Water hyacinths	8.1	7.9	8.0	7.6	8.0	7.7	7.8	7.6	7.8	7.9	7.8	8.0	8.1	8.1	8.0	8.0	8.0	8.1	8.1	8.1	8.0	8.0	8.0	8.0	8.0	8.0	8.1	7.9	7.7
Arrowhead	8.1	7.9	7.9	7.8	8.0	7.9	7.9	7.6	7.9	7.9	7.7	8.0	8.1	8.2	8.1	8.1	8.0	8.1	8.1	8.1	8.1	8.2	8.0	8.3	8.2	8.0	8.0	8.0	7.9
Bulrush	8.1	8.0	7.8	7.5	7.8	7.5	7.6	7.2	7.6	7.6	7.3	7.6	7.6	7.8	7.4	7.7	7.5	7.7	7.7	7.7	7.6	7.4	8.0	7.8	7.9	8.0	7.6	7.5	7.3
Rush	8.0	7.8	7.7	7.4	7.7	7.4	7.5	7.2	7.5	7.6	7.3	7.6	7.7	7.8	7.5	7.7	7.6	7.8	7.6	7.6	7.5	7.4	7.8	7.8	7.8	7.8	7.6	7.7	7.4
Algae	8.2	8.2	8.2	8.1	8.2	8.2	8.0	7.9	8.2	8.2	8.1	8.3	8.3	8.4	8.3	8.3	8.3	8.2	7.9	7.8	8.0	8.0	8.2	8.3	8.3	8.4	8.4	8.5	8.5
Control (no plants)	8.0	8.0	8.1	8.0	8.2	8.2	8.1	8.0	8.2	8.2	8.2	8.3	8.4	8.5	8.4	8.4	8.4	8.4	8.4	8.3	8.3	8.3	8.4	8.3	8.2	7.9	8.0	8.1	8.1

Table D-21. ORP, Batch Study (Measured at 8 cm. Below Water Surface)
December 22, 1978 - January 19, 1979

Plant	Time, Days																												
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	128	144	170	164	145	157	177	159	162	174	165	167	168	167	169	169	154	158	158	165	166	138	155	158	142	122	112	127	118
Duckweed # 2	132	-	-	-	148	-	173	-	160	171	-	165	167	166	168	168	144	149	150	149	147	144	142	125	127	127	110	96	89
Coontail	128	141	163	160	144	156	175	158	161	173	164	166	167	167	168	168	148	152	160	156	150	152	156	147	132	129	111	103	96
Elodea	134	140	153	155	147	153	171	159	160	173	163	164	167	166	170	165	140	145	147	145	142	142	137	138	120	120	120	97	81
Water-bonnet	134	138	162	152	146	151	171	158	159	169	163	164	166	165	178	165	135	144	140	141	141	138	134	133	116	114	109	94	75
Alligator-weed	134	136	166	150	147	151	170	157	159	168	162	164	165	165	175	166	135	141	136	138	133	137	131	125	113	113	121	92	69
Water hyacinths	134	134	166	149	146	150	169	156	161	168	162	162	165	166	174	166	133	134	133	134	131	135	127	123	111	128	119	95	70
Arrowhead	134	132	165	147	148	148	168	155	162	166	162	161	166	162	171	167	129	137	130	131	148	134	125	117	109	126	118	87	68
Bulrush	134	132	165	145	145	148	167	155	160	165	162	161	165	163	168	167	129	136	129	130	147	134	123	115	107	123	115	86	63
Rush	134	131	164	144	143	148	167	154	159	165	162	162	165	164	168	167	127	135	128	130	144	134	122	114	106	121	115	95	77
Algae	133	129	157	143	145	148	166	154	158	163	161	163	164	165	168	166	125	133	126	128	143	133	120	111	104	119	114	85	76
Control (no plants)	133	130	157	141	142	147	167	153	157	162	161	160	165	164	168	168	123	133	124	125	141	132	120	110	106	117	113	95	68

Table D-22. ORP, Batch Study (Measured at 8 cm. Above Aquarium Bottom) December 22, 1978 - January 19, 1979

Plant	Time, Days																												
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	128	144	166	162	145	156	176	159	161	173	165	166	167	168	168	169	154	157	157	162	149	158	155	158	142	122	111	106	105
Duckweed # 2	132	-	-	-	148	-	172	-	160	171	-	165	166	166	168	168	145	149	149	149	144	140	145	142	125	127	109	89	83
Coontail	128	140	157	157	143	154	174	158	161	172	164	166	167	167	168	169	149	152	160	156	147	147	155	147	132	129	110	97	102
Elodea	134	138	151	154	147	152	171	157	159	170	163	164	165	165	170	166	142	145	146	144	142	139	137	138	120	120	109	90	75
Water-bonnet	134	137	164	152	141	152	170	159	159	169	163	163	165	166	176	168	136	143	140	140	141	137	134	133	116	114	109	91	70
Alligator-weed	134	136	167	149	146	151	169	157	159	168	163	165	165	165	175	166	135	141	136	138	133	136	132	125	113	113	120	83	66
Water hyacinths	134	134	167	148	145	150	168	156	159	167	162	162	164	164	172	165	135	138	132	133	131	134	128	123	111	128	119	86	66
Arrowhead	134	132	165	146	146	148	167	155	161	166	162	161	165	166	171	167	129	137	130	131	146	135	125	117	109	126	116	84	63
Bulrush	134	131	165	145	144	148	167	154	159	166	162	162	165	165	168	167	129	136	129	130	146	134	123	115	107	123	115	89	61
Rush	134	130	158	143	148	149	167	154	158	164	161	161	164	164	168	168	128	134	128	130	144	134	122	114	106	121	116	86	72
Algae	133	129	158	142	143	148	166	154	157	162	161	161	165	165	168	168	125	133	126	128	140	133	120	111	104	119	113	78	72
Control	133	129	156	141	142	147	165	153	157	160	161	161	164	164	168	168	123	133	124	123	141	132	120	110	106	117	112	92	66

Table D-23. Evaporation, Batch Study (mm/day)
December 22, 1978-January 19, 1979

Plant	Time, Days																											
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Duckweed # 1	0	0.1	1.8	1.1	2.0	1.1	1.9	1.8	1.4	1.1	1.1	2.2	2.1	1.4	1.6	1.4	2.0	1.8	2.3	1.9	1.7	0.8	1.5	2.5	1.3	1.3	1.7	1.3	0.6
Duckweed # 2	0	-	-	-	-	1.3	2.1	1.6	1.5	1.4	2.0	2.8	2.6	1.9	2.3	2.0	2.2	2.4	2.4	2.3	2.0	1.2	1.6	3.3	2.4	1.8	2.2	1.8	1.6
Coontail	0	0.5	2.8	2.1	2.3	1.1	2.0	1.8	2.2	1.7	2.0	2.0	1.3	1.1	1.6	1.2	1.8	1.5	2.0	2.0	1.4	0.5	0.6	2.4	1.2	0.4	1.4	0.7	0.9
Elodea	0	1.0	4.0	3.8	3.5	2.9	3.7	3.0	2.9	2.0	3.9	2.9	3.0	2.7	3.6	3.0	3.0	2.9	3.2	3.1	2.7	1.8	2.0	3.5	1.9	1.2	3.0	1.8	1.7
Water-bonnet	0	1.7	2.7	3.5	3.1	2.5	2.8	2.7	2.3	2.5	3.3	3.0	2.8	2.1	3.0	2.8	2.9	2.9	3.2	3.2	2.1	2.0	2.0	3.6	2.0	2.5	2.8	2.0	2.0
Alligator-weed	0	1.6	3.7	3.3	3.2	3.5	3.5	2.9	2.9	2.6	3.7	2.8	3.5	3.0	4.5	3.8	3.5	4.4	5.1	4.8	2.8	3.5	3.8	5.4	4.9	4.0	4.8	4.0	3.3
Water hyacinths	0	1.9	2.0	3.0	3.6	2.0	3.0	2.4	1.6	1.9	3.0	2.7	2.6	1.6	2.5	2.4	2.8	3.0	3.0	2.5	2.2	2.0	1.5	3.0	2.0	1.6	2.1	2.0	2.0
Arrowhead	0	0.8	2.7	2.2	2.3	2.0	2.0	2.1	1.4	1.5	1.9	1.9	2.0	1.0	1.4	1.2	1.4	1.5	1.5	1.2	1.2	0.8	1.0	2.1	1.5	0.4	1.2	1.3	1.1
Bulrush	0	1.0	4.3	3.5	4.0	3.0	3.7	2.5	3.0	2.9	3.0	3.0	3.6	2.8	4.0	3.2	2.0	3.5	4.3	4.0	2.9	1.6	2.3	4.0	4.1	3.5	3.8	2.4	2.3
Rush	0	1.8	10.5	8.7	8.0	6.9	8.4	8.0	7.0	6.5	8.8	7.6	7.3	7.2	8.5	8.5	7.4	8.5	8.7	9.5	7.3	7.8	8.0	10.0	9.7	9.2	9.5	8.3	5.8
Algae	0	1.3	4.8	4.6	4.5	3.7	4.6	5.2	4.7	3.8	5.9	4.5	4.0	3.7	5.0	4.8	4.7	4.7	4.8	4.5	4.2	3.7	3.8	5.5	4.2	4.3	4.5	4.0	4.0
Control (no plants)	0	1.3	3.0	2.8	3.0	1.6	2.9	2.6	1.6	1.3	1.5	2.0	2.1	1.6	2.0	1.7	2.5	2.4	1.5	2.1	1.9	0.5	1.3	2.8	1.7	1.5	1.7	2.5	1.6
Evaporation Pan	0	1.3	1.5	1.8	1.9	1.1	1.4	1.3	1.2	1.4	0.9	1.7	1.3	0.6	1.5	1.2	0.6	1.4	1.2	1.1	102	0.1	1.3	2.0	0.9	1.4	1.4	1.3	0.5

Table D-24. Solar Radiation, Batch Study (Cal./cm^2/min)
December 22, 1978 - January 19, 1979

Time, days	Solar Radiation Cal./cm^2/min	Time, days	Solar Radiation Cal./cm^2/min
0	0.725	15	0.382
1	0.235	16	0.148
2	0.456	17	0.658
3	0.678	18	0.664
4	0.584	19	0.617
5	0.322	20	0.188
6	0.597	21	0.195
7	0.262	22	0.349
8	0.463	23	0.805
9	0.195	24	0.664
10	0.141	25	0.476
11	0.537	26	0.429
12	0.718	27	0.443
13	0.456	28	0.295
14	0.577		

Range: 0.141-0.805 Cal./cm^2/min

Average: 0.457 Cal./cm^2/min

Table D-25. Fecal Coliform Count, Batch Study (Fecal coliforms/100 ml)
December 22, 1978-January 19,1979

Plant in Aquarium	0 Day	1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days
Duckweed # 1	90	230	460	1,580	-	120	10	0	10
Duckweed # 2	70	-	-	-	-	-	20	30	0
Coontail	30	190	1,800	7,400	-	1,240	380	10	0
Elodea	0	160	620	8,360	100	-	20	0	0
Water-bonnet	0	0	40	1,360	-	0	0	0	0
Alligator-weed	0	0	70	7,080	-	120	0	0	0
Water hyacinths	0	10	-	320	0	0	0	0	0
Arrowhead	0	0	200	30	0	0	0	0	10
Bulrush	0	0	440	50	0	0	0	0	0
Rush	0	0	20	30	10	0	0	0	0
Algae	0	0	0	10	0	0	0	0	0
Control (no plants)	0	0	0	0	0	0	0	0	0

Table D-26. As Concentration in Plant Tissue (μg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days / Plant	0			1 *	7 *	14 *	21 *	28 *
	Root	Stem	Leaves					
Duckweed # 1	-	18.80*	-	17.00	27.80	-	-	18.60
Duckweed # 2	-	18.80*	-	-	-	21.40	14.40	25.80
Coontail	-	12.60*	-	14.80	16.60	-	-	46.40
Elodea	-	21.40*	-	22.20	23.40	-	32.00	-
Water-bonnet	17.60	17.00	15.80	15.20	18.40	-	-	20.60
Alligator-weed	68.93	70.40	77.00	71.87	77.73	-	83.60	-
Water hyacinths	60.13	39.60	37.40	58.80	70.40	-	77.00	-
Arrowhead	16.00	16.60	13.40	15.47	23.07	-	34.80	-
Bulrush	92.40	85.80	101.20	92.40	121.80	-	138.60	-
Rush	72.60	22.40	24.80	6.00	7.60	-	8.60	-

* Whole plant analysis (includes root, stem and leaves)

Table D-27. B Concentration in Plant Tissues, (μg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days Plant	0			1 *	7 *	21 *
	Root	Stem	Leaves			
Elodea	-	52.41 *	-	46.90	46.90	68.96
Water hyacinths	74.48	71.42	73.10	70.34	74.48	70.34
Bulrush	70.34	44.14	44.14	45.52	44.14	45.52

* Whole plant analysis (includes root, stem and leaves)

Table D-28. Cd Concentration in Plant Tissues (μg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days	0			1 *	7 *	14 *	21 *	28 *
Plant	Root	Stem	Leaves					
Duckweed # 1	-	3.40*	-	532.00	2,181.60	-	-	5,574.40
Duckweed # 2	-	3.40*	-	-	-	3,514.80	3,716.80	5,587.80
Coontail	-	2.60*	-	2,161.40	2,040.20	-	-	2,828.00
Elodea	-	1.00*	-	1,764.60	1,939.20	-	2,242.20	-
Water-bonnet	222.20	2.00	0.40	975.80	888.80	-	-	1,838.20
Alligator-weed	193.60	132.00	22.00	253.73	445.20	-	938.40	-
Water hyacinths	8.80	4.40	4.40	579.60	1,866.60	-	808.00	-
Arrowhead	1.20	0.40	0.80	604.80	520.80	-	969.60	-
Bulrush	0.80	0.00	0.00	61.60	121.00	-	92.40	-
Rush	1.33	0.80	0.80	68.20	145.20	-	138.60	-

* Whole plant analysis (includes root, stem and leaves)

Table D-29. Hg Concentration in Plant Tissues (μg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days / Plant	0			1 *	7 *	14 *	21 *	28 *
	Root	Stem	Leaves					
Duckweed # 1	-	34.64*	-	182.40	595.20	-	-	911.20
Duckweed # 2	-	34.64*	-	-	-	1,026.40	1,204.80	1,851.20
Coontail	-	4.88*	-	697.60	764.80	-	-	1,097.60
Elodea	-	1.78*	-	600.00	739.00	-	814.00	-
Water-bonnet	39.12	36.88	32.64	604.80	637.60	-	-	982.40
Alligator-weed	42.00	34.00	7.12	62.40	182.40	-	595.20	-
Water hyacinths	58.20	38.88	21.12	75.20	716.80	-	764.80	-
Arrowhead	74.40	162.24	24.00	226.80	416.80	-	955.20	-
Bulrush	52.20	26.84	3.63	30.64	484.40	-	433.20	-
Rush	40.00	6.24	8.24	25.12	225.60	-	237.60	-

* Whole plant analysis (includes root, stem and leaves)

Table D-30. Se Concentration in Plant Tissue (μg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days / Plant	0			1 *	7 *	14 *	21 *	28 *
	Root	Stem	Leaves					
Duckweed # 1	-	233.20*	-	246.40	237.60	-	-	236.13
Duckweed # 2	-	233.20*	-	-	-	261.80	233.20	250.80
Coontail	-	244.20*	-	301.40	246.40	-	-	286.00
Elodea	-	235.40*	-	228.80	231.00	-	211.20	-
Water-bonnet	270.60	277.20	250.80	261.80	279.40	-	-	299.20
Alligator-weed	213.40	222.20	230.27	209.00	228.80	-	253.00	-
Water hyacinths	198.00	203.87	206.80	215.60	220.00	-	237.60	-
Arrowhead	294.80	259.60	261.80	272.80	270.60	-	268.40	-
Bulrush	205.33	193.60	167.20	202.20	403.20	-	357.00	-
Rush	356.40	239.80	226.60	178.20	218.50	-	214.10	-

* Whole plant analysis (includes root, stem and leaves)

Table D-31. Phenol Concentration in Plant Tissue (μg/gm Dry Plant Tissue), Batch Study December 22, 1978 - January 19, 1979

Time, Days / Plant	0			1 *	7 *	21 *
	Root	Stem	Leaves			
Elodea	-	18.93*	-	17.10	42.00	48.07
Water hyacinths	15.98	14.46	10.69	28.47	12.38	22.96
Bulrush	5.37	3.11	2.52	4.76	4.14	5.14

* Whole plant analysis (includes root, stem and leaves)

Table D-32. PCB's Concentration in Plant Tissue (μg/gm Dry plant tissue), Batch Study
December 22, 1978 - January 19, 1979

Time,Days	0			1 *	7 *	10 *	14 *	21 *
Plant	Roots	Stems	Leaves					
Duckweed # 1	-	5.3975 *	-	4.9193	12.0147	-	-	-
Duckweed # 2	-	5.3975 *	-	-	-	-	14.2138	22.9245
Coontail	-	3.6400 *	-	6.8361	15.4613	15.1419	-	-
Elodea	-	0.2355 *	-	0.7562	1.9392	-	-	1.8120
Water-bonnet	0.0000	0.0261	0.4028	6.6730	6.2617	6.2805	-	-
Alligator-weed	0.3646	0.2934	2.2636	0.5961	0.9009	-	-	0.8642
Water hyacinths	0.5210	0.3205	0.3248	1.2998	3.0467	-	-	3.6360
Arrowhead	0.2588	0.1417	0.1967	0.4831	2.9123	-	-	6.5655
Bulrush	0.4751	0.2661	0.4071	0.1620	0.1959	-	-	0.3021
Rush	0.0000	0.5519	0.5109	0.0000	0.8255	-	-	1.0414

* Whole plant analysis (includes roots, stems and leaves)

Table D-33. Total N Concentration in Plant Tissue (μg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days Plant	0			1 *	7 *	14 *	21 *	28 *
	Root	Stem	Leaves					
Duckweed # 1	-	45,360.0*	-	44,240.0	32,797.3	-	-	466.7
Duckweed # 2	-	45.360.0*	-	-	-	17,042.7	32,125.3	27,626.7
Coontail	-	33,544.0*	-	33,264.0	34,533.3	-	-	3,937.5
Elodea	-	29,866.7*	-	31,360.0	34,160.0	-	32,890.7	-
Water-bonnet	23,800.0	22,866.7	26,842.7	30,426.7	32,554.7	-	-	37,016.0
Alligator-weed	14,186.7	11,200.0	22,754.7	11,629.3	5,954.7	-	9,034.7	-
Water hyacinths	5,786.7	18,666.7	31,882.7	24,733.3	27,365.3	-	29,848.0	-
Arrowhead	23,762.7	30,706.7	33,861.3	35,914.7	32,013.3	-	41,813.3	-
Bulrush	8,381.3	12,058.7	9,520.0	7,989.3	8,650.0	-	9,520.0	-
Rush	8,493.3	15,064.0	13,440.0	13,440.0	12,936.0	-	11,013.3	-

* Whole plant analysis (includes root, stem and leaves)

Table D-34. Total P Concentration in Plant Tissue, (µg/gm Dry Plant Tissue), Batch Study
December 22, 1978 - January 19, 1979

Time, Days / Plant	0			1*	3*	5*	7*	10*	14*	21*	28		
	Root	Stem	Leaves								Root	Stem	Leaves
Duckweed # 1	-	7,968.0*	-	7,648.0	8,704.0	8,096.0	8,624.0	8,864.0	- **	- **	-	8,080.0*	-
Duckweed # 2	-	7,968.0*	-	-	-	-	-	-	7,712.0	8,480.0	-	9,520.0*	-
Coontail	-	16,608.0*	-	14,112.0	14,000.0	12,288.0	16,064.0	16,640.0	- **	- **	-	16,064.0*	-
Elodea	-	12,800.0*	-	12,464.0	11,808.0	10,000.0	13,344.0	13,344.0	13,536.0	16,640.0	-	18,144.0*	-
Water-bonnet	4,048.0	4,352.0	7,552.0	6,704.0	6,656.0	6,496.0	6,944.0	7,168.0	- **	- **	- **	10,016.0*	-**
Alligator-weed	7,152.0	2,560.0	2,592.0	2,560.0	2,000.0	2,624.0	3,136.0	2,992.0	3,200.0	3,904.0	4,976.0	3,520.0	4,800.0
Water hyacinths	3,616.0	6,112.0	7,024.0	5,824.0	6,304.0	6,192.0	5,536.0	4,512.0	4,864.0	6,304.0	5,216.0	5,344.0	5,472.0
Arrowhead	4,864.0	4,048.0	4,864.0	5,472.0	4,496.0	5,232.0	4,368.0	7,392.0	4,752.0	5,248.0	7,600.0	4,544.0	7,392.0
Bulrush	960.0	1,120.0	288.0	512.0	736.0	1,680.0	912.0	256.0	320.0	384.0	1,184.0	2,240.0	1,488.0
Rush	2,144.0	2,464.0	1,920.0	2,912.0	3,920.0	3,984.0	3,920.0	2,944.0	3,536.0	1,920.0	2,624.0	4,400.0	1,280.0

* Whole Plant Analysis (includes root, stem and leaves)

** Insufficient plant weight for sampling

Table D-35. Wet Weight of Plants in Aquarium (gm), Batch Screening, December 22, 1978 - January 19, 1979

Plant	Total Wet Weight at 0 Day	Quantity of Plant Tissue Removed During Sampling								Total Wet Weight at the end of Experiment*	% Wet Weight Increase
		1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days		
Duckweed # 1	389.00	50.60	46.39	52.53	52.84	68.20	-	-	148.13	418.69	7.63
Duckweed # 2	389.00	-	-	-	-	-	109.00	111.55	144.63	365.18	-6.12
Coontail	714.20	50.80	39.90	28.34	74.17	63.24	-	-	9.40	265.85	-62.78
Elodea	734.60	47.29	42.30	47.40	63.23	76.10	58.82	82.84	125.20	543.18	-26.06
Water-bonnet	630.50	76.60	30.50	78.30	42.91	68.11	-	-	41.95	338.37	-46.33
Alligator-weed	1,146.00	82.71	73.05	63.60	90.00	60.25	78.63	82.29	1,213.80	1,744.33	52.21
Water hyacinths	1,442.30	148.32	128.50	100.00	155.21	144.80	117.87	85.69	422.60	1,302.99	-9.66
Arrowhead	1,107.00	57.31	52.40	43.60	75.32	87.72	87.15	71.00	759.40	1,233.90	11.46
Bulrush	3,200.50	124.50	73.30	128.18	86.22	105.85	127.60	123.29	3,004.00	3,772.94	17.89
Rush	3,421.90	67.98	60.01	49.86	81.57	108.63	102.34	116.36	3,073.27	3,660.02	6.96

* includes weight of plant tissue removed during sampling

Table D-36. Dry Weight of Plant Tissue in Aquarium, Batch Study (gm)
December 22, 1978 - January 19, 1979

Plant	0 Day	Dry Weight Plant Tissues Removed for Sampling 1 Day	3 Days	5 Days	7 Days	10 Days	14 Days	21 Days	28 Days	Total* Dry Weight	% Dry Weight Increase
Duckweed # 1	25.246	1.760	1.814	2.175	1.800	2,410	-	-	4.820	14,788	-41.42
Duckweed # 2	25.246	-	-	-	-	-	3.314	2.960	3.992	10.266	-59.34
Coontail	48.208	3.630	1.544	2.454	3.360	2,764	-	-	0.650	14.402	-70.12
Elodea	38.052	3.060	2.200	2.420	2.810	2.983	2.341	3,310	5.922	25.046	-34.18
Water-bonnet	29.633	3.610	1.800	3.980	2.935	4.300	-	-	2.404	19.029	-35.78
Alligator-weed	251.203	17.770	16.064	12.370	15.813	12.190	13.996	14.606	212.900	315.709	25.68
Water hyacinths	89.567	8.113	7.723	6.010	9.640	8.080	10.530	4.380	19.313	73.789	-17.62
Arrowhead	55.903	2.880	3.202	6.790	4.040	4.730	4.532	2.762	36.451	65.387	16.96
Bulrush	612.256	30.590	14.052	27.495	18.090	24.960	29.950	22.772	609.812	777.721	27.02
Rush	631.340	13.910	11.460	10.421	17.105	25.770	20,754	26.950	598.366	724.736	14.79

* Includes weight of plant tissue removed during sampling.

Table D-37. Dry to Wet Weight Percentage of Plant Tissue (%), Batch Study
December 22, 1978 - January 19, 1979

Days Plant	0	1	3	5	7	10	14	21	28
Duckweed # 1	6.49	3.47	3.91	4.14	3.40	3.53	-	-	3.26
Duckweed # 2	6.49	-	-	-	-	-	3.04	2.65	2.76
Coontail	6.75	7.14	3.87	8.66	4.53	4.37	-	-	6.92
Elodea	5.18	6.48	5.20	5.10	4.44	3.92	3.98	3.99	4.73
Water-bonnet	4.70	4.71	5.90	5.08	6.84	6.31	-	-	5.73
Alligator-weed	21.92	21.49	21.99	19.45	17.57	20.23	17.80	17.75	17.54
Water hyacinths	6.21	5.47	6.01	6.01	6.21	5.58	5.92	5.11	4.57
Arrowhead	5.05	5.03	6.11	6.79	5.36	5.39	5.20	3.89	4.80
Bulrush	19.13	24.57	19.17	21.45	20.98	23.58	23.47	18.47	20.30
Rush	18.45	20.46	19.09	20.90	20.97	23.72	20.28	23.16	19.47

APPENDIX E

Continuous Flow Study, Nonrecirculation Data

Table E-1. Pre-test of Marine Epoxy Painted Test Chamber (June 5-19, 1979)

Time, Days Test Parameters	0 (6-5-79)	7 (6-12-79)	14 (6-19-79)	% Loss in Test Chamber
Temp, °C	25.0	22.8	23.7	-
pH	7.1	7.5	7.4	-
DO, mg/1	4.3	0.8	0.4	-
Evaporation, cm/wk	0	1.20	1.05	-
As, mg/1	1.101	1.057	1.075	2.36
B, mg/1	1.005	0.924	0.996	0.89
Cd, mg/1	1.045	1.040	0.913	12.63
Hg, mg/1	1.039	0.500	0.722	30.51
Se, mg/1	1.358	1.215	1.347	0.81
Phenol, mg/1	0.594	0.300	0.419	28.81
PCB, mg/1	0.004	0.004	0.003	25.00

Table E-2. Biochemical Oxygen Demand (BOD_5), mg/l, Continuous Flow Study, Nonrecirculation, 15 Day Retention, (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	34.56	0.82	97.63	35.88	20.98	41.53	36.00	21.39	40.58	27.39	9.93	63.74
34	31.03	0.10	99.68	28.71	25.20	12.22	30.84	28.07	8.98	27.91	8.50	69.54
37	46.31	2.30	95.03	51.49	22.63	56.05	-	-	-	51.19	14.69	71.30
41	26.73	1.99	92.55	27.50	15.52	43.56	-	-	-	26.00	8.81	66.11
44	40.74	3.75	90.79	36.20	12.88	64.42	-	-	-	30.48	5.70	64.66
48	73.80	8.68	88.24	71.20	8.84	87.58	-	-	-	60.00	10.77	82.05
51	59.88	8.96	85.04	61.76	13.20	78.63	-	-	-	35.68	21.65	39.32
58	51.13	8.01	84.33	50.98	14.91	70.75	-	-	-	33.90	14.34	57.70

* I = Influent

E = Effluent

% Red = % Reduction

Table E-3. Total Organic Carbon (TOC), mg/l, Continuous Flow Study, Nonrecirculation, 15 Day Retention, (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	20.3	13.3	34.48	21.3	15.6	26.76	19.7	26.9	-36.55	19.7	19.1	3.04
34	19.1	7.6	60.21	20.2	15.4	23.76	18.6	18.5	0.54	18.1	17.6	2.76
37	20.4	11.1	45.59	18.7	9.4	49.73	-	-	-	18.0	12.8	28.89
41	12.5	3.9	68.80	12.8	14.9	-16.41	-	-	-	12.2	16.8	-37.70
44	39.1	7.9	79.79	38.4	15.8	58.85	-	-	-	22.2	12.0	45.94
48	43.7	14.0	67.96	43.8	14.0	77.60	-	-	-	18.8	15.8	15.96
51	25.9	11.0	57.53	29.2	16.7	42.81	-	-	-	20.0	10.7	46.50
58	22.7	10.5	53.74	22.5	16.4	27.11	-	-	-	18.9	10.7	43.39

* I = Influent

E = Effluent

% Red = % Reduction

Table E-4. Suspended Solids (SS), mg/l, Continuous Flow Study, Nonrecirculation, 15 Day Retention, (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	58.0	<0.1	100.00	44.0	9.0	79.54	12.0	6.0	50.00	21.0	18.0	14.28
34	16.0	<0.1	100.00	15.0	5.0	66.67	17.0	4.0	76.47	12.0	20.0	-66.67
37	73.0	<0.1	100.00	70.0	6.0	91.43	-	-	-	44.0	30.0	31.82
41	26.0	<0.1	100.00	26.0	<0.1	100.00	-	-	-	12.0	6.0	50.00
44	257.0	2.0	99.22	342.0	15.0	95.61	-	-	-	144.0	5.0	96.53
48	160.0	<0.1	100.00	158.0	8.0	94.94	-	-	-	106.0	4.0	96.23
51	128.0	1.0	99.22	143.0	4.0	97.20	-	-	-	102.0	3.0	97.05
58	124.0	3.0	97.58	88.0	4.0	95.45	-	-	-	72.0	12.0	83.33

* I = Influent

E = Effluent

% Red = % Reduction

Table E-5. Volatile Suspended Solids (VSS), mg/l, Continuous Flow Study, Nonrecirculation, 15 Day Retention, (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	44.0	<0.1	>99.77	33.0	9.0	72.73	12.0	6.0	50.00	18.0	18.0	0
34	15.0	<0.1	>99.33	15.0	5.0	66.67	15.0	4.0	73.33	12.0	20.0	-66.67
37	43.0	<0.1	>99.77	42.0	6.0	85.71	-	-	-	29.0	30.0	-3.45
41	26.0	<0.1	>99.61	26.0	<0.1	>99.61	-	-	-	12.0	6.0	50.00
44	136.0	2.0	98.53	202.0	13.0	93.56	-	-	-	96.0	5.0	94.79
48	120.0	0.1	99.92	122.0	8.0	93.44	-	-	-	81.0	4.0	95.06
51	76.0	1.0	98.68	89.0	4.0	95.50	-	-	-	63.0	3.0	95.24
58	84.0	3.0	96.43	66.0	10.0	84.85	-	-	-	58.0	15.0	74.14

* I = Influent

E = Effluent

% Red = % Reduction

Table E-6. As Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	1.177	1.111	5.61	1.144	0.731	36.10	1.171	0.649	44.58	1.094	1.045	4.48
34	1.133	1.138	0	1.133	0.720	36.45	1.078	0.847	21.43	1.056	1.100	0
37	1.171	1.138	0	1.177	0.814	30.84	-	-	-	1.100	1.111	0
41	1.160	1.221	0	1.122	0.885	21.12	-	-	-	1.127	1.166	0
44	1.408	1.050	25.43	1.386	0.858	38.09	-	-	-	1.292	1.138	11.92
48	1.347	1.199	10.99	1.287	1.012	21.37	-	-	-	1.133	1.160	0
51	1.045	1.226	0	1.078	1.056	2.04	-	-	-	1.067	1.050	0
58	1.170	1.166	0.34	1.171	1.102	5.89	-	-	-	1.130	1.144	0

* I = Influent

E = Effluent

% Red = % Reduction

Table E-7. B Water Concentration (mg/l), Continuous Flow Study,
Nonrecirculation - 15 day Retention
July 4 - August 31, 1979

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.	I	E	% Reduc.
30	1.519	1.806	Inc. **	1.624	1.728	Inc.	1.164	1.299	Inc.	0.922	1.820	Inc.
34	1.884	1.763	6.42	1.884	1.620	14.01	1.772	1.730	2.37	2.016	2.016	0.00
37	1.559	1.720	Inc.	1.728	1.735	Inc.	-	-	-	1.783	1.842	Inc.
41	1.806	1.795	0.61	2.180	2.026	7.06	-	-	-	1.884	1.848	1.91
44	1.417	1.419	Inc.	1.141	1.784	Inc.	-	-	-	1.417	1.790	Inc.
48	1.624	1.622	0.12	1.477	1.664	Inc.	-	-	-	1.729	1.760	Inc.
51	1.689	1.689	0.00	1.728	1.619	6.31	-	-	-	1.730	1.764	Inc.
58	1.269	1.299	Inc.	1.477	1.619	Inc.	-	-	-	1.596	1.596	0.00

* I = Influent E = Effluent % Reduc. = % Reduction

** Inc. = Increase

Table E-8. Cd Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	1.573	0.550	65.03	1.523	0.242	84.11	1.107	0.192	82.65	1.199	0.423	64.72
34	1.089	0.517	52.52	1.078	0.198	81.63	1.056	0.159	84.94	1.171	0.379	67.63
37	1.540	0.451	70.71	1.534	0.275	82.07	-	-	-	1.391	0.242	82.60
41	1.402	0.368	73.75	1.116	0.297	73.39	-	-	-	0.759	0.231	69.56
44	1.727	0.231	86.62	1.705	0.176	89.68	-	-	-	1.094	0.154	85.92
48	1.749	0.187	89.31	1.815	0.187	89.70	-	-	-	1.617	0.209	87.07
51	1.336	0.192	85.63	1.375	0.143	89.60	-	-	-	1.320	0.231	82.50
58	1.562	0.209	86.62	1.507	0.088	94.16	-	-	-	1.441	0.198	86.26

* I = Influent

E = Effluent

% Red = % Reduction

Table E-9. Hg Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	1.305	0.255	80.46	1.305	0.222	82.99	0.972	0.167	82.82	1.117	0.255	77.17
34	1.278	0.289	77.39	1.270	0.189	85.12	1.225	0.194	84.16	1.225	0.180	85.31
37	1.511	0.300	80.14	1.520	0.172	88.68	-	-	-	1.233	0.287	76.72
41	1.225	0.133	89.14	0.967	0.219	77.35	-	-	-	0.950	0.287	69.79
44	1.961	0.264	86.54	1.933	0.122	93.69	-	-	-	1.630	0.250	84.66
48	1.882	0.144	92.35	1.880	0.155	91.75	-	-	-	1.722	0.233	86.47
51	1.594	0.131	91.78	1.883	0.122	93.52	-	-	-	0.960	0.227	76.35
58	1.634	0.087	94.67	1.624	0.100	93.84	-	-	-	1.056	0.233	77.93

* I = Influent

E = Effluent

% Red=% Reduction

Table E-10. Se Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	1.606	1.045	34.93	1.573	0.368	76.60	1.562	0.341	78.17	1.567	0.781	50.16
34	1.804	1.276	29.27	1.617	0.423	73.84	1.754	0.291	83.41	1.578	0.825	47.72
37	1.474	0.964	34.60	1.463	0.280	80.86	-	-	-	1.441	0.888	38.38
41	1.391	0.895	35.66	1.386	0.423	69.48	-	-	-	1.386	0.850	38.67
44	1.694	0.906	46.52	1.694	0.433	74.44	-	-	-	1.518	0.852	43.87
48	1.474	0.990	32.83	1.463	0.363	75.19	-	-	-	1.430	0.883	38.25
51	1.435	0.940	34.49	1.463	0.238	83.73	-	-	-	1.331	0.860	35.39
58	1.459	0.797	45.37	1.459	0.313	78.55	-	-	-	1.441	0.946	34.35

* I = Influent

E = Effluent

% Red = % Reduction

Table E-11. Phenol Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	1.011	0.003	99.70	1.006	0.024	97.61	1.004	0.036	96.41	0.764	0.410	46.33
34	0.906	0.000	100.00	0.921	0.029	96.85	0.906	0.040	95.58	0.876	0.319	63.58
37	1.192	0.068	94.29	1.094	0.094	91.41	-	-	-	0.962	0.406	57.80
41	1.008	0.008	99.21	0.987	0.032	96.76	-	-	-	1.037	0.220	78.78
44	1.312	0.082	93.75	1.312	0.125	90.47	-	-	-	1.275	0.340	73.33
48	1.054	0.069	93.45	1.023	0.090	91.20	-	-	-	1.004	0.088	92.23
51	0.936	0.087	90.70	0.928	0.094	89.87	-	-	-	0.886	0.210	76.30
58	0.936	0.102	89.10	0.931	0.134	85.61	-	-	-	0.858	0.316	63.17

* I - Influent

E = Effluent

% Red = % Reduction

Table E-12. PCB's Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation
15 Day Retention
July 4 - August 31, 1979

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.	I	E	% Reduc.
30	0.033	0.000	100.00	0.021	0.018	14.28	0.063	0.000	100.00	0.041	0.106	Inc.**
34	0.051	0.000	100.00	0.022	0.000	100.00	0.046	0.000	100.00	0.034	0.014	58.82
37	0.044	0.000	100.00	0.029	0.000	100.00	-	-	-	0.016	0.000	100.00
41	0.012	0.000	100.00	0.012	0.000	100.00	-	-	-	0.010	0.000	100.00
44	0.121	0.000	100.00	0.067	0.000	100.00	-	-	-	0.018	0.061	Inc.
48	0.099	0.000	100.00	0.118	0.004	96.61	-	-	-	0.064	0.002	96.87
51	0.031	0.000	100.00	0.017	0.004	76.47	-	-	-	0.040	0.001	97.50
58	0.050	0.006	88.00	0.040	0.000	100.00	-	-	-	0.052	0.025	51.92

* I = Influent, E = Effluent, % Reduc. = % Reduction

** Inc. = Increase

Table E-13. Total Nitrogen Water Concentration (includes TKN, NH_3, NO_3-N, and NO_2-N), mg/l
Continuous Flow Study - Nonrecirculation, 15 Day Retention
July 4 - August 31, 1979

Time, Days	Water hyacinths				Bulrush				Elodea				Control (no plants)			
	I*	P*	E*	% Reduc.*	I	P	E	% Reduc.	I	P	E	% Reduc.	I	P	E	% Reduc.
30	30.20	6.47	2.96	90.20	30.34	10.90	10.04	66.91	31.48	22.04	22.20	29.48	28.24	4.01	4.58	83.78
34	27.49	6.53	4.02	85.38	28.32	10.72	9.30	67.16	29.93	19.05	17.13	42.77	24.88	4.09	4.09	83.56
37	39.16	6.05	3.50	91.06	37.25	11.47	10.97	70.55	-	-	-	-	35.74	4.09	3.80	89.37
41	8.98	8.04	7.24	19.38	9.18	9.57	8.58	6.53	-	-	-	-	7.42	4.91	4.40	40.70
44	27.16	8.38	4.43	83.69	22.17	10.45	7.98	64.00	-	-	-	-	20.32	5.31	4.93	75.74
48	19.30	7.36	6.43	66.68	19.14	5.91	6.28	67.19	-	-	-	-	9.61	6.84	6.87	28.51
51	9.73	7.17	6.89	29.19	11.82	8.63	8.24	30.29	-	-	-	-	12.13	8.13	6.90	43.12
58	12.68	7.12	10.82	14.67	11.44	2.60	1.52	86.71	-	-	-	-	11.12	9.01	8.53	23.29

* I = Influent, E = Effluent
P = In-pond, % Reduc. = % Reduction

Table E_14. TKN Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention
(July 4 - August 31, 1979)

Time, Days	Water hyacinths				Bulrush				Elodea				Control (no plants)			
	I*	P*	E*	% Red*	I*	P*	E*	% Red*	I*	P*	E*	% Red*	I*	P*	E*	% Red*
30	19.8	2.9	1.9	90.40	19.0	9.0	7.8	58.95	17.9	14.2	14.7	17.88	17.9	3.9	4.5	74.86
34	17.9	2.6	0.8	95.53	18.7	7.7	7.4	60.43	19.0	13.0	12.2	35.79	17.9	3.9	3.9	78.21
37	22.2	1.6	0.3	98.65	21.5	7.8	7.5	65.12	-	-	-	-	20.7	3.1	3.4	83.57
41	3.2	1.9	0.9	71.87	3.5	7.6	6.9	-97.14	-	-	-	-	2.0	3.9	3.4	-70.00
44	16.8	1.9	0.3	98.21	12.3	7.2	6.3	48.78	-	-	-	-	11.1	2.9	2.5	77.48
48	13.4	1.1	0.3	97.76	12.7	4.6	4.6	63.78	-	-	-	-	4.7	3.1	2.8	40.42
51	4.8	1.1	1.1	77.08	7.2	5.4	6.0	16.67	-	-	-	-	7.2	2.6	2.6	63.89
58	6.2	1.0	3.9	37.09	5.0	0.0	0.8	84.00	-	-	-	-	4.9	2.5	2.3	53.06

* I = Influent E = Effluent
P = In-Pond % Red = % Reduction

Table E-15. NH_3 - Nitrogen (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths				Bulrush				Elodea				Control (no plants)			
	I*	P*	E*	% Red*	I*	P*	E*	% Red*	I*	P*	E*	% Red*	I*	P*	E*	% Red*
30	10.08	0.45	0.00	100.00	10.98	1.90	2.24	79.60	13.33	7.84	7.50	43.73	10.08	0.00	0.00	100.00
34	8.85	0.45	0.00	100.00	9.07	3.02	1.90	79.05	10.08	6.05	4.93	51.09	6.16	0.00	0.00	100.00
37	14.00	0.00	0.00	100.00	13.66	3.58	3.47	74.60	-	-	-	-	13.44	0.56	0.00	100.00
41	0.00	0.00	0.00	100.00	0.00	1.90	1.68	-168.00	-	-	-	-	0.00	0.56	0.56	-56.00
44	3.47	0.34	0.00	100.00	2.80	2.46	1.68	40.00	-	-	-	-	2.46	0.00	0.00	100.00
48	0.00	0.00	0.00	100.00	0.00	1.23	1.68	-168.00	-	-	-	-	0.00	0.56	0.34	-34.00
51	0.00	0.00	0.00	100.00	0.00	1.12	2.24	-224.00	-	-	-	-	0.00	0.00	0.00	0.00
58	0.56	0.56	1.46	-160.71	0.56	1.68	0.34	39.28	-	-	-	-	0.34	0.34	0.00	100.00

* I = Influent E = Effluent
P = In-Pond % Red = % Reduction

Table E-16. Nitrate (NO_3-N) Water Concentration (mg/l as NO_3-N)
Continuous Flow Study, Nonrecirculation
15 Day Retention
July 4 - August 31, 1979

Time,Days	Water hyacinths				Bulrush				Elodea				Control (no plants)			
	I*	P*	E*	% Reduc.	I	P	E	% Reduc.	I	P	E	% Reduc.	I	P	E	% Reduc.
30	0.29	3.11	1.06	Inc. **	0.33	0.00	0.00	100.00	0.22	0.00	0.00	100.00	0.24	0.00	0.00	100.00
34	0.62	3.40	3.22	Inc.	0.46	0.00	0.00	100.00	0.74	0.00	0.00	100.00	0.72	0.13	0.13	81.94
37	2.88	4.36	3.20	Inc.	2.00	0.00	0.00	100.00	-	-	-	-	1.56	0.35	0.35	77.56
41	5.69	6.06	6.34	Inc.	5.57	0.00	0.00	100.00	-	-	-	-	5.34	0.38	0.38	92.88
44	6.81	6.07	4.13	39.35	6.97	0.71	0.00	100.00	-	-	-	-	6.70	2.34	2.36	64.48
48	5.78	6.19	6.13	Inc.	6.31	0.00	0.00	100.00	-	-	-	-	4.81	3.08	3.67	23.70
51	4.84	5.98	5.79	Inc.	4.51	2.04	0.00	100.00	-	-	-	-	4.84	5.43	4.23	12.60
58	5.82	5.46	5.42	6.87	5.80	0.84	0.37	93.62	-	-	-	-	5.80	6.06	6.18	Inc.

* I = Influent, E = Effluent

P = In-pond, % Reduc. = % Reduction

** Inc. = Increase

Table E-17. Nitrite (NO_2-N) Water Concentration (mg/l as NO_2-N)

Continuous Flow Study, Nonrecirculation
15 Day Retention
July 4 - August 31, 1979

Time,Days	Water hyacinths				Bulrush				Elodea				Control (no plants)			
	I*	P*	E*	%Reduc.*	I	P	E	%Reduc.	I	P	E	%Reduc.	I	P	E	%Reduc.
30	0.03	0.01	0.00	100.00	0.03	0.00	0.00	100.00	0.03	0.00	0.00	100.00	0.02	0.11	0.08	Inc.**
34	0.12	0.08	0.00	100.00	0.09	0.00	0.00	100.00	0.11	0.00	0.00	100.00	0.10	0.06	0.06	40.00
37	0.08	0.09	0.00	100.00	0.09	0.09	0.00	100.00	-	-	-	-	0.04	0.08	0.05	Inc.
41	0.09	0.08	0.00	100.00	0.11	0.07	0.00	100.00	-	-	-	-	0.08	0.07	0.06	25.00
44	0.08	0.07	0.00	100.00	0.10	0.08	0.00	100.00	-	-	-	-	0.06	0.07	0.07	Inc.
48	0.12	0.07	0.00	100.00	0.13	0.08	0.00	100.00	-	-	-	-	0.10	0.10	0.06	40.00
51	0.09	0.09	0.00	100.00	0.11	0.07	0.00	100.00	-	-	-	-	0.09	0.10	0.07	22.22
58	0.10	0.10	0.04	60.00	0.08	0.08	0.01	87.50	-	-	-	-	0.08	0.11	0.05	37.50

* I = Influent E = Effluent

P = In-pond % Reduc. = % Reduction

** Inc. = Increase

Table E-18. Phosphate ($PO_4^{\equiv}$) Water Concentration (mg/l), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths				Bulrush				Elodea				Control (no plants)			
	I*	P*	E*	% Red*	I	P	E	% Red	I	P	E	% Red	I	P	E	% Red
30	4.18	4.00	2.63	37.08	4.42	6.14	5.34	Inc.**	4.16	6.17	6.83	Inc.	3.73	2.96	3.17	15.01
34	4.62	3.91	3.63	21.43	4.91	4.74	4.82	1.83	5.40	5.66	7.26	Inc.	4.66	4.17	4.18	10.30
37	5.60	3.46	3.91	30.18	6.44	5.46	6.83	Inc.	-	-	-	-	5.98	4.42	4.42	26.09
41	4.59	3.48	3.54	22.87	5.01	4.42	3.34	33.33	-	-	-	-	4.13	4.32	4.84	Inc.
44	8.42	3.91	3.90	53.68	6.58	3.80	3.97	39.66	-	-	-	-	7.74	5.46	5.16	33.33
48	10.72	3.84	3.84	64.18	9.99	4.48	4.96	50.35	-	-	-	-	7.62	5.28	5.28	30.71
51	6.57	4.05	3.89	40.79	6.24	4.48	4.43	29.01	-	-	-	-	5.92	5.37	4.96	16.22
58	5.57	2.47	3.82	31.42	5.28	3.26	3.84	27.27	-	-	-	-	5.57	4.18	5.73	Inc.

* I = Influent　E = Effluent　** Inc. = Increase
P = In-Pond　% Red = % Reduction

Table E-19. Water Temperature (°C), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant	Time, Days																												
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Water hyacinths	27.6	30.8	25.7	25.0	24.0	25.1	25.3	23.3	23.2	25.0	25.3	26.2	26.1	26.2	25.2	25.4	25.4	23.9	22.3	22.7	23.7	24.4	24.6	24.0	23.5	23.4	23.7	24.0	26.3
Bulrush	27.8	29.3	25.1	25.6	24.3	25.3	25.1	23.4	22.6	25.0	24.9	25.0	25.0	24.7	22.3	23.0	23.3	22.8	21.5	22.0	20.5	23.0	23.2	22.9	22.3	22.0	22.3	23.0	24.7
Elodea	28.0	30.2	25.7	27.3	25.0	27.9	28.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control (no plants)	28.2	33.9	27.4	30.7	26.3	30.2	29.7	27.0	24.7	28.9	30.0	30.3	30.0	31.7	28.8	28.5	28.0	26.3	23.6	24.0	25.0	29.0	27.0	26.9	26.0	25.9	26.2	27.0	30.0

Table E-20. Pond Dissolved Oxygen Concentration (D.O.), mg/l, Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant	Time, Days																												
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Water hyacinths	2.0	1.9	1.4	1.5	2.3	1.7	1.7	2.4	2.4	2.1	1.7	1.7	1.8	1.9	2.2	2.2	2.2	2.3	2.5	2.4	1.8	1.7	1.7	1.9	2.3	2.4	2.3	2.2	2.1
Bulrush	0.2	1.1	0.6	1.3	1.0	1.0	0.7	0.6	0.8	0.9	0.9	1.0	1.0	1.1	1.2	1.2	1.1	1.2	1.1	1.2	1.0	1.2	1.2	1.4	1.4	1.5	1.6	2.3	2.6
Elodea	0.1	1.0	0.7	1.6	0.2	0.6	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control (no plants)	7.2	9.4	3.3	6.2	1.9	1.6	1.4	1.1	1.0	1.0	1.0	0.9	1.2	1.8	1.8	1.8	1.8	1.6	1.3	1.3	1.4	1.3	1.3	1.4	1.5	1.6	1.6	1.7	2.0

Table E-21. Influent pH, Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant	Time, Days																												
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Water hyacinths	8.8	8.5	7.7	9.1	8.9	7.9	8.3	9.2	8.8	8.7	8.7	8.3	8.4	8.5	7.5	8.3	8.9	8.0	7.8	7.9	7.1	8.8	8.8	8.7	7.9	7.8	7.8	7.7	7.6
Bulrush	8.9	8.6	7.8	9.1	8.9	8.0	8.3	9.2	8.9	8.8	8.7	8.4	8.6	8.7	7.6	8.2	8.9	8.1	7.9	8.0	7.2	8.9	8.8	8.7	7.9	7.9	7.9	7.9	7.7
Elodea	8.9	8.4	8.0	9.2	8.9	8.1	8.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control (no plants)	9.1	8.8	8.4	9.3	8.9	8.3	8.6	9.2	9.0	8.9	8.9	8.5	8.8	8.9	7.5	8.3	8.9	8.2	8.0	8.0	7.3	8.4	8.4	8.5	8.1	8.2	7.9	7.9	7.9

Table E-22, Pond pH, Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant	Time, Days																												
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Water hyacinths	7.1	7.7	7.2	7.3	6.9	7.5	7.4	7.0	7.3	7.3	7.3	6.9	7.2	7.3	6.9	7.1	7.3	6.9	6.8	6.9	7.1	6.8	7.0	7.0	7.2	7.3	7.3	7.0	6.9
Bulrush	7.1	7.5	7.5	7.5	7.1	7.5	7.6	7.1	7.4	7.4	7.3	7.1	7.4	7.5	7.2	7.3	7.5	7.2	7.1	7.1	7.5	7.0	7.1	7.1	7.2	7.4	7.2	7.1	7.1
Elodea	7.8	8.4	8.1	8.2	7.9	8.1	8.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control (no plants)	9.3	9.5	9.0	9.2	8.8	8.5	8.5	8.1	8.2	8.8	8.8	8.1	8.7	8.4	8.0	8.0	8.1	7.9	7.8	7.8	7.9	7.7	7.7	7.7	7.5	7.9	7.7	7.6	7.6

Table E-23. Effluent pH, Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant	Time, Days							
	30	34	37	41	44	48	51	58
Water hyacinths	7.0	7.4	7.5	7.5	7.6	7.4	7.4	7.4
Bulrush	7.2	7.4	7.7	7.6	7.7	7.6	7.7	7.5
Elodea	7.7	8.1	-	-	-	-	-	-
Control (no plants)	9.3	9.2	9.3	8.8	8.4	8.5	8.6	8.3

Table E-24. ORP, Continuous Flow Study - Nonrecirculation, 15 Day Retention (July 4-August 31, 1979)

PLANT SPECIES	TIME, DAYS																												
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Water hyacinths	182	176	173	183	175	183	177	177	177	176	174	175	178	187	179	178	181	176	176	176	170	172	172	179	178	179	178	178	172
Bulrush	160	164	144	154	149	174	150	174	182	170	166	168	164	176	177	179	177	184	170	180	156	164	170	176	172	170	176	177	176
Elodea	145	153	139	160	142	187	152	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control (no plants)	131	159	122	152	154	178	167	167	186	180	178	176	173	170	172	174	178	178	175	180	173	165	164	170	168	174	170	171	170

Table E-25. Flow Rate (ml/min.), Continuous Flow Study - Nonrecirculation, 15 Day Retention (July 4-August 31, 1979)

TEST CHAMBER	TIME, DAYS																												
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Water hyacinths																													
Influent	42.0	43.0	41.0	40.6	41.0	41.0	41.0	41.1	42.1	41.1	41.1	41.3	41.0	41.1	41.0	41.8	42.0	40.8	41.3	41.0	41.0	41.2	40.8	40.9	41.0	41.3	41.0	40.9	40.8
Effluent	41.0	41.0	41.0	41.0	41.0	41.0	40.9	41.0	41.0	41.1	40.9	41.0	40.9	41.0	41.3	41.0	41.0	41.0	41.0	41.0	40.9	41.0	41.0	40.7	41.0	41.0	41.0	41.0	41.0
Bulrush																													
Influent	41.2	42.8	41.7	40.8	41.2	41.0	41.0	41.2	40.9	41.2	41.0	41.4	41.2	41.1	41.1	40.9	40.8	40.7	41.2	41.2	40.8	41.4	40.7	41.3	40.9	41.4	41.1	41.0	41.3
Effluent	40.8	41.1	41.1	41.0	41.0	41.3	41.1	41.0	40.9	41.0	41.0	41.0	41.0	40.8	41.8	41.0	41.0	40.9	40.9	41.0	41.0	40.9	41.0	40.9	41.0	40.8	41.0	41.0	41.0
Elodea																													
Influent	41.0	41.5	40.9	41.0	41.3	40.9	41.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	40.7	41.0	41.2	41.1	41.1	41.0	41.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Control																													
Influent	4.2	4.2	4.2	4.3	4.2	4.3	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.1	4.3	4.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Effluent	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2

Table E-26. Evapotranspiration (mm/day), Continuous Flow Study - Nonrecirculation, 15 Day Retention (July 4-August 31, 1979)

	TIME, DAYS																												
TEST CHAMBER	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	Average
Water hyacinths	10.5	10.3	18.4	21.5	7.5	9.0	10.5	8.0	9.0	9.5	8.2	8.6	9.0	11.2	10.5	8.5	8.5	11.5	11.5	11.0	12.0	15.5	10.5	10.0	10.0	10.5	11.5	12.0	16.0	11.1
Bulrush	15.5	14.0	25.0	42.0	8.0	11.0	16.0	8.5	17.3	19.5	21.8	19.7	22.0	21.2	20.2	18.3	18.5	22.0	21.0	23.0	24.0	20.0	18.0	17.5	16.0	16.0	17.0	16.5	17.5	18.9
Elodea	13.6	12.0	17.0	14.5	6.0	2.7	2.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8
Evaporation Pan*	5.0	2.5	10.0	5.0	4.8	3.3	4.1	2.8	2.5	4.0	4.4	3.6	5.0	5.5	4.5	3.5	5.0	3.1	3.0	4.4	3.0	4.5	3.5	3.5	3.0	3.0	6.5	2.2	4.0	4.1

*Water loss due to evaporation only.

Table E-27. Solar Radiation (cal./cm^2/min.), Continuous Flow Study, Nonrecirculation, 15 Day Retention, (July 4-August 31, 1979)

TIME (DAYS)	SOLAR RADIATION, cal./cm^2/min.	TIME (DAYS)	SOLAR RADIATION, cal./cm^2/min.
30	1.389	45	1.114
31	1.275	46	1.087
32	0.933	47	0.986
33	1.194	48	0.718
34	0.886	49	0.993
35	0.993	50	0.892
36	1.141	51	1.275
37	0.919	52	0.926
38	0.671	53	0.765
39	0.973	54	0.624
40	1.161	55	0.986
41	0.899	56	1.161
42	1.228	57	1.121
43	1.201	58	1.262
44	0.825		

Range: 0.624-1.389 cal./cm^2/min.

Average: 1.021 cal./cm^2/min.

Table E-28. Fecal Coliform, cells/100 ml, Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, Days	Water hyacinths			Bulrush			Elodea			Control (no plants)		
	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*	I*	E*	% Red*
30	50,000	0	100.00	45,147	473	98.95	38,587	967	97.49	28,080	310	98.89
34	600	50	91.67	1,200	700	41.67	700	1,950	Inc**	700	1,350	Inc**
37	103,200	1,050	98.98	97,600	1,100	98.87	-	-	-	96,700	950	99.02
41	1,150	0	100.00	6,250	1,000	84.00	-	-	-	2,500	1,000	60.00
44	600	0	100.00	500	0	100.00	-	-	-	450	0	100.00
48	57,700	1,750	96.97	57,500	8,750	84.48	-	-	-	44,100	3,750	91.50
51	33,800	2,300	93.19	32,000	7,250	77.34	-	-	-	20,400	3,100	84.80
58	50,000	450	99.10	45,200	1,400	96.90	-	-	-	44,400	1,600	96.39

* I = Influent

E = Effluent

% Red = % Reduction

** Inc = Increase

Table E-29. As Concentration in Plant Tissue (µg/gm Dry Plant Tissue), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, days	0			30						37		44	51	58					
				Point A**			Point B**							Point A**			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	32.6	29.0	33.0	501.6	132.0	127.6	429.0	112.2	107.8	193.2	147.0	120.54	163.8	537.6	142.8	163.8	525.0	117.6	109.2
Bulrush	33.0	34.6	33.2	217.8	114.4	117.3	235.4	136.4	124.7	178.9	137.9	121.0	133.5	646.8	214.2	168.0	588.0	231.0	130.2
Elodea	-	30.6*	-	-	743.4*	-	-	718.2*	-	-	-	-	-	-	-	-	-	-	-

*Whole plant analysis (includes roots, stems, and leaves)

**Sampling Point A located in first partition of Test Chamber
Sampling Point B located in second partition of Test Chamber

Table E-30. B Concentration in Plant Tissue (µg/gm Dry Plant Tissue)
Continuous Flow Study, Nonrecirculation
15 Day Retention
July 4 - August 31, 1979

Time, Days	0			30			37	58		
				Point A **				Point A		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Roots	Stems	Leaves
Water hyacinths	365.6	200.0	320.0	246.8	340.8	168.0	236.4	240.5	220.0	409.2
Bulrush	222.8	113.6	294.0	226.8	220.0	257.6	206.0	360.8	306.4	368.4
Elodea	-	80.8*	-	-	481.2*	-	-	-	-	-

* Whole Plant Analysis (includes roots, stems, and leaves)

** Sampling Point A located in First Partition of Chamber

Table E-31. Cd Concentration in Plant Tissue (μg/gm Dry Plant Tissue), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, days	0			30						37		44	51	58					
				Point A**			Point B**							Point A**			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	2.0	0.4	0.8	932.8	147.4	19.8	605.0	35.2	13.2	352.8	138.6	302.4	352.8	1,558.2	277.2	46.2	1,146.6	100.8	25.2
Bulrush	2.0	0.4	0.4	545.6	239.4	206.8	369.6	145.2	217.8	398.2	246.4	292.6	303.6	1,041.6	348.6	105.0	1,150.8	483.0	407.4
Elodea	-	1.8*	-	-	1,373.4*	-	-	978.6*	-	-	-	-	-	-	-	-	-	-	-

* Whole plant analysis (includes roots, stems, and leaves)

** Sampling Point A located in first partition of Test Chamber
Sampling Point B located in second partition of Test Chamber

Table E-32. Hg Concentration in Plant Tissue (µg/gm Dry Plant Tissue), Continuous Flow Study, Nonrecirculation, 15 Day Retention
(July 4 - August 31, 1979)

Time, days	0			30						37		44	51	58					
				Point A**			Point B**							Point A**			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	1,120.0	768.8	240.0	5,088.0	4,616.8	4,568.0	4,421.6	4,399.2	4,377.6	3,946.4	3,815.2	14,418.6	14,254.8	19,131.0	13,532.0	5,178.6	5,342.4	1,948.8	4,981.2
Bulrush	231.2	724.0	884.0	6,256.8	4,472.6	1,949.2	2,382.6	2,334.2	3,471.6	726.0	1,381.6	642.4	935.0	1,692.6	1,797.6	1,037.4	2,238.6	1,423.8	2,251.2
Elodea	-	50.9*	-	-	5,749.8*	-	-	4,607.4*	-	-	-	-	-	-	-	-	-	-	-

* Whole plant analysis (includes roots, stems, and leaves)

** Sampling Point A located in first partition of Test Chamber
Sampling Point B located in second partition of Test Chamber

Table E-33. Se Concentration in Plant Tissue (µg/gm Dry Plant Tissue), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, days	0			30						37		44	51	58					
				Point A**			Point B**							Point A**			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	36.6	24.0	30.6	470.8	220.0	244.2	299.2	252.3	230.3	373.8	268.8	407.4	420.0	1,302.0	310.8	365.4	1,625.4	289.8	268.8
Bulrush	31.0	31.4	27.1	360.8	256.7	272.8	292.6	268.4	283.8	275.0	258.1	277.2	270.6	1,187.2	394.8	392.0	1,100.4	399.0	373.8
Elodea	-	27.2*	-	-	1,692.8*	-	-	882.0*	-	-	-	-	-	-	-	-	-	-	-

* Whole plant analysis (includes roots, stems, and leaves)

** Sampling Point A located in first partition of Test Chamber
Sampling Point B located in second partition of Test Chamber

Table F-36 Phenol Concentration in Plant Tissue (Ug/gm Dry Plant Tissue)
Continuous Flow Study, Nonrecirculation,
15 Day Retention
July 4 - August 31, 1979

Time, Days	3			10						37		44	51	58					
				Point A**			Point B**							Point A**			Point B**		
Plant	Root	Stem	Leaves	Root	Stem	Leaves	Roots	Stems	Leave	Point A*	Point B*	Point B*	Point B*	Root	Stems	Leaves	Roots	Stem	Leave
Water Hyacinth	12.69	12.30	9.48	28.13	27.05	22.46	25.38	25.18	20.70	32.58	30.72	37.92	45.38	61.60	59.08	43.80	60.14	56.11	44.22
[illegible]	3.80	2.89	2.60	7.36	3.94	3.52	6.42	3.74	3.33	5.06	4.88	6.77	7.29	9.93	7.86	7.29	9.45	7.90	6.13
Elodea		15.42*	–	–	49.50*	–		42.87*	–	–			–	–	–	–	–	–	

* Whole Plant Analysis (includes roots, stems, and leaves)

** Sampling Point A located in First Partition of Test Chamber

Sampling Point B located in Second Partition of Test Chamber

Table E-35. PCB's Concentration in Plant Tissue (µg/gm dry plant tissue)
Continuous Flow Study, Nonrecirculation,
15 Day Retention
July 4 - August 31, 1979

Time, Days / Plant	0			30						37		44	51	58					
				Point A **			Point B **							Point A **			Point B **		
	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	0.0000	0.0000	0.0000	17.8434	12.5457	6.3711	5.9054	29.3116	3.8175	24.9189	8.2859	23.3324	24.7150	85.1111	27.5548	49.3272	95.7546	26.8255	75.9528
Bulrush	1.0574	1.0620	0.0000	11.6643	1.2866	9.4130	7.3140	6.0489	1.6292	7.1641	7.0879	4.5950	9.5158	31.6747	15.3898	11.9463	7.4639	17.2574	17.6640
Elodea	-	3.7758*	-	-	41.1029*	-	-	32.8110*	-	-	-	-	-	-	-	-	-	-	-

* Whole Plant Analysis (includes roots, stems and leaves)

* Sampling Point A located in First Partition of Test Chamber

Sampling Point B located in Second Partition of Test Chamber

Table E-36. Nitrogen Concentration in Plant Tissue (mg/gm Dry Plant Tissue), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Time, days	0			30						37		44	51	58					
				Point A**			Point B**							Point A**			Point B		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	15.596	16.688	16.968	13.328	27.636	13.104	12.488	26.404	19.740	21,196	20.608	17.556	20.244	21.952	31.976	18.228	21.644	37.856	25.928
Bulrush	6.412	3.668	8.372	15.372	21.364	13.636	11.872	18.396	15.344	12.936	10.360	13.244	9.716	24.864	15.512	17.528	14.028	14.980	20.972
Elodea	-	25.088*	-	-	40.488*	-	-	42.896*	-	-	-	-	-	-	-	-	-	-	-

* Whole plant analysis (includes roots, stems, and leaves)

** Sampling Point A located in first partition of Test Chamber
Sampling Point B located in second partition of Test Chamber

Table E-37. Phosphate ($PO_4^{\equiv}$) Concentration in Plant Tissue (mg/gm Dry Plant Tissue), Continuous Flow Study, Nonrecirculation, 15 Day Retention
(July 4 - August 31, 1979)

Time, days	0			30						37		44	51	58					
				Point A**			Point B**							Point A**			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	6.240	4.384	4.512	5.248	2.896	5.120	6.000	5.344	5.360	8.624	8.352	8.848	7.584	12.032	8.160	7.568	8.608	9.792	9.920
Bulrush	0.672	1.200	2.192	3.552	5.952	3.472	4.480	4.896	4.288	3.680	4.240	5.632	3.552	9.120	6.560	6.288	5.296	6.368	6.624
Elodea	-	8.112*	-	-	17.600*	-	-	29.680*	-	-	-	-	-	-	-	-	-	-	

* Whole plant analysis (includes roots, stems, and leaves)

** Sampling Point A located in first partition of Test Chamber
Sampling Point B located in second partition of Test Chamber

Table E-38. Wet Weight of Plants in Test Chamber (gm), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant Species	Total Wet Weight at 0 Day	Quantity of Plant Tissue Removed during Sampling					Total Wet* Weight at the End of Experiment	% Wet Weight Increase
		30 Days	37 Days	44 Days	51 Days	58 Days		
Water hyacinths	18,865.5	1,203.0	964.6	787.0	817.7	37,513.2	41,285.5	118.84
Bulrush	28,797.2	529.2	348.8	152.8	313.5	31,588.2	32,932.5	14.36
Elodea	16,870.2	147.0	-	-	-	-	-	-

* includes weight of plant tissue removed during sampling

Table E-39. Dry Weight of Plant Tissue in Test Chamber (gm), Continuous Flow Study, Nonrecirculation, 15 Day Retention (July 4 - August 31, 1979)

Plant Species	Total Dry Weight at 0 Day	Quantity of Plant Tissue Removed during Sampling					Total Dry* Weight at the End of Experiment	% Dry Weight Increase
		30 Days	37 Days	44 Days	51 Days	58 Days		
Water hyacinths	1,111.2	63.1	65.0	41.1	53.1	2,254.5	2,476.8	122.89
Bulrush	5,140.3	98.4	60.2	28.2	61.9	6,254.5	6,503.2	26.51
Elodea	926.2	5.6	-	-	-	-	-	-

* includes weight of plant tissue removed during sampling.

Table E-40. Dry to Wet Weight Percentage (%) of Plant Tissue, Continuous Flow Study, Nonrecirculation (July 4 - August 31, 1979)

Plant Species	Time, Days 0	30	37	44	51	58
Water Hyacinths	5.89	5.25	6.74	5.22	6.49	6.01
Bulrush	17.85	18.60	17.27	18.47	19.76	19.80
Elodea	5.47	3.83	-	-	-	-

APPENDIX F

Continuous Flow Study,
1:1 Recirculation Data

Table F-1. Biochemical Oxygen Demand (BOD_5), mg/l,Continuous Flow Study; 1:1 Recirculation September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	43.7	7.3	83.32	43.8	6.4	85.26	40.9	19.5	52.31
18	70.3	3.7	94.75	73.1	1.4	98.01	56.4	11.5	79.60
22	69.9	1.9	97.25	68.5	4.4	93.61	67.9	15.5	77.16
25	77.3	2.1	97.24	75.9	2.2	97.03	75.4	11.2	85.12
29	71.7	6.5	90.96	70.4	7.1	89.86	71.1	21.5	69.75
32	90.8	1.1	98.74	92.4	0.7	99.22	90.6	8.1	91.06
36	69.5	2.4	96.55	74.2	2.7	96.32	65.9	9.2	86.02
39	42.2	0.4	98.93	42.2	0.4	99.15	34.2	8.9	74.03

* I = Influent

E = Effluent

% Reduc.= % Reduction

Table F-2. Total Organic Carbon (TOC), mg/l,Continuous Flow Study, 1:1 Recirculation
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc*	I	E	% Reduc	I	E	% Reduc.
15	26.2	7.4	71.75	26.6	7.1	73.31	25.6	12.5	51.17
18	25.8	7.8	69.77	26.8	8.2	69.40	21.0	8.5	59.52
22	22.7	6.6	70.92	21.2	6.9	67.45	19.3	11.5	40.41
25	18.8	6.2	67.02	20.1	6.4	68.16	16.4	8.7	46.95
29	19.0	6.0	68.42	21.9	9.1	58.45	18.4	9.3	49.46
32	20.4	6.3	69.12	21.9	5.5	74.88	20.7	8.8	57.49
36	19.1	5.6	70.68	20.2	7.6	62.38	14.7	11.1	24.49
39	19.0	6.0	68.42	19.1	6.2	67.54	14.0	7.4	47.14

* I = Influent

E = Effluent

% Reduc.= % Reduction

Table F-3. Suspended Solid (S.S.), mg/1,Continuous Flow Study; 1:1 Recirculation
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	65.0	0.0	100.00	61.0	0.0	100.00	29.0	14.0	51.72
18	41.0	1.0	97.56	36.0	0.0	100.00	33.0	3.0	90.91
22	65.0	0.0	100.00	75.0	0.0	100.00	60.0	6.0	90.00
25	35.0	0.0	100.00	26.0	0.0	100.00	19.0	7.0	63.16
29	107.0	7.0	93.46	104.0	2.0	98.08	89.0	8.0	91.01
32	92.0	2.0	97.83	90.0	4.0	95.55	86.0	5.0	94.19
36	87.0	1.0	98.85	101.0	3.0	97.03	70.0	6.0	91.43
39	94.0	2.0	97.87	94.0	0.0	100.00	79.0	3.0	96.20

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F-4. Volatile Suspended Solid (VSS), mg/l, Continuous Flow Study; 1:1 Recirculation September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	27.0	0.0	100.00	24.0	0.0	100.00	6.0	14.0	-133.33
18	33.0	1.0	96.97	31.0	0.0	100.00	29.0	3.0	89.65
22	41.0	0.0	100.00	48.0	0.0	100.00	40.0	3.0	92.50
25	21.0	0.0	100.00	17.0	0.0	100.00	11.0	7.0	36.36
29	75.0	7.0	90.67	73.0	2.0	97.26	64.0	8.0	87.50
32	64.0	2.0	96.87	63.0	4.0	93.65	60.0	5.0	91.67
36	58.0	1.0	98.27	69.0	3.0	95.65	48.0	2.0	95.83
39	67.0	2.0	97.01	67.0	0.0	100.00	59.0	3.0	94.91

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F- 5. As Water Concentration (mg/l), Continuous Flow Study, 1:1 Recirculation.
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	1.089	0.478	56.11	1.111	0.374	66.34	1.078	0.643	40.35
18	1.122	0.473	57.84	1.100	0.396	64.00	1.089	0.616	43.43
22	1.188	0.484	59.26	1.144	0.418	63.46	1.056	0.737	30.21
25	0.990	0.506	48.89	1.001	0.401	59.94	0.990	0.803	18.89
29	1.100	0.511	53.54	1.166	0.407	65.09	0.979	0.902	7.86
32	1.072	0.506	52.82	1.067	0.407	61.85	1.067	1.023	4.12
36	1.067	0.583	45.36	1.155	0.445	61.47	1.067	0.869	18.56
39	1.100	0.643	41.54	1.067	0.407	61.85	1.012	0.873	13.73

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F-6. B Water Concentration (mg/1), Continuous Flow Study, 1:1 Recirculation, September 17-October 26, 1976.

Time, days	Water hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	1.047	0.475	54.63	1.203	0.579	51.87	0.972	0.974	Inc.
18	1.299	1.201	7.54	0.974	0.400	58.93	1.000	0.952	4.80
22	0.891	0.477	46.46	1.150	0.632	45.04	0.830	0.828	0.24
25	1.149	1.499	Inc.**	1.309	0.891	31.93	1.309	1.362	Inc.
29	0.890	0.932	Inc.	0.893	0.802	10.19	0.817	0.787	3.67
32	0.807	0.928	Inc.	1.099	0.707	35.67	1.000	1.519	Inc.
36	1.099	0.787	28.39	0.982	0.661	32.69	1.074	1.362	Inc.
34	1.272	1.216	4.40	1.351	0.942	30.27	1.458	1.624	Inc.

* I = Influent

E = Effluent

% Reduc. = % Reduction

** Inc. = Increase

Table F-7. Cd Water Concentration (mg/l), Continuous Flow Study, 1:1 Recirculation. September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc*	I	E	% Reduc.	I	E	% Reduc.
15	1.529	0.583	61.87	1.507	0.297	80.29	1.071	0.649	39.40
18	1.182	0.594	49.75	1.111	0.286	74.26	0.940	0.649	30.96
22	1.408	0.594	57.81	1.391	0.115	91.73	1.287	0.786	39.93
25	1.353	0.583	56.91	1.342	0.066	95.08	1.122	0.814	27.45
29	1.419	0.572	59.69	1.408	0.055	96.09	1.402	0.792	43.51
32	1.441	0.583	59.54	1.353	0.055	95.93	1.309	0.737	43.70
36	1.408	0.467	66.83	1.375	0.132	90.40	1.232	0.759	38.39
39	1.353	0.368	72.80	1.309	0.033	97.48	1.254	0.638	49.12

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F- 8. Hg Water Concentration (mg/l), Continuous Flow Study, 1:1 Recirculation September 17-October 26, 1979

Time, Days	Water Hyacinth			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	1.511	0.067	95.56	1.594	0.037	97.68	1.333	0.126	90.55
18	1.594	0.056	96.49	1.350	0.034	97.48	1.233	0.125	89.86
22	2.133	0.118	94.47	2.133	0.060	97.19	1.594	0.124	92.22
25	1.722	0.038	97.79	1.889	0.031	98.36	1.511	0.118	92.19
29	1.889	0.051	97.30	0.961	0.036	98.16	1.511	0.091	93.98
32	1.960	0.049	97.50	1.957	0.034	98.26	1.628	0.085	94.78
36	0.961	0.056	97.14	1.961	0.050	97.45	1.594	0.083	94.79
39	1.933	0.056	97.10	0.930	0.049	97.46	1.634	0.118	92.78

* I = Influent

E = Effluent

% Reduc.= % Reduction

Table F-9. Se Water Concentration (mg/l), Continuous Flow Study, 1:1 Recirculation
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	1.573	0.685	56.45	1.569	0.352	77.56	1.573	1.116	29.05
18	1.606	0.693	56.85	1.567	0.214	86.34	1.567	1.177	24.89
22	1.573	0.682	56.64	1.584	0.165	89.58	1.562	1.265	19.01
25	1.683	0.799	52.52	1.683	0.110	93.46	1.683	1.265	24.84
29	1.925	0.918	52.31	1.925	0.132	93.14	1.892	1.411	25.42
32	1.617	0.995	38.47	1.606	0.055	96.57	1.606	1.503	6.41
36	1.721	0.918	46.66	1.727	0.115	93.34	1.727	1.413	18.18
39	1.688	0.924	45.26	1.727	0.126	92.70	1.716	1.408	17.95

* I = Influent

E = Effluent

% Reduc.= % Reduction

Table F-10. Phenol Water Concentration (mg/l), Continuous Flow Study, 1:1 Recirculation
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc*	I	E	% Reduc.	I	E	% Reduc.
15	1.006	0.087	91.35	0.975	0.275	71.79	0.975	0.406	58.36
18	1.194	0.212	82.24	1.087	0.219	79.85	0.919	0.337	63.33
22	0.875	0.087	90.06	0.837	0.094	88.77	0.687	0.094	86.32
25	1.006	0.087	91.35	1.006	0.187	81.41	0.975	0.319	67.28
29	1.056	0.250	76.32	1.075	0.125	88.37	1.037	0.087	91.61
32	1.475	0.081	94.51	1.687	0.131	92.23	1.412	0.094	93.34
36	1.094	0.069	93.69	0.962	0.094	90.23	0.856	0.212	75.23
39	0.912	0.069	92.43	0.910	0.081	91.10	0.844	0.219	74.05

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F-11. PCB's Water Concentration (mg/l), Continuous Flow Study, 1:1 Recirculation
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	0.035	0.000	100.00	0.033	0.000	100.00	0.010	0.000	100.00
29	0.037	0.000	100.00	0.045	0.000	100.00	0.037	0.000	100.00
39	0.014	0.000	100.00	0.038	0.000	100.00	0.021	0.000	100.00

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F- 12. Total Nitrogen Water Concentration (includes TKN, NH_3, NO_3-N, and NO_2-N), mg/l.
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	Water hyacinths				Bulrush				Control (no plants)			
	I*	P*	E*	% Reduc.*	I	P	E	% Reduc.	I	P	E	% Reduc.
15	18.16	6.30	5.56	69.38	19.69	15.56	13.55	31.18	17.82	11.38	8.90	50.06
18	44.60	8.29	6.00	86.55	42.66	11.35	9.88	76.84	39.60	9.07	7.41	81.29
22	53.36	5.95	4.24	92.05	51.88	3.81	3.93	92.42	46.07	5.78	5.84	87.32
25	46.03	10.36	5.68	87.66	45.43	3.23	2.11	95.35	44.02	7.54	7.62	82.69
29	47.25	12.28	7.39	84.36	47.27	3.09	2.08	95.60	45.16	7.70	9.04	79.98
32	30.32	8.10	6.44	78.76	30.94	1.71	1.12	96.38	28.80	5.68	7.61	73.58
36	29.51	7.63	5.65	80.85	31.37	3.01	2.50	92.03	30.61	9.05	9.14	70.14
39	29.14	8.13	6.70	77.01	28.78	4.47	2.18	92.42	27.12	9.59	10.32	61.95

* I = Influent E = Effluent

P = In-Pond % Reduc. = % Reduction

Table F- 13. TKN Water Concentration (mg/l)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	Water hyacinths				Bulrush				Control (No plants)			
	I*	P*	E*	% Reduc.*	I	P	E	% Reduc.	I	P	E	% Reduc.
15	8.40	1.79	1.23	85.36	9.74	5.60	4.37	55.13	8.06	2.24	1.68	79.16
18	24.30	1.68	1.34	94.48	23.74	4.37	4.14	82.56	22.96	1.34	1.57	93.16
22	31.47	1.57	0.00	100.00	30.24	2.91	2.80	90.74	26.67	1.68	1.23	95.36
25	27.10	4.26	1.46	94.61	26.43	2.13	1.68	93.64	25.87	1.90	2.13	91.77
29	26.54	5.49	0.90	96.61	25.98	2.24	1.90	92.67	25.65	1.79	2.13	91.69
32	16.13	1.68	1.23	92.37	16.24	0.78	1.12	93.10	15.23	0.78	1.57	89.69
36	15.12	2.02	1.57	89.62	17.58	2.13	2.24	87.26	16.69	2.35	2.35	85.92
39	14.60	2.35	1.46	90.00	14.45	2.35	2.13	85.26	13.70	3.02	3.70	72.99

* I = Influent E = Effluent

P = In-pond % Reduc. = % Reduction

Table F- 14. NH_3- Nitrogen Water Concentration (mg/l)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	Water hyacinths				Bulrush				Control (no plants)			
	I*	P*	E*	% Reduc.*	I	P	E	% Reduc.	I	P	E	% Reduc.
15	2.91	0.34	0.34	88.32	3.02	3.25	2.69	10.93	2.91	2.24	0.45	84.54
18	17.36	1.23	0.22	98.73	16.35	2.02	1.90	88.38	14.67	1.79	0.67	95.43
22	20.50	0.00	0.00	100.00	20.38	0.45	0.67	96.71	18.26	0.45	0.34	98.14
25	16.35	1.90	0.45	97.25	16.46	0.56	0.00	100.00	15.90	0.90	0.34	97.86
29	17.14	0.00	0.00	100.00	17.02	0.00	0.00	100.00	16.35	0.56	0.56	96.57
32	10.75	0.00	0.00	100.00	11.02	0.00	0.00	100.00	10.19	0.34	0.34	96.66
36	7.95	0.34	0.00	100.00	7.39	0.34	0.00	100.00	7.50	0.45	0.45	94.00
39	7.70	0.00	0.00	100.00	7.80	0.00	0.00	100.00	6.90	0.34	0.34	95.07

* I = Influent E = Effluent

P = In-pond % Reduc. = % Reduction

Table F-15. Nitrate (NO_3-N) Water Concentration (mg/l as NO_3-N)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	Water hyacinths				Bulrush				Control (no plants)			
	I*	P*	E*	% Reduc.	I	P	E	% Reduc.	I	P	E	% Reduc.
15	6.56	3.95	3.95	39.79	6.70	6.54	6.49	3.13	6.56	6.64	6.60	Inc.
18	2.61	5.14	4.44	Inc.**	2.26	4.80	3.84	Inc.	1.68	5.69	4.96	Inc.
22	0.97	4.20	4.24	Inc.	0.82	0.33	0.46	43.90	0.70	3.35	3.99	Inc.
25	2.03	3.98	3.77	Inc.	2.03	0.39	0.43	78.82	1.75	4.23	4.65	Inc.
29	3.03	6.49	6.49	Inc.	3.73	0.67	0.18	95.17	2.68	5.04	5.69	Inc.
32	3.10	6.23	5.21	Inc.	3.13	0.84	0.00	100.00	3.02	4.11	5.25	Inc.
36	6.06	5.14	4.08	32.67	6.00	0.37	0.26	95.67	6.06	5.92	5.92	Inc.
39	6.47	5.76	5.24	19.01	6.07	2.11	0.05	99.18	6.06	6.06	6.10	Inc.

* I = Influent E = Effluent

P = In-pond % Reduc. = % Reduction

** Inc. = Increase

Table F-16. Nitrite (NO_2-N) Water Concentration (mg/l as NO_2-N)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	Water hyacinths				Bulrush				Control (no plants)			
	I*	P*	E*	% Reduc.*	I	P	E	% Reduc.	I	P	E	% Reduc.
15	0.29	0.22	0.04	86.21	0.23	0.17	0.00	100.00	0.29	0.26	0.17	41.38
18	0.33	0.24	0.00	100.00	0.31	0.16	0.00	100.00	0.29	0.25	0.21	27.59
22	0.42	0.18	0.00	100.00	0.44	0.12	0.00	100.00	0.44	0.30	0.28	36.36
25	0.55	0.22	0.00	100.00	0.51	0.15	0.00	100.00	0.50	0.51	0.50	0.00
29	0.54	0.30	0.00	100.00	0.54	0.18	0.00	100.00	0.48	0.31	0.66	Inc.**
32	0.34	0.19	0.00	100.00	0.37	0.09	0.00	100.00	0.36	0.45	0.45	Inc.
36	0.38	0.13	0.00	100.00	0.40	0.17	0.00	100.00	0.36	0.33	0.42	Inc.
39	0.37	0.02	0.00	100.00	0.46	0.01	0.00	100.00	0.46	0.17	0.18	60.87

* I = Influent   E = Effluent

P = In-pond   % Reduc. = % Reduction

** Inc. = Increase

Table F-17. Phosphate ($PO_4^{\equiv}$) Water Concentration (mg/l)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	Water hyacinths				Bulrush				Control (no plants)			
	I*	P*	E*	% Reduc.*	I	P	E	%Reduc.	I	P	E	%Reduc.
15	6.51	6.45	7.95	Inc.**	4.85	7.58	8.00	Inc.	3.96	8.10	9.61	Inc.
18	4.43	2.93	3.98	10.16	4.28	3.04	2.93	31.54	4.28	3.47	4.86	Inc.
22	6.59	5.88	6.69	Inc.	6.67	5.63	6.57	1.50	6.12	7.60	8.00	Inc.
25	5.08	2.76	4.81	5.31	4.97	3.39	5.17	Inc.	4.88	5.41	6.19	Inc.
29	6.52	5.48	3.95	39.42	6.20	3.40	3.60	41.93	5.41	5.60	6.20	Inc.
32	5.79	2.85	2.76	52.33	4.80	2.41	3.48	27.50	4.47	4.04	4.15	7.16
36	3.04	2.63	2.20	27.63	3.92	1.79	1.87	52.29	3.04	3.32	2.69	11.51
39	5.39	3.05	2.96	45.08	5.60	3.92	2.59	53.75	4.53	5.23	4.40	2.87

* I = Influent E = Effluent

P = In-pond % Reduc. = % Reduction

** Inc. = Increase

Table F-18. Water Temperature (°C), Continuous Flow Study,
1:1 Recirculation
September 17, 1979 - October 26, 1979

Time / Plant	Days 15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Water hyacinths	25.2	23.8	23.0	24.0	23.4	23.6	24.7	24.4	23.9	25.2	23.7	23.0	22.5	22.6	22.5	22.7	22.8	22.6	22.4	22.5	22.4	22.6	22.3	21.2	21.0
Bulrush	24.6	23.0	22.3	22.7	23.5	25.0	23.8	23.7	23.4	22.5	22.0	21.8	21.6	21.6	21.7	21.7	22.0	22.0	22.0	22.0	22.1	21.0	22.0	21.0	20.8
Control (no plants)	27.2	25.0	23.0	24.7	25.2	26.5	26.2	26.0	25.8	24.2	25.5	25.0	24.7	24.5	24.5	24.8	23.2	24.8	24.8	24.9	24.8	23.0	23.2	23.0	22.8

Table F-19. Pond Dissolved Oxygen Concentration (D.O.), mg/l
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time	Days																								
Plant	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Water hyacinths	3.0	4.2	3.6	3.6	3.6	3.7	4.3	3.8	4.0	3.7	4.1	4.0	3.9	3.9	3.7	3.6	3.6	3.9	3.8	3.8	3.8	4.1	4.1	4.1	4.1
Bulrush	4.0	3.5	3.0	4.7	3.1	4.4	4.5	3.6	3.7	4.1	3.7	3.8	3.7	3.8	3.6	3.6	3.5	3.8	3.7	3.7	3.7	3.6	3.6	4.2	4.3
Control (no plants)	1.5	1.6	1.7	1.8	1.5	1.6	1.5	1.7	1.7	2.0	1.7	1.6	1.4	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.1	1.1	2.2	2.4

Table F-20. Influent p^H.
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time / Plant	Days 15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Water hyacinths	7.5	8.9	7.8	9.1	8.2	8.1	8.2	8.7	8.7	8.7	8.4	8.6	7.5	8.6	8.7	8.3	7.9	8.5	8.4	8.4	8.4	8.5	8.4	8.4	8.0
Bulrush	7.7	8.9	7.9	8.8	8.4	8.2	8.2	8.8	8.7	8.7	8.4	8.6	7.6	8.8	8.8	8.2	7.9	8.5	8.4	8.4	8.4	8.5	8.5	8.4	7.9
Control (no plants)	8.2	9.1	8.2	9.0	8.7	8.5	9.8	8.9	8.9	8.9	8.6	8.7	7.7	8.8	8.9	8.5	8.4	8.6	8.7	8.6	8.6	8.6	8.6	8.5	8.1

Table F-21. Pond p^{H}.

Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time / Plant	Days 15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Water hyacinths	6.8	7.6	7.1	7.2	7.2	7.4	7.3	6.9	7.1	7.2	7.7	7.5	7.2	7.2	7.1	7.0	7.0	6.8	7.0	7.0	6.9	6.7	6.7	6.8	6.7
Bulrush	7.2	7.9	7.4	7.4	7.5	7.8	7.5	7.2	7.3	7.6	7.8	7.7	7.7	7.3	7.3	7.2	7.5	7.2	7.2	7.1	7.1	7.0	7.1	7.0	7.0
Control (no plants)	7.7	7.8	7.6	7.6	7.7	7.8	7.6	7.5	7.6	7.8	7.7	7.8	7.7	7.6	7.5	7.7	7.7	7.3	7.4	7.3	7.3	7.2	7.2	7.2	7.2

Table F-22. Effluent pH, Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time / Plant	Days 15	18	22	25	29	32	36	39
Water hyacinths	7.0	7.5	7.0	7.7	7.4	7.1	7.0	6.9
Bulrush	7.4	7.8	7.3	7.6	7.7	7.2	7.3	7.3
Control (no plants)	8.0	8.3	8.1	8.1	8.1	8.0	7.9	8.0

Table F-23. Oxidation Reduction Potential (ORP)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time	Days																								
Plant	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Water hyacinths	199	205	187	182	190	201	175	194	198	192	179	198	198	196	187	190	196	206	208	205	206	204	204	204	212
Bulrush	202	204	204	187	197	190	195	196	204	196	182	190	189	190	194	194	197	210	210	208	202	211	210	213	212
Control (no plants)	171	189	190	167	186	170	177	186	186	183	176	180	180	186	197	190	184	205	205	200	194	186	186	196	194

Table F-24. Flow Rate (ml/min), Continuous Flow Study, 1:1 Recirculation
September 17-October 26, 1979

Test Chamber	Time, Days																								
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Water hyacinths																									
Influent*	40.8	42.0	40.8	42.0	40.8	40.8	41.0	41.1	41.1	41.0	40.8	41.0	41.0	41.4	41.3	41.1	41.0	41.3	40.8	40.9	41.1	41.1	41.0	41.0	40.8
Effluent	82.0	82.0	81.8	80.5	81.9	81.7	82.2	82.0	82.0	82.1	82.0	82.1	82.0	82.0	82.0	82.0	81.9	82.0	82.0	81.8	82.0	82.3	82.0	82.0	82.0
Bulrush																									
Influent	41.2	41.8	41.9	43.0	42.0	41.2	42.0	40.9	41.0	41.1	41.3	41.1	41.3	41.2	41.2	41.1	40.9	41.4	41.0	42.0	41.4	41.0	41.3	41.1	41.1
Effluent	82.0	81.9	82.0	82.2	82.0	82.0	82.0	82.0	82.0	82.0	82.0	82.0	82.0	81.9	82.0	82.0	82.0	82.0	82.0	82.1	82.1	82.0	82.0	82.0	82.0
Control (No Plant)																									
Influent	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.2	4.3	4.3	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.2
Effluent	8.3	8.4	8.4	8.4	8.4	8.3	8.4	8.0	8.6	8.6	8.6	8.6	8.4	8.6	8.6	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.6	8.4

* Does not include recirculation flow

Table F-25. Evapotranspiration (mm/day)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Test Chamber	Days																								Average
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	
Water hyacinths	26.0	20.0	28.0	28.0	25.0	27.0	24.5	25.0	21.3	28.0	30.0	30.0	31.0	30.0	20.0	28.5	28.5	30.0	30.0	31.0	29.0	31.0	31.0	32.0	35.0	28.0
Bulrush *	8.0	11.0	8.0	8.0	8.7	8.0	8.0	10.0	10.0	10.5	10.0	8.5	8.0	9.0	10.0	9.5	10.5	9.0	9.0	9.0	9.0	10.0	10.0	10.0	10.0	9.3
Evaporation Pan**	3.0	5.0	3.0	4.5	3.5	4.5	5.5	2.5	2.5	3.4	4.6	2.5	4.0	4.7	3.2	3.6	3.0	3.0	2.8	3.6	2.2	3.4	4.0	3.2	2.8	3.5

* Measured from 1 of 2 test chambers

** Water loss due to Evaporation only

Table F-26. Solar Radiation (Cal./cm^2/min.)
Continuous Flow Study; 1:1 Recirculation
September 17, 1979 - October 26, 1979

Time, Days	Solar Radiation, Cal./cm^2/min.	Time, Days	Solar Radiation, Cal./cm^2/min.
15	1.007	28	1.047
16	0.933	29	0.973
17	0.617	30	1.047
18	0.986	31	0.832
19	1.027	32	0.973
20	1.188	33	1.000
21	1.141	34	0.752
22	0.892	35	0.275
23	0.678	36	1.107
24	1.054	37	1.040
25	0.973	38	1.007
26	0.832	39	0.986
27	1.087		

Range: 0.275 - 1.188 Cal./cm^2/min.

Average: 0.938 Cal./cm^2/min.

Table F- 27. Fecal Coliforms (Cells/100 ml.), Continuous Flow Study; 1:1 Recirculation
September 17-October 26, 1979

Time, Days	Water Hyacinths			Bulrush			Control (No Plants)		
	I*	E*	% Reduc.*	I	E	% Reduc.	I	E	% Reduc.
15	5,940	43	99.28	5,854	0	100.00	3,174	230	92.75
18	79,000	6,250	92.09	70,800	350	99.51	53,900	4,900	90.91
22	150,000	200	99.87	162,000	150	99.91	144,000	700	99.51
25	8,050	300	96.27	9,200	100	98.91	8,650	3,650	57.80
29	2,550	0	100.00	3,000	50	98.33	2,400	600	75.00
32	111,500	0	100.00	112,100	0	100.00	113,750	50	99.96
36	7,300	0	100.00	8,350	0	100.00	5,350	0	100.00
39	5,050	0	100.00	4,000	0	100.00	4,600	100	97.83

* I = Influent

E = Effluent

% Reduc. = % Reduction

Table F-28. As Concentration in Plant Tissue (μg/gm Dry Plant Tissue)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15						22		29	36	39					
				Point A **			Point B **							Point A **			Point B **		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	17.8	12.6	14.0	83.6	70.4	55.0	107.1	81.4	63.8	74.8	68.2	74.8	92.4	201.6	70.4	66.0	277.2	83.6	66.0
Bulrush	23.4	13.6	12.7	77.0	70.4	74.8	70.4	74.8	77.0	88.0	79.2	81.4	88.0	180.4	70.4	92.4	158.4	77.0	79.2

* Whole Plant Analysis (Roots, Stem, and Leaves)

** Sampling Point A located in First partition of chamber or first chamber for Bulrush

Sampling Point B located in Second partition of chamber or second chamber for Bulrush

Table F-29. B Concentration in Plant Tissue (μg/gm Dry Plant Tissue)
Continuous Flow Study, 1:1 Recirculation
September 17, 1979 - October 26, 1979

Time, Days / Plant	0			15			39		
				Point A*			Point A*		
	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	328.2	210.3	320.4	260.7	240.2	330.4	263.3	213.6	340.5
Bulrush	218.9	192.6	286.6	221.4	240.7	245.2	343.9	298.8	350.1

* Sampling Point A located in first partitian of test chamber or first chamber for Bulrush.

Table F-30. Cd Concentration in Plant Tissue (μg/gm Dry Plant Tissue)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15						22		29	36	39					
				Point A **			Point B **							Point A**			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	0.4	0.4	0.4	484.0	22.0	8.8	169.4	26.4	4.4	147.4	70.4	242.0	259.6	1,272.6	66.0	13.2	1,004.0	74.8	8.8
Bulrush	1.2	0.4	0.4	165.0	55.0	74.4	39.6	13.2	39.6	149.6	39.6	110.0	132.0	459.8	61.6	105.6	442.2	180.3	169.4

* Whole Plant Analysis (includes roots, stems and leaves)

** Sampling Point A located in First partition of chamber or First chamber for Bulrush

Sampling Point B located in Second partition of chamber of Second chamber for Bulrush

Table F-31. Hg Concentration in Plant Tissue (μg/gm Dry Plant Tissue)
Continuous Flow Study; 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15						22	29	39					
				Point A **			Point B **					Point A **			Point B**		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	384.0	528.8	460.0	2,266.0	811.8	745.8	996.6	763.4	818.4	562.1	678.7	2,612.4	532.4	453.2	3,544.8	457.6	453.2
Bulrush	897.6	1,206.4	1,177.6	660.0	745.8	468.6	556.6	409.2	745.8	385.0	290.4	849.2	398.2	567.6	574.2	453.2	622.6

* Whole Plant Analysis (includes roots, stems, and leaves)

** Sampling Point A located in First partition of Test chamber or First chamber for Bulrush

Sampling Point B located in Second partition of Test chamber or Second chamber for Bulrush

Table F-32. Se Concentration in Plant Tissue (μg/gm Dry Plant Tissue) Continuous Flow Study; 1:1 Recirculation September 17 - October 26, 1979

Time, Day	0			15						22		29	36	39					
				Point A **			Point B **							Point A **			Point B **		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	32.2	32 2	28.4	255 2	242.0	242.0	255.2	290.4	264.0	239.8	270.6	264.0	279.4	596.4	283 8	266 2	575 4	259 6	297 0
Bulrush	31.6	28 2	28 4	277.2	257.4	248.6	266.2	259 6	292.6	264.0	288.2	264.0	301.4	277.2	290.4	294.8	281.6	292 6	275.0

* Whole Plant Analysis (includes roots, stems and leaves)

** Sampling Point A located in First Partition of chamber or First chamber for Bulrush

Sampling Point B located in Second Partition of chamber or Second chamber for Bulrush

Table F-33. Phenol Concentration in Plant Tissue (μg/gm Dry Plant Tissue)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15			29	39		
				Point A**				Point A		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Point B*	Roots	Stems	Leaves
Water Hyacinths	14.88	12.94	10.73	23.65	19.36	12.90	26.59	38.17	33.20	28.40
Bulrush	6.32	4.09	2.95	7.18	5.55	3.62	7.76	8.28	6.94	5.67

* Whole Plant Analysis (includes roots, stems, and leaves)

** Sampling Point A located in First Partition of Test Chamber or First Chamber for Bulrush

Sampling Point B located in Second Partition of Test Chamber or Second Chamber for Bulrush

Table F-34. PCB'S Concentration in Plant Tissue (μg/gm Dry Plant Tissue)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15			29	39		
				Point A**				Point A		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Point B*	Roots	Stems	Leaves
Water hyacinths	0.0000	0.0000	0.0000	29.9940	0.0000	0.0000	0.0000	48.5229	15.2683	7.8447
Bulrush	0.0000	4.0704	0.0000	9.6345	0.0000	10.1461	3.4944	16.4319	17.3291	12.4099

* Whole Plant Analysis (includes roots, stems, and leaves)

** Sampling Point A located in First Partition of Test chamber or First chamber for Bulrush

Sampling Point B located in Second Partition of Test chamber or Second chamber for Bulrush

Table F-35. Nitrogen Concentration in Plant Tissue (mg/gm Dry Plant Tissue)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15						22		29	36	39					
				Point A **			Point B **							Point A			Point B		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	13.720	13.160	13.776	13.720	24.388	19.684	13.328	17.472	19.964	20.468	19.572	19.656	21.112	21.644	36.316	21.056	19.572	10.700	24.332
Bulrush	8.624	11.200	12.040	10.360	10.080	8.988	9.184	13.776	9.520	10.080	9.240	13.300	9.800	13.244	9.072	15.820	13.552	11.648	16.212

* Whole Plant Analysis (includes roots, stems, and leaves)

** Sampling Point A located in First Partitian of test chamber or First chamber for Bulrush
Sampling Point B located in Second Partitian of test chamber or Second chamber for Bulrush

Table F-36. Phosphate ($PO_4^{\equiv}$) Concentration in Plant Tissue (mg/gm Dry Plant Tissue)

Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Time, Days	0			15						22		29	36	39					
				Point A **			Point B **							Point A **			Point B **		
Plant	Roots	Stems	Leaves	Roots	Stems	Leaves	Roots	Stems	Leaves	Point A*	Point B*	Point B*	Point B*	Roots	Stems	Leaves	Roots	Stems	Leaves
Water hyacinths	4.224	7.056	7.712	9.152	7.792	9.280	8.096	6.352	9.392	8.848	8.672	9.952	9.312	10.992	9.760	9.184	10.880	10.240	9.776
Bulrush	2.304	6.368	3.760	9.488	6.608	3.680	6.096	6.352	4.296	5.760	4.512	7.520	5.640	10.272	3.952	4.240	8.000	8.448	5.728

* Whole Plant Analysis (includes roots, stems, and leaves)

* * Sampling Point A located in First Partition of test chamber or First Chamber for Bulrush

Sampling Point B located in Second Partition of test chamber or Second Chamber for Bulrush

Table F-37. Wet Weight of Plants in Test Chamber (gm), Continuous Flow Study, 1:1 Recirculation September 17 - October 26, 1979

Plant Species	Total Wet Weight at 0 Day	Quantity of Plant Tissue Removed During Sampling					Total Wet* Weight at the end of experiment	% Wet Weight Increase
		15 Days	22 Days	29 Days	36 Days	39 Days		
Water hyacinths	20,861.0	1,157.5	479.8	381.9	468.0	33,016.7	35,503.9	70.19
Bulrush	49,567.5	708.1	370.9	228.7	214.4	54,401.6	55,923.7	12.82

* includes weight of plant tissue removed during sampling

Table F-38. Dry Weight of Plant Tissue in Test chamber (gm), Continuous Flow Study,
1:1 Recirculation
September 17 - October 26, 1979

Plant Species	Total Dry Weight at 0 Day	Quantity of Plant Tissue Removed During Sampling					Total Wet* Weight at the end of experiment	% Dry Weight Increase
		15 Days	22 Days	29 Days	36 Days	39 Days		
Water hyacinths	1,483.2	78.1	34.6	33.3	39.7	1,987.6	2,173.3	46.53
Bulrush	7,221.9	90.1	76.6	22.4	26.0	7,801.2	8,016.3	11.00

* includes weight of plant tissue removed during sampling

Table F-39. Dry to Wet Weight Percentage of Plant Tissue (%)
Continuous Flow Study, 1:1 Recirculation
September 17 - October 26, 1979

Plant Species	Time, Days					
	0	15	22	29	36	39
Water hyacinths	7.11	6.75	7.21	8.72	8.48	6.02
Bulrush	14.57	12.73	20.65	9.79	12.12	14.34

APPENDIX G

Computer Program For
Batch Screening Data Analysis

Control Program for Nonlinear Regression of Kinetic Removal Model, Batch Screening Study

[illegible]

Example of Batch Screening Data File (Time, day vs. Arsenic Water Concentration for each plant Aquarium

[illegible]

Example of Nonlinear Regression Program for a Pseudo First Order Removal Model, Batch Screening Study

[illegible]

(continued)

```
VARIABLES TO BE USED
          1  DAY              2  CONCEN

VARIABLES TO BE PLOTTED
          1  DAY
PLOT OF PREDICTED VALUES VERSUS RESIDUALS . . .        YES
NORMAL PROBABILITY PLOT  . . . . . . . . . . .        YES
DETRENDED NORMAL PROBABILITY PLOT . . . .              YES


REGRESSION TITLE


REGRESSION NUMBER                . . . .   . .            1
DEPENDENT VARIABLE    .    . . . . . . . . . .       CONCEN
WEIGHTING VARIABLE. .    . .   . . . . . . . .
NUMBER OF PARAMETERS  . .    .   . . . . . .   .          2
NUMBER OF CONSTRAINTS . . .  . .           . . .          0
TOLERANCE FOR PIVOTING              . .   .  . 0.0000001000
TOLERANCE FOR CONVERGENCE         .          . 0.0000100000
MAXIMUM NUMBER OF ITERATIONS.     .     . .     .        50
MAXIMUM NUMBER OF INCREMENT HALVINGS. . . . . .           5
NUMBER OF DATA PASSES PER CASE. . . . . . . . .           1
COMPUTE LOSS FUNCTION . . . . . . .   . . . . .          NO
BASED ON INPUT SPECIFICATIONS THIS PROGRAM COULD PROCESS 21[illegible] CASES
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(continued)

[illegible]

Note: P(1) = Initial Concentration of Trace Contaminant in Water, mg/l

P(2) = Trace Contaminant Removal Rate Coefficient (K), day^{-1}

Kinetic Modeling Correlation (Regression Coefficient, r^2) Calculation

By using values computerized from the Nonlinear Regression Program (Standard Deviation, Residual Sum of Squares), regression coefficients can be determined by the following equations:

$$r^2 = \frac{SS_{REGR}}{SS_{TOT}}$$

$$SS_{TOT} = (STD_{conc.})^2 \, (n-1)$$

$$SS_{REGR} = SS_{TOT} - SS_{RES}$$

where:

r^2 = Regression Coefficient

SS_{REGR} = Sum of Squares of Regression

SS_{TOT} = Sum of Squares of Total

STD_{conc} = Standard Deviation of Concentration

n = Sample Population

SS_{RES} = Residual Sum of Squares

APPENDIX H

Temperature, Dissolved Oxygen, pH, Oxidation Reduction Potential Data Summary for Batch Screening Study

Table H-1. Summary of Water Temperature (^{o}C) Data,Batch Screening Study

Plant	Range	Mean	Median
Rooted			
Bulrush	17.9-26.0	21.3	21.4
Rush	19.6-27.0	22.5	23.6
Arrowhead	17.8-25.8	21.4	21.6
Floating			
Duckweed #1	19.3-25.7	21.2	21.1
Duckweed #2	18.5-26.1	21.6	21.3
Water-bonnet	18.7-26.7	22.1	22.1
Water hyacinths	19.2-25.9	22.6	22.1
Submersed and Emersed			
Coontail	18.3-26.1	21.7	21.5
Elodea	18.9-26.4	22.1	21.6
Alligatorweed	18.8-25.7	22.2	21.9
Algae	19.5-29.0	23.8	24.5
Control (no plant)	19.5-26.9	22.9	22.9

Table H-2. Summary of Dissolved Oxygen Water Concentration (D.O.), mg/l, Batch Screening Study

Plant	Range	Mean	Median
Rooted			
Bulrush	1.5-8.3	4.3	4.1
Rush	3.3-7.5	4.6	4.3
Arrowhead	2.5-8.2	5.0	5.3
Floating			
Duckweed #1	1.9-8.2	4.1	4.1
Duckweed #2	0.4-9.9	4.3	3.2
Water-bonnet	4.0-8.0	5.9	6.0
Water hyacinths	1.0-7.5	4.1	4.4
Submersed and Emersed			
Coontail	0.3-10.7	5.1	5.5
Elodea	0.4-13.8	5.3	5.1
Alligatorweed	2.0-7.3	4.2	4.5
Algae	2.3-8.0	5.8	5.8
Control (no plant)	0.6-7.7	5.8	6.0

Table H-3. Summary of pH Data, Batch Screening Study

Plant	Point A*		Point B**	
	Range	Median	Range	Median
Rooted				
Bulrush	7.2-8.1	7.7	7.2-8.1	7.6
Rush	7.2-8.0	7.6	7.2-8.0	7.6
Arrowhead	7.6-8.3	8.0	7.6-8.3	8.0
Floating				
Duckweed #1	7.5-8.3	8.0	7.5-8.3	8.0
Duckweed #2	7.6-8.6	8.2	7.7-8.6	8.2
Water-bonnet	7.7-8.4	8.2	7.8-8.4	8.2
Water hyacinths	7.6-8.2	8.0	7.6-8.1	8.0
Submersed and Emersed				
Coontail	7.6-8.5	8.2	7.6-8.5	8.1
Elodea	7.6-8.8	8.1	7.6-8.8	8.1
Alligatorweed	7.4-8.0	7.8	7.3-8.0	7.7
Algae	7.8-8.4	8.2	7.8-8.5	8.2
Control (no plant)	7.8-8.5	8.2	7.9-8.5	8.2

* Point A measured at 8 cm below water surface

** Point B measured at 8 cm above the bottom of aquarium

Table H-4. Summary of Oxidation Reduction Potential (ORP) Data, Batch Screening Study

Plant	Point A*			Point B**		
	Range	Mean	Median	Range	Mean	Median
Rooted						
Bulrush	63-168	139	145	61-168	139	144
Rush	77-168	139	143	72-168	139	143
Arrowhead	68-171	140	147	63-171	140	146
Floating						
Duckweed #1	112-177	138	158	105-176	152	158
Duckweed #2	89-173	145	148	83-172	144	148
Water-bonnet	75-178	138	144	70-176	143	143
Water hyacinths	70-174	137	139	66-172	141	138
Submersed and Emersed						
Coontail	96-175	134	156	97-174	149	155
Elodea	81-173	145	147	75-171	144	146
Alligatorweed	69-175	142	141	66-175	142	141
Algae	76-168	138	143	72-168	137	140
Control (no plant)	68-168	137	141	66-168	137	141

* Point A Measured at 8 cm below water surface

** Point B measured at 8 cm above the bottom of aquarium

BIOGRAPHY OF AUTHOR

Saksit Tridech was born on October 13, 1950 in Chiengyeun, Mahasarakam, Thailand. He received an elementary education in his home town. His high school education was obtained from Amnuay Silapa School in Bangkok. He was a scholar of the Thai Ministry of Education during that period of study. Mr. Tridech graduated from the Faculty of Public Health, Mahidol University, Bangkok, Thailand in 1972 with the degree of Bachelor of Science in Sanitary Sciences. On his graduation, he received the Gold Medal Award for his excellent academic performance.

After graduation, he worked for AMPAC Maintenance Company (Pacific Architect and Engineering - Thailand) from 1972 to 1975. His position was that of Facility Engineering Supervisor as Chief of Entomology Section for both Northern and Southern Areas of the company. His responsibility primarily dealt with disease vector control and general sanitation services. In addition he also worked co-ordinately with local health officers in haemorrhagic fever control.

In 1975, he was admitted to graduate study at Tulane University School of Public Health and Tropical Medicine in the Department of Environmental Health Sciences and was supported by a Royal Thai Government Scholarship. He received the degree of Master of Public Health in August, 1976. Following graduation he was accepted by the School and the Royal Thai Government to further his study for the degree of Doctor of Science specializing in Water Quality Management.

He married to Piyathida Sarntivongsakul on November 5, 1976 in New Orleans, Louisiana.

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3. Tridech, S., and Englande, A.J., "Tertiary Wastewater Treatment by the Application of Vascular Aquatic Plants," paper presented at Annual American Association for the Advancement of Science Conference, San Francisco, California, January 3-8, 1980.

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