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**PHOSPHORUS CHEMISTRY UNDER AEROBIC AND ANAEROBIC  
CONDITIONS IN MODEL TWO-CELLED WASTE STABILIZATION PONDS**

*The University of Oklahoma*

**PH.D.**

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GRADUATE COLLEGE

PHOSPHORUS CHEMISTRY UNDER AEROBIC AND ANAEROBIC CONDITIONS IN  
MODEL TWO-CELLED WASTE STABILIZATION PONDS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

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BY

GARY DAVID MILLER

Norman, Oklahoma

1980

PHOSPHORUS CHEMISTRY UNDER AEROBIC AND ANAEROBIC CONDITIONS IN  
MODEL TWO-CELLED WASTE STABILIZATION PONDS

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PHOSPHORUS CHEMISTRY UNDER AEROBIC AND ANAEROBIC  
CONDITIONS IN MODEL TWO-CELLED  
WASTE STABILIZATION PONDS

CHAPTER 1

INTRODUCTION

Waste stabilization ponds have been increasingly used in the United States in the last 60 years for the treatment of domestic sewage. In 1945 there were a reported 45 sewage lagoons in a few states. By 1978 there were more than 4,000 lagoons throughout the nation (U. S. Environmental Protection Agency, 1978). These ponds are especially useful in small communities where the amount of land needed is available and net evaporation rates are high. Among the advantages of waste stabilization ponds are their ease of construction, need for few and relatively untrained personnel, and low costs of construction, maintenance, and operation.

Until recent years little data existed on the microbial and chemical reactions that occur within waste stabilization ponds. It was not known, for example, how to relate effluent characteristics to lagoon design, hydraulic or organic loading rates, or climate conditions. Because of increasingly stringent limitations on municipal wastewater effluents including more restrictive biochemical oxygen demand (BOD)

and suspended solids standards, the continued use of sewage lagoons to meet these standards has been questioned. Other reported problems of sewage lagoons include noxious hydrogen sulfide and other odors, algae blooms, bothersome vegetative growth, and excessive algae in the effluent. The results of more recent studies indicate that waste stabilization ponds can be effective for secondary treatment of municipal wastewater with proper design and operation.

With the possibility of nutrient concentration limitations being formulated for wastewater effluents in the near future, increasing attention has been given to the effectiveness of the removal of phosphorus and other nutrients in sewage lagoons. While the phosphorus chemistry of lake systems has been intensively studied over the past 40 years, very little attention has been given to the fate of phosphorus within the various types of sewage lagoons and the design, climatic and operation factors affecting the level of phosphorus in the effluent. Studies of lake chemistry suggest that such oxygen, pH and redox potential changes can influence the sorption and desorption of phosphorus from the sediments.

The purpose of this investigation was to determine the fate of phosphorus in a laboratory simulation of a sewage lagoon under environmental conditions similar to that in the south central U.S. during late summer. During late summer the photosynthetic and respiratory activities of algae are most intense and the most rapid and extreme daily changes occur between aerobic and anaerobic conditions with accompanying pH and oxidation-reduction (redox) potential variations.

Two other points of inquiry were: (1) to develop a materials balance for radiophosphorus ( $P - 32$ ) at various times during the operation of the model systems to estimate the portion of phosphorus in the sediment and bulk water under aerobic and anaerobic conditions, and (2) to establish a correlation between total phosphorus and orthophosphate concentrations and radiophosphorus activity in the bulk water. By establishing this correlation the concentration of total phosphorus or orthophosphate can be estimated by the measured radiophosphorus activity.

These objectives were met by using three model two-celled sewage lagoons. Two of the duplicate model lagoons were operated at a higher organic loading rate and one at a lower organic loading rate. The seedwater and sediment were obtained from a local waste stabilization pond. These systems were stabilized to summer conditions and an abundant growth of algae was established. A known amount of radiophosphorus was then added to each tank under highly oxygenated (lighted) conditions and the radiophosphorus was allowed to equilibrate for about one week under these conditions. The tanks were then each sampled at twelve locations for materials balance and correlation analysis of parameters. The oxygen level, pH and redox potential were then allowed to decline under night-like (darkened) conditions for about one week. The tanks were each sampled at twelve locations when the pH declined to near 8 and again when the pH declined to near 7 in each of the tanks. Then the lights were turned on for another week and the tanks were again sampled at twelve locations as the pH increased from near 7 to about 8 and to 9 or greater under oxygenated conditions. A second cycle

of decreasing the oxygen level, pH and redox potential under unlighted conditions and increasing these parameters under lighted conditions and intensive sampling was performed.

In the following chapter a review of general phosphorus chemistry, current understanding of freshwater phosphorus chemistry, and the literature on phosphorus in waste stabilization ponds is presented. Following this, a more detailed description of the materials, methods, and procedures used in this research is given. The experimental results and analysis of these results are presented in the next chapter. A summary of the study is presented in the concluding chapter. Finally, more detailed data and description is presented in the appendices.

## CHAPTER II

### LITERATURE REVIEW

Considerable research has been conducted over the years on the importance of phosphorus in the environment. The majority of this research has centered on the role of phosphorus as a cause of fertilization (and subsequently eutrophication) in lakes and streams. Relatively little research has focused on the phosphorus chemistry of waste stabilization ponds. First, this chapter briefly describes the environmental sources and forms of phosphorus. The chemistry of phosphorus in lakes is then reviewed with an emphasis on bulk water chemistry and sediment-water interactions. Biological and other environmental (limnological) influences on phosphorus chemistry in lakes are also briefly described. Finally, a more detailed review of phosphorus chemistry in waste stabilization ponds is given. This includes a general description of the chemical biological, and physical environment of ponds as it influences phosphorus transformations and a brief review of laboratory and field studies that describe phosphorus chemistry in ponds.

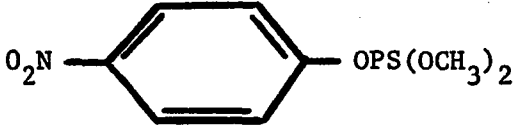
#### Forms and Sources of Phosphorus

Phosphorus occurs almost exclusively in nature in the fully oxidized state as phosphate. It occurs in all known minerals as orthophosphate. The forms of dissolved phosphorus that occur in natural

waters and some examples of these forms are shown in Table II-1, which is adapted from Stumm and Morgan (1970). Phosphorus is introduced into waters the dissolved form from natural weathering of rocks and soil, from soil fertilization, from biological transfer and from the use of soluble phosphorus compounds in detergents, water treatment and industry. Inorganic condensed phosphates are enzymatically synthesized in all plants and animals or can be man-made (as in detergents) but do not occur naturally in minerals. Polyphosphates and metaphosphates are used in water treatment operations primarily for scale prevention and corrosion control. Organic phosphorus compounds that occur in solids and in natural waters are the products of biological growth. There is very little known about the specific dissolved organic compounds or groups of organic phosphorus compounds that occur in waste effluents (Stumm and Morgan, 1970). Due to analytical limitations one can only estimate that perhaps 15 to 30 percent of the total phosphorus in lake waters is in the soluble organic form (Rigler, 1964).

The pH governs the distribution of several acid and base species of orthophosphate and condensed phosphates in solution. From a pH of 5 to 9 the specie  $\text{H}_2\text{PO}_4^{2-}$  is the predominant form of orthophosphate. At neutral pH the most prevalent pyrophosphate species are  $\text{H}_2\text{P}_2\text{O}_7^{3-}$ . The effect of pH on orthophosphate forms is shown in Figure II-1 (adapted from Stumm and Morgan, 1970).

Table II-1  
DISSOLVED PHOSPHORUS FORMS OF POSSIBLE SIGNIFICANCE  
IN NATURAL WATERS<sup>a</sup>

| <u>Form</u>                               | <u>Representative Compounds</u><br><u>Or Species</u>  |
|---|---|
| <u>Orthophosphate</u>                     | $\text{H}_2\text{PO}_4^-$ , $\text{HPO}_4^{2-}$ , $\text{PO}_4^{3-}$ , $\text{FeHPO}_4^+$                   |
| <u>Inorganic condensed phosphates</u>     |   |
| Pyrophosphate                             | $\text{H}_2\text{P}_2\text{O}_7^{2-}$ , $\text{HP}_2\text{O}_7^{3-}$ , $\text{P}_2\text{O}_9^{4-}$          |
| Tripolyphosphate                          | $\text{H}_2\text{P}_3\text{O}_{10}^{3-}$ , $\text{HP}_3\text{O}_{10}^{4-}$ , $\text{P}_3\text{O}_{10}^{5-}$ |
| Trimetaphosphate                          | $\text{HP}_3\text{O}_9^{2-}$ , $\text{P}_3\text{O}_9^{3-}$ , $\text{CaP}_3\text{O}_9^-$                     |
| <u>Organic Orthophosphates</u>            |   |
| Sugar Phosphates                          | Glucose-1-phosphate, adenosine monophosphate  |
| Inositol Phosphates                       | Inositol monophosphate,<br>Inositol Hexaphosphate   |
| Phospholipids                             | Glycerophosphate, Phosphatidic acids, phosphatidyl choline  |
| Phospho amides                            | Phosphocreatin, phosphoarginine   |
| Phosphoproteins                           |   |
| <u>Organic condensed phosphates</u>       | Adenosine-5'-triphosphate,<br>coenzyme A  |
| <u>Phosphorus - containing pesticides</u> |                         |

<sup>a</sup>Adapted from Stumm and Morgan (1970).



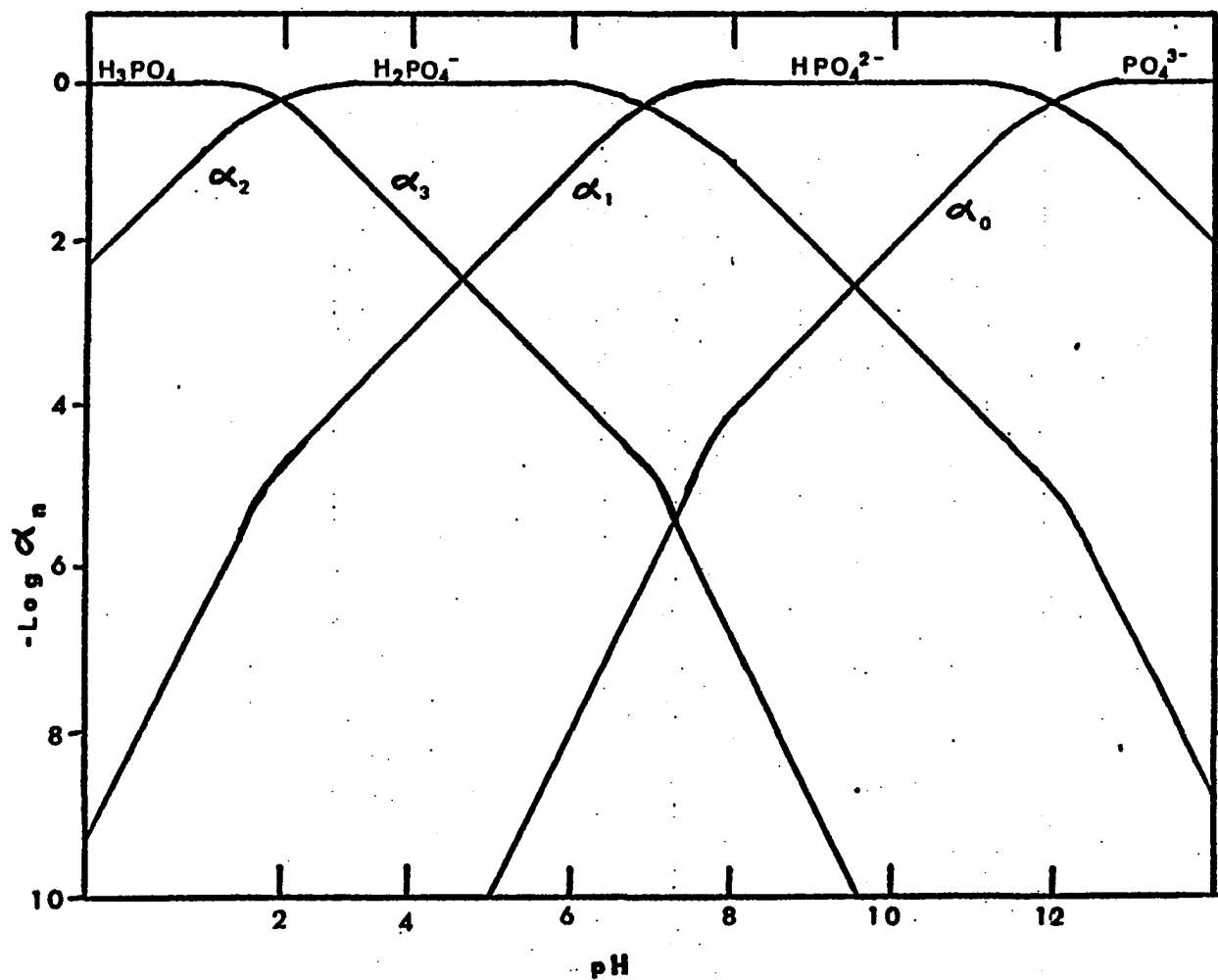


Figure II-1: The Effect of pH on Various Orthophosphate Forms  
(Stumm and Morgan, 1970)

## Phosphorus in Lakes

Eutrophication of natural bodies of water continues to be of great concern. For most lakes the control of phosphorus from external sources appears to some investigators to be the most effective strategy for controlling algae and other aquatic plant growth (Lee, Rast and Jones, 1978; Thomas, 1978; Syers, Harris and Armstrong, 1973; and Tsai and Huang, 1979). While other factors or nutrients such as carbon, nitrogen, iron, sodium or vitamin B<sub>12</sub> may be limiting to biological growth at a particular time (Massey and Robinson, 1971; Schindler, 1971; and Lange, 1973); phosphorus does not have a gaseous phase (the phosphorus cycle is a sedimentary cycle) and can be most easily kept to a minimum in external sources. However, to effectively control eutrophication other trace elements may have to be minimized (Lange, 1973). Also, phosphorus may be limiting for a portion of a year and nitrogen be limiting at other times (Yoshimura, 1932) because of changes in equilibrium chemistry.

Considerable research in recent years has greatly increased our understanding of phosphorus chemistry in the bulk water and sediments of lakes. This section briefly summarizes current understanding of lake phosphorus chemistry to gain insight into similar processes that may occur in sewage lagoons.

### Phosphorus Chemistry of Lake Waters

One representation of the phosphorus cycle in lake water is shown in Figure II-2, which is adopted from Phillips (1974). In this figure, external sources of phosphorus (allochthonous) such as inflowing

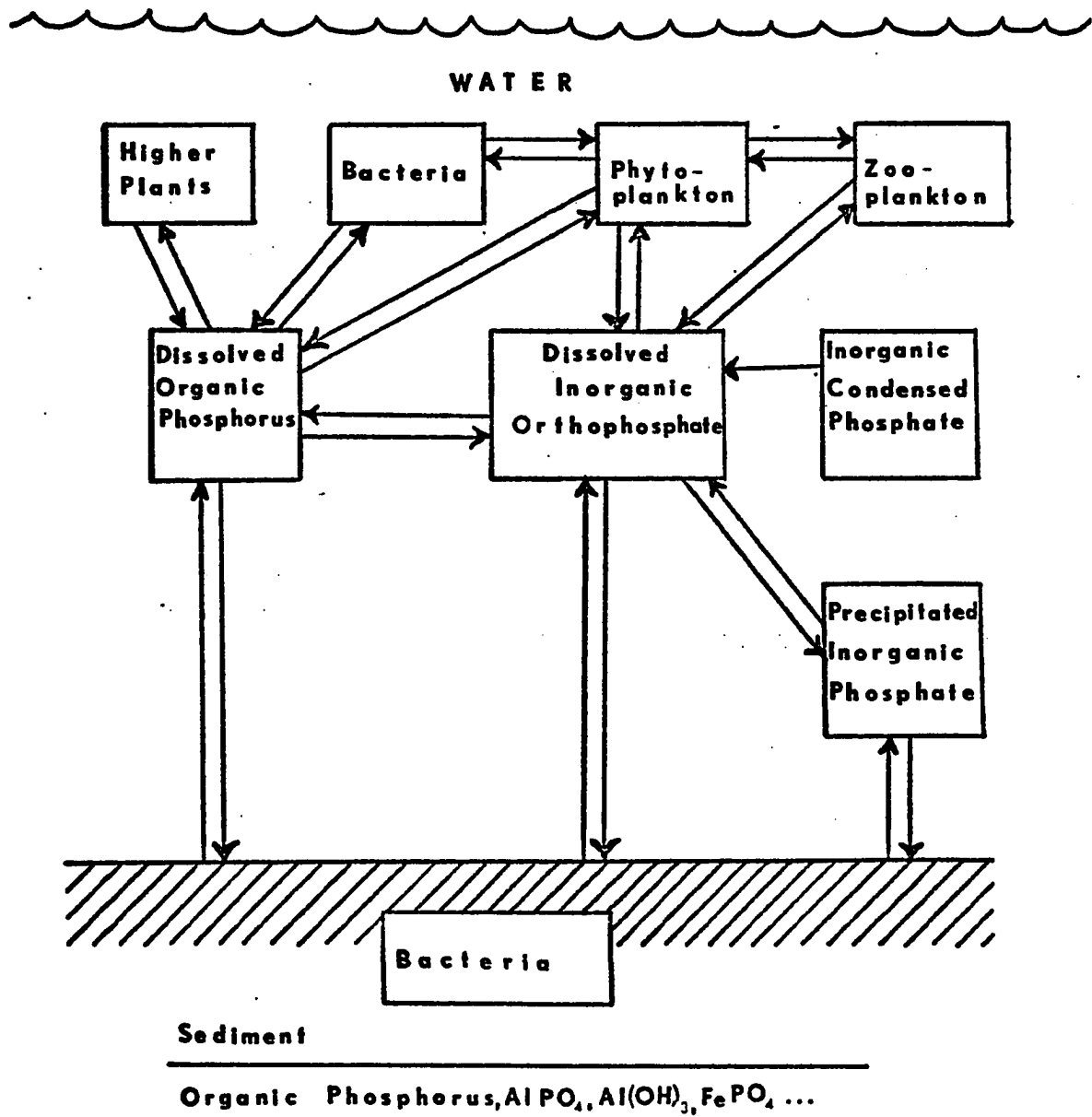


Figure II-2 Phosphorus Locations and Transformations in a Body of Water (Phillips, 1974)

streams and runoff from the local watershed as well as losses of phosphorus in outflows are not considered. External sources along with internal sources, such as decaying aquatic plants in the littoral region, contribute phosphorus to the epilimnion.

Biological processes (including, for example, photosynthesis, metabolism and waste excretion) in the lake result in the uptake, transformation, and excretion of various forms of inorganic and organic forms of phosphorus. In fact, Hutchinson (1944) reported that minor changes in nutrient levels including phosphorus can result in the succession of one algae species by another. The role of bacteria and other microorganisms in the uptake of phosphorus has been studied by Harris (1957). He reported that almost all radiophosphorus (P - 32) found in certain zooplankton was obtained through feeding on bacteria and that zooplankton could not directly utilize inorganic radiophosphorus. Bacteria are able to quickly transform inorganic phosphorus to organic forms which can then either be excreted or be used by feeding organisms such as zooplankton. It has also been shown that in lakes rapid exchange mechanisms exist between phosphate and algae (Lean, 1973). Lean also demonstrated that algae excrete certain organic compounds containing phosphorus. Three minutes after radiophosphorus was added to lake water almost 80 percent of the isotope was in the particulate form (removed by filtration) and an organic fraction with a molecular weight of about 250 and another much larger colloidal or aggregate fraction were identified.

Excreted forms of phosphorus can either be reassimilated from the water by organisms or may be sorbed on or precipitated (like insoluble phosphates of calcium or iron) to the sediments (Hwang, Lackie,

and Huang, 1976). Depending on chemical conditions, described below, phosphorus may then be desorbed from the sediments to the bulk water and assimilated by organisms or may remain associated with the sediment for long periods (Golterman, 1973). Various forms of phosphorus may also be lost from the bulk water of lakes through the settling of phytoplankton and higher plant and animal remains to the sediment. Some easily biodegradable phosphorus components such as orthophosphate and sugar phosphate may be released or decomposed prior to reaching the sediment. Much of the remaining phosphorus material is slowly degraded by heterotrophic microorganisms in the sediment. In most lakes the largest portion of phosphorus is in the particulate form and associated with the sediment. Only a relatively small fraction of the phosphorus is in the aqueous phase (Hayes and Phillips, 1958). In one interesting study, Whitten and Goodnight (1967) found that tubificid worms can accumulate radiophosphorus from water, bacteria and the sediment. They also demonstrated that certain minnows feeding on the worms accumulated radiophosphorus in their tissues which could then be excreted to the bulk water. There are a variety of physical, chemical and biological mechanisms affecting phosphorus cycling in lakes.

#### Sediment - Water Interactions

From the preceding discussion it can be seen that sediments play an important and active role in phosphorus chemistry in lakes. Numerous investigators have devised a wide variety of experiments to study phosphorus interactions with lake sediments. Since similar interactions may occur in waste stabilization ponds the most relevant of these lake studies are described in some detail below.

Radiophosphorus has been used by many investigators to study phosphorus exchange between the sediment and water in lakes. Perhaps the first experimentors were Hutchinson and Bowen (1947). They added 10 millicuries of radiophosphorus to a 14 acre eutrophic and stratified lake in Connecticut and found mixing in the epilimnion and within a week a 1,000-fold concentration of  $^{32}\text{P}$  in the tissues of certain littoral plants. A later experiment by Hutchinson and Bowen (1950) found complete equilibrium of  $^{32}\text{P}$  between the water and solids within a week with a subsequent gain of  $^{32}\text{P}$  by the hypolimnion attributed to sedimentation of plankton and feces and to removal from the mud. Another early study by Coffin, et al. (1949), in which 100 millicuries of  $^{32}\text{P}$  was added to a stratified acid-bog lake, showed the radiophosphorus to be barely detectable in the surface water after eight weeks. Rigler (1956) also added  $^{32}\text{P}$  to an acid-bog lake and found 77 percent of the radiophosphorus was lost in the outflow and three percent lost to the sediment. Rigler attributed this loss to a rapid turnover of phosphorus between the epilimnion and littoral organisms.

Numerous other investigators have also observed a loss of radiophosphorus from the water when added to a lake. Hayes, et al. (1952) doubted the disappearance of radiophosphorus was evidence of growth stimulation but attributed it to an active exchange between the water phosphorus and available phosphorus in the lake solids. They found the turnover time in an unstratified 10 acre lake in Nova Scotia to be 5.4 days for the water and 39 days for the solids.

Seasonal variations in the amount of phosphorus released from lake sediments have been noted. For example, Ryding and Forsberg (1976)

investigated three lakes in Sweden and found substantial amounts of phosphorus were released from the sediments during the summer. Similar results were found by Stevens and Gibson (1976) for Lough Neagh in Northern Ireland when the water overlying the sediment was depleted of oxygen but not anoxic. Theis and McCabe (1978) studied seasonal variations in phosphorus sorption and release tendencies in two hypereutrophic lakes in the United States. They found that during aerobic periods phosphorus was taken up by the sediments and released during anoxic periods. Uptake of phosphorus was found to be proportional to the overlying phosphorus concentration while phosphorus release was correlated with average interstitial phosphorus concentrations. In contrast, several others have noted a correlation of phosphorus release rates between the existing concentration gradient from sediment pore water to overlying water (Stumm and Leckie, 1971; Digiano, 1971; Fillos and Biswas, 1976; and Kamp-Nielsen, 1974). Temporal variations in the phosphate concentrations at a depth of 20 meters for Lake Esrom in Denmark have also been demonstrated (Kamp-Nielsen, 1976).

A variety of chemical and physical factors are thought to influence the release and sorption of phosphorus with sediments. Some have suggested oxygen conditions primarily influence phosphorus release from sediments (Mortimer, 1941, 1942; Fillos and Swanson, 1975). A study by Lee, Sonzogni and Spear (1976) demonstrated substantial release of phosphorus from lake sediments under oxygenated conditions which can stimulate blue-green algal blooms in late spring- early summer. They also found the release of phosphorus from sediments under anoxic conditions during the summer, but on an annual basis the sediments are sinks for phosphorus.

Other factors thought to influence phosphorus release from sediments include the phosphorus content in the sediments and interstitial water (Stumm and Leckie, 1971; Wildung and Schmidt, 1973; and Sanville, Powers and Gahler, 1974), the pH (Graneli, 1975; Lijklema, 1976; McPhearson, Sinclair and Hayes, 1958; and Holdren and Armstrong, 1980), organic substances (Tessenow, 1972; Hallberg, et al., 1973), turbulence (Sullivan, 1967; and Lee, 1970), water temperature (Wildung and Schmidt, 1973; Kamp-Nielsen, 1975; and Holdren and Armstrong, 1980) and redox potential (Hayes and Phillips, 1958; Lijklema, 1976; Ku, DiGiano and Feng, 1978; and Holdren and Armstrong, 1980).

A subject of considerable research and discussion in recent years has been the effect of eliminating phosphorus from external sources on lake eutrophication. Generally it has been postulated that incoming phosphates that have been accumulating in lake sediments may become a source of phosphate for algal growth after phosphorus loading is restricted. Anaerobic sediment release of phosphorus in White Lake, Michigan averaged  $38.0 \text{ mg P/m}^2/\text{day}$  total dissolved phosphorus, and it was concluded that this release rate could potentially contribute nutrients sufficient to support plant growths and delay water quality improvements from sewage diversion (Freedman and Canale, 1977). Similar conclusions were reached by Golterman (1976) in a laboratory and lake study and by Syers, Harris and Armstrong (1973) in a review of phosphorus and lake sediment literature. In fact, a model developed by DiGiano and Snow (1976) predicted that because of phosphorus storage in lake sediments, reducing the input of phosphorus to the lake would continue to produce a substantial release of phosphorus from the sediments for at least ten years.



Nevertheless, Lee, Sonzogni and Spear (1976) concluded that lake sediments generally are a potential source of phosphorus over limited periods of the year and that since most lake sediments act as a phosphorus sink on an annual basis significant reductions in external phosphorus contributions will result in significant improvement in water quality.

Phosphorus in any form is readily absorbed by sediments without being immediately incorporated into protoplasm (Odum, 1971). Sediments in natural systems act as a phosphorus reservoir with the phosphorus concentration in the overlying waters buffered by the solubility and adsorption or ion exchange equilibria at the sediment-water interface (Stumm and Morgan, 1970).

The movement of phosphorus between lake water and the sediment has been related to changes in iron, manganese, calcium, magnesium, carbonate, silica, fluoride, sulfate, hydroxide and hydrogen ions (Banoub, 1976; and Hesse, 1973). The most important forms of phosphorus in lake sediments appear to be those associated with the forms of iron (Theis and McCabe, 1978; Syers, Harris and Armstrong, 1973; Serruya, 1971; and Shukla, et al., 1971). Aluminum and calcium phosphates have also been suggested as important forms in the literature (Syers, Harris, and Armstrong, 1973; Stumm and Morgan, 1970; and Hesse, 1973).

#### The Iron-Phosphate System

Einsele (1936) was apparently among the first to suggest the possible importance of iron in phosphate chemistry in lakes. In laboratory systems Einsele found  $\text{FePO}_4$  precipitated under oxidizing conditions, and as the pH increased to 6, less phosphate was sorbed into the hydrous

ferric oxide gel. A thin film of ferric hydroxophosphate complex was found by Mortimer (1941, 1942) at the sediment-water interface under oxygenated conditions in both laboratory and field studies. Under anoxic conditions phosphate was released from the sediment.

Stumm and Morgan (1970) have used solubility product considerations to predict which phosphorus compounds are thermodynamically stable and can theoretically form. They state that reduction of phosphate containing Fe(III) precipitates along with decomposition of sedimented plankton are the two main mechanisms for the accumulation of soluble phosphate in oxygen-deficient bottom layers of lakes and ponds during stagnation periods. Iron interacts with orthophosphate forming phosphate-iron (III) complexes such as  $\text{FeHPO}_4^+$ . But under slightly acid conditions pure  $\text{FePO}_4(\text{s})$  will be precipitated. Under neutral or slightly alkaline conditions the precipitate is probably a metastable ferric compound containing both  $\text{PO}_4^{3-}$  and  $\text{OH}^-$  in variable proportions, depending on the pH. Chemical reactions of Fe (III) and many organic bases are similar to those with orthophosphate.

These predictions of iron-phosphate chemistry based on laboratory solubility considerations are supported by some field studies but are not supported by observations in other natural systems. Inorganic phosphorus fractionation schemes, based on work by Chang and Jackson (1957) and its modifications, in which certain reagents such as  $\text{NH}_4\text{F}$  are used to solubilize and extract the inorganic phosphorus contained in minerals like variscite and apatite, are commonly used in lake studies to obtain information on forms of inorganic phosphorus in the sediment. However, Williams et al. (1971a and 1971b) since found that problems can result from using

this scheme or its modifications on lake sediments. Care must therefore be taken when interpreting data obtained with these methods.

In a study using cores from Lough Neagh, Rippey (1976) found an increase in phosphorus release rate with pH above 8 and suggested a basic ferric phosphate or ferrosferric hydroxyphosphate system was exhibited. A similar result was also found by Anderson (1975) on lake sediments. However, laboratory studies on mud from Lake Constance (Banoub, 1976) showed total iron,  $\text{PO}_4^{3-}$  and ferrous ions to sometimes appear to be released independently or successively. And Kamp-Nielsen (1974) found a decrease of phosphorus release rate as pH increased above 8 in his lake studies.

#### The Calcium-Carbonate-Phosphate System

Some have suggested that phosphorus may be a co-precipitant on  $\text{CaCO}_3$  under periods of active photosynthesis (Gessner, 1939 as quoted in Banoub, 1976) especially in hard-water lakes. In fact, for hard-water lakes the calcium-carbonate-phosphate system may be predominant in controlling phosphorus sorption and desorption. In these lakes calcium and magnesium bicarbonates are present in highest concentration during low oxygen conditions in the hypolimnion. Therefore, in hard-water lakes where the calcium-carbonate-phosphate system predominates phosphorus would be expected to precipitate under aerobic conditions and to be released during anaerobic conditions.

Solubility product criteria have also been used by Stumm and Morgan (1970) to postulate the formation in lake sediments of minerals resembling hydroxyapatite,  $\text{Ca}_5\text{OH}(\text{PO}_4)_3(\text{s})$ . Their conclusion was that

hydroxyapatite tends to buffer the total phosphate concentration in water. However, the minerals hypothesized by Stumm and Morgan may have quite different surface properties than those formed in lakes and the concentration of dissolved inorganic P (3.1 micrograms per milliliter) used by them is higher than commonly occurs in lake or interstitial waters (Syers, Harris and Armstrong, 1973).

There is at least some evidence that calcium does play a prominent role in phosphate chemistry in some lakes. For example, in the Great Lakes dissolved inorganic phosphorus concentration data was explained by a simple equilibrium model involving hydroxyapatite (Kramer, 1967 and Sutherland et al., 1966). In western Lake Erie, Gerhold and Thompson (1969) found hydroxyapatite to be the principal phosphate mineral present, in an amorphous form, and that under optimum conditions phosphate was released at a sufficient rate to keep algae at a maximum growth rate.

However, some investigators feel the role of hydroxyapatite in phosphate chemistry is generally not so important. Williams et al., (1971a) found the Madison Lakes to be supersaturated with hydroxyapatite while only small amounts of apatite were found in upper sediments in these lakes. In fact, Lee (1970) maintains that little or no evidence exists that hydroxyapatite plays a major role in phosphorus chemistry in either lake waters or sediments.

#### The Aluminum-Phosphate System

Stumm and Morgan (1970) have suggested that aluminum may also play an important role in phosphate chemistry. Their hypothesis is that

phosphates can be sorbed onto clay between aluminum ( $\text{Al}^{3+}$ ) ions. This sorption of phosphates and polyphosphates appears to involve two mechanisms, (1) chemical bonding of the anions to positively charged edges of the clays, and (2) substitution of phosphates for silicate in the clay structures. In general, a lower pH favors high phosphate adsorption by clays. Maximum sorption of orthophosphate on montmorillonite occurs at pH 5-6 while sorption by kaolinite is greatest at a pH near 3. At a pH of 6, when  $\text{AlPO}_4(\text{s})$  is minimally soluble, precipitation of aluminum phosphate is possible in theory if the dissolved inorganic phosphorus level exceeds  $3 \times 10^{-6} \text{ M}$  or about 0.1 milligram per liter. However, at a pH of 6,  $\text{FePO}_4(\text{s})$  will theoretically maintain a level of dissolved inorganic phosphorus of approximately 1.0 milligram per liter (Syers, Harris and Armstrong, 1973).

In summary, Stumm and Morgan (1970) conclude that from a pH of 4.5 to 6.5, phosphorus is bound to the solid phase by Fe (III) and Al (III) either by precipitation or adsorption. From a pH of 7 to 9 very little phosphorus becomes sorbed on the sediments. At higher pH values the tendency for the precipitation of phosphorus increases and appears to be related to the decreasing solubility of calcium phosphate (apatite). Overall, phosphorus concentration at the sediment-water interface, especially at higher pH values appears to be buffered by hydroxyapatite.

Lake investigations have shown, on the other hand, that phosphorus chemistry can vary with the type of lake chemistry. In calcareous sediments calcium-bound phosphorus occurs while in noncalcareous sediments iron-and aluminum-bound phosphorus forms generally occur. In either type of lake system phosphorus may be sorbed on sediments or desorbed depending on the pH and redox conditions as described above.

### Organic Forms of Phosphorus and Lake Sediments

Organic phosphorus compounds such as nucleic acids and phospholipids are present in lake sediments from microbial synthesis of inorganic phosphorus and from the remains of plants and animals. Organic forms of phosphorus entering lakes will eventually be deposited on the sediments and mineralize slowly because organic forms are not readily taken up by microorganisms (Hesse, 1973). While there is a lack of direct methods to measure total organic phosphorus in sediments, certain specific phosphorus compounds have been identified. For example, in nine Wisconsin lakes, adenosine triphosphate (ATP) ranged from 0.34 to 9.5 micrograms ATP per gram of sediment (Lee et al., 1971). In four Wisconsin lake sediments inositol hexa- and penta-phosphates ranging from 16 to 34 micrograms per gram were measured (Sommers et al., 1972).

Phosphate esters can be sorbed at their phosphate group. This sorption should be similar to the sorption of inorganic phosphorus on sediments (Syers, Harris and Armstrong, 1973). The organic portion of organic phosphorus compounds may also interact with sediments (Anderson, 1967 and Sommers, 1971 as quoted in Syers, Harris and Armstrong, 1973). Mechanisms for the sorption of organic phosphorus compounds have not been extensively studied. Van der Waals forces and other weak interactions have been suggested as playing a minor role in the retention of all organic phosphate esters (Syers, Harris and Armstrong, 1973). Greaves and Wilson (1969) attributed the retention of DNA on montmorillonite to physical adsorption.

## Biological Influences on Phosphorus Chemistry of Lake Sediments

Aquatic plants and animals can influence the cycling and chemistry of phosphorus through their physical and biological activities. Vertical burrowing or bioturbation of aquatic invertebrates such as oligochaete worms, insect larvae, crustaceans and bivalve molluscs, has been shown to increase the release of redox potential ( $E_H$ ) sensitive phosphorus from lake muds (Petr, 1976). The rate of release depends on other physical and chemical factors such as the strength of the attraction of phosphorus to the substrate.

The rate of radiophosphorus movement across the sediment water interface as affected by bioturbation has been studied by Neame (1976) and by Holdren and Armstrong (1980). Neame reported that the stirring activities of fauna in the oxidized zone largely mediated the flux of about 650 micrograms phosphorus per square meter per day. Loss of phosphorus from insect emergence and fish feeding averaged 33 and 23 micrograms phosphorus per square meter per day, respectively, in his late summer study of Lake Castle in California. Settling detritus contributed an average of 380 micrograms phosphorus per square meter per day. Holdren and Armstrong (1980) found that bioturbation had a greater effect on phosphorus release rates from intact sediment cores from four Wisconsin lakes than any other factor investigated.

Tubificid worm burrowing (Davis, Thurlow, and Brewster, 1975 and Davis, 1974) and chironomid activity (Gallepp, 1977) have been studied as they affect phosphorus release from sediments. These organisms predominantly occur in the upper 16 centimeters of lake sediments and most disturbance occurs in the upper 5 centimeters or so. Therefore, it seems

most of the biological influence on sediment-water interactions of phosphorus occurs in this area.

In addition to physical influences, microorganisms influence phosphorus chemistry by controlling environmental factors which determine the solubility equilibria (pH,  $E_H$ , type of residual organic matter, etc.) (Stumm and Morgan, 1970). Some evidence does exist that organisms such as algae and bacteria can remove sufficient phosphorus from lake sediments to maintain growth. This was shown with the use of radiophosphorus in systems containing sediments as the only source of phosphorus (Syers, Harris, and Armstrong, 1973).

#### Limnological Influences on Phosphorus Chemistry of Lake Sediments

Lee (1970) has shown that the transport of phosphorus and other minerals to lake water from the sediments depends on diffusion rates, the extent of turbulent mixing, and perhaps the upward movement of groundwater through the sediment. These same physical factors can also affect the transport of oxygen to the sediment which influences the redox potential. Turbulent mixing appears to be of greater importance in sediment-water phosphorus cycling in lakes than does diffusion. In fact, for lakes with poorly packed, loose, low density sediments, turbulent mixing may influence several centimeters of the surface layer.

#### Phosphorus in Facultative Lagoons Under Summer Conditions

Facultative lagoons or waste stabilization ponds are similar to small lakes in that they have inflow and outflow, are a collection of water in contact with sediments in a basin, are exposed to similar



sunlight and wind conditions, and support a variety of plant and animal life. For those reasons chemical and biological processes in each can be expected to be similar. However, there are certain important differences between lagoons and small lakes. The design of facultative lagoons generally provides for a relatively shallow depth and a constant organic loading. This organic loading, including abundant nutrients like phosphorus and nitrogen for bacterial and algal growth, is the primary reason why the rates and types of chemical and biological processes in lagoons may differ from those in lakes, and why experiments from one cannot always be directly applied to the other.

Facultative lagoons have a surface aerobic layer, a middle layer that supports facultative bacteria, and an anaerobic bottom sludge layer. Depths generally range from three to five feet although deeper ponds have been successfully operated (Gloyna, 1971). More than one pond or cell may be used, either in series or in parallel, to accomplish stabilization of the organic matter. First cells have higher loading rates than following cells and generally their anaerobic area is larger. Second and later cells generally support dense populations of algae in the summer and have larger aerobic zones.

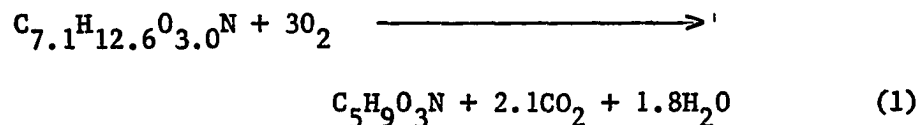
#### General Chemistry and Biology of Lagoons

Oxygenation of lagoons is by the photosynthetic activity of algae and surface aeration from wind action and diffusion. Because light penetration is limited to about one meter or less, oxygenation by algal photosynthetic activity is restricted to the upper layer. According to Gloyna (1971) the major biological reactions taking place in

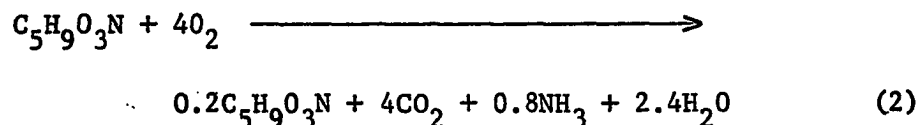
waste stabilization ponds are: (a) oxidation of organic material by aerobic bacteria; (b) nitrification of protein and other nitrogenous material by aerobic bacteria; (c) reduction of organic material by anaerobic bacteria living in bottom deposits and liquids; and (d) oxygenation of surface liquids by algae. Bacteria and algae usually predominate in waste stabilization ponds and protozoa and rotifers may be present under certain loading conditions. The types of microbial populations are not only influenced by the organic loading rate, but other factors such as degree of mixing and physical design can also influence their predominance (McKinney, 1962).

As wastewater enters a lagoon two main groups of organisms, bacteria and algae, act together to utilize the contents. Bacteria are first to act upon the biodegradable fraction of wastewater by two basic metabolic reactions. These reactions, bacterial synthesis and endogenous respiration, have been represented as follows by McKinney (1974).

Synthesis (reaction 1):

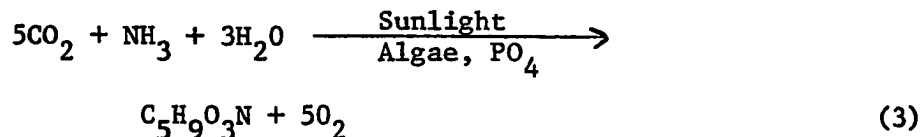


Endogenous Respiration (reaction 2)



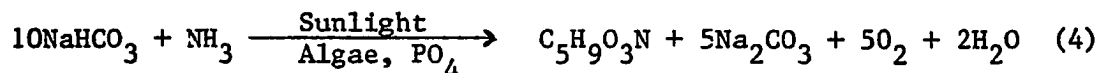
As a result of both of these reactions, oxygen is required, while carbon dioxide, water, ammonia nitrogen, and various solids including new bacteria cells are produced. Oxygen is supplied, and carbon dioxide used

by algae in a synthesis reaction as follows in reaction 3:



This algal synthesis reaction predominates over respiration during the daytime in the presence of light and supplies a portion of the oxygen needed by bacteria to stabilize the waste. However, at night algal cells predominantly undergo endogenous respiration similar to bacterial cells (reaction 2) and require oxygen while producing carbon dioxide and new algal cells. This change between the synthesis reaction (photosynthesis) by algae during the day and endogenous respiration at night causes diurnal variations in oxygen concentration in the water. This variation is most pronounced during late summer (July and August) when light intensity and length of daylight are greatest. An example of the variation in dissolved oxygen that can occur is shown in Figure II-3, reproduced from King (1976) for a lagoon in Missouri during one 24 hour period in the summer. A variation of up to 40 milligrams per liter in dissolved oxygen concentration was measured. Similar variations have been noted by Aguirre and Gloyna (1970) in pilot scale ponds and by Mills (1961) who noted that no oxygen could be measured in facultative ponds two hours after sunset, but the ponds recovered quickly in the morning.

Another source of carbon in sewage for algal growth, in addition to organic matter, is alkalinity. This use of alkalinity by algae can be represented by reaction 4 (McKinney, 1974):



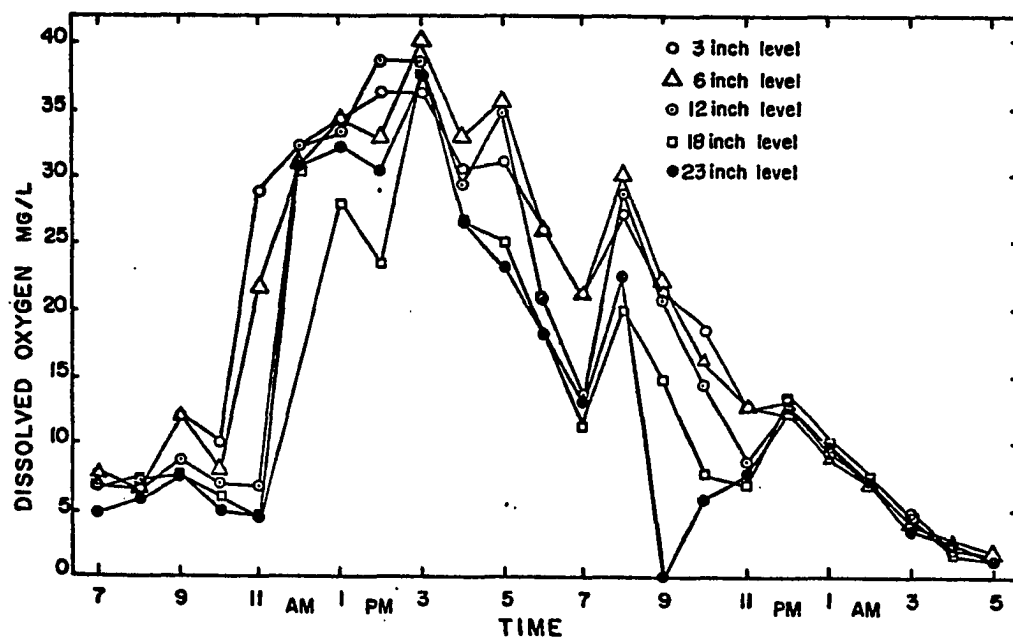
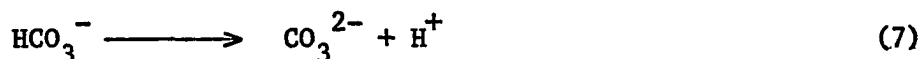
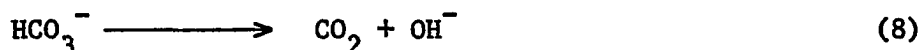


Figure II-3: Diurnal Variation of Dissolved Oxygen at Five Levels of the Bear Creek Lagoon, Columbia, Missouri, on August 18-19, 1968. (King, 1976)

One of the results of this reaction is the conversion of inorganic carbon to organic carbon. For example, if 300 mg/l alkalinity as  $\text{CaCO}_3$  is present in the sewage, about half would be converted by the algae to the carbonate form which results in the pH being raised. The pH is also influenced by the production of carbon dioxide during bacterial synthesis (reaction 1), bacterial respiration (reaction 2), algal synthesis (reaction 3) and algal respiration (reaction 2). The carbonate buffer system as shown in reactions 5 through 7 determines the effect the production or consumption of carbon dioxide will have on pH.



Carbon dioxide production tends to decrease the pH as a result of hydrogen ion formation. However, as  $\text{CO}_2$  produced from bacterial synthesis is used by algae during photosynthesis, the bicarbonate ion ( $\text{HCO}_3^-$ ) can dissociate into carbon dioxide and hydroxyl ions as shown in reaction 8.



This production of hydroxyl ions results in an increase in the pH during the day to values greater than 9 and perhaps as high as 10 or 11 under extreme algal photosynthetic activity (Drews, 1966). The pH in sewage lagoons drops rapidly until equilibrium is reached at around 7 when photosynthetic activity ceases at night. This results in a diurnal variation in pH which is most extreme during the summer months. It is common

in many lagoons for the pH to gradually increase with time throughout the summer (King, 1976). One report of this diurnal variation by King (1976) is shown in Figure II-4, for the same day and lagoon as the diurnal dissolved oxygen variation shown in Figure II-3. The maximum pH was reached in mid afternoon with minimum pH values recorded about 12 hours later. Similar diurnal variations in pH during the summertime have been reported by Aguirre and Gloyna (1970).

These extreme diurnal variations in pond chemistry during summer months can be expected to influence phosphorus chemistry. According to some lake studies described earlier, phosphorus may be sorbed or precipitated on pond sediments under high pH and oxygen conditions during the day and released from the sediments under lower pH and oxygen conditions at night. However, as described below, no systematic study under field or laboratory conditions has been undertaken to demonstrate possible changes in phosphorus chemistry in lagoons under these extreme pH and oxygen conditions. Instead, most studies of lagoons have measured phosphorus in the effluent at one particular time in an attempt to determine the removal rate of phosphorus in the treatment process. In fact, a very wide range of removal rates has been reported, suggesting little is understood of the chemical conditions affecting phosphorus chemistry in lagoons.

#### Sources and Forms of Phosphorus in Lagoons

While several investigators have reported on the concentration of total phosphorus present in raw wastewater and have estimated the phosphorus contribution per person, few have reported the relative

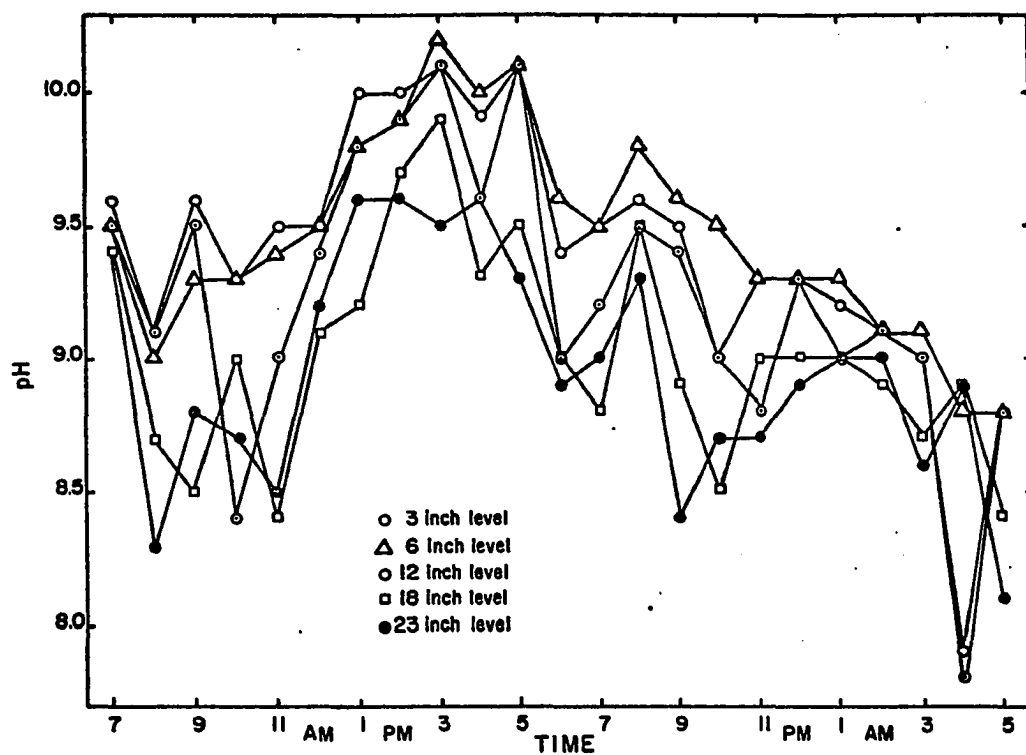


Figure II-4: Diurnal Variation of pH at Five Levels of the Bear Creek Lagoon, Columbia, Missouri, on August 18-19, 1968. (King, 1976)

amounts of the various forms of phosphorus present. For example, Nesbitt (1966 and 1969) pointed out that organic phosphorus in organic matter and cell protoplasm, and complex inorganic phosphates and soluble inorganic orthophosphate may occur in wastewater; but he did not present measured concentrations of these forms, although he reported a value of 8 milligrams of total phosphorus in trickling filter effluents.

In a literature review by Hetling and Carcich (1973) of phosphorus concentration and loading values, they found a range of total phosphorus concentration (milligrams per liter) in raw wastewaters of 0.6 in 1901 to 24.3 in 1960. Reported loadings ranged from 0.6 to 8.5 grams of total phosphorus per capita per day. For both concentration and loading, the authors noted a general historical increase with a slight leveling off in reported values in recent years. Wuhrmann (1968) has reported a loading rate for raw wastewater of 3 grams phosphorus per capita per day.

Williams and Malhotra (1974) found raw wastewater in an aerated lagoon in Michigan to contain 3.5 to 5.5 mg/l with an average of 4.7 mg/l of total phosphorus during August of 1973. However, they reported an average total phosphorus concentration in the influent for 6 months of 12.0 mg/l. Leckie and Stumm (1970) report that total phosphorus concentrations in raw wastewater range from 5 to 20 mg/l with 15 to 35 percent present as soluble orthophosphate.

One other possible source of phosphorus loading, rainwater, should also be noted. Leckie and Stumm (1970) report a total phosphorus concentration in rainwater ranging from 0.004 to 0.03 mg/l while Fruh (1968) reports up to 0.1 mg/l of phosphorus may be present.



### Phosphorus Removal In Lagoons

Investigations of the removal of phosphorus from wastewater effluents, such as by chemical precipitation, have been more numerous and more extensive than have studies on phosphorus interactions within wastewater treatment processes (see, for example, Leckie and Stumm, 1970; Nesbitt, 1966; and Goodman and Mikkelsen, 1970).

Concentrations from 3 to 10 mg/l of total phosphorus in treated wastewater, with 50 to 90 percent of that being orthophosphate, has been reported by Leckie and Stumm (1970). Allum et al., (1978) and Reynolds et al., (1976) also measured total phosphorus levels in wastewater but used composite sampling and did not measure diurnal or seasonal variations in concentrations.

Several researchers have measured some forms of phosphorus in wastewater and lagoon effluents to estimate the amount of phosphorus removed in the treatment process. Total phosphorus and orthophosphorus concentrations were reported by Pierce (1974) for raw sewage and the effluents of 5 cells in a lagoon system operated in series by the city of Belding, Michigan. The results of this analysis for one day in the summer (the time of day of sample collection was not given) are shown in Table II-2. In this study orthophosphorus constituted from 53 to 80 percent of the total phosphorus. Removal rates for phosphorus were variable with phosphorus levels decreasing through the first two cells and some increases in concentrations noted in the effluents of following cells. Dissolved oxygen levels were not measurable in the first cell where phosphorus levels were highest and when the oxygen and pH increased

Table II-2: Phosphorus and Dissolved Oxygen Concentration (mg/l) and pH  
of 5 Lagoons Operated in Series at Belding, Michigan on  
July 21, 1972 (Pierce, 1974)

| Influent         |      | Effluent |        |        |        |        |
|------------------|------|----------|--------|--------|--------|--------|
| Raw Sewage       |      | Pond 1   | Pond 2 | Pond 3 | Pond 4 | Pond 5 |
| Total Phosphorus | 12.5 | 9.9      | 3.0    | 2.5    | 4.4    | 2.9    |
| Orthophosphorus  | 10.0 | 7.8      | 1.6    | 2.0    | 3.4    | 2.3    |
| Dissolved Oxygen | 0.0  | 0.0      | 27.8   | 11.2   | 5.0    | 10.8   |
| pH               | 7.1  | 7.3      | 8.6    | 8.6    | 8.0    | 8.6    |

rapidly in cell 2 the phosphorus level declined. Changes in the concentration of total phosphorus in the effluent of cell 5 during the winter and summer were also reported by Pierce (1974) and are shown in Table II-3. Again, the time of day of sample collection was not given. During the winter months, total phosphorus concentrations in the effluent generally increased perhaps indicating either decreasing phosphorus removal or desorption of phosphorus by the sediments. During the summer total phosphorus concentrations were generally lower than the winter levels and a slight decrease occurred during the summer sampling period. Dissolved oxygen concentrations ranged from 5.0 to 10.9 mg/l in the winter and from 9.4 to 17.5 mg/l in the summer.

Pierce (1974) also reported on the total phosphorus concentration in the effluent from a 3-celled lagoon in Chesterfield Township, Michigan. Samples of the effluent were collected twice daily. The results of the total phosphorus measurements are presented in Table II-4. The range in total phosphorus values for the months from January, 1973 to May, 1974 are shown. Generally, measured total phosphorus levels were higher in the winter than in the summer but, once again, the time of day the samples were taken was not specified.

The results of an extensive survey of the performance of lagoons throughout the United States have been reported by Barsom (1973). Among the data he collected is that shown in Table II-5, which shows reported total phosphate measurements in facultative lagoons in several states. Although the time of day and time of year for the sampling was not given, the range in phosphate levels reported is noteworthy. Influent concentrations were highest in the southcentral

TABLE II-3: Total Phosphorus Concentration (mg/l) of Pond 5 Effluent  
at Belding, Michigan (Pierce, 1974)

| <u>DATE</u> | <u>TOTAL-P</u> | <u>DATE</u> | <u>TOTAL-P</u> | <u>DATE</u> | <u>TOTAL-P</u> |
|-------------|----------------|-------------|----------------|-------------|----------------|
| 1973        |                | 1974        |                | 1974        |                |
| 11-5        | 2.7            | 1-15        | 3.4            | 4-26        | 2.8            |
| 11-7        | 3.9            | 1-18        | 3.6            | 4-29        | 2.9            |
| 11-13       | 3.9            | 1-22        | 4.0            | 5-1         | 3.0            |
| 11-20       | 3.9            | 1-25        | 4.4            | 5-6         | 3.2            |
| 11-22       | 3.5            | 1-29        | 5.1            | 5-7         | 2.8            |
|             |                |             |                | 5-8         | 2.7            |
|             |                |             |                | 5-13        | 2.5            |

TABLE II-4: Total Phosphorus Concentration (mg/l) in the Effluent of  
3-Cell Lagoons in Chesterfield Township, Michigan (Pierce, 1974)

| DATE | TOTAL-P | DATE | TOTAL-P | DATE | TOTAL-P | DATE | TOTAL-P |
|------|---------|------|---------|------|---------|------|---------|
| 1973 |         |      |         |      |         | 1974 |         |
| Jan  | 2.8-6.0 | May  | 3.0-6.9 | Sept | 0.5-2.5 | Jan  | 4.2-6.7 |
| Feb  | 5.2-8.4 | June | 3.2-4.8 | Oct  | 2.2-6.3 | Feb  | 1.9-6.3 |
| Mar  | 5.5-7.2 | July | 1.5-4.1 | Nov  | 1.6-2.9 | Mar  | 3.0-7.6 |
| Apr  | 3.4-6.1 | Aug  | 1.6-3.0 | Dec  | 2.7-4.5 | Apr  | 1.7-3.1 |
|      |         |      |         |      |         | May  | 1.6-2.8 |

**TABLE II-5: Total Phosphate (PO<sub>4</sub>) Reduction in Facultative Oxidation Lagoons (mg/l) (Barsom, 1973)**

| Location   | Influent | Effluent | % Removal | Reference                        |
|------------|----------|----------|-----------|----------------------------------|
| California | 34.0     | 32.0     | 5.6       | Oswald, Golueke and Tyler, 1967  |
| Illinois   | 17.0     | 10.4     | 38.8      | Busch, 1965                      |
| Missouri   | 42.6     | 8.2      | 80        | Neel, McDermott and Monday, 1961 |
| "          | 42.6     | 9.7      | 76        | "                                |
| "          | 42.6     | 13.8     | 67        | "                                |
| "          | 42.6     | 12.8     | 70        | "                                |
| "          | 42.6     | 12.8     | 70        | "                                |
| "          | 42.6     | 9.1      | 78.6      | "                                |
| "          | 44.0     | 10.8     | 93        | Clare, Neel and Monday, 1960     |
| "          | 44.0     | 8.0      | 82        | "                                |
| "          | 44.0     | 6.9      | 84        | "                                |
| "          | 44.0     | 6.6      | 85        | "                                |
| Ohio       | 6.0      | 5.6      | 7         | Horning, et al., 1964            |
| "          | 6.0      | 5.4      | 10        | "                                |
| Oklahoma   | 65.9     | 18.0     | 24        | Reid, Wilcomb and Assenzo, 1965  |
| "          | 81.8     | 26.4     | 68        | "                                |
| "          | 73.4     | 34.2     | 53        | "                                |
| "          | 83.0     | 38.2     | 54        | "                                |
| "          | 82.5     | 37.5     | 55        | "                                |
| "          | 81.3     | 39.5     | 51        | "                                |
| "          | 88.4     | 38.8     | 56        | "                                |
| "          | 19.5     | 51.9     | (166)     | Technical Services Program, 1966 |
| "          | 22.0     | 3.7      | 83        | "                                |

states of Missouri and Oklahoma, while the removal rate of total phosphate in the effluent ranged from a high of 93% to a low in one case where there was a reported 166% increase. Barsom (1973) also reported on the total phosphate in the effluent in 41 facultative lagoons in Texas. The data, which were taken in 1971 from unpublished monthly operating records from the Texas Water Quality Board, ranged from 0 mg/l up to 620 mg/l total phosphate. The average effluent concentration was 234.3 mg/l total phosphate for the 41 lagoons, which is higher than that reported by most others. Barsom offered no apparent explanation for these widely varying results, and stated that little significance could be attached to these few lagoon installations.

Other reports of phosphorus removal rates include summer removal rates of 58-80% while winter removal rates were minimal (Porges and MacKenthun, 1963) and an average reduction of 60% in total phosphorus in 5 Canadian lagoons with the greatest reductions in the early summer months (Fisher, Dryan and Van Fleet, 1968). Also, phosphorus removals in wastewater lagoons were reported as ranging from 10 to 40% by Bogan (1962) while Reid and Assenzo (1965) reported total phosphate (as  $\text{PO}_4^{3-}$ ) removals in seven Oklahoma ponds ranged from 14.5 to 89%, sampled once every two weeks for about  $2\frac{1}{2}$  years.

In a study of seasonal orthophosphate reduction in a sewage lagoon at Karnatak University in India by Rodgi, Kanabur, and Nimbargi (1974) considerable variation in the effluent (6.5 to 22.7 mg/l) was noted. Considerable variation in the percent orthophosphate reduction in the effluent was also found. A 19% reduction in orthophosphate was found in December and the greatest average of orthophosphate reduction

(36 to 57%) was measured during the summer months of March to June. These samples were taken at three times per day. The authors suggest that phosphorus reduction in sewage lagoon effluents depends mainly on algal activity, pH, light, and temperature.

Two general mechanisms for the removal of phosphorus have been described in the literature. These two mechanisms are by chemical precipitation from the wastewater when the pH is raised, and by metabolic uptake and adsorption of phosphorus by algal cells. Chemical precipitation at high pH levels in the form of calcium phosphate has been suggested by several investigators (Pipes, 1961; Nesbit, 1973; and Fitzgerald and Rohlich, 1964). Since algal synthesis plays an important part in determining the pH in a lagoon, as described earlier, algae are thought to indirectly influence the precipitation of phosphorus. Due to the second mechanism, metabolic uptake and adsorption of phosphorus by algal cells, Nesbitt (1966) has suggested some method of harvesting algae is necessary to limit phosphorus leaving a lagoon in the effluent. Nesbitt (1966) further suggested that to remove phosphorus from lagoon effluents it is also necessary to remove organic matter, operate in a warm climate to ensure continuous biological activity and provide artificial lighting, (especially at night) for continuous photosynthesis.

The role of algae and, more recently, of water hyacinths in reducing phosphorus levels in lagoon effluents has been investigated (see, for example, Gates and Borchardt, 1964; Bogan 1961; Bogan, Albertson and Pluntze, 1960; and Ember, 1978). Several investigators have studied the use of algae to raise the pH in lagoon effluents to reduce phosphorus levels. For example, in laboratory flasks incubated at 24°C and with



an illumination at the surface of 175 foot candles Fitzgerald and Rohlich (1965) reported phosphorus levels in secondary effluent from Madison, Wisconsin were reduced from 6.0 to 0.3 mg P/l in 14 days. They attributed much of this removal to increased pH as a result of algal photosynthesis. In a laboratory contact tank with a 1000 foot candle light source and an algae growth tank with an 800 foot candle light source, Bogan (1961) measured a reduction in orthophosphate from 9.7 mg P/l to 1.6 mg P/l. Also, in laboratory studies, Witt and Borchardt (1960) found that phosphorus was removed at a rate of 0.28 mg P/hr with an optimum light intensity of 400 to 600 foot candles and a temperature between 20° and 30°C in a mixed culture of Scenedesmus and Chlorella ( $9 \times 10^6$  cells/ml). Greer and Ziebell (1972) also found orthophosphate was precipitated at high pH levels in the form of hydroxylapatite in outdoor pools 1 meter deep containing heavy algal blooms and other organisms including clams. They concluded that beds of clams can aid in phosphorus removal by filtering the hydroxyl-apatite-algae suspension. This treatment method is capable of removing 0.930 mg/day of phosphorus in 15.0 mg/l phosphate water.

Of course, it must be noted that algae also influence phosphorus removal when photosynthetic activity ceases at night and the pH level drops. When the pH drops below 8.0 Fitzgerald (1961) found that previously precipitated phosphorus will redissolve. Fitzgerald also found that in ponds with a depth of 2 to 3.5 feet and retention times of 9 to 10 days, there was a direct correlation between pH and phosphorus removal. Removal of phosphorus was reportedly high in the summer while effluent levels often exceeded influent levels in the winter.

## Other Environmental Factors Affecting Phosphorus

### Chemistry in Lagoons

Several other factors are important in the chemistry of sewage lagoons including temperature, wind mixing, lighting, loading, retention time and types of bacteria and algae. Each of these factors is briefly described below.

Not only does temperature affect the metabolism rate of micro-organisms in a lagoon but sudden changes in temperature can also affect the types and relative abundance of organisms present. Under normal conditions the metabolism rate of bacteria and algae doubles with each  $10^{\circ}\text{C}$  increase in temperature. If the temperature changes rapidly the bacteria are able to respond quickest. As a result, the rate of oxygen use can increase faster than oxygen production when the temperature rises. A rapid decrease in water temperature often corresponds to low wind speeds and mixing conditions which results in the algae settling (McKinney, 1974).

Algal growth rates generally reach a maximum between  $25^{\circ}\text{C}$  and  $30^{\circ}\text{C}$  (Bartch, 1961) and lagoon temperatures rarely exceed this range. However, above  $30^{\circ}\text{C}$  bacteria continue to use oxygen at an increased rate while algal production of oxygen decreases.

During the summer when heating rates are high and wind rates are low thermal stratification of ponds often result (Aguirre and Gloyna, 1970). Waters above the thermocline generally are well oxygenated by algal photosynthesis, while waters below the thermocline are usually anaerobic.

Wind is important in lagoon chemistry by promoting surface reaeration, deaeration under supersaturated conditions, and mixing of the contents (Watters, et al., 1973). However, wind speeds around lagoons may be reduced by sheltering trees, hills and a surrounding berm. Under very quiescent conditions certain nonmotile algae may settle out of the euphotic zone.

As described earlier, sunlight is used by algae as a source of energy in photosynthesis. The overall rate of (photosynthesis) is determined by the rate of sunlight energy adsorption (Varma and Talbot, 1965). Therefore, such factors as latitude, elevation, cloud cover, and season are important in determining oxygen production rates by algae.

The depth to which sufficient light penetrates for photosynthesis, the euphotic zone, can vary from about an inch to about three feet or more in lagoons depending on the intensity of the solar radiation and on the density of algae cells. At light intensities less than 400 to 600 foot candles, the saturation level for algae, the rate of photosynthesis decreases (Bartsch, 1961). From about 500 foot candles up to about 1,000 foot candles the photosynthetic rate is independent of the light intensity. At intensities above 1,000 to 4,000 foot candles photosynthesis is inhibited (Oswald, 1960). In one study, Towne and Davis (1957) found that only 1% of surface light penetrated to a depth of 6 inches in lagoons in the Dakotas. Mutual shading of individual algae cells in thick cultures can exert a greater influence on oxygen production than daytime variations in light intensity according to conclusions by Herman and Gloyna (1958).

The minimum amount of sunlight needed by Chlorella for growth has been measured at about 24 foot candles, while its maximum rate of photosynthesis occurs at 600 foot candles (Gloyna, 1968). Available solar energy on a bright day is about 9,000 foot candles (300 Langleys) in the temperate zone at the surface (Oswald and Gotaas, 1955).

The loading rate of  $BOD_5$  and the detention time are important design factors in determining the type and rate of biological processes that occur in the lagoon and, to some extent, the amount of treatment. In geographical areas such as the southcentral United States where winter ice cover is not common, it has been shown that loading rates up to 200 lb.  $BOD_5$ /acre/day are feasible (Neel, McDermott and Monday, 1961; Mills, 1961; and Horning et al., 1965).

A survey of facultative lagoon design criteria used in the U.S. during 1968-69 has been conducted by Canter and Englande (1970). They reported that while recommended organic loading varies with latitude, states across the south have an average design loading of 44 lb.  $BOD_5$ /acre/day (range of 30 to 50 lb.  $BOD_5$ /acre/day). This is an average population per acre of 267, with a range of 175-300 people per acre. This same study found that southern states have an average designed detention time of 31 days, with a range of 20 to 45 days reported. In general, recommended organic loading increases and detention time decreases as latitude location decreases and climatic conditions become milder.

While it is not necessary to understand the microbiology of lagoons to design and operate them, it helps to understand the changes

and reactions that occur daily and throughout the year. Because of environmental conditions including high organic loading rates only a relatively few bacterial, algal and protozoan species commonly occur in sewage lagoons.

Predominant bacteria reported in waste stabilization ponds are Pseudomonas, Flavobacterium, Alcaligenes, Achromobacter, and coliforms (McKinney, 1974; Gloyna, 1971; Zajic, 1971; McKinney, 1962; and Gann, Collier and Lawrence, 1968). Other bacteria reported in sewage lagoons include Azotobacter (Gloyna, 1968) and such pathogens as Salmonella (Towne and Davis, 1957; Malina and Yousef, 1964; Marais, 1966; and Slanetz, et al., 1972). Gann, Collier and Lawrence (1968) found that in an aerobic layer of laboratory ponds 65% of the total bacteria were Achromobacter; 25% were Pseudomonas; and 5% were Flavobacterium. The same relative proportions of these organisms were also found in field ponds in central Oklahoma. The field ponds had organic loadings ranging from 15 to 60 lbs. BOD<sub>5</sub>/acre/day.

It appears that the predominance of a species over others primarily depends on the relative abilities to metabolize the particular waste. For example, whenever a relatively high protein content occurs Alcaligenes and Flavobacterium are likely to predominate. Pseudomonas species occur widely because they are very adaptable to diverse environmental conditions and can metabolize many organic substrates (Gloyna, 1971).

It has been known for a long time that during treatment in sewage lagoons the number of pathogenic bacteria is greatly reduced, but the reasons for this reduction have not been established. At first it

was believed that antibiotics were produced by algae, but no evidence of this has been found (McKinney, 1962). More recent reasons given for this die-off include dilution and mixing, aggregation and sedimentation, the presence of toxic substances, predation, sunlight, temperature, availability of nutrients (Gloyna, 1971) and natural competition (McKinney, 1962). Probably predation and natural competition in a generally hostile environment are the most important factors in bacterial die-off. It is important that retention time and protection against short-circuiting in lagoons be sufficient to insure adequate reduction of coliforms and pathogenic bacteria that may be present.

As described earlier, algae have a very strong influence on the chemistry of sewage lagoons. Several investigators have tried to determine the environmental conditions that result in the predominance of a particular algae type. Generally, it has not been possible to find a correlation between the predominant species that develop in a pond and its geographical location; the degree of organic loading; the degree of pretreatment given the sewage; or the type of pretreatment (Fitzgerald and Rohlich, 1958).

However, algae predomination does depend, at least to some extent, on the types and concentrations of nutrients in the sewage. High nutrient levels favor phytoflagellates such as Euglena and Chlorella, while lower nutrient levels favor the filamentous green algae such as Spirogyra and Ulothrix (McKinney, 1962). The algal organism with the highest adaptability is Euglena as identified by Gloyna (1968), followed by Chlamydomonas, Micractinium, Ankistrodesmus, Scenedesmus and Chlorella. It was also noted by Gloyna (1968) that Euglena and Chlamydomonas tend to

dominate in cooler weather while various green algae (Chlorophyta) increase during warmer conditions. Motile flagellated algae such as Euglena, Chlamydomonas, and Phacus can easily move to optimum light levels which helps them to predominate in sewage lagoons. Sharp projections on green nonflagellated algae such as Closterium, Ankistrodesmus and Scenedesmus maximize surface area per unit mass and help them remain in the euphotic zone. A list of algae species reported in sewage lagoons is presented in Table II-6. Motile, non-motile and filamentous algae are all represented. Of the species of algae listed in Table II-6 the most frequently reported are Ankistrodesmus, Chlamydomonas, Chlorella, Euglena, Micractinium, Oscillatoria, and Scenedesmus.

During high growth periods in the summer algal densities in sewage lagoons typically become very great. For example, in pilot-scale facultative ponds the number of areal standard units per milliliter near the surface was about 40,000 (Davis and Gloyna, 1970) during the summer. The number of algal organisms per milliliter ranged from about 42,000 to 276,000 for these same ponds. Algae from the Chlorophyta and Cyanophyta divisions were most common in all pond systems, while Euglenophyta were predominant during early and late winter and Chrysophata have been noted much less frequently.

Virus reduction in lagoons has not been as extensively studied as the die-off of bacteria or the occurrence of algae. While the retention time in lagoons greatly reduces the concentration of viruses, some human enteric viruses have been reported to survive conventional treatment processes including chlorination (Shuval, et al., 1967). Strains of poliovirus, coxsackievirus, echovirus, reovirus and infectious hepatitis virus have been found in wastewater (Berg, 1967).

Table II-6: Algae Reported in Sewage Lagoons

| Algal Division and Genera            | Reference*                 |
|--------------------------------------|----------------------------|
| <b>Cyanophyta (Blue-green algae)</b> |                            |
| Anabaena                             | 1,2,3,4                    |
| Anacystis                            | 1,3,4                      |
| Aphanizomenon                        | 2                          |
| Aphanocapsa                          | 5                          |
| Lyngbya                              | 6,2                        |
| Microcystis                          | 6,2,5                      |
| Oscillatoria                         | 1,6,3,4,5,7,8              |
| Phormidium                           | 1,3,4                      |
| Spirulina                            | 9,6                        |
| <b>Chlorophyta (Green Algae)</b>     |                            |
| Actinastrum                          | 6,4,8                      |
| Ankistrodesmus                       | 10,9,1,6,2,3,4,11          |
| Carteria                             | 4,3                        |
| Chlamydomonas                        | 12,10,14,1,2,3,4,18,5,11,7 |
| Chlorella                            | 12,13,14,1,6,2,4,11,8      |
| Chlorococcum                         | 6                          |
| Chlorogonium                         | 2,3,4                      |
| Chodatella                           | 2                          |
| Cladophora                           | 15                         |
| Closterium                           | 3,4                        |
| Coelastrum                           | 2                          |
| Crucigenia                           | 2                          |
| Desmid                               | 6                          |
| Eudorina                             | 11                         |
| Goleukinia                           | 2                          |
| Micractinium                         | 12,16,9,1,6,2,3,4,7        |
| Mougeotia                            | 8                          |
| Oocystis                             | 6                          |
| Palmellococcus                       | 17                         |
| Pandorina                            | 2,4,11                     |
| Pediastrum                           | 5                          |
| Pleodorina                           | 6                          |
| Scenedesmus                          | 12,16,10,17,1,6,2,3,4,11   |
| Selanastrum                          | 2                          |
| Spriogyra                            | 13                         |
| Staurostrum                          | 8                          |
| Ulothrix                             | 13                         |
| Vaucheria                            | 13                         |



Table II-6: (Continued)

| Algal Division and Genera                               | Reference*                          |
|---|-------------------------------------|
| <b>Englenophyta(Pigmented flagellates)</b>              |                                     |
| Euglena   | 12,13,16,10,9,17,1,6,2,4,<br>11,7,8 |
| Phacus  | 6,4,11                              |
| Rhodomonas  | 17                                  |
| Trachelomonas   | 2                                   |
| <b>Chrysophyta (Yellow-green to golden brown algae)</b> |                                     |
| Asterionella  | 2                                   |
| Botryococcus  | 2,8                                 |
| Cyclotella  | 2                                   |
| Fragillaria   | 2                                   |
| Mallomonas  | 2                                   |
| Navicula  | 12,3,4,5                            |
| Nitzschia   | 2                                   |
| Synedra   | 2                                   |
| Synura  | 2                                   |

- \* 1 - Gloyna, 1968  
 2 - Zajic, 1971  
 3 - Lewis and Smith, 1973  
 4 - McKinney, 1974  
 5 - Reynolds et al., 1974  
 6 - Aguirre and Gloyna, 1970  
 7 - Walter and Bugbee, 1974  
 8 - Canter, Miller and Sammy, 1976  
 9 - Marais, 1966  
 10 - Mackenthun, 1964  
 11 - Rodgi, Kanabur and Nimbargi, 1974  
 12 - Wilson, 1960  
 13 - McKinney, 1962  
 14 - Fisher, 1968  
 15 - Svore, 1968  
 16 - Mills, 1961  
 17 - Thirumurthi and Nashashibi, 1962  
 18 - Middlebrooks and Marshall, 1974

A 3-year virologic study on the sewage lagoons at Santee, California has been conducted by England, et al. (1965). This system includes primary settling, an activated sludge unit, 30 day retention in a 16-acre pond, filtration through natural sand and gravel, and chlorination. They found an average virus removal of 91% for the study.

Another study by Slanetz et al., (1972) investigated the fate of enteric viruses in three New Hampshire pond systems. They were able to isolate enteric viruses from a majority of the effluent samples from these three ponds throughout the year.

Free swimming protozoa including Paramecium, Glaucoma, Colpidium and Euplotes have been observed in sewage lagoons. Protozoa show predominance according to the level of organic concentration, similar to bacteria. High organic concentration often stimulates the growth of flagellates such as Chilamonas which quickly yield to free swimming flagellates such as those mentioned above. Since protozoa prey on bacteria and algae for food the protozoal population changes with the bacteria and algae population. Stalked ciliates such as Vorticella and Epi-stylis grow when the bacterial population decreases. Under conditions of very low organic loading (less than 10 lb. BOD<sub>5</sub>/acre/day) and high oxygen concentration higher organisms such as Daphnia, Cyclops and Rotaria appear. Under certain conditions these microscopic animals can contribute to the clarification of lagoon effluents by predation on algae and bacteria (McKinney, 1962; McKinney, 1974; Gloyna, 1968; and Dinges, 1973).

Aquatic insects have also been identified in sewage lagoons. In 18 central Missouri ponds Kimberle and Enns (1968) found 60 species of aquatic insects. More than 94% of the total number of insects collected

from the ponds were one or more of three species of midges, Clyptotendipes Babipes, Chironomus plumosus, and Tanypus punctipennis. Mosquito species were also observed including Culex tarsalis and Culex pipiens.

#### Summary

Phosphorus usually occurs in the fully oxidized phosphate form and results in natural waters from weathering, biological transfer, and various activities of man such as fertilization and use of detergents. Organic forms of phosphorus are the products of biological growth. These organic forms frequently become associated with the sediment of lakes through settling of particulates where they are slowly mineralized.

In lakes a variety of physical and biochemical processes influence phosphorus chemistry. Major physical influences on phosphorus chemistry include mixing, diffusion, and water temperature. The biological process of photosynthesis, metabolism and excretion influence phosphorus chemistry and are in turn influenced by concentrations and forms of phosphorus. For example, it has been suggested that eutrophication of fresh water lakes can frequently be most easily controlled by limiting phosphorus availability. In addition, algal species occurrence is greatly influenced by the level and forms of phosphorus available. Bioturbation can increase the release of phosphorus from the sediment while littoral vegetation has been found to readily uptake various forms of phosphate. Bacteria readily assimilate inorganic forms of phosphorus and rapidly exchange this phosphorus with algae. Phosphorus is also sorbed and desorbed with the sediment depending on specific chemical conditions that are only partially understood as described below.

When radiophosphorus is added to a lake most of it rapidly becomes associated with the sediment and usually within a week a steady state relationship between the overlying water and the sediment is established. However, seasonal variations in phosphorus chemistry have been found. One study showed a release of phosphorus from sediments during the summer. Under aerobic conditions phosphorus was found to be taken up by the sediments and released under anoxic conditions. In addition to the dissolved oxygen concentration, the oxidation-reduction potential, pH, turbulence, and the presence of organic substances all influence phosphorus chemistry.

It is thought that the presence of iron, aluminum and calcium ions may play an important role in phosphorus chemistry in natural waters. For example, in hardwater lakes a calcium-carbonate-phosphate system may predominate with phosphorus precipitated under oxygenated conditions and released from the sediment during anaerobic conditions. In addition, the total phosphorus concentration in the bulk water may be buffered by hydroxyapatite. An iron-phosphate complex is thought to be precipitated under oxygenated conditions and released under anoxic conditions. However, in field studies thought to be dominated by iron-phosphate chemistry, the results are not consistent. Some studies showed a release of phosphate from the sediment when the pH is above 8, while other studies have demonstrated the opposite. In systems predominated by aluminum-phosphate chemistry sorption of phosphorus onto the clay is thought to occur by either chemical bonding or substitution for silicate under low pH (5 to 6) conditions.

In general, phosphorus is thought to be bound to the sediment by Fe (III) or Al (III) by either precipitation or adsorption when the

pH ranges from about 4.5 to 6.5 in natural lakes. When the pH ranges from about 7.0 to 9.0 phosphorus is not as readily sorbed onto the sediment, and when the pH is above 9.0 precipitation of phosphorus by calcium phosphate (apatite) is thought to occur. However, specific phosphorus chemistry varies with the type of lake chemistry, such as if it is calcareous or not, and is strongly influenced by oxygen content, oxidation-reduction potential, and pH conditions.

Sewage lagoons differ from lakes primarily in their shallow depth and continuous organic loading. Lagoons are oxygenated by photosynthesis and wind aeration and are dominated by bacteria and algae. These organisms exert an influence on phosphorus chemistry by a series of synthesis and respiration reactions which result in a stabilizing of the organic matter, a raising of the dissolved oxygen concentration and pH in the daytime during active photosynthetic periods, and a lowering of the dissolved oxygen concentration and pH at night during periods of respiration by both the algae and bacteria. These diurnal variations are most pronounced during late summer. Dissolved oxygen levels may range from nearly immeasurable at night up to about 40 mg/l in the afternoon. Observed values of pH range from as high as 10 or 11 in the day to about 7 at night.

While these diurnal variations in dissolved oxygen concentration and pH have been studied and well documented in lagoons, no systematic diurnal study of phosphorus chemistry has been performed. One study, for example, found the concentration of total phosphorus in raw wastewater to range from 5 to 20 mg/l with 15 to 35% of it being soluble orthophosphate. In the effluent total phosphorus levels ranged from

3 to 10 mg/l with 50 to 90% of it being soluble orthophosphate. The removal of phosphorus is thought to occur by chemical precipitation at high pH levels and by metabolic uptake by algae and other organisms.

Similar measurements have been taken of the phosphorus levels in the influent and effluent of sewage lagoons to estimate phosphorus removal rates. These experiments have generally found the removal rate of phosphorus to be higher in the summer than in the winter. However, these estimates are based on samples taken at one or maybe two times during the day. No overall phosphorus materials balance has been reported for a sewage lagoon to determine the actual phosphorus removal rate or to identify diurnal and seasonal variations in phosphorus chemistry that may occur.

Other characteristics of sewage lagoons of importance to phosphorus chemistry include temperature, wind-mixing, sunlight, organic loading rate, detention time, and the types of organisms present. The water temperature of lagoons affects the types and abundance of organisms present and the rate of chemical and biological activity. For algae the maximum growth rate generally occurs from 25 to 30°C. Thermal stratification of the lagoon may also occur in the summer which may result in an oxygen gradient between the surface and bottom.

The intensity of sunlight and length of daylight influence the rate of photosynthesis by algae. The saturation level occurs for algae and the maximum rate of photosynthesis is attained at about 400 to 600 foot candles. From about 500 to 1,000 foot candles the rate of photosynthesis remains constant. As sunlight increases from 1,000 to 4,000 foot candles the rate of photosynthesis becomes inhibited.

Organic loading rates vary by latitude and by practice in the U.S. In the southern states a range of 30 to 50 lbs. BOD<sub>5</sub>/acre/day is commonly recommended. An average detention time of 31 days with a range of 20 to 45 days was found for states in this area in one study.

Bacteria are most abundant near the influent of sewage lagoons and generally decrease in number with distance from the influent. The most common types of bacteria are Pseudomonas, Flavobacterium, Alcaligenes, Achromobacter, and coliforms.

A wide variety of algal types have been identified in sewage lagoons depending in part on organic loading rates and location within the lagoon. Species of Chlorophyta such as Ankistrodesmus, Chlamydomonas, Chlorella, Micractinium, and Scenedesmus; Euglenophyta such as Euglena; and Cyanophyta such as Oscillatoria have been commonly reported. Species of Chrysophyta occur much less frequently. Various viruses, protozoa and other higher life forms including aquatic insects have also been reported to occur in sewage lagoons.

## CHAPTER III

### METHODS AND PROCEDURES

Much consideration was given to developing a model system that would, as much as possible, closely simulate the environmental conditions of a waste stabilization pond in the southern U. S. under summer conditions. Major factors for consideration included hydraulic and organic loading rates, phosphorus loading, liquid depth, sediment type and depth, the number of cells or ponds, evaporation rate, lighting, temperature and wind. These major factors simulated in the model systems are summarized in Table III-1. In this chapter, the preparation of the model system is first described including a discussion of each of the major factors simulated. Following this a description of the sampling procedures is given. Next, the radioisotope techniques used are described. Finally, the chemical, biological and physical methods of analysis are explained.

#### Preparation of the Model System

Three steel tanks of 1,125 liters (about 300 gallons) liquid capacity with inside dimensions of 1.067 meters (3 feet, 6 inches) in height, a diameter of 1.156 meters (3 feet, 9½ inches), and a circumference of about 3.658 meters (12 feet) were obtained for the model



TABLE III-1: Summary of Design Considerations for  
Model Waste Stabilization Ponds

| Factor                                     | Typical Value<br>or<br>Oklahoma Design        | Model Pond<br>Design         | Comment on<br>Simulation                        |
|--|---|------------------------------|---|
| Liquid depth                               | 2 to 6 feet                                   | 3 feet                       | Common  |
| Number of cells                            | 1 to several                                  | 2                            | Common  |
| Organic Loading<br>Rate (BOD) <sub>5</sub> | 30 to 50 lbs/<br>acre/day                     | 30 and 50 lbs/<br>acre/day   | Typical design<br>range simulated               |
| Hydraulic Load-<br>ing & Detention<br>Time | -<br>(mean of 31<br>days)                     | 9.3 gallons/day<br>32 days   | Common detention<br>time                        |
| Phosphorus<br>Loading                      | 5 to 20 mg/l                                  | 4.45 to 7.40<br>mg/l         | Common  |
| Sediment Depth                             | 1 foot/28 years<br>0.25 feet/year             | 3 inches                     | Estimated 1 to 7<br>years of accumula-<br>tion  |
| Evaporation<br>Rate                        | 8.2 inches/month<br>in summer                 | 8.2 inches/<br>month         | liquid level and<br>effluent volume<br>adjusted |
| Lighting                                   | Average 4,500<br>ft. candles in<br>August     | 660 to 1,300<br>ft. candles  | Exceeds saturation<br>level of algae            |
| Temperature                                | 20 to 30°C                                    | 25 to 30° C                  | Maximum range for<br>algae growth               |
| Wind                                       | 7 to 8 meters/<br>second average<br>in summer | about 7 meters<br>per second | Limited mixing                                  |

lagoon systems. Each of the tanks was divided approximately in half into two cells by  $\frac{1}{2}$ -inch plywood baffles with dimensions of 1.067 meters by 1.156 meters. A notch 7.62 centimeters (3 inches) by 45.72 centimeters (18 inches) was cut in each baffle to allow flow from one side (cell A-B) to the other (cell C-D). The insides of the tanks and the baffles were cleaned and coated with 2 coats of red primer. Following this a coat of coal tar epoxy resin was applied and allowed to dry (cure) for 7 days. These coatings were chosen to prevent rusting, the leaching of chemicals from the walls, and the sorption of phosphorus on to the walls.

Two cells in each model tank were sampled at two locations, near the notch in the baffle and near the influent/effluent structures as shown in Figure III-1. Four water columns in each tank were sampled at depths of 3, 18, and 33 inches. The samples taken at the 3 inch depth were representative of the top 6 inches of the water where biological activity was expected to be greatest. The 18-inch depth samples were representative of the 6-inch to 30-inch deep water or 24 inches of water column depth where biological activity and interaction with the sediment were assumed to be reduced. The 33-inch deep samples were taken to be representative of the bottom 6 inches of water column depth where the water was anticipated to be most interacting with the sediment. At the bottom of each water column, eight sediment samplers were located. Along the exterior walls and baffles, eight sets of samplers to measure biological uptake of phosphorus-32 were located near each water column. These sets of samplers consisted of planchets at depths of 3, 18 and 33 inches. The water column sampling effort for material balance estimation is shown in Figure III-2. The sediment, wall and liquid sampling

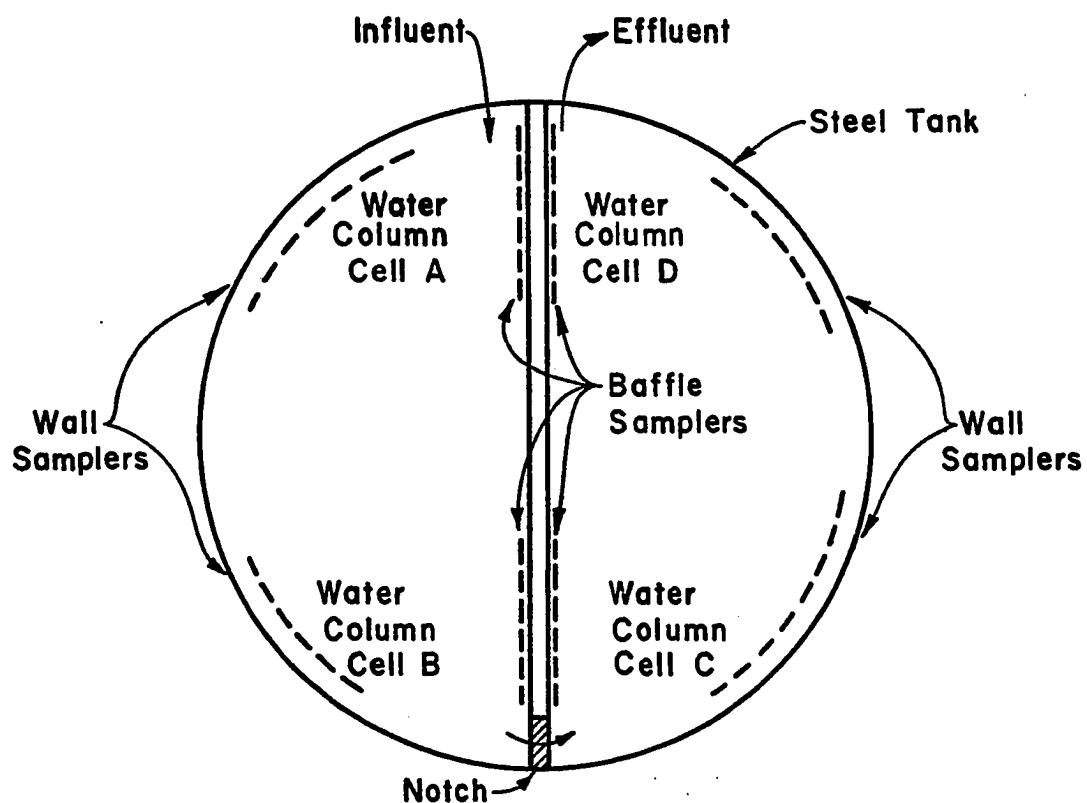


Figure III-1: Model Tank Sampling Areas -- Water Columns

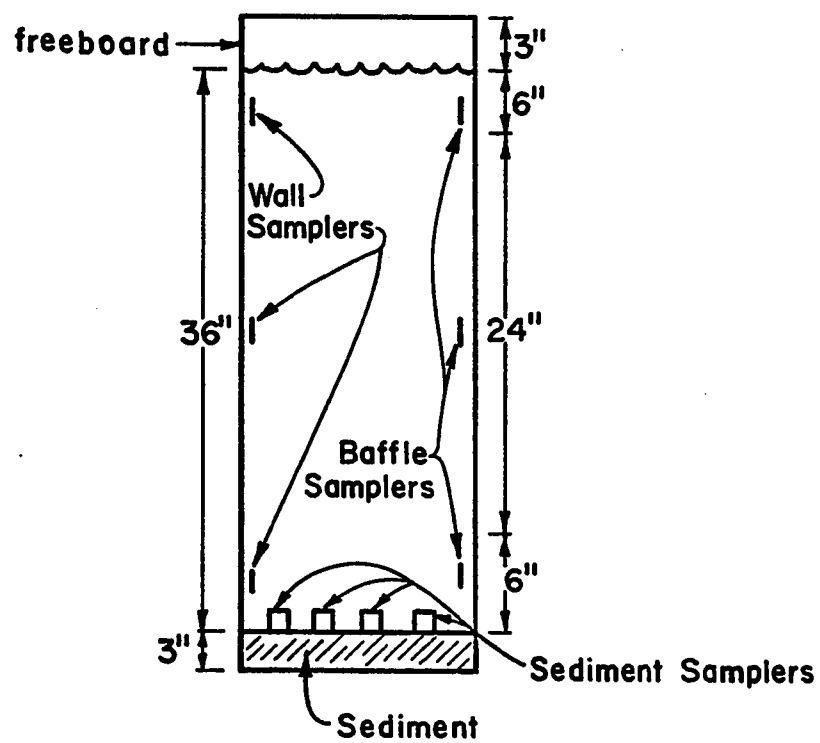


Figure III-2: Water Column Sampling Set-Up

Techniques are described more fully later in this chapter under sampling procedures and parameters measured. The liquid depth of 3 feet and the number of cells (2) are common for facultative ponds in the southern U. S. as shown in Table III-1.

The experimental set-up of each tank that is described below is shown in Figure III-3 from the side view, Figure III-4 from the top view and pictured in Figure III-5. Each tank system consisted of an influent holding bottle (polypropylene carboys) of about 18-liter capacity. The influent sewage was allowed to flow by gravity into the tanks in 3/16-inch inside diameter tygon tubing. The flow was controlled by a clamp and from 4 to 6 hours was needed to empty each bottle. The bottles were filled between 8:00 and 9:00 a.m. and between 5:00 and 6:00 p.m. each day. Approximately half of the influent was loaded into each tank each of these times. The effluent tubing was also 3/16-inch inside diameter tygon. A constant water level in the tanks was maintained by the effluent structure and the effluent was allowed to flow by gravity and collected in 55-gallon drums for storage until the radioactivity in the drums was low enough for dilution and discharge. As will be described below, one tank (1) was loaded at the rate of 30 pounds BOD<sub>5</sub> per acre per day, and tanks 2 and 3 were loaded at a rate of 50 pounds BOD<sub>5</sub> per acre per day, with synthetic sewage prepared daily.

Samples of sediment and initial seed water were obtained from the waste stabilization pond at Blanchard, Oklahoma. This 2-celled pond system serves a population of about 1,600 persons and includes no major industrial waste sources. It is located approximately 15 miles southwest of the University of Oklahoma in the south central part of the State.

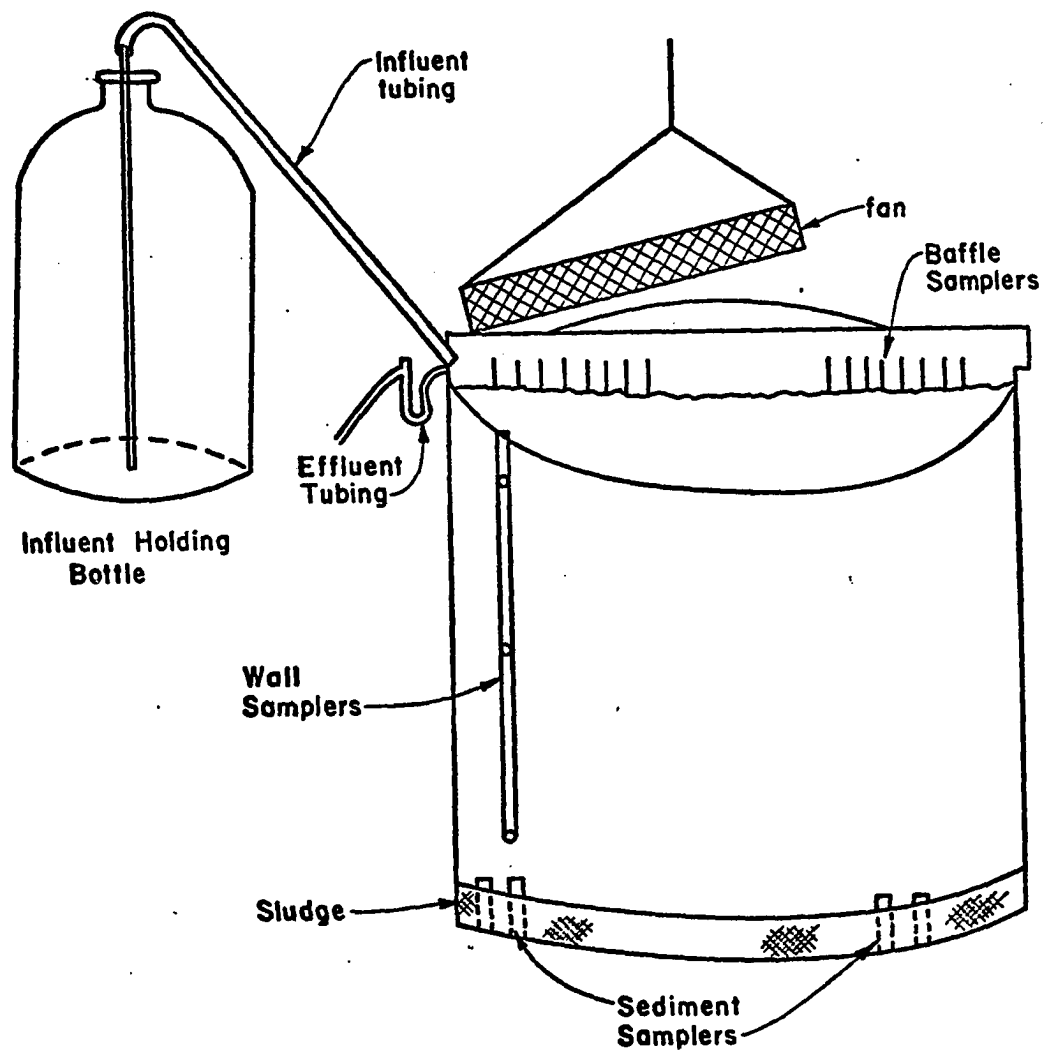


Figure III-3: Experimental Model Waste Stabilization Pond Systems (Side View)

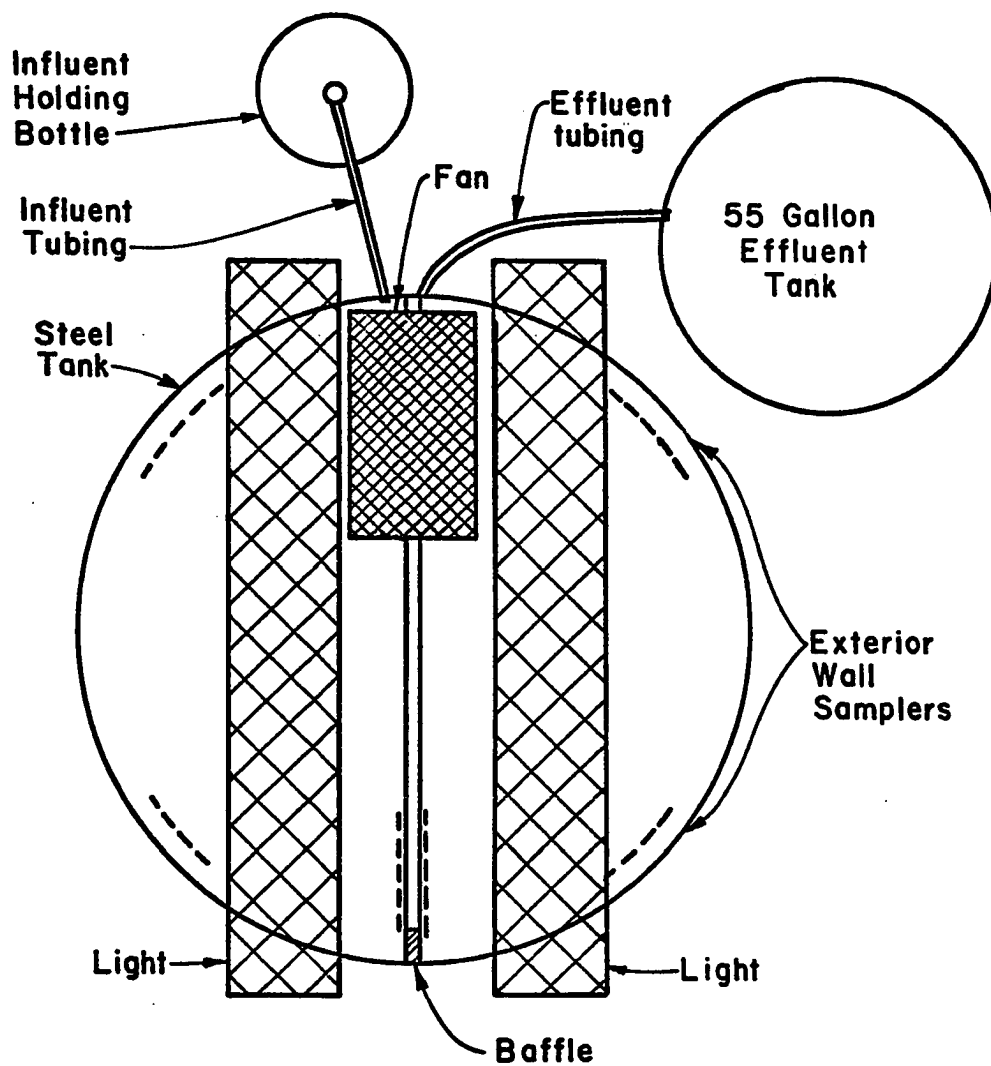


Figure III-4: Experimental Model Waste Stabilization Ponds Systems (Top View)



Figure III-5: Experimental Set-up Photograph



The total surface area of the Blanchard ponds is about 6 acres. The volume of the ponds is estimated to be about 6.65 million gallons. The liquid depth in pond 1 averages 2.4 feet at the present time due to sedimentation. Initially, this cell was constructed for a liquid depth of about 4 feet. Pond 2 is slightly larger than pond 1 and has an average liquid depth of about 4 feet. The retention time is estimated to range from 29 to over 100 days, with an average of about 60 days.

An examination of the wastewater effluent quality records of the pond system was made to determine the treatment performance. Samples of the effluent are usually obtained in the late morning or early afternoon. The monthly average BOD<sub>5</sub> of the effluent usually ranges between 25 mg/l and 50 mg/l. Maximum BOD<sub>5</sub> values were found in the middle summer (July) and early fall (October and November), while minimum values occurred in early summer (June) and during the winter (December through February). Monthly average suspended solid measurements showed similar variations, ranging from about 35 mg/l to 210 mg/l. Maximum suspended solids values were noted in late summer (September), while minimum values were recorded in the early winter (November through January). The pH measurements of the effluent ranged from about 7.5 to about 9.8. Maximum values were found during late summer (July through September), and minimum values during the early summer (May). These effluent characteristics appear to be fairly typical of sewage lagoons in this part of the south central U. S.

This pond system was chosen as a source for initial seed water and sediment, in summary, because it is close to The University of Oklahoma, the pond type and sizes are similar to many others in the area, the

effluent characteristics are not of sufficient quality to consistently meet secondary standards, which is common in many pond systems, and the town was very cooperative in lending its assistance.

During February, 1979, samples of sediment and seed for cell A-B of the model tanks were obtained from near the middle of the first pond of the Blanchard system, and samples for cell C-D of the model tanks were obtained from the middle of the second pond of the Blanchard system. The sediment samples were collected with an Eckman dredge. Both the pond water and sediment samples were placed in separate 55-gallon drums for transport to the laboratory and immediate placement in the model tanks. Initially, 40.0 liters of sediment were placed in each cell of each tank (or 80.0 liters in each tank) to a depth of about 7.62 centimeters (3 inches). This depth was chosen to simulate the role of the sediment in phosphorus chemistry.

Studies of sludge accumulation in sewage lagoons have shown a wide variety of deposition rates. The rate of sludge accumulation in lagoons may be quite appreciable but depends on the quantity of sewage treated, its suspended solids content (Varadarajan, et al., 1973), and the type of lagoon system. In one study in Mississippi, it was found that in 15 lagoons the estimated average rate of sludge accumulation was one foot every 28 years, most of which was inorganic silt (Middlebrooks, Panagiotour and Williford, 1965). Sludge accumulated at the rate of 0.24 feet per year in an anaerobic lagoon treating packinghouse wastes (Saucier, no date). On the other hand, Parker and Skeery (1968) found sludge depths ranging from 2 to 30 feet in various types of lagoons depending on the sampling location, the time of the year, and the number

of years the lagoon has been in operation. Using the rate of one foot sludge accumulation every 28 years, three inches of sludge would represent seven years of accumulation. With an accumulation rate of 0.25 feet per year, three inches of sludge would represent one year of accumulation.

The movement of phosphorus in the sludge of a sewage lagoon has not been investigated. Some studies on lakes and other bodies of water have indicated that an undisturbed mud-water system may release only a small amount of phosphorus (Hasler, 1957, and Zicher, Berger and Hasler, 1956). For an estuary in Georgia, Pomeroy, et al. (1965), showed that 10 cm of sediment (3.94 inches) contain enough exchangeable phosphate to replace the phosphorus in the water at least 25 times. In experiments on the release of phosphorus from lake sediments, Fillos (1976) used about 13 cm (5.1 inches) of sediment to give results indicative of the natural system. In an eutrophied lake, Schlinder, et al. (1976), found that recently deposited material was mixed to a depth of 5 to 10 cm (2.0 to 3.9 inches) with an average sedimentation rate of 0.10 cm per year. Short cores (15 to 30 cm or 5.9 to 11.8 inches) of the sediment were used in their experiments. Wood (1975) suggested that turbulent exchange, microbial activity and the movement of certain biota are generally important in the movement of material across the mud-water interface in lakes. The extent of this bioturbation depends on the depth and the vertical distribution of benthic macrofauna which varies according to the nature of food and the amount of oxygen in the habitat (Petr, 1976). Chironomids are generally found in the top 15 cm (5.9 inches) although they have been found one meter deep.

In sewage lagoons where the liquid depth is only about 3 feet the

sediment may be very loosely packed and the amount of sediment available for phosphorus exchange on a diurnal basis may be extended beyond three inches in some cases. However, wind action has not been shown to significantly affect the distribution of sludge in a lagoon (Middlebrooks, Panagiotou and Williford, 1965), and three inches of sludge in the model ponds is felt to be sufficient to simulate its effects on phosphorus chemistry over the time period of this study.

The model systems were loaded with a synthetic sewage so the concentration of phosphorus, total nitrogen, and BOD<sub>5</sub> could be controlled. This synthetic sewage consisted of powdered milk, 10 percent raw sewage, dipotassium phosphate (K<sub>2</sub>HPO<sub>4</sub>) and tap water. This synthetic sewage has been described by Herman and Gloyna (1958) and the composition of 250 mg/l BOD<sub>5</sub> was given by them as:

|                                 |            |
|---------------------------------|------------|
| Starlac milk                    | 380.0 mg/l |
| K <sub>2</sub> HPO <sub>4</sub> | 28.2 mg/l  |
| Sewage seed                     | 10.0 mg/l  |

The hydraulic and organic loading rates of the model system were chosen to represent the range of design criteria found in the south central states.

The synthetic sewage used in this study consisted of Lucerne Instant Nonfat Dry Milk (fortified with vitamins A and D), potassium phosphate (K<sub>2</sub>HPO<sub>4</sub>), primary treated sewage seed from Norman, Oklahoma, and tap water. No free chlorine residual was detected in the tap water. The materials used to make synthetic sewage were initially tested before set-up to determine its BOD<sub>5</sub>. As shown in Table III-2, five aliquots from each of two batches of synthetic sewage were incubated and found to

**Table III-2: BOD<sub>5</sub> of Synthetic Sewage**

| ALIQUOT            | BATCH    |          |
|--------------------|----------|----------|
|                    | A        | B        |
| 1                  | 240 mg/l | 230 mg/l |
| 2                  | 240 mg/l | 265 mg/l |
| 3                  | 255 mg/l | 230 mg/l |
| 4                  | 235 mg/l | 240 mg/l |
| 5                  | 250 mg/l | 260 mg/l |
| Average            | 244 mg/l | 245 mg/l |
| Standard Deviation | 8.22     | 16.58    |

be very close to the value found by Herman and Gloyna. The  $BOD_5$  of the synthetic sewage was checked periodically throughout the experimentation and never found to vary by more than 10 percent.

Detention times of 20 to 45 days with a mean of 31 days were found for ponds in the southern part of the U. S. (Canter and Englands, 1970). For this study a design detention time (based on the influent volume) of 32 days was chosen. With a capacity of 1.125 liters the hydraulic loading is 35.2 liters per day, or 9.3 gallons per day.

The organic loading design criteria for southern states ranges from 30 to 50 lbs.  $BOD_5$ /acre/day (Canter and Englands, 1970). In this study one tank (1) was loaded at approximately 30 lbs.  $BOD_5$ /acre/day and the other two tanks (2 and 3) were loaded at approximately 50 lbs.  $BOD_5$ /acre/day. Thus the effects on phosphorus chemistry of two different organic loading rates were studied, and a comparison between two tanks with the same organic loading rates could be made.

The synthetic sewage composition added to each tank is shown in Table III-3. The surface area of each tank is about  $2.59 \times 10^{-4}$  acres. The equivalent of 50 pounds  $BOD_5$  is about  $2.27 \times 10^7$  milligrams. About  $1.36 \times 10^7$  milligrams are equal to 30 pounds  $BOD_5$ . By multiplication,  $5.88 \times 10^3$  mg of  $BOD_5$  must be added to each tank each day for a 50-pound  $BOD_5$ /acre/day loading rate, and  $3.52 \times 10^3$  mg of  $BOD_5$  must be added for a 30-pound  $BOD_5$ /acre/day loading rate. Thus, 23.53 and 14.08 times the 250 mg/l  $BOD_5$  formulation given by Herman and Gloyna (1958) gives the formulation for 50- and 30-pound  $BOD_5$ /acre/day, respectively, for the model tanks.

An initial  $BOD_5$  loading of the tanks was made to approximate

Table III-3: Composition of Synthetic Sewage

30 pounds BOD<sub>5</sub>/acre/day (Tank 1)

|                                 |              |
|---------------------------------|--------------|
| Powdered Milk                   | 5.364 grams  |
| K <sub>2</sub> HPO <sub>4</sub> | 0.398 grams  |
| Domestic Sewage                 | 0.141 liters |
| Total Volume                    | 35.2 liters  |

50 pounds BOD<sub>5</sub>/acre/day (Tanks 2 and 3)

|                                 |              |
|---------------------------------|--------------|
| Powdered Milk                   | 8.941 grams  |
| K <sub>2</sub> HPO <sub>4</sub> | 0.663 grams  |
| Domestic Sewage                 | 0.235 liters |
| Total Volume                    | 35.2 liters  |

actual operating conditions and to facilitate the acclimation period. Each cell of each tank was loaded with a synthetic sewage solution at a concentration that would occur at the midpoint in that cell. A typical BOD<sub>5</sub> concentration at the influent of lagoons is about 250 mg/l. Effluent concentrations may be about 30 mg/l. The reduction of the BOD<sub>5</sub> is a logarithmic relationship. With a total detention time of 32 days, the midpoint of cell A-B is 8 days, and of cell C-D is 24 days. The expected BOD<sub>5</sub> concentrations with time in this theoretical lagoon are shown in Figure III-6. As shown in that Figure, after 8 days about 150 mg/l concentration BOD<sub>5</sub> could be expected. This was the concentration of BOD<sub>5</sub> initially loaded in the first cell of each tank. After 24 days the BOD<sub>5</sub> concentration as shown in Figure III-6 could be expected to be reduced to about 50 mg/l. This was the concentration of BOD<sub>5</sub> initially loaded in the second cell of each tank.

The concentration of total phosphorus, orthophosphate, and total nitrogen (Kjeldahl) in the synthetic sewage was estimated to characterize the influent and to obtain the nutrient loading to the tanks. Phosphorus concentrations in 50 pounds BOD<sub>5</sub>/acre/day synthetic sewage are shown in Table III-4. Two batches of sewage were tested. For the two batches, the total phosphorus averaged 7.38 mg/l. Orthophosphate concentrations averaged about 88 percent of total phosphorus. Similar measurement of 30 pounds BOD<sub>5</sub>/acre/day synthetic sewage were made. The total phosphorus and orthophosphate concentrations were almost exactly 60 percent of those reported in Table III-4. Loadings on Tanks 2 and 3 were about 260 mg per day total phosphorus, and 230 mg per day orthophosphate. Tank 1 was loaded at the rate of about 155 mg per day total phosphorus, and about 140 mg per day orthophosphate.



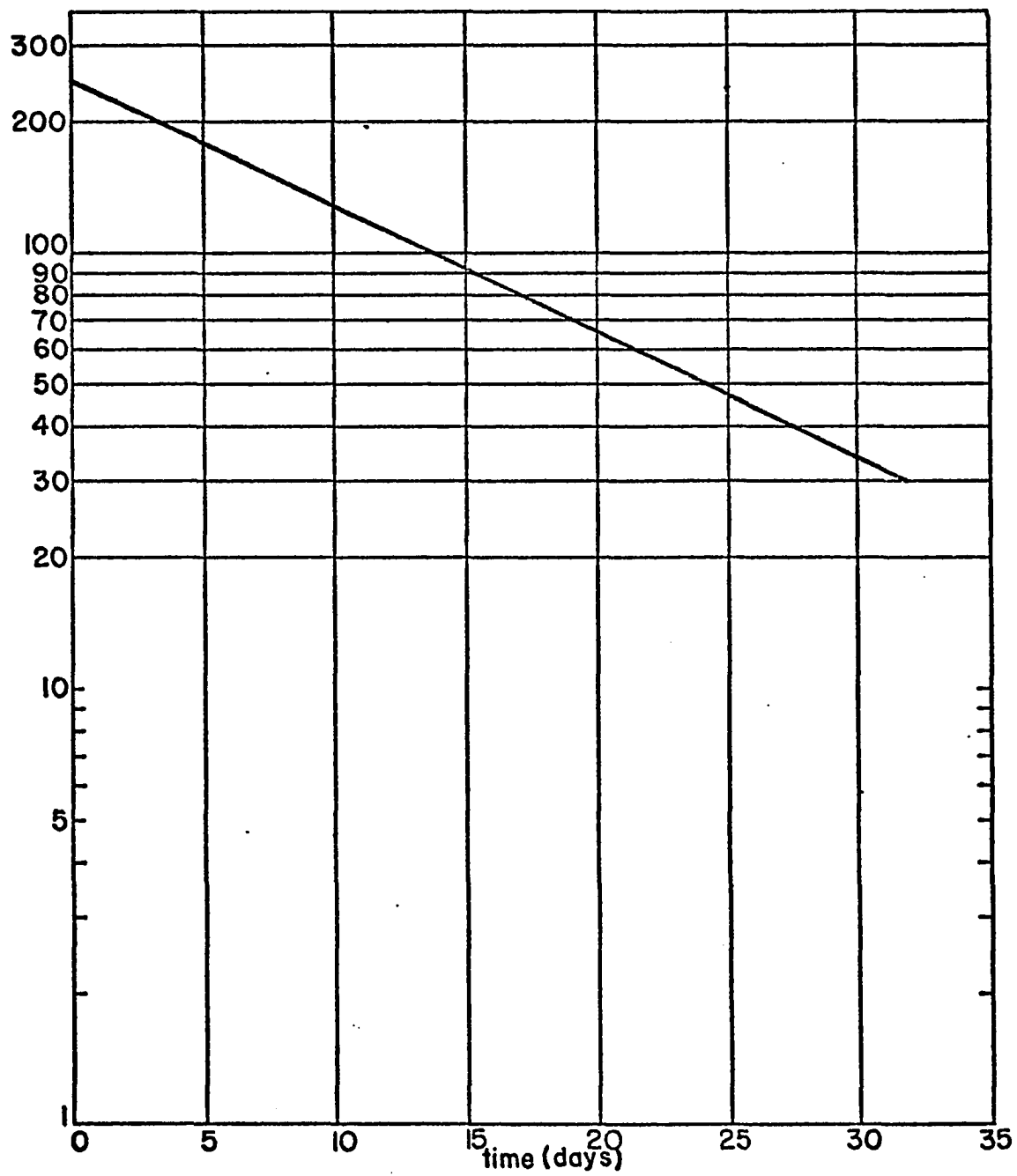


Figure III-6: Relationship of  $BOD_5$  with Time in a Theoretical Lagoon for Initial Loading

**Table III-4: PHOSPHORUS CONCENTRATIONS IN 50 POUNDS  
BOD<sub>5</sub>/ACRE/DAY SYNTHETIC SEWAGE (mg/l)**

| Aliquot            | Total Phosphorus |         | Orthophosphate |         |
|--------------------|------------------|---------|----------------|---------|
|                    | Batch A          | Batch B | Batch A        | Batch B |
| 1                  | 7.40             | 7.50    | 6.55           | 6.60    |
| 2                  | 7.45             | 7.35    | 6.50           | 6.45    |
| 3                  | 7.20             | 7.40    | 6.40           | 6.55    |
| 4                  | 7.35             | 7.30    | 6.45           | 6.50    |
| 5                  | 7.35             | 7.45    | 6.50           | 6.55    |
| Average            | 7.35             | 7.40    | 6.48           | 6.53    |
| Standard Deviation | 0.09             | 0.08    | 0.06           | 0.06    |

Total Kjeldahl nitrogen was also determined on two batches of 50 pounds BOD<sub>5</sub>/acre/day synthetic sewage as shown in Table III-5. The two batches averaged 12.24 mg/l total Kjeldahl nitrogen. On this basis Tanks 2 and 3 were loaded at the rate of about 430.8 mg per day total kjeldahl nitrogen. Similar analyses were performed on 30 pounds BOD<sub>5</sub>/acre/day synthetic sewage, and Tank 1 was loaded at about 60 percent of Tanks 2 and 3, or about 260 mg per day total kjeldahl nitrogen.

An attempt to simulate the evaporation rate that occurs in waste stabilization ponds in central Oklahoma was made. The evaporation in the laboratory was anticipated to equal or exceed that experienced in the field because of the dry heat and constant wind applied. When evaporation in the model ponds was in excess of that estimated to occur in field ponds, deionized water was added to make up the difference. The volume of evaporation was estimated at the time materials balance was measured by the difference between the influent and the effluent volumes. In operation the effluent volume approximated the predicted amount as shown in Table III-6 and only small additions of deionized water were necessary.

Seasonal evaporation rates in waste stabilization ponds have not commonly been measured but are expected to differ from lakes, although similar trends of increased net evaporation in the summer are expected. One estimate of pond evaporation rates for Oklahoma has been made (Schornick and Streebin, 1977). A summary of an estimate of pond evaporation for central Oklahoma is shown in Table III-7 for May through August. The average monthly estimated evaporation rate for ponds during this period is about 8.2 inches, or 0.273 inches (0.02275 feet) per day.

**Table III-5: TOTAL KJELDAHL NITROGEN CONCENTRATIONS IN  
50 POUNDS BOD<sub>5</sub>/ACRE/DAY SYNTHETIC SEWAGE**

| Aliquot            | Batch |       |
|--------------------|-------|-------|
|                    | A     | B     |
| 1                  | 12.15 | 12.20 |
| 2                  | 12.15 | 12.20 |
| 3                  | 12.20 | 12.30 |
| 4                  | 12.25 | 12.30 |
| 5                  | 12.30 | 12.35 |
| Average            | 12.21 | 12.27 |
| Standard Deviation | 0.07  | 0.07  |

**Table III-6: ESTIMATED AND MEASURED EFFLUENT VOLUMES  
DURING THE OPERATION OF THE MODEL TANKS**

| Days of Accumulation | Estimated Volume (liters) | Measured Volume (liters) |        |        |
|----------------------|---------------------------|--------------------------|--------|--------|
|                      |                           | Tank 1                   | Tank 2 | Tank 3 |
| 6.3                  | 176.6                     | 147.6                    | 155.2  | 153.3  |
| 3.6                  | 100.0                     | 101.3                    | 97.8   | 98.2   |
| 4.0                  | 111.5                     | 110.0                    | 112.4  | 110.5  |
| 4.4                  | 123.1                     | 124.2                    | 122.5  | 120.5  |
| 5.0                  | 139.4                     | 136.5                    | 134.3  | 141.3  |
| 4.6                  | 127.8                     | 130.4                    | 125.6  | 130.0  |
| 4.0                  | 111.5                     | 112.2                    | 111.4  | 108.5  |
| 5.0                  | 139.4                     | 140.3                    | 136.7  | 135.2  |
| 2.0                  | 55.8                      | 54.5                     | 55.0   | 56.0   |

**Table III-7: ESTIMATE OF NET EVAPORATION OF POND WATER  
IN OKLAHOMA MAY THROUGH AUGUST**

| Month  | Total Inches<br>Class A Pan<br>Evaporation <sup>a</sup> | Lagoon<br>Evaporation <sub>b</sub><br>Coefficient <sup>b</sup> | Monthly<br>Lagoon<br>Evaporation (inches) |
|--------|---|--|---|
| May    | 7.44 .  | 1.263 .  | 9.397                                     |
| June   | 8.36  | 1.372  | 11.470                                    |
| July   | 9.12  | 0.772  | 7.041                                     |
| August | 8.2-  | 0.592  | 4.854                                     |

<sup>a</sup> These class A pan evaporations are a twelve year average for these months taken at Lake Overholser near Oklahoma City. (Oklahoma Water Resources Board, 1971)

<sup>b</sup> These coefficients were derived for the eastern portion of the Canadian River area in central Oklahoma by Schornick and Streebin, 1977.

Each model tank has a surface area of about 1.05 square meters, or 11.3 square feet. About 0.257 cubic feet (0.02275 feet x 11.3 square feet) were estimated to be evaporated each day. This is about 1.92 gallons or 7.28 liters per day. With an inflow of about 35.16 liters per day the effluent should be 27.88 liters or 7.36 gallons. This increases the holding time to about 40 days.

The laboratory model system was located indoors and both natural lighting through nearby windows and artificial lighting was supplied. Artificial lighting was supplied mainly by one fluorescent lighting fixture about 6 inches above the water surface of each cell of each tank. Each fluorescent fixture consisted of four 40-watt Cool White lamps. A distant (about 10 feet) incandescent (tungsten) light of 250 watts was also used. The light intensity over the water surfaces was measured at several locations at night as shown in Table III-8. The lights were kept turned on during the periods when the algal photosynthesis (day conditions) was being stimulated as indicated in Table III-9, and were turned off during periods when algal and bacterial respiration (night-like conditions) were being simulated.

It was necessary to operate the tanks under prolonged lighted and darkened conditions as shown in Table III-9 to obtain the desired changes in dissolved oxygen and pH. As shown in that table initially the dissolved oxygen and pH levels were high. The lights were turned off for about 7.6 days until the pH declined to near 7 and the dissolved oxygen level declined to about 0.00 mg/l throughout the tank. Lighted conditions were then maintained for about 9.4 days until the pH increased to above 9 and the dissolved oxygen level increased to above 8 mg/l near

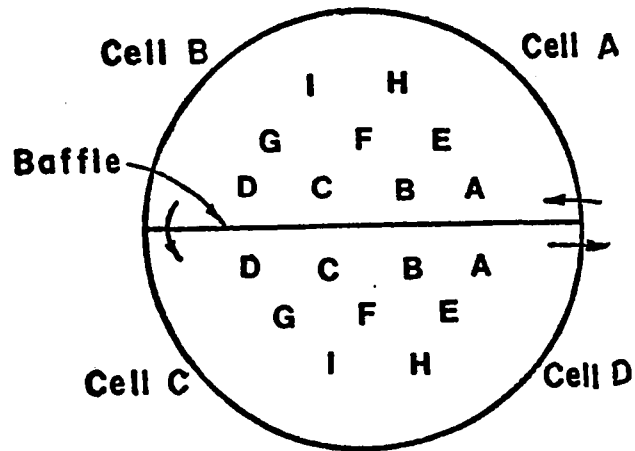
**Table III-8: MEASURES OF ARTIFICIAL SOURCE LIGHT  
INTENSITY AT THE SURFACE OF EACH  
MODEL TANK (FOOT-CANDLES AT NIGHT)**

| Location <sup>a</sup> |   | Tank |      |      |
|-----------------------|---|------|------|------|
|                       |   | 1    | 2    | 3    |
| Cell A-B              | A | 720  | 710  | 720  |
|                       | B | 730  | 730  | 720  |
|                       | C | 740  | 720  | 730  |
|                       | D | 730  | 720  | 720  |
|                       | E | 1000 | 1010 | 1010 |
|                       | F | 990  | 1020 | 1010 |
|                       | G | 1000 | 1000 | 1010 |
|                       | H | 670  | 660  | 670  |
|                       | I | 660  | 670  | 680  |
| Cell C-D              | A | 710  | 720  | 740  |
|                       | B | 720  | 720  | 730  |
|                       | C | 730  | 720  | 740  |
|                       | D | 720  | 710  | 730  |
|                       | E | 1010 | 1020 | 1000 |
|                       | F | 1020 | 1030 | 1000 |
|                       | G | 1000 | 1020 | 1010 |
|                       | H | 690  | 690  | 670  |
|                       | I | 670  | 690  | 680  |



Table III-8 (Continued)

- <sup>a</sup> The location in each tank of the light intensity measurements is shown below:



- <sup>b</sup> Tank 1 was loaded at about 30 lbs BOD<sub>5</sub>/acre/day and Tanks 2 and 3 were loaded at about 50 lbs BOD<sub>5</sub>/acre/day.

**Table III-9: SCHEDULE OF MATERIAL BALANCE SAMPLING  
MEASUREMENTS AND LIGHTING CONDITIONS**

| <b>Material Balance Measurement</b> | <b>Days Since Materials Balance Measurement</b> | <b>Lighting Conditions Since Last Material Balance Measurement</b> | <b>Comments</b>                             |
|-------------------------------------|---|--|---|
| <b>Start (Initial Spike)</b>        | <b>0</b>  | <b>On</b>  | <b>Dissolved oxygen and pH high</b>         |
| <b>1</b>                            | <b>6.3</b>                                      | <b>On</b>  | <b>Dissolved oxygen and pH high</b>         |
| <b>2</b>                            | <b>3.6</b>                                      | <b>Off</b>   | <b>Dissolved oxygen and pH intermediate</b> |
| <b>3</b>                            | <b>4.0</b>                                      | <b>Off</b>   | <b>Dissolved oxygen and pH low</b>          |
| <b>4</b>                            | <b>4.4</b>                                      | <b>On</b>  | <b>Dissolved oxygen and pH intermediate</b> |
| <b>5</b>                            | <b>5.0</b>                                      | <b>On</b>  | <b>Dissolved oxygen and pH high</b>         |
| <b>6</b>                            | <b>4.6</b>                                      | <b>Off</b>   | <b>Dissolved oxygen and pH intermediate</b> |
| <b>7</b>                            | <b>4.0</b>                                      | <b>Off</b>   | <b>Dissolved oxygen and pH low</b>          |
| <b>8</b>                            | <b>5.0</b>                                      | <b>On</b>  | <b>Dissolved oxygen and pH intermediate</b> |
| <b>End</b>                          | <b>2.0</b>                                      | <b>On</b>  | <b>Dissolved oxygen and pH high</b>         |

the surface in each tank. A darkened period of 8.6 days and a lighted period of 7.0 days were necessary to repeat the variations in pH and dissolved oxygen. This slower rate of change in these parameters and biological activity in the laboratory than in the field is probably the result of several factors including limited mixing, less intense lighting and the lower volume to surface area ratio.

The lighting system should simulate the spectral distribution of sunlight as much as possible and be of sufficient intensity to stimulate the maximum rate of algal photosynthesis. The spectral distribution of sunlight and artificial lighting is shown in Figure III-7. The ultraviolet part of the spectrum is very important because this part of the spectrum has a bactericidal or a growth limiting effect. The infrared portion of the spectrum supplies heat which speeds up bacterial metabolism. The spectral distribution of the visible part of the spectrum is important because the adsorption spectrum of chlorophyll a, the most important light adsorbing pigment in green algae, is not even but is heavily dependent on the violet and red parts of the visible spectrum.

In choosing the artificial lighting system, the spectral distributions of both fluorescent and incandescent lighting were considered. As shown in Figure III-7, neither of these individual spectrums are suitable alone because of the lack of infrared in the fluorescent and the lack of ultraviolet in the incandescent. However, the combination of fluorescent, incandescent and natural sunlight used supplied the proper wavelengths of lighting.

The average solar radiation in the southwest U. S. in August is about 500 langleys per day (gram-calories per square centimeter) which

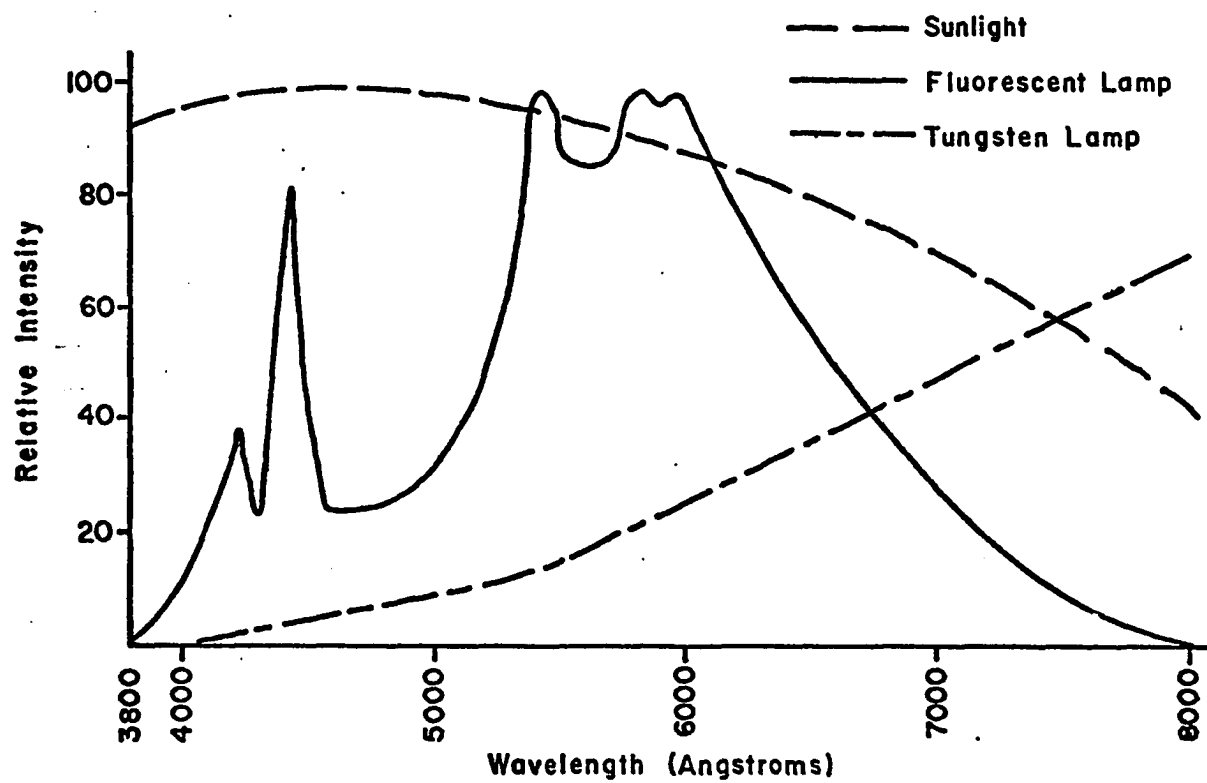


Figure III-7: Light Spectral Distributions

is about 40 langleys per hour. This is about 4,500 foot-candles. Odum (1971) indicates that 1 langley per minute multiplied by 6.7 gives an approximate illuminance expressed as foot-candles. The illuminance supplied by the artificial lighting was much lower than the average that occurs in the field in the southern part of the U. S. However, as noted in Chapter II, the saturation level for algae is generally from about 500 to 1,000 foot-candles (Oswald, 1960). Mutual shading of algal cells in thick cultures quickly reduces the intensity of light with depth in a pond. While intense sunlight may actually inhibit algal photosynthesis at the very surface of ponds the thick cultures and mutual shading provide for abundant oxygen production during the day in the euphotic zone. The intensity of light at the surface in each of the tanks in the afternoon on a cloudless day was also measured as shown in Table III-10. While the lighting intensity is still less than naturally occurs adequate lighting is supplied at the surface for maximum algal growth. The bactericidal effects of sunlight may not be simulated and the depth of algal photosynthesis may be less than in a field pond. Measurements of light intensity with depth were not made.

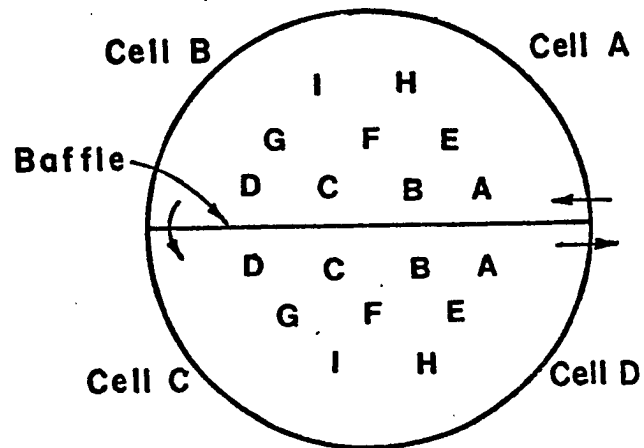
A window fan was placed over each model tank as previously shown in Figures III-3, III-4 and III-5, to simulate wind and to provide limited mixing. Average wind speed for the summer in central Oklahoma is from about 7 to 8 meters per second (about 15 to 18 miles per hour) in both the mornings and afternoons (Holzworth, 1972). Wind speeds around lagoons may be reduced by sheltering trees, hills, and a surrounding berm. However, the ratio of the surface area to depth of field lagoons is much larger than the ratio for the model tanks. Consequently, mixing due to

Table III-10: MEASURES OF NATURAL AND ARTIFICIAL  
SOURCE LIGHT INTENSITY AT THE SURFACE  
OF EACH MODEL TANK (FOOT-CANDLES)

| Location <sup>a</sup> |   | Tank <sup>b</sup> |      |      |
|-----------------------|---|-------------------|------|------|
|                       |   | 1                 | 2    | 3    |
| Cell 1                | A | 970               | 990  | 1020 |
|                       | B | 960               | 990  | 1030 |
|                       | C | 960               | 990  | 1020 |
|                       | D | 950               | 990  | 1010 |
|                       | E | 1210              | 1260 | 1300 |
|                       | F | 1200              | 1250 | 1290 |
|                       | G | 1200              | 1250 | 1290 |
|                       | H | 950               | 1000 | 1080 |
|                       | I | 940               | 990  | 1080 |
| Cell 2                | A | 940               | 990  | 1030 |
|                       | B | 940               | 980  | 1030 |
|                       | C | 940               | 970  | 1010 |
|                       | D | 930               | 980  | 1020 |
|                       | E | 1140              | 1220 | 1280 |
|                       | F | 1130              | 1230 | 1280 |
|                       | G | 1130              | 1210 | 1270 |
|                       | H | 830               | 860  | 880  |
|                       | I | 830               | 850  | 880  |

Table III-10 (Continued)

- <sup>a</sup> The location in each tank of the light intensity measurements is shown below:



- <sup>b</sup> Tank 1 was loaded at about 30 lbs BOD<sub>5</sub>/acre/day and Tanks 2 and 3 were loaded at about 50 lbs BOD<sub>5</sub>/acre/day.

wind action is much more limited in the model tanks. The fans over the model tanks were directed down towards the surface and away from the influent/effluent structures. The wind at the notch end of the baffle was estimated to be about 15 miles per hour. Small ripples on the surface of the tanks were noted emanating from the center near the baffle outwards towards the exterior walls. These ripples probably produced limited mixing at the surface and may have reduced light penetration.

The temperature of the water in the tanks was controlled by room heaters and by ventilation for cooling at night when necessary. By these means the temperature of the water was maintained between 25 and 30° C during the operational phase, and ranged from 17 to 34° C during the acclimation period. As noted in Chapter II, algal growth generally reaches a maximum between 25 and 30° C (Bartch, 1961).

#### Sampling Procedure and Parameters Measured

The objectives of the sampling effort were to generally characterize the behavior of the model systems during the acclimation and operational phases, to provide a basis for correlation analysis between phosphorus concentration and other parameters, and to determine by mass balance the amount of phosphorus in the various compartments of each model system under the range of environmental conditions experienced. The parameters measured and the sampling schedule employed for each of these three objectives are outlined below. Table III-11 shows a summary of the parameters measured for each of these objectives. The acclimation phase lasted approximately 8 months, and after spiking the tanks with phosphorus-32, they were operated and sampled for 39 days.



Table III-11: SUMMARY OF PARAMETERS MEASURED  
FOR EACH SAMPLING OBJECTIVE

| Parameter                               | Sampling Objective      |                      |                  |
|---|-------------------------|----------------------|------------------|
|   | General Characteristics | Correlation Analysis | Material Balance |
| Algae genera                            | A*                      | ---                  | ---              |
| Bacteria genera                         | A                       | ---                  | ---              |
| BOD <sub>(5)</sub>                      | A                       | ---                  | ---              |
| Dissolved Oxygen                        | A & O**                 | X                    | ---              |
| Orthophosphate, water                   | A & O                   | X                    | ---              |
| Orthophosphate, sediment interstitial   | A                       | ---                  | ---              |
| pH                                      | A & O                   | X                    | ---              |
| Phosphorus-32, effluent                 | ---                     | ---                  | X                |
| Phosphorus-32, sediment                 | ---                     | ---                  | X                |
| Phosphorus-32, walls                    | ---                     | X                    | X                |
| Phosphorus-32, bulk water               | ---                     | X                    | X                |
| Phosphorus, total interstitial sediment | A                       | ---                  | ---              |
| Phosphorus, total sediment              | A                       | ---                  | ---              |
| Phosphorus, total water                 | A & O                   | X                    | ---              |
| Redox potential                         | A & O                   | X                    | ---              |
| Temperature, water                      | A & O                   | X                    | ---              |

\*A = measured during acclimitization phase, \*\* O = measured during operational phase

During the acclimation phase algae and bacteria genera present in the bulk water were sampled weekly for four weeks prior to the operational phase. The  $BOD_5$  of the bulk water was measured on a weekly basis during the entire acclimation phase. The  $BOD_5$  of the feed water was checked monthly. Dissolved oxygen, pH and temperature measurements of the bulk water were taken daily during this phase. The orthophosphate and total phosphorus concentrations of the bulk water were measured on a weekly basis during the acclimation phase. The redox potential was measured daily during the last four weeks of the acclimation phase. Analysis of the sediment for total phosphorus, orthophosphate concentration of the interstitial water, and total phosphorus concentration of the interstitial water was performed once immediately after collection of the samples. All samples during the acclimation phase were taken at a depth of about 3 inches in the center of each cell of each tank. Some dissolved oxygen, temperature, pH and redox measurements of the water column at depths of 3, 18, and 33 inches were also taken during this phase. During the operational phase dissolved oxygen, orthophosphate of the bulk water, pH, redox potential, and temperature measurements were taken twice daily (in the morning between 8:00 and 9:00 and in the evening between 5:00 and 6:00) at a depth of 3 inches in the center of each cell of each tank. When material balance measurements were taken (on the schedule outlined below), dissolved oxygen, orthophosphate, pH, total phosphorus, redox potential and temperature were measured at depths of 3, 18 and 33 inches in each of the two water columns in each cell of each tank.

Samples for correlation analysis were taken on a daily basis

from the center of each cell at a depth of 3 inches, and were taken at the time materials balance was determined during the operational phase from each water column in each cell in each tank at depths of 3, 18 and 33 inches. Therefore, two sets of correlation analysis were performed. The first set includes measurements of dissolved oxygen, orthophosphate, pH, redox potential and temperature taken twice daily. The second set of measurements on which correlation analysis was performed include dissolved oxygen, orthophosphate, pH, total phosphorus, redox potential, temperature, phosphorus-32 content of the walls and radiophosphorus content of the bulk water. These samples were collected at depths of 3, 18 and 33 inches in each of the 12 water columns (4 in each tank) examined at the times materials balance was determined.

Materials balance of phosphorus-32 in each tank was determined eight times during the operation of the model pond systems. These determinations were made as summarized in Table III-12. Six days were allowed after the phosphorus-32 was initially spiked for a limited amount of mixing and equilibration under aerobic conditions. The lights were then turned off and oxygen levels allowed to decline. Material balance determinations were then made when the pH reached about 8, and at about 7 to simulate night conditions. The lights were then turned back on and the pH and dissolved oxygen levels allowed to rise while material balance determinations were made when the pH reached about 8 and rose above 9 as usually occurs during the day in the field. The lights were then turned back off and the cycle repeated with three more material balance determinations made.

**Table III-12: SCHEDULE FOR MATERIAL BALANCE DETERMINATIONS**

| <b>Material<br/>Balance</b> | <b>Days After<br/>Initial Spike</b> | <b>Range of<br/>Dissolved Oxygen<br/>Concentrations</b> | <b>Range of<br/>pH<br/>Measurements</b> |
|-----------------------------|-------------------------------------|---|---|
| <b>1</b>                    | <b>6</b>                            | <b>8.00-8.50</b>  | <b>8.95-9.30</b>                        |
| <b>2</b>                    | <b>10</b>                           | <b>2.20-2.55</b>  | <b>7.95-8.25</b>                        |
| <b>3</b>                    | <b>14</b>                           | <b>0.00</b>   | <b>7.00-7.20</b>                        |
| <b>4</b>                    | <b>18</b>                           | <b>5.00-5.30</b>  | <b>7.90-8.10</b>                        |
| <b>5</b>                    | <b>23</b>                           | <b>9.65-10.50</b>                                       | <b>8.90-9.20</b>                        |
| <b>6</b>                    | <b>28</b>                           | <b>2.00-2.40</b>  | <b>7.70-7.95</b>                        |
| <b>7</b>                    | <b>32</b>                           | <b>0.00</b>   | <b>6.80-7.25</b>                        |
| <b>8</b>                    | <b>37</b>                           | <b>5.00-5.60</b>  | <b>7.95-8.25</b>                        |

Each of the four water columns of each tank was divided into five compartments; bulk water, sediment, exterior walls, baffle walls, and strings of the sediment samplers. In addition, the cumulative amount of phosphorus-32 in the effluent from each tank was a compartment. Therefore, for each tank there were six compartments when the phosphorus-32 content in each compartment of each water column was added. These six compartments are the bulk water, the sediment, the exterior walls, the baffle walls, the strings for the sediment samplers, and the effluent. The sampling and analysis for radiophosphorus is described in more detail below.

#### Radiophosphorus Techniques

Two types of samples and counting techniques were used. Liquid samples (bulk water and effluent) were counted with a NaI(Tl) well crystal scintillation system which was adjusted for optimum counting efficiency and standardized with a known activity and quantity of phosphorus-32 relative to the amount supplied. Two milliliter samples were counted in high-density polypropylene omni-vials (from Markson Science Inc.) with a 4 milliliter capacity. The standardization procedure for liquid samples is described below. Solid samples from the walls, baffles, strings, and sediment were counted in an internal proportional system on which the relative counting efficiency by the mass of the sample was determined as described below. Planchets 2 inches in diameter were used for all samples after the planchets were cleaned, dried and weighed before placement in the tanks. It was then necessary after collection to dry and tare the samples to determine the mass of sample for self-adsorption

correction. Optimum settings of the internal proportional system for beta counting had been previously determined.

Optimum operation of the scintillation counting system was established previous to spiking the model systems. Two millicuries of phosphorus-32 were initially obtained from New England Nuclear as dipotassium phosphate in 1 milliliter of water solution. Two milliliters of a diluted aliquot of the phosphorus-32 were added to each of several sample vials. A voltage response curve was then prepared for the background and for the samples. The optimum instrument setting was the point where the ratio of the net counting rate to the background was the highest.

A second order of phosphorus-32 (15 millicuries) as dipotassium phosphate in 1 milliliter of water solution was obtained from New England Nuclear to establish the relative efficiency of the counting instruments and to add to the model pond systems. This sample was diluted with de-ionized water to 200 milliliters in a volumetric flask (dilution 1). At this point there were  $7.5 \times 10^{-2}$  millicuries in each milliliter of water. For spiking each model system 60 milliliters of dilution 1 were volumetrically placed in a plastic bottle for transport to the laboratory. Initially, 4.5 millicuries of phosphorus-32 were placed in each model tank.

The relative efficiency of the scintillation system was established by taking 50 microliters of dilution 1 water and diluting into 20.0 milliliters (dilution 2). Two milliliters of dilution 2 water (at  $1.875 \times 10^{-4}$  millicuries per milliliter) were added to five sample vials to make a total of  $3.75 \times 10^{-4}$  millicuries or  $8.325 \times 10^5$  theoretical

disintegrations per minute in each. Each of these vials was counted four times for one minute and the average decay corrected counting rate used to determine the relative efficiency of the counting system. The results of this procedure are summarized in Table III-13. The average relative counting efficiency of the scintillation system was found to be about 6.75 percent with a standard deviation of the five mean counting rates of 722.7 counts per minute. This standard deviation is about 1.3 percent of the average of the five mean counting rates.

The relative efficiency of the internal proportional counting system for a range of sample masses (and thus self-absorptions) was established by adding a known amount of phosphorus-32 to a range of amounts of sediment. Two batches of sediment were used for this determination. To each of the flasks was added 576.0 milliliters of sediment (measured in a graduated cylinder), 20.0 milliliters of deionized wash water, and 4.00 milliliters of dilution 1 ( $7.5 \times 10^{-2}$  millicuries per milliliter) phosphorus-32 water. This is dilution 3. Thus,  $3.0 \times 10^{-1}$  millicuries were added to a total volume of 600.0 milliliters of sediment. There were  $1.11 \times 10^6$  theoretical disintegrations per minute for each milliliter in each of the two flasks. Twenty-four planchets were then cleaned and weighed. From each flask 5 milliliters of sediment solution (dilution 3) was added to each of 3 planchets, 10 milliliters added to 3 others, 15 milliliters added to 3 others, and 20 milliliters added to 3 others. This is illustrated in Table III-14. These were then dried and counted, correcting for decay. The planchets with the sediment from dilution 3 were then tared and a linear regression performed to determine the correction factor for self-absorption by weight of sample. The amount

**Table III-13: DETERMINATION OF RELATIVE COUNTING  
EFFICIENCY OF THE LIQUID SCINTILLATION SYSTEM**

| Standard Sample | Number of One Minute Counts | Mean of The Counts | Standard Deviation of The Counts | Decay Corrected Mean Count Rate (9 Days) |
|-----------------|-----------------------------|--------------------|----------------------------------|--|
| 1               | 4                           | 37,079.50          | 728.51                           | 57,387.64                                |
| 2               | 4                           | 36,013.00          | 553.59                           | 55,737.03                                |
| 3               | 4                           | 36,028.50          | 654.85                           | 55,761.02                                |
| 4               | 4                           | 36,337.50          | 848.34                           | 56,239.25                                |
| 5               | 4                           | 35,971.25          | 372.40                           | 55,672.41                                |

Average of the five means = 56,159.47

Standard deviation of the five means = 722.71

$$\begin{aligned}
 \text{The relative counting efficiency} &= \frac{56,159.47 \text{ counts per minute}}{8.325 \times 10^5 \text{ disintegrations per minute}} \\
 &= 6.75\%
 \end{aligned}$$



**Table III-14: SUMMARY OF EXPERIMENTAL SET-UP FOR  
INTERNAL PROPORTIONAL COUNTER RELATIVE  
EFFICIENCY DETERMINATION**

| Number of Planchets |         | Added<br>Volume of<br>Dilution 3<br>(milliliters) | Theoretical<br>Disintegrations<br>Per Minute |
|---------------------|---------|---|--|
| Flask A             | Flask B |   |  |
| 3                   | 3       | 5   | $5.55 \times 10^6$                           |
| 3                   | 3       | 10  | $1.11 \times 10^7$                           |
| 3                   | 3       | 15  | $1.67 \times 10^7$                           |
| 3                   | 3       | 20  | $2.22 \times 10^7$                           |

of self-absorption increases in a logarithmic relationship as mass increase. Therefore, linear regressions were performed on the natural logarithm of the weight versus the measured counts per minute. This line was compared to a linear regression of the natural logarithm of the average weight of the 5, 10, 15 and 20 milliliter batches of samples, and the theoretical disintegrations per minute in those samples. This process is illustrated in Tables III-15 and III-16, and Figure III-8. The raw data is presented in Appendix A for the linear regression of the actual counts per minute, and in Appendix B for the linear regression of the average weight and the theoretical counts per minute.

Each planchet in the internal proportional counter was counted four times for one minute each time. After each one minute count the planchets were rotated  $90^{\circ}$  to compensate for geometry (distribution of the sediment on the planchet) variations. In both of these linear regression calculations the data points for no weight of sediment and no net counts per minute were included.

As shown in Appendix A and B the correlation coefficients for the linear regressions are high. For the measured counts in Appendix A the correlation coefficient is 0.94. The regression formula is

$$y = 0.483x + 0.107$$

x = million counts per minute

y = ln weight of sample (X10) in grams

For the theoretical counts in Appendix B the correlation coefficient is 0.96 and the regression formula is:

$$y = 0.11 x + 0.366$$

x = million disintegrations per minute (theoretical)

y = ln weight of sample (X10) in grams

**Table III-15: SELF-ABSORPTION CORRECTION DATA FOR DETERMINING  
THE RELATIVE EFFICIENCY OF THE INTERNAL PROPORTIONAL  
COUNTING PROCEDURE (ACTUAL CORRECTED COUNTS PER MINUTE)**

| Volume of<br>Dilution 1<br>(ml) | Decay Corrected<br>Average Counts<br>Per Minute | Sediment<br>Weight<br>(grams) | ln (10XWeight<br>in Grams) |
|---------------------------------|---|-------------------------------|----------------------------|
| Flask A                         |   |                               |                            |
| 5                               | 2,516.682.4                                     | 0.4719                        | 1.552                      |
| 5                               | 2,725.139.4                                     | 0.4290                        | 1.456                      |
| 5                               | 2,296,387.5                                     | 0.3868                        | 1.353                      |
| 10                              | 3,519,326.7                                     | 0.7182                        | 1.972                      |
| 10                              | 3,723,113.3                                     | 0.6790                        | 1.915                      |
| 10                              | 3,594,714.5                                     | 0.5407                        | 1.688                      |
| 15                              | 4,036,564.6                                     | 1.2712                        | 2.543                      |
| 15                              | 4,359,046.6                                     | 1.2686                        | 2.540                      |
| 15                              | 4,558,990.4                                     | 0.9099                        | 2.208                      |
| 20                              | 5,131,142.6                                     | 1.2917                        | 2.559                      |
| 20                              | 5,369,729.3                                     | 1.3950                        | 2.635                      |
| 20                              | 5,605,650.3                                     | 1.5066                        | 2.712                      |
| Flask B                         |   |                               |                            |
| 5                               | 2,154,778.1                                     | 0.2990                        | 1.095                      |
| 5                               | 2,372,403.0                                     | 0.2872                        | 1.055                      |
| 5                               | 2,446,248.5                                     | 0.3627                        | 1.288                      |
| 10                              | 3,604,823.4                                     | 0.4689                        | 1.545                      |
| 10                              | 3,520,283.4                                     | 0.5872                        | 1.770                      |
| 10                              | 3,704,790.1                                     | 0.4640                        | 1.535                      |
| 15                              | 4,576,432.3                                     | 0.9949                        | 2.297                      |
| 15                              | 4,706,047.7                                     | 0.8049                        | 2.086                      |
| 15                              | 4,722,960.8                                     | 0.9082                        | 2.206                      |
| 20                              | 4,639,205.0                                     | 1.1122                        | 2.409                      |
| 20                              | 4,610,673.2                                     | 1.2261                        | 2.506                      |
| 20                              | 4,035,304.6                                     | 1.1936                        | 2.480                      |

**Table III-16: SELF-ABSORPTION CORRECTION DATA FOR  
 DETERMINING THE RELATIVE EFFICIENCY OF THE  
 INTERNAL PROPORTIONAL COUNTING PROCEDURE  
 (THEORETICAL COUNTS PER MINUTE AND AVERAGE WEIGHT)**

| Volume of<br>Dilution 1<br>(ml) | Theoretical<br>Corrected Average<br>Counts Per Minute | Average<br>Weight (grams)<br>Flask A&B | ln (10XWeight in<br>Grams) |
|---------------------------------|---|--|----------------------------|
| 5                               | 5,550,000   | 0.3728                                 | 1.316                      |
| 10                              | 11,100,000  | 0.5763                                 | 1.751                      |
| 15                              | 16,650,000  | 1.0263                                 | 2.329                      |
| 20                              | 22,200,000  | 1.2875                                 | 2.555                      |

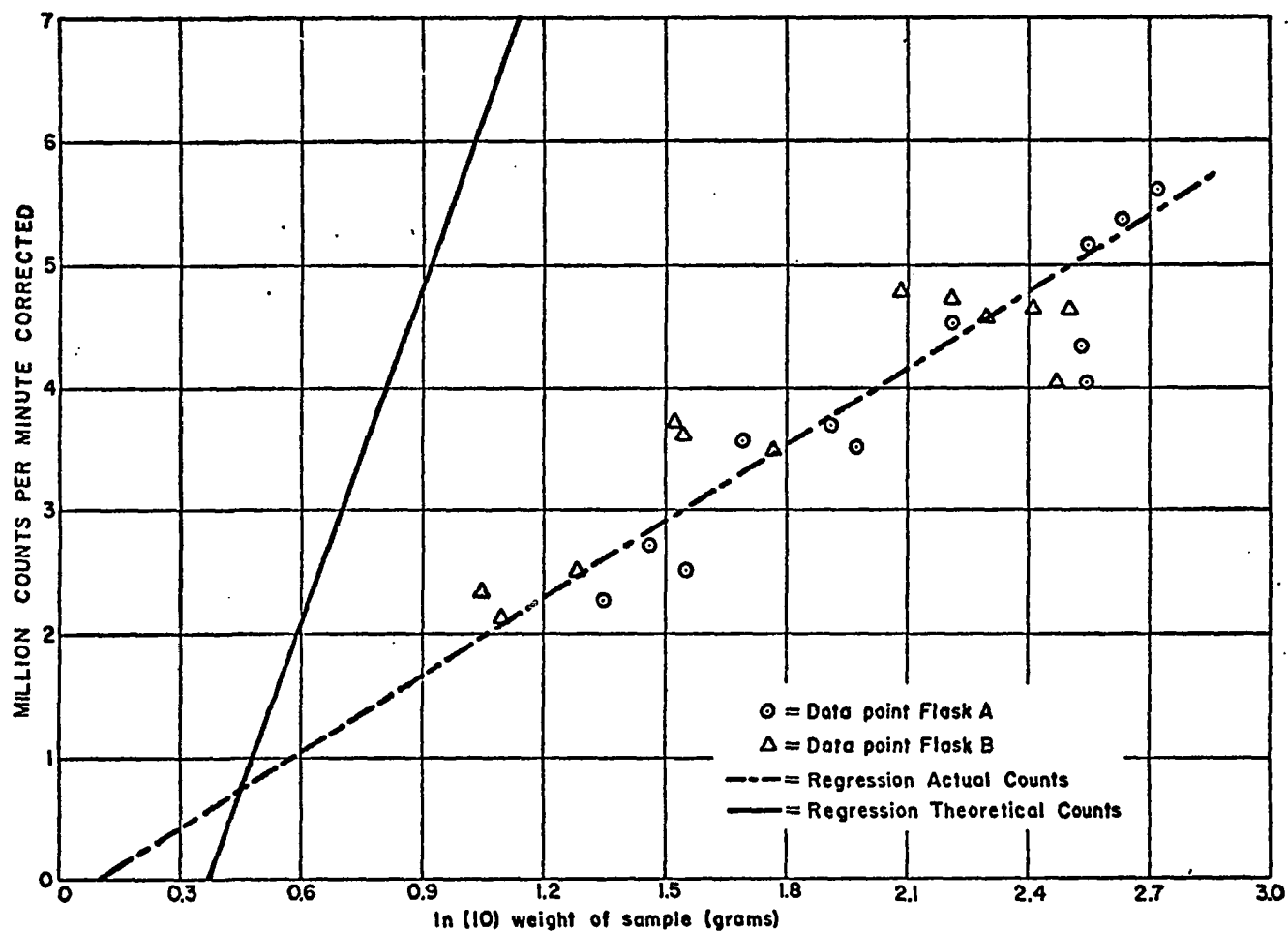


Figure III-8: Linear Regression of Decay Corrected Counts per Minute and Theoretical Counts per Minute versus Sample Weight for Self-Absorption Correction

Wall and baffle samples to estimate the sorption of phosphorus-32 by biological growth on these surfaces were collected for the material balance calculations. These samples consisted of two-inch diameter aluminum planchets coated with the same materials as the walls of the tanks (two coats of red primer and one coat of coal tar epoxy resin). These planchets were suspended by polyester thread at depths below the surface of about 3, 18 and 33 inches. Eight sets of three planchets as shown in Figure III-9 were suspended along the wall and the baffle near each water column sampled. Thus, there were 16 sets of three planchets for each water column, and 64 sets of three planchets in each tank (or 576 planchets total).

When the wall and baffle planchets were collected for material balance measurement one set of three planchets (at 3-, 18- and 33-inch depths) was collected from the wall and one from the baffle of each water column. The strings were cut and placed in a previously weighed planchet for drying and counting. Each of the planchets was scraped of its biological growth and the scrapings placed in a previously weighed planchet for drying and counting. Following counting the scraping and planchet were dried at 103° C and tared for self-absorption correction calculations.

The sediment samples were located in each tank as shown in Figure III-10. Eight sediment samplers were placed under each water column. These samplers consisted of a 15-millimeter inside diameter by 82.5 millimeter (height) pyrex glass test tube in a glass collar about 19 millimeters inside diameter by 76 millimeters in height. Two polyester threads were glued to the sediment samplers and taped to the

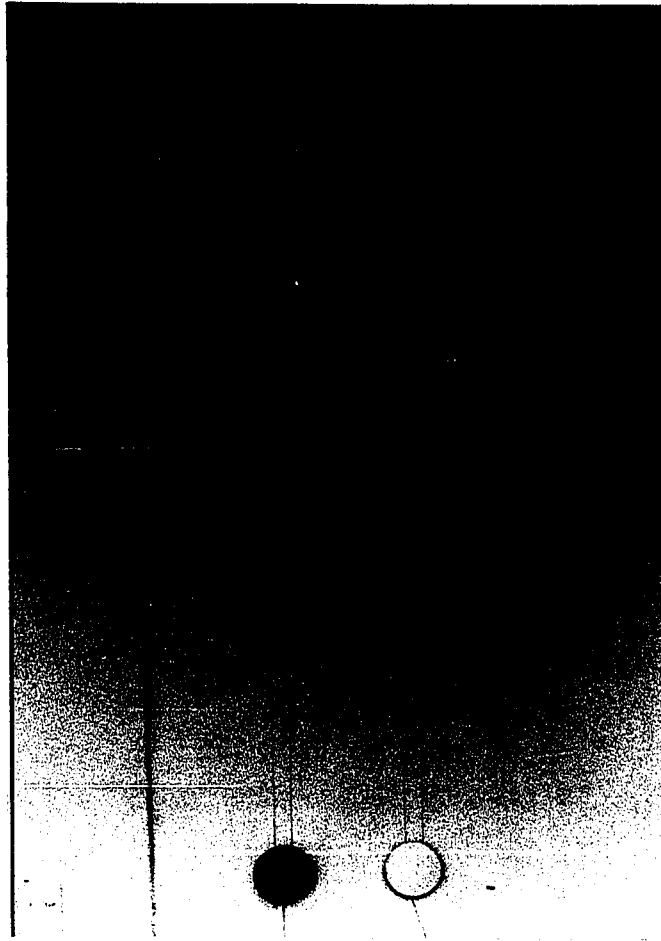


Figure III-9: Picture of Planchet Set-up

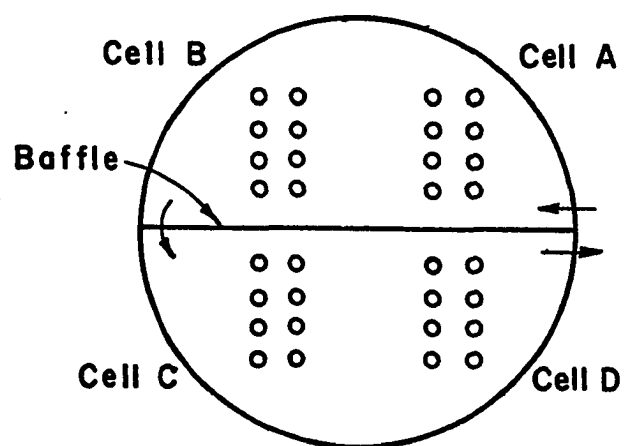


Figure III-10: Location of Sediment Samplers in Each Tank



outside of the tanks for retrieval. The collars were glued to the bottom of the tanks and were used to minimize sediment disturbance as samples were withdrawn.

Sediment was placed in the test tubes at the time sediment was collected and transported to the lab from the Blanchard lagoon system. The sediment in each 55-gallon drum from the lagoon was stirred with a metal rod for 10 minutes and grab samples (five samples of about 250 ml) were composited and poured into the test tubes. This composite aliquot was constantly stirred while filling the test tubes to maintain a representative amount of sediment in each. The test tubes each contained 14.6 ml of sediment. Immediately after the sediment samplers were placed in the tanks the sediment from the 55-gallon drums was placed in the tanks on their respective sides of the baffle. That is, the sediment from the first pond of the Blanchard system was placed on the influent side of baffle, and sediment from the second pond of the Blanchard system was placed on the effluent side of the baffle.

The sediment samples were collected when materials balance was measured. One sediment sample was withdrawn from each water column for each of the eight materials balances. The strings from the sediment samplers were cut and placed in a previously weighed planchet for drying and counting. The sediment from the test tube was poured into two previously weighed planchets (the test tube was washed with deionized water), dried, and counted. Following counting the sediment and planchet and strings and planchet were dried at 103<sup>0</sup> C and tared for self-absorption correction calculations.

Liquid sampling for phosphorus-32 was done on a daily basis at a depth of 3 inches. The samples were collected with a glass pipette. Bulk water samples for material balance measurements were collected with a glass rod at depths of 3, 18 and 33 inches and placed in a beaker for further analysis. Effluent samples were also collected at the time material balance measurements were made. The volume of the effluent was first measured and then the effluent was stirred for 5 minutes with a glass rod. Four two-milliliter effluent samples were collected from each tank and the average activity used to estimate the amount of phosphorus-32 in this compartment.

One other group of bulk water samples was also taken. The initial phosphorus-32 spike was made with a cool dilution (about 20° C) and the plastic transport bottles rinsed five times with deionized water. The 4.5 millicuries of phosphorus-32 were placed in each tank with a pipette at a depth of about 6 inches near the influent. This was done to minimize any possible short-circuiting of the flow of the initial spike along the surface of the tanks. The initial spike was made at 10:00 a.m. after biological, chemical, and physical characterization of each tank. Samples of the bulk water from each water column in each tank were taken at  $\frac{1}{4}$ ,  $\frac{1}{2}$ , 1, 2, 3, 8, 16 and 22 hours after spiking at a depth of 3 inches. This was done to monitor the initial fate of the phosphorus-32 in the water. The 22-hour sample was taken at 8:00 a.m. the morning following the initial spiking. After this time all phosphorus-32 samples were collected twice daily (except for Sunday) between 8:00 and 9:00 a.m. and 5:00 and 6:00 p.m.

### Chemical, Biological and Physical Methods of Analysis

As described in the section on sampling procedures and parameters measured, analyses were performed on the sediment-sludge used in the model tanks, on the biology and chemistry of the tanks during the acclimation phase and on the chemistry of the tanks during the operational phase of this study. The analytical methods used are briefly described below and summarized in Table III-17. The sampling schedule for each of these parameters and the radioanalytical techniques used have been described above.

Biological analysis consisted of identification and some quantification of algae and major bacterial genera and total bacteria. The algae near the surface were examined in a Sedgewick-Rafter counting cell. They were collected in glass bottles and preserved with Transeau's solution. Ten random fields were examined in each milliliter and two counting cells were examined for each sample collected. The algae were identified to genera according to Smith (1950) and reported as abundant, common or rare.

Major bacterial genera were isolated and enumerated by the technique described by Gann, Collier and Lawrence (1968). Total bacteria were enumerated by the technique described by Jourdan (1969). With this technique for total bacteria one milliliter of the appropriate dilution was placed in a plastic petri dish. Nutrient agar at a temperature of 43 to 45° C was poured into the dish in sufficient quantity to completely cover the bottom (at least 15 milliliters). The plates were then mixed gently by swirling and incubated in an inverted position at  $36 \pm 1^{\circ}$  C for  $24 \pm 2$  hours. The plates with between 30 and 300 colonies were observed after this incubation period for all bacterial colonies and the appropriate dilution factor applied which constitutes total bacteria per volume.

Table III-17: METHODS USED FOR CHEMICAL, BIOLOGICAL AND PHYSICAL ANALYSIS

| Parameter                             | Analytical Method  | Reference                                   |
|---------------------------------------|--|---|
| Algal genera                          | Sedgewich-Rafter Counting Cell   | Standard Methods (1971) and Smith (1950)    |
| Bacteria genera and total             | Nutrient Agar  | Gann, Collier and Lawrence (1968)           |
| Biochemical Oxygen Demand (5 day)     | Membrane Electrode after Incubation  | Standard Methods (1971)                     |
| Dissolved Oxygen                      | Membrane Electrode (in situ)   | Standard Methods (1971)                     |
| Orthophosphate - Bulk Water           | Ascorbic Acid Reduction and Colorimetric Analysis  | EPA (1974)                                  |
| Orthophosphate - Interstitial Water   | Centrifugation, Ascorbic Acid Reduction and Colorimetric Analysis                            | EPA (1974)                                  |
| pH                                    | Glass Electrode  | Standard Methods (1971)                     |
| Total Phosphorus - Bulk Water         | Persulfate Acid Digestion, Ascorbic Acid Reduction and Colorimetric Analysis                 | Standard Methods (1971)                     |
| Total Phosphorus - Interstitial Water | Centrifugation, Persulfate Acid Digestion, Ascorbic Acid Reduction and Colorimetric Analysis | Standard Methods (1971)                     |
| Total Phosphorus - Sediment           | Perchloric Acid Digestion, Ascorbic Acid Reduction and Colorimetric Analysis                 | Standard Methods (1971) and Anderson (1976) |
| Oxidation-Reduction Potential         | Platinum Electrode   | Light (1972)                                |
| Temperature                           | Thermometer  |   |

For major bacteria genera (Pseudomonas, Achromobacter, and Flavobacterium), one-tenth milliliter of sample was inoculated by spreading on a previously prepared nutrient agar plate with a bent glass rod. The plates were then inverted and incubated for 24, 48, and 72 hours at  $25 \pm 2^{\circ}$  C. The plates were removed at these times for counting with a Quebec colony counter using the following key:

|                         |  |
|-------------------------|--|
| <u>Pseudomonas</u> :    | colorless to buff-colored<br>4 mm. in diameter<br>developed at 24 hrs. at $25 \pm 2^{\circ}$ C |
| <u>Achromobacter</u> :  | colorless<br>2 mm. in diameter<br>developed in 48 hrs. at $25 \pm 2^{\circ}$ C                 |
| <u>Flavobacterium</u> : | bright yellow<br>22 mm. in diameter<br>developed in 72 hrs. at $25 \pm 2^{\circ}$ C            |

The BOD<sub>5</sub> and dissolved oxygen were measured according to procedures described in Standard Methods (1971) with the use of a membrane electrode and dissolved oxygen meter (YSI Model 57). The pH was measured in vitro using a Photovolt pH meter. The oxidation-reduction (redox) potential was determined in vitro with a platinum electrode allowing a 15-minute equilibration time. A photovolt pH meter was used and standardized with a known oxidation-reduction potential as described by Light (1972). This calibration procedure is summarized below. The standard solution of +475 mv was prepared as follows:

39.21 grams ferrous ammonium sulfate  
48.22 grams ferric ammonium sulfate  
56.2 milliliters concentrated sulfuric acid

These chemicals were dissolved in deionized water and diluted to one liter. The solution was stored in a closed glass bottle.

Orthophosphate in water was determined by the Ascorbic Acid method followed by colorimetric analysis described in Methods for Chemical Analysis of Water and Wastes (EPA, 1974). For the determination of total phosphorus and orthophosphate concentrations of the sediment, interstitial water samples of sediment were first centrifuged at 5000 RPM for 10 minutes in a Storvall SS-3 centrifuge. An aliquot of the supernatant was withdrawn from each centrifuge tube for later analysis. Total phosphorus was determined by persulfate acid digestion followed by ascorbic acid reduction and colorimetric analysis as described in Standard Methods (1971). Total phosphorus in the sediment was determined by the perchloric acid method as described in Standard Methods (1971), and by Anderson (1976) who used this method on lake sediments.

## CHAPTER IV

### PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

As described in Table III-10 the results of the experiment will be discussed in three parts. These are the characterization of each tank during the acclimation phase, characterization and analysis by correlation during the operational phase (two parts) and materials balance measurements.

#### Acclimation Phase

Immediately after collection of the sediment from the Blanchard pond, it was measured for total phosphorus content. In addition, the total phosphorus and orthophosphate concentration of the interstitial water was measured after centrifugation. The results of this analysis are presented in Table IV-1. Most of the phosphorus was found to be associated with the solid material of the sediment samples and most of the phosphorus in solution in the interstitial water was in the total phosphorus form.

The  $BOD_5$  of the middle of each tank was measured weekly during the entire acclimation phase. The results of these measurements are summarized in Figures IV-1 through IV-3 for each of the tanks. In each of the tanks the  $BOD_5$  of Cell A-B was higher than that of Cell C-D and the  $BOD_5$  generally decreased during this period. The  $BOD_5$  of Tank 1, Cell A-B was initially about 110 mg/l and decreased to about 90 mg/l

Table IV-1: Initial Phosphorus Content of Sediment

| Sample  | Total<br>Phosphorus<br>Dry Weight<br>(mg/g) | Phosphorus<br>Interstitial<br>(mg/l) | Orthophosphate<br>Interstitial<br>(mg/l) |
|---------|---|--------------------------------------|--|
| 1       | 6.10  | 0.16                                 | 0.04                                     |
| 2       | 5.60  | 0.14                                 | 0.04                                     |
| 3       | 5.40  | 0.14                                 | 0.04                                     |
| 4       | 4.80  | 0.10                                 | 0.02                                     |
| Average | 5.48  | 0.135                                | 0.135                                    |



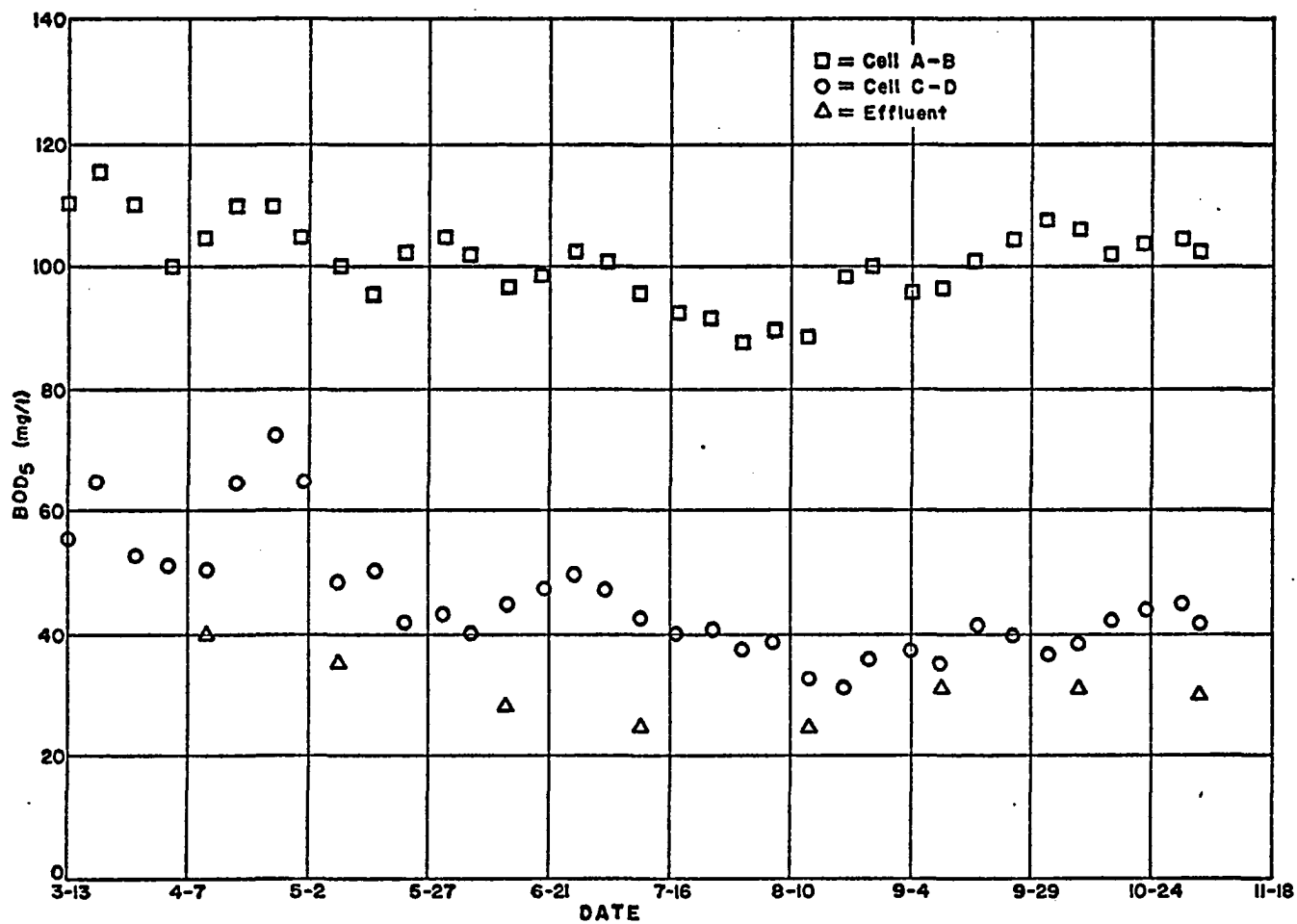


Figure IV-1: BOD<sub>5</sub> of Tank 1 at a Depth of 3 Inches

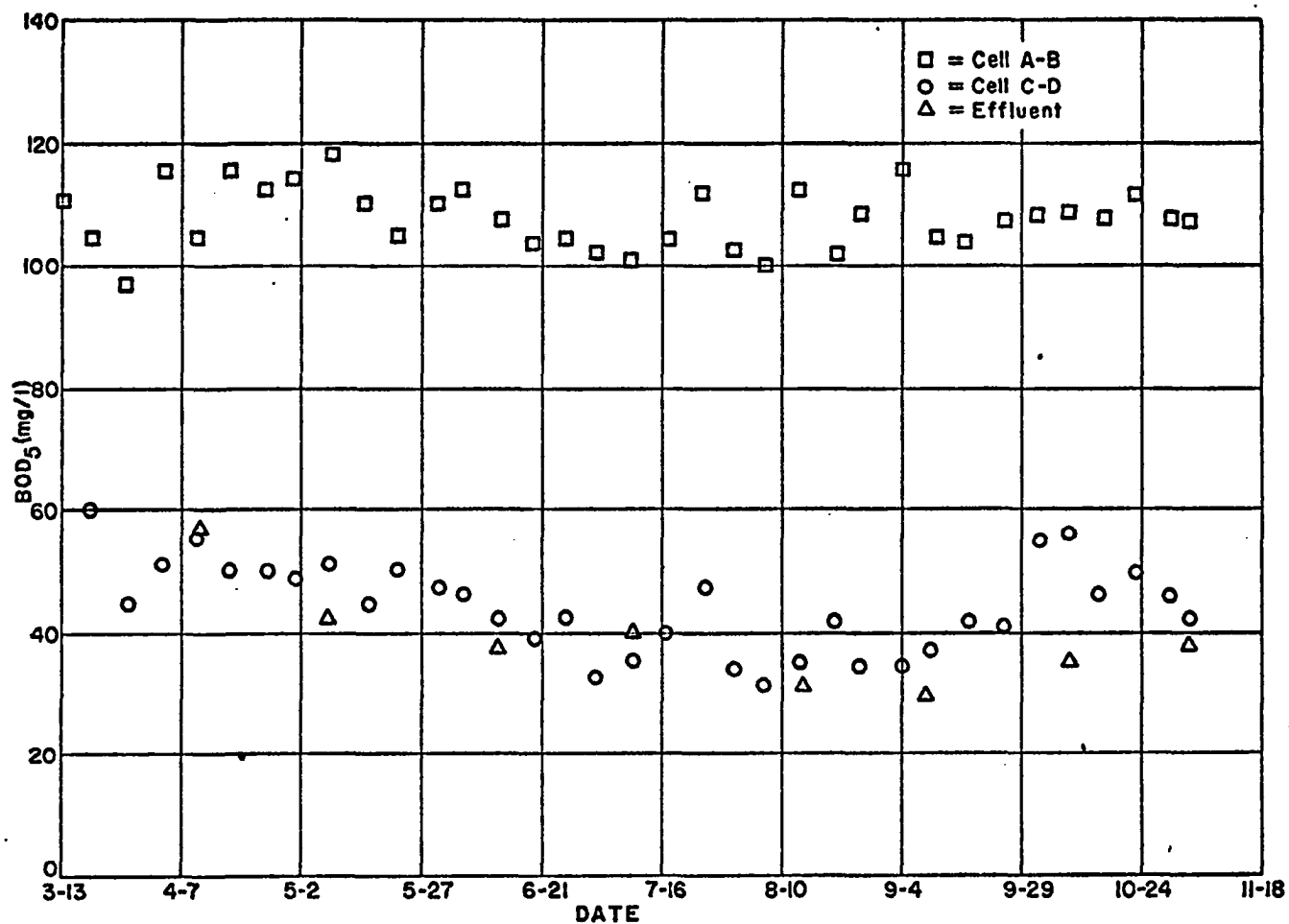


Figure. IV-2: BOD<sub>5</sub> of Tank 2 at a Depth of 3 Inches

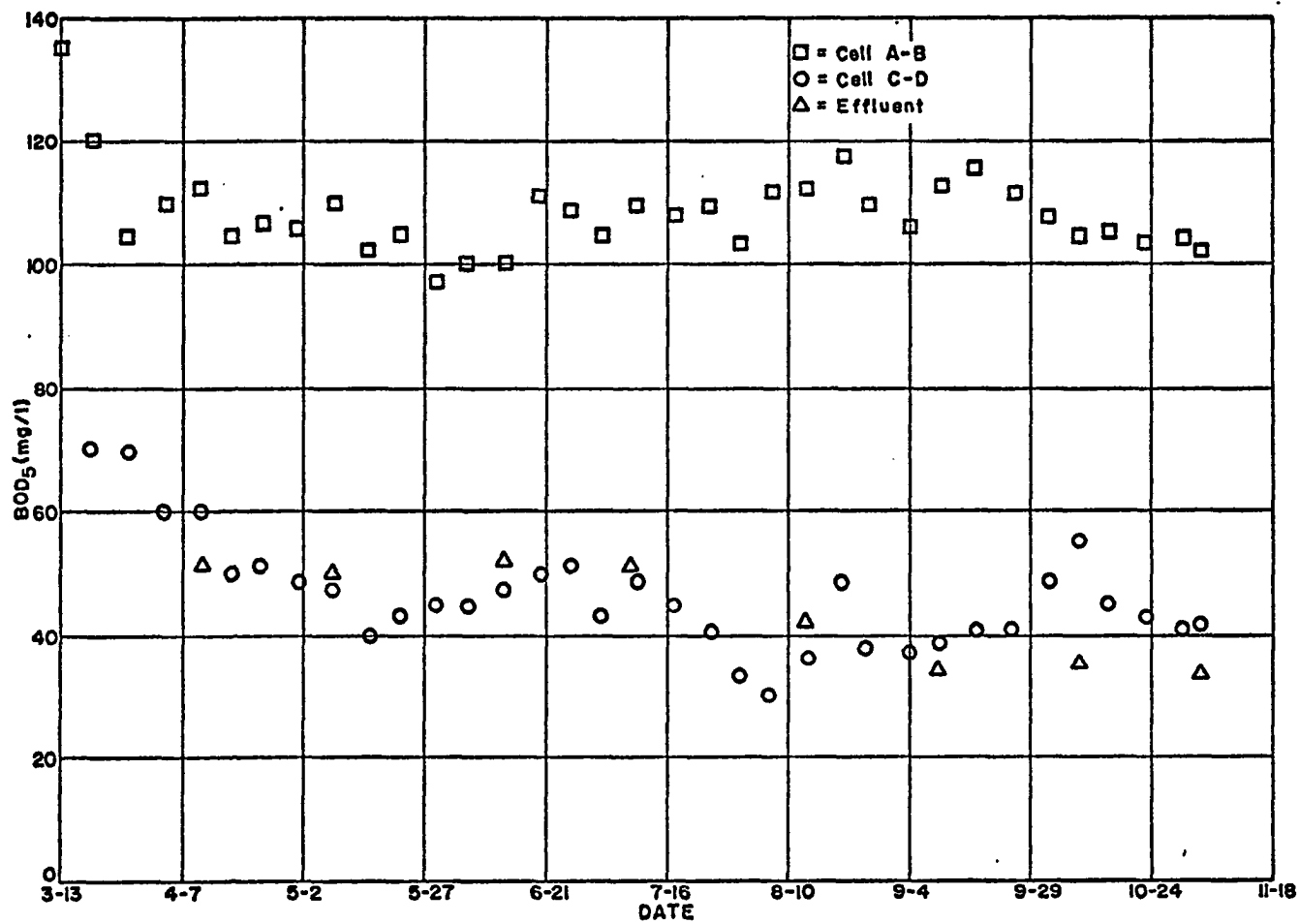


Figure IV-3:  $BOD_5$  of Tank 3 at a Depth of 3 Inches

before increasing back to about 105 mg/l. The BOD<sub>5</sub> of Cell C-D of Tank 1 was initially about 60 mg/l and declined to about 30 mg/l.

The BOD<sub>5</sub> of Tanks 2 and 3 was generally higher than Tank 1. For example, in Tank 3 Cell A-B the initial BOD<sub>5</sub> was about 135 mg/l and declined to about 105 mg/l. In Cell C-D the BOD<sub>5</sub> was initially above 100 mg/l and declined to about 45 mg/l. The BOD<sub>5</sub> of the effluent of each tank followed the pattern exhibited by Cell C-D.

During the four weeks prior to the introduction of radiophosphorus each of the tanks was sampled for total bacteria, Pseudomonas, Achromobacter, and Flavobacterium. Table IV-2 shows the results of these samples for Tank 1. Total bacteria were generally greatest in Cell A-B and most (65 to 77 percent) were Achromobacter. Similar results were found for Tanks 2 and 3 as shown in Table IV-3 and Table IV-4. Total bacteria were greatest in Cell A-B in both tanks. Achromobacter accounted for 68 to 80 percent of the bacteria in Tank 2 and 65 to 74 percent in Tank 3. Generally, the number of total bacteria was greater in Tank 1 than either Tank 2 or 3.

The algae present in each tank were also identified at the same time bacteria samples were taken. Table IV-5, IV-6 and IV-7 summarize the results of the algae observed. In Tank 1 Anabaena, a blue-green filament, and Chlorella, a green single-cell, were observed to occur abundantly in all samples. Oscillatoria, a blue-green filament, and Botryococcus, a colonial green alga, were observed to be common in most samples. Both occurred most frequently in Cell A-B. Scenedesmus, a colonial green alga, and Euglena, a motile single-cell, increased in frequency of observance during the sampling period. Euglena occurred

Table IV-2: Bacteria in Tank 1 During Acclimation Phase  
(Number of Bacteria per Milliliter)

| Type of Bacteria      | October 16 |           | October 23 |           | October 30 |           | November 3 |           |
|-----------------------|------------|-----------|------------|-----------|------------|-----------|------------|-----------|
|                       | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  |
| Total Bacteria        | 2,456,000  | 2,546,000 | 2,735,000  | 2,442,000 | 2,606,000  | 2,608,000 | 2,792,000  | 2,500,000 |
| <u>Pseudomonas</u>    | 258,000    | 184,000   | 216,000    | 190,000   | 222,000    | 182,000   | 208,000    | 176,000   |
| <u>Achromobacter</u>  | 1,890,000  | 1,792,000 | 1,910,000  | 1,822,000 | 1,742,000  | 1,876,000 | 1,814,000  | 1,808,000 |
| <u>Flavobacterium</u> | 288,000    | 216,000   | 258,000    | 304,000   | 246,000    | 322,000   | 312,000    | 310,000   |

Table IV-3: Bacteria in Tank 2 During Acclimation Phase  
(Number of Bacteria per Milliliter)

| Type of Bacteria      | October 16 |           | October 23 |           | October 30 |           | November 3 |           |
|-----------------------|------------|-----------|------------|-----------|------------|-----------|------------|-----------|
|                       | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  |
| Total Bacteria        | 2,294,000  | 1,192,000 | 2,416,000  | 2,002,000 | 2,334,000  | 1,898,000 | 2,274,000  | 1,910,000 |
| <u>Pseudomonas</u>    | 118,000    | 220,000   | 300,000    | 212,000   | 246,000    | 216,000   | 236,000    | 194,000   |
| <u>Achromobacter</u>  | 1,634,000  | 806,000   | 1,712,000  | 1,594,000 | 1,802,000  | 1,414,000 | 1,734,000  | 1,520,000 |
| <u>Flavobacterium</u> | 94,000     | 128,000   | 122,000    | 122,000   | 114,000    | 116,000   | 102,000    | 92,000    |

Table IV-4: Bacteria in Tank 3 During Acclimation Phase  
(Number of Bacteria per Milliliter)

| Type of Bacteria      | October 16 |           | October 23 |           | October 30 |           | November 3 |           |
|-----------------------|------------|-----------|------------|-----------|------------|-----------|------------|-----------|
|                       | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  | Cell A-B   | Cell C-D  |
| Total Bacteria        | 2,408,000  | 2,159,000 | 2,296,000  | 2,002,000 | 2,054,000  | 1,994,000 | 2,016,000  | 2,008,000 |
| <u>Pseudomonas</u>    | 202,000    | 96,000    | 210,000    | 166,000   | 198,000    | 142,000   | 186,000    | 140,000   |
| <u>Achromobacter</u>  | 1,664,000  | 1,514,000 | 1,702,000  | 1,402,000 | 1,334,000  | 1,414,000 | 1,388,000  | 1,408,000 |
| <u>Flavobacterium</u> | 316,000    | 290,000   | 276,000    | 322,000   | 272,000    | 278,000   | 298,000    | 286,000   |

Table IV-5: Algae Observed in Tank 1 During Acclimation Phase

| Genus               | October 16                       |              | October 23   |              | October 30   |              | November 3   |              |
|---------------------|----------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                     | Cell A-B                         | Cell C-D     | Cell A-B     | Cell C-D     | Cell A-B     | Cell C-D     | Cell A-B     | Cell C-D     |
| <u>Anabaena</u>     | Abundant                         | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     |
| <u>Oscillatoria</u> | Common                           | Rare         | Common       | Common       | Common       | Common       | Common       | Common       |
| <u>Chlorella</u>    | Abundant                         | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     |
| <u>Micractinium</u> | Not Observed                     | Not Observed | Not Observed | Rare         | Not Observed | Not Observed | Not Observed | Not Observed |
| <u>Scenedesmus</u>  | Rare                             | Common       | Rare         | Common       | Common       | Common       | Common       | Common       |
| <u>Euglena</u>      | Rare                             | Rare         | Not Observed | Not Observed | Rare         | Common       | Rare         | Common       |
| <u>Botryococcus</u> | Common                           | Common       | Common       | Rare         | Common       | Rare         | Common       | Common       |
| <u>Oocystis</u>     | Not Observed                     | Not Observed | Not Observed | Not Observed | Not Observed | Not Observed | Not Observed | Rare         |
| <u>Ulothrix</u>     | Abundantly attached to the walls |              |              |              |              |              |              |              |



Table IV-6: Algae Observed in Tank 2 During Acclimation Phase

| Genus                 | October 16                       |              | October 23   |              | October 30   |              | November 3   |              |
|-----------------------|----------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                       | Cell A-B                         | Cell C-D     | Cell A-B     | Cell C-D     | Cell A-B     | Cell C-D     | Cell A-B     | Cell C-D     |
| <u>Anabaena</u>       | Common                           | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     | Abundant     |
| <u>Oscillatorra</u>   | Rare                             | Rare         | Rare         | Common       | Common       | Common       | Common       | Common       |
| <u>Ankistrodesmus</u> | Common                           | Common       | Common       | Common       | Common       | Abundant     | Common       | Common       |
| <u>Chlorella</u>      | Abundant                         | Abundant     | Abundant     | Abundant     | Common       | Common       | Common       | Common       |
| <u>Micractinium</u>   | Common                           | Common       | Rare         | Common       | Rare         | Common       | Not Observed | Not Observed |
| <u>Scenedesmus</u>    | Abundant                         | Common       | Abundant     | Common       | Common       | Common       | Rare         | Common       |
| <u>Chlamydomonas</u>  | Not Observed                     | Not Observed | Not Observed | Not Observed | Not Observed | Not Observed | Not Observed | Common       |
| <u>Euglena</u>        | Not Observed                     | Rare         | Not Observed | Common       | Not Observed | Common       | Rare         | Common       |
| <u>Botryococcus</u>   | Common                           | Rare         | Not Observed | Common       | Rare         | Rare         | Rare         | Abundant     |
| <u>Oocystis</u>       | Common                           | Common       | Rare         | Not Observed | Rare         | Rare         | Common       | Rare         |
| <u>Ulothrix</u>       | Abundantly attached to the walls |              |              |              |              |              |              |              |

Table IV-7: Algae Observed in Tank 3 During Acclimation Phase

| Genus                 | October 16                       |              | October 23   |              | October 30   |              | November 3   |              |
|-----------------------|----------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                       | Cell A-B                         | Cell C-D     | Cell A-B     | Cell C-D     | Cell A-B     | Cell C-D     | Cell A-B     | Cell C-D     |
| <u>Anabaena</u>       | Abundant                         | Abundant     | Abundant     | Abundant     | Common       | Abundant     | Common       | Abundant     |
| <u>Oscillatoria</u>   | Common                           | Rare         | Rare         | Rare         | Common       | Common       | Abundant     | Common       |
| <u>Ankistrodesmus</u> | Rare                             | Not Observed | Not Observed | Not Observed | Common       | Rare         | Common       | Rare         |
| <u>Chlorella</u>      | Common                           | Common       | Common       | Common       | Abundant     | Common       | Abundant     | Common       |
| <u>Scenedesmus</u>    | Common                           | Common       | Common       | Common       | Common       | Common       | Common       | Common       |
| <u>Chlamydomonas</u>  | Not Observed                     | Rare         | Not Observed | Rare         | Not Observed | Rare         | Rare         | Not Observed |
| <u>Euglena</u>        | Not Observed                     | Rare         | Not Observed | Rare         | Not Observed | Common       | Common       | Common       |
| <u>Botryococcus</u>   | Common                           | Rare         | Rare         | Not Observed | Not Observed | Not Observed | Not Observed | Not Observed |
| <u>Oocystis</u>       | Not Observed                     | Not Observed | Not Observed | Not Observed | Not Observed | Rare         | Rare         | Rare         |
| <u>Ulothrix</u>       | Abundantly attached to the walls |              |              |              |              |              |              |              |

more commonly in Cell C-D of the tank. Both Micractinium and Oocystis, a colonial green algae, were observed in only one sample. Ulothrix, a green filament, occurred abundantly along the walls and baffle.

In Tanks 2 and 3, Anabaena and Chlorella were both observed to occur abundantly in almost all samples. One major difference between these cells was in the increase in Botryococcus observed in Tank 2 Cell C-D while in Tank 3 this alga decreased in observance. Scenedesmus was commonly observed in all samples from Tank 3 while it declined in occurrence in Tank 2. In both tanks Oscillatoria, the green colony, Ankistrodesmus, and Euglena increased in frequency between successive samples. Chlamydomonas, a mobile Chlorophytan, occurred only rarely in Tank 3 and was not observed in Tank 2 until the last samples taken from Cell C-D where it occurred commonly. Micractinium occurred only in Tank 2 and declined in frequency of observance. Oocystics appeared to decline and then increase in Tank 2 while in Tank 3 it was not observed except rarely in the latest samples. Ulothrix was also observed to grow abundantly attached to the walls and baffle of each tank.

During the acclimation phase the dissolved oxygen, pH and temperature were measured daily in the center of each cell, and the oxidation-reduction potential was measured daily during the four weeks prior to the introduction of radiophosphorus. Both the orthophosphate and total phosphorus concentration of each cell were measured daily during the acclimation phase. The results of the chemical and physical analyses are summarized below.

The dissolved oxygen at a depth of 3 inches of Cell A-B of each tank is shown in Figure IV-4, IV-5, and IV-6. Similar levels were observed

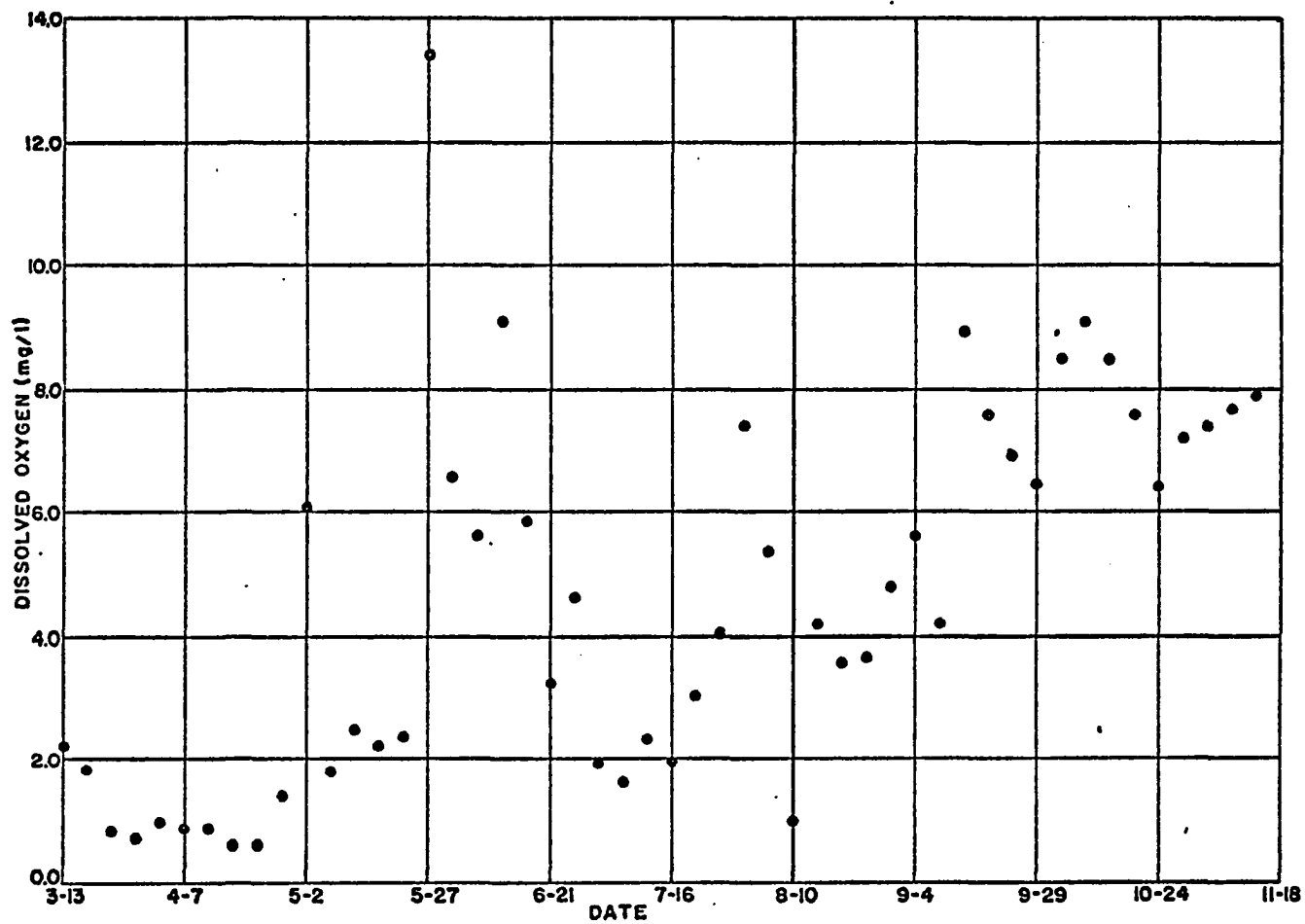


Figure IV-4: Dissolved Oxygen of Tank 1 During Acclimation Phase (Cell A-B)

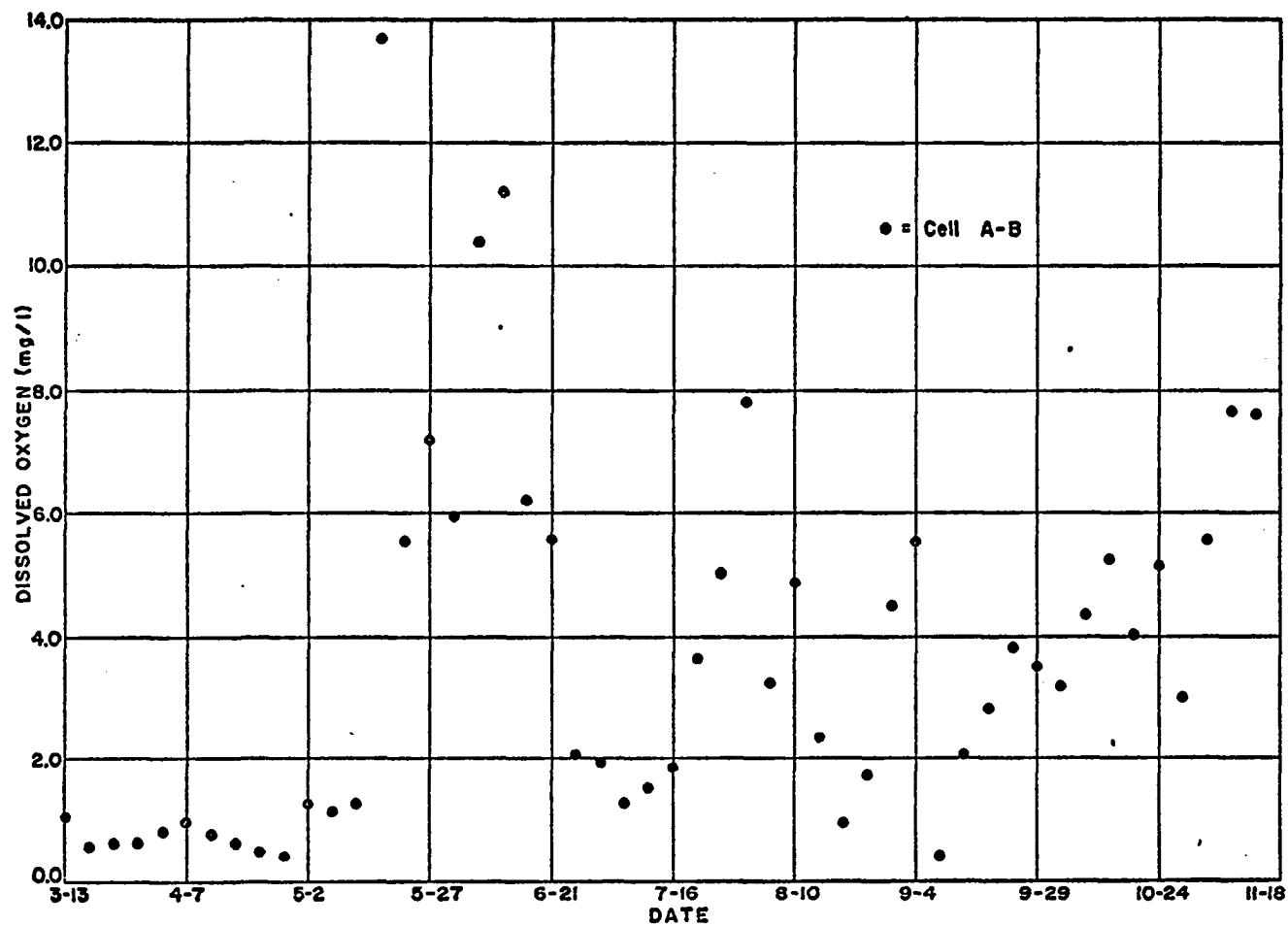


Figure IV-5: Dissolved Oxygen of Tank 2 During Acclimation Phase (Cell A-B)

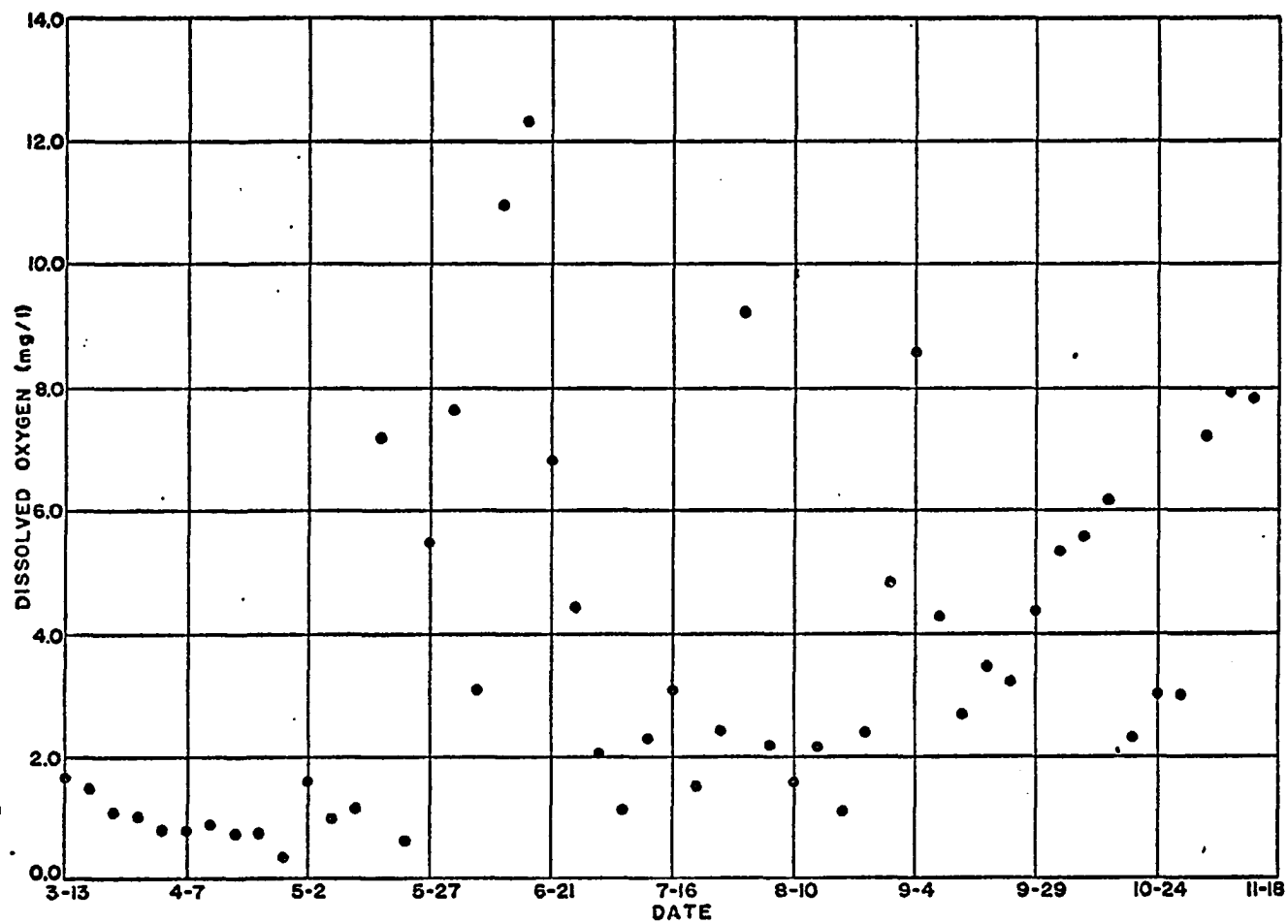


Figure IV-6: Dissolved Oxygen of Tank 3 During Acclimation Phase (Cell A-B)

in the second cell of each tank. From March 13 until around May 1 the dissolved oxygen in each cell was below 1.0 mg/l. Tank 1 was aerated for 12 hours by bubbling diffused air into the water at a depth of about 30 inches. Following this, Tanks 2 and 3 were aerated in a similar manner. When the dissolved oxygen level in the tanks declined the tanks were again aerated around the first part of June. At this point the lights over each tank were left on 24 hours per day until about the first of October when a normal light and dark cycle was resumed. This allowed the tanks to recover from anaerobic conditions and to establish an algal growth capable of maintaining aerobic conditions. However, daily variations in dissolved oxygen levels (and pH and redox potential) did not approach those that occur in waste stabilization ponds during the summer. It was therefore necessary to operate the tanks under lighted conditions for about four days and darkened conditions for about four days to simulate the chemical changes that occur in the field. The rate of biological activity in the tanks was apparently less than occurs in the field. This is thought to be due primarily to the light intensity in the laboratory tanks being considerably less than occurs in the field even though the intensity of light at the surface was above saturation for algae as reported in the literature.

The pH and redox potential measurements taken during the acclimation period are summarized in Figures IV-7 through IV-12. The pH generally increased in all three tanks throughout this period. Increases occurred following increases in dissolved oxygen concentration. This can be observed by comparing Figure IV-4 through IV-6 with the corresponding Figure IV-7 through IV-9. The redox potential of Cell A-B of each tank

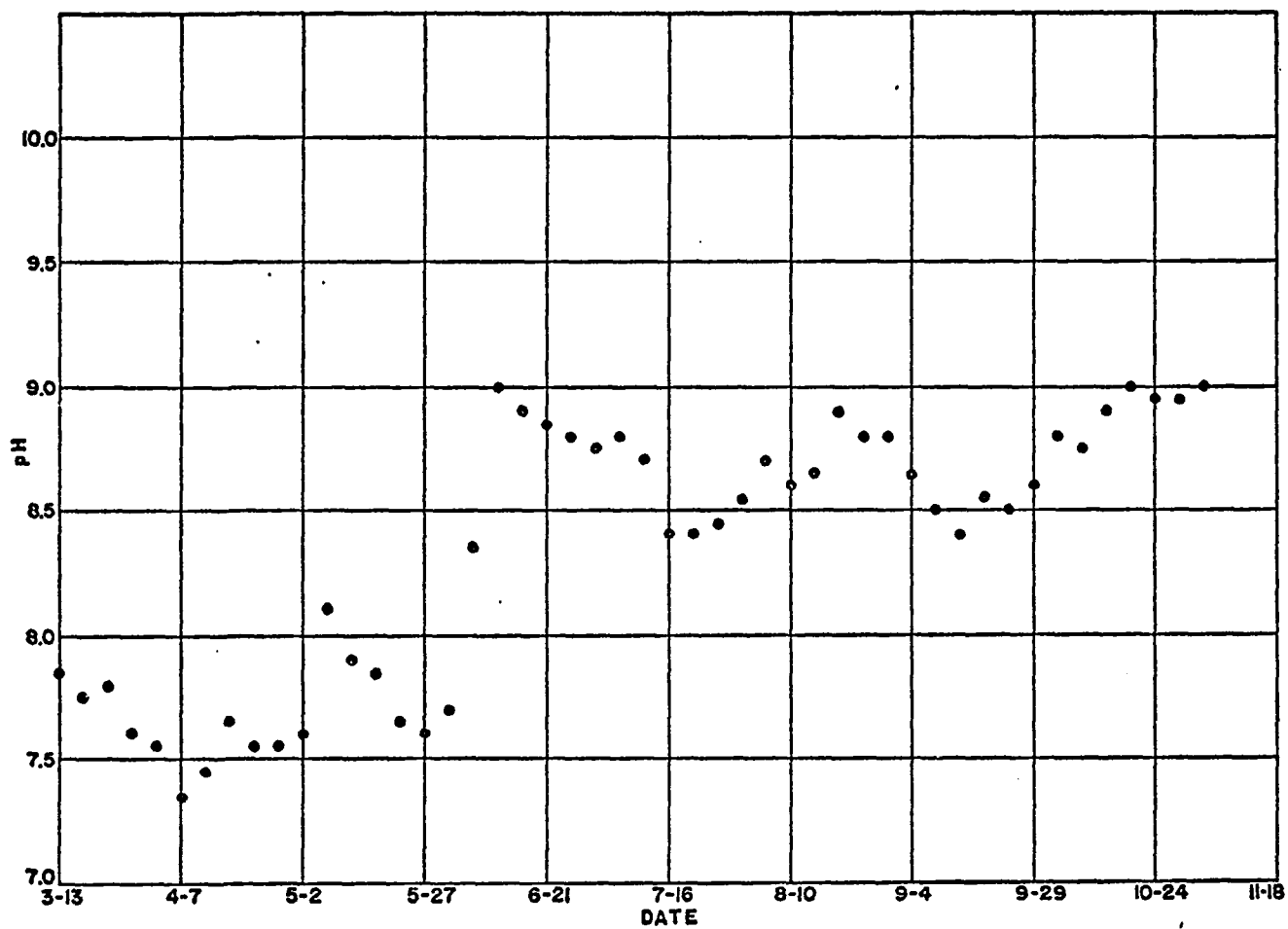


Figure IV-7: pH of Tank 1 During Acclimation Phase (Cell A-B)



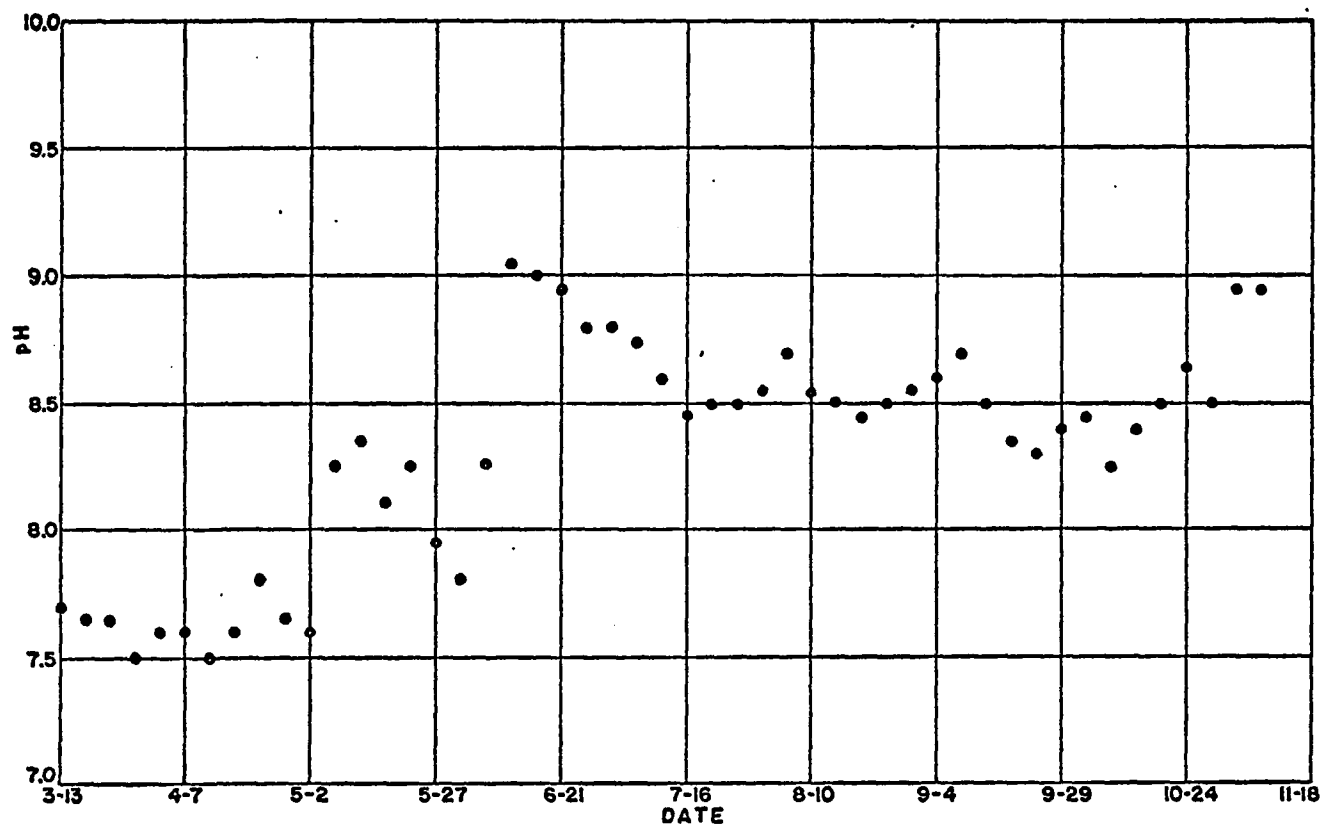


Figure IV-8: pH of Tank 2 During Acclimation Phase (Cell A-B)

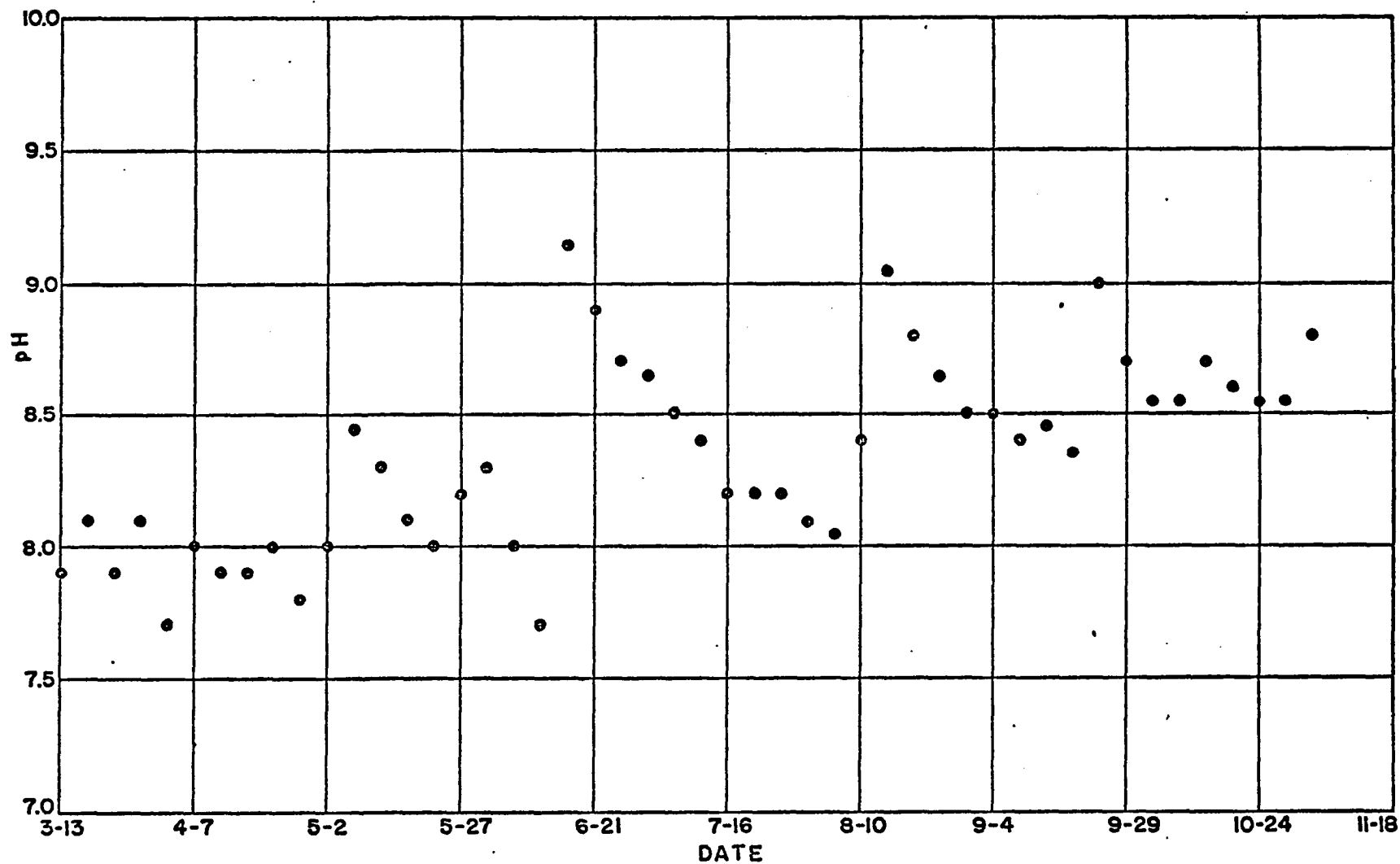


Figure IV-9: pH of Tank 3 During Acclimation Phase (Cell A-B)

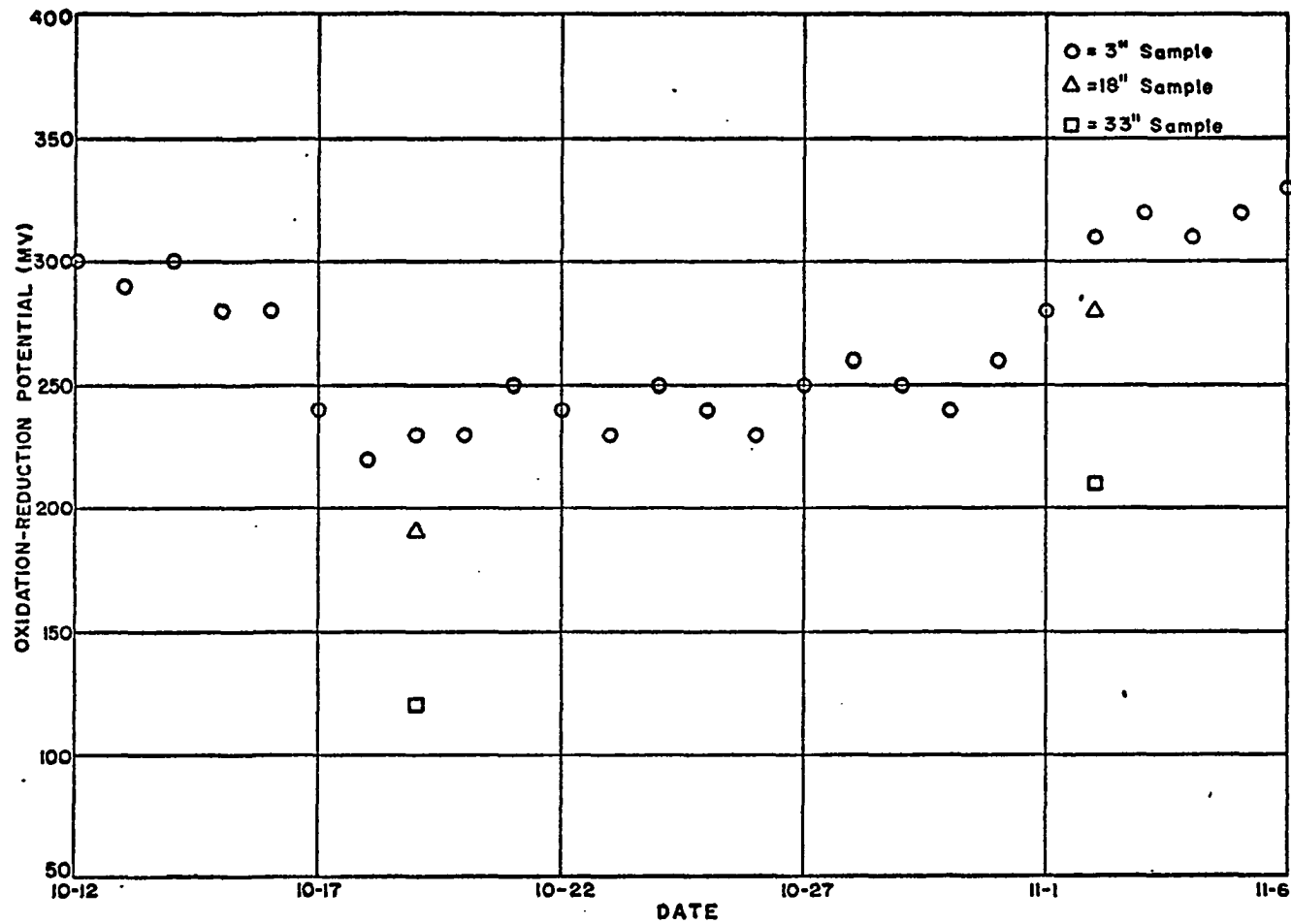


Figure IV-10: Oxidation Reduction Potential of Tank 1 During Acclimation Phase (Cell A-B)

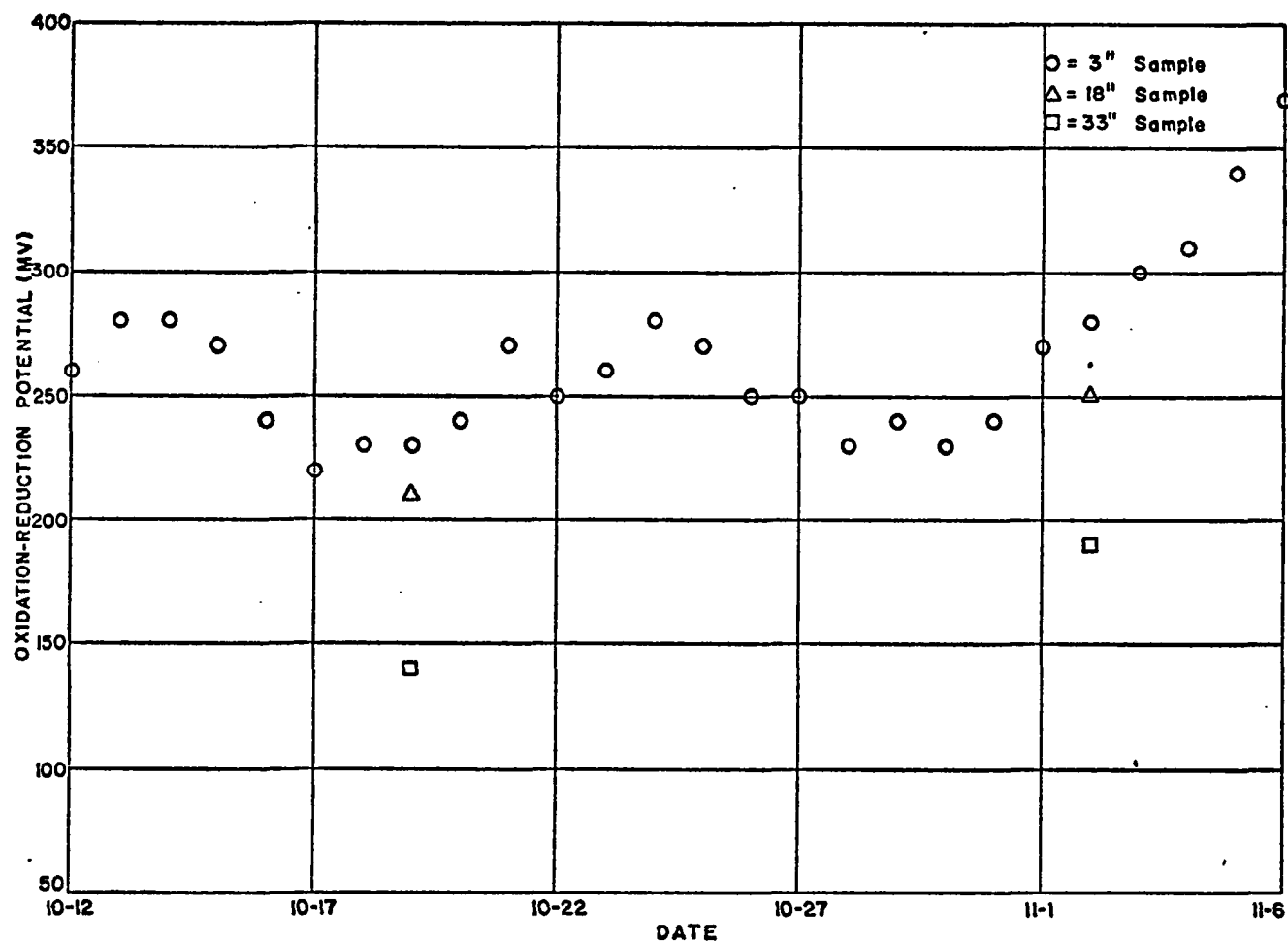


Figure IV-11: Oxidation Reduction Potential of Tank 2 During Acclimation Phase (Cell A-B)

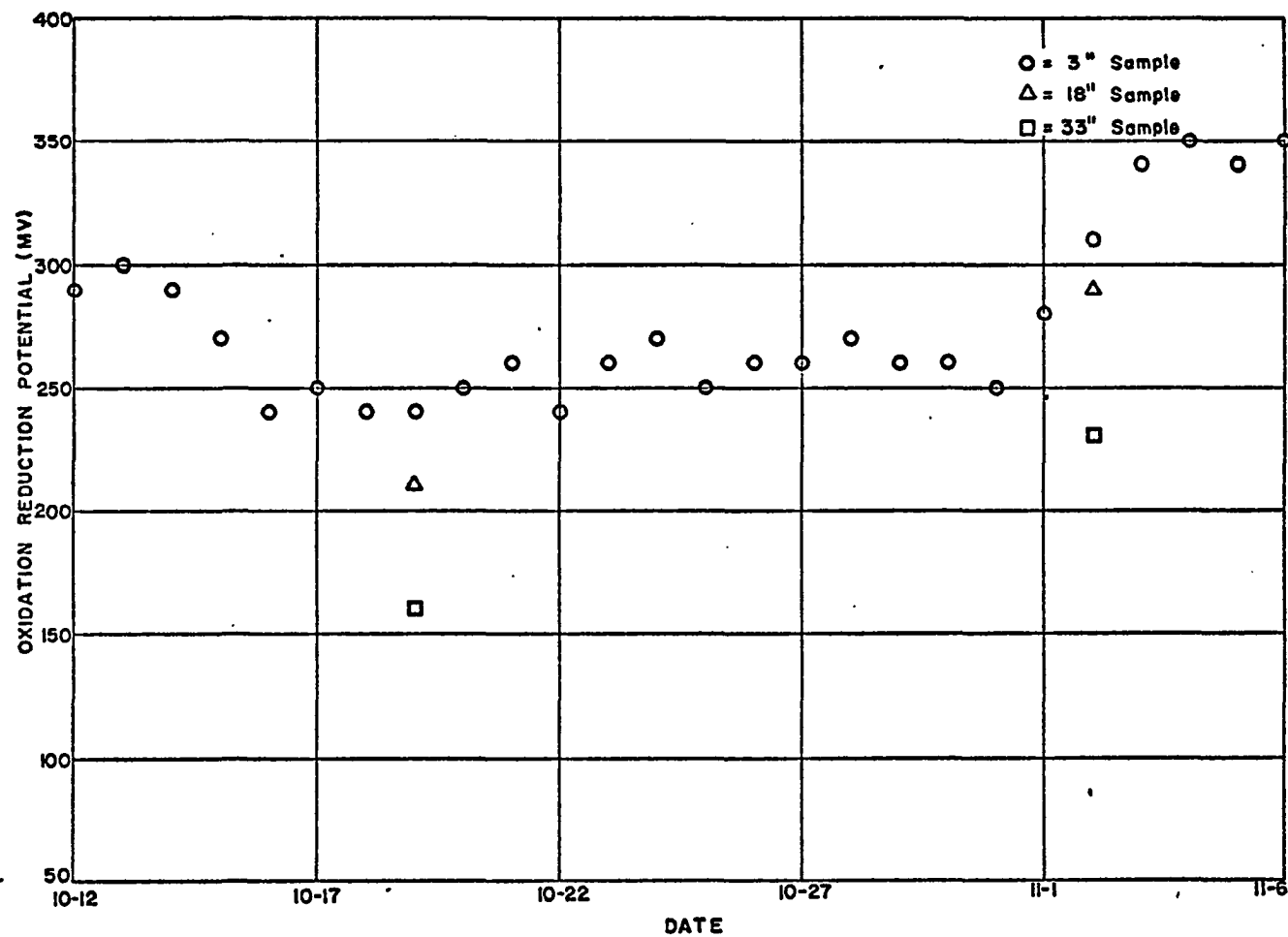


Figure IV-12: Oxidation Reduction Potential of Tank 3 During Acclimation Phase (Cell A-B)

also generally followed the changes in dissolved oxygen concentration during the last four weeks of this period. The redox potential measurements on October 19 and November 2 indicate oxidizing conditions existed throughout the water column at the start of the experimental phase. Similar results were obtained for Cell C-D for each tank for both pH and redox potential.

The temperature of Tank 1 Cell C-D during the acclimation phase is shown in Figure IV-13. The temperature in each of the other cells of each tank showed similar changes with no cell having a temperature more than 1.5°C greater or less than that shown in Figure IV-13. During most of the acclimation phase the temperature was between 20-30°C which is optimum for algal growth and productivity.

The total phosphorus and orthophosphate concentrations (range and average) found in each cell is shown in Table IV-8. Generally, Tank 1 had slightly lower total phosphorus levels in the tanks remained relatively constant throughout the acclimation phase. A higher percentage of the phosphorus was in the orthophosphate form in Cell C-D of each tank and phosphorus levels were higher in Cell A-B than in Cell C-D as is commonly reported from field studies of waste stabilization ponds.

#### Operational Phase Correlation Analysis

The two parts of the correlation and regression analysis during the operational phase are those measurements taken on a daily or twice daily basis and those measurements taken during the materials balance efforts. The data obtained over time and the resulting correlation analysis of each of these parts is described in the following. The analysis applied to the data in this section includes Pearson Correlations

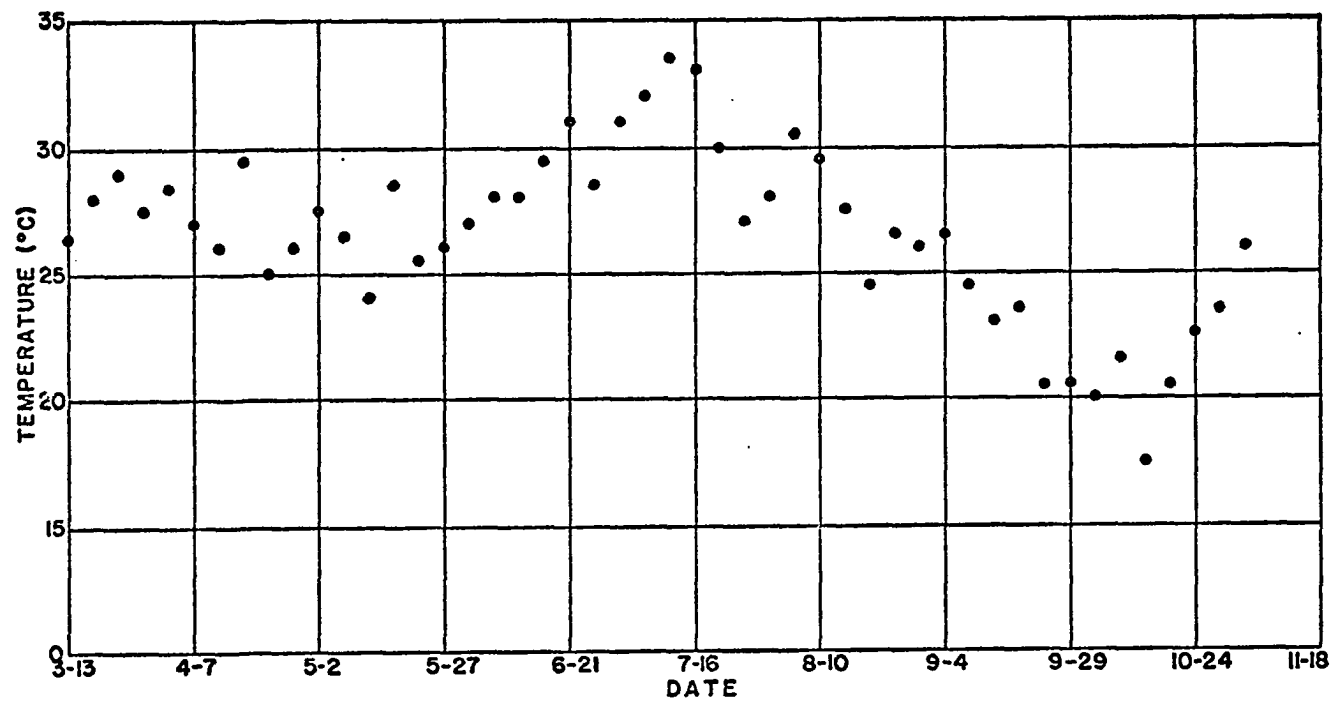


Figure IV-13: Temperature of Tank 1 During Acclimation Phase (Cell C-D)

Table IV-8: Total Phosphorus and Orthophosphate Concentration Measured During Acclimation Phase (mg/l)

|   |         | Tank 1    |          | Tank 2    |          | Tank 3    |          |
|---|---------|-----------|----------|-----------|----------|-----------|----------|
| Parameter   |         | Cell A-B  | Cell C-D | Cell A-B  | Cell C-D | Cell A-B  | Cell C-D |
| Total Phosphorus  | Range   | 10.2-15.1 | 8.7-10.3 | 11.1-15.0 | 8.2-9.8  | 10.9-15.4 | 8.4-10.4 |
|   | Average | 12.4      | 9.2      | 12.8      | 9.0      | 12.6      | 9.2      |
| Orthophosphate  | Range   | 4.9-10.4  | 3.7-8.2  | 5.5-9.8   | 3.4-7.8  | 5.6-10.0  | 3.6-8.7  |
|   | Average | 7.4       | 6.1      | 7.7       | 6.4      | 7.8       | 6.5      |
| Average Orthophosphate as a Percent of Average Total Phosphorus |         | 60.2      | 66.1     | 60.1      | 70.9     | 61.9      | 70.7     |



in the Statistical Package for the Social Sciences. Tests of significance were two-tailed because both positive and negative correlations were considered important.

#### Correlation of Daily Data

The correlation of each of the parameters with the time measured on a daily basis are shown in Table IV-9. The pH, temperature, orthophosphate of the water, total phosphorus of the water and radiophosphorus concentration of the water all generally decreased slightly with time. There was no significant correlation between the dissolved oxygen content of the tanks and time. The redox potential decreased with time significantly in Tank 2 Cell C-D and Tank 3 Cell A-B.

The dissolved oxygen concentration in each tank was about 8.0 mg/l and declined to near 0.0 mg/l after about 14 days. The dissolved oxygen then increased to above the initial level under lighted conditions after about 23 days. After about 32 days the dissolved oxygen levels in all tanks declined to about 0.0 mg/l under darkened conditions and rose to above 10.0 mg/l by about the 39th day under lighted conditions. Similar variations in pH between 7 and 10 units, and redox potential between 100 and 410 mv were also noted. The radiophosphorus concentration (decay corrected) in the bulk water surface declined throughout the operational phase due to loss in the effluent and to the walls, sediment, and deeper water.

The correlation coefficients of the parameters measured on a daily basis during the operational phase are given in Tables IV-10 through IV-15. Dissolved oxygen varied significantly as the pH and redox potential varied in each cell. Less significant and more variable

Table IV-9: Correlation Coefficients of Hours with Parameters in Center of Each Cell at a Depth of 3 Inches for Measurements Taken Daily (with Significance)

| PARAMETER                    | LOCATION OF SAMPLE    |                       |                       |                       |                       |                       |
|------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                              | Tank 1<br>Cell A-B    | Tank 1<br>Cell C-D    | Tank 2<br>Cell A-B    | Tank 2<br>Cell C-D    | Tank 3<br>Cell A-B    | Tank 3<br>Cell C-D    |
| Dissolved oxygen             | -0.23212<br>(0.02407) | -0.23159<br>(0.02434) | -0.25258<br>(0.01555) | -0.24650<br>(0.01776) | -0.22239<br>(0.02931) | -0.22244<br>(0.02928) |
| pH                           | -0.39108<br>(0.00031) | -0.36416<br>(0.00077) | -0.36302<br>(0.00080) | -0.34399<br>(0.00144) | -0.33950<br>(0.00165) | -0.35908<br>(0.00090) |
| Temperature                  | -0.51412<br>(0.00000) | -0.49751<br>(0.00000) | -0.54698<br>(0.00000) | -0.61792<br>(0.00000) | -0.56537<br>(0.00000) | -0.42229<br>(0.00010) |
| Redox potential              | -0.21256<br>(0.03550) | -0.33261<br>(0.00202) | -0.29798<br>(0.00523) | -0.43762<br>(0.00005) | -0.45050<br>(0.00003) | -0.23003<br>(0.02513) |
| Orthophosphate<br>of water   | -0.78878<br>(.000000) | -0.70187<br>(0.00000) | -0.78080<br>(0.00000) | -0.78721<br>(0.00000) | -9.75419<br>(0.00000) | -0.60417<br>(0.00000) |
| Total phosphorus<br>of water | -0.91489<br>(0.00000) | -0.81026<br>(0.00000) | -0.88627<br>(0.00000) | -0.81347<br>(0.00000) | -0.86151<br>(0.00000) | -0.34661<br>(0.00133) |
| Phosphorus - 32<br>of water  | -0.91978<br>(0.00000) | -0.90958<br>(0.00000) | -0.76825<br>(0.00000) | -0.72436<br>(0.00000) | -0.74168<br>(0.00000) | -0.56493<br>(0.00000) |

Table IV-10: Correlation Coefficients for Parameters Measured Daily for Tank 1,  
Cell A-B, Depth 3 Inches (73 Samples)

| Parameters  | Dissolved<br>Oxygen<br>(mg/l) | Temperature<br>(°C) | pH                 | Redox<br>Potential<br>(mv) | Orthophosphate<br>Concentration<br>(mg/l) | Total<br>Phosphorus<br>Concentration | P-32 Content<br>of the Bulk<br>Water-Decay<br>Corrected<br>(Avg.cpm) |
|---|-------------------------------|---------------------|--------------------|----------------------------|---|--------------------------------------|--|
| Dissolved<br>Oxygen<br>(mg/l)                                       | -                             | -0.2907<br>P=0.006  | 0.9501<br>P=0.000  | 0.9403<br>P=0.000          | 0.3556<br>P=0.001                         | 0.2633<br>P=0.012                    | 0.3251<br>P=0.003  |
| Tempera-<br>ture (°C)   |                               | -                   | -0.2106<br>P=0.037 | -0.3112<br>P=0.004         | 0.3772<br>P=0.001                         | 0.4537<br>P=0.000                    | 0.4264<br>P=0.000  |
| pH  |                               |                     | -                  | 0.9430<br>P=0.000          | 0.4872<br>P=0.000                         | 0.3797<br>P=0.000                    | 0.4750<br>P=0.002  |
| Redox<br>Potential  |                               |                     |                    | -                          | 0.3676<br>P=0.001                         | 0.2240<br>P=0.028                    | 0.3258<br>P=0.002  |
| Orthophos-<br>phate Con-<br>centration<br>(mg/l)                    |                               |                     |                    |                            | -   | 0.8339<br>P=0.000                    | 0.7604<br>P=0.000  |
| Total Phospho-<br>rus Concentra-<br>tion (mg/l)                     |                               |                     |                    |                            |   | -                                    | 0.8003<br>P=0.000  |
| P-32 Content<br>of the Bulk<br>Water Decay Cor-<br>rected (Avg.cpm) |                               |                     |                    |                            |   |                                      | -  |

Table IV-11: Correlation Coefficients for Parameters Measured Daily for Tank 1,  
Cell C-D, Depth 3 Inches (73 Samples)

| Parameters  | Dissolved<br>Oxygen<br>(mg/l) | Temperature<br>(°C) | pH                 | Redox<br>Potential<br>(mv) | Orthophosphate<br>Concentration<br>(mg/l) | Total<br>Phosphorus<br>Concentration | P-32 Content<br>of the Bulk<br>Water-Decay<br>Corrected<br>(Avg.cpm) |
|---|-------------------------------|---------------------|--------------------|----------------------------|---|--------------------------------------|--|
| Dissolved<br>Oxygen<br>(mg/l)                                       | -                             | -0.4069<br>P=0.000  | 0.9491<br>P=0.000  | 0.9070<br>P=0.000          | 0.3595<br>P=0.001                         | 0.4374<br>P=0.000                    | 0.2062<br>P=0.040  |
| Tempera-<br>ture (°C)   |                               | -                   | -0.3457<br>P=0.001 | -0.4152<br>P=0.000         | 0.2602<br>P=0.013                         | 0.2023<br>P=0.043                    | 0.4234<br>P=0.000  |
| pH  |                               |                     | -                  | 0.9536<br>P=0.000          | 0.3856<br>P=0.000                         | 0.5238<br>P=0.000                    | 0.3010<br>P=0.005  |
| Redox<br>Potential  |                               |                     |                    | -                          | 0.3498<br>P=0.001                         | 0.5402<br>P=0.000                    | 0.2817<br>P=0.008  |
| Orthophos-<br>phate Con-<br>centration<br>(mg/l)                    |                               |                     |                    |                            | -   | 0.7304<br>P=0.000                    | 0.5651<br>P=0.000  |
| Total Phospho-<br>rus Concentra-<br>tion (mg/l)                     |                               |                     |                    |                            |   | -                                    | 0.7114<br>P=0.000  |
| P-32 Content<br>of the Bulk<br>Water Decay Cor-<br>rected (Avg.cpm) |                               |                     |                    |                            |   |                                      | -  |

Table IV-12: Correlation Coefficients for Parameters Measured Daily for Tank 2,  
Cell A-B, Depth 3 Inches (73 Samples)

| Parameters  | Dissolved<br>Oxygen<br>(mg/l) | Temperature<br>(°C) | pH                 | Redox<br>Potential<br>(mv) | Orthophosphate<br>Concentration<br>(mg/l) | Total<br>Phosphorus<br>Concentration | P-32 Content<br>of the Bulk<br>Water-Decay<br>Corrected<br>(Avg.cpm) |
|---|-------------------------------|---------------------|--------------------|----------------------------|---|--------------------------------------|--|
| Dissolved<br>Oxygen<br>(mg/l)                                       | -                             | -0.3446<br>P=0.001  | 0.9641<br>P=0.000  | 0.9228<br>P=0.000          | 0.2447<br>P=0.018                         | 0.2003<br>P=0.045                    | 0.3535<br>P=0.001  |
| Tempera-<br>ture (°C)   |                               | -                   | -0.2889<br>P=0.007 | -0.3336<br>P=0.002         | 0.3800<br>P=0.000                         | 0.5500<br>P=0.000                    | 0.3385<br>P=0.002  |
| pH  |                               |                     | -                  | 0.9655<br>P=0.000          | 0.2558<br>P=0.014                         | 0.2434<br>P=0.019                    | 0.4487<br>P=0.000  |
| Redox<br>Potential  |                               |                     |                    | -                          | 0.1847<br>P=0.059                         | 0.1794<br>P=0.064                    | 0.3805<br>P=0.000  |
| Orthosphos-<br>phate Con-<br>centration<br>(mg/l)                   |                               |                     |                    |                            | -   | 0.8377<br>P=0.000                    | 0.5282<br>P=0.000  |
| Total Phospho-<br>rus Concentra-<br>tion (mg/l)                     |                               |                     |                    |                            |   | -                                    | 0.5388<br>P=0.000  |
| P-32 Content<br>of the Bulk<br>Water Decay Cor-<br>rected (Avg.cpm) |                               |                     |                    |                            |   |                                      | -  |

Table IV-13: Correlation Coefficients for Parameters Measured Daily for Tank 2,  
Cell C-D, Depth 3 Inches (73 Samples)

| Parameters  | Dissolved<br>Oxygen<br>(mg/l) | Temperature<br>(°C) | pH                 | Redox<br>Potential<br>(mv.) | Orthophosphate<br>Concentration<br>(mg/l) | Total<br>Phosphorus<br>Concentration | P-32 Content<br>of the Bulk<br>Water-Decay<br>Corrected<br>(Avg.cpm) |
|---|-------------------------------|---------------------|--------------------|-----------------------------|---|--------------------------------------|--|
| Dissolved<br>Oxygen<br>(mg/l)                                       | -                             | -0.2134<br>P=0.035  | 0.9694<br>P=0.000  | 0.8681<br>P=0.000           | -0.0495<br>P=0.339                        | 0.2177<br>P=0.032                    | -0.0628<br>P=0.299   |
| Tempera-<br>ture (°C)   |                               | -                   | -0.1890<br>P=0.055 | -0.0435<br>P=0.357          | 0.4781<br>P=0.000                         | 0.3621<br>P=0.001                    | 0.5146<br>P=0.000  |
| pH  |                               |                     | -                  | 0.9188<br>P=0.000           | 0.0401<br>P=0.368                         | 0.3678<br>P=0.001                    | 0.0081<br>P=0.473  |
| Redox<br>Potential  |                               |                     |                    | -                           | 0.1714<br>P=0.073                         | 0.4627<br>P=0.000                    | 0.1647<br>P=0.082  |
| Orthophos-<br>phate Con-<br>centration<br>(mg/l)                    |                               |                     |                    |                             | -   | 0.6750<br>P=0.000                    | 0.8567<br>P=0.000  |
| Total Phospho-<br>rus Concentra-<br>tion (mg/l)                     |                               |                     |                    |                             |   | -                                    | 0.6026<br>P=0.000  |
| P-32 Content<br>of the Bulk<br>Water Decay Cor-<br>rected (Avg.cpm) |                               |                     |                    |                             |   |                                      | -  |

Table IV-14: Correlation Coefficients for Parameters Measured Daily for Tank 3,  
Cell A-B, Depth 3 Inches. (73 Samples)

| Parameters   | Dissolved<br>Oxygen<br>(mg/l) | Temperature<br>(°C) | pH                 | Redox<br>Potential<br>(mv) | Orthophosphate<br>Concentration<br>(mg/l) | Total<br>Phosphorus<br>Concentration | P-32 Content<br>of the Bulk<br>Water-Decay<br>Corrected<br>(Avg. cpm) |
|--|-------------------------------|---------------------|--------------------|----------------------------|---|--------------------------------------|---|
| Dissolved<br>Oxygen<br>(mg/l)  | -                             | -0.3984<br>P=0.000  | 0.9519<br>P=0.000  | 0.8199<br>P=0.000          | 0.2688<br>P=0.011                         | 0.3718<br>P=0.001                    | 0.3212<br>P=0.003   |
| Tempera-<br>ture (°C)  |                               | -                   | -0.3012<br>P=0.005 | -0.2457<br>P=0.018         | 0.4137<br>P=0.000                         | -0.3679<br>P=0.001                   | 0.3551<br>P=0.001   |
| pH   |                               |                     | -                  | 0.9090<br>P=0.000          | 0.2714<br>P=0.010                         | 0.4109<br>P=0.000                    | 0.4187<br>P=0.000   |
| Redox<br>Potential   |                               |                     |                    | -                          | 0.2409<br>P=0.020                         | 0.3951<br>P=0.000                    | 0.3614<br>P=0.001   |
| Orthophos-<br>phate Con-<br>centration<br>(mg/l)                     |                               |                     |                    |                            | -   | 0.8420<br>P=0.000                    | 0.6708<br>P=0.000   |
| Total Phospho-<br>rus Concentra-<br>tion (mg/l)                      |                               |                     |                    |                            |   | -                                    | 0.7336<br>P=0.000   |
| P-32 Content<br>of the Bulk<br>Water Decay Cor-<br>rected (Avg. cpm) |                               |                     |                    |                            |   |                                      | -   |

Table IV-15: Correlation Coefficients for Parameters Measured Daily for Tank 3,  
Cell C-D, Depth 3 Inches (73 Samples)

| Parameters  | Dissolved<br>Oxygen<br>(mg/l) | Temperature<br>(°C) | pH                 | Redox<br>Potential<br>(mv) | Orthophosphate<br>Concentration<br>(mg/l) | Total<br>Phosphorus<br>Concentration | P-32 Content<br>of the Bulk<br>Water-Decay<br>Corrected<br>(Avg.cpm) |
|---|-------------------------------|---------------------|--------------------|----------------------------|---|--------------------------------------|--|
| Dissolved<br>Oxygen<br>(mg/l)                                       | -                             | -0.4497<br>P=0.000  | 0.9474<br>P=0.000  | 0.8841<br>P=0.000          | 0.0447<br>P=0.354                         | -0.0163<br>P=0.446                   | -0.1180<br>P=0.160   |
| Tempera-<br>ture (°C)   |                               | -                   | -0.3502<br>P=0.001 | -0.3075<br>P=0.004         | 0.4950<br>P=0.000                         | 0.3612<br>P=0.001                    | 0.3744<br>P=0.001  |
| pH  |                               |                     | -                  | 0.8990<br>P=0.000          | 0.1767<br>P=0.067                         | 0.0792<br>P=0.253                    | -0.0162<br>P=0.446   |
| Redox<br>Potential  |                               |                     |                    | -                          | 0.2488<br>P=0.017                         | 0.2340<br>P=0.023                    | -0.0660<br>P=0.290   |
| Orthophos-<br>phate Con-<br>centration<br>(mg/l)                    |                               |                     |                    |                            | -   | 0.7916<br>P=0.000                    | 0.3438<br>P=0.001  |
| Total Phospho-<br>rus Concentra-<br>tion (mg/l)                     |                               |                     |                    |                            |   | -                                    | 0.3544<br>P=0.001  |
| P-32 Content<br>of the Bulk<br>Water Decay Cor-<br>rected (Avg.cpm) |                               |                     |                    |                            |   |                                      | -  |



relationships occurred between dissolved oxygen and temperature, orthophosphate, total phosphorus, and radiophosphorus concentration in the bulk water. The absolute values of the correlation coefficient for temperature with the other parameters were generally not consistently above 0.5. The pH of all samples varied as the dissolved oxygen and redox potential and varied much less consistently with the other parameters.

The orthophosphate generally varied as the total phosphorus and radiophosphorus concentration of the bulk water with all  $r$  values ranging from 0.6750 to 0.8420 and 0.3438 to 0.8576, respectively. The correlation coefficients for total phosphorus and radiophosphorus concentration ranged from 0.3544 to 0.8003.

Of particular note in Table IV-10 through IV-15 is the correlation of total phosphorus and orthophosphate concentration with the decay corrected radiophosphorus concentration of the bulk water. For both cells of Tank 1 and Tank 2 the correlations are significant for both cells but less in Cell C-D ( $r$  values are approximately 0.35 with a significant positive relationship between changes in total phosphorus and orthophosphate concentrations and radiophosphorus concentration of the bulk water).

#### Correlation of Materials Balance Efforts Data

For the eight materials balance efforts intensive sampling was conducted at depths of 3 inches, 18 inches and 33 inches at four locations in each tank for dissolved oxygen, pH, temperature, redox potential, orthophosphate and total phosphorus concentration of the water, and radiophosphorus concentration. In addition, at each of these locations the

external walls, baffle walls, and the sediment were sampled for radiophosphorus content. Thus, ten parameters were sampled at twelve locations in each tank at the eight materials balance efforts.

The correlation coefficients of each of the ten parameters measured with time are given in Table IV-16, IV-17, and IV-18. Dissolved oxygen, pH, and redox potential did not vary regularly or significantly with time. Instead, these parameters declined under darkened conditions and increased under lighted conditions as described earlier. The temperature decreased with time in all tanks but this decrease was generally not statistically significant at the 95% level indicating variation of temperature with time at all three depths.

The orthophosphate and total phosphorus did decrease significantly with time (at a 95% confidence level) in most sampling locations at a depth of 3 inches. However, at depths of 18 inches and 33 inches the change in the concentration of these parameters was highly variable with no consistent trend over time. The decay corrected radiophosphorus concentration in the bulk water decreased with time at all locations in the top except Tank 3 Cell A. However, at 18 inches and 33 inches depth the relationship with time was much more variable as well be discussed below in the materials balance measurements. Radiophosphorus in the exterior walls, baffle and sediment of each tank was also highly variable over time at all three depths measured.

Correlations of the parameters measured during the materials balance efforts are given in Tables IV-19 through IV-30 for Tank 1, Tables IV-31 through IV-42 for Tank 2 and Tables IV-43 through IV-54 for Tank 3. In all tanks at all depths there were significant correlations (at the

Table IV-16: Correlation Coefficients of Hours with Parameters at Depth Top (3") for Materials Balance Measurements (with Significance)

| Parameter                       | LOCATION OF SAMPLE    |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |
|---------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                                 | Tank 1<br>Loc A       | Tank 1<br>Loc B       | Tank 1<br>Loc C       | Tank 1<br>Loc D       | Tank 2<br>Loc A       | Tank 2<br>Loc B       | Tank 2<br>Loc C       | Tank 2<br>Loc D       | Tank 3<br>Loc A       | Tank 3<br>Loc B       | Tank 3<br>Loc C       | Tank 3<br>Loc D       |
| Dissolved oxygen                | -0.13098<br>(0.3786)  | -0.13876<br>(0.37157) | -0.13969<br>(0.37074) | -0.12932<br>(0.38010) | -0.15200<br>(0.35968) | -0.14937<br>(0.36204) | -0.14279<br>(0.36794) | -0.14279<br>(0.36545) | -0.13155<br>(0.37809) | -0.13752<br>(0.37269) | -0.12664<br>(0.38254) | -0.13245<br>(0.37727) |
| pH                              | -0.33863<br>(0.20597) | -0.34589<br>(0.20067) | -0.34374<br>(0.20223) | -0.25853<br>(0.26821) | -0.34394<br>(0.20208) | -0.32311<br>(0.21751) | -0.32231<br>(0.21811) | -0.30827<br>(0.22879) | -0.29644<br>(0.23794) | -0.28753<br>(0.24493) | -0.32401<br>(0.21683) | -0.32371<br>(0.21705) |
| Temperature                     | -0.59684<br>(0.05914) | -0.60236<br>(0.05702) | -0.51016<br>(0.09823) | -0.57449<br>(0.06818) | -0.56028<br>(0.07431) | -0.60298<br>(0.05678) | -0.66317<br>(0.03651) | -0.63419<br>(0.04553) | -0.67602<br>(0.03285) | -0.54687<br>(0.08036) | -0.55222<br>(0.07792) | -0.54091<br>(0.08313) |
| Redox Potential                 | -0.01916<br>(0.48204) | -0.06849<br>(0.43599) | -0.22954<br>(0.29255) | -0.21424<br>(0.30521) | -0.12479<br>(0.38422) | -0.14754<br>(0.35358) | -0.45171<br>(0.13060) | -0.36993<br>(0.18353) | -0.42427<br>(0.14740) | -0.45424<br>(0.12910) | -0.12906<br>(0.38034) | -0.12950<br>(0.37994) |
| Orthophosphate of water         | -0.72029<br>(0.02194) | -0.32190<br>(0.21842) | -0.77385<br>(0.01212) | -0.43970<br>(0.08360) | -0.75009<br>(0.01605) | -0.68978<br>(0.02917) | -0.65042<br>(0.04038) | -0.80836<br>(0.00748) | -0.47265<br>(0.11846) | -0.64887<br>(0.04087) | -0.35393<br>(0.19486) | -0.47749<br>(0.11574) |
| Total phosphorus of water       | -0.85187<br>(0.00362) | -0.90444<br>(0.00101) | -0.62742<br>(0.04793) | -0.78820<br>(0.01007) | -0.77366<br>(0.01214) | -0.94699<br>(0.00018) | -0.49179<br>(0.10789) | -0.59978<br>(0.04801) | -0.90008<br>(0.00116) | -0.85249<br>(0.00358) | -0.00950<br>(0.49109) | -0.24127<br>(0.28243) |
| Phosphorus -32 of water         | -0.87001<br>(0.00248) | -0.98243<br>(0.00001) | -0.98021<br>(0.00001) | -0.97338<br>(0.00002) | -0.67910<br>(0.03200) | -0.73896<br>(0.01811) | -0.74226<br>(0.01748) | -0.97262<br>(0.00003) | -0.34655<br>(0.20019) | -0.90509<br>(0.00099) | -0.94391<br>(0.00021) | -0.81805<br>(0.00654) |
| Phosphorus -32 of exterior wall | -0.01314<br>(0.48768) | 0.14611<br>(0.36496)  | 0.11646<br>(0.39180)  | 0.44859<br>(0.13246)  | 0.19384<br>(0.32277)  | -0.32297<br>(0.21761) | -0.34615<br>(0.20048) | 0.28079<br>(0.25027)  | -0.22315<br>(0.29764) | 0.04476<br>(0.45809)  | -0.29650<br>(0.23790) | -0.25469<br>(0.27135) |
| Phosphorus -32 of baffle        | -0.35481<br>(0.19423) | -0.42378<br>(0.14771) | 0.38739<br>(0.17152)  | 0.76352<br>(0.01374)  | 0.19808<br>(0.31910)  | 0.82872<br>(0.00550)  | 0.43379<br>(0.14146)  | 0.71079<br>(0.02405)  | 0.42884<br>(0.14453)  | 0.56072<br>(0.07412)  | 0.72903<br>(0.02009)  | 0.05746<br>(0.44625)  |
| Phosphorus -32 of sediment      | -0.93898<br>(0.00027) | -0.82247<br>(0.00610) | -0.76793<br>(0.01303) | -0.87731<br>(0.00210) | -0.22008<br>(0.30024) | -0.88192<br>(0.00188) | -0.56099<br>(0.07400) | -0.62360<br>(0.04926) | 0.11282<br>(0.39513)  | -0.83269<br>(0.00514) | -0.50550<br>(0.10064) | -0.89976<br>(0.00117) |

Table IV-17: Correlation Coefficients of Hours with Parameters at Depth Middle (18") for Materials Balance Measurements (with Significance)

| PARAMETER                       | LOCATION OF SAMPLE    |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |
|---------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                                 | Tank 1<br>Loc A       | Tank 1<br>Loc B       | Tank 1<br>Loc C       | Tank 1<br>Loc D       | Tank 2<br>Loc A       | Tank 2<br>Loc B       | Tank 2<br>Loc C       | Tank 2<br>Loc D       | Tank 3<br>Loc A       | Tank 3<br>Loc B       | Tank 3<br>Loc C       | Tank 3<br>Loc D       |
| Dissolved oxygen                | -0.12055<br>(0.38807) | -0.13459<br>(0.37534) | -0.12734<br>(0.38190) | -0.11858<br>(0.38987) | -0.15128<br>(0.36032) | -0.14680<br>(0.36434) | -0.14753<br>(0.36369) | -0.14321<br>(0.36756) | -0.13375<br>(0.37610) | -0.14213<br>(0.36854) | -0.13412<br>(0.37576) | -0.11921<br>(0.38929) |
| pH                              | -0.34094<br>(0.20428) | -0.31884<br>(0.22073) | -0.37001<br>(0.18348) | -0.27792<br>(0.25256) | -0.39353<br>(0.16732) | -0.36642<br>(0.18599) | -0.37088<br>(0.18287) | -0.33494<br>(0.20869) | -0.34411<br>(0.20196) | -0.30180<br>(0.23377) | -0.27774<br>(0.25270) | -0.30073<br>(0.23461) |
| Temperature                     | -0.51749<br>(0.09451) | -0.39688<br>(0.16515) | -0.47067<br>(0.11958) | -0.52472<br>(0.09091) | -0.60449<br>(0.05621) | -0.62277<br>(0.04955) | -0.66646<br>(0.03555) | -0.65648<br>(0.03851) | -0.57979<br>(0.06598) | -0.69255<br>(0.02847) | -0.63604<br>(0.04501) | -0.56641<br>(0.07163) |
| Redox Potential                 | -0.26838<br>(0.26022) | -0.22702<br>(0.29437) | -0.33940<br>(0.20540) | -0.22561<br>(0.29556) | -0.35267<br>(0.19576) | -0.14020<br>(0.37028) | -0.42592<br>(0.14636) | -0.34295<br>(0.20281) | -0.55477<br>(0.07676) | -0.48575<br>(0.11117) | -0.18042<br>(0.33440) | -0.23615<br>(0.28670) |
| Orthophosphate of water         | -0.20479<br>(0.31331) | -9.64611<br>(0.04174) | 0.29151<br>(0.24179)  | 0.28015<br>(0.25078)  | -0.63498<br>(0.04537) | -0.44129<br>(0.13687) | -0.90515<br>(0.00099) | -0.15842<br>(0.35395) | -0.57146<br>(0.06947) | -0.66739<br>(0.03529) | -0.56919<br>(0.07044) | -0.84040<br>(0.00449) |
| Total phosphorus of water       | -0.69970<br>(0.02669) | -0.87783<br>(0.00208) | -0.84557<br>(0.00409) | -0.79531<br>(0.00914) | -0.52144<br>(0.09253) | -0.16483<br>(0.34825) | -0.87061<br>(0.00245) | 0.02924<br>(0.03808)  | -0.65791<br>(0.05891) | -0.57276<br>(0.06891) | 0.28787<br>(0.24455)  | -0.82561<br>(0.00579) |
| Phosphorus -32 of water         | -0.81806<br>(0.00654) | -0.86885<br>(0.00255) | -0.87053<br>(0.00246) | -0.40900<br>(0.15718) | -0.89507<br>(0.00133) | -0.69850<br>(0.06300) | -0.58708<br>(0.02698) | -0.69850<br>(0.07442) | -0.84774<br>(0.00392) | -0.46461<br>(0.12305) | -0.73126<br>(0.01963) | -0.34285<br>(0.20288) |
| Phosphorus -32 of exterior wall | -0.85087<br>(0.00370) | 0.90066<br>(0.00114)  | 0.44774<br>(0.13297)  | 0.29116<br>(0.24207)  | 0.51343<br>(0.09656)  | 0.00855<br>(0.49198)  | 0.53312<br>(0.08683)  | -0.30228<br>(0.23340) | -0.40011<br>(0.16301) | -0.04955<br>(0.45362) | 0.06378<br>(0.44032)  | 0.55174<br>(0.07813)  |
| Phosphorus -32 of baffle        | -0.17027<br>(0.34343) | -0.72827<br>(0.02024) | 0.69382<br>(0.02814)  | 0.63131<br>(0.04660)  | 0.30590<br>(0.23061)  | 0.04176<br>(0.46089)  | 0.79913<br>(0.00867)  | 0.52415<br>(0.09119)  | 0.55330<br>(0.97742)  | -0.33475<br>(0.20882) | 0.41471<br>(0.15998)  | -0.42007<br>(0.15006) |
| Phosphorus -32 of sediment      | -0.93888<br>(0.00027) | -0.82247<br>(0.00610) | -0.76793<br>(0.01303) | -0.87731<br>(0.00210) | -0.22008<br>(0.30024) | -0.88192<br>(0.00188) | -0.56009<br>(0.07400) | -0.62360<br>(0.04926) | 0.11954<br>(0.38900)  | -0.83269<br>(0.00514) | -0.50550<br>(0.10064) | -0.89976<br>(0.00117) |

Table IV-18: Correlation Coefficients of Hours with Parameters at Depth 33" (Bottom) for Materials Balance Measurements (with Significance)

| Parameter                      | Location of Sample    |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |
|--------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|                                | Tank 1<br>Loc A       | Tank 1<br>Loc B       | Tank 1<br>Loc C       | Tank 1<br>Loc D       | Tank 2<br>Loc A       | Tank 2<br>Loc B       | Tank 2<br>Loc C       | Tank 2<br>Loc D       | Tank 3<br>Loc A       | Tank 3<br>Loc B       | Tank 3<br>Loc C       | Tank 3<br>Loc D       |
| Dissolved Oxygen               | -0.10260<br>(0.40504) | -0.09002<br>(0.41606) | -0.12347<br>(0.38541) | -0.11705<br>(0.38541) | -0.14975<br>(0.36169) | -0.16024<br>(0.35232) | -0.15304<br>(0.35875) | -0.16925<br>(0.34434) | -0.12130<br>(0.38739) | -0.11734<br>(0.39100) | -0.12644<br>(0.38272) | -0.13061<br>(0.37694) |
| pH                             | -0.35850<br>(0.19131) | -0.34270<br>(0.20299) | -0.33839<br>(0.20615) | -0.32423<br>(0.21667) | -0.40637<br>(0.15759) | -0.37775<br>(0.17911) | -0.35575<br>(0.19355) | -0.35188<br>(0.19633) | -0.36551<br>(0.18663) | -0.33210<br>(0.21079) | -0.26783<br>(0.26046) | -0.24679<br>(0.27420) |
| Temperature                    | -0.49208<br>(0.10774) | -0.40234<br>(0.16154) | -0.50852<br>(0.09907) | -0.72188<br>(0.02159) | -0.51352<br>(0.09652) | -0.61482<br>(0.05095) | -0.62511<br>(0.04873) | -0.55136<br>(0.07830) | -0.52177<br>(0.09237) | -0.55366<br>(0.07727) | -0.58045<br>(0.06570) | -0.45563<br>(0.13160) |
| Redox Potential                | -0.35561<br>(0.19365) | -0.29724<br>(0.23732) | -0.38623<br>(0.17231) | -0.40784<br>(0.15794) | -0.52523<br>(0.09066) | -0.30321<br>(0.23268) | -0.47021<br>(0.11945) | -0.49926<br>(0.10391) | -0.35771<br>(0.19216) | -0.22170<br>(0.29686) | -0.14369<br>(0.36713) | -0.24556<br>(0.23563) |
| Orthophosphate of Water        | -0.73671<br>(0.01894) | -0.63323<br>(0.04595) | -0.66375<br>(0.03634) | -0.41070<br>(0.15607) | -0.51231<br>(0.09713) | -0.81136<br>(0.00725) | -0.47770<br>(0.11562) | -0.46519<br>(0.12271) | 0.16503<br>(0.34807)  | -0.78998<br>(0.00983) | -0.12339<br>(0.36549) | -0.12521<br>(0.38384) |
| Total Phosphorus of Water      | -0.49134<br>(0.10213) | -0.82236<br>(0.00611) | -0.71827<br>(0.02238) | 0.39310<br>(0.16767)  | -0.53499<br>(0.08593) | 0.05097<br>(0.41518)  | -0.73131<br>(0.01962) | -0.27639<br>(0.25377) | 0.30830<br>(0.22676)  | -0.32592<br>(0.21241) | -0.11804<br>(0.33036) | -0.55402<br>(0.44946) |
| Phosphorus-32 of Water         | 0.54756<br>(0.07912)  | -0.43873<br>(0.13842) | -0.29561<br>(0.23857) | -0.63896<br>(0.04405) | -0.24727<br>(0.27746) | -0.37683<br>(0.18290) | 0.04845<br>(0.45465)  | -0.31648<br>(0.22252) | -0.18292<br>(0.33230) | 0.25310<br>(0.27766)  | 0.44518<br>(0.11137)  | -0.76836<br>(0.43611) |
| Phosphorus-32 of Exterior Wall | 0.30882<br>(0.22836)  | -0.13059<br>(0.37868) | 0.40965<br>(0.15676)  | -0.83255<br>(0.00516) | -0.37770<br>(0.42745) | -0.17071<br>(0.34304) | -0.62609<br>(0.04839) | 0.14165<br>(0.36897)  | 0.63678<br>(0.04411)  | 0.20495<br>(0.30974)  | -0.24446<br>(0.27946) | -0.97047<br>(0.05303) |
| Phosphorus-32 of Baffle        | -0.57735<br>(0.06699) | -0.33140<br>(0.20983) | 0.23762<br>(0.28548)  | 0.33784<br>(0.20655)  | 0.15551<br>(0.35655)  | 0.26158<br>(0.26573)  | 0.45651<br>(0.12777)  | 0.27285<br>(0.25662)  | 0.60014<br>(0.05787)  | -0.14662<br>(0.36450) | 0.24571<br>(0.27875)  | -0.09226<br>(0.41400) |
| Phosphorus-32 of Sediment      | -0.93888<br>(0.00027) | -0.82247<br>(0.00610) | -0.76793<br>(0.01303) | -0.87731<br>(0.00210) | -0.22008<br>(0.30024) | -0.68192<br>(0.00188) | -0.56099<br>(0.07400) | -0.62360<br>(0.04926) | 0.11282<br>(0.39513)  | -0.83269<br>(0.00514) | -0.50550<br>(0.10064) | -0.89976<br>(0.00117) |

Table IV-19: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell A, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9459<br>P=0.000 | -0.5235<br>P=0.091 | 0.9452<br>P=0.000    | 0.3374<br>P=0.207                   | 0.5549<br>P=0.077                     | 0.3370<br>P=0.207  | -0.4979<br>P=0.105   | -0.2497<br>P=0.275   | 0.4444<br>P=0.135                                      |
| pH   |                         | -                 | -0.3869<br>P=0.172 | 0.9123<br>P=0.001    | 0.4636<br>P=0.124                   | 0.6928<br>P=0.028                     | 0.4969<br>P=0.105  | -0.6515<br>P=0.040   | -0.4402<br>P=0.138   | 0.5955<br>P=0.060                                      |
| Temperature (°C)   |                         |                   | -                  | -0.5732<br>P=0.069   | -0.2822<br>P=0.249                  | 0.2536<br>P=0.272                     | 0.5080<br>P=0.099  | 0.3344<br>P=0.209  | -0.1389<br>P=0.371   | 0.3955<br>P=0.166                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.4088<br>P=0.157                   | 0.4827<br>P=0.113                     | 0.2826<br>P=0.249  | -0.6551<br>P=0.039   | -0.1828<br>P=0.332   | 0.3044<br>P=0.232                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.8310<br>P=0.005                     | 0.7840<br>P=0.011  | -0.1655<br>P=0.348   | -0.0223<br>P=0.479   | 0.7230<br>P=0.021                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.8108<br>P=0.007  | -0.2240<br>P=0.297   | -0.3747<br>P=0.180   | 0.9317<br>P=0.000                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.1862<br>P=0.329   | -0.2230<br>P=0.298   | 0.9083<br>P=0.001                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.4908<br>P=0.108  | -0.1052<br>P=0.402                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.3611<br>P=0.190                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-20: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell A, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9280<br>P=0.000 | -0.5960<br>P=0.059 | 0.9498<br>P=0.000    | 0.6025<br>P=0.057                   | -0.0705<br>P=0.434                    | 0.3760<br>P=0.179  | -0.0167<br>P=0.484   | -0.3442<br>P=0.202   | 0.4356<br>P=0.140                                      |
| pH   | -                       | -                 | -0.4907<br>P=0.108 | 0.9496<br>P=0.000    | 0.6428<br>P=0.043                   | 0.0883<br>P=0.418                     | 0.4647<br>P=0.123  | 0.0926<br>P=0.414  | -0.2668<br>P=0.262   | 0.5858<br>P=0.064                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.5083<br>P=0.099   | -0.4053<br>P=0.160                  | 0.6563<br>P=0.039                     | 0.4115<br>P=0.156  | 0.5803<br>P=0.066  | 0.1280<br>P=0.381  | 0.3178<br>P=0.222                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.7196<br>P=0.022                   | -0.1051<br>P=0.402                    | 0.4870<br>P=0.111  | 0.0083<br>P=0.492  | -0.4521<br>P=0.130   | 0.5421<br>P=0.083                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | -0.1732<br>P=0.341                    | 0.3327<br>P=0.210  | 0.0672<br>P=0.437  | -0.3738<br>P=0.181   | 0.3361<br>P=0.208                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.5305<br>P=0.088  | 0.8035<br>P=0.008  | 0.3651<br>P=0.187  | 0.6230<br>P=0.049                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | 0.7340<br>P=0.019  | -0.0056<br>P=0.495   | 0.9044<br>P=0.001                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.4763<br>P=0.116  | 0.7822<br>P=0.001                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.0361<br>P=0.466                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-21: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell A, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9087<br>P=0.001 | -0.6008<br>P=0.058 | 0.9369<br>P=0.000    | 0.4477<br>P=0.133                   | 0.4529<br>P=0.130                     | -0.4222<br>P=0.149   | -0.1991<br>P=0.318   | 0.6979<br>P=0.027  | 0.4201<br>P=0.150                                      |
| pH   | -                       | -                 | -0.5681<br>P=0.071 | 0.9772<br>P=0.000    | 0.6630<br>P=0.037                   | 0.5044<br>P=0.101                     | -0.4936<br>P=0.107   | -0.5191<br>P=0.094   | 0.7776<br>P=0.012  | 0.6069<br>P=0.055                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.5148<br>P=0.096   | 0.0258<br>P=0.476                   | 0.0945<br>P=0.412                     | -0.1109<br>P=0.397   | 0.3676<br>P=0.185  | -0.0727<br>P=0.432   | 0.2841<br>P=0.248                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.5657<br>P=0.072                   | 0.4476<br>P=0.133                     | -0.5329<br>P=0.087   | -0.3741<br>P=0.181   | 0.8319<br>P=0.005  | 0.6201<br>P=0.050                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.7746<br>P=0.012                     | -0.4765<br>P=0.116   | -0.5589<br>P=0.075   | 0.5974<br>P=0.059  | 0.7880<br>P=0.010                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | -0.7626<br>P=0.014   | -0.0767<br>P=0.428   | 0.5167<br>P=0.095  | 0.6027<br>P=0.057                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.1284<br>P=0.381   | -0.6480<br>P=0.041   | -0.6471<br>P=0.041                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -0.2852<br>P=0.247   | -0.3153<br>P=0.223                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.7529<br>P=0.016                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |



Table IV-22: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell B, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9489<br>P=0.000 | -0.5852<br>P=0.064 | 0.9688<br>P=0.000    | 0.3535<br>P=0.195                   | 0.2260<br>P=0.295                     | 0.1295<br>P=0.380  | 0.2679<br>P=0.261  | -0.5448<br>P=0.081   | 0.4044<br>P=0.160                                      |
| pH   | -                       | -                 | -0.4862<br>P=0.111 | 0.9201<br>P=0.001    | 0.4289<br>P=0.144                   | 0.3704<br>P=0.183                     | 0.2970<br>P=0.237  | 0.0596<br>P=0.444  | -0.5584<br>P=0.075   | 0.6417<br>P=0.043                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.6522<br>P=0.040   | -0.1867<br>P=0.329                  | 0.5009<br>P=0.103                     | 0.6409<br>P=0.043  | 0.0631<br>P=0.441  | 0.8872<br>P=0.002  | 0.1548<br>P=0.357                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.5175<br>P=0.095                   | 0.1728<br>P=0.341                     | 0.0591<br>P=0.445  | 0.1518<br>P=0.360  | -0.6075<br>P=0.055   | 0.3938<br>P=0.167                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.4795<br>P=0.115                     | 0.3378<br>P=0.207  | -0.3134<br>P=0.225   | -0.1198<br>P=0.369   | 0.5723<br>P=0.069                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.9426<br>P=0.000  | 0.0410<br>P=0.462  | 0.4727<br>P=0.118  | 0.7944<br>P=0.009                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.0608<br>P=0.443   | 0.5341<br>P=0.086  | 0.7514<br>P=0.016                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.2329<br>P=0.289  | -0.2217<br>P=0.299                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -0.0624<br>P=0.442                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-23: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell B, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9501<br>P=0.000 | -0.5635<br>P=0.073 | 0.9706<br>P=0.000    | 0.1139<br>P=0.394                   | 0.1512<br>P=0.360                     | 0.4223<br>P=0.149  | -0.1827<br>P=0.333   | 0.1174<br>P=0.391  | 0.3980<br>P=0.164                                      |
| pH   | -                       | -                 | -0.4945<br>P=0.106 | 0.9615<br>P=0.000    | 0.1486<br>P=0.363                   | 0.3385<br>P=0.206                     | 0.5373<br>P=0.085  | -0.3619<br>P=0.189   | 0.3242<br>P=0.217  | 0.6078<br>P=0.055                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.6139<br>P=0.053   | 0.0803<br>P=0.425                   | 0.5083<br>P=0.099                     | 0.4022<br>P=0.162  | -0.5131<br>P=0.097   | -0.1504<br>P=0.079   | 0.0301<br>P=0.472                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.1374<br>P=0.373                   | 0.2238<br>P=0.297                     | 0.4242<br>P=0.147  | -0.1919<br>P=0.324   | 0.1058<br>P=0.402  | 0.5009<br>P=0.103                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.4146<br>P=0.154                     | 0.5181<br>P=0.094  | -0.4663<br>P=0.122   | 0.1588<br>P=0.191  | 0.4534<br>P=0.130                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.8949<br>P=0.001  | -0.8163<br>P=0.007   | 0.8672<br>P=0.003  | 0.7330<br>P=0.019                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.9047<br>P=0.001   | 0.8331<br>P=0.005  | 0.7242<br>P=0.021                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -0.3458<br>P=0.004   | -0.7525<br>P=0.016                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.6351<br>P=0.045                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-24: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell B, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9060<br>P=0.001 | -0.3440<br>P=0.202 | 0.9242<br>P=0.001    | -0.0633<br>P=0.441                  | -0.2975<br>P=0.237                    | -0.5631<br>P=0.073   | 0.8004<br>P=0.009  | 0.4837<br>P=0.112  | 0.3459<br>P=0.201                                      |
| pH   | -                       | -                 | -0.3881<br>P=0.171 | 0.9591<br>P=0.000    | 0.0884<br>P=0.418                   | -0.1495<br>P=0.362                    | -0.4878<br>P=0.110   | 0.6311<br>P=0.047  | 0.5752<br>P=0.068  | 0.6473<br>P=0.041                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.3559<br>P=0.193   | 0.3799<br>P=0.177                   | 0.7905<br>P=0.010                     | 0.5847<br>P=0.064  | -0.1677<br>P=0.346   | -0.2838<br>P=0.248   | 0.0120<br>P=0.489                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | -0.0695<br>P=0.435                  | -0.1663<br>P=0.347                    | -0.5275<br>P=0.090   | 0.7560<br>P=0.015  | 0.5439<br>P=0.082  | 0.5554<br>P=0.076                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.6947<br>P=0.028                     | 0.5140<br>P=0.096  | -0.2943<br>P=0.240   | 0.3868<br>P=0.172  | 0.3127<br>P=0.225                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.6392<br>P=0.044  | -0.2032<br>P=0.315   | -0.0044<br>P=0.496   | 0.4109<br>P=0.156                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.2435<br>P=0.281   | 0.1860<br>P=0.330  | 0.0595<br>P=0.444                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.4067<br>P=0.159  | 0.2800<br>P=0.251                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.3170<br>P=0.222                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-25: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell C, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9438<br>P=0.000 | -0.5984<br>P=0.059 | 0.9367<br>P=0.000    | 0.5917<br>P=0.061                   | 0.5617<br>P=0.074                     | 0.2199<br>P=0.300  | 0.7926<br>P=0.009  | 0.2826<br>P=0.249  | 0.3679<br>P=0.185                                      |
| pH   | -                       | -                 | -0.5243<br>P=0.091 | 0.9499<br>P=0.000    | 0.6972<br>P=0.027                   | 0.5612<br>P=0.074                     | 0.4109<br>P=0.156  | 0.6742<br>P=0.033  | 0.1468<br>P=0.364  | 0.4986<br>P=0.104                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.6491<br>P=0.041   | -0.0524<br>P=0.451                  | 0.0318<br>P=0.470                     | 0.4895<br>P=0.109  | -0.5542<br>P=0.077   | -0.5376<br>P=0.085   | 0.2543<br>P=0.0272                                     |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.6485<br>P=0.041                   | 0.6266<br>P=0.048                     | 0.2790<br>P=0.252  | 0.6075<br>P=0.055  | 0.3546<br>P=0.173  | 0.4612<br>P=0.125                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.7669<br>P=0.013                     | 0.7678<br>P=0.013  | 0.4004<br>P=0.163  | -0.0701<br>P=0.434   | 0.6042<br>P=0.025                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.6708<br>P=0.034  | 0.2098<br>P=0.309  | 0.3883<br>P=0.171  | 0.7069<br>P=0.025                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.0730<br>P=0.432   | -0.3346<br>P=0.209   | 0.8339<br>P=0.005                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.1048<br>P=0.402  | -0.1757<br>P=0.339                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -0.0642<br>P=0.440                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-26: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell C, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9414<br>P=0.000 | -0.6297<br>P=0.047 | 0.9136<br>P=0.001    | -0.0073<br>P=0.493                  | -0.0920<br>P=0.414                    | 0.0487<br>P=0.454  | 0.2990<br>P=0.236  | -0.3095<br>P=0.228   | 0.3621<br>P=0.189                                      |
| pH   | -                       | -                 | -0.5407<br>P=0.083 | 0.9668<br>P=0.000    | -0.2368<br>P=0.286                  | 0.1353<br>P=0.375                     | 0.3361<br>P=0.208  | 0.1164<br>P=0.392  | -0.4840<br>P=0.112   | 0.5112<br>P=0.098                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.5331<br>P=0.087   | 0.2267<br>P=0.295                   | 0.5562<br>P=0.076                     | 0.3553<br>P=0.194  | -0.2151<br>P=0.305   | -0.2080<br>P=0.311   | 0.2096<br>P=0.309                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | -0.1188<br>P=0.390                  | 0.0014<br>P=0.499                     | 0.3518<br>P=0.196  | -0.0122<br>P=0.489   | -0.5984<br>P=0.059   | 0.5839<br>P=0.064                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | -0.5120<br>P=0.097                    | -0.5225<br>P=0.092   | 0.2097<br>P=0.309  | -0.1398<br>P=0.371   | 0.1051<br>P=0.402                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.7517<br>P=0.016  | -0.1871<br>P=0.329   | -0.2564<br>P=0.270   | 0.3709<br>P=0.183                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.5745<br>P=0.068   | -0.6187<br>P=0.051   | 0.5926<br>P=0.061                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.3825<br>P=0.175  | -0.3145<br>P=0.224                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -0.9315<br>P=0.000                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-27: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell C, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9354<br>P=0.000 | -0.5842<br>P=0.064 | 0.8558<br>P=0.003    | -0.3417<br>P=0.204                  | -0.2093<br>P=0.309                    | -0.5553<br>P=0.077   | -0.3245<br>P=0.216   | -0.2106<br>P=0.308   | 0.3608<br>P=0.190                                      |
| pH   | -                       | -                 | -0.5369<br>P=0.085 | 0.9572<br>P=0.000    | -0.1003<br>P=0.407                  | -0.1289<br>P=0.380                    | -0.5140<br>P=0.096   | -0.5689<br>P=0.071   | -0.3935<br>P=0.167   | 0.4803<br>P=0.114                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.4572<br>P=0.127   | 0.3551<br>P=0.194                   | 0.6621<br>P=0.037                     | 0.8147<br>P=0.007  | 0.2734<br>P=0.256  | 0.3468<br>P=0.200  | 0.3752<br>P=0.180                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | -0.0947<br>P=0.412                  | -0.2215<br>P=0.299                    | -0.3186<br>P=0.221   | -0.5891<br>P=0.062   | -0.4704<br>P=0.120   | 0.6031<br>P=0.057                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.6516<br>P=0.040                     | 0.1864<br>P=0.329  | -0.2906<br>P=0.243   | -0.4928<br>P=0.107   | 0.0737<br>P=0.431                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.2205<br>P=0.300  | 0.0626<br>P=0.441  | 0.2042<br>P=0.314  | 0.3024<br>P=0.233                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | 0.3923<br>P=0.168  | 0.0303<br>P=0.472  | 0.3077<br>P=0.229                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.3949<br>P=0.166  | -0.3776<br>P=0.178                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.0286<br>P=0.473                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-28: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell D, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9577<br>P=0.000 | -0.5991<br>P=0.058 | 0.9386<br>P=0.000    | 0.5026<br>P=0.102                   | 0.2816<br>P=0.250                     | 0.1898<br>P=0.326  | 0.6449<br>P=0.042  | -0.4424<br>P=0.136   | 0.3941<br>P=0.167                                      |
| pH   |                         | -                 | -0.5528<br>P=0.078 | 0.9738<br>P=0.000    | 0.4148<br>P=0.153                   | 0.3748<br>P=0.180                     | 0.3421<br>P=0.203  | 0.4972<br>P=0.105  | -0.5768<br>P=0.067   | 0.4370<br>P=0.139                                      |
| Temperature (°C)   |                         |                   | -                  | -0.5881<br>P=0.063   | -0.0058<br>P=0.495                  | 0.1360<br>P=0.374                     | 0.4985<br>P=0.104  | -0.5891<br>P=0.062   | -0.2694<br>P=0.259   | 0.4551<br>P=0.129                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.4525<br>P=0.130                   | 0.3890<br>P=0.170                     | 0.2872<br>P=0.245  | 0.4788<br>P=0.115  | -0.5132<br>P=0.097   | 0.4141<br>P=0.154                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.6945<br>P=0.028                     | 0.4681<br>P=0.121  | 0.1142<br>P=0.394  | -0.3115<br>P=0.226   | 0.6600<br>P=0.037                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.7602<br>P=0.014  | -0.4839<br>P=0.112   | -0.4812<br>P=0.114   | 0.5911<br>P=0.061                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.4028<br>P=0.161   | -0.8695<br>P=0.003   | 0.8401<br>P=0.005                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.0227<br>P=0.479  | -0.0306<br>P=0.471                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.7861<br>P=0.010                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-29: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell D, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9436<br>P=0.000 | -0.6852<br>P=0.030 | 0.9436<br>P=0.000    | 0.3719<br>P=0.182                   | -0.4297<br>P=0.144                    | 0.1091<br>P=0.399  | -0.0977<br>P=0.409   | 0.1516<br>P=0.360  | 0.3847<br>P=0.173                                      |
| pH   |                         | -                 | -0.6287<br>P=0.048 | 0.9780<br>P=0.000    | 0.5250<br>P=0.091                   | -0.3271<br>P=0.215                    | 0.1980<br>P=0.319  | -0.1791<br>P=0.336   | -0.1023<br>P=0.405   | 0.4525<br>P=0.130                                      |
| Temperature (°C)   |                         |                   | -                  | -0.6554<br>P=0.039   | -0.7007<br>P=0.026                  | 0.9322<br>P=0.000                     | 0.1524<br>P=0.359  | -0.1026<br>P=0.404   | -0.2476<br>P=0.277   | 0.3727<br>P=0.182                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.5002<br>P=0.103                   | -0.3723<br>P=0.182                    | -0.0052<br>P=0.495   | -0.0463<br>P=0.457   | -0.0503<br>P=0.453   | 0.4400<br>P=0.138                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | -0.6156<br>P=0.052                    | 0.0002<br>P=0.500  | -0.2197<br>P=0.301   | -0.0262<br>P=0.475   | -0.2441<br>P=0.280                                     |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.3007<br>P=0.235  | -0.2245<br>P=0.296   | -0.4265<br>P=0.146   | 0.6407<br>P=0.043                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.5929<br>P=0.061   | -0.3187<br>P=0.221   | 0.2176<br>P=0.302                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.1761<br>P=0.338  | -0.2669<br>P=0.261                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.2414<br>P=0.282                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |



Table IV-30: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 1, Cell D, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9286<br>P=0.000 | -0.4872<br>P=0.110 | 0.9223<br>P=0.001    | -0.1869<br>P=0.329                  | 0.3717<br>P=0.182                     | -0.5244<br>P=0.091   | 0.3951<br>P=0.166  | -0.5492<br>P=0.056   | 0.3870<br>P=0.172                                      |
| pH   | -                       | -                 | -0.3723<br>P=0.182 | 0.9788<br>P=0.000    | -0.1988<br>P=0.318                  | 0.3051<br>P=0.231                     | -0.4092<br>P=0.157   | 0.6351<br>P=0.045  | -0.7820<br>P=0.011   | 0.4742<br>P=0.118                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.2772<br>P=0.253   | 0.3912<br>P=0.169                   | -0.4832<br>P=0.113                    | 0.6131<br>P=0.007  | 0.3254<br>P=0.216  | 0.1856<br>P=0.330  | 0.5748<br>P=0.066                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | -0.1490<br>P=0.362                  | 0.2350<br>P=0.288                     | -0.3326<br>P=0.210   | 0.6177<br>P=0.051  | -0.7117<br>P=0.024   | 0.5969<br>P=0.059                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | -0.7084<br>P=0.025                    | 0.7112<br>P=0.024  | 0.2819<br>P=0.249  | 0.2683<br>P=0.260  | 0.1978<br>P=0.319                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | -0.5568<br>P=0.076   | -0.2032<br>P=0.315   | -0.0109<br>P=0.490   | -0.1900<br>P=0.326                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | 0.3365<br>P=0.208  | 0.3872<br>P=0.172  | 0.3354<br>P=0.208                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -0.6856<br>P=0.030   | 0.6534<br>P=0.039                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -0.3470<br>P=0.0200                                    |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-31: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell A, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9519<br>P=0.000 | -0.5161<br>P=0.095 | 0.9330<br>P=0.000    | 0.4234<br>P=0.148                   | 0.0512<br>P=0.452                     | 0.2764<br>P=0.254  | 0.5978<br>P=0.059  | 0.3942<br>P=0.167  | 0.0313<br>P=0.471                                      |
| pH   | -                       | -                 | -0.4662<br>P=0.122 | 0.9535<br>P=0.000    | 0.5224<br>P=0.092                   | 0.1094<br>P=0.398                     | 0.2988<br>P=0.236  | 0.4497<br>P=0.132  | 0.2383<br>P=0.285  | 0.0190<br>P=0.482                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.6219<br>P=0.050   | 0.2191<br>P=0.301                   | 0.6303<br>P=0.047                     | 0.3944<br>P=0.167  | -0.4652<br>P=0.123   | -0.4167<br>P=0.152   | 0.2391<br>P=0.284                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.2866<br>P=0.246                   | -0.1081<br>P=0.399                    | 0.0647<br>P=0.440  | 0.3767<br>P=0.179  | 0.2042<br>P=0.314  | -0.2089<br>P=0.310                                     |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.5152<br>P=0.096                     | 0.9334<br>P=0.000  | 0.3422<br>P=0.203  | 0.2698<br>P=0.259  | 0.6614<br>P=0.037                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.5818<br>P=0.065  | 0.0891<br>P=0.417  | 0.1436<br>P=0.367  | 0.2334<br>P=0.287                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | 0.3291<br>P=0.213  | 0.3495<br>P=0.198  | 0.6672<br>P=0.030                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.8678<br>P=0.003  | 0.5156<br>P=0.095                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.3281<br>P=0.214                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-32: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell A, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9318<br>P=0.000 | -0.4979<br>P=0.105 | 0.8735<br>P=0.002    | 0.0131<br>P=0.488                   | 0.2783<br>P=0.252                     | -0.0311<br>P=0.471   | 0.2751<br>P=0.255  | 0.7405<br>P=0.018  | 0.0211<br>P=0.460                                      |
| pH   | -                       | -                 | -0.3827<br>P=0.175 | 0.9562<br>P=0.000    | 0.1918<br>P=0.325                   | 0.4796<br>P=0.115                     | 0.1659<br>P=0.347  | 0.1527<br>P=0.359  | 0.4846<br>P=0.112  | 0.0555<br>P=0.448                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.3873<br>P=0.172   | 0.5318<br>P=0.087                   | 0.3096<br>P=0.228                     | 0.8029<br>P=0.008  | -0.3248<br>P=0.216   | -0.4494<br>P=0.132   | 0.4109<br>P=0.156                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.0493<br>P=0.454                   | 0.5606<br>P=0.074                     | 0.0784<br>P=0.427  | 0.1804<br>P=0.334  | 0.4270<br>P=0.146  | -0.1307<br>P=0.379                                     |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.3846<br>P=0.173                     | 0.8397<br>P=0.005  | 0.0229<br>P=0.479  | -0.0743<br>P=0.431   | 0.7690<br>P=0.013                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.5124<br>P=0.097  | 0.2104<br>P=0.308  | -0.0828<br>P=0.423   | 0.3487<br>P=0.199                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.3148<br>P=0.224   | -0.2595<br>P=0.267   | 0.5709<br>P=0.070                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.6173<br>P=0.051  | 0.3560<br>P=0.193                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.1273<br>P=0.382                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-33: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cella, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (dg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9055<br>P=0.001 | -0.5054<br>P=0.101 | 0.8826<br>P=0.002    | -0.0994<br>P=0.407                  | -0.5161<br>P=0.095                    | -0.3427<br>P=0.203   | 0.8352<br>P=0.005  | 0.4841<br>P=0.112  | -0.0293<br>P=0.473                                     |
| pH   | -                       | -                 | -0.4315<br>P=0.143 | 0.9816<br>P=0.000    | -0.0140<br>P=0.487                  | -0.3372<br>P=0.207                    | -0.3713<br>P=0.183   | 0.6515<br>P=0.040  | 0.2554<br>P=0.271  | 0.0515<br>P=0.452                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.2964<br>P=0.238   | 0.6895<br>P=0.029                   | 0.6875<br>P=0.030                     | 0.6944<br>P=0.028  | -0.4434<br>P=0.136   | -0.2630<br>P=0.265   | 0.3073<br>P=0.230                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.1391<br>P=0.371                   | -0.2501<br>P=0.275                    | -0.2557<br>P=0.271   | 0.6430<br>P=0.043  | 0.2102<br>P=0.309  | 0.0796<br>P=0.246                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.1325<br>P=0.377                     | 0.3967<br>P=0.165  | -0.1653<br>P=0.348   | -0.0913<br>P=0.415   | 0.2865<br>P=0.246                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.6168<br>P=0.052  | -0.4784<br>P=0.115   | -0.6387<br>P=0.044   | 0.1456<br>P=0.365                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.0996<br>P=0.407   | -0.2405<br>P=0.283   | 0.6592<br>P=0.038                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.7298<br>P=0.020  | 0.1910<br>P=0.325                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.1579<br>P=0.354                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-34: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell B, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9490<br>P=0.000 | -0.4741<br>P=0.118 | 0.9479<br>P=0.000    | 0.1658<br>P=0.347                   | 0.2829<br>P=0.249                     | 0.3162<br>P=0.223  | 0.5150<br>P=0.096  | -0.0999<br>P=0.407   | 0.4510<br>P=0.131                                      |
| pH   |                         | -                 | -0.4282<br>P=0.145 | 0.9710<br>P=0.000    | 0.2174<br>P=0.303                   | 0.4363<br>P=0.140                     | 0.3457<br>P=0.201  | 0.5499<br>P=0.070  | -0.2031<br>P=0.315   | 0.6132<br>P=0.053                                      |
| Temperature (°C)   |                         |                   | -                  | -0.5712<br>P=0.070   | 0.3770<br>P=0.179                   | 0.4580<br>P=0.127                     | 0.3543<br>P=0.195  | -0.2999<br>P=0.235   | -0.6860<br>P=0.030   | 0.2713<br>P=0.258                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.0293<br>P=0.473                   | 0.2598<br>P=0.267                     | 0.1834<br>P=0.332  | 0.4369<br>P=0.140  | -0.0596<br>P=0.444   | 0.4799<br>P=0.114                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.8111<br>P=0.007                     | 0.7010<br>P=0.026  | 0.6473<br>P=0.041  | -0.3733<br>P=0.181   | 0.4881<br>P=0.110                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.6801<br>P=0.032  | 0.5216<br>P=0.092  | -0.6355<br>P=0.045   | 0.8670<br>P=0.003                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.5328<br>P=0.087  | -0.7392<br>P=0.018   | 0.6790<br>P=0.032                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.0439<br>P=0.459  | 0.4946<br>P=0.106                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.6956<br>P=0.028                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-35: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell B, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (ppm) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                      | 0.9297<br>P=0.000 | -0.4839<br>P=0.112 | 0.9675<br>P=0.000    | 0.3357<br>P=0.208                   | -0.3518<br>P=0.196                    | 0.5151<br>P=0.096  | 0.7983<br>P=0.009  | 0.5764<br>P=0.067  | 0.4475<br>P=0.133                                      |
| pH   | -                      | -                 | -0.3928<br>P=0.168 | 0.9575<br>P=0.000    | 0.4766<br>P=0.116                   | -0.3751<br>P=0.180                    | 0.6174<br>P=0.051  | 0.7737<br>P=0.012  | 0.7115<br>P=0.024  | 0.6515<br>P=0.040                                      |
| Temperature (°C)   | -                      | -                 | -                  | -0.5456<br>P=0.081   | -0.1501<br>P=0.361                  | 0.6629<br>P=0.037                     | -0.1504<br>P=0.361   | -0.6165<br>P=0.052   | -0.7035<br>P=0.026   | 0.2748<br>P=0.255                                      |
| Redox Potential (mv)   | -                      | -                 | -                  | -                    | 0.4554<br>P=0.128                   | -0.4169<br>P=0.152                    | 0.5350<br>P=0.086  | 0.7603<br>P=0.014  | 0.6658<br>P=0.036  | 0.4749<br>P=0.117                                      |
| Orthophosphate Concentration (mg/l)                          | -                      | -                 | -                  | -                    | -                                   | -0.5086<br>P=0.099                    | 0.7567<br>P=0.015  | 0.1936<br>P=0.323  | 0.1998<br>P=0.318  | 0.5452<br>P=0.081                                      |
| Total Phosphorus Concentration (mg/l)                        | -                      | -                 | -                  | -                    | -                                   | -                                     | -0.3923<br>P=0.168   | -0.3030<br>P=0.233   | -0.5497<br>P=0.079   | -0.1885<br>P=0.327                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                      | -                 | -                  | -                    | -                                   | -                                     | -  | 0.4355<br>P=0.140  | 0.3625<br>P=0.189  | 0.7162<br>P=0.023                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                      | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.7301<br>P=0.020  | 0.1661<br>P=0.347                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                      | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.2871<br>P=0.245                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                      | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-36: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell B, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9148<br>P=0.001 | -0.4771<br>P=0.116 | 0.9333<br>P=0.000    | 0.2229<br>P=0.298                   | 0.6222<br>P=0.050                     | -0.2828<br>P=0.249   | -0.0034<br>P=0.497   | 0.3955<br>P=0.166  | 0.4620<br>P=0.125                                      |
| pH   |                         | -                 | -0.4039<br>P=0.161 | 0.9776<br>P=0.000    | 0.4836<br>P=0.112                   | 0.6554<br>P=0.039                     | -0.3965<br>P=0.165   | -0.1097<br>P=0.398   | 0.1427<br>P=0.368  | 0.6644<br>P=0.036                                      |
| Temperature (°C)   |                         |                   | -                  | -0.4027<br>P=0.161   | -0.3385<br>P=0.206                  | -0.7192<br>P=0.022                    | 0.8434<br>P=0.004  | 0.2388<br>P=0.285  | -9.2597<br>P=0.267   | 0.2618<br>P=0.266                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.4486<br>P=0.132                   | 0.5775<br>P=0.067                     | -0.3784<br>P=0.178   | -0.1904<br>P=0.326   | 0.1380<br>P=0.372  | 0.5521<br>P=0.078                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | -0.0109<br>P=0.490                    | 0.0989<br>P=0.408  | 0.0967<br>P=0.410  | -0.2458<br>P=0.279   | 0.7459<br>P=0.017                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | -0.6449<br>P=0.042   | 0.1208<br>P=0.388  | 0.0115<br>P=0.489  | 0.3459<br>P=0.201                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.5554<br>P=0.076  | 0.2260<br>P=0.295  | 0.1365<br>P=0.374                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.3863<br>P=0.172  | 0.3060<br>P=0.231                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.0840<br>P=0.422                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-37: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell C, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9622<br>P=0.000 | -0.3464<br>P=0.200 | 0.8652<br>P=0.003    | 0.1719<br>P=0.342                   | -0.0332<br>P=0.469                    | 0.0742<br>P=0.431  | -0.4963<br>P=0.105   | 0.7167<br>P=0.023  | 0.1592<br>P=0.353                                      |
| pH   |                         | -                 | -0.2930<br>P=0.241 | 0.9487<br>P=0.000    | 0.4106<br>P=0.145                   | 0.1950<br>P=0.322                     | 0.3178<br>P=0.222  | -0.2731<br>P=0.256   | -0.8026<br>P=0.008   | 0.2422<br>P=0.282                                      |
| Temperature (°C)   |                         |                   | -                  | -0.1162<br>P=0.392   | 0.1730<br>P=0.341                   | 0.0717<br>P=0.433                     | 0.3091<br>P=0.228  | 0.2378<br>P=0.285  | -0.0383<br>P=0.464   | 0.2537<br>P=0.272                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.5285<br>P=0.089                   | 0.3374<br>P=0.207                     | 0.4533<br>P=0.130  | -0.0683<br>P=0.436   | -0.9117<br>P=0.001   | 0.2235<br>P=0.297                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.7048<br>P=0.025                     | 0.9235<br>P=0.001  | 0.5954<br>P=0.060  | -0.5418<br>P=0.083   | 0.3253<br>P=0.216                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.7688<br>P=0.013  | 0.8308<br>P=0.005  | -0.5041<br>P=0.101   | -0.1871<br>P=0.329                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.5992<br>P=0.058  | -0.4963<br>P=0.105   | 0.3529<br>P=0.196                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | -0.1335<br>P=0.376   | -0.2174<br>P=0.303                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | 0.0951<br>P=0.411                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |



Table IV-38: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell c, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9496<br>P=0.000 | -0.3027<br>P=0.233 | 0.8527<br>P=0.004    | 0.3701<br>P=0.183                   | -0.1194<br>P=0.389                    | 0.4557<br>P=0.128  | -0.1519<br>P=0.360   | 0.0338<br>P=0.468  | 0.1654<br>P=0.348                                      |
| pH   |                         | -                 | -0.2304<br>P=0.292 | 0.9628<br>P=0.000    | 0.5742<br>P=0.068                   | 0.1348<br>P=0.375                     | 0.6448<br>P=0.042  | -0.3097<br>P=0.228   | -0.1297<br>P=0.380   | 0.2572<br>P=0.269                                      |
| Temperature (°C)   |                         |                   | -                  | -0.2756<br>P=0.254   | 0.3857<br>P=0.173                   | 0.5203<br>P=0.093                     | 0.0077<br>P=0.493  | -0.4568<br>P=0.128   | -0.5936<br>P=0.060   | 0.3013<br>P=0.234                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.6618<br>P=0.037                   | 0.2540<br>P=0.272                     | 0.7281<br>P=0.020  | -0.3278<br>P=0.214   | -0.1760<br>P=0.338   | 0.2843<br>P=0.247                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.8149<br>P=0.007                     | 0.8639<br>P=0.003  | -0.3602<br>P=0.190   | -0.7661<br>P=0.013   | 0.6849<br>P=0.030                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.6639<br>P=0.036  | -0.3483<br>P=0.199   | -0.7126<br>P=0.024   | 0.4866<br>P=0.111                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.0246<br>P=0.477   | -0.7063<br>P=0.025   | 0.7343<br>P=0.019                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.0514<br>P=0.452  | 0.2000<br>P=0.317                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.9047<br>P=0.001                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  |  |

Table IV-39: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell C, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (kg/l) | pH                 | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|--------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | 0.9175<br>P=0.001       | -0.2957<br>P=0.238 | -0.2954<br>P=0.239 | -0.7754<br>P=0.012   | -0.4216<br>P=0.149                  | -0.1419<br>P=0.149                    | -0.6650<br>P=0.369   | 0.7007<br>P=0.036  | -0.4891<br>P=0.026   | 0.0643<br>P=0.421                                      |
| pH   | -                       | -                  | -                  | 0.9413<br>P=0.000    | -0.1970<br>P=0.320                  | 0.1217<br>P=0.387                     | -0.6937<br>P=0.028   | 0.7442<br>P=0.017  | -0.7156<br>P=0.023   | 0.2327<br>P=0.290                                      |
| Temperature (°C)   | -                       | -                  | -                  | -0.2849<br>P=0.247   | 0.5726<br>P=0.069                   | 0.6502<br>P=0.040                     | 0.3900<br>P=0.170  | 0.1402<br>P=0.370  | 0.0457<br>P=0.457  | 0.2889<br>P=0.244                                      |
| Redox Potential (mv)   | -                       | -                  | -                  | -                    | -0.0527<br>P=0.451                  | 0.1679<br>P=0.346                     | -0.5689<br>P=0.071   | 0.6571<br>P=0.038  | -0.6807<br>P=0.032   | 0.3439<br>P=0.202                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                  | -                  | -                    | -                                   | 0.8006<br>P=0.008                     | 0.3226<br>P=0.218  | -0.1657<br>P=0.347   | 0.0104<br>P=0.490  | 0.0365<br>P=0.466                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                  | -                  | -                    | -                                   | -                                     | 0.0258<br>P=0.476  | 0.2977<br>P=0.237  | -0.4884<br>P=0.110   | 0.3011<br>P=0.234                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                  | -                  | -                    | -                                   | -                                     | -  | -0.3086<br>P=0.229   | 0.4575<br>P=0.127  | -0.3807<br>P=0.176                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                  | -                  | -                    | -                                   | -                                     | -  | -  | -0.6625<br>P=0.037   | 0.1621<br>P=0.351                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                  | -                  | -                    | -                                   | -                                     | -  | -  | -  | -0.4300<br>P=0.144                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                  | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-40: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell D, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9537<br>P=0.000 | -0.3544<br>P=0.194 | 0.8524<br>P=0.004    | -0.0709<br>P=0.434                  | 0.1769<br>P=0.338                     | 0.0334<br>P=0.469  | 0.6246<br>P=0.049  | 0.0017<br>P=0.498  | 0.4657<br>P=0.122                                      |
| pH   |                         | -                 | -0.3441<br>P=0.202 | 0.9456<br>P=0.000    | 0.1383<br>P=0.372                   | 0.4205<br>P=0.150                     | 0.2127<br>P=0.306  | 0.5128<br>P=0.097  | -0.2089<br>P=0.310   | 0.6051<br>P=0.056                                      |
| Temperature (°C)   |                         |                   | -                  | -0.2949<br>P=0.239   | 0.4106<br>P=0.156                   | 0.0888<br>P=0.417                     | 0.6007<br>P=0.058  | -0.2762<br>P=0.254   | -0.2917<br>P=0.242   | 0.0511<br>P=0.452                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.2896<br>P=0.243                   | 0.4483<br>P=0.133                     | 0.3162<br>P=0.223  | 0.3312<br>P=0.211  | -0.4276<br>P=0.145   | 0.5499<br>P=0.079                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.6704<br>P=0.034                     | 0.9129<br>P=0.001  | -0.6417<br>P=0.043   | -0.8598<br>P=0.003   | 0.2605<br>P=0.267                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.6020<br>P=0.057  | -0.1048<br>P=0.402   | -0.4617<br>P=0.125   | 0.5536<br>P=0.077                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.4784<br>P=0.115   | -0.7924<br>P=0.010   | 0.5063<br>P=0.100                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.4791<br>P=0.115  | 0.1917<br>P=0.325                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.2008<br>P=0.317                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-41: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell D, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9423<br>P=0.000 | -0.2064<br>P=0.312 | 0.8199<br>P=0.006    | 0.1804<br>P=0.335                   | -0.2828<br>P=0.249                    | -0.0061<br>P=0.494   | 0.8288<br>P=0.005  | -0.4652<br>P=0.123   | 0.4574<br>P=0.127                                      |
| pH   |                         | -                 | -0.2024<br>P=0.315 | 0.9556<br>P=0.000    | 0.4157<br>P=0.153                   | -0.0924<br>P=0.414                    | 0.1188<br>P=0.390  | 0.8281<br>P=0.006  | -0.5279<br>P=0.089   | 0.6027<br>P=0.057                                      |
| Temperature (°C)   |                         |                   | -                  | -0.2756<br>P=0.254   | -0.2423<br>P=0.282                  | -0.2621<br>P=0.265                    | 0.3544<br>P=0.195  | -0.1105<br>P=0.397   | -0.3886<br>P=0.171   | 0.1540<br>P=0.358                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.5984<br>P=0.059                   | 0.0424<br>P=0.460                     | 0.1004<br>P=0.406  | 0.7419<br>P=0.018  | -0.5031<br>P=0.102   | 0.6561<br>P=0.039                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.7300<br>P=0.020                     | 0.3912<br>P=0.169  | 0.0984<br>P=0.408  | -0.4434<br>P=0.136   | 0.0818<br>P=0.424                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.5325<br>P=0.087  | -0.3012<br>P=0.234   | -0.0474<br>P=0.456   | -0.4237<br>P=0.148                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.0579<br>P=0.446   | -0.6297<br>P=0.047   | -0.1935<br>P=0.323                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | -0.1750<br>P=0.339   | -0.6343<br>P=0.046                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.1870<br>P=0.329                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-42: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 2, Cell D, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9146<br>P=0.001 | -0.2917<br>P=0.242 | 0.8238<br>P=0.006    | -0.0539<br>P=0.450                  | 0.4324<br>P=0.142                     | -0.4328<br>P=0.142   | -0.7527<br>P=0.016   | -0.8840<br>P=0.002   | 0.4009<br>P=0.163                                      |
| pH   |                         | -                 | -0.3278<br>P=0.214 | 0.9510<br>P=0.000    | -0.1908<br>P=0.325                  | 0.1995<br>P=0.318                     | -0.3685<br>P=0.185   | -0.6402<br>P=0.044   | -0.7353<br>P=0.019   | 0.5668<br>P=0.062                                      |
| Temperature (°C)   |                         |                   | -                  | -0.1957<br>P=0.321   | 0.7180<br>P=0.022                   | 0.4933<br>P=0.107                     | 0.2416<br>P=0.282  | 0.0173<br>P=0.484  | 0.0753<br>P=0.430  | 0.0243<br>P=0.477                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | -0.1634<br>P=0.0350                 | 0.1575<br>P=0.355                     | -0.3387<br>P=0.206   | -0.6083<br>P=0.055   | -0.6046<br>P=0.056   | 0.7129<br>P=0.024                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.8230<br>P=0.006                     | 0.5828<br>P=0.065  | -0.1814<br>P=0.334   | -0.2483<br>P=0.277   | -0.2583<br>P=0.268                                     |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.1249<br>P=0.384  | -0.5316<br>P=0.088   | -0.6300<br>P=0.047   | -0.1605<br>P=0.352                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.0889<br>P=0.417  | 0.2737<br>P=0.256  | -0.4165<br>P=0.152                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.6528<br>P=0.082  | 0.0259<br>P=0.476                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.3504<br>P=0.197                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-43: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell A, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9456<br>P=0.000 | -0.4982<br>P=0.104 | 0.7589<br>P=0.015    | -0.1598<br>P=0.353                  | 0.2780<br>P=0.253                     | 0.3195<br>P=0.220  | -9.4569<br>P=0.128   | -0.1523<br>P=0.359   | 0.0551<br>P=0.448                                      |
| pH   |                         | -                 | -0.4363<br>P=0.140 | 0.9103<br>P=0.001    | -0.1300<br>P=0.379                  | 0.3678<br>P=0.185                     | 0.4005<br>P=0.163  | -0.4492<br>P=0.132   | -0.3575<br>P=0.192   | -0.0966<br>P=0.410                                     |
| Temperature (°C)   |                         |                   | -                  | -0.2967<br>P=0.238   | 0.6426<br>P=0.043                   | 0.5219<br>P=0.092                     | 0.0898<br>P=0.416  | 0.5827<br>P=0.065  | 0.1003<br>P=0.407  | 0.2207<br>P=0.300                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | -0.2419<br>P=0.282                  | 0.3731<br>P=0.181                     | 0.2393<br>P=0.284  | -0.4292<br>P=0.144   | -0.5708<br>P=0.070   | -0.2799<br>P=0.251                                     |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.5163<br>P=0.095                     | 0.6586<br>P=0.038  | 0.6989<br>P=0.027  | 0.3373<br>P=0.207  | 0.5153<br>P=0.096                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.4281<br>P=0.145  | 0.3122<br>P=0.226  | -0.3766<br>P=0.179   | -0.0097<br>P=0.491                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.0373<br>P=0.465  | 0.2521<br>P=0.274  | 0.4947<br>P=0.106                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.0972<br>P=0.409  | 0.2098<br>P=0.309                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | 0.8857<br>P=0.002                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-44: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell A, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9319<br>P=0.000 | -0.4847<br>P=0.112 | 0.7735<br>P=0.012    | 0.7033<br>P=0.026                   | 0.1728<br>P=0.341                     | 0.4879<br>P=0.110  | 0.0373<br>P=0.465  | -0.6075<br>P=0.055   | 0.0683<br>P=0.436                                      |
| pH   |                         | -                 | -0.4681<br>P=0.212 | 0.8956<br>P=0.001    | 0.6827<br>P=0.031                   | 0.3936<br>P=0.167                     | 0.5699<br>P=0.070  | 0.3396<br>P=0.205  | -0.7681<br>P=0.013   | -0.1180<br>P=0.390                                     |
| Temperature (°C)   |                         |                   | -                  | -0.2647<br>P=0.263   | 0.1463<br>P=0.365                   | 0.0829<br>P=0.423                     | 0.4409<br>P=0.137  | -0.1644<br>P=0.349   | 0.1650<br>P=0.348  | 0.2408<br>P=0.283                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.5963<br>P=0.059                   | 0.7424<br>P=0.017                     | 0.6146<br>P=0.052  | 0.444<br>P=0.135   | -0.9022<br>P=0.001   | -0.3463<br>P=0.200                                     |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.1818<br>P=0.333                     | 0.8583<br>P=0.003  | 0.0839<br>P=0.422  | -0.3985<br>P=0.164   | 0.4915<br>P=0.108                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.4189<br>P=0.151  | 0.5624<br>P=0.073  | -0.7637<br>P=0.014   | -0.6018<br>P=0.057                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.2328<br>P=0.289  | -0.5987<br>P=0.058   | 0.2118<br>P=0.307                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | -0.5559<br>P=0.076   | -0.2699<br>P=0.259                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | 0.4790<br>P=0.115                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-45: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell A, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9080<br>P=0.001 | -0.5538<br>P=0.077 | 0.9098<br>P=0.001    | 0.8242<br>P=0.006                   | 0.6094<br>P=0.054                     | -0.4136<br>P=0.154   | -0.3776<br>P=0.178   | -0.5484<br>P=0.080   | 0.0776<br>P=0.428                                      |
| pH   |                         | -                 | -0.5342<br>P=0.086 | 0.9732<br>P=0.000    | 0.7770<br>P=0.012                   | 0.5792<br>P=0.066                     | -0.5853<br>P=0.064   | -0.5995<br>P=0.058   | -0.6080<br>P=0.055   | -0.1523<br>P=0.359                                     |
| Temperature (°C)   |                         |                   | -                  | -0.4873<br>P=0.110   | -0.8420<br>P=0.004                  | -0.7092<br>P=0.024                    | 0.7750<br>P=0.012  | 0.0781<br>P=0.427  | -0.0066<br>P=0.494   | 0.2039<br>P=0.314                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.7183<br>P=0.022                   | 0.5718<br>P=0.069                     | -0.5456<br>P=0.081   | -0.5072<br>P=0.100   | -0.6163<br>P=0.052   | -0.1148<br>P=0.393                                     |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.5420<br>P=0.083                     | -0.5195<br>P=0.094   | -0.2913<br>P=0.242   | -0.3644<br>P=0.187   | -0.1836<br>P=0.331                                     |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | -0.8240<br>P=0.006   | -0.1928<br>P=0.324   | -0.2030<br>P=0.315   | 0.1638<br>P=0.349                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.2708<br>P=0.258  | 0.0187<br>P=0.482  | 0.2785<br>P=0.252                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.7195<br>P=0.022  | -0.2033<br>P=0.315                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.2732<br>P=0.256                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |



Table IV-46: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell B, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9479<br>P=0.000 | -0.5906<br>P=0.062 | 0.7683<br>P=0.013    | -0.0361<br>P=0.467                  | 0.3619<br>P=0.189                     | 0.0374<br>P=0.465  | 0.4728<br>P=0.118  | -0.1302<br>P=0.379   | 0.3776<br>P=0.178                                      |
| pH   |                         | -                 | -0.5600<br>P=0.074 | 0.8975<br>P=0.001    | -0.1173<br>P=0.391                  | 0.4055<br>P=0.159                     | 0.0795<br>P=0.426  | 0.4346<br>P=0.141  | -0.1373<br>P=0.373   | 0.5796<br>P=0.066                                      |
| Temperature (°C)   |                         |                   | -                  | -0.4268<br>P=0.146   | 0.6966<br>P=0.027                   | 0.4248<br>P=0.147                     | 0.7115<br>P=0.024  | -0.2835<br>P=0.248   | -0.2726<br>P=0.257   | 0.0545<br>P=0.449                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | -0.0931<br>P=0.413                  | 0.4040<br>P=0.160                     | 0.1572<br>P=0.355  | 0.2512<br>P=0.274  | -0.3633<br>P=0.188   | 0.7320<br>P=0.019                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.7791<br>P=0.011                     | 0.9012<br>P=0.001  | 0.0898<br>P=0.416  | -0.3392<br>P=0.206   | 0.2157<br>P=0.304                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.8997<br>P=0.001  | 0.1545<br>P=0.357  | -0.3349<br>P=0.209   | 0.6459<br>P=0.042                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.0465<br>P=0.456  | -0.4402<br>P=0.137   | 0.5619<br>P=0.074                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.5423<br>P=0.082  | -0.1002<br>P=0.407                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.5428<br>P=0.082                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-47: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell B, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9253<br>P=0.000 | -0.4374<br>P=0.139 | 0.8475<br>P=0.004    | 0.5285<br>P=0.089                   | 0.2691<br>P=0.260                     | 0.3793<br>P=0.177  | 0.0297<br>P=0.472  | -0.5982<br>P=0.059   | 0.3773<br>P=0.178                                      |
| pH   | -                       | -                 | -0.4172<br>P=0.152 | 0.9200<br>P=0.001    | 0.7570<br>P=0.015                   | 0.5828<br>P=0.065                     | 0.2266<br>P=0.295  | 0.2742<br>P=0.256  | -0.3564<br>P=0.193   | 0.6115<br>P=0.054                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.1703<br>P=0.343   | 0.0787<br>P=0.426                   | 0.0615<br>P=0.442                     | 0.4437<br>P=0.135  | -0.2334<br>P=0.289   | 0.5217<br>P=0.092  | 0.2266<br>P=0.295                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.7505<br>P=0.016                   | 0.5494<br>P=0.079                     | 0.2290<br>P=0.293  | 0.3354<br>P=0.208  | -0.1896<br>P=0.326   | 0.7021<br>P=0.026                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.9239<br>P=0.001                     | 0.2191<br>P=0.301  | 0.3055<br>P=0.231  | 0.1686<br>P=0.345  | 0.8172<br>P=0.007                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.0406<br>P=0.462  | 0.5373<br>P=0.085  | 0.4341<br>P=0.141  | 0.7119<br>P=0.024                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.3434<br>P=0.203   | -0.1438<br>P=0.367   | 0.1092<br>P=0.398                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.5708<br>P=0.070  | 0.1892<br>P=0.327                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.1121<br>P=0.396                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-48: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell B, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9091<br>P=0.001 | -0.5398<br>P=0.084 | 0.9463<br>P=0.000    | 0.6349<br>P=0.045                   | 0.6636<br>P=0.036                     | -0.3987<br>P=0.164   | -0.4511<br>P=0.131   | 0.6197<br>P=0.051  | 0.3476<br>P=0.199                                      |
| pH   |                         | -                 | -0.5074<br>P=0.100 | 0.9706<br>P=0.000    | 0.7507<br>P=0.016                   | 0.6034<br>P=0.057                     | -0.7161<br>P=0.023   | -0.6991<br>P=0.027   | 0.6430<br>P=0.043  | 0.6299<br>P=0.047                                      |
| Temperature (°C)   |                         |                   | -                  | -0.5399<br>P=0.084   | 0.0757<br>P=0.429                   | -0.1226<br>P=0.386                    | 0.4309<br>P=0.143  | 0.4195<br>P=0.150  | -0.2386<br>P=0.285   | 0.0886<br>P=0.417                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.7324<br>P=0.019                   | 0.7125<br>P=0.024                     | -0.6122<br>P=0.053   | -0.5587<br>P=0.075   | 0.6146<br>P=0.052  | 0.4920<br>P=0.108                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.7325<br>P=0.019                     | -0.4166<br>P=0.152   | -0.3086<br>P=0.229   | 0.4025<br>P=0.161  | 0.8087<br>P=0.008                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | -0.1514<br>P=0.360   | -0.1341<br>P=0.376   | 0.5207<br>P=0.093  | 0.2311<br>P=0.291                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.8834<br>P=0.002  | -0.5024<br>P=0.102   | -0.6312<br>P=0.047                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | -0.6985<br>P=0.027   | -0.4983<br>P=0.104                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | 0.2311<br>P=0.291                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-49: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell C, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9303<br>P=0.000 | -0.6871<br>P=0.030 | 0.8988<br>P=0.001    | -0.5277<br>P=0.089                  | -0.1367<br>P=0.373                    | -0.0125<br>P=0.488   | -0.0291<br>P=0.473   | 0.0340<br>P=0.468  | 0.4117<br>P=0.155                                      |
| pH   |                         | -                 | -0.5565<br>P=0.076 | 0.9026<br>P=0.001    | -0.3610<br>P=0.190                  | 0.0055<br>P=0.495                     | 0.2111<br>P=0.308  | 0.0670<br>P=0.437  | -0.2514<br>P=0.274   | 0.7034<br>P=0.026                                      |
| Temperature (°C)   |                         |                   | -                  | -0.7444<br>P=0.017   | 0.6120<br>P=0.053                   | -0.0305<br>P=0.471                    | 0.5786<br>P=0.066  | 0.1593<br>P=0.353  | -0.3783<br>P=0.178   | -0.1380<br>P=0.372                                     |
| Redox Potential (mv)   |                         |                   |                    | -                    | -0.4912<br>P=0.108                  | 0.1146<br>P=0.394                     | 0.0890<br>P=0.417  | 0.1233<br>P=0.386  | -0.1911<br>P=0.325   | 0.5486<br>P=0.080                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.4852<br>P=0.111                     | 0.4503<br>P=0.131  | 0.2885<br>P=0.244  | -0.4096<br>P=0.157   | 0.2519<br>P=0.274                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.2969<br>P=0.238  | 0.7495<br>P=0.016  | -0.5196<br>P=0.093   | 0.4216<br>P=0.149                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | 0.5490<br>P=0.079  | -0.8416<br>P=0.004   | 0.5146<br>P=0.096                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | -0.4364<br>P=0.140   | 0.2635<br>P=0.264                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.6832<br>P=0.031                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-50: Correlation Coefficients for Parameter Measured During Materials Balance Efforts for Tank 3, Cell C, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9388<br>P=0.000 | -0.5560<br>P=0.076 | 0.9205<br>P=0.001    | -0.3918<br>P=0.169                  | 0.1288<br>P=0.381                     | -0.4304<br>P=0.144   | -0.5313<br>P=0.088   | -0.2683<br>P=0.260   | 0.4185<br>P=0.151                                      |
| pH   | -                       | -                 | -0.4691<br>P=0.120 | 0.8736<br>P=0.002    | -0.2162<br>P=0.304                  | 0.0693<br>P=0.436                     | -0.2753<br>P=0.255   | -0.4528<br>P=0.130   | -0.2591<br>P=0.268   | 0.6983<br>P=0.027                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.6126<br>P=0.053   | 0.6851<br>P=0.030                   | -0.3951<br>P=0.166                    | 0.7371<br>P=0.018  | 0.0383<br>P=0.464  | -0.2359<br>P=0.287   | -0.0489<br>P=0.454                                     |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | -0.3920<br>P=0.168                  | 0.1616<br>P=0.351                     | -0.3023<br>P=0.233   | -0.2337<br>P=0.289   | -0.2259<br>P=0.295   | 0.4087<br>P=0.157                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.2618<br>P=0.266                     | 0.7551<br>P=0.015  | -0.0427<br>P=0.460   | -0.4434<br>P=0.136   | 0.3040<br>P=0.232                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | -0.0219<br>P=0.480   | -0.2594<br>P=0.267   | -0.1097<br>P=0.398   | -0.0527<br>P=0.451                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | 0.1470<br>P=0.364  | -0.0565<br>P=0.447   | 0.1653<br>P=0.348                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | 0.3123<br>P=0.226  | -0.0597<br>P=0.444                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -0.1996<br>P=0.318                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |

Table IV-51: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell C, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9347<br>P=0.000 | -0.4937<br>P=0.107 | 0.9670<br>P=0.000    | -0.4090<br>P=0.157                  | 0.5598<br>P=0.075                     | -0.4453<br>P=0.134   | -0.0397<br>P=0.463   | 0.3982<br>P=0.164  | 0.3875<br>P=0.171                                      |
| pH   |                         | -                 | -0.4140<br>P=0.154 | 0.8975<br>P=0.001    | -0.2985<br>P=0.236                  | 0.3566<br>P=0.193                     | -0.6156<br>P=0.052   | 0.1911<br>P=0.325  | 0.3471<br>P=0.200  | 0.6694<br>P=0.035                                      |
| Temperature (°C)   |                         |                   | -                  | -0.5655<br>P=0.072   | 0.3223<br>P=0.218                   | -0.1366<br>P=0.374                    | -0.1892<br>P=0.327   | 0.4240<br>P=0.148  | -0.2907<br>P=0.242   | -0.0752<br>P=0.430                                     |
| Redox Potential (mv)   |                         |                   |                    | -                    | -0.5074<br>P=0.100                  | 0.5309<br>P=0.088                     | -0.3989<br>P=0.164   | -0.1409<br>P=0.370   | 0.3032<br>P=0.233  | 0.3540<br>P=0.195                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | -0.5447<br>P=0.081                    | 0.4052<br>P=0.160  | -0.1576<br>P=0.355   | -0.1578<br>P=0.355   | 0.1041<br>P=0.403                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | -0.0966<br>P=0.410   | -0.0550<br>P=0.449   | -0.0320<br>P=0.470   | -0.0292<br>P=0.473                                     |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.6985<br>P=0.027   | -0.4125<br>P=0.155   | -0.5715<br>P=0.069                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | -0.0317<br>P=0.470   | 0.5058<br>P=0.100                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.0504<br>P=0.453                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-52: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell D, Depth 3 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9299<br>P=0.000 | -0.5934<br>P=0.060 | 0.8596<br>P=0.003    | 0.0235<br>P=0.478                   | -0.0870<br>P=0.419                    | 0.1002<br>P=0.407  | 0.5270<br>P=0.090  | -0.4899<br>P=0.109   | 0.1828<br>P=0.332                                      |
| pH   |                         | -                 | -0.4991<br>P=0.104 | 0.8940<br>P=0.001    | 0.2634<br>P=0.264                   | 0.0264<br>P=0.475                     | 0.3642<br>P=0.188  | 0.5747<br>P=0.068  | -0.3616<br>P=0.189   | 0.4527<br>P=0.130                                      |
| Temperature (°C)   |                         |                   | -                  | -0.7407<br>P=0.018   | 0.0678<br>P=0.437                   | 0.0262<br>P=0.475                     | 0.3830<br>P=0.174  | -0.3245<br>P=0.216   | 0.1792<br>P=0.336  | 0.4717<br>P=0.119                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.3099<br>P=0.228                   | 0.1584<br>P=0.354                     | 0.2397<br>P=0.284  | 0.5860<br>P=0.063  | -0.2282<br>P=0.293   | 0.1646<br>P=0.348                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.9010<br>P=0.001                     | 0.8445<br>P=0.004  | -0.2307<br>P=0.291   | -0.0697<br>P=0.435   | 0.4608<br>P=0.125                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.6074<br>P=0.055  | -0.4827<br>P=0.113   | -0.2362<br>P=0.287   | 0.1115<br>P=0.396                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.0012<br>P=0.499   | 0.0419<br>P=0.461  | 0.8146<br>P=0.007                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.1135<br>P=0.394  | 0.3105<br>P=0.227                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | -0.0062<br>P=0.494                                     |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

Table IV-53: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell D, Depth 18 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9434<br>P=0.000 | -0.5976<br>P=0.059 | 0.8716<br>P=0.002    | -0.0365<br>P=0.466                  | 0.0956<br>P=0.411                     | -0.5874<br>P=0.063   | 0.1504<br>P=0.361  | 0.3293<br>P=0.213  | 0.1743<br>P=0.340                                      |
| pH   | -                       | -                 | -0.4398<br>P=0.138 | 0.9020<br>P=0.001    | 0.1007<br>P=0.406                   | 0.1485<br>P=0.363                     | -0.3831<br>P=0.174   | 0.0237<br>P=0.478  | 0.5390<br>P=0.084  | 0.4344<br>P=0.141                                      |
| Temperature (°C)   | -                       | -                 | -                  | -0.6253<br>P=0.049   | 0.4939<br>P=0.107                   | 0.5237<br>P=0.091                     | 0.5441<br>P=0.082  | -0.6567<br>P=0.038   | -0.2177<br>P=0.302   | 0.5428<br>P=0.082                                      |
| Redox Potential (mv)   | -                       | -                 | -                  | -                    | 0.1659<br>P=0.347                   | 0.1297<br>P=0.380                     | -0.2610<br>P=0.266   | 0.2017<br>P=0.316  | 0.6765<br>P=0.033  | 0.2767<br>P=0.254                                      |
| Orthophosphate Concentration (mg/l)                          | -                       | -                 | -                  | -                    | -                                   | 0.8821<br>P=0.002                     | 0.5472<br>P=0.080  | -0.7243<br>P=0.021   | 0.4452<br>P=0.134  | 0.6898<br>P=0.029                                      |
| Total Phosphorus Concentration (mg/l)                        | -                       | -                 | -                  | -                    | -                                   | -                                     | 0.2850<br>P=0.247  | -0.6299<br>P=0.047   | 0.0928<br>P=0.413  | 0.6340<br>P=0.046                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -0.4262<br>P=0.146   | 0.3493<br>P=0.198  | 0.3073<br>P=0.230                                      |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -0.1388<br>P=0.372   | -0.5730<br>P=0.069                                     |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | 0.5083<br>P=0.099                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       | -                       | -                 | -                  | -                    | -                                   | -                                     | -  | -  | -  | -  |



Table IV-54: Correlation Coefficients for Parameters Measured During Materials Balance Efforts for Tank 3, Cell D, Depth 33 Inches (8 Samples)

| Parameters   | Dissolved Oxygen (mg/l) | pH                | Temperature (°C)   | Redox Potential (mv) | Orthophosphate Concentration (mg/l) | Total Phosphorus Concentration (mg/l) | P-32 Content of the Bulk Water-Decay Corrected (millicuries) | P-32 Content of Exterior Walls-Decay Corrected (millicuries) | P-32 Content of Baffle Walls-Decay Corrected (millicuries) | P-32 Content of Sediment-Decay Corrected (millicuries) |
|--|-------------------------|-------------------|--------------------|----------------------|-------------------------------------|---------------------------------------|--|--|--|--|
| Dissolved Oxygen (mg/l)                                      | -                       | 0.9420<br>P=0.000 | -0.6776<br>P=0.032 | 0.7886<br>P=0.010    | 0.0233<br>P=0.478                   | 0.3022<br>P=0.233                     | -0.5814<br>P=0.065   | 0.0848<br>P=0.421  | -0.3368<br>P=0.207   | 0.1727<br>P=0.341                                      |
| pH   |                         | -                 | -0.6125<br>P=0.053 | 0.8839<br>P=0.002    | 0.1370<br>P=0.373                   | 0.3263<br>P=0.215                     | -0.5661<br>P=0.072   | 0.2418<br>P=0.282  | -0.3065<br>P=0.230   | 0.3816<br>P=0.175                                      |
| Temperature (°C)   |                         |                   | -                  | -0.6440<br>P=0.042   | -0.0902<br>P=0.416                  | -0.1987<br>P=0.319                    | 0.2945<br>P=0.239  | 0.5247<br>P=0.091  | 0.4494<br>P=0.132  | 0.4211<br>P=0.149                                      |
| Redox Potential (mv)   |                         |                   |                    | -                    | 0.2754<br>P=0.255                   | 0.3986<br>P=0.164                     | -0.3074<br>P=0.229   | 0.2697<br>P=0.259  | -0.2478<br>P=0.277   | 0.3712<br>P=0.183                                      |
| Orthophosphate Concentration (mg/l)                          |                         |                   |                    |                      | -                                   | 0.8647<br>P=0.003                     | 0.2644<br>P=0.263  | 0.0820<br>P=0.423  | 0.7194<br>P=0.022  | 0.2741<br>P=0.256                                      |
| Total Phosphorus Concentration (mg/l)                        |                         |                   |                    |                      |                                     | -                                     | 0.0882<br>P=0.418  | 0.0288<br>P=0.473  | 0.7382<br>P=0.018  | 0.2057<br>P=0.313                                      |
| P-32 Content of the Bulk Water-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       | -  | -0.0448<br>P=0.458   | 0.3565<br>P=0.193  | -0.1390<br>P=0.371                                     |
| P-32 Content of Exterior Walls-Decay Corrected (millicuries) |                         |                   |                    |                      |                                     |                                       |  | -  | 0.1159<br>P=0.392  | 0.9524<br>P=0.000                                      |
| P-32 Content of Baffle Walls-Decay Corrected (millicuries)   |                         |                   |                    |                      |                                     |                                       |  |  | -  | 0.2082<br>P=0.310                                      |
| P-32 Content of Sediment-Decay Corrected (millicuries)       |                         |                   |                    |                      |                                     |                                       |  |  |  | -  |

95% confidence level) between dissolved oxygen and pH, dissolved oxygen and redox potential and pH and redox potential. The other correlations at this confidence level were less consistent between all the other pairs of parameters. Since only eight measurements were taken the degrees of freedom were much less for this analysis than for the seventy-three measurements taken at each location for correlation analysis on a daily basis. Probably a more accurate picture of the relationships between the parameters measured can best be obtained from that daily analysis.

There were some other fairly consistent significant correlation relationships during the materials balance efforts between certain of the parameters as listed in Table IV-55. Although more consistent significant relationships were not obtained between orthophosphate and total phosphorus and radiophosphorus of the bulk water, as hoped, these relationships were obtained during the analysis of the daily data. Some caution must therefore be taken in using one of these three parameters to estimate the value of any of the others at a given time and location.

#### Materials Balance Measurements

During eight times and conditions as listed in Table IV-11 sampling of the tanks was undertaken to determine the fate and movement of the radiophosphorus. The radiophosphorus in the bulk water was sampled at three depths at each of four locations in each tank. The four locations are the middle of Cells A, B, C and D as shown in Figure IV-13. The liquid samples were corrected for decay and counting efficiency, multiplied by the size of the compartment and converted to millicuries. Solid samples were collected from the walls and sediment in each of the four cells in each tank. These samples were also corrected

Table IV-55: Description of Some of the Significant Correlations Between Parameters Obtained During Materials Balance Efforts

| Parameter Pair                                    | Description of Significant Correlations   |
|---|---|
| Orthophosphate and Total phosphorus of Bulk Water | Tank 1 Bottom Depth<br>Tank 2 Cells C&D All Depths<br>Tank 3 Cells C&D All Depths |
| Orthophosphate and Radiophosphorus of Bulk Water  | Tank 2 Top and Middle Depths<br>Tank 3 Top Depth                                  |
| Radiophosphorus of Bulk Water and of Sediment     | Tank 1 Cell A and Top Depth   |

for decay, counting efficiency and loss by self-absorption, multiplied by the size of the compartment and converted to millicuries. The total of the radiophosphorus in each tank was found by summing that in each compartment including the cumulative amount in the effluent. The procedure used to correct for counting efficiency and self-absorption loss was described in Chapter III. The factors calculated to determine the amount of radiophosphorus in each compartment are summarized in Table IV-56. The calculation of these factors is detailed in Appendix C.

The results of the calculation of radiophosphorus content of each of the compartments and for each of the tanks are summarized in Table IV-57 and IV-58. As shown in Table IV-57 in Tanks 1 and 3 generally more than 90 percent of the total radiophosphorus initially placed in these tanks was accounted for by this method. This accounting rate is very acceptable when considering the uncertainty in the sampling, measurement and analysis methods used. In Tank 2 an average of about 86 percent of the radiophosphorus was accounted for which is only marginally acceptable since about 14 percent or 0.63 millicuries of the radiophosphorus initially placed in that tank was not accounted for on the average.

Table IV-58 shows the breakdown by compartment of the radiophosphorus content in each tank at the time materials balance efforts were made. Most of the radiophosphorus accounted for was in the bulk water. In Tank 1 which was loaded at a lesser rate the amount of radiophosphorus in the bulk water was about 10 percent greater than in Tanks 2 and 3. In those tanks there was a larger percentage of the radiophosphorus associated with the solid phase compartments including the sediment, the exterior walls and the baffle walls.

Table IV-56: Summary of Compartment Size  
Factors Used In Materials  
Balance Estimations

| Compartment                        | Cell A | Cell B | Cell C | Cell D |
|------------------------------------|--------|--------|--------|--------|
| Bulk Water                         |        |        |        |        |
| Top                                | 19.851 | 19.851 | 19.851 | 19.851 |
| Middle                             | 79.403 | 79.403 | 79.403 | 79.403 |
| Bottom                             | 19.851 | 19.851 | 19.851 | 19.851 |
| Sediment                           | 1.369  | 1.369  | 1.369  | 1.369  |
| Strings of<br>Sediment<br>Samplers | 8*     | 8*     | 8*     | 8*     |
| Baffle                             |        |        |        |        |
| Top                                | 43.45  | 37.72  | 37.72  | 43.45  |
| Middle                             | 173.80 | 162.33 | 162.33 | 173.80 |
| Bottom                             | 43.45  | 43.45  | 43.45  | 43.45  |
| Strings                            | 8*     | 8*     | 8*     | 8*     |
| Exterior<br>Wall                   |        |        |        |        |
| Top                                | 68.25  | 68.25  | 68.25  | 68.25  |
| Middle                             | 273.00 | 273.00 | 273.00 | 273.00 |
| Bottom                             | 68.25  | 68.25  | 68.25  | 68.25  |
| Strings                            | 8*     | 8*     | 8*     | 8*     |

\*The size of the string compartment decreased by 1 for each materials balance effort after the first.

Table IV-57: Radiophosphorus Accounted for During Materials Balance Determinations  
(Millicuries and Percent of Radiophosphorus Applied)

| Container | Materials Balance Effort |                    |                   |                    |                   |                   |                   |                   | Average           |
|-----------|--------------------------|--------------------|-------------------|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|           | 1                        | 2                  | 3                 | 4                  | 5                 | 6                 | 7                 | 8                 |                   |
| Tank 1    | 4.3679<br>(97.06)        | 4.3219<br>(96.04)  | 4.4835<br>(99.63) | 4.5168<br>(100.37) | 4.1332<br>(91.85) | 4.0015<br>(88.92) | 4.1164<br>(91.48) | 3.9595<br>(87.99) | 4.2376<br>(94.17) |
| Tank 2    | 3.8165<br>(84.81)        | 3.6797<br>(81.77)  | 3.8766<br>(86.15) | 3.9685<br>(88.19)  | 4.2010<br>(93.36) | 4.0046<br>(88.99) | 3.6031<br>(80.07) | 3.8342<br>(85.20) | 3.8730<br>(86.07) |
| Tank 3    | 4.0454<br>(89.90)        | 4.6534<br>(103.41) | 4.2183<br>(93.74) | 4.4439<br>(98.75)  | 4.2609<br>(94.69) | 4.3791<br>(97.31) | 4.1762<br>(92.80) | 3.9610<br>(88.02) | 4.2673<br>(94.83) |

Table IV-58: Radiophosphorus Content of Compartments During Materials Balance Determinations (Millicuries and Percent in Compartment of that Determined)

| Tank | Compartment      | Materials Balance (Millicuries and %) at Days after Initial Spike |                   |                   |                   |                   |                   |                   |                   |
|------|------------------|---|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|      |                  | 1 (6.3)   | 2 (10.0)          | 3 (14.0)          | 4 (18.4)          | 5 (23.4)          | 6 (28.0)          | 7 (32.0)          | 8 (37.0)          |
| 1    | Bulk Water       | 2.9275<br>(67.02)   | 2.8596<br>(66.17) | 2.7890<br>(62.21) | 2.7374<br>(60.60) | 2.6100<br>(63.15) | 2.5672<br>(64.16) | 2.5423<br>(61.76) | 2.3389<br>(59.07) |
|      | Sediment         | 0.3139<br>(7.19)  | 0.2900<br>(6.71)  | 0.2631<br>(5.87)  | 0.2700<br>(5.98)  | 0.2789<br>(6.75)  | 0.2306<br>(5.76)  | 0.2003<br>(4.87)  | 0.1900<br>(4.80)  |
|      | Exterior Walls   | 0.5998<br>(13.73)   | 0.5302<br>(12.27) | 0.6494<br>(14.48) | 0.6531<br>(14.46) | 0.4604<br>(11.14) | 0.3483<br>(8.70)  | 0.4405<br>(10.70) | 0.4686<br>(11.83) |
|      | Baffle Walls     | 0.1890<br>(4.33)  | 0.2959<br>(6.85)  | 0.3185<br>(7.10)  | 0.3781<br>(8.37)  | 0.2351<br>(5.69)  | 0.2637<br>(6.59)  | 0.3191<br>(7.75)  | 0.2966<br>(7.49)  |
|      | Sediment Strings | 0.0530<br>(1.21)  | 0.0285<br>(0.66)  | 0.0598<br>(1.33)  | 0.0335<br>(0.74)  | 0.0294<br>(0.71)  | 0.0277<br>(0.67)  | 0.0171<br>(0.42)  | 0.0117<br>(0.30)  |
|      | Effluent         | 0.2847<br>(6.52)  | 0.3177<br>(7.35)  | 0.4037<br>(9.00)  | 0.4447<br>(9.85)  | 0.5194<br>(12.57) | 0.5640<br>(14.09) | 0.5971<br>(14.51) | 0.6537<br>(16.51) |
|      |                  | 2.1811<br>(57.15)   | 2.1462<br>(58.33) | 2.1360<br>(55.10) | 2.0986<br>(52.88) | 1.9905<br>(47.38) | 1.9475<br>(48.63) | 1.9789<br>(54.92) | 1.8615<br>(48.55) |
| 2    | Bulk Water       | 0.3263<br>(8.55)  | 0.3200<br>(8.70)  | 0.3057<br>(7.89)  | 0.3100<br>(7.81)  | 0.3201<br>(7.62)  | 0.3096<br>(7.73)  | 0.2404<br>(6.67)  | 0.2302<br>(6.00)  |
|      | Sediment         | 0.7029<br>(18.42)   | 0.6109<br>(16.60) | 0.7196<br>(18.56) | 0.7341<br>(18.50) | 1.0452<br>(24.88) | 0.9092<br>(22.70) | 0.5746<br>(15.95) | 0.8308<br>(21.67) |
|      | Exterior Walls   | 0.3417<br>(8.95)  | 0.2257<br>(6.13)  | 0.3336<br>(8.61)  | 0.4596<br>(11.58) | 0.4706<br>(11.20) | 0.4347<br>(10.86) | 0.3957<br>(10.98) | 0.4595<br>(11.98) |
|      | Baffle Walls     | 0.0576<br>(1.51)  | 0.0875<br>(2.38)  | 0.0427<br>(1.10)  | 0.0255<br>(0.64)  | 0.0221<br>(0.53)  | 0.0210<br>(0.52)  | 0.0100<br>(0.28)  | 0.0054<br>(0.14)  |
|      | Sediment Strings | 0.2069<br>(5.42)  | 0.2894<br>(7.86)  | 0.3390<br>(8.74)  | 0.3407<br>(8.59)  | 0.3525<br>(8.39)  | 0.3826<br>(9.55)  | 0.4035<br>(11.20) | 0.4468<br>(11.65) |
|      | Effluent         | 2.3848<br>(58.95)   | 2.3322<br>(50.12) | 2.3629<br>(56.02) | 2.3119<br>(52.02) | 2.1482<br>(50.42) | 2.1229<br>(48.48) | 2.2057<br>(52.82) | 2.0816<br>(52.55) |
|      |                  | 0.4817<br>(11.91)   | 0.4600<br>(9.89)  | 0.4026<br>(9.54)  | 0.3884<br>(8.74)  | 0.4400<br>(10.33) | 0.4200<br>(9.59)  | 0.3599<br>(8.62)  | 0.3299<br>(8.33)  |
| 3    | Bulk Water       | 0.6165<br>(15.24)   | 1.1245<br>(24.17) | 0.5926<br>(14.05) | 0.8441<br>(18.99) | 0.7774<br>(18.24) | 0.8220<br>(18.77) | 0.6236<br>(14.93) | 0.6196<br>(15.64) |
|      | Sediment         | 0.2886<br>(7.13)  | 0.3698<br>(7.95)  | 0.4418<br>(10.47) | 0.4793<br>(10.79) | 0.4365<br>(10.24) | 0.5400<br>(12.33) | 0.4849<br>(11.61) | 0.3510<br>(8.86)  |
|      | Exterior Walls   | 0.0464<br>(1.15)  | 0.0453<br>(0.97)  | 0.0313<br>(0.74)  | 0.0231<br>(0.52)  | 0.0229<br>(0.54)  | 0.0166<br>(0.38)  | 0.0134<br>(0.32)  | 0.0058<br>(0.15)  |
|      | Baffle Walls     | 0.2274<br>(5.62)  | 0.3216<br>(6.91)  | 0.3871<br>(9.18)  | 0.3971<br>(8.94)  | 0.4359<br>(10.23) | 0.4576<br>(10.45) | 0.4887<br>(11.70) | 0.5731<br>(14.47) |
|      | Sediment Strings |   |                   |                   |                   |                   |                   |                   |                   |
|      | Effluent         |   |                   |                   |                   |                   |                   |                   |                   |
|      |                  |   |                   |                   |                   |                   |                   |                   |                   |

This can be seen more clearly in Table IV-59 where the percentage of radiophosphorus in each compartment of that remaining in the tank is given. In a steady state system where such parameters as dissolved oxygen, pH and redox potential were maintained at a constant level the radiophosphorus in the sediment would be expected to increase with time. In each of the tanks in this study which were operated under changing environmental conditions there were increases and decreases in the radiophosphorus content of the sediment suggesting possible sorption and desorption activity. Generally, it appears that in all three tanks the sediment gained radiophosphorus during oxidized conditions and lost radiophosphorus during reducing conditions.

The hypothesis that radiophosphorus was sorbed and desorbed by the sediment would be strengthened by uptake and release in other compartments. The radiophosphorus content of the whole bulk water compartment generally declined in each tank due, at least partially, to outflow to the effluent. Changes in radiophosphorus content of the exterior wall and baffle wall compartments varied inconsistently with the changes in the sediment. The sediment sampler strings compartment radiophosphorus content decreased during the experiment because of its small size and rapid decrease in size. It played only a minor role in the movement of radiophosphorus in all cases, being less than 3 percent of the total.

Of particular interest are the changes in radiophosphorus content of the three depths of bulk water that was sampled. This is summarized in Table IV-60. A comparison of the bottom compartment in each of the tanks in this table with the sediment compartment in Table IV-58 shows that as the radiophosphorus content of the sediment increased



Table IV-59: Percent of Radiophosphorus Remaining in Each Tank in Each Compartment for Materials Balance Determinations

| Tank | Compartment      | Materials Balance Determination (Days After Initial Spike) |          |          |          |          |          |          |          |
|------|------------------|--|----------|----------|----------|----------|----------|----------|----------|
|      |                  | 1 (6.3)  | 2 (10.0) | 3 (14.0) | 4 (18.4) | 5 (23.4) | 6 (28.0) | 7 (37.0) | 8 (37.0) |
| 1    | Bulk Water       | 71.70  | 71.42    | 68.36    | 67.22    | 72.22    | 74.68    | 72.24    | 70.75    |
|      | Sediment         | 7.69   | 7.24     | 6.45     | 6.63     | 7.72     | 6.71     | 5.69     | 5.75     |
|      | Exterior Walls   | 14.69  | 13.24    | 15.92    | 16.04    | 12.74    | 10.13    | 12.52    | 14.18    |
|      | Baffle Walls     | 4.63   | 7.39     | 7.81     | 9.29     | 6.51     | 7.67     | 9.07     | 8.97     |
|      | Sediment Strings | 1.30   | 0.71     | 1.46     | 0.82     | 0.81     | 0.81     | 0.49     | 0.35     |
| 2    | Bulk Water       | 60.42  | 63.30    | 60.38    | 57.85    | 51.72    | 53.77    | 61.85    | 54.95    |
|      | Sediment         | 9.04   | 9.44     | 8.64     | 8.55     | 8.32     | 8.55     | 7.51     | 6.80     |
|      | Exterior Walls   | 19.47  | 18.02    | 20.34    | 20.24    | 27.16    | 25.10    | 17.96    | 24.53    |
|      | Baffle Walls     | 9.47   | 6.66     | 9.43     | 12.67    | 12.23    | 12.00    | 12.37    | 13.56    |
|      | Sediment Strings | 1.60   | 2.58     | 1.21     | 0.70     | 0.57     | 0.58     | 0.31     | 0.16     |
| 3    | Bulk Water       | 62.46  | 53.84    | 61.68    | 57.13    | 56.16    | 54.13    | 59.82    | 61.44    |
|      | Sediment         | 12.62  | 10.62    | 10.51    | 9.60     | 11.50    | 10.71    | 9.76     | 9.74     |
|      | Exterior Walls   | 16.15  | 25.96    | 15.47    | 20.86    | 20.32    | 20.96    | 16.91    | 18.29    |
|      | Baffle Walls     | 7.56   | 8.54     | 11.53    | 11.84    | 11.41    | 13.77    | 13.15    | 10.36    |
|      | Sediment Strings | 1.22   | 1.05     | 0.82     | 0.57     | 0.60     | 0.42     | 0.36     | 0.17     |

Table IV-60: Radiophosphorus Content of Bulk Water with Depth During Materials Balance Measurements (Millicuries)

| Location |        | Materials Balance Effort (Days After Initial Spike) |          |          |          |          |          |          |          |
|----------|--------|---|----------|----------|----------|----------|----------|----------|----------|
|          |        | 1 (6.3)   | 2 (10.0) | 3 (14.0) | 4 (18.4) | 5 (23.4) | 6 (28.0) | 7 (32.0) | 8 (37.0) |
| Tank 1   | Top    | 0.44327   | 0.40985  | 0.38124  | 0.37033  | 0.350355 | 0.30052  | 0.28075  | 0.22126  |
|          | Middle | 2.1929  | 2.1672   | 2.0813   | 2.0703   | 1.9997   | 1.9465   | 1.9415   | 1.8779   |
|          | Bottom | 0.29131   | 0.28251  | 0.32646  | 0.29676  | 0.25997  | 0.32021  | 0.32006  | 0.23973  |
|          | Total  | 2.92748   | 2.84946  | 2.78900  | 2.73739  | 2.610025 | 2.56723  | 2.54231  | 2.33889  |
| Tank 2   | Top    | 0.39996   | 0.3813   | 0.36623  | 0.37005  | 0.34897  | 0.33801  | 0.3196   | 0.28018  |
|          | Middle | 1.4525  | 1.4201   | 1.3990   | 1.3795   | 1.3417   | 1.3095   | 1.3013   | 1.2613   |
|          | Bottom | 0.32859   | 0.34475  | 0.37078  | 0.34902  | 0.29986  | 0.29994  | 0.35799  | 0.32003  |
|          | Total  | 2.18105   | 2.14615  | 2.13601  | 2.09857  | 1.99053  | 1.94745  | 1.97889  | 1.86151  |
| Tank 3   | Top    | 0.36015   | 0.34447  | 0.33606  | 0.32988  | 0.30871  | 0.29237  | 0.30007  | 0.26992  |
|          | Middle | 1.67070   | 1.6356   | 1.6363   | 1.6033   | 1.5195   | 1.5005   | 1.5009   | 1.4384   |
|          | Bottom | 0.35395   | 0.35208  | 0.3905   | 0.3787   | 0.3200   | 0.33005  | 0.40469  | 0.37331  |
|          | Total  | 2.38480   | 2.33215  | 2.36286  | 2.31188  | 2.14821  | 2.12292  | 2.20566  | 2.08163  |

the content of the bottom compartment of the bulk water decreased and vice versa. This is especially consistent for Tanks 2 and 3. The radiophosphorus content of the bottom level of the bulk water was usually greatest at materials balance efforts 3 and 7 and minimal at materials balance effort 5. The top and middle levels of the bulk water generally declined throughout the materials balance efforts in the operational phase. The diffusion or transport of any radiophosphorus released from the sediment above the bottom level of the bulk water may have been minimal because of the limited mixing that apparently occurred in the tanks. In the field much more mixing and transport of released phosphorus to the upper layers of waste stabilization ponds may occur.

Table IV-61 shows the percent of the radiophosphorus in the bulk water in each of the three levels sampled. Generally, the percentage of radiophosphorus in the top layer declined throughout the operational phase in all three tanks while the content of the middle layer remained relatively constant and the content of the bottom layer showed peaks at efforts 3 and 7 and minimums at efforts 1 and 5. This further suggests that some interaction between the bottom layer of the bulk water and the sediment occurred.

A breakdown by cell of the radiophosphorus content of the compartments other than the bulk water and the effluent is given in Table IV-62, IV-63, IV-64 for each of the tanks. The radiophosphorus was evenly distributed in each of the cells in the sediment and sediment sampler strings in all three tanks. Also, all of the cells in Tanks 1 and 3 showed a decrease in the radiophosphorus content of the sediment compartment through the first three materials balance efforts. The

Table IV-61: Percent of Radiophosphorus Remaining in Bulk Water with Depth for Materials Balance Determinations

| Location |        | Materials Balance Determination (Days After Initial Spike) |          |          |          |          |          |          |          |
|----------|--------|--|----------|----------|----------|----------|----------|----------|----------|
|          |        | 1 (6.3)  | 2 (10.0) | 3 (14.0) | 4 (13.4) | 5 (23.4) | 6 (28.0) | 7 (32.0) | 8 (37.0) |
| Tank 1   | Top    | 15.14  | 14.33    | 13.67    | 13.53    | 13.42    | 11.71    | 11.04    | 9.46     |
|          | Middle | 74.91  | 75.79    | 74.63    | 75.63    | 76.62    | 75.82    | 76.37    | 80.29    |
|          | Bottom | 9.95   | 9.88     | 11.71    | 10.84    | 9.96     | 12.47    | 12.59    | 10.25    |
| Tank 2   | Top    | 18.34  | 17.77    | 17.15    | 17.63    | 17.53    | 17.36    | 16.15    | 15.05    |
|          | Middle | 66.60  | 66.17    | 65.50    | 65.74    | 67.40    | 67.24    | 65.76    | 67.76    |
|          | Bottom | 15.07  | 16.06    | 17.36    | 16.63    | 15.06    | 15.40    | 18.09    | 17.19    |
| Tank 3   | Top    | 15.10  | 14.77    | 14.22    | 14.27    | 14.37    | 13.77    | 13.60    | 12.97    |
|          | Middle | 70.06  | 70.13    | 69.25    | 69.35    | 70.73    | 70.68    | 68.05    | 69.10    |
|          | Bottom | 14.84  | 15.10    | 16.53    | 16.38    | 14.90    | 15.55    | 18.35    | 17.93    |

Table IV-62: Radiophosphorus Content of Exterior Wall, Baffle Wall, Sediment and Sediment Strings in Tank 1 During Materials Balance Measurements (in Millicuries)

| Location |                  | Materials Balance Effort (Days After Initial Spike) |          |          |          |          |          |           |          |
|----------|------------------|---|----------|----------|----------|----------|----------|-----------|----------|
|          |                  | 1 (6.3)   | 2 (10.0) | 3 (14.0) | 4 (18.4) | 5 (23.4) | 6 (28.0) | 7 (32.0)  | 8 (37.0) |
| Cell A   | Exterior Wall    | 0.30200   | 0.28366  | 0.4062   | 0.3658   | 0.1588   | 0.09576  | 0.1584    | 0.1463   |
|          | Baffle Wall      | 0.03570   | 0.043277 | 0.07701  | 0.05104  | 0.02530  | 0.03567  | 0.0309    | 0.0626   |
|          | Sediment         | 0.07484   | 0.07039  | 0.06776  | 0.06844  | 0.06881  | 0.06025  | 0.05714   | 0.05700  |
|          | Sediment Strings | 0.01377   | 0.009549 | 0.02136  | 0.01082  | 0.00651  | 0.009936 | 0.007147  | 0.003055 |
| Cell B   | Exterior Wall    | 0.09470   | 0.07070  | 0.1074   | 0.1034   | 0.1188   | 0.1280   | 0.1390    | 0.1421   |
|          | Baffle Wall      | 0.06331   | 0.13382  | 0.13458  | 0.1405   | 0.07767  | 0.07422  | 0.0917    | 0.0478   |
|          | Sediment         | 0.082901  | 0.06925  | 0.04837  | 0.05292  | 0.05314  | 0.04976  | 0.04463   | 0.04337  |
|          | Sediment Strings | 0.01570   | 0.009382 | 0.02021  | 0.01093  | 0.007203 | 0.009677 | 0.006716  | 0.003278 |
| Cell C   | Exterior Wall    | 0.10101   | 0.08828  | 0.08655  | 0.09605  | 0.1135   | 0.07244  | 0.0878    | 0.1196   |
|          | Baffle Wall      | 0.063856  | 0.034414 | 0.01851  | 0.07991  | 0.05239  | 0.06448  | 0.0841    | 0.0627   |
|          | Sediment         | 0.07056   | 0.06871  | 0.06525  | 0.06914  | 0.07103  | 0.06678  | 0.05818   | 0.05211  |
|          | Sediment Strings | 0.01415   | 0.008133 | 0.002391 | 0.002694 | 0.006967 | 0.001763 | 0.0009425 | 0.002692 |
| Cell D   | Exterior Wall    | 0.102056  | 0.087556 | 0.04927  | 0.08780  | 0.06942  | 0.05213  | 0.0553    | 0.0605   |
|          | Baffle Wall      | 0.026135  | 0.084373 | 0.08835  | 0.1066   | 0.07975  | 0.08930  | 0.1123    | 0.1235   |
|          | Sediment         | 0.08560   | 0.08167  | 0.08174  | 0.07953  | 0.08591  | 0.05384  | 0.04035   | 0.03753  |
|          | Sediment Strings | 0.01207   | 0.001434 | 0.01580  | 0.009023 | 0.008760 | 0.006302 | 0.002293  | 0.002675 |

Table IV-63: Radiophosphorus Content of Exterior Wall, Baffle Wall, Sediment and Sediment Strings in Tank 2 During Materials Balance Measurements (in Millicuries)

| Location |                  | Materials Balance Effort (Days After Initial Spike) |          |          |          |          |          |           |           |
|----------|------------------|---|----------|----------|----------|----------|----------|-----------|-----------|
|          |                  | 1 (6.3)   | 2 (10.0) | 3 (14.0) | 4 (18.4) | 5 (23.4) | 6 (28.0) | 7 (32.0)  | 8 (37.0)  |
| Cell A   | Exterior Wall    | 0.26002   | 0.21596  | 0.38295  | 0.3338   | 0.5801   | 0.4424   | 0.2339    | 0.4762    |
|          | Baffle Wall      | 0.147736  | 0.04567  | 0.11306  | 0.2281   | 0.2475   | 0.1195   | 0.1135    | 0.19108   |
|          | Sediment         | 0.07468   | 0.07509  | 0.08168  | 0.07988  | 0.08111  | 0.08075  | 0.07366   | 0.07224   |
|          | Sediment Strings | 0.01852   | 0.01943  | 0.01318  | 0.009161 | 0.008488 | 0.009100 | 0.003358  | 0.001986  |
| Cell B   | Exterior Wall    | 0.22073   | 0.20152  | 0.1510   | 0.2129   | 0.2562   | 0.2263   | 0.1321    | 0.1896    |
|          | Baffle Wall      | 0.0923  | 0.07688  | 0.07237  | 0.08596  | 0.09360  | 0.1204   | 0.0819    | 0.1261    |
|          | Sediment         | 0.1288  | 0.10362  | 0.09872  | 0.09776  | 0.09882  | 0.09239  | 0.08343   | 0.08055   |
|          | Sediment Strings | 0.01380   | 0.01311  | 0.01200  | 0.004975 | 0.003758 | 0.002697 | 0.0007728 | 0.0004728 |
| Cell C   | Exterior Wall    | 0.08821   | 0.08731  | 0.07647  | 0.06447  | 0.04879  | 0.08549  | 0.07964   | 0.0712    |
|          | Baffle Wall      | 0.04960   | 0.05263  | 0.06876  | 0.07017  | 0.05711  | 0.07278  | 0.0816    | 0.0761    |
|          | Sediment         | 0.05558   | 0.07424  | 0.06205  | 0.06913  | 0.07040  | 0.06828  | 0.04333   | 0.04119   |
|          | Sediment Strings | 0.01662   | 0.04745  | 0.01705  | 0.007178 | 0.006325 | 0.006513 | 0.005141  | 0.00247   |
| Cell D   | Exterior Wall    | 0.13389   | 0.106148 | 0.10914  | 0.1229   | 0.1602   | 0.1550   | 0.1290    | 0.0937    |
|          | Baffle Wall      | 0.05203   | 0.050566 | 0.10914  | 0.07537  | 0.07232  | 0.1220   | 0.1187    | 0.0661    |
|          | Sediment         | 0.06727   | 0.06708  | 0.05038  | 0.06323  | 0.06977  | 0.06820  | 0.04002   | 0.03622   |
|          | Sediment Strings | 0.00862   | 0.007488 | 0.00044  | 0.004194 | 0.003523 | 0.002662 | 0.000709  | 0.0005014 |

Table IV-64: Radiophosphorus Content of Exterior Wall, Baffle Wall, Sediment and Sediment Strings in Tank 3 During Materials Balance Measurements (in Millicuries)

| Location |                  | Materials Balance Effort (Days After Initial Spike) |          |          |          |          |          |          |           |
|----------|------------------|---|----------|----------|----------|----------|----------|----------|-----------|
|          |                  | 1 (6.3)   | 2 (10.0) | 3 (14.0) | 4 (18.4) | 5 (23.4) | 6 (28.0) | 7 (32.0) | 8 (37.0)  |
| Cell A   | Exterior Wall    | 0.26518   | 0.6185   | 0.2963   | 0.3388   | 0.3336   | 0.4025   | 0.3104   | 0.1603    |
|          | Baffle Wall      | 0.03138   | 0.02237  | 0.02560  | 0.2021   | 0.2099   | 0.2153   | 0.2324   | 0.1363    |
|          | Sediment         | 0.11495   | 0.11498  | 0.14569  | 0.14573  | 0.15234  | 0.13977  | 0.12746  | 0.18819   |
|          | Sediment Strings | 0.009247  | 0.009882 | 0.01035  | 0.002052 | 0.004533 | 0.004534 | 0.003508 | 0.0008812 |
| Cell B   | Exterior Wall    | 0.13177   | 0.27118  | 0.109175 | 0.12269  | 0.2260   | 0.1976   | 0.1260   | 0.1903    |
|          | Baffle Wall      | 0.062115  | 0.13956  | 0.09806  | 0.09730  | 0.0944   | 0.1323   | 0.0930   | 0.0645    |
|          | Sediment         | 0.10877   | 0.09611  | 0.08039  | 0.08124  | 0.08277  | 0.08053  | 0.07543  | 0.07421   |
|          | Sediment Strings | 0.01412   | 0.01614  | 0.003699 | 0.008971 | 0.007428 | 0.004182 | 0.003651 | 0.001815  |
| Cell C   | Exterior Wall    | 0.06263   | 0.07298  | 0.05519  | 0.05279  | 0.03754  | 0.1553   | 0.0649   | 0.0575    |
|          | Baffle Wall      | 0.03824   | 0.03287  | 0.042395 | 0.06933  | 0.04705  | 0.08619  | 0.0580   | 0.0473    |
|          | Sediment         | 0.12128   | 0.11440  | 0.06859  | 0.07411  | 0.09912  | 0.09776  | 0.08224  | 0.07741   |
|          | Sediment Strings | 0.01632   | 0.005289 | 0.008433 | 0.007947 | 0.007378 | 0.004961 | 0.003181 | 0.001405  |
| Cell D   | Exterior Wall    | 0.15691   | 0.16185  | 0.1494   | 0.2256   | 0.1803   | 0.2219   | 0.1223   | 0.2114    |
|          | Baffle Wall      | 0.15686   | 0.175026 | 0.04528  | 0.1105   | 0.08513  | 0.1063   | 0.1014   | 0.1029    |
|          | Sediment         | 0.13674   | 0.13451  | 0.10789  | 0.08733  | 0.10579  | 0.10194  | 0.07473  | 0.06006   |
|          | Sediment Strings | 0.006256  | 0.01401  | 0.008845 | 0.004109 | 0.003571 | 0.002878 | 0.003098 | 0.001747  |

content of these compartments then increased by the fifth materials balance effort and decreased after that. Tank 2 showed similar changes in radiophosphorus content of the sediment in each of the cells but less consistently than the other two tanks.

The changes in the radiophosphorus content of the exterior wall and baffle wall of each cell are difficult to interpret. In Tank 1 most of the radiophosphorus was in Cell A for the first 4 materials balance efforts. The content for all cells was similar for the last 4 efforts. In Tank 2 the radiophosphorus content of Cell A of the exterior wall reached a peak at materials balance effort 5 and decreased to materials balance 7. In general, the radiophosphorus content of the other cells in the exterior wall of this tank showed similar changes; decreasing from materials balance 1 to 3, increasing to effort 5 and decreasing to effort 7. In Tank 3, all of the cells showed decreases in their radiophosphorus content between materials balance efforts 2 and 3 and between 6 and 7. Results between the other efforts were more variable. More of the radiophosphorus in the exterior walls of this tank remained in Cell A than in any other cell until the last materials balance effort. In the baffle wall of Tank 1 the radiophosphorus content was greatest in Cells B and C. There was a decrease in the content between efforts 4 and 5 and a general increase between efforts 5 and 7. Throughout the experiment there was a general increase in the content of Cell D. In Tanks 2 and 3 more of the radiophosphorus in the baffle wall compartment was generally in Cell A than in other cell. In Tank 2 there was a general slight increase in the radiophosphorus content of Cells B, C and D. The content of Cell A reached a peak at materials balance effort 5 and decreased to effort 7



before increasing at the last effort. In Tank 3 peaks in the radiophosphorus content of Cell A were reached at efforts 3 and 7 which is quite different from Tank 2. After about the third materials balance effort the radiophosphorus content of Cells B, C and D of Tank 3 remained stable with a maximum cumulative content found on effort 6.

In summary, this analysis indicates that some sorption and desorption of radiophosphorus with the sediment occurred in each of the tanks. The results were variable with each tank behaving differently. The movement of radiophosphorus was limited at least in part by the minimal mixing and perhaps the lesser growth and activity of algae in the tanks compared to field conditions in the late summer.

## CHAPTER V

### SUMMARY AND CONCLUSIONS

The preceding chapters presented the current understanding of phosphorus chemistry in aquatic environments and described the experimental activities undertaken and results obtained. In this chapter, literature pertaining to phosphorus chemistry in waste stabilization ponds is first summarized. Next, the objectives of this research and the experimental system are described. Finally, the results of the experiment, conclusions and some recommendations for further study are presented.

Relatively little attention has been given to the phosphorus chemistry of waste stabilization ponds. Most investigators of phosphorus in waste stabilization ponds have only collected a few samples, usually of the effluent, and analyzed them for orthophosphate or sometimes total phosphorus. Some have measured the phosphorus content of the influent and the effluent in an attempt to estimate the removal rate. Rarely is the time of day, the exact location of the sample and associated environmental and chemical conditions given. A few studies have attempted to measure various forms of phosphorus present throughout a waste stabilization pond system at a particular time. A few have also attempted to measure the changes in phosphorus content of a pond at one location

during a season or year. These investigators have found wide variations in phosphorus removal rates and in phosphorus concentrations in waste stabilization ponds. The concentration of total phosphorus in the influent ranged from 5 to 20 mg/l in one study. The effluent had a total phosphorus concentration ranging from 3 to 10 mg/l and a much higher portion of it (50 to 90%) being soluble orthophosphate. The phosphorus not accounted for in the effluent is thought to be associated with the sediment as a result of chemical precipitation at high pH levels and by the settling of algae and other phosphorus containing organisms. Removal rates of phosphorus in lagoons generally are reported highest in the summer. But these removal rates are highly variable ranging from a net gain in one study to greater than 90% removal in others. No overall materials balance for phosphorus has been reported for either field or laboratory model waste stabilization ponds to identify actual removal rates or to identify diurnal or seasonal variations in phosphorus chemistry.

There is evidence from studies of phosphorus chemistry in lakes that phosphorus may be sorbed or desorbed on sediment as the environmental conditions vary. Generally, current understanding is that phosphorus is often released from lake sediments during the summer under anaerobic conditions, and under aerobic conditions lake sediments take up phosphorus and act as a sink. In hard water lakes a calcium-carbonate-phosphate system may predominate phosphorus chemistry with the total phosphorus level buffered by hydroxyapatite. In other lakes an iron-phosphate complex or aluminum-phosphate complex system may predominate. In these lakes the phosphorus is bound to the sediment by either

precipitation or adsorption when the pH is below about 7. Between a pH range of 7 and 9 the phosphorus is not as readily adsorbed. Above a pH of 9 precipitation by calcium phosphate (apatite) probably occurs. The specific chemistry of phosphorus in lakes is influenced by a wide variety of physical, chemical and biological factors such as temperature, dissolved oxygen content, pH, redox potential, metabolism and excretion, bioturbation, and mixing. Therefore, variations in phosphorus chemistry may occur between lakes and seasonally within a lake.

During late summer pronounced diurnal variations in dissolved oxygen content, pH and redox potential have been documented for waste stabilization ponds in the south central U.S. For example, nearly immeasurable levels of dissolved oxygen occur late at night. These levels may reach super saturated conditions above 40 mg/l during the afternoon and early evening. The pH may also range from a low of about 7 at night to a high of 10 or 11 during the day. It is the hypothesis of this research that these extreme variations in dissolved oxygen content and pH may influence the diurnal sorption and desorption of phosphorus on waste stabilization pond sediments. Specifically, it is hypothesized that phosphorus is released from pond sediments between pH range of 7 to 9 and under deoxygenated conditions and is taken up by the sediment under oxygenated conditions and elevated pH values.

The objective of this research was to determine the fate of phosphorus in a laboratory simulation of a waste stabilization pond under environmental conditions similar to those in the south central U.S. during the late summer. Two subordinate objectives were identified to determine the fate of phosphorus in the model pond systems.

The first subordinate objective involved measurements for materials balance of phosphorus at eight times during the operation of the model systems to determine the portion of phosphorus in the sediment and bulk water under aerobic and anaerobic conditions. The establishment of a correlation between total phosphorus and orthophosphate concentrations and radiophosphorus activity in the bulk water was the second subordinate objective.

Three steel tanks of about 300 gallon capacity each were used to model a two-celled waste stabilization pond. One tank was operated at an organic loading rate (with synthetic sewage) of 30 pounds BOD<sub>5</sub>/acre/day (Tank 1) and the other two (Tanks 2 and 3) were operated at 50 pounds BOD<sub>5</sub>/acre/day. Each tank had a detention time of 32 days (about 40 days considering evaporation). Phosphorus was loaded at the rate of 4.45 mg/l in Tank 1 and 7.40 mg/l in Tanks 2 and 3. A liquid depth of 3 feet and a sediment depth of 3 inches was used in each tank. Temperature and wind were also simulated as much as possible to approximate field conditions. Lighting supplied was both natural and artificial and at the surface exceeded the reported saturation level for algae. However, the levels measured at the surface of the model tanks were less than reported for field conditions and may have resulted in reduced rates of photosynthetic productivity. It was thus necessary to operate the tanks under prolonged lighted and darkened periods to simulate the chemical changes that occur in field ponds.

During the 8 month acclimation phase biological growth was established and chemical conditions measured and compared to field waste stabilization ponds. The types and numbers of bacteria present were

similar to observations in field ponds. Algae types identified are also commonly reported in field ponds but the abundant growth of Ulothrix along the walls and baffle of the model tanks does not occur in field ponds.

It was necessary to aerate each of the tanks during the middle of the acclimation phase to promote aerobic conditions. However, diurnal variations in dissolved oxygen and pH were less than occurs under field conditions. This made it necessary to operate the tanks under continuous lighted conditions of about 4 days followed by about 4 days of darkened conditions. This reduced rate of biological activity is thought to be the result of several factors including the lessened light intensity, the limited mixing due to the small surface area to volume ratio, and the abundant growth of algae attached to the walls which may have reduced the abundance of algae in the bulk water.

Correlation analysis of the parameters measured on a daily basis (73 measurements at each of 6 locations, 2 in each tank) showed that the dissolved oxygen concentration, pH, and redox potential varied similarly when tested at the 99% level of significance. Significant correlations (at the 99% level) between total phosphorus concentration and decay-corrected radiophosphorus concentration, and orthophosphate concentration and decay-corrected radiophosphorus concentration, were also found. Less consistent changes were found in these parameters measured during the eight materials balance efforts (at 36 locations, 3 depths and 4 locations in each tank). However, during the materials balance efforts significant correlations at the 95% significance level were found between dissolved oxygen concentration and pH, between

dissolved oxygen concentration and redox potential, and between pH and redox potential. Other significant correlations (at the 95% confidence level) were found at several locations between orthophosphate and total phosphorus concentrations of the bulk water and between the orthophosphate concentrations and decay corrected radiophosphorus concentration of the bulk water.

At most locations the correlation analyses on a daily basis were significant at the 95% confidence level between dissolved oxygen concentration, pH and redox potential each, and between orthophosphate concentration, total phosphorus concentration, and the decay-corrected radiophosphorus content of the bulk water. In otherwords, as dissolved oxygen levels, pH and redox potential increased so did the orthophosphate, total phosphorus and decay corrected radiophosphorus concentrations. This relationship was not consistently found in Cell C-D of Tank 2 and Cell C-D of Tank 3. Also, during the materials balance efforts significant correlations were generally not found between each of the total phosphorus and orthophosphate concentration, the decay-corrected radiophosphorus content of the bulk water, and the radiophosphorus content of the sediment parameters. This was at least partially due to the small number of samples (8) collected at each location.

During materials balance determinations more than 84% of the radiophosphorus was accounted for on the average in each of the tanks. In Tanks 1 and 3 an average of almost 95% of the radiophosphorus was accounted for. Most of the radiophosphorus remained in the bulk water. The tanks with a higher organic loading rate had less radiophosphorus

in the bulk water with a greater portion associated with the sediment and the walls. Increases and decreases in the radiophosphorus content of the sediment were noted throughout the experiment suggesting possible sorption and desorption as environmental conditions changed. In all three tanks it was found that the sediment gained radiophosphorus during oxidized conditions and lost radiophosphorus during reducing or deoxygenated conditions. Exchange of radiophosphorus between the sediment and the nearby bulk water (bottom depth) was noted. Under reducing conditions as the radiophosphorus content of the bottom compartment of the bulk water increased the content of the sediment compartment decreased. The opposite trend was also noted as the environmental conditions become oxidized.

All three of the tanks responded differently to the addition of radiophosphorus and an organic load. Tanks 2 and 3 loaded at 50 lbs. BOD<sub>5</sub>/acre/day responded somewhat more similarly to each other than to Tank 1 which was operated at an organic loading rate of 30 lbs. BOD<sub>5</sub>/acre/day. For example, Tanks 2 and 3 had slightly higher biological growth and less radiophosphorus remained in the bulk water of these tanks than in Tank 1. However, all three tanks showed similar variations in dissolved oxygen content, pH and redox potential but Tank 2 often showed less of a response to changes in lighting conditions than the other tanks. Each tank had its own algal community composition and each showed different movements of radiophosphorus throughout the operational period.

This laboratory experimental research generally shows that there is a dynamic diurnal relationship between phosphorus in the bulk water and in the sediment of waste stabilization ponds in the late



summer in the south central U.S. Specifically, it appears that phosphorus may move to the sediment and be sorbed during highly oxygenated conditions which occur during the afternoon and early evening. Under reducing conditions phosphorus may be released from the sediment to the bulk water. These conditions occur primarily at late night and early morning. It therefor appears that during the summer phosphorus may be minimized in the effluent by selectively discharging only during the late afternoon and the early evening. Discharging at selected depths may also minimize phosphorus discharges. Samples of the phosphorus content of the bulk water in waste stabilization ponds usually taken on a once daily basis during the morning or afternoon in the summer do not adequately represent the phosphorus content of the bulk water in the south central U.S. More intensive diurnal sampling is necessary to understand the phosphorus chemistry in waste stabilization ponds.

Two types of further studies are needed to better understand the relationship of phosphorus between pond sediments and the overlying water. One type of study involves laboratory model sediment/water systems enclosed in containers and operated under controlled conditions. These systems could be similar to those used by investigators into the phosphorus chemistry of sediments in lakes such as Holdren and Armstrong (1980), Freedman and Canale (1977), or Fillos (1976). Each of these investigators were able to simulate and monitor the sediment-water environment of a lake in the laboratory under carefully controlled conditions.

Holdren and Armstrong (1980) studied intact sediment cores from epilimnetic areas in four Wisconsin lakes. The cores were incubated in the laboratory to determine the effects of redox changes, mixing intensity,

temperature, bioturbation, and sediment type on sediment phosphorus release. Freedman and Canale (1977) reported a three phase study to study sediment nutrient regeneration in White Lake, Michigan. The three phases included measuring the nutrient concentrations in the sediments, a laboratory study to simulate the lake bottom and measure the sediment/water nutrient flux, and an in-situ study of actual conditions of nutrient release. Fillos (1976) used Lake Mohegan, New York sediments to simulate in the laboratory the oxygen uptake rate and the phosphorus release rate to the overlying water under different environmental conditions.

The second type of studies that are needed includes in-situ monitoring of waste stabilization pond conditions of nutrient release. Such studies would need to include some intensive diurnal sampling of the phosphorus concentration at various depths of the water in the late summer. It would also be desirable to include some year round sampling of phosphorus concentrations to determine seasonal variations. The effects of turbulent mixing, bioturbation and sediment type of phosphorus chemistry also need to be determined in field studies.

With these combined laboratory and field studies one should be able to gain a better understanding of phosphorus chemistry in waste stabilization ponds. Some further understanding of phosphorus chemistry in lakes and streams may also be gained. Finally, with this information operating procedures to minimize phosphorus in the effluents of waste stabilization ponds, reduce the pollution of receiving waters, and to extend the usefulness of waste stabilization ponds for waste treatment to small communities may be devised.

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## APPENDIX A

RAW DATA AND LINEAR REGRESSION OF THE MEASURED COUNTS  
PER MINUTE FOR SELF-ABSORPTION CORRECTION OF SOLID  
SAMPLES IN THE INTERNAL PROPORTIONAL COUNTER

Table A-1: SEDIMENT WEIGHT VERSUS COUNTS PER MINUTE FOR SELF-ABSORPTION CORRECTION

| Volume of Dilution 3 (ml) | Raw Average of 4 Counts Per Minute | Standard Deviation of Raw Counts | Average of 3 Counts Per Minute Background | Standard Deviation of Background Counts |
|---------------------------|------------------------------------|----------------------------------|---|---|
| <u>Flask A</u>            |                                    |                                  |   |   |
| 5                         | 1,275,866.25                       | 22,143.09                        | 49.00                                     | 3.00                                    |
| 5                         | 1,381,463.25                       | 45,705.89                        | 49.00                                     | 3.00                                    |
| 5                         | 1,164,122.50                       | 21,979.57                        | 49.00                                     | 3.00                                    |
| 10                        | 1,784,048.75                       | 84,456.83                        | 49.00                                     | 3.00                                    |
| 10                        | 1,887,351.25                       | 57,373.37                        | 49.00                                     | 3.00                                    |
| 10                        | 1,822,264.00                       | 68,245.95                        | 49.00                                     | 3.00                                    |
| 15                        | 1,088,867.50                       | 16,642.35                        | 41.67                                     | 7.06                                    |
| 15                        | 1,175,854.00                       | 39,724.08                        | 41.67                                     | 7.06                                    |
| 15                        | 1,229,787.00                       | 31,502.36                        | 41.67                                     | 7.06                                    |
| 20                        | 1,384,195.75                       | 31,116.74                        | 41.67                                     | 7.06                                    |
| 20                        | 1,448,476.25                       | 54,725.30                        | 41.67                                     | 7.06                                    |
| 20                        | 1,512,113.75                       | 31,265.66                        | 41.67                                     | 7.06                                    |
| <u>Flask B</u>            |                                    |                                  |   |   |
| 5                         | 1,146,654.00                       | 18,125.44                        | 49.00                                     | 2.58                                    |
| 5                         | 1,262,457.00                       | 61,793.99                        | 49.99                                     | 2.58                                    |
| 5                         | 1,301,751.75                       | 75,312.44                        | 49.00                                     | 2.58                                    |
| 10                        | 1,827,388.25                       | 83,780.40                        | 49.00                                     | 3.00                                    |
| 10                        | 1,784,533.75                       | 72,752.43                        | 49.00                                     | 3.00                                    |
| 10                        | 1,878,063.00                       | 70,778.83                        | 49.00                                     | 3.00                                    |
| 15                        | 1,234,491.75                       | 57,027.85                        | 41.67                                     | 7.06                                    |
| 15                        | 1,293,731.00                       | 46,950.08                        | 41.67                                     | 7.06                                    |
| 15                        | 1,274,016.50                       | 42,939.27                        | 41.67                                     | 7.06                                    |
| 20                        | 2,351,732.00                       | 126,031.24                       | 49.00                                     | 3.00                                    |
| 20                        | 2,337,268.75                       | 58,832.40                        | 49.00                                     | 3.00                                    |
| 20                        | 2,045,605.75                       | 135,146.00                       | 49.00                                     | 3.00                                    |

Table A-1: (Continued)

| Days for Decay Correction | Decay Corrected Net Average Counts per Minute | Sediment Weight (grams) | ln (10XWeight in Grams) |
|---------------------------|---|-------------------------|-------------------------|
| <u>Flask A</u>            |   |                         |                         |
| 14                        | 2,516,682.4                                   | 0.4719                  | 1.552                   |
| 14                        | 2,725,139.4                                   | 0.4290                  | 1.456                   |
| 14                        | 2,296,387.5                                   | 0.3868                  | 1.353                   |
| 14                        | 3,519,326.7                                   | 0.7182                  | 1.972                   |
| 14                        | 3,723,113.3                                   | 0.6790                  | 1.915                   |
| 14                        | 3,594,714.5                                   | 0.5407                  | 1.688                   |
| 27                        | 4,036,564.6                                   | 1.2712                  | 2.543                   |
| 27                        | 4,359,046.6                                   | 1.2686                  | 2.540                   |
| 27                        | 4,558,990.4                                   | 0.9099                  | 2.208                   |
| 27                        | 5,131,142.6                                   | 1.2917                  | 2.559                   |
| 27                        | 5,369,729.3                                   | 1.3950                  | 2.635                   |
| 27                        | 5,605,650.3                                   | 1.5066                  | 2.712                   |
| <u>Flask B</u>            |   |                         |                         |
| 13                        | 2,154,778.1                                   | 0.2990                  | 1.095                   |
| 13                        | 2,372,403.0                                   | 0.2872                  | 1.055                   |
| 13                        | 2,446,248.5                                   | 0.3627                  | 1.288                   |
| 14                        | 3,604,823.2                                   | 0.4689                  | 1.545                   |
| 14                        | 3,520,283.4                                   | 0.5872                  | 1.770                   |
| 14                        | 3,704,790.1                                   | 0.4640                  | 1.535                   |
| 27                        | 4,576,432.3                                   | 0.9949                  | 2.297                   |
| 27                        | 4,796,047.7                                   | 0.8049                  | 2.086                   |
| 27                        | 4,722,960.8                                   | 0.9082                  | 2.206                   |
| 14                        | 4,639,205.0                                   | 1.1122                  | 2.409                   |
| 14                        | 4,610,673.2                                   | 1.2261                  | 2.506                   |
| 14                        | 4,035,304.6                                   | 1.1936                  | 2.480                   |

Using data in the "Decay Corrected Net Average Counts per Minute" column with the data in the "ln (10) weight" column the correlation coefficient is about 0.942 which is significant at the 1 percent level. The slope of the regression line is about  $4.83 \times 10^{-7}$ . For the following million counts per minute (x) the corresponding ln (10) weight (y) is:

|       |           |
|-------|-----------|
| x = 0 | y = 0.107 |
| = 1   | 0.590     |
| = 2   | 1.073     |
| = 3   | 1.556     |
| = 4   | 2.039     |
| = 5   | 2.522     |
| = 6   | 3.005     |
| = 7   | 3.488     |

## APPENDIX B

LINEAR REGRESSION OF THE THEORETICAL DISINTEGRATIONS PER  
MINUTE AND AVERAGE WEIGHT FOR SELF-ABSORPTION  
CORRECTION OF SOLID SAMPLES IN THE  
INTERNAL PROPORTIONAL COUNTER

**Table B-1: AVERAGE SEDIMENT WEIGHT VERSUS  
THEORETICAL DISINTEGRATIONS PER MINUTE  
FOR SELF-ABSORPTION CORRECTION**

| Volume of Dilution 3<br>(ml) Flask A and B | Theoretical<br>Disintegrations<br>Per Minute | Average Weight<br>(grams) | ln (10XWeight<br>in Grams) |
|--|--|---------------------------|----------------------------|
| 5  | $5.55 \times 10^6$                           | 0.3728                    | 1.3159                     |
| 10   | $1.11 \times 10^7$                           | 0.5763                    | 1.7514                     |
| 15   | $1.67 \times 10^7$                           | 1.0263                    | 2.3285                     |
| 20   | $2.22 \times 10^7$                           | 1.2875                    | 2.5553                     |

The theoretical disintegrations per minute in dilution 3 for each milliliter was determined by the following: 4.00 ml of  $7.5 \times 10^{-2}$  mc/ml (dilution 1) =  $3.0 \times 10^{-1}$  mc in each 600 ml of sediment. Thus, there were  $\frac{3.0 \times 10^{-1} \text{ ml}}{600 \text{ ml}} = 5.0 \times 10^{-4}$  mc/m. This is  $(5.0 \times 10^{-4} \text{ mc/ml}) (2.22 \times 10^9 \text{ dpm/mc}) = 1.11 \times 10^6$  disintegrations per milliliter.

The average weight is taken from the data in Table A-1 "Sediment Weight (grams)": where flasks A and B are combined as shown below:

| Volume of<br>Sediment (ml) | Sediment<br>Weight<br>(grams) |                            | Average<br>Weight<br>(grams) |
|----------------------------|-------------------------------|----------------------------|------------------------------|
|                            | Flask A                       | Flask B                    |                              |
| 5                          | 0.4719<br>0.4290<br>0.3863    | 0.2990<br>0.2872<br>0.3627 | 0.3728                       |
| 10                         | 0.7182<br>0.6790<br>0.5407    | 0.4689<br>0.5872<br>0.4640 | 0.5763                       |
| 15                         | 1.2712<br>1.2686<br>0.9099    | 0.9949<br>0.8049<br>0.9082 | 1.0263                       |
| 20                         | 1.2917<br>1.3950<br>1.5066    | 1.1122<br>1.2261<br>1.1936 | 1.2875                       |

The correlation coefficient of the theoretical disintegrations per minute and  $\ln(10)$  weight including the data point (0,0) is about 0.956 which is significant at the 1 percent level. The slope of the regression line is about  $1.103 \times 10^{-7}$ . For the following million disintegrations per minute (x) the corresponding  $\ln(10)$  weight (y) is:

|       |           |
|-------|-----------|
| x = 0 | y = 0.366 |
| = 1   | = 0.476   |
| = 2   | = 0.586   |
| = 3   | = 0.697   |
| = 4   | = 0.807   |
| = 5   | = 0.917   |
| = 6   | = 1.028   |
| = 7   | = 1.138   |

## APPENDIX C

### COMPARTMENT SIZES USED TO ESTIMATE MATERIALS BALANCE OF RADIOPHOSPHORUS



The tanks were divided into the following compartments: the top 6 inches of bulk water volume, the middle 2 feet of bulk water volume, the bottom 6 inches of bulk water volume, the sediment, the strings attached to the sediment samplers, the top 6 inches of baffle area, the middle 2 feet of baffle area, the bottom 6 inches of baffle area, the top six inches of exterior wall area, the middle 2 feet of exterior wall area, and the bottom 6 inches of exterior wall area. Because there was a 0.25 foot by 1.5 foot notch in the baffle the area for the top and middle compartments of each cell in the baffle had to be considered individually. The tanks were divided into four cells or water columns as shown in Figure 4-13 and the ratio of the size of the compartment relative to the size of the sample used to estimate the radiophosphorus content of the compartment. This ratio was multiplied by the decay corrected and counting efficiency corrected radioactivity of the sample. In all compartments other than the baffle the sizes of the compartments were the same in each of the cells.

The volume of bulk water in each tank was estimated as described below. The volume of water in each tank ( $V_T$ ) is equal to the volume of each tank less the volume of the baffle. The volume of water is obtained as follows:

$$V_T = \pi r_T^2 h_T - w_b h_b l_b \text{ of baffle}$$

where

$r_T$  = radius of the tank

$h_T$  = height of the water in the tank

$w_b$  = width of baffle

$h_b$  = height of the water on the baffle

$l_b$  = length of the baffle

$$\begin{aligned}
V_T &= \pi (3.792/2)^2 (3.0) - (3.79)(3.0)(0.021) - (0.25)(1.5)(0.021) \\
&= 33.874 \text{ ft}^3 - 0.2291 \text{ ft}^3 \\
&= 33.645 \text{ ft}^3 \\
&= 952.833 \text{ liters}
\end{aligned}$$

The volume of water in each cell is one-fourth that in the tank or 238.208 liters. The top 6 inches of water is 39.701 liters in each cell. The middle 2 feet is 158,805 liters in each cell and the bottom 6 inches of water is 39.701 liters. Since a two milliliter sample was taken from the bulk water the ratio of the compartment size to sample size for each of these levels is as follows:

$$\text{Top: } \frac{39,701 \text{ milliliters}}{2 \text{ milliliters}} = 19,851$$

$$\text{Middle: } \frac{158,805 \text{ milliliters}}{2 \text{ milliliters}} = 79,403$$

$$\text{Bottom: } \frac{39,701 \text{ milliliters}}{2 \text{ milliliters}} = 19,851$$

The volume of the sediment in each tank ( $V_s$ ) is found by the following equation:

$$V_s = \pi r^2 h_s$$

where:

$h_s$  = the height or depth of the sediment

$$\begin{aligned}
V_s &= \pi (3.792/2)^2 (0.25) \\
&= 2.823 \text{ ft}^3 \\
&= 79.944 \text{ liters}
\end{aligned}$$

Since each cell contains one-fourth of the sediment in each tank there are 19.986 liters in each cell. Each sediment sampler contains 14.6 milliliters of sediment so the ratio of each sediment compartment to sediment sample is as follows:

$$\frac{19,986 \text{ milliliters}}{14.6 \text{ milliliters}} = 1,369$$

Each of the four cells in each tank also contain 8 sets of sediment sampler strings. For each materials balance effort the ratio of sediment string compartment size to sample size is shown in Table J-1. This compartment is not one that is present in field ponds and is the only compartment which is consumed in the sampling effort.

As shown in Figure J-1 the baffles were notched between Cells B and C and therefore the wetted surface area of baffle in these cells in the top two compartments is less than in Cells A and D. The area of notch in the baffle is 0.25 feet wide times 1.5 feet deep which is 0.375 square feet. For cells A and D the total baffle area is the radius of the tank times the height of the water column or:

$$\begin{aligned} \text{Baffle Area A and D} &= (3.792/2)(3.0) \\ &= 5.6875 \text{ ft}^2 \end{aligned}$$

Each planchet has an area of  $0.02182 \text{ ft}^2$ . For these two cells the ratio of the compartment size to sample size for each of the three levels is as follows:

$$\begin{aligned} \text{Top: } & \frac{0.9479 \text{ ft}^2}{0.02182 \text{ ft}^2} = 43.45 \\ \text{Middle: } & \frac{3.792 \text{ ft}^2}{0.02182 \text{ ft}^2} = 173.80 \\ \text{Bottom: } & \frac{0.9479 \text{ ft}^2}{0.02182 \text{ ft}^2} = 43.45 \end{aligned}$$

The bottom compartment of the baffle is the same size for each of the four compartments but the size of the top and middle compartments of the baffle in Cells B and C are less than those for Cells A and D. The surface area of the top compartment of the baffle in Cells B and C is 1.646 ft. by 0.5 ft. which equals  $0.823 \text{ ft}^2$  or a ratio with the planchet samplers of 37.72 to 1. The surface area of the middle compartment of the baffle in these cells is  $3.542 \text{ ft}^2$  which gives a ratio with the planchet samplers of 162.33.

The total wetted perimeter in each tank is given by the following equation:

$$\begin{aligned} P &= \pi dh \\ &= \pi(3.792)(3.0) \\ &= 35.74 \text{ ft}^2 \end{aligned}$$

The wetted perimeter in each cell is  $8.934 \text{ ft}^3$ . The top 6 inches represents an area of about  $1.49 \text{ ft}^2$  and a ratio to the planchet samplers of  $1.49 \text{ ft}^2 / 0.02182 \text{ ft}^2$  or 68.25 to 1. This is also the ratio represented in the bottom compartment. The middle compartment represents an area of about  $5.96 \text{ ft}^2$  and a ratio to the planchet samplers of  $5.96 \text{ ft}^2 / 0.02182 \text{ ft}^2$  or 273.00 to 1.

The radiophosphorus associated with the exterior wall and baffle strings was also considered. The size of this compartment was treated the same as the sediment sampler strings compartment. Also, the cumulative amount of radiophosphorus lost from the tanks in the effluent was accounted for as described in Chapter III. The size of the effluent compartment at each of the materials balance efforts was given in Table 3-5.