DETERMINATION OF HYDRAULIC AND TREATMENT CHARACTERISTICS OF THREE WASTEWATER STABILIZATION PONDS IN JAMAICA

by

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(Under the Direction of MATTHEW C. SMITH)

ABSTRACT

The ability to reliably predict the fluid flow through a pond and relate these hydraulic characteristics to pond treatment performance is clearly very a valuable tool to the design engineer and treatment system operation manager. Therefore, once the retention time, removal efficiency and dispersion coefficient are determined then the appropriate flow equation (Plug, Complete mixed or Dispersed Flow) can be used to predict the degree of treatment of incoming pollutants. Dye tracing, using Rhodamine WT and Fluorescein to determine retention time and dispersion coefficient was attempted. Due to dye quenching, the dye tracing had to be abandoned and two analytic methods were used instead to determine the hydraulic characteristics.

It was found that up to 80% of the BOD was removed with a retention time of approximately 4.9 days in the first of the three facultative ponds, with an average of 33% reduction in the other two ponds (retention time of about 2 days).

INDEX WORDS: Wastewater treatment ponds, Montego Bay, Jamaica
Nitrogen removal, Ammonia, Total Kjeldahl nitrogen (TKN),
Biochemical oxygen demand, Dye tracing, Rhodamine WT,
Fluorescein, Grease Traps, Quenching.

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DEDICATION

To my mom, Mrs. Sevelyn Gray

For the fulfillment of a dream and the result of your many prayers

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I acknowledge my God for working with, in and through me, for strengthening me and for using this project to help me grow closer to Him.

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1   INTRODUCTION

1.1 **Background**

Waste stabilization ponds or oxidation ponds are defined as designed reactors constructed through excavation and compaction of earth to create reservoirs capable of holding wastewater for predetermined periods of time (Oswald, 1995). Waste stabilization ponds are designed to provide a controlled environment for wastewater treatment (Kellner and Pires, 2002). Of all the low-tech, low cost natural treatment systems, wastewater stabilization ponds are the most widely used, and have been employed for over 3,000 years (Grau, 1996; Nguyen and Shieh, 2000; Reed, et. al., 1995; Soares et. al, 1996; Soler et. al., 1995).

Stabilization ponds used to treat wastewater have the advantages of not only being low cost, but are easily designed; and offer flexibility, economical use of energy, and ease of operation (Pearson, 1996; Xian-wen, 1995; Zhen-bin et. al., 1993). Further, Oswald (1995) stated that, if pond systems were correctly designed and managed in order to cultivate anaerobic and aerobic bacteria and green micro-algae, then such systems would decompose waterborne organic wastes effectively and efficiently, and would help reduce some of the problems associated with the treatment and disposal of wastewater.

The problems associated with the disposal of domestic and other liquid wastes have grown with the world's population. The problems are particularly acute in developing countries where only 32% of the population has adequate excreta and sewage disposal services and the situation is worsening. In the future, over one billion

Less Developed Country citizens are expected to join those already living in urban areas. The situation becomes more complicated when one realizes that the people requiring sanitation services will be very poor. Where water carriage systems are proposed, the first treatment option which should always be considered is the use of stabilization ponds, because in many instances, they represent the most cost effective and efficient way of treating domestic sewage flows (Arthur, 1983; Meiring and Oellerman, 1995 and Saidam, et. al., 1995).

In addition about 90% of the ponds in the United States are used in small communities with less than 10,000 residents and are reported to be very effective in wastewater treatment (Flynn, 1982). Therefore, the choice of a waste stabilization pond system for the treatment of wastewater for the relatively small community of Montego Bay, Jamaica was a good one. However, each system is unique and even with the well established success of ponds; there is a need to investigate the hydraulic characteristics and treatment efficiencies of the Montego Bay pond system in order to compare the findings against established theoretical design characteristics.

1.2   **Purpose of this Study**

This study has a dual purpose. To determine the hydraulic characteristics and the treatment efficiencies of the pond system, in order to compare the findings against those proposed by the system designers. However, research is truly useless if it is not practically applied. Therefore, the second purpose of this study is, to apply the knowledge gained from the research to predict future treatment capabilities of the system as the number of customers served by the ponds increases. As a contribution to

academia, this information will subsequently indicate whether or not this pond system behaves similarly to others built using similar design criteria and that are operating under similar conditions. This is possible because, although each pond system is unique, all have certain fundamental similarities (Dinges, 1982).

1.3 <u>Why this Study is Unique</u>

Wastewater stabilization ponds are biological treatment systems, whose processes and operations are highly dependent on the environmental conditions, external and insitu. Environmental conditions, including temperature, rainfall, wind speeds and light intensity are highly variable and any given combination of these environmental parameters is usually unique to a given location. Thus, each pond will operate under a unique set of environmental variables. This makes each pond system unique.

Dinges (1982) agreed with the above assertion when he made this statement; "no two stabilization pond systems perform exactly alike as each is a separate entity whose character is governed by prevailing environmental conditions and sewage characteristics". Each pond has its own individual characteristics with regards to influent flows and loads; shape; and environmental conditions (Shilton and Harrison, 2003). Therefore, the stabilization pond system located at Bogue in Montego Bay, Jamaica is part of a unique system, operating under highly localized weather and uniquely tropical climatic conditions. It is therefore, not too great a leap of logic to conclude that any study, even a reproduction of similar studies, on this pond system is truly a unique venture.

1.4   Objectives

The overall aim of this thesis is to determine the hydraulic efficiency of a series of three waste stabilization ponds and to compare this finding with the design values put forward at the time of construction of the plant.

The specific objectives of the project are:

1. To design and perform dye tracing studies to determine the actual hydraulic retention time and dispersion coefficient. Therefore the hydraulic flow regime present in the ponds can be ascertained.

2. To determine input and output concentrations of BOD and nitrogen in order to evaluate the kinetics of the treatment mechanisms occurring in the pond.

3. Using the above information, predict the future treatment performance of this system.

1.5   Thesis Overview

This thesis consists of five chapters. The current chapter gives a summary of the problem to be studied, the purpose and uniqueness of this project, and the specific objectives. Chapter 2 results from a review of the literature as related to the problem under study, in order to provide the reader with the relevant background information pertinent to this research. Chapter 3 is a discussion of various approaches to pond monitoring as found in literature and a description of the actual experimentation as performed during the study. Chapter 4 presents the results from the monitoring exercise. Chapter 5 summaries the conclusions and discusses the results of the research including how the research addressed the objectives of the project.

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2   LITERATURE REVIEW

2.1   <u>Overview of Chapter</u>

This literature review starts with a definition of wastewater and an itemization of its constituents. The review then moves on to a discussion of water quality standards and the need for treatment of wastewater in order to meet these quality criteria, progressing through an overview of treatment objectives and the different types of treatment systems currently in use. The focus then narrows to a discussion of Natural Treatment Systems (NTS), particularly Waste Stabilization Ponds.

The different types of stabilization ponds are then considered, with principal consideration given to Facultative ponds, because the ponds under study are for all intents and purposes considered to be facultative (even though two of the three are called Maturation ponds). An evaluation of the removal of the wastewater constituents; Biochemical Oxygen Demand (BOD) and nitrogen in facultative ponds then follows, amalgamating the preceding sections. Facultative pond design is reviewed, with special emphasis on BOD and nitrogen removal as primary design variables, followed by a general review of the influences of fluid flow and mixing in ponds.

The literature review continues with a discussion of dye tracing as a means of determining hydraulic retention time, with particular attention to fluorescent dyes. The chapter then finishes with a review of Rhodamine WT and Fluorescein, the two fluorescent dyes chosen to conduct the tracer studies and two analytical methods for determining removal efficiency and dispersion number.

2.2 <u>Wastewater Characteristics</u>

Simply defined, wastewater is the flow of used water from a community (Drinan, 2001). A more formal definition of wastewater is; a combination of the liquid or water-carried wastes removed from residences, institutions, commercial and industrial establishments, together with ground-water, surface-water, and storm-water (Hammer, 1991; Tchobanoglous and Burton, 1989). Thus, wastewater is essentially the water supply of the community after it has been fouled by various users; potable water that now contains pollutants (Canter and Harfouche, 2000; Rudolf, 1955; Tchobanoglous and Burton, 1989).

Pollutants are foreign substances (organic, inorganic, radiological, or biological), which degrade the quality of water to a level where they constitute a hazard to the environment and/or to human health or impair the usefulness of the water (Warren, 1971). On a macro-scale, pollutants in wastewater are generally only about 0.06% solids; dissolved or suspended material, carried in a 99.94% water flow (Arthur, 1983; Gray, 1989; Rudolf, 1955). Arthur (1983); Drinan (2001) and Gray, (1989) indicated that these solids are about 70% organic (proteins, carbohydrates and fats) and 30% inorganic (mainly salts, grit and metals). However, there are several micro-constituents in wastewater relevant to the health and safety of human beings and to the environment. These constituents can be classified as physical, biological and chemical (Crites and Tchobanoglous, 1998; Nguyen and Shieh, 2000). Table 2.1 shows a breakdown of these constituent (Henze, 1995):

Table 2.1: <u>Wastewater Components</u>

Components	Of Special Interest	Environmental Effects
Micro-organisms	Pathogenic bacteria, Virus and worm eggs	Risk when bathing, and eating shellfish.
Biodegradable Organics	Undigested food, leaves etc.	Oxygen depletion in rivers, lakes and ponds
Other organics	Detergent, pesticides, fats, solvents.	Toxic effects, bio-accumulation
Nutrients	Nitrogen, phosphorus	Eutrophication, oxygen depletion, toxic effects
Metals	Hg, Pb, Cu, Ni	Toxic effects, bio-accumulation
Other inorganics	Acids, bases, etc	Corrosion and toxic effects

2.2.1 <u>Physical Parameters</u>

Physical parameters are those pollutants with characteristics to which the senses respond. These pollutants include suspended solids, turbidity, color, taste, odor and temperature (Gray, 1989; Peavy et. al., 1985). Suspended solids can be either inorganic, such as clay and silt, or organic particles such as plant fibers or algal cells (Peavy et. al., 1985). Henze (1995) defines suspended solid as material that is retained on a filter of pore size 1.6 μm. Turbidity is a measure of the extent to which the passage of light thru water is impeded (Viessman and hammer, 1998). Turbidity is usually

caused by colloidal material such as clay, silt, and metal oxides from soil that either scatters or absorbs the light (Tchobanoglous and Burton, 1989).

Water in contact with organic debris such as leaves, weeds or wood is normally colored by the tannin and humic acid that they contain. Taste and odor are often confused. That is, substances that produce an odor in water will also impart taste. These substances include minerals, metals and salts (Tchobanoglous and Burton, 1989; Vesilind, et. al., 1988). In general, physical parameters interfere with the transmission of light, are aesthetically displeasing and can cause disruption in aquatic ecology (Viessman and Hammer, 1998).

2.2.2   Biological Parameters

From the perspective of human water use and consumption, the most important biological parameter is pathogens; disease-causing organisms. These include bacteria, viruses and protozoa (Tchobanoglous and Burton, 1989). Bacteria are unicellular organisms which possess no well-defined nucleus, and reproduce by fission (Rudolf, 1955). Viruses are small microbes with simple structure consisting of protein and nucleic acid (DNA or RNA). They are parasitic, in that they require a host cell for their reproduction (Forster, 1985; Hammer, 1991). Protozoa are single-celled animals. In general protozoa grow in groups or colonies. They have well-defined nuclei, sometimes more than one (Rudolf, 1955). These microbes cause diseases whose symptoms include vomiting and diarrhea, gastrointestinal disorders, high fever, ulceration of the intestines, possible nerve damage and even death (Schmitz, 1996).

2.2.3   Chemical Parameters

Total dissolved solids, alkalinity, hardness, fluorides, metals, organics and nutrients are common chemical constituents found in wastewater (Tchobanoglous and Burton, 1989). Total dissolved solids consist of those solids that remain after filtration followed by evaporation of the filtrate (Viessman and hammer, 1998). These usually impart aesthetically displeasing color, tastes and odors to water (Crites and Tchobanoglous, 1998).

Alkalinity is the quantity of ions in water that will react to neutralize hydrogen ions or acids (Henze, 1995; Tchobanoglous and Burton, 1989). Alkaline materials usually found in water include phosphates (PO_4^{2-}), carbonates (CO_3^{2-}), bicarbonates (HCO_3^{-}) and hydroxides (OH^{-}). The latter three components are by far the most common constituents of alkalinity. In addition to their mineral origin, these substances can originate from Carbon dioxide, which is readily available from the atmosphere and have a profound effect on the treatment and physiochemical parameters of wastewater. When present in large quantities, alkaline material gives potable water a bitter taste (King, 1976). In addition, alkaline material reacts with certain cations; precipitating out of solution, resulting in pipe blockages. (Tchobanoglous and Burton, 1989; Peavy, et. al., 1985)

Hardness is the concentration of multivalent metallic cations in solution. These multivalent metallic ions include calcium, magnesium and aluminum. At supersaturated levels, the hardness cations will react with anions in the water to form solid precipitate. Hardness can cause economic loss, since hard water requires the use of more soap

than non-hard water and a reduction in the efficiency of boilers (Crites and Tchobanoglous, 1998; Viessman and Hammer, 1998).

Metals exist as ions in water and can be non-toxic (most metals are non-toxic at low concentrations) and toxic (Vesilind et. al. 1988). The most common non-toxic metal is sodium. However, excessively high concentrations of sodium give water a bitter taste. Other common non-toxic metals include, iron and manganese. Toxic metal differ from non-toxic ones in that they are harmful to humans and other organisms in small quantities. Some toxic metals found in water include, arsenic, lead and mercury (Viessman and hammer, 1998). These metals can cause birth defects, infertility and even death to aquatic plants and animals (Schmitz, 1996).

With respect to water quality, the most important organics are those that are biodegradable (Vesilind, et. al., 1988). Biodegradable material consists of organics that are utilized for food by microorganisms. If oxygen is not limiting microbes may decompose organics aerobically, that is, they use oxygen as an oxidant in the respiration process. The amount of oxygen consumed during the respiration process is called Biochemical Oxygen Demand; BOD (Viessman and hammer, 1998). When wastewater with high levels of dissolved biodegradable material is released into a river, lake or sea, the oxygen demand may exceed the natural reaeration rate. This can cause major fish kills among other ecological disasters (Gray, 1989).

Phosphorus and nitrogen are the two most common nutrients of concern in water quality (Dinges, 1982). Phosphorus is usually a limiting nutrient in aquatic bodies. Therefore when phosphorus is available, rapid growth of aquatic plants usually occurs, resulting in harmful algal blooms, and anoxic conditions. Nitrogen is an inherent

component in the cells of all living organism. As such, increased concentrations of nitrogen cause particular species to grow in excess and may disrupt an ecosystem, causing species shift (Lai and Lam, 1997; Schmitz, 1996).

2.3   <u>**Water Quality Standards**</u>

The presence of the above pollutants can make a particular body of water unfit for human and environmental activities. The removal or reduction of these constituents is governed by water quality standards. In everyday conversations about water quality, the term "standard" usually replaces criterion. However, strictly speaking, a standard is a specific limitation established by regulations and required by law. While a criterion, is a concentration or level of a substance that reasonably assures safety of organisms and ensures the quality of the water containing that substance (Warren, 1971; Schmitz, 1996). Thus, a criterion is used to develop a standard.

Therefore, water quality standards vary according to the proposed use of the water (Arthur, 1983). Uses include human consumption, agricultural, fish and wildlife propagation, industrial, aesthetics and recreational activities (Drinan, 2001). In assessing the quality of a water body, an inventory based on the presence or absence of various pollutants is taken. Hence, water quality is an assessment of the physical, biological and chemical criteria contingent upon the proposed use of the particular water body compared against the benchmark of a particular standard. It is the satisfaction of these standards and the prevention or reduction of the impact of these pollutants on the environment and on human health and lifestyle that determine the level of treatment required on a particular body of water.

2.4   <u>Wastewater Treatment</u>

Fundamentally, there are two major reasons for treating wastewater. Namely, to prevent pollution and thereby protect the environment; and to protect public health by safeguarding water supplies and preventing the spread of water-borne diseases (Gray, 1989; Tchobanoglous and Burton, 1989; Warren, 1971). Gray (1989) specifies the following as the means by which these mandates are accomplished:

1. Converting waste material present in wastewater into stable oxidized end products, which can be safely discharged to inland and coastal waters without any or very minimal adverse ecological effects;

2. Ensuring wastewater is effectively disposed of on a regular and reliable basis without nuisance or offence;

3. Recycling and recovering the valuable components of wastewater.

Wastewater treatment or management systems take effluent from water users as influent to treatment facilities, treats the waste-stream in a series of unit processes, and then discharges (out-fall) to a receiving body, such as a river (Drinan, 2001). These unit processes are designed to remove or reduce the amount of the relevant pollutants to a safe level. Water is usually considered safe when particular pollutant(s) is (are) reduced to acceptable standards or removed entirely (Dart and Stratton, 1980).

Gray (1989) classified these unit processes as preliminary treatment, primary (sedimentation) treatment, secondary (biological) treatment, tertiary treatment, and sludge treatment.

- Preliminary treatment can be defined as the removal and disintegration of large solids, the removal of grit, and the separation of storm water. Oil and grease are also removed at this stage if present in large quantities (Gray, 1989). The primary purposes of pretreatment are to condition the wastewater with respect to subsequent treatment processes, to remove materials that may interfere with downstream treatment processes and equipment, and to minimize the accumulation of material in downstream processes (Crites and Tchobanoglous, 1998; Gantz, et. al., 2000).

- Primary (sedimentation) treatment is the removal of settleable solids; that is, "those pollutants that will either settle out or float" (Flynn, 1982). More formally, primary treatment is defined as the removal of 50-70% of the suspended solids and 25-40% of the BOD from the influent (Crites and Tchobanoglous, 1998). These usually form sludge.

- The major purpose of secondary treatment is to remove the soluble BOD that escape primary treatment and to provide further removal of suspended solids (Flynn, 1982). Secondary (biological) treatment is the oxidation of dissolved and colloidal organics in the presence of micro-organisms. More specifically, it is the removal of biodegradable organics and suspended solids to prescribed levels; typically 30 mg/L (EPA, 2000).

- Tertiary treatment is further treatment of a biologically treated effluent to remove BOD, bacteria, suspended solid, specific toxic compounds or nutrients to enable the final effluent to comply with more stringent standards (Burns, et. al., 2000).

- Sludge treatment is the dewatering, stabilization and disposal of sludge (Buchanan and Reuter, 2000).

Waste management systems use a combination of the above processes to fulfill their mandates. All unit processes depend, to some degree on natural responses such as gravity for sedimentation, or biological organisms for oxidation to carry out the secondary and tertiary processes (Reed, et. al, 1995). Thus, there are two types of waste treatment systems; conventional and natural treatment systems. Conventional treatment systems use high energy inputs such as motors for the production of oxygen, and high chemical inputs to bring about the treatment responses. This energy input is usually to expedite natural treatment responses (Arthur, 1983).

When water, soil, plants, microorganisms and the atmosphere interact in the natural environment, various physical, chemical and biological processes occur (Tchobanoglous and Burton, 1989). Some of these interactions facilitate and provide wastewater treatment. However, the exact efficiency and effectiveness of these processes is not easily ascertained. To effectively estimate and project treatment on a given quantity of wastewater, a controlled environment is required. The provision of a controlled environment in which natural responses facilitate wastewater treatment is an inherent characteristic of Natural Treatment Systems (NTS).

NTS are man-made structures, which harness naturally occurring processes in the environment and simulate the treatment responses associated with those processes to treat wastewater in a controlled and measurable manner (Kellner and Pires, 2002). Reed, et. al (1995) defines NTS as systems specifically designed to utilize natural responses to the maximum possible degree to obtain the intended waste treatment or

management goal. That is, these systems depend primarily on natural responses in nature to achieve their intended purpose (Peavy, et. al., 1985).

2.4.1   Types of Natural Treatment Systems

Natural systems for effective wastewater treatment are available in three major categories: wetlands, land treatment systems, and aquatic treatment systems (Reed, et. al, 1995). Wetlands are lands where the water table is at and/or above the ground surface long enough each year to maintain, saturated soil conditions (less than 0.6m depth) and the growth of related vegetation such as cattail, bulrush, and reeds (Reed, et. al, 1995; Tchobanoglous and Burton, 1989).

Land treatment is the controlled application of wastewater onto the land surface to achieve a designed degree of treatment through natural physical, chemical, and biological processes within the plant-soil-water matrix (Crites and Tchobanoglous, 1998; Dinges, 1982; Reed, et. al., 1995). Depending on the level of treatment required, the site characteristics and design objectives, a designer can choose among slow rate, rapid infiltration or overland flow land treatment systems (Crites and Tchobanoglous, 1998).

Aquatic treatment is defined as the use of aquatic plants and/or animals as a component in a wastewater treatment system. These usually refer to pond systems and other aquatic systems. The two are distinguished by the presence of large plant species as in hyacinth aquatic systems or microscopic plants such as algae as in the case of waste stabilization ponds (Reed, et. al., 1995).

2.5 <u>Ponds</u>

A wastewater pond, also known as a stabilization pond, oxidation pond, and sewage lagoon, consists of a large, shallow earthen basin or impoundment in which wastewater is retained for a defined detention or retention period to facilitate natural purification processes in order to provide the necessary degree of treatment (Arceivala, 1973; Hosetti and Frost, 1998; Mara, et. al., 1992; Reed, et al, 1995; Peavy et. al, 1985; Viessman and Hammer, 1998). When categorized according to the nature of the relationship between the insitu conditions and naturally occurring microorganisms, ponds are a sub-group of a general class of wastewater systems called suspended-culture biological systems. In suspended cultures, the microorganisms are suspended in the wastewater either as single cells or as clusters of cells called flocs. The cells or flocs are surrounded by the wastewater, which contains their food and other essential elements (Ray, 1995; Tchobanoglous and Burton, 1989).

These organisms, feed on pollutants within the wastewater, removing them completely, reducing the concentrations or converting them to less harmful substances, thus bringing about treatment. Hence, in general the treatment mechanism in ponds consists of the reservoir effect (enabling ponds to absorb organic and inorganic shock loadings), primary sedimentation (to facilitate the settling of settable solids) and the aerobic and anaerobic bacterial digestion of waste (Arthur, 1983). The treatment of wastewater in ponds, therefore, exploits the physical and biochemical interactions that occur naturally between organisms and their environs to remove pathogens, suspended solids, phosphates, BOD, ammonia and nitrates (Hurse and Connor, 1999; Salter, et al., 2000). Figure 2.1 illustrates the overall treatment process in ponds.
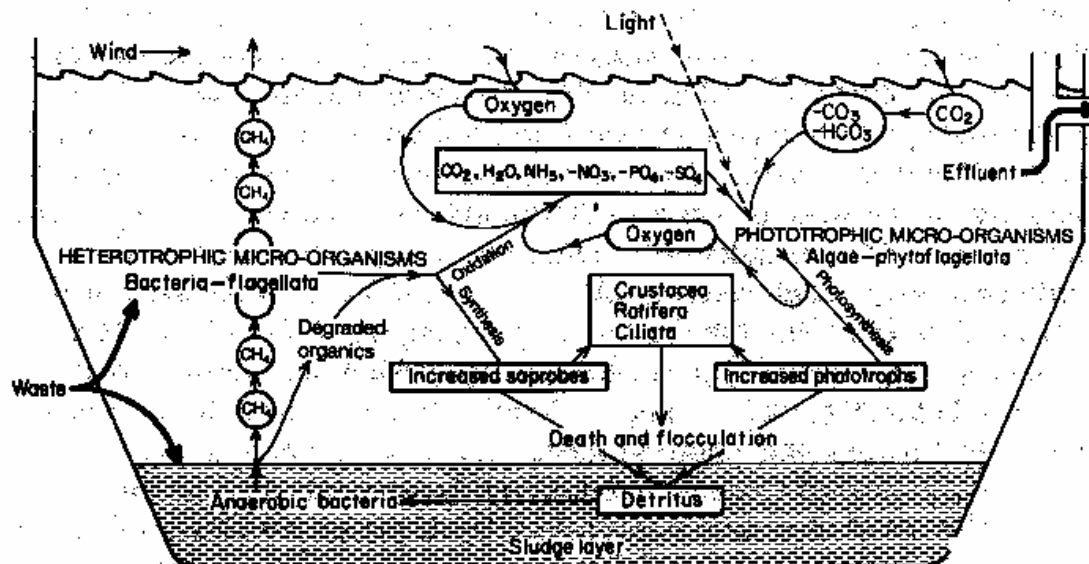
Figure 2.1: Summary of Heterotrophic and Phototrophic Activities in Ponds

Source: Gray (1989)

2.5.1 <u>Types of Organisms in Ponds</u>

The biological processes in ponds are carried out by a diversified group of organisms. In general, these organisms may be categorized as, producers, consumers and decomposers and include fungi, protozoa, bacteria and algae (Henze, et. al., 1995; Nguyen and Shieh, 2000). The plants, mainly algae, are producers, the animals, mainly protozoa ingest and digest synthesized organic substrate, are consumers and the decomposers, mainly fungi and bacteria, reduce organic material to basic inorganic constituents (Gloyna, 1976).

Fungi are filamentous, chlorophylless plants. They are composed of branching threads called hyphae. Fungi are strictly heterotrophic organisms deriving their energy from the oxidation of organic substances. They are very effective and economical at decomposing organic matter (Nguyen and Shieh, 2000; Rudolf, 1955). However, they are not important to the treatment process in ponds because they are thought to be

restricted because of the high pH caused by the photosynthetic activity of algae (Dinges, 1982; Gray, 1989; McKinney, 1976).

This is also the case for protozoans. Except for the phototrophic flagellates, they do not appear to have a significant role in the treatment process as they are out-competed for the dispersed bacteria by the zooplankton; Cladocera, which also feed on protozoans. Therefore, bacteria and algae are the two most important treatment organisms within ponds (Goulden, 1976; Gray, 1989).

2.5.1.1   <u>Bacteria</u>

The dominant bacteria found in ponds belong to the genera Pseudomonas, Achromobacter and Flavobacterium, these are obligate aerobes. Other types include coliform bacteria, methane bacteria, sulphate reducers and the purple non-sulphur bacteria (Veenstra, et. al., 1995). The purple photosynthetic bacteria of the family Thiorhodaceae can occur in significant numbers, they oxidize sulphides using carbondioxide as a hydrogen acceptor, thus alleviating odors (Dinges, 1982; Gray, 1989; Rudolf, 1955; Tchobanoglous and Burton, 1989). Additionally, there are two nitrifying bacteria, Nitrosomonas and Nitrobacter (Dinges, 1982; Tchobanoglous and Burton, 1989).

Bacteria decompose food using two types of metabolic processes: the dissimilation or breaking down of food material which takes place inside or outside the cell; and assimilation or synthetic process which occurs within the cell. Food substances which are in a suspended form are unable to go through the cell membrane and are thus metabolically unavailable to the bacteria. Therefore, enzymes are secreted,

bringing about the dissimilation of the complex food substances, which are subsequently assimilated (Rudolf, 1955; Gray, 1989).

2.5.1.2   Algae

Algae are plants containing photosynthetic pigments. Different algae contain pigments colors such as green, yellow, orange, blue, red, or brown and are categorized accordingly (Rudolf, 1955). Although there is a succession of dominant algal species during the year, generally only one or two species will be dominant at any one time. The most commonly recorded genera are: Chlorella, Euglena, Micractinium and Microcystis (Mara, 2000, Saidam, et. al., 1995). Dinges (1982) reported that the green phytoplankton algae are the most abundant and impart the green color characteristic of aerobic and facultative ponds.

The physiological characteristic of this group is its ability to utilize radiant energy to produce oxygen and biomass. The oxygenation capacity of different algae varies appreciably; blue-green algae are less efficient than the green algae (Gray, 1989). It is actually the presence or absence of algae within the water column and their corresponding oxygen production that is the most common basis for pond classification.

2.5.2   Categories of Ponds

Ponds are classified in different ways by different authors. Arthur (1983) classified ponds according to the relative dominance of the two processes; contingent upon the availability of oxygen, by which organic material expressed as BOD_5 is

removed; anaerobically and aerobically. Tchobanoglous and Burton (1989) classified ponds into aerobic, maturation, facultative and anaerobic categories. Maturation ponds are the same depth as Facultative ponds but experience lighter loadings (Gray, 1989). While Hosetti and Frost (1998), Reed, et. al. (1995), Malina and Rios (1976) and Mara, (2000) proposed three basic classification of ponds, based on the dominant type of biological reactions occurring in the ponds. Namely:

1. Aerobic Ponds

2. Anaerobic Ponds

3. Facultative Ponds

4. Aerated Ponds or lagoons: lagoons are distinguished from ponds in that additional oxygen is provided by artificial means, while the bulk of the oxygen in ponds is provided by photosynthesis (Peavy, et. al, 1985).

2.5.2.1   Aerobic Ponds

Shallow ponds in which dissolved oxygen is present at all depths are called aerobic ponds or high-rate aerobic ponds. They are usually 12-18 in deep. This allows light to penetrate the full depth, which enables algae to flourish and photosynthesize along the entire water column (Crites and Tchobanoglous, 1998; Nguyen and Shieh, 2000; Peavy, et. al, 1985; Reed, et. al, 1995). They are most frequently used as additional treatment processes beyond secondary treatment. Therefore, aerobic ponds are often referred to as "polishing" or "tertiary" ponds (Peavy, et. al, 1985).

2.5.2.2 **Anaerobic Ponds**

Deep ponds in which oxygen is absent except for a relatively thin surface layer are called anaerobic ponds. These ponds are usually constructed with a depth of 8-12ft, but can have depths of up to 30 ft. Anaerobic ponds operate under heavy BOD loading rates as the primary units in a pond system, and rely totally on anaerobic digestion to achieve organic removal (Arthur, 1983; Gray, 1989; Nguyen and Shieh, 2000). Thus, they are usually used for the partial treatment of strong organic wastewater that contains a high concentration of solids (Dinges, 1982; Eckenfelder and O'connor, 1961; Gray, 1989; Nguyen and Shieh; 2000; Peavy, et. al, 1985; Tchobanoglous and Burton, 1989).

The solids settle out and are gradually digested, resulting in a significant reduction in BOD (Eckenfelder and O'connor, 1961; Forster, 1985). The digestion process is carried out by two distinct groups of bacteria. The facultative anaerobic bacteria hydrolyze or convert complex organic compounds into simpler organic molecules, primarily organic acids, while the strict anaerobic methane forming bacteria transform the organic acid into methane and carbon dioxide, resulting in 70-85% BOD removal (Malina and Rios, 1976; Tchobanoglous and Burton, 1989). The partially clarified effluent is usually discharged to another treatment process for further treatment.

2.5.2.3 **Facultative Ponds**

The term facultative stabilization pond is derived from the description of two general groups of bacteria; facultative aerobes and facultative anaerobes. Facultative

aerobic bacteria would normally utilize free dissolved oxygen, but can exist under anaerobic conditions by obtaining oxygen from nitrates or carbonates (Dinges, 1982). Facultative ponds operate under a lighter organic loading than anaerobic ponds, enabling algae to develop in the surface layers. These algae photosynthesize, thus producing oxygen. This production results in an oxygen rich layer called an oxypause. Below this oxypause, anaerobic digestion continues in the absence of oxygen (Arthur, 1983). Thus, in the surface layers, the dominant populations are algae and aerobic bacteria, while in the bottom layers and in the sediment, anaerobic populations predominate (Forster, 1985).

Treatment is therefore brought about by a combination of aerobic, anaerobic, and facultative bacteria within three distinct zones classified according to oxygen availability (Arceivala, 1973; Nguyen and Shieh, 2000; Tchobanoglous and Burton, 1989). Under favorable conditions, facultative ponds in which active purification is occurring in all three zones may be used as the total treatment system for municipal wastewater (Gray, 1989; Peavy, et. al, 1985). Therefore, facultative ponds are considered to be a comprehensive method of treating whole or raw wastewater (Dart and Stretton, 1980; Gray, 1989; Oswald, 1995).

The boundary between the aerobic and anaerobic zones is not stationary and considerable interaction exists between the zones. Organic acids and gases, products of decomposition in the anaerobic zone, are released and become soluble food for organisms in the aerobic zone. Biological solids produced in the aerobic zone settle to the bottom, providing food for the anaerobic benthic organisms (Gray, 1989). Mixing by wind action and penetration by sunlight may extend the aerobic area downward.

Conversely, calm water and weak lighting result in the anaerobic layer rising toward the surface. Diurnal changes in light conditions may also result in diurnal fluctuations in the aerobic-anaerobic interface (Peavy, et. al., 1989).

The volume through which the presence of dissolved oxygen fluctuates is called the facultative zone (Peavy et. al., 1989). Soluble and colloidal organic materials are oxidized by aerobic and facultative bacteria by using oxygen produced by algae growing near the surface. Carbon dioxide (CO_2) produced by oxidation of organics serves as a source of carbon for the algae. Therefore, a special relationship exists between the bacteria and algae in the aerobic zone. Here the bacteria use oxygen as an electron acceptor to oxidize the wastewater organics to stable end products such as CO_2, nitrate (NO^{3-}) and phosphate (PO_4^{3-}). The algae in turn use these compounds as a material source, and with sunlight as an energy source, produce oxygen as a product. The oxygen is then used by the bacteria. Such mutually beneficial arrangements, called symbiotic relationships, often occur in nature (Forster, 1985; Pearson, et. al., 1987; Peavy, et. al., 1989; Ward and King, 1976). The symbiotic relationship within the surface zone can be represented as follows (Peavy, et. al, 1989; Arthur, 1983):

$$\text{Photosynthesis:} \quad CO_2 + 2H_2O \rightarrow \underset{new\,cell}{(CH_2O)} + O_2 + H_2O \qquad (2\text{-}1)$$

$$\text{Respiration:} \quad CH_2O + O_2 \rightarrow CO_2 + H_2O \qquad (2\text{-}2)$$
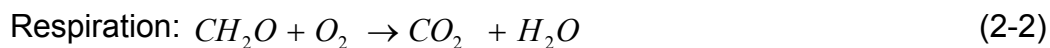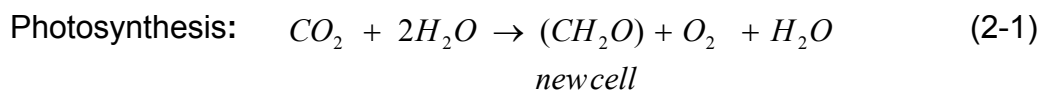
Of all the types of ponds, facultative ponds are by far the most common and most closely resemble the purification processes that occur in the natural environment (Fritz, 1985;). The major applications of facultative ponds are the treatment of agricultural, industrial and domestic wastewaters (Dinges, 1982; Polprasert and Agarwalla, 1995).

Facultative ponds are known to produce effective and efficient treatment of wastewater and are adept at removing pollutants particularly pathogens, BOD and nitrogen. So much so that most facultative ponds are designed based on the removal of these pollutants especially BOD and nitrogen (Fritz, 1985; Gray, 1989; Reed, et. al., 1995; Ward and King, 1976).

2.6 Biochemical Oxygen Demand (BOD$_5$)

Municipal wastewater contains a high percentage of biodegradable organics. Biodegradable organic contaminants can be in either dissolved or suspended form (Reed, et. al., 1995). These organics are usually starches, fats, proteins, alcohols, acids and esters (Rudolf, 1955; Mudrack and Kunst, 1983). These contaminants are referred to as biodegradable because they are utilized or degraded by microorganisms in the environment. Microbial utilization of dissolved organics can be accompanied by oxidation (addition of oxygen to, or the deletion of hydrogen from, elements of the organic molecule) or by reduction (addition of hydrogen to or deletion of oxygen from). The oxidation process is by far more energy efficient and is predominant in oxygen rich environs. Thus, dissolved organics have a characteristic oxygen-demanding nature and can be said to exert an oxygen demand (BOD) on a water body when microbes utilize organics for food (Eckenfelder and O'connor, 1961; Peavy, et. al, 1985; Tchobanoglous and Burton, 1989). BOD is the quantity of oxygen required for biochemical oxidation under specific conditions; which indirectly is a measurement of oxygen requirements of unstable biodegradable material oxidized through the agencies of living organisms and in the presence of oxygen (Rudolf, 1955; Viessman and Hammer, 1993).

The total damage caused by discharging wastewater, which is usually rich in dissolved organics, into receiving waters is expressed and quantified by three established analytical tests; COD (chemical oxygen demand), TOD (total oxygen demand) and BOD. These tests measure the amount of oxygen that a liter of wastewater takes from receiving waters as its organic pollutants are degraded by oxygen consuming bacteria (Arthur, 1983; Henze, 1995; Liptak, 2000). The distinguishing factor among the three tests is, BOD is a measure of the biodegradable carbon in organic matter, COD gives a measure of the total organic matter without distinguishing between compounds which are biodegradable and those that are not, while TOD is a measure of all oxygen demanding substances in the sample, including nitrogenous compounds (Henze, 1995).

Bod$_5$ means a 5-day Biochemical Oxygen Demand test in which bacteria instead of chemicals is used to oxidize the organic pollutants (Dart and Stretton, 1980; Eckenfelder and O'connor, 1961; Gray, 1989; Henze, 1995; Mudrack and Kunst, 1983). The BOD analysis was developed to determine the oxygen demand caused by micro-organisms in polluted waters, that is, the rate of oxygen use. This would indirectly indicate the severity or extent of the pollution, that is, it provides a relative measure of wastewater strength and not its absolute biodegradability (Mara and Horan, 1993; Mudrack and Kunst, 1983). The BOD test was first used for measuring the oxygen consumption in a stream by filling two bottles with stream water, measuring the DO in one, and placing the other in the stream. In a few days, the second bottle was retrieved, and the DO was measured. The difference in the oxygen levels was the BOD, or oxygen demand, in milligrams of oxygen used per liter of sample (Vesilind, et. al, 1988).

However, oxygen demand is a function of temperature and time, that is, metabolic activity increases significantly at higher temperatures and the amount of oxygen used increased with time. Light is also an important variable, and variation in light intensity causes fluctuations in oxygen content, especially in natural waters (Gray, 1989; Liptak, 2000). Thus, the test had to be standardized. The temperature chosen for this is 20^oC, a time of five days and the sample placed in the dark (Henze, 1995; Liptak, 2000; Vesilind, et. al, 1988; Viessman and hammer, 1998). The test is conducted in a standard BOD bottle of volume 300mL, with the sample appropriately diluted to ensure that all the oxygen is not used up during the five-day period (Vesilind, et. al., 1988).

2.6.1 <u>BOD Removal in Facultative Ponds</u>

Facultative ponds which are properly designed and maintained can give a BOD reduction ranging from 75% to 90% for domestic sewage (Arceivala, 1973). Gray (1989) describes the removal process in facultative ponds as follows: as organic matter enters the basin, the settleable and flocculated colloidal matter settles to the bottom to form a sludge layer where organic matter is decomposed anaerobically. The remainder of the organic matter, which is either soluble or suspended, passes into the body of the water where decomposition is mainly aerobic or facultative, and occasionally anaerobic.

In the sludge layer, the settled solids are anaerobically broken down, with methane, nitrogen and carbon dioxide being released together with a variety of soluble degradation products. The gases escape to the atmosphere, and constitute up to 30% of the BOD load removed from the pond. The soluble degradation products, such as ammonia, organic acids, and inorganic nutrients are also released, and subsequently

oxidized aerobically in the water column. The hydrogen sulfide released from the

decomposition of the sludge is also oxidized aerobically in the water column, thus

preventing odors (Arceivala, 1973). Figures 2.2 illustrates the BOD removal pathways in

facultative ponds.
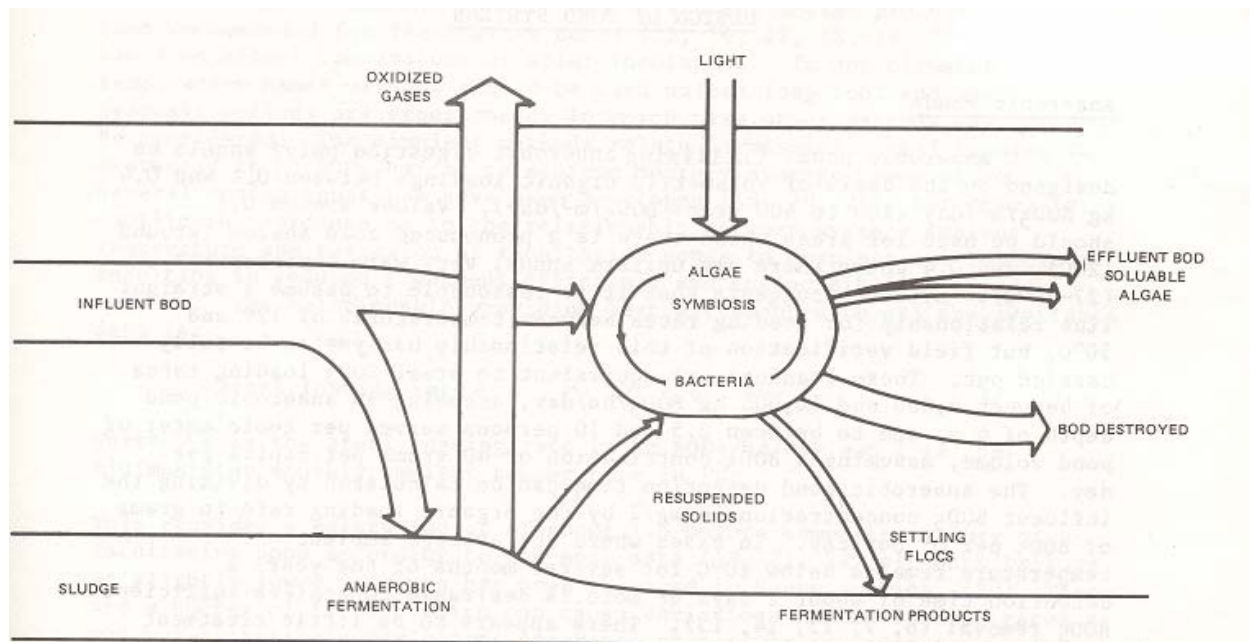
Figure 2.2: Pathway of BOD Removal in Facultative Ponds
Source: Arthur (1983)

2.7 Nitrogen

Nitrogen is an essential nutrient for biological growth, normally comprising about

12-14% of the cell mass as protein (Barnes and Bliss, 1983; Lai and Lam, 1997).

However, in large quantities, nitrogen can be toxic to living organisms (Horne, 1995; Lai

and Lam, 1997). The following is a list of the problems that can be caused by excess

nitrogen in aquatic milieux:

- Ammonia is toxic to aquatic organisms, especially the higher forms such as fish, at concentration as low as 0.5 mg/L. Molecular NH_3 is the most toxic form and predominates at high pH. Thus, ammonia toxicity is most severe where conditions, such as discharge of alkaline wastewater, or rapid photosynthesis leading to depletion of bicarbonates that results in elevation of pH (Hammer, 1991; Kurosu, 2001; Mudrack and Kunst, 1983; Schmitz, 1996).

- Nitrification, the oxidation of ammonia to nitrate, in the receiving water can exert a significant oxygen demand. As the total nitrogenous oxygen demand may not be reduced significantly by non-nitrifying treatment plants, nitrification can cause severe depletion of the dissolved oxygen resources of surface waters (Mudrack and Kunst, 1983).

- Nitrification in treatment plants, receiving streams, or soils of effluent irrigation areas, can give rise to high nitrate concentrations in surface waters or ground waters. Where such waters are used for drinking water supplies, these high nitrate levels can cause infant methaemoglobinaemia, if the water is used in preparing powdered formula for infants up to the age of six months (Reed, et. al., 1995). Up to this age infants have incompletely developed digestive systems, which accumulate nitrate ions instead of breaking them down. If these nitrate ions enter the blood stream then they become attached to haemoglobin. This prevents effective oxygen transport by the blood and the infant in effect suffocates to death (Kelter, et. al., 1997; Schmitz, 1996).

- Nitrogen is an essential plant nutrient, so that increase nitrogen loads can stimulate the growth of aquatic plants and algae, causing eutrophication

(Ferrara and Avci, 1983; Hammer, 1991; Kurosu, 2001; Reed, et. al., 1995). As well growths being unaesthetic, these growths exert a high oxygen demand during the night leading to large diurnal fluctuations in dissolved oxygen to the detriment of other life forms (Barnes and Bliss, 1983).

- Ammonia in waters used for water supply increases the chlorine dosage required to achieve disinfection (Crites and Tchobanoglous, 1998).

Nitrogen exists in several forms or oxidation states in the environment. These range from organic and ammonium nitrogen (oxidation state 3^-), to nitrogen gas (0), to nitrite (3^+), and nitrate (5^+). As a result, nitrogen is present in wastewater in a variety of forms or species (Reed, et. al., 1995). The nitrogen species that are predominantly found in wastewater are ammonia nitrogen, particulate or organic nitrogen, nitrite, and nitrate (Gomez, et al., 1995; Henze, et. al., 1995; Horne, 1995; Lai and Lam, 1997; Sotirakou, et. al., 1999). About sixty percent (60%) of the nitrogen in domestic sewage is principally ammonium and forty percent (40%) organic nitrogen, with only small amounts of nitrite and nitrate (<1%). The chief sources of nitrogen being Urea and proteins (Gray, 1989; Puckett, 1995; Viessman and Hammer, 1998).

Historically, BOD, Total Suspended Solids (TSS) and fecal coliform bacterial count have been used as criteria for assessing the efficiency of wastewater treatment plants (Muttamara and Puetpaiboon, 1996). To some degree, this was caused by inadequate information about the biological and chemical mechanisms involved in nitrogen removal in waste stabilization ponds (Diab, et al., 1993; Lai and Lam, 1997; Reed, et. al., 1995). In addition, there is some disagreement among researchers about the nitrogen removal capabilities of wastewater treatment ponds. For example,

Muttamara and Puetpaiboon (1996), Gomez, et. al. (1995), Lai and Lam (1997), Silva, et. al. (1995), Rakkoed, et. al., (1999) reported a 46-90% removal efficiency, while Diab et. al. (1993) concluded that nitrification does not occur in oxidation ponds, unless they are continually mixed.

However, in recent times more attention is being given to the control of nutrients in receiving water bodies, especially nitrogen since nitrogen is often the limiting factor for algal growth (Lai and Lam, 1997; Soares, et al., 1996). Further, while nitrate, nitrite and particulate-N (algae and bacteria) concentrations are less than 5mg/L in influent wastewater streams, particulate nitrogen (algal cells) in wastewater treatment system's effluent may be recycled downstream and even 1mg/L of nitrate is sufficient to cause eutrophication (Horne, 1995). Therefore, nitrogen removal is becoming increasingly important in wastewater treatment.

2.7.1   Nitrogen Removal in Facultative Ponds

Transformations from one oxidation state to the other causes a shift in the dominant nitrogen species, which results in removal, reduction and/or rendering harmless of nitrogen forms in wastewater (Barnes and Bliss, 1983; Reed, et. al., 1995). Principal biological transformations that occur in facultative ponds are de-amination (ammonification), assimilation, biological uptake, sedimentation, nitrification, denitrification, and ammonia volatilization (Holbrook, et. al., 2000). However, there is disagreement among researchers about the major nitrogen removal pathway in facultative ponds.

Nitrification-denitrification is the pathway of choice for several authors, including Gomez, et. al., (1995); Hurse and Connor, 1999; Lai and Lam, (1997); Muttamara and Puetpaiboon, (1996); and Silva, et al., (1995). Silva, et.al. (1995) quotes Reed (1985) as saying that denitrification is only a theoretical possibility for permanent nitrogen loss in ponds and nitrification-denitrification is not likely to be the major mechanism for nitrogen removal in pond systems.

Reed et. al. (1995) listed plant or algal uptake, nitrification and denitrification, adsorption, sludge deposition, and ammonia volatilization. While ammonia volatilization is consider to be the major pathway (Middlebrooks, et. al., 1999; Pano and Middlebrooks, 1982 and Soares, et al., 1996). Kurosu (2001) agreed with this theory, adding that both algae assimilation and ammonia volatilization are major pathways, but only if the dominant nitrogen species is ammonia. However, if nitrate is the dominant nitrogen species, then denitrification is the major removal pathway. Ferrara and Avci, (1983) disagree stating that ammonia volatilization accounts for a very small faction of total nitrogen removal, with sedimentation of organic nitrogen the removal method of choice and ammonia is usually lost from ponds by biological activity. A diagrammatic representation of these processes is given below in Figure 2.3.
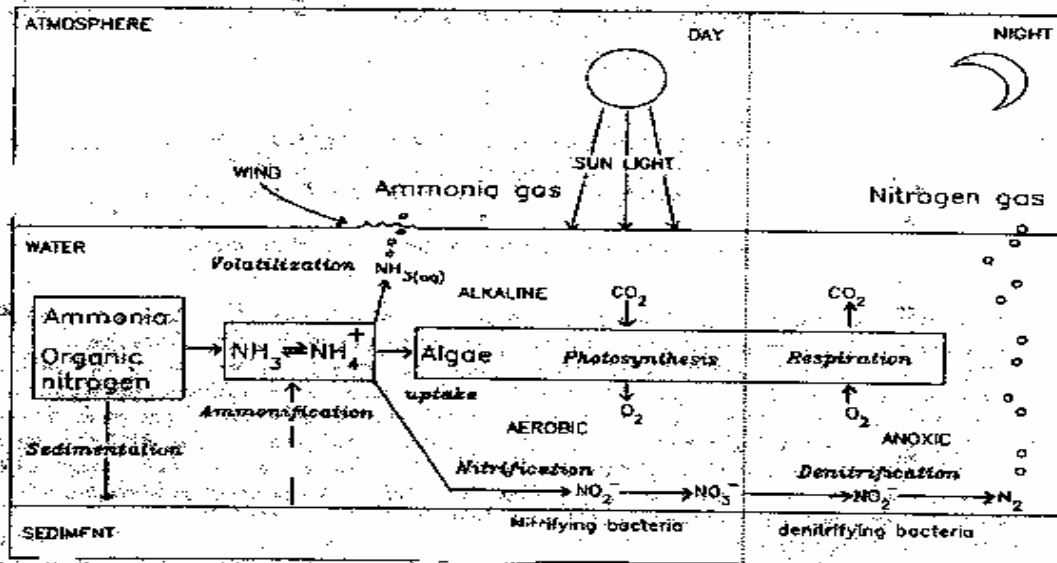
Figure 2.3: Principal Biochemical and Physical Pathways for Nitrogen Removal in Waste Stabilization Ponds

Source: Lai and Lam (1997)

2.7.1.1 <u>Nitrification</u>

Wastewater influents entering facultative ponds usually have a substantial concentration of ammonia (Azov and Tregubova, 1995). Ammonia is oxidized to nitrate in the environment and in biological wastewater treatment by two groups of chemo-autotrophic bacteria, operating in sequence (Azov and Tregubova, 1995; Barnes and Bliss, 1983). The first step is the oxidation of ammonia to nitrite by members of the genus, Nitrosomonas. Nitrite is then further oxidized to nitrate by the second group of bacteria, usually by members of the genus Nitrobacter (Azov and Tregubova, 1995; Barnes and Bliss, 1983; Holbrook, et. al., 2000).

These oxidations can be represented as (Holbrook, et. al., 2000):

$$2NH_4^+ + 3O_2 \xrightarrow{\quad Nitrosomonas \quad} 2NO_2^- + 4H^+ + 2H_2O + energy$$

$$2NO_2^- + 2O_2 \xrightarrow{\quad Nitrobacter \quad} 2NO_3^- + energy \qquad\qquad (2\text{-}3)$$

$$2NH_4^+ + 2O_2 \longrightarrow 2NO_3^- + 2H^+ + H_2O + energy$$
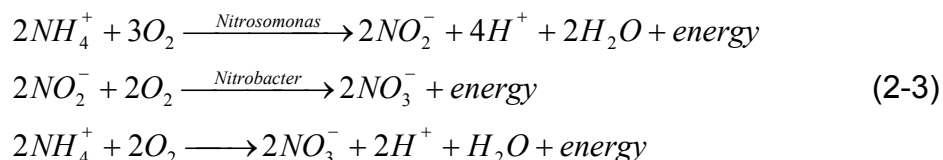
Treatment by nitrification does not remove ammonia, but converts it to nitrate, thereby eliminating problems of toxicity to fish and reducing the nitrogen oxygen demand of the effluent (Viessman and Hammer, 1998). However, if the level of nitrates rises above 2 parts per million (p.p.m), there is the risk of methaemoglobinaemia and eutrophication (Dart and Stretton, 1980). Therefore, to reduce or remove these risk nitrates must undergo denitrification.

2.7.1.2   Denitrification

In the absence of a ready supply of molecular dissolved oxygen for use in respiration many heterotrophic bacteria are able to use of nitrate as an alternative electron acceptor. This process, called denitrification, results in the reduction of nitrate, first to nitrite and then to nitrogen gas (Barnes and Bliss, 1983; Lai and Lam, 1997). Energy yield is lower than that acquired from oxygen respiration; therefore, denitrification is only effective at low dissolved oxygen concentration. An external carbon source is also required for the maximum reaction rate (Barnes and Bliss, 1983; Marsili-Libeili and Giunti, 2002). Carbon sources are readily available in facultative ponds in the form of biodegradable organics. These reduction reactions can be represented as (Viessman and Hammer, 1998):

$$3O_2 + 2CH_3OH \rightarrow 2CO_2 + 4H_2O$$
$$6NO_3^- + 5CH_3OH \rightarrow 3N_2\uparrow + 2CO_2\uparrow + 7H_2O + 6OH^- \qquad (2\text{-}4)$$
$$2NO_2^- + CH_3OH \rightarrow N_2\uparrow + CO_2\uparrow + H_2O + 2OH^-$$
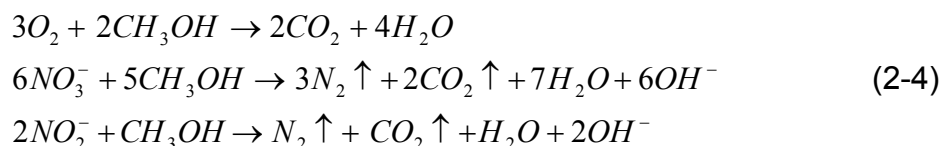
Therefore, effective treatment of ammonia via transformation route must

incorporate both nitrification and denitrification. Facultative ponds are particularly adept

at this process, because they offer both the oxygen rich surface layers, to facilitate

nitrification and the anaerobic subsurface ideal for denitrification. However, not all

ammonia leaves the system via this route.

2.7.1.3 Ammonia Volatilization

Silva, et al. (1995) proposed that ammonia volatilization is the major route for

nitrogen removal, since the pH in ponds is usually above seven. Maynard, et. al. (1999)

agreed that volatilization is possible, but only occurred when pH values exceeded ten.

Lai and Lam (1997) reported that the carbon dioxide consumed by actively

photosynthesizing algae exceed those supplied by organic degradation, resulting in an

increase in pH. Since, total ammonia nitrogen in water existed in an equilibrium with

dissolved ammonia (NH$_3$) and ammonium ion (NH_4^+), and alkaline pH shifts the

equilibrium towards gaseous ammonia, then volatilization is predominant. Reed et. al.

(1995) reported that up to 80% of the total nitrogen loss is due to volatilization.

2.8 Factors Affecting the Removal of BOD and Nitrogen from Facultative Ponds

BOD and nitrogen removal from facultative ponds are biologically intensive

processes. Therefore, all factors affecting biological systems or mechanisms will tend to

affect the efficiency of their removal. In general these include: climate, pond geometry and hydraulics and, wastewater characteristics. Various researchers have reported significant correlation between various factor and BOD removal.

BOD removal is depended on temperature (Brian and Li, 1992; Saqqar and Pescod, 1995; von Sperling, 1996; Thirumurthi, 1974; Veenstra, et. al., 1995; Zhao and Zhang, 1991), solar radiation (Shelef and Kanarek, 1995; Thirumurthi, 1974), baffles (Muttamara and Puetpaiboon, 1997), suspended solid removal (Saqqar and Pescod, 1995), organic loading (Shelef and Kanarek, 1995; Thirumurthi, 1974; Veenstra, et. al., 1995;), retention time (Veenstra, et. al., 1995), the presence of cellular enzymes (Hosetti and Frost, 1994), and dissolved oxygen (Brian and Li, 1992; Thirumurthi, 1974).

Nitrogen removal from waste treatment ponds also depends on several factors. These include, the number of baffles (Muttamara and Puetpaiboon, 1997), retention time (Meisheng, et.al., 1992; Muttamara and Puetpaiboon, 1997; Silva, et al, 1995; Soares, et al., 1996), Chlorophyll content or amount of algae (Horne, 1995; Lai and Lam, 1997;), temperature (Azov and Tregubova,1995; Gomez, et al., 1995; Lai and Lam, 1997), light irradiance (Azov and Tregubova,1995; Gomez, et al., 1995;), pH (Gomez, et al., 1995;Lai and Lam, 1997), depth (Gomez, et al., 1995; Silva, et al., 1995), dissolved oxygen (Lai and Lam, 1997;) and geometry (Silva, et al., 1995; Soares et al, 1996). Hurse and Connor (1999) reported that parameters having a significant to substantial influence on nitrogen removal include temperature, algal concentration and dissolved oxygen. Using Regression tests, Kurosu (2001) disagrees with this finding, stating that total nitrogen removed was not significantly correlated with water temperature and solar radiation.

2.8.1 <u>Temperature</u>

The biological assimilation and organic degradation that occurs in ponds are related to water quality, temperature, light and pond mixing. Of all the factors, temperature is the most important one influencing these processes (Zhao and Zhang, 1991). Temperature has a profound effect on wastewater micro-organisms, reaeration rate, oxygen stability and other biochemical reactions (Gaddad and Rodgi, 1987; Gray, 1989).

It affects the structure, composition and distribution of the microbes by influencing the enzyme activity with the bacteria cell, thus varying the performance of the ponds. For example an increase in temperature up to 40^oC results in a corresponding increase in removal of both BOD and nitrogen, a result that coincides with bacteria grow, which is optimal at 30^oC(Gaddad and Rodgi, 1987; Gray, 1989). A marked rise or fall in temperature causes a change in the phase, DO level and bio-chemical rate (Zhao and Zhang, 1991).

Temperature affects photosynthetic oxygen production as well as other biological reactions. Optimum oxygen production is obtained at about 20^oC, and limiting lower and upper values appear to be about 4^oC and 37^oC respectively (Gloyna, 1971). It should be noted, that an increase in temperature would also cause a corresponding increase in bacteria growth, therefore, oxygen utilization would also increase (Gaddad and Rodgi, 1987). Further, as temperature increases the solubility of oxygen decreases. This therefore means that an increase in temperature does not guarantee a linear increase in biologically available oxygen.

2.8.2   <u>pH</u>

Azov and Shelef (1987) indicated that of all the parameters which determine the performance of ponds, the pH is one of the most complicated. The pH of the water determines the ratios of the carbonate system species in the pond as well as the ratio of free ammonia to ammonium ion. One possible reason for this is the diurnal change of pH in ponds, which is mainly due to algae and bacteria activity. Algae take up Carbondioxide (CO_2) during the daylight to carry out photosynthesis, replacing the oxygen used for the respiration of the bacteria and algae. However, during the night an increase output of CO_2 is evident due to respiration by both algae and bacteria, with no oxygen replenishment (Kayombo, et. al., 2002).

2.8.3   <u>Dissolved Oxygen (DO)</u>

DO within ponds mainly originate from photosynthetic activity, with secondary contribution from the atmosphere by natural reaeration through the water surface. The hourly variation of pH, temperature and DO appear to follow the pattern of the diurnal cyclic nature of sunlight intensity on the processes in the pond (Kayombo, 2002). The concentration of DO within the pond is a function of pH, CO_2 concentration and temperature. Kayombo, et. al. (2002) reported that pH above 8 is produced by photosynthetic rate that demand more CO_2 than the quantities produced by respiration and decomposition of organics, this in turn causes an increase in ammonia concentration, which is toxic to algae. The net result is pH within the pond restrict algal activity, which varies the photosynthetic activity of algae, causing variation in DO concentration. The presence of oxygen facilitates aerobic oxidation and the nitrification

process. While reduction in oxygen, facilitate anaerobic oxidation and the denitrification process (Barnes and Bliss, 1983; Lai and Lam, 1997).

2.8.5 <u>Retention Time</u>

Hydraulic Retention Time (HRT) is the time water molecules reside in the pond from the time of entering to when they leave (Denbigh and Turner, 1984; Sincero and Sincero, 1996). Simply, the longer wastewater stays within the pond, the longer it will be in contact with bacteria, and hence the more treatment will be possible (Meisheng, et. al., 1992). Therefore, factors such as short circuiting and baffles that affect the retention time will also influence the BOD and nitrogen removal efficiency. Muttamara and Puetpaiboon (1997) reported increase in removal of total nitrogen, ammonia and COD, with the introduction of baffles. The rational for this increase was given as, the baffle arrangement induce near plug-flow conditions and lengthen the flow path of the wastewater stream, thus increasing the organic carbon and nitrogen removal efficiency.

It can be concluded from the review of the literature that there are several factors that influence the removal of both BOD and nitrogen. Namely, temperature, dissolved oxygen, pH and retention time. It is these factors along with others that are used for monitoring pond performance and criteria for pond design. Hosetti and Frost (1998) reported that effluents from biological treatment units are usually monitored in terms of DO, BOD, bacteria, pH, phosphates, ammonia nitrogen and Total Suspended Solids (TSS). However organic loading, temperature and retention time are normally used to design for treatment in facultative ponds (Reed, et. al. 1995).

2.9   Facultative Pond Design

Facultative pond design is usually based on BOD removal with the majority of the suspended solids removed in the primary cell of a pond system (Reed et. al. 1995). Several approaches to the design of ponds have been proposed. The more common methods include areal loading rate, plug flow model, completely mixed model and dispersion model, with the assumption that there is no solids recycling (Peavy, et. al, 1985; Reed, et. al, 1995; Zhao and Zhang, 1991). The latter three models are function of the degree of mixing within the pond.

2.9.1   Areal Loading Rate Method

This method relates organic loading and/or hydraulic retention time with some other environmental parameter such as temperature or solar radiation. These criteria are assumed to ensure satisfactory performance as long as the system is operated below the recommended standard (Reed, et. al., 1995). The simplest methods relate permissible areal loading rate expressed in kg BOD_5/ha/day to minimum monthly average temperature.

Arthur (1983) proposed the following equation for design of Facultative ponds using the areal loading rate.

$$\text{Areal Loading Rate } (\lambda_s) = 20T - 60 \qquad\qquad (2\text{-}5)$$

Where: T = mean minimum monthly temperature in $^{\circ}C$

λ_s = areal loading rate in Kg BOD_5/ha/day

The above empirical formula provides a 1.5 safety factor before complete failure.

Gloyna (1976) proposed the following empirical equation for the design of facultative wastewater stabilization ponds:

$$V = (3.5*10^{-5})(Q)(L_a)[\theta^{(35-T)}](f)(f`) \qquad (2-6)$$

Where V = pond volume, m^3

Q = influent flow rate, L/d

L_a = ultimate influent BOD or COD, mg/L

θ = temperature correction coefficient = 1.085

T = pond temperature, ^{o}C

f = algal toxicity factor, f =1 for domestic wastes and many industrial

wastes.

f`= sulfide or other immediate chemical oxygen demand. F`= 1 for SO$_4$

equivalent ion concentration of less than 500mg/l

In this equation, the surface area is the critical parameter. Therefore, the effective depth used to establish the surface area must be minimal. BOD removal, using the above equation ranges from 80-90% based on unfiltered influent samples and filtered effluent samples. Gloyna (1976) recommended a one meter depth, to control potential growth of emergent vegetation, and to avoid stratification during hot months.

2.9.2   Effect of Mixing

Ponds go through periods of gentle mixing owing to the wind and temperature effects. The extent of mixing depends on the magnitude of these effects and pond geometry (Sarikaya et. al., 1987). Arthur (1983) reported that this was advantageous, since efficient absorption of shock-loadings and equalization of loading peaks are

dependent upon achieving reasonably good mixing of the influent throughout the pond contents. Mixing is also important to minimize hydraulic short-circuiting in ponds, and to achieve a good vertical distribution of both oxygen and algae in facultative ponds. Further, non-motile algae which are the most efficient oxygen producers rely on pond mixing to bring them into the surface layers of the ponds where light intensity is greatest. Mixing also destroys thermal stratification (Arthur, 1983).

For design purposes, ponds are categorized according to hydraulic flow regimes, the most common type being vertically mixed ponds. Vertically mixed ponds can be further classified according to the degree of mixing in axial direction as plug-flow, completely mixed-flow and dispersed-flow ponds and various combinations of these models (Sarikaya et. al., 1987; Zhao and Zhang, 1991).

2.9.2.1 <u>Plug Flow Model for BOD Removal</u>

In plug-flow ponds it is assumed that there is no mixing in axial direction or dispersion number d = 0 (Sarikaya, et. al., 1987). The ideal plug flow reactor is a tube with particles of liquid entering and discharging in the same sequence. The residence time of each particle is equal to the mean residence time. That is the reactor has a single residence time (Viessman and Hammer, 1998; Werner and Kale, 2000).

$$C_e = C_i \ell x p^{-kt} \qquad\qquad (2\text{-}7)$$

Where: C_i = influent BOD concentration, mg/L

C_e = effluent BOD concentration, mg/L

K_t = the plug flow first order BOD removal coefficient, d^{-1}

t = hydraulic residence time

The reaction rate varies with BOD loading rate, but is normally determined via the following equation:

$$K_t = K_{20}(1.09)^{T-20} \qquad (2\text{-}8)$$

Where K_t = reaction rate at temperature T, d^{-1}

K_{20} = reaction rate at 20°C, d^{-1}

T = operating water temperature, °C.

2.9.2.2 Completely Mixed Model for BOD Removal

In completely mixed flow ponds it is assumed that there is complete mixing in the axial direction or dispersion number d = ∞ (Sarikaya, et. al., 1987). That is, the content of the system is uniformly and continuously redistributed. Particles entering are dispersed immediately throughout the system and leave in proportion to their concentration. That is, all particles have equal probability of leaving the system at any given moment (Viessman and hammer, 1998; Werner and Kadlec, 2000).

$$C = \left(\frac{C_o}{1+kt}\right)^n \quad \text{(Reed, et al., 1995; Sarikaya, et al., 1987)} \quad (2\text{-}9)$$

Where: n = number of equal-sized pond cells in series.

The influence of the water temperature on the reaction rate is estimated by the following equation:

$$k_{cT} = k_{c35}(1.085)^{T-35} \qquad (2\text{-}10)$$

Where: k_{cT} = reaction rate at water temperature T, d^{-1}

k_{c35} = reaction rate at $35^{o}C$ = $1.2d^{-1}$

T = operating water temperature, ^{o}C

2.9.2.3   <u>Dispersion Model for BOD Removal</u>

The above flow types are ideal cases. However, most waste stabilization ponds have flow regimes that fall between these two flow types; that is, they are dispersed-flow reactors. Longitudinal flow passing through the ponds has variations in flow velocities, also called shear flow, that result in axial intermixing (Viessman and hammer, 1998; Werner and Kadlec, 2000). Esen and Al-Shayji (1999) and Reed et al. (1995) used the Wehner-Wilhelm equation to describe this flow regime. This equation assumed that ponds are chemical reactors which exhibit first order kinetics and non-ideal mixing, and can be used for any kind of influent and effluent parameter. The equation is as follows:

$$\frac{C}{C_o} = \frac{4a\ell xp^{(1/2d)}}{(1+a)^2 * \ell xp^{(a/2d)} - (1-a)^2 * \ell xp^{(-a/2d)}} \qquad (2\text{-}11)$$

Where: C = effluent BOD or nitrogen concentration, mg/l

C$_o$ = influent BOD or nitrogen concentration, mg/l

$$a = \sqrt{1 + 4Ktd}$$

Where: K = the first order reaction rate constant, d^{-1},

t = hydraulic retention time, d,

d = dimensionless dispersion number, where

$$d = \frac{H}{\upsilon * L} = \frac{Ht}{L^2} \qquad (2\text{-}12)$$

Where: H = axial or longitudinal dispersion coefficient, area per unit time,

ν = fluid velocity, m/s

L = length of travel path of a typical particle

Reed, et. al. (1995) used the Thirumurthi charts, which is a plot of the dimensionless term kt versus the percentage of BOD remaining for dispersion numbers ranging from zero for ideal flow to infinity for completely mixed systems, to determine the dispersion number for a particular pond system. To improve the selection of d for use in the Wehner-Wilhelm equation Polpradert and Bhattarai developed the following equation:

$$D = \frac{0.18[t\upsilon(W + 2d)]^{0.489}(W)^{1.511}}{Ld^{1.489}} \qquad (2\text{-}13)$$

Where: D = dimensionless dispersion number

υ= kinematic viscosity, m^2/d

d = liquid depth of pond, m

W = width of pond, m

L = length of pond, m

The reaction rate coefficient can be estimated from the same equation for that of plug-flow. Even so, this improvement still has its drawback in that tracer studies have to

be used to determine hydraulic residence time. However, Reed et. al. (1995) suggests that the actual hydraulic residence time can be assumed to be that of half the theoretical hydraulic residence time.

2.9.3   Nitrogen Removal

Ponds are also designed incorporating nitrogen removal in the design equation. Two common models are suggested by the literature (Middlebrooks, et. al., 1999 and Reed, et. al., 1995). These models assume plug and completely mixed flows and that the major nitrogen removal pathway is via ammonia volatilization (Middlebrooks, et. al., 1999). Ammonia-N removal in facultative wastewater stabilization lagoons can occur through the following three processes (Middlebrooks, et al., 1999):

- Gaseous ammonia stripping to the atmosphere,
- Ammonia assimilation in algal biomass, and
- Biological nitrification.

2.9.3.1   Plug Flow for Nitrogen Removal

The following equation is used to determine the nitrogen removal in facultative ponds assuming plug-flow.

$$N_e = N_o \ell x p^{-K_T \left[t + 60.6 \left(pH - 6.6 \right) \right]}$$

(2-15)

Where N_e = effluent total nitrogen, mg/L

N_o = influent total nitrogen, mg/L

K_T = temperature dependent rate constant

$$K_T = K_{20}(\theta)^{(T-20)}$$ (2-16)

K_{20} = rate constant at 20°C = 0.0064

θ = 1.039

t = detention time in system, d

pH = pH of near surface bulk liquid

Reed, et. al. (1995) suggests the following equation for estimating pH values using values of alkalinity.

$$pH = 7.3\ell xp^{0.0005(ALK)}$$ (2-17)

Where: ALK = expected influent alkalinity mg/L

To determine pond water temperature:

$$T = \frac{0.5AT_a + QT_i}{0.5A + Q}$$ (2-18)

Where A = Surface area of pond, m^2

T_a = ambient air temperature, °C

T_i = influent temperature, °C

Q = influent flow rate, m^3/d.

2.9.3.2 Complete Mixed Model for Nitrogen Removal

For nitrogen removal in facultative ponds assuming complete-mix conditions Middlebrooks, et al. (1999) and Reed, et. al. (1995) proposed the following:

$$N_e = \frac{N_o}{1 + t(0.000576\ T - 0.00028\ )\ell xp^{\ (1.080 - 0.042\ T\,)(pH - 6.6)}} \qquad (2\text{-}19)$$

Where: pH = pH of near surface bulk liquid. All other parameters defined as before.

The common factors for the above design equations are that of influent and effluent species, temperature, pH, reaction rate coefficient, dispersion coefficient and residence time. The latter three parameters characterize the hydraulic profile of the ponds.

2.10   Tracer Studies

In order to determine the BOD and nitrogen removal efficiency of the wastewater stabilization ponds a hydraulic profile of the ponds must be determined. That is, the dispersion coefficient and actual retention times must be determined. Shilton (2001) quotes Finney and Middlebrooks (1980) as saying "The hydraulic detention time is used in many of the design methods and yet very little research has been done in determining factors influencing actual hydraulic residence time. Consistent prediction of pond performance by any design method without accurate projections of hydraulic residence time is impossible."

The dispersion coefficient is used to determine if the ponds have a plug, completely mixed or non-ideal or dispersed flow regime. After this is determined, then the appropriate first order removal equation is chosen in conjunction with the retention time, in order to determine the pollutant removal rate constant. To determine the dispersion coefficient and the retention time, tracing is normally done. Tracing is the use of natural or introduced materials to study mixing and rates of movement within water

bodies (Wilson, 1968). The material used to determine the hydraulic flow regime is called a tracer.

In hydrologic tracing, any dissolved, suspended or floating material used to determine the path and/or rate of movement and dispersion of similar materials in the water is considered a tracer (Wilson, 1968). To be effective, a tracer should be water soluble, detectable at low concentrations, have minimal background interference, inexpensive and reasonably stable. Commonly used tracers include lithium chloride, salinity or conductivity, radioactive materials, pontacyl pink, Rhodamine B and WT and Fluorescein. The latter four are categorized as fluorescent dyes (Marecos do Monte and Mara, 1987; Martin and M[c]Cutcheon, 1999). Fluorescent dye tracing are now widely used and are the most common method used in hydrology to determine hydraulic regimes and parameters (Smart and Laidlaw, 1977).

2.10.1 Fluorescence and Fluorescent Dyes

Fluorescence is a sub-category of a broader field of study, luminescence. Luminescence is the emission of photons from electronically excited states (Lakowicz, 1983). This emission is not accompanied by heat and hence is often called cold light. Luminescence can be categorized as fluorescence and phosphorescence, the nature of the ground and excited electronic states being the distinguishing characteristic. For both phenomenons, the substance is raised to a higher energy state usually by the absorption of radiant energy (Hercules, 1966; Lakowicz, 1983; White and Argauer, 1970).

The electronic or energy states of molecules can be grouped into two broad categories, namely singlet and triplet states. A singlet state is one in which all the electrons in the molecule have their spins paired (Hercules, 1966; Lakowicz, 1983). In the singlet excited state, the electron in the higher-energy orbital has the opposite spin orientation as the second electron in the lower orbital (Lakowicz, 1983). In the triplet states these electrons are unpaired, that is, their spins have the same orientation (Hercules, 1966; Lakowicz, 1983). Phosphorescence is the emission which results from transition between states of different multiplicity; a triplet-singlet transition. Fluorescence is the emission which results from the return to the lower orbital of the paired electron, that is, a singlet-singlet transition (Hercules, 1966; Lakowicz, 1983). The physical distinction between these two phenomenons is the length of the process. In the case of fluorescence the energy emission ceases in about 10^{-8} sec after the excitation source is removed, and if it persists for a longer time than this, the term phosphorescence is used (Lakowicz, 1983; White and Argauer, 1970).

Before an atom or molecule absorbs energy, it is said to be in its ground state, or the state of lowest energy (Hercules, 1966). When a compound become irradiated or absorb a photon of the appropriate energy, the electrons become excited and move to electron orbital of higher energy. An orbital is defined as that volume element of space in which there is a high probability (99.99%) of finding an electron. The molecule is now in what is called an excited state, but it geometry and electron distribution remain the same (Hercules, 1966).

At this point, the molecule can undergo a number of vibrational levels before it emits the absorbed radiation or it can emit a photon of energy and return to its original

state. In this state, the molecule has a completely different electron distribution from the ground state; a different geometry and therefore the bonds will undergo different intensities and type of vibration (Hercules, 1966; White and Argauer, 1970; Winefordner, et al., 1972).

Once a molecule arrives at the lowest vibrational level after energy absorption, it can do a number of things, one of which is to return to the ground state by photon emission. This process is called fluorescence (Hercules, 1966; Schulman, 1977). Wilson (1968) defines fluorescence as the type of luminescence, in which certain substances immediately emit radiation at a lower frequency and longer wavelength upon irradiation by an external source; emission ceases when the source is removed. Thus, the entire process consists of absorption of energy from an external source such as the sun, excitation of the electrons of the fluorescent substance, resulting in enlarged electron orbitals and emission of energy in the form of photons or light (Wilson, 1968).

2.10.2   Types of Fluorescent Dyes

The United States Geological Survey (USGS) recommends the use of four dyes for tracer studies. Namely, Rhodamine B, Pontacyl Pink, Rhodamine WT, and Fluorescein. In General, they are good tracers because they are:

- ✓ Water soluble,
- ✓ Highly detectable, strongly fluorescent (convert a high percentage of absorbed energy into emitted energy) and easily isolated from background,
- ✓ Harmless at low concentrations,

✓ Inexpensive,

✓ Reasonable stable in normal stream environment.

Fluorescein and Rhodamine WT are two of the most commonly used tracer dyes. Fluorescein has been used since the end of the nineteenth century. While it is detectable in low concentrations, it readily photo-degrades. Rhodamine WT was specifically developed for tracing work, it is the fluorescent tracer dye of choice, in that it is relatively inexpensive, resistant to adsorption and meets all of the above requirements and is approved for use by the Environmental Protection Agency. Applications of this dye include tracking pesticide spills, determining sewer flows to determine hydraulic limits, calculating time of travel and identifying dispersion patterns (Smart and Laidlaw, 1977; Wilson, 1968).

Rhodamine WT is a highly fluorescent material with the unique ability to absorb green light and emit red light, therefore it visibly appears red. Very few compounds have this property, so interferences from other substances are very rare. This makes Rhodamine WT a highly specific tracer. The amount of red light emitted is directly proportional to the concentration of the dye, up to 100 parts per billion (100 μg/L). Relative fluorescence readings, dye concentrations, dilution factors, dye travel time, and other parameters provide valuable data used to draw conclusions regarding the water system being studied (Cortuvo, 1988). In addition several researchers have used Rhodamine WT as the tracer when determining the hydraulic flow regime of facultative ponds. These include Shilton et. al. (2000); Simi and Mitchell (1999); Nameche and Vassel (1996); Macdonald and Ernst (1986); Mangelson and Watters (1972).

Fluorescein visually appears yellow/green, depending on its concentration and under UV light as lime green. Based on biochemical oxygen demand (BOD) studies, the dye is biodegradable with 65% of the available oxygen consumed in 7 days. The dye is resistant to absorption on most suspended matter in fresh and salt water. However, compared to Bright Dyes FWT Red products it is significantly less resistant to degradation by sunlight and when used in fluoremetry, and stands out much less clearly against background fluorescence (Kingscote Chemical).

Tracer studies provide one of the better sources of information for evaluating the hydraulic characteristics of exiting ponds, but it is impractical to perform tracer studies under every possible hydraulic condition (Esen and Al-Shayji, 1999; Martin and McCutcheon, 1999). Therefore, Esen and Al-Shayji (1999) used a least squares and Reed et. al. (1995) a trial and error method to estimate the first order reaction constant k and the dispersion number d, using the Wehner-Wilhelm equation for describing pond performance. This method will be further discussed in chapters 4 and 5.

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3   METHODOLOGY AND EXPERIMENTAL PLAN

3.1   <u>Overview of Chapter</u>

Chapter 3 is divided into two main sections. The chapter begins with a review of various methods of pond monitoring as seen in the literature, followed by the actual methodology used in this project. Both sections consist of a discussion of sampling methodology and sample handling techniques, followed by analytic procedures for monitoring pond Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Nitrogen, Specific Conductivity, Temperature, Dissolved Oxygen (DO), pH and tracer study techniques

Sampling methodology and handling techniques deal with how to evaluate the performance of a pond system. This includes physical descriptions of the system location, the system and the individual ponds. The evaluation is then completed with an analysis of the physiochemical and chemical parameters within the ponds. A discussion of the various methods used by researchers to analyze individual parameters is included. An evaluation of tracer studies; as found in the literature and the method and technique that were actually used on this project, is included. Finally, due to concern about excessive influent grease and the potential for system overload, a survey of food preparation establishments was carried out and the appropriate literature included.

Experimental Plan: From Literature

Most biological systems function effectively without human interference. However, the stabilization pond is a man made, albeit biological ecosystem governed by the nature of the communities that it supports and the prevailing environmental conditions in which it is maintained (Hosetti and Frost, 1998). As stated in chapter one, ponds are the most widely used biological wastewater treatment system, but their design is often sub-optimal since designers use methods of design that are too conservative (Arthur, 1983; Shelef and Kanarek, 1995; Pearson, et al., 1987a).

In designing ponds it is the interrelationships between the microscopic fauna and flora and the chemistry of their circumstances that is manipulated to ensure breakdown of organic refuse (Hosetti and Frost, 1998). Hence, monitoring rates of change using biological and chemical techniques provide useful information for adjusting retention times or creating additional pond basins to enhance the treatment process of existing ponds and more efficient future designs (Hosetti and Frost, 1998). Therefore there is a great need for reliable and standardized collection, analysis and presentation of pond performance data (Pearson et al., 1987a).

3.2.1   Sampling Methodology

Pearson et al. (1987a) suggests that the first step in evaluating the performance of a pond system is to give a physical description of the system. This description includes information about the location of the system, the pond complex and the individual ponds. Details of the climatic conditions, the latitude, longitude, altitude, population of the community being served and any other geographical data are important to locating the system. Any description of the pond complex must include the

number, type and arrangement of the ponds, the availability of pre and post treatments, flow measurement devices and the final destination of the effluent from the system. Finally, the individual pond (s) under study is described. An adequate description includes the dimensions, inlet and outlet structures, designed flow, organic loading along with existing data on influent and effluent quality of the ponds.

After locating the complex, describing the system and outlining the features of each pond, it is then time to characterize the chemical and biological activities within the ponds. This assessment is usually required to ensure that the pond system meets local discharge guidelines or standards. Further, measurements of effluent quality also form an integral part of studies on treatment efficiency and the verification of design performance (Pearson, 1987b). For this, a sample of the pond water is required.

The Oxford American Dictionary and Thesaurus defines a sample as: "a small part or quantity intended to show what the whole is like." Therefore, the objective is to acquire a sample that is representative of the insitu conditions within the pond. This is very difficult for two reasons. The first is that most effluent flows fluctuate rapidly both in composition and rate of flow over time. Secondly, the composition of the samples may change before they can be analyzed (Dart and Stretton, 1980). The accuracy of the results, therefore, not only relies on good analytical techniques and competent technicians but also on careful representative sampling (Pearson, et al. 1987b). Therefore, the need to obtain samples that are representative of actual insitu conditions and to determine ways of effectively preserving the integrity of those samples until they are analyzed cannot be overemphasized (Pearson, et al., 1987a).

3.2.1.1 <u>Sampling to Account for Fluctuations</u>

The concentration of the various determinants in a wastewater stream will vary due to random and systematic changes. To account for the wastewater flow fluctuations and to provide samples that are representative, the best technical solution would be to use an online automatic instrument to provide continuous analyses of the pollutant of interest. However, this approach is rarely applicable, because suitable instrumentation for such analysis are either inappropriate for field application, unavailable or too expensive (ISO, 1992). Thus, the type and frequency of sampling must be manipulated to make allowances for the various sources of variation in quality.

The types of sampling techniques available are grab or spot sample, column sample and composite or flow weighted sample (Soares, et al., 1996). A grab sample is a discrete volume taken all at once, randomly (with respect to time and location) from the pond (ISO, 1992; Pierce, et al., 1998). This is particularly appropriate where there are little variations in the volume and composition of the waste stream or for use in effluent standard compliance requirements. Grab samples taken at varying pond depths are called column samples. There are two types of composite sampling; Time-weighted and flow-weighted. Time-weighted composite sample consist of spot samples of equal volume taken at constant intervals during the sampling period. The flow-weighted composite samples consist of spot samples taken and mixed in such a way that the sample volume is proportional to the effluent flow or volume during the sampling period. A flow-weighted composite sample can be taken at constant intervals, but with varying sample volumes that are proportional to the flow at the sampling time (ISO, 1992).

Most parameters should be measured on 24-h flow weighted composite samples (Pearson, et al., 1987a). That is, a grab sample every hour for 24 hours mixed in proportion to the flow at that time. The 24-h flow-weighted composite samples can be obtained as follows (Pearson, et al., 1987a):

- In an automatic sampler which takes grab samples every hour, with subsequent manual flow-weighting.
- By taking grab samples every, 1, 2 or at most 3 hours, with subsequent manual flow weighting.

From the literature, researchers used various sampling techniques during routine monitoring programs. In general raw sewage was collected via 24-h flow weighted composite. This was carried out once, sometimes twice per week between 0800 –1000 hrs at the inlet to the system (Marecos de Monte and Mara, 1987; Pearson, et al., (1987a b); Silva, et al., 1995; Sinkjaer, et al., 1996; Soares, et al., 1996; and Soler, et al., 1995). Santos and Oliveira (1987) used 24-h for both raw and effluent wastewater sample collections; this was made possible by the availability of automatic samplers.

Pearson, et al. (1987b) argued that column samples were as equivalent to mean daily samples as serial flow-weighted composite samples especially for pond effluent. This type of sampling was also carried out once per week at about 0800 at the pond outlet and consisted of mixing equal volumes of column samples to form a composite. This type of sampling was also used by Ghrabi et al., 1993; Pearson et al., 1995; Racault, 1993; Silva, et al. (1995); and Soares, et al. (1996). Other researchers seem to disagree with this school of thought, preferring grab samples. Grab samples are usually taken around the same time at mid depth. Among them are, Lai and Lam (1997);

Nurdogan and Oswald (1995); Racault (1993); Rakkoed, et al. (1999); Soler, et al. (1995); and Zimmo, et al. (2000)

Once the type of sampling is decided upon, the frequency of sample collection and the length of the sampling period should then be considered and allowances made for diurnal variations, variations between days of the week, variations between weeks and seasons (ISO, 1992). Samples should be collected during the most favorable and the least favorable seasons of the year when pond performance is likely to be best and worst respectively; that is during the hottest and coldest months. Pearson, et al., (1987a) suggested that sampling should be done weekly during a 5-week period in the middle of each season selected for sampling, with sampling done on a different day each week to account for daily variations in influent and effluent quality. Muttamara and Puetpaiboon (1996) indicated that the length of the sampling period should be about twice the theoretical retention time.

3.2.1.2   Sampling to Preserve Sample Quality

Wastewater is susceptible to being changed to differing extents as a result of physical, chemical or biological reactions which may take place between the time of sampling and the analysis (ISO, 1985). This is particularly true when the chemical composition is being examined (Dart and Stretton, 1980). The extent of these reactions is a function of the chemical and biological nature of the sample, its temperature, its exposure to light, the nature of the sample container, and the time between sampling and analysis. Therefore, the sampling, handling and analysis have to be designed to

minimize these reactions and in the case of many parameters, to analyze the sample with a minimum of delay (ISO, 1985).

3.2.1.3 <u>Sample Handling Techniques</u>

Despite numerous investigations, it is impossible to give absolute rules which will enable water samples to be stored without modification of their composition. In general the variations which take place in the water samples are due to biological processes; therefore handling techniques are geared towards reducing these processes (ISO, 1985). Recommendations are listed in Table 3.1.

3.2.2 <u>Analytical Procedures</u>

Pearson, et al. (1987a) suggested that the procedures described in Standard Methods for the Examination of Water and Wastewater are generally recommended for the various analytical procedures required for pond monitoring programs. However, other methods are used by researchers. The chemical analysis discussed below are BOD, TSS and the various nitrogen species are usually measured in the laboratory, while the physiochemical parameters are usually measured insitu using available instrumentation and include; temperature, DO, pH, and specific conductivity.

Table 3.1: <u>Techniques for Preservation of Samples</u> (ISO, 1985)

Parameter to be Studied	Type of container P = polyethylene G = glass	Preservation Technique	Place of Analysis	Maximum Recommended Preservation Time	Sampling
BOD	P or G	Cooling to between 2 to 5 °C and storage in the dark	Lab	As soon as possible or 6-24 hours	24-hr composite samples for influent, grab samples for effluent
Nitrogen, Ammonical and Kjeldahl	P or G	Acidification to pH < 2 with H_2SO_4 and cooling between 2 and 5 °C	Lab	24hours	24-hr composite samples for influent, grab samples for effluent
Nitrogen as nitrate	P or G	Acidification to pH < 2 with H_2SO_4 and cooling between 2 and 5 °C	Lab	24 hours	24-hr composite samples-influent, grab samples for effluent
Nitrogen as nitrite	P or G	Acidification to pH < 2 with H_2SO_4 and cooling	Lab	As soon as possible	24-hr composite samples for influent, grab samples for effluent

Dissolve Oxygen	-	-	On site	Insitu	Insitu at 10 cm depth measurements at 0800, 1200, and 1600h are recommended to create a profile
pH	-	-	On site	Insitu	Measurements between 0800 and 1000 h
Specific Conductivity	P or G	-	On site or lab	Insitu or within 24hours	Measurements between 0800 and 1000 h
Suspended Solid	P or G	-	Lab	24hours	24-hr composite samples for influent, grab samples for effluent
Temperature	-	-	On site	Insitu	Measurements of maximum and minimum temperatures at pond mid-depth.

3.2.2.1 <u>Biochemical Oxygen Demand (BOD)</u>

Most researchers determine BOD using the methods listed in Standard Methods. Such researchers include: Gaddad and Rodgi (1987), Ghrabi, et al. (1993), Soler, et al. (1995) Pedahzur, et al. (1993), Rakkoed, et al. (1999), and Veenstra, et al. (1995). Silva, et al. (1995) determined BOD concentration according to the standard BOD bottle dilution procedure and the dissolved oxygen was measured electronically with an oxygen-sensitive membrane probe connected to a dissolve oxygen meter.

The test is conducted in a standard BOD bottle of volume 300mL, with the sample appropriately diluted to ensure that all the oxygen is not used up during the five-day period (Vesilind, et al., 1988). The BOD is calculated from the following equation:

$$BOD = \frac{I - F}{D} \qquad (3\text{-}1)$$

Where: I = initial DO of bottle with sample, mg/L

F = final DO of bottle with sample, mg/L

D = dilution of sample.

The following is an excerpt from the Standard Methods for the Examination of Water and Wastewater (1992). BOD is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewaters, effluents, and polluted waters. The method consists of filling with sample, to overflowing, an air tight standard BOD bottle and incubating it at 20 $^{\circ}$C $\pm$ 1 for five days. Mara and Horan (1993) discussed the possibility of shortening the time, by

increasing the temperature to 35°C. Dissolved oxygen is measured initially and after incubation, and the BOD is computed from the difference between the two DO values.

The test has its widest application in measuring waste loadings to treatment plants and in evaluating the efficiency (BOD removal) of such treatment systems. BOD values cannot be compared unless the results have been obtained under identical test conditions. The test is of limited value in measuring the actual oxygen demand of surface waters. The extrapolation of test results to actual stream oxygen demands is highly questionable because laboratory environment does not reproduce stream conditions, such as temperature, sunlight, biological population, water movement, and oxygen concentration. However, due to its popularity, it is often used for easy comparison between similar studies.

3.2.2.1   Total Suspended Solids (TSS)

From the literature reviewed, all researchers used the method found in Standard Methods to evaluate TSS. Example researchers such as Ghrabi, et al. (1993), Nurdogan and Oswald (1995), Rakkoed, et al. (1999), Pedahzur, et al. (1993), Soler, et al. (1995), Veenstra, et al. (1995) indicated their use of this method. The method includes the filtering of a well mixed sample through a weighed standard filter (example: Whatman type GF/F 0.45μm) and the residue retained on the filter is dried to a constant weight at 103 – 105°C. The increase in weight of the filter represents the TSS. Standard deviations for various weights are listed in Standard Methods, indicating the precision of the test.

3.2.2.2   <u>Nitrogen</u>

The main nitrogen species determined by researchers in the literature are Total

Kjeldhal Nitrogen (TKN), ammonia, organic nitrogen, nitrate and nitrite. The methods for

determining TKN includes: method as indicated by Standard Method (Rakkoed, et al.,

1999; Lai and Lam, 1997 (using the Aquatic automatic flow inject analyzer); and

mineralization followed by Kjeldhal analysis Santos and Oliveira, 1987). Ammonia was

determined by the following methods: the use of specific electrodes (Santos and

Oliveira, 1987); Standard Methods (Azov and Tregubova, 1995; Gaddad and Rodgi,

1987; Ghrabi, et al.,1993; Lai and Lam, 1997; Soler et al. 1995; Zimmo, et al., 2000);

field kits, such as Hach DR/2000 field kit (Veenstra, et.al., 1995), and Nessler

colorimetric method following distillation (Silva, et al.,1995; Nurdogan and Oswald,

1995; Zimmo, et al., 2000).

Organic nitrogen was determined by methods listed in (Rakkoed, et al., 1999;

Soler et al., 1995; Zimmo, et al., 2000) and by Nessler colorimetric method after macro-

Kjeldahl digestion (Silva, et al., 1995). Nitrite was analyzed by the diazotization method

while nitrate by specific ion electrodes (Santos and Oliveira, 1987); Azov and

Tregubova, 1995;and Lai and Lam, 1997 using Standard Method. Zimmo, et al. (2000)

used Standard Method to determine nitrite, but used Advance Water Quality Procedures

Manual by Hach to determine nitrate. Silva, et al. (1995) measured nitrite

calorimetrically by the diazotisation method while nitrate was determined by the

colorimetric chromotropic acid method as found in Standard Method. Nurdogan and

Oswald (1995) determined Nitrate-plus-nitrite content by the hydrazine reduction

method and ammonium by the hypochlorite method.

3.2.2.3   <u>Specific Conductivity</u>

Conductivity, k, is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions; on their total concentration, mobility and valence; and on the temperature of measurement. Conductivity is the reciprocal of resistance, where the unit of resistance is the ohm (Ω). Conductivity of a solution is measured between two spatially fixed and chemically inert electrodes. To avoid polarization at the electrode surfaces the Conductivity measurement is made with an alternating current signal. The Conductivity, G of a solution is directly proportional the electrode surface area, A, and inversely proportional to the distance, L between the electrodes.

$$G = k\left(\frac{A}{L}\right)$$
(3-2)

The constant of proportionality, k, is called conductivity (specific Conductivity). It is a characteristic property of the solution between the electrodes. The unit of k is ohm/cm or since the reciprocal of ohm is called siemens, Conductivity is measured in siemens/cm. (Standard Methods, 1992). Soler et al. (1995) measured conductivity insitu with a Crison conductivity meter.

3.2.2.4   <u>Temperature</u>

Pearson et al. (1987a) suggests that temperature be monitored by suspending a maximum-and-minimum thermometer at mid depth in each pond at 0800hr and read 24 hours later. Researchers measured temperature onsite using a variety of instrumentation. Soares, et al. (1996) used a mercury-filled Celsius thermometer;

Gomez, et al. (1995) measured with a Ponselle oximeter; Lai and Lam, (1997),

Pedahzur, et al. (1993) and Silva, et al. (1995) used a YSI dissolved oxygen meter;

Zimmo, et al. (2000) used a Hach pH meter; and Soler et al. (1995) a Crison

temperature meter.

3.2.2.5   Dissolved Oxygen

DO is usually measured on site, however Gaddad and Rodgi (1987) and Hosetti

and Frost (1994) estimated DO values using methods found in Standard Method. Lai

and Lam (1997) and Soler, et al. (1995) measured on site using YSI dissolved oxygen

meter while Zimmo, et al. (2000) used a Hach DO meter.

3.2.2.7   pH

pH can be measured both in the laboratory and in the field. Azov and Tregubova

(1995) and Veenstra, et al. (1995) measured on site but did not specify the instrument

used. Silva, et al. (1995) measured pH electronically using Pye Unicam pH meter with a

combined pH electrode and a temperature compensator probe. Gomez, et al. (1995)

and Lai and Lam, (1997) measured in the laboratory using bench top Orion pH meter.

Hosetti and Frost (1994) used a digital pH meter. Soler, et al. (1995) used a Radiometer

pH meter. Pedahzur, et al. (1993) used a Radiometer Copenhagen pH meter and

Ghrabi, et al. (1993) used the method listed in Standard Method.

3.2.3 **Tracer Study**

Oswald (1995) defined ponds as designed or process reactors. If a complete velocity distribution map for the fluid can be ascertained, then it is possible to predict the behavior of the vessel as a reactor. However, while this information would be invaluable, the attendant complexities make the task impractical. Thus, a simplified approach is to determine how long the individual molecules stay in the vessel or more precisely the distribution of residence times of the flowing fluid (Levenspiel, 1995).

This is due to the fact that there is an intermediate degree of mixing occurring, not fully plug and not completely mixed (Werner and Kadlec, 2000). Thus, individual molecules require different lengths of time to pass through the vessel. Hence the distribution of these times is called the exit age distribution or the residence time distribution (RTD) (Levenspiel, 1995; Metcalfe, 1997). This non-ideal flow pattern is a result of the different routes that the flowing liquid move through the pond, which creates different travel times (Viessman and Hammer, 1998). Thus, the hydraulic character of a process reactor is defined by the residence time distribution (RTD) of individual particles of the liquid flowing through the system or the distribution of times that parcels of water spend in the system (Sincero and Sincero, 1996; Viessman and Hammer, 1998; Werner and Kadlec, 2000). Several physical phenomena can contribute to the distribution of travel times, including vegetation, wind mixing, vertical and transverse velocity profiles and thermal stratification (Kellner and Pires, 2002; Werner and Kadlec, 2000).

Due to shear forces water moves more slowly along the bottom than in the surface layers. Fisher, et al. (1979) define shear flow as the advection (transport by an

imposed current system such as a river) of fluid at different velocities at different

positions; this is the characteristic velocity profile of turbulent flow where the water flows

faster with increasing elevation above the bed of the pond, that is the existence of

velocity gradients normal to the direction of flow (Denbigh and Turner, 1984). The

overall effect is the creation of different rates of flows of the individual water molecules,

thus a change in the overall residence time for treatment.

Thermal stratification can also cause a change in the residence time by varying

the treatment volume. When a liquid is thermally stratified, two distinct layers exist. The

layers are the epilimnion, a layer close to the surface, with higher temperature and with

smaller density and the hypolimnion, the layer close to the bottom, with lower

temperature and thus higher density. The result is a density gradient which impairs

mass flow between the layer, thus, compromising the vertical mixing of the pond. As a

result the volume occupied by the hypolimnion becomes a dead zone, decreasing the

volume actually used for treatment (Kellner and Pires, 2002). Density stratification also

induces non-uniform velocity distribution and circulatory flow which may lead to short-

circuiting and to transverse velocity profiles (Agunwamba, 1992). Viessman and

Hammer (1998) concluded that since the routes through the pond differ in travel times,

the actual retention time ranges from less than to greater than the theoretical detention

time (which assumes that no stagnation, short-circuiting or dead zone exists), and is

defined as:

$$t_R = \frac{V}{Q} \qquad (3\text{-}3)$$

Where: t_R = theoretical mean residence time

V = volume of pond

Q = rate of flow through the pond

Therefore, based on the above discussion, the actual retention or residence time differs from the theoretical retention time. The actual retention time can be determined by a stimulus-response experiment (Levenspiel, 1995). That is, the introduction of a conservative tracer to the influent during steady-state flow. A steady state flow occurs when the concentration of the composition does not change with time at a given position. That is, any part of the system usually tends towards a time-invariant state and the variation in composition shows itself between one region of the system and another (Denbigh and Turner, 1984). The concentration of the tracer at the output is measured over an extended period in order to develop an output tracer distribution or a Retention Time Distribution (RTD) curve. For analysis purposes RTD is defined as the probability density function of the amount of time that a particle spends in the system and is scaled such that the integration of the curve is unity. The curve is then used to evaluate the actual retention time (Kadlec, 1994; Rash and Liehr, 1999; Viessman and Hammer, 1998).

With the effluent flow measurements and tracer concentrations, a RTD can be constructed from the following formula (Rash and Liehr, 1999; Kadlec, 1994):

$$E(t) = \frac{Q_e C(t)}{\int_0^\infty Q_e C(t)dt} = \frac{C(t)}{\int_0^\infty C(t)dt} \qquad (3\text{-}4)$$

Where: E (t) = RTD function, 1/day

t = time, day

Q_e = water flow rate, m^3/day (for steady state this is a constant)

C (t) = exit tracer concentration, g/m^3

The first moment of the RTD function represents the residence time. This is the first absolute moment of the tracer detention time, which is the average time that a tracer particle spends in the system. This is represented as follows (Rash and Liehr, 1999; Simi and Mitchell, 1999):

$$\bar{t} = \int t * E(t)dt \qquad (3\text{-}5)$$

The spread of the tracer responds curve, since it represents a continuous distribution, may be measured by calculating the variance σ^2 of the distribution about its mean. This is the second moment of the RTD function and physically means the dispersion number, d of the system. In general the variance is given by:

$$\sigma^2 = \int_0^\infty \left(t - \bar{t}\right)^2 E(t)dt \qquad (3\text{-}6)$$

If a tracer concentration C_o is applied to the input, and at time, t_R the output contains the tracer at the same concentration, then the dispersion number d=0 and the flow is considered plug flow (Kadlec, 1994; Sarikaya, et al., 1987; Viessman and Hammer, 1998). For dispersed flow the retention time curve is normally skewed. That is, the curve elongates where the concentration of the tracer gradually approaches zero. Thus, the relationship between variance and the dispersion number is given by (Viessman and Hammer, 1998): all variables as defined previously.

$$\sigma_\theta^2 = \frac{\sigma^2}{\bar{t}^2} = 2\frac{D}{uL} - \left(2\frac{D}{uL}\right)^2 \left(1 - \ell xp^{uL/D}\right) \qquad \textbf{(3-7)}$$

$$\sigma^2 = \frac{\sum t_i^2 C_i}{\sum C_i} - \bar{t}^2$$

(3-8)

Where: σ_θ^2 = normalized variance, dimensionless

σ^2 = variance, day^2

$\bar{t}$ = mean retention time (time to the centroid of the distribution), day

Where: $\bar{t} = \frac{\sum t_i C_i}{\sum C_i}$ (3-9)

3.2.3.1 <u>Types of Tracing Techniques</u>

Tracer technique is a relatively inexpensive way of measuring stream discharge and other water quality effects (Fischer, et al., 1979). There are two methods of tracer release: release of a single "slug" of a concentrate tracer and continuous injection over an extended period at a constant rate of a diluted mixture of tracer. The slug release method is much easier because it is not necessary to have a device capable of a continuous release at constant rate, but the continuous release method is probably more accurate and requires fewer samples. The slug injection is more commonly used to estimate time of travel and dispersion while continuous release offers advantages for estimating steady state wastewater dilutions (Fischer et al., 1979; Martin and McCutcheon; 1999).

3.2.3.1.1 <u>Continuous Release</u>

In continuous release method a solution containing dye at concentration C_i is injected into the system at discharge rate Q_i. The discharge of the system is found by going a sufficient distance downstream to allow adequate cross sectional mixing, allowing sufficient time for the concentration in the system to reach equilibrium, and taking a few samples (theoretically only one is necessary). The system discharge is given by:

$$Q = Q_i C_i / C_s \qquad (3-10)$$

Where: C_s = concentration of sample

3.2.3.1.2 <u>Slug Injection</u>

The slug injection technique features a discrete amount (impulse load) of tracer poured or injected into the stream over a short time period. At the measurement site, which is chosen far enough down stream to ensure complete cross sectional mixing, the concentration is measured continuously at equal time intervals from the first arrival of tracer until all has passed (Fischer, et al., 1979). The dye cloud movement at the centroid of the mean flow defines time of travel. The changing dye cloud distribution defines dispersion (Martin and McCutcheon, 1999).

The time-concentration or RTD curves developed from these concentration measurements are normally Gaussian or bell-shaped, being skewed toward the leading edge. Other anomalies or inconsistencies in the shape of the curve can indicate problems associated with the sampling study, such as unsteadiness of flow. Simi and

Mitchell (1999) indicate that an asymmetrical curve means that there are dead zones.

The presence of two separate peaks clearly indicates the presence of two parallel

paths, where the first peak indicates the shorter route (Batchelor and Loots, 1997). If the

standard deviation is large, then this suggests the presence of short-circuiting flow

paths and circulatory zones. Also, a large difference between the observed mean

detention period and the nominal detention period suggest the presence of zones of

stagnation in the system (Persson, et al., 1999).

The area under the curve represents the total tracer mass and is estimated by

integrating the area under the RTD curve (Fischer, et al., 1979; Martin and

McCutcheon, 1999). Therefore, the total mass passing the sampling point during a

sampling period of length T_s is:

$$M = \int_0^{T_s} CQdt \qquad\qquad (3\text{-}11)$$

Where: M = the total amount of tracer added.

Q = the flow rate of the system and is assumed to be constant

during the measurement.

t = time, usually in seconds or days.

C = the tracer concentration passing the sampling location as a

function of time.

For this project, the dyes, Fluorescein and Rhodamine WT were chosen and the

handheld Fluorometer AquafluorTM by Turner Designs was used to detect them.

Rhodamine WT dye has been developed specifically for tracer studies (Smart and

Laidlaw, 1977). The Fluorescein was also chosen to do simultaneous tracing, thus

reducing the number of dye runs necessary and also to offer some comparison for photo-degradation of the dyes. The instrument was made specifically for Rhodamine WT and Fluorescein detection, with a minimum detection of 0.4ppb of the dyes. Therefore, in order to allow for dye degradation and optimal detection ten times this concentration is chosen.

3.2.3.2   Concentration of Dye Required

$$C_{ave} = \frac{M_{dye}}{V_{pond}} \qquad (3\text{-}12)$$

Where: C_{ave} = average concentration

M_{dye} = specific mass/gravity of dye; Rhodamine (1.19) and Fluorescein (1.03)

V_{pond} = Volume of pond

Rearranging give:

$$M_{dye} = C_{ave} * V_{pond} \qquad (3\text{-}13)$$

Example: The total volume of one pond is approximately 80,000m^3.

$$= 4\text{x}10^{-9} \text{ gram dye/ gram water} * 1.19 * 80,000\text{m}^3$$

$$= 0.38\text{x}10^{-3}\text{m}^3$$

$$= 0.4 \text{ L}$$

Therefore, for one String, the volume of dye required is 1.2L per test.

3.3 **Methodology: As Carried Out in Project**

The actual experiment as carried out in the project is listed below. It is a combination of what was found in literature and what seemed to work at the actual site of study, contingent upon the availability of resources.

3.3.1 **Physical Description of Pond Complexes**

3.3.1.1 **Location**

The North-coast Wastewater Treatment System is located at Bogue, Montego Bay, Jamaica. Jamaica with capital city, Kingston, is the largest English speaking island in the Caribbean Sea, with an area of approximately 11,000km^2 and a population of 2.6 million people. The climate is considered tropical marine, with the annual rainfall of 77in, and a mean daily temperature of 26-28 ^{o}C (Statistical Institute of Jamaica, 2002). Montego Bay is geographically situated at latitude 18° 28' N, longitude 77° 20' SW and at an altitude 63m, with a population of approximately 182,600. Montego Bay has an area of approximately 595 km^2, lies on the northwestern coast of the island and is considered the tourist capital of Jamaica. The closest meteorological station is located at the Sangster's International Airport in Montego Bay, about 2 miles away (as the crow flies) from the pond system. The wastewater treatment plant serves the Montego Bay proper, including businesses, a large number of hotels, private homes and schools.

3.3.1.2 **Pond Complex**

The Bogue sewage treatment works were constructed under a comprehensive north coast sewage scheme between 1995 and 1999 that involved the design and

implementation of similar operational schemes in Ocho Rios and Negril. The Bogue

system has been in operation under the National Water Commission since August 1999

and it currently collects approximately 8,300 to 9,500 m^3/day (2.2 to 2.5 MGD) of

wastewater generated by in the Montego Bay area. The treatment works has a stated

capacity of 37,000 m^3/day (10MGD), a maximum volume of over 500,000 m^3 (163

Billion Gallons) and sits on a total area of 100ac, 90% of which is occupied by the

ponds. The sewage treatment pond system consists of:

1. **Preliminary Treatment Works**: this include an upward flow receiving

   basin, from the last pump on the sewerage system, screens and four grit

   chambers. (Appendix 3.1)

2. **Flow Measurement**: Grit chambers are controlled by a Parshall flume,

   equipped with an ultrasonic water surface elevation transmitter calibrated

   to measure flow. (Appendix 3.1). The system up to this point in the

   process is aimed at the removal of gross solids, sediment, flow

   measurement and the control of flow through to the ponds.

3. **Three Sets of Waste Stabilization Ponds**. The Parshall flume empties

   into an end basin that has three gated-valves, each of which leads into a

   series of ponds. There are three sets of ponds. Each set consists of three

   ponds each, arranged in series (Appendix 3.2). Example string 1 consist

   of ponds, F1 (Facultative), M1.1 and M1.2. (Maturation), forming a serial

   set, which means that the effluent of F1 is the influent of M1.1 and the

   effluent of M1.1, is the influent of M1.2. Thus, string 1, 2 or 3 consists of a

   receiving facultative pond, followed by two maturation ponds. Thus, there

are a total of nine ponds, three facultative and six maturation ponds. There

are no interconnecting pipes between each series, which reduces the

flexibility of the system. However, the Jamaica Public Service company

(Power Company) has implemented an effluent reuse project that involves

taking the treated effluent from the ponds to cool their generators and for

making demineralized water, returning the water after cooling it. This offer

some sort of recirculation to the system. The effluent from each series is

collected and discharged without further treatment into the Montego Bay

River at the end of treatment. The Montego Bay River then empties in the

sea, about half of a mile from discharge point.

3.3.1.3 <u>Individual Ponds</u>

Each pond is lined with high density PVC plastic that is safely entrenched into

concrete at the top of the embankment. The berms are wide enough to accommodate

two full size cars simultaneously. The inlet structures of the facultative ponds doubles as

a grease trap. That is, the water flowing from the Headworks flows into rectangular

cistern structure 6ft *3 ft *6ft. The water exits the bottom of the cistern into the pond,

while the incoming grease floats to the top, where it is removed. The outlet structure

also plays a dual role. Water flows into the bottom of a cistern of similar size to the inlet,

flows upwards and over a broad crested weir. The weir is fitted with a graduated staff,

for head or flow measurement. Since water is taken from the bottom, the outlet structure

also acts as a scum guard. Finally, the ponds are fitted with fixed baffle curtains, with a

maximum of two per pond.

The sewage treatment plant at Bogue is licensed by the Natural Resources
Conservation Authority (NRCA), under the Natural Resources Conservation Authority
Act and The Natural Resources Conservation (Permits and Licenses) Regulation of
1996 to treat wastewater and to discharge effluent in the Montego Bay River (NRCA,
2001). A breakdown of the permit is as follows:

Table 3.2: <u>Effluent Limit Required by NRCA</u>

Parameters	Effluent Limit
BOD	20/40 mg/L
TSS	20/40 mg/L
Total Nitrogen	10/35 mg/L
Phosphates	4 mg/L
COD	100/150mg/L
pH	6-9
Faecal Coliform	1000 MPN/100 mL

Table 3.2: <u>**Influent Wastewater Characteristics**</u>

Population equivalent	87,889
Wastewater flow	20076 m^3/d
Influent BOD strength	182 mg/L
Influent FC concentration	10^7 cfu/100 ml
Mean monthly air temp.	25 ^{o}C (77 ^{o}F).

The process design equation used to determine the organic loading on the first ponds (that is the primary facultative pond), is an empirical areal loading formulae. This is as follows:

$$L_s = 350(1.107 - 0.002T)^{T-25}$$

Where: L_s = surface loading, kg/ha/d

T = the design temperature.

Average daily temperature in Montego Bay is 25°C. This gives a BOD surface loading on the primary facultative pond of 350 kg/ha/d. For the design of the maturation ponds, plug flow was assumed and a K_b value of 6.20d^{-1} was chosen, using the equation:

$$K_b = 2.6(1.19)^{T-20}$$

Design Summary (LTI (1994)**):**

Primary Facultative Pond:

Mid-depth area   = 97677 m^2

Depth   = 1.5 m (5 ft)

Mean hydraulic retention time = 7.3 d

Primary Maturation Pond:

Mid-depth area $= 80306 \text{ m}^2$

Depth $= 1.25$ m (4 ft)

Mean hydraulic retention time= 5 d

Secondary Maturation Pond:

Mid-depth $= 80306 \text{ m}^2$

Depth $= 1.25$ m (4 ft)

Mean hydraulic retention time= 5 d

Design Final effluent quality:

BOD $= < 20$ mg/L filtered

SS $= < 30$ mg/L

FC $= 211$cfu/100 ml okay statistically to meet 200

Standard.

NO_3 $= < 10$ mg/L

The system comprises three ponds in series with a total retention time of 17.3 days.

Total mid-depth area $= 25.84$ ha

Total pond area (x1.25) $= 32.29$ ha or 80.72 acres

Since the ponds were constructed, monitoring operations by the National Water Commission Laboratory and the North Coast Wastewater District has determined the following:

Table 3.3: <u>Area, Volume and Depth of Individual Ponds</u>

Pond	Surface Area (m^2)	Water Volume (m^3)	Mid-depth (m)
F1	58, 958	88, 437	1.50
M1.1	30,690	38,363	1.25
M1.2	28, 689	35, 862	1.25
F2	60, 944	91,416	1.50
M2.1	31,816	39, 796	1.30
M2.2	29,971	37, 463	1.20
F3	58,434	87,651	1.50
M3.1	29,948	37,435	1.25
M3.2	37,016	46, 270	1.00

Average wastewater flow is 3.5 MGD. The average BOD and TSS values determined from monitoring 2000-2003 are as follows:

Table 3.4: <u>Average BOD and TSS values, 2000-2003</u>

Sample Point	BOD/ mg/L	TSS/ mg/L
Influent	97	116
Effluent	39	90

3.3.2 <u>Weekly Sampling and Daily Monitoring</u>

Weekly sampling started on Wednesday, April 16, 2003. For the first three weeks, samples were collected on Wednesdays, and were used as trial runs in order to test the procedures and methodologies. Thereafter, sampling continued on consecutive days (Thursday, Friday, Saturday, etc.) for the weeks following until June 16, 2003. Samples were collected using a Lamotte water column sampler. Grab samples were collected at the outlets and sometimes in the middle of Ponds F1, M1.1 and M1.2 of String 1. These samples were column weighted. That is, samples were taken from the water column at 1, 2 and 3 ft depths, and then equal volumes were collected and mixed to form the composite. Flow weighted samples were taken of the influent every hour from 0600 to 1800 with corresponding flow reading recorded from the flow meter at the Headwork.

Wastewater flow is highly variable and is dependent on the usage requirements of the community. Therefore, the flow into the plant was not constant during the day. Hence, the characteristics of the influent changed with the time of day. This results in variable organic loading on the ponds. The flow weighted sampling was done in order to determine the organic loading on the system. In order to determine the organic loading, the average daily flow and the strength (BOD) of the influent wastewater must be noted. This is established by making composite samples.

As noted above, a composite sample takes into account the changes in wastewater characteristics throughout the day. Ideally, a sample taken every hour for 24 hours, and mixed in proportion to the flow at that time, is required. However, this would require an automatic sampler which was not available. The literature suggested that a

reasonably representative sample can be made by sampling every hour between 0600 and 1800 hours (with a bare minimum taken between 0600 and 1200). 0600 was chosen to start sampling because this is normally the time when the wastewater generated starts increasing from the nighttime low. This was a well chosen sampling period because from the results obtained, on average about 53% of the total daily flow occurs within this time period (Section 4.3.7). The overall sampling period lasted a total of nine weeks, from which seven weeks will be used for data analysis, the literature suggests five week sampling period. Therefore, sampling took place over a total of sixty-three days, with forty-nine days used in the actual analysis period. Using an average flow of 3.5 MGD and a total volume of String as 163,662 m^3, the theoretical retention time is 12 days. The literature suggests that the sampling period should last at least twice the theoretical retention time, thus this condition was met.

Once collected, the samples were placed in a freezer and cooled to 0-4°C until it was time for analysis. This was done in order to prevent algae from photosynthesizing and to slow the metabolic rate of the insitu bacteria, thus preserving the integrity of the samples. The samples were analyzed for BOD and TSS, and some samples were analyzed for TKN and Ammonia. The samples to be analyzed for nitrogen were all frozen, since they had to be sent to Kingston (three hours away) for analysis. The samples were all analyzed within 24 hours for nitrogen and within 6 - 24 hours for BOD and TSS, after collection. The flow weighted samples were analyzed individually and then volumes weighted according to flow were mixed and analyzed to determine flow weighted average of these parameters. Analysis for the parameters was carried out

according to the methods described in Standard Methods for the Examination of Water and Wastewater (APHA, 1992).

Daily monitoring of the physiochemical parameters was carried out between March 25, 2003 and July 16, 2003. Between March 25, 2003 and April 16, 2003 only dissolve oxygen and temperature were monitored, because only a Hach DO meter was available. After this time, a YSI Hydrolab Multimeter was used to measure, dissolve oxygen (mg/L), temperature (^{o}C), pH, specific Conductivity (μS cm^{-1}) and depth (ft). These parameters where measured at depths1, 2 and 3 ft. From these a depth average of the collected data was then computed Monitoring was carried out between 0800-1000 hours and the Hydrolab was calibrated for each parameter daily.

3.3.3   Determination of Hydraulic Retention Time and Dispersion Number

The literature indicated that for the tracer study to be comparable and relevant to the stated removal equations then steady state conditions must be established within the system. Rakkoed, et al. (1999) stated that steady state conditions were considered to have occurred when the effluent Chemical Oxygen Demand (COD) concentrations were relatively constant for one cycle of Hydraulic Retention Time (HRT). From the weekly monitoring program carried out by the National Water Commission Laboratory, it was found that between March 3, 2003 and April 7, 2003, the effluent COD stayed around 121 mg/L. Thus, steady state conditions were assumed to have been achieved.

The actual dye study started on July 2, 2003. Samples were collected at the inlet and outlet of each of the three ponds, namely Pond F1, Pond M1.1 and Pond M1.2. The

fluorescence was determined using the handheld Fluorometer AquafluorTM by Turner Designs dual channel Fluorometer (dual channel; reads both Rhodamine and Fluorescein). The purpose of these tests was to determine the background fluorescence caused by the algae and other compounds in the water. It was found that fluorescence varied throughout the day. This is expected since fluorescence is a function of temperature. These initial trials ran until July 21, 2003, at which time the dye was placed in the pond.

Two types of dyes were placed in the pond for the dye study, namely Rhodamine and Fluorescein. 5 liters (5% active ingredient) and 1146.3822 grams (tablet) slug of Rhodamine (20% active ingredient) and 5 liters slug of Fluorescein were used. The dyes were placed in the pond at approximately 1630 hours at the outlet of the Headworks, to ensure complete mixing and to simulate the actual flow into the ponds. The first visible sign of the dyes' arrival at the inlet of Pond F1 was approximately 1638 hours.

Based on ballpark calculations, neglecting the presence of the baffles, the retention time based on a 24 hour flow reading taken from the pond and the pond volume, is about 7 days. The literature suggests that, actual retention time is about 50% of the theoretical retention time (Reed, et al., 1995). With this in mind readings were taken on Pond F1 in the mornings at approximately 0900 for the first 3 days. On day 4 readings were taken in the morning and afternoon about 1700hr. Day 5 saw an increase in the frequency of readings to every 3 hours and finally to every hour on and after day 6.

Since fluorescence is highly temperature depended and considering that, based on daily temperature reading, pond water temperature is highly variable, the samples collected were placed in the freezer (at freezer dial position 1) for 30 minutes to cool to a common temperature. To account for absorption by algae, and photo-degradation of the dyes, separate experiments were set up. The first consisted of 50ml of each dye in 15 gallons of pure water. This experiment was to determine the effect of pure sunlight. The second experiment consisted of both dyes in pond water in a glass beaker, and the third had both dyes in a black closed container. These latter experiments were to determine the absorption due to algae and photo-degradation and algae absorption only respectively.

From the readings which ran until August 5, 2003, it was found that there was no visible or obvious change in the fluorescence. That is the characteristic increase and decrease of dye concentration indicating the passage of the dyes cloud never appeared. The following conclusions are proposed:

- The dye may be absorbed by the algae,

- The concentration of the dye placed in the pond is lower than the algae concentration.

- The presence of other fluorescing substances such as clothes brighteners is masking the dye.

The clothes brightener theory was tested by using some detergent to see if and how it masked the dye. This was carried out by measuring the fluorescence of a known concentration of dye and a mixture of soap solution. The dye was mixed with the varying concentrations of soap and the fluorescence measured. The result is that the

fluorescence of the dye was reduced as the concentration of the soap increased. This

process in know as quenching. Quenching is the suppression of fluorescence and the

results from the action of other substances in solution with the dye. Therefore, due to

time and budgetary constrains, the dye tracing study had to be abandoned in favor of

the statistical determination of the hydraulic characteristics.

3.3.4 Determination of Dispersion Number and Retention Time

The most accurate method for determination of dispersion characteristic of

existing ponds is by tracer studies (Esen and Al-Shayji, 1999; Winefordner, et al., 1972).

However, other methods exist to assess the hydraulic regime of ponds. One such

method is by the statistical least-squares method. Esen and Al-Shayji (1999) developed

a least-squares scheme for estimation of the first-order reaction rate constant k and the

dispersion number d, using the Wehner-Wilhelm equation for dispersed flow, as the

basic equation describing pond performance, using the pond performance parameters,

such as inlet and outlet BOD and nitrogen concentration. Reed, et al. (1995) also used

the Wehner-Wilhelm equation as the basis for a trial and error method. These methods

will be discussed in detail in Chapter 4.

3.3.5 Hypothesis

Since routes through the pond differ in travel times, the effluent age distribution

of a non-ideal system extends from less than to greater than the theoretical detention

time (Viessman and Hammer, 1993). Therefore, the actual retention time will differ from

the theoretical time. Also, the turbulence due to the shear flow velocity causes a non-

ideal flow that falls between ideal plug and completely mixed flow. Therefore, the flow

regime within the ponds will more closely follow the dispersed flow regime, rather than the idealized plug and completely mixed flow.

3.4   Grease Trap Survey

The Waste Stabilization ponds are very efficient at removing biological waste. However, the system is easily over loaded by excess incoming grease. Over the monitoring period, incoming grease has cause pond failure (low DO readings, excessive floating scum and odor) on several occasions. In an effort to assess the situation, a program was developed to audit grease trap devices of food preparation facilities in and around the Montego Bay area. The purposes of this program are as follows:

- To determine the number of food preparation facilities with grease traps.
- To assess the capacity, performance and maintenance of existing grease traps.

3.4.1   What is a Grease Trap?

A grease trap is a device used for removing oil and grease from wastewater. A grease trap is necessary because when grease and oils enter the sewer system they cause problems by separating from the wastewater and accumulating on the inside of sewer pipes. Over time, these deposits get larger as more grease and other solid material continue to build up (Gary and Sneddon, 1999; Joshua, et al., 1994). Grease deposits reduce the capacity of sewer pipes and cause sewage overflows, offensive odor and an unhealthy environment. The cleaning of grease deposits from sewers is difficult and can be dangerous and is carried out at considerable cost (Chu and Ng, 2000; HKEPD, 2002). Further, untreated grease can cause overloading of the pond

system used to treat domestic wastewater. Ponds are not designed to handle grease and oils in excessive quantities, therefore, greasy streams must be removed or pretreated by a mechanical plant before they enter the ponds.

3.4.2   How Grease Traps Work

A typical grease trap has the following components: a flow restrictor, an inlet, two or three baffles, a lid and air-tight seal and an outlet. The performance of grease traps is highly dependent on how well they are constructed and maintained. Water draining to the grease trap passes through a flow control fitting which regulates the speed of the water to the capacity of the trap. As the water enters the grease trap at this controlled rate of flow it is free of turbulence. It then passes over a series of separator baffles (baffles are scientifically placed to allow efficient separating of grease and oils and should be easily removable) that are designed to cause greases, fats and oils to become separated and released from the wastewater. Once released, these contaminants rise to the top of the grease tap by natural flotation and are accumulated until removed. The wastewater now relieved of over 90% of the oils and greases, continues to flow through the trap and into the sanitary sewer system (Gary and Sneddon, 1999; HKEPD, 2002).

3.4.3 Accessing Grease Trap Capacity

The minimum requirements for Grease Trap Design are:

- **Provide sufficient capacity to slow down the passing wastewater, giving greasy waste the opportunity to separate out.** A grease trap

should be able to hold all the kitchen wastewater entering it during times of maximum water use for a period of 20 minutes. A grease trap connected to a single sink should not be smaller than 250 liter (55 gallon) capacity. A larger grease trap is used if more than one fixture is connected (Chu and Ng, 2000; HKEPD, 2002).

- **Prevent wastewater entering the grease trap from mixing up to the top greasy waste layer.** A baffle should be present at the top inlet to slow down the incoming wastewater and keep it separate from the top waste layer. The inlet pipe should end in a 90° downwards bend so that incoming wastewater enters the trap at least 100mm below the water surface. The inlet pipe should NOT terminate above the liquid surface such that wastewater drops into the trap (Gary and Sneddon, 1999).

These two design recommendations were used as the basis for the survey. The results listed in Appendix 4.1.

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4   RESULTS

4.1   Chapter Overview

Experiments for this project took place in three major phases. The first phase consisted of dissolve oxygen (DO) and temperature daily monitoring only, because only a Hach dissolve oxygen meter was available. The second phase saw daily monitoring of DO, temperature, pH, specific conductivity and depth and weekly sampling for analysis of biochemical oxygen demand (BOD), total suspended solids (TSS) and other nitrogen species. Tracer studies were conducted during the third and final phase. The results and corresponding analysis are therefore presented in that order.

4.2   Phase 1: Initial DO and Temperature Readings

Dissolved oxygen (DO) and temperature monitoring of String 1 and the Headworks were conducted between March 25, 2003 and April 16, 2003 using the Hach dissolved oxygen and temperature monitor. Monitoring was conducted at random times during the day and sometimes twice per day; morning and afternoon. The variation of oxygen within the system indicates qualitatively, the efficiency of the treatment processes and is an approximate quantitative alarm which indicates the possible overloading of the system. That is, a fall in DO over a monitoring period indicates that the ponds are becoming anoxic and some management strategy must be implemented

to prevent odor formation. Temperature is measured with DO, because the DO capacity of water is a function of temperature.

4.2.1 Headworks

The sample points at the Headwork were at the inlet and outlet (Appendix 3.1). The averages of DO and temperature readings over the sampling period were 1.27mg/L and 27.95 ^{o}C at the inlet and 1.28mg/L and 27.96^{o}C at the outlet respectively. These are typical DO readings since incoming wastewater has high organic loading and thus a high BOD. This is physically manifested in a low DO reading. Also, there is very little difference between the inlet and outlet values, because there is a short distance between the inlet and the outlet. Further, very little, if any secondary treatment takes place, only removal of macro-solids; hence there is little reduction in organics.

Table 4.2.1: Headwork

Showing: Minimum, Maximum and Median of DO and Temperature

SAMPLING POINT	DO/mg/L			Temperature/^{o}C		
	MIN	MAX	MED	MIN	MAX	MED
INLET	0.11	1.60	1.40	26.90	29.00	27.90
OUTLET	0.08	1.64	1.37	25.40	29.10	28.10

NB. Mean and Median are both measures of central tendencies. Since the mean is greatly affected by extreme values, the median is sometimes a better "average" of what takes place in the system and is therefore listed here also. The maximum and minimum

values indicate the spread or range of values experienced by the system. These indicate the possible operational DO and temperature that exist in the system.

4.2.2   String One

String one consists of one facultative pond, F1 and two maturation ponds, M1.1 and M1.2. This string was operational during the monitoring period and received all of the incoming flow to the system.

Table 4.2.2: String 1

Showing: Summary of Maximum, Minimum, Median and Average for Ponds.

POND	DO/mg/L				Temperature/^{o}C			
	MIN	MAX	AVE	MED	MIN	MAX	AVE	MED
F1	6.16	13.21	8.71	8.86	26.75	32.5	29.86	29.03
M1.1	5.60	13.90	8.52	9.52	25.98	33.03	29.8	28.73
M1.2	5.87	14.87	9.35	9.66	25.89	32.55	28.61	28.69

4.2.2.1   Pond F1

The sampling points for pond F1 were located at the inlet, outlet and two other points located midway between the inlet and outlet (Appendix 3.2), namely, Mark 325 and Across from Blue Pipe (A/B). The DO and temperature averages and median are given in the table below:

Table 4.2.3: <u>Pond F1</u>

Showing: Average and Median of DO and Temperature

Parameter	Inlet	Mark 325	A/B	Outlet
DO, AVG. mg/L	8.63	8.73	8.88	8.60
DO, MEDIAN mg/L	9.60	9.47	9.70	6.68
TEMPERATURE, AVG, ^{o}C	30.00	29.62	29.77	30.03
TEMPERATURE, MEDIAN	29.10	29.20	28.80	29.00

Table 4.2.4: <u>Pond F1</u>

Showing: Minimum and Maximum DO and Temperature

SAMPLING POINT	DO/mg/L		Temperature/^{o}C	
	MIN	MAX	MIN	MAX
INLET	6.10	12.68	27.10	32.90
MARK 325	6.96	11.20	26.90	31.60
A/C BLUE PIPE	5.94	11.42	26.40	32.90
OUTLET	5.64	17.53	26.60	32.60

4.2.2.2   <u>Pond M1.1</u>

The sampling points for pond M1.1 were, Inlet, Outlet and two points midway between inlet and outlet (Appendix 3.2), namely, Across from Last Packet (A/c pack.) and Mark 390. The DO and temperature averages are given in the table below:

Table 4.2.5: Pond M1.1

Showing: Average and Median of DO and Temperature

Parameter	Inlet	A/c pack.	Mark 390	Outlet
DO, AVG. mg/L	8.49	8.42	8.59	8.56
MEDIAN	9.86	8.76	9.71	9.75
TEMPERATURE, AVG. ^{o}C	30.12	30.27	29.42	29.39
TEMEPERATURE, MEDIAN	29.05	28.90	28.50	28.45

Table 4.2.6: POND M1.1

Showing the Minimum and Maximum DO and Temperature

SAMPLING POINT	DO/mg/L		Temperature/^{o}C	
	MIN	MAX	MIN	MAX
INLET	6.33	11.66	25.70	33.70
A/C LAST PACK.	5.01	13.01	25.80	34.20
MARK 390	6.20	12.70	26.20	32.20
OUTLET	4.84	18.20	26.20	32.00

4.2.2.3   Pond M1.2

The sampling points for M1.2 were Inlet, Outlet and two points midway between inlet and outlet (Appendix 3.2), namely, Mark 380 and Tar mark. The DO and temperature averages are given in the table below:

Table 4.2.7: Pond M1.2

Showing the Average and Median DO and Temperature

Parameter	Inlet	Mark 380	Tar	Outlet
DO, AVG. mg/L	9.13	9.32	9.35	9.58
DO, MEDIAN	9.56	9.78	9.63	9.65
TEMPERATURE, AVG, ^{o}C	28.49	29.01	28.49	28.69
TEMPERATURE, MEDIAN	28.50	29.15	28.50	28.60

Table 4.2.8: Pond M1.2

Showing the Minimum and Maximum DO and Temperature

SAMPLING POINT	DO/mg/L		Temperature/^{o}C	
	MIN	MAX	MIN	MAX
INLET	3.61	13.09	25.70	33.60
MARK 380	5.54	15.5	25.90	33.30
TAR	7.14	12.84	25.90	31.50
OUTLET	7.20	18.06	26.00	31.80

In general Dissolved Oxygen concentrations increased from Headworks to Pond M1.2, with Headworks showing the lowest concentrations and Pond M1.2 showing the highest. The Headworks experienced the lowest temperatures, Pond F1 the highest temperatures and sight reduction in the next two ponds. Ponds M1.1 and M1.2 experienced similar temperatures, probably because they are at the same elevations.

4.3 <u>**Phase 2: Physiochemical and Chemical Parameters**</u>

Sampling and insitu readings were done at the Headwork and at the outlet of the three ponds in String One (Appendix 3.2). At the Headwork samples and readings were taken at one depth, while at the outlet of the ponds, monitoring was conducted at depths 1, 2 and 3 ft. The values for the ponds were subsequently depth averaged. That is, after sample analysis and parameter measurement for each depth, the results were then averaged. The results in this phase are presented on a month by month basis. An overall picture is then painted when the correlation analysis for the entire Phase 2 sampling and measurement period is presented.

4.3.1 <u>**Physiochemical Parameters for April**</u>

Table 4.3.1.1: <u>**Temperature**</u>

TEMPERATURE				
DATE	**HEADWORKS**	**POND F1**	**POND M1.1**	**POND M1.2**
16/04/03	27.86	29.10	27.86	27.79
17/04/03	27.76	29.05	27.47	27.77
18/04/03	27.81	29.37	28.11	27.97
19/04/03	27.89	30.19	29.05	29.47
20/04/03	27.95	29.24	29.06	28.99
22/04/03	27.70	28.67	28.02	28.00
23/04/03	27.76	28.30	28.30	28.15
24/04/03	27.96	28.94	28.81	28.78
25/04/03	27.95	29.73	28.97	28.86
28/04/03	28.30	29.75	29.55	29.12
29/04/03	28.22	30.02	29.62	29.50
30/04/03	28.21	29.07	29.48	29.70
Mean	**27.95**	**29.29**	**28.69**	**28.68**
Median	**27.92**	**29.17**	**28.89**	**28.82**
Max	**28.30**	**30.19**	**29.62**	**29.70**
Min	**27.70**	**28.30**	**27.47**	**27.77**

Refer to CHART 4.3.1.1: **April's Temperature Variation Across the System**

CHART 4.3.1.1: APRIL'S TEMPERATURE VARIATION ACROSS SYSTEM
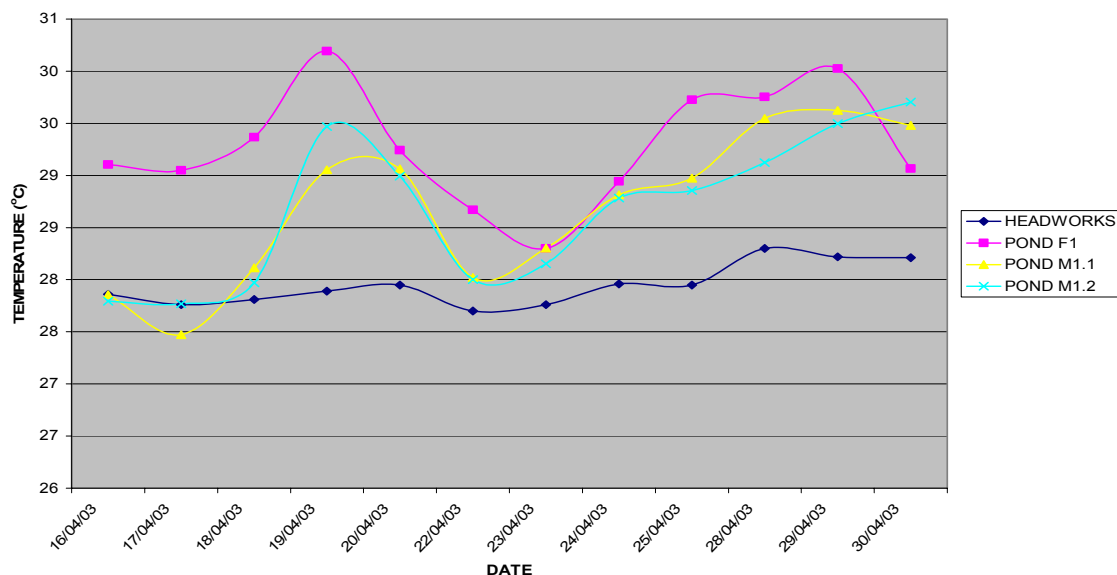
Table 4.3.1.2: Dissolved Oxygen

DISSOLVED OXYGEN				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
16/04/03	4.75	14.94	2.16	5.02
17/04/03	1.02	14.61	3.76	2.29
18/04/03	1.27	8.73	5.35	4.85
19/04/03	1.61	15.00	12.02	14.10
20/04/03	3.95	12.79	14.22	14.67
22/04/03	0.69	14.78	13.08	15.60
23/04/03	2.12	11.30	11.36	15.09
24/04/03	1.78	14.79	12.36	15.39
25/04/03	2.68	15.12	12.87	12.43
28/04/03	3.31	15.12	10.26	13.82
29/04/03	1.25	14.52	13.03	12.99
30/04/03	1.56	5.75	13.90	14.44
Mean	**2.17**	**13.12**	**10.36**	**11.95**
Median	**1.70**	**14.70**	**12.19**	**14.10**
Max	**4.75**	**15.12**	**14.22**	**15.60**
Min	**0.69**	**5.75**	**2.16**	**2.29**

Refer to CHART 4.3.1.2: **April's DO Variation Across the System**

CHART 4.3.1.2: APRIL'S DISSOLVED OXYGEN VARIATION ACROSS SYSTEM
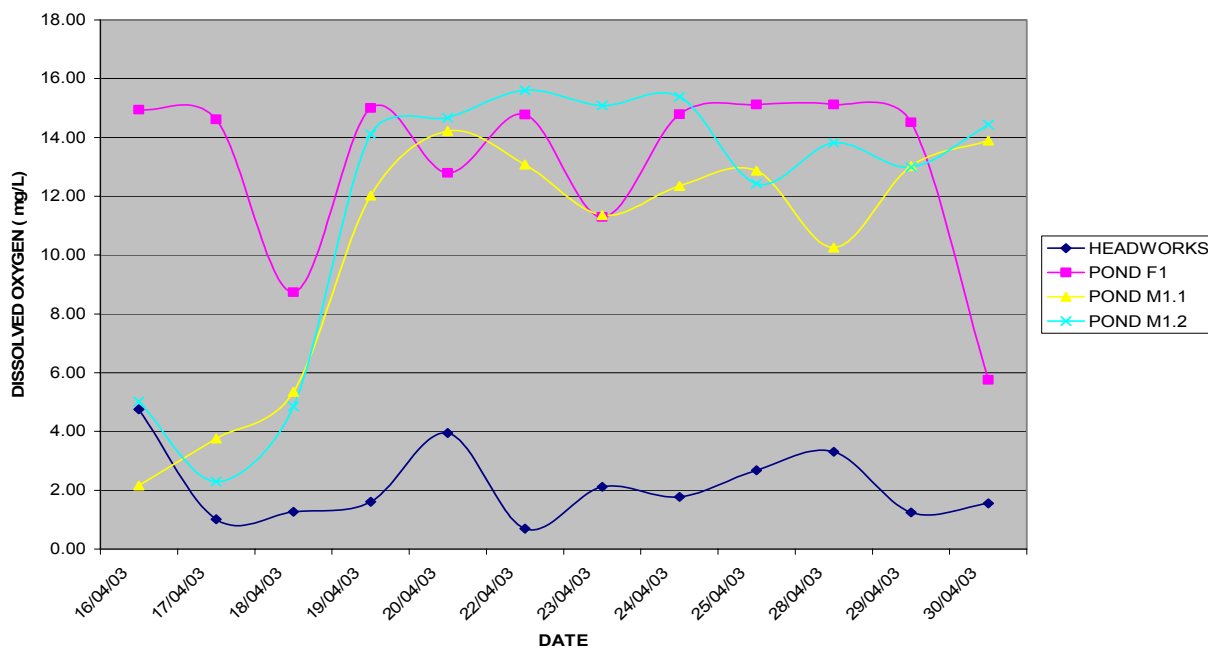
Table 4.3.1.3: pH

DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
16/04/03	7.08	8.88	8.81	8.87
17/04/03	7.70	9.00	8.70	8.83
18/04/03	7.33	9.18	8.79	8.96
19/04/03	7.63	9.33	9.20	9.52
20/04/03	8.02	8.95	9.40	9.58
22/04/03	7.75	8.93	9.24	9.66
23/04/03	7.36	8.75	9.20	9.65
24/04/03	7.65	8.89	9.22	9.65
25/04/03	7.53	9.03	9.30	9.60
28/04/03	7.56	9.02	9.09	9.43
29/04/03	7.60	9.01	9.26	9.50
30/04/03	7.51	8.49	9.33	9.62
Mean	**7.56**	**8.96**	**9.13**	**9.41**
median	**7.58**	**8.98**	**9.21**	**9.55**
Max	**8.02**	**9.33**	**9.40**	**9.66**
Min	**7.08**	**8.49**	**8.70**	**8.83**

Refer to CHART 4.3.1.3: **April's pH Variation Across the System**

CHART 2.3: APRIL'S PH VARIATION ACROSS SYSTEM
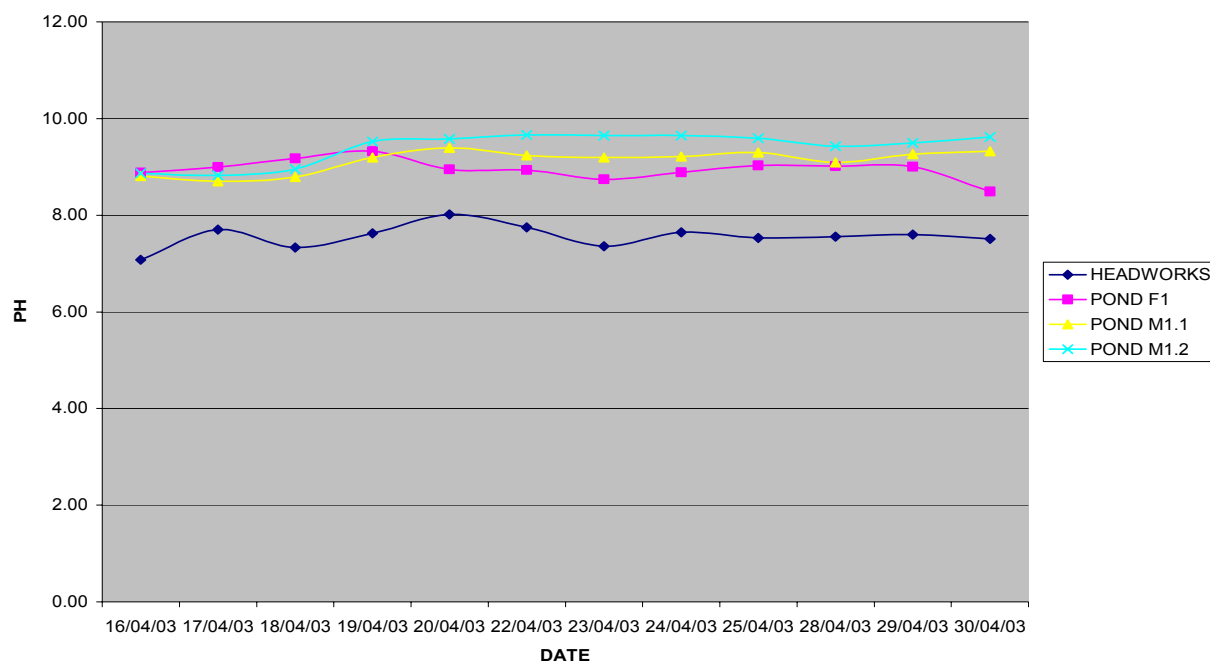
Table 4.3.1.4: Specific Conductivity

SPECIFIC CONDUCTIVITY				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
16/04/03	1080.00	918.67	935.00	929.00
17/04/03	1016.00	906.33	925.33	916.00
18/04/03	1090.00	889.33	904.67	880.00
19/04/03	1082.00	852.67	864.33	819.33
20/04/03	1063.00	908.33	837.67	814.67
22/04/03	1026.00	943.33	905.00	826.00
23/04/03	1510.00	957.00	888.67	805.67
24/04/03	1080.00	965.67	895.00	805.33
25/04/03	1012.00	941.33	886.33	805.00
28/04/03	980.00	945.00	893.67	818.67
29/04/03	1149.00	949.33	896.33	817.00
30/04/03	1140.00	989.00	885.00	819.67
Mean	1102.33	930.50	893.08	838.03
Median	1080.00	942.33	894.33	819.00
Max	1510.00	989.00	935.00	929.00
Min	980.00	852.67	837.67	805.00

Refer to CHART 4.3.1.4: **April's Conductivity Variation Across the System**

CHART 4.4.1.4: APRIL'S S.CONDUCTANCE VARIATION ACROSS SYSTEM
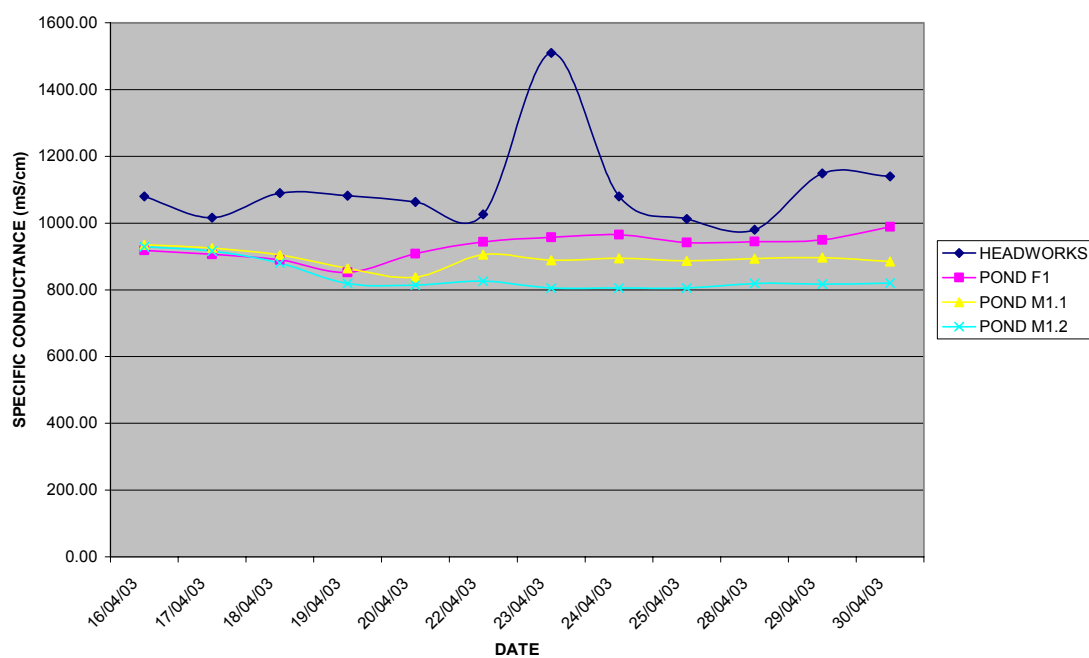
Tables 4.3.1.5 to 4.3.1.8 illustrate the variation of the measured parameters of the

individual Monitoring Points as a function of time.

Table 4.3.1.5: Headworks

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
16/04/03	27.86	4.75	1080.00	7.08
17/04/03	27.76	1.02	1016.00	7.70
18/04/03	27.81	1.27	1090.00	7.33
19/04/03	27.89	1.61	1082.00	7.63
20/04/03	27.95	3.95	1063.00	8.02
22/04/03	27.70	0.69	1026.00	7.75
23/04/03	27.76	2.12	1510.00	7.36
24/04/03	27.96	1.78	1080.00	7.65
25/04/03	27.95	2.68	1012.00	7.53
28/04/03	28.30	3.31	980.00	7.56
29/04/03	28.22	1.25	1149.00	7.60
30/04/03	28.21	1.56	1140.00	7.51
AVE	**27.95**	**2.17**	**1102.33**	**7.56**
MEDIAN	**27.92**	**1.70**	**1080.00**	**7.58**
MAX	**28.30**	**4.75**	**1510.00**	**8.02**
MIN	**27.70**	**0.69**	**980.00**	**7.08**

Refer to CHART 4.3.1.5: **Headworks: Variation of Parameters for April**

CHART 4.3.1.5: HEADWORK: VARIATION OF PARAMETERS FOR APRIL
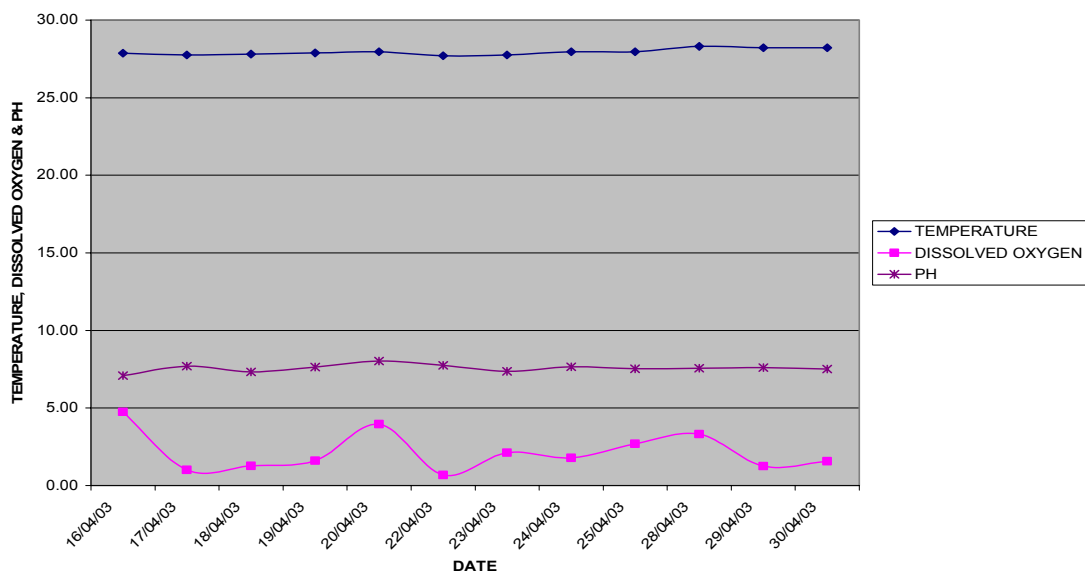
Table 4.3.1.6: Pond F1

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
16/04/03	29.10	14.94	918.67	8.88
17/04/03	29.05	14.61	906.33	9.00
18/04/03	29.37	8.73	889.33	9.18
19/04/03	30.19	15.00	852.67	9.33
20/04/03	29.24	12.79	908.33	8.95
22/04/03	28.67	14.78	943.33	8.93
23/04/03	28.30	11.30	957.00	8.75
24/04/03	28.94	14.79	965.67	8.89
25/04/03	29.73	15.12	941.33	9.03
28/04/03	29.75	15.12	945.00	9.02
29/04/03	30.02	14.52	949.33	9.01
30/04/03	29.07	5.75	989.00	8.49
30/04/03	31.73	14.41	956.00	8.98
Mean	**29.47**	**13.22**	**932.46**	**8.96**
Median	**29.24**	**14.61**	**943.33**	**8.98**
Max	**31.73**	**15.12**	**989.00**	**9.33**
Min	**28.30**	**5.75**	**852.67**	**8.49**

Refer to CHART 4.3.1.6: **F1: Variation of Parameters for April**

CHART 4.3.1.6 : F 1: VARIATION OF PARAMETERS FOR APRIL
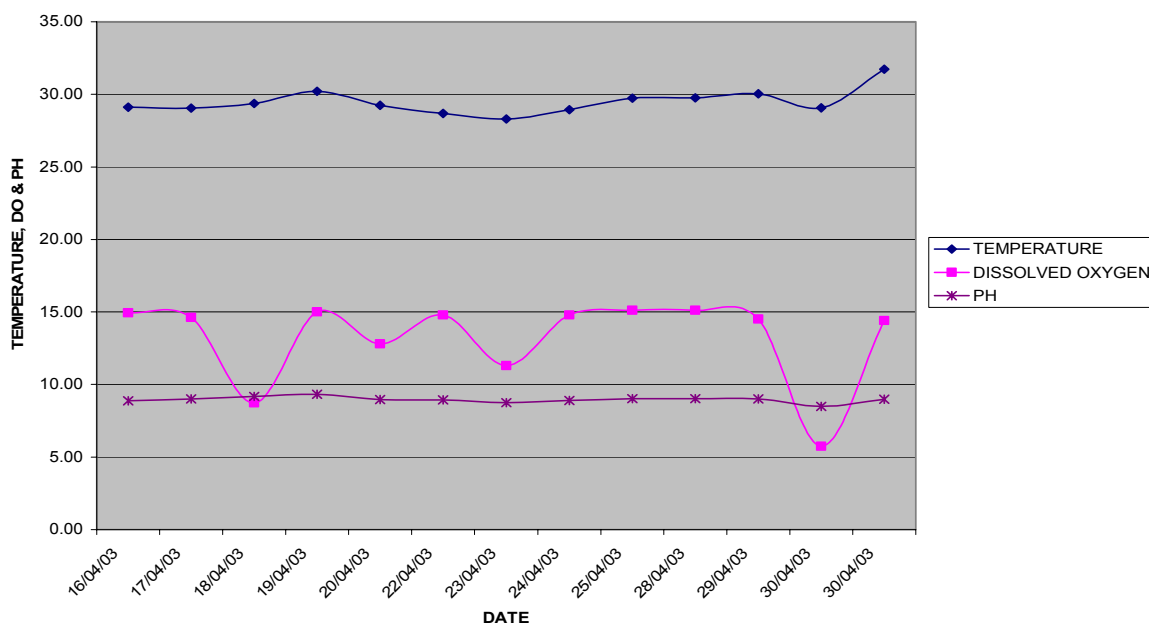
Table 4.3.1.7: Pond M1.1

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
16/04/03	27.86	2.16	935.00	8.81
17/04/03	27.47	3.76	925.33	8.70
18/04/03	28.11	5.35	904.67	8.79
19/04/03	29.05	12.02	864.33	9.20
20/04/03	29.06	14.22	837.67	9.40
22/04/03	28.02	13.08	905.00	9.24
23/04/03	28.30	11.36	888.67	9.20
24/04/03	28.81	12.36	895.00	9.22
25/04/03	28.97	12.87	886.33	9.30
28/04/03	29.55	10.26	893.67	9.09
29/04/03	29.62	13.03	896.33	9.26
30/04/03	29.48	13.90	885.00	9.33
30/04/03	31.00	14.80	865.00	9.43
AVE	28.87	10.70	890.92	9.15
MEDIAN	28.97	12.36	893.67	9.22
MAX	31.00	14.80	935.00	9.43
MIN	27.47	2.16	837.67	8.70

Refer to CHART 4.3.1.7: **M1.1: Variation of Parameters for April**

CHART 4.3.1.7: M1.1 VARIATION OF PARAMETERS FOR APRIL
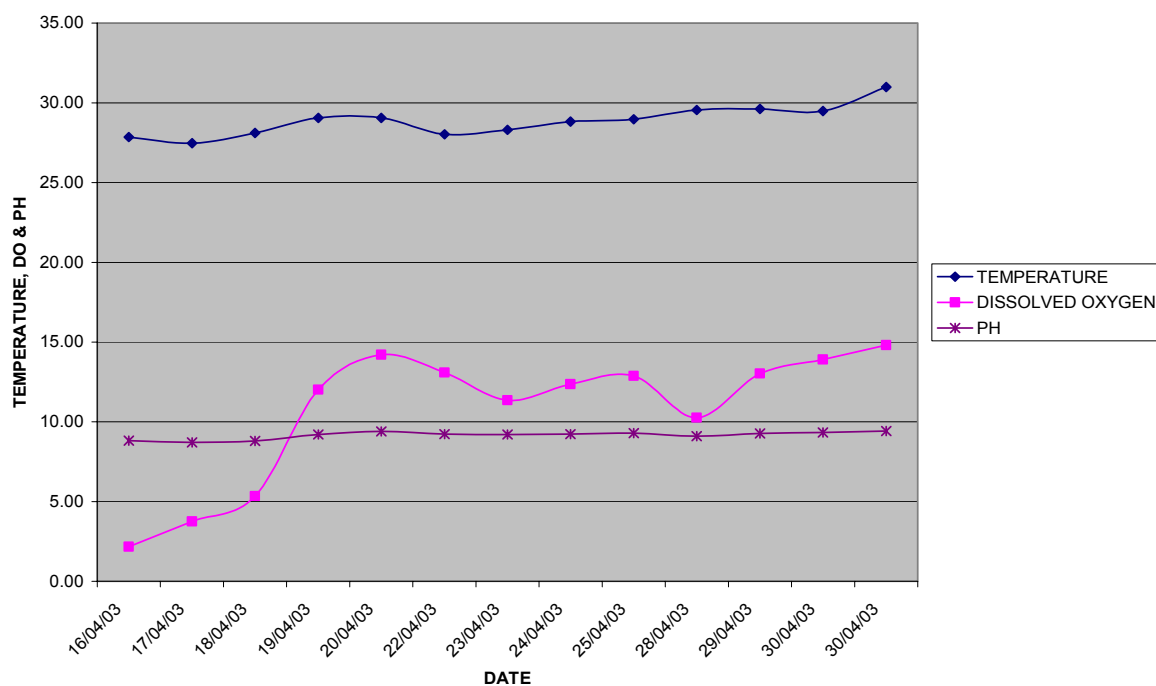
Table 4.3.1.8: Pond M1.2

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
16/04/03	27.79	5.02	929.00	8.87
17/04/03	27.77	2.29	916.00	8.83
18/04/03	27.97	4.85	880.00	8.96
19/04/03	29.47	14.10	819.33	9.52
20/04/03	28.99	14.67	814.67	9.58
22/04/03	28.00	15.60	826.00	9.66
23/04/03	28.15	15.09	805.67	9.65
24/04/03	28.78	15.39	805.33	9.65
25/04/03	28.86	12.43	805.00	9.60
28/04/03	29.12	13.82	818.67	9.43
29/04/03	29.50	12.99	817.00	9.50
30/04/03	29.70	14.44	819.67	9.62
30/04/03	31.85	14.59	783.33	9.83
AVE	28.92	11.95	833.82	9.44
MEDIAN	28.86	14.10	818.67	9.58
MAX	31.85	15.60	929.00	9.83
MIN	27.77	2.29	783.33	8.83

Refer to CHART 4.3.1.8: **M1.2: Variation of Parameters for April**

CHART 4.3.1.8: M1.2: VARIATION OF PARAMETERS FOR APRIL
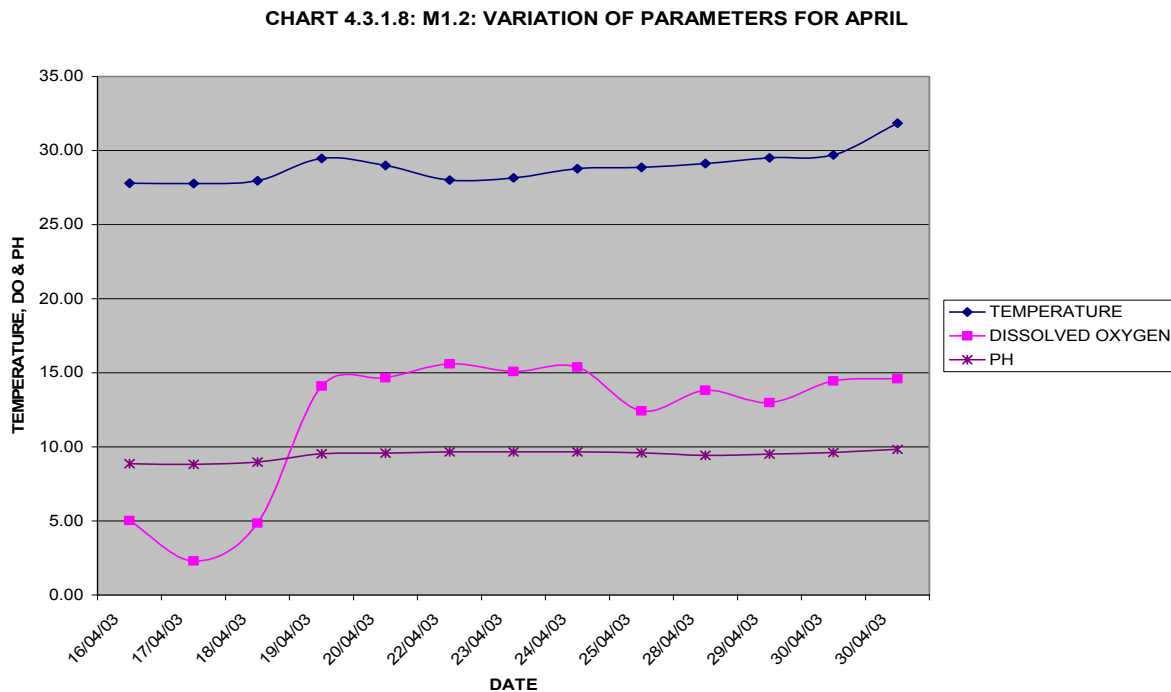
4.3.2   Physiochemical Parameters for May

The month of May saw a number of operational changes. That is, the splitting of flow to String 1 and 2. This cause the flow through String 1 to be considerably reduced resulting in stagnation. The result is a lowering of the DO levels. Since F1 is first in the series, it is the first to be affected and thus suffered from wide extremes of DO concentrations. On close inspection of the data it can be seen that when the flow was channeled through String 1 only the dissolved oxygen level increased. This is operationally significant, in that, the entire system has a capacity of 10MGD, currently only about a third of that is received, thus, one string is sufficient. For the rest of the monitoring period, only one string was therefore operational.

CHART 4.3.2.1:MAY'S TEMPERATURE VARIATION ACROSS SYSTEM
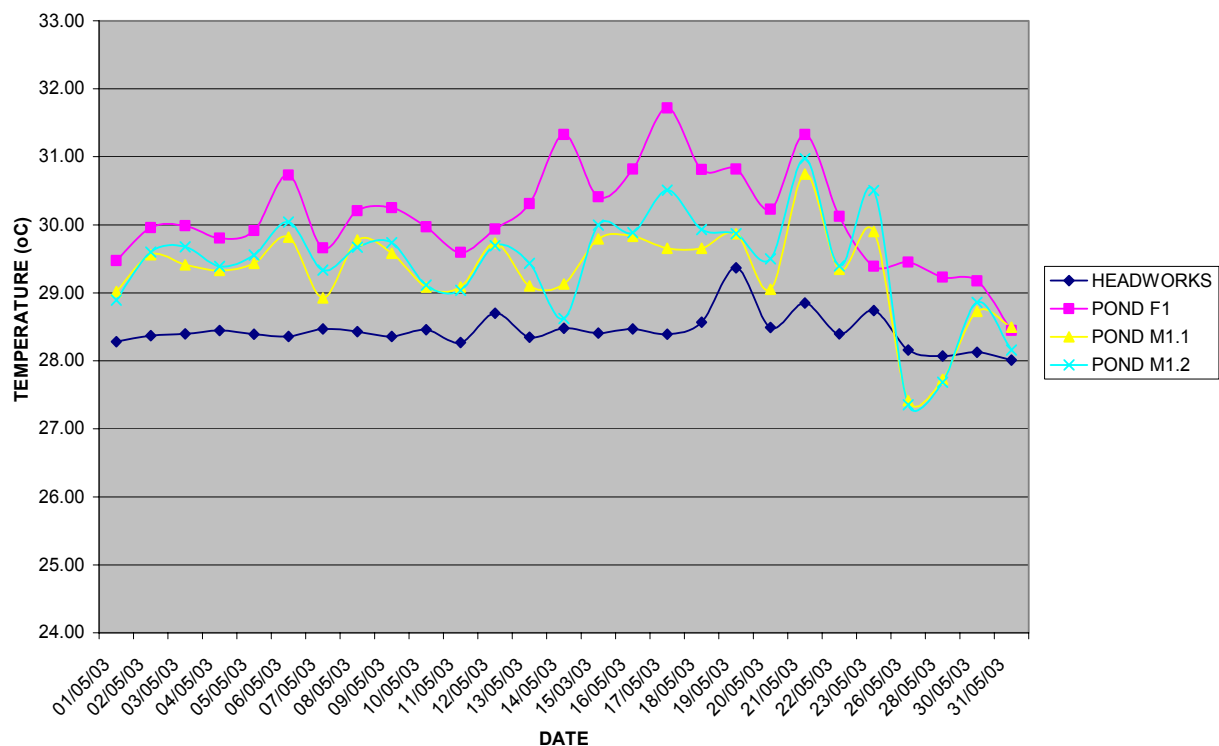
Table 4.3.2.1: <u>Temperature</u>

TEMPERATURE				
DATE	HEADWORK	POND F1	POND M1.1	POND M1.2
01/05/03	28.28	29.47	29.02	28.90
02/05/03	28.37	29.96	29.56	29.60
03/05/03	28.40	29.99	29.41	29.68
04/05/03	28.45	29.81	29.33	29.39
05/05/03	28.39	29.92	29.43	29.56
06/05/03	28.36	30.73	29.82	30.04
07/05/03	28.47	29.66	28.93	29.34
08/05/03	28.43	30.21	29.78	29.67
09/05/03	28.36	30.25	29.59	29.74
10/05/03	28.46	29.97	29.09	29.12
11/05/03	28.27	29.59	29.09	29.04
12/05/03	28.70	29.94	29.73	29.69
13/05/03	28.35	30.31	29.11	29.43
14/05/03	28.48	31.33	29.13	28.62
15/03/03	28.41	30.41	29.79	30.00
16/05/03	28.47	30.82	29.83	29.89
17/05/03	28.39	31.72	29.66	30.51
18/05/03	28.57	30.81	29.66	29.93
19/05/03	29.37	30.82	29.87	29.87
20/05/03	28.49	30.23	29.05	29.50
21/05/03	28.85	31.33	30.75	30.98
22/05/03	28.40	30.12	29.35	29.40
23/05/03	28.74	29.39	29.90	30.51
26/05/03	28.16	29.45	27.41	27.35
28/05/03	28.07	29.23	27.73	27.69
30/05/03	28.13	29.17	28.73	28.86
31/05/03	28.01	28.45	28.50	28.16
Mean	**28.44**	**30.12**	**29.31**	**29.42**
Median	**28.40**	**29.99**	**29.41**	**29.56**
Max	**29.37**	**31.72**	**30.75**	**30.98**
Min	**28.01**	**28.45**	**27.41**	**27.35**

Refer to CHART 4.3.2.1: **May's Temperature Variation Across System**

CHART 4.3.2.2: MAY'S DISSOLVED OXYGEN VARIATION ACROSS SYSTEM
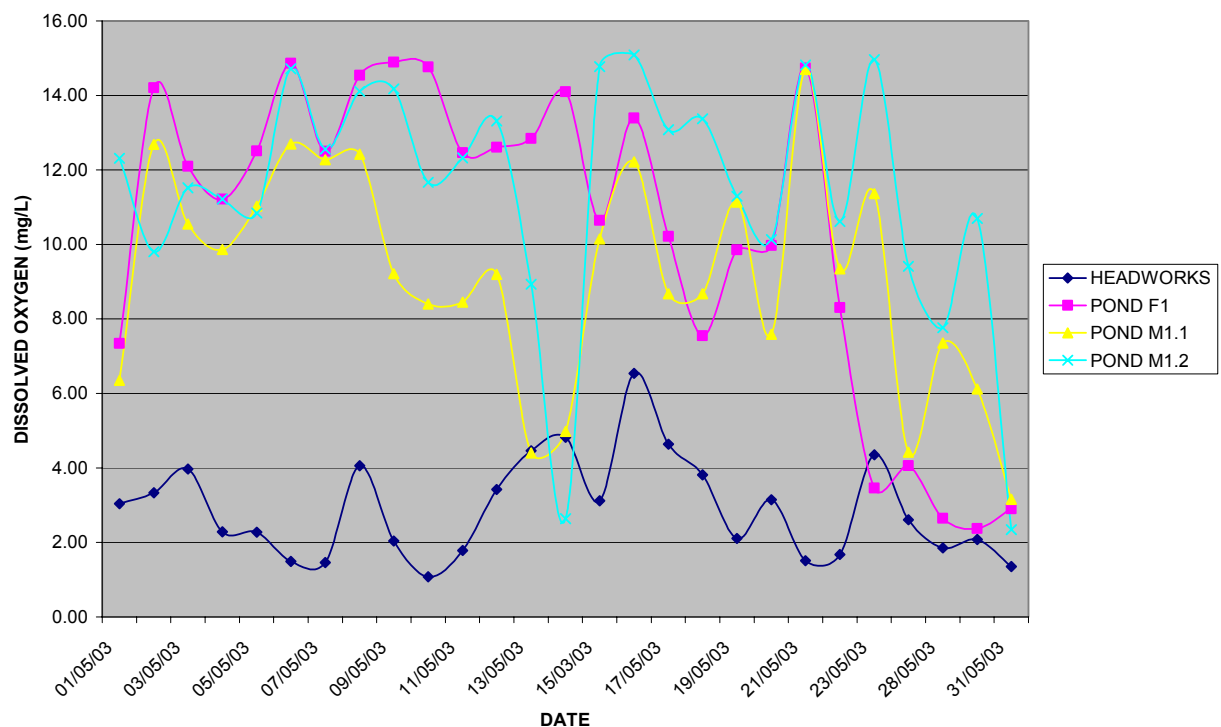
CHART 4.3.2.3: MAY'S PH VARIATION ACROSS SYSTEM
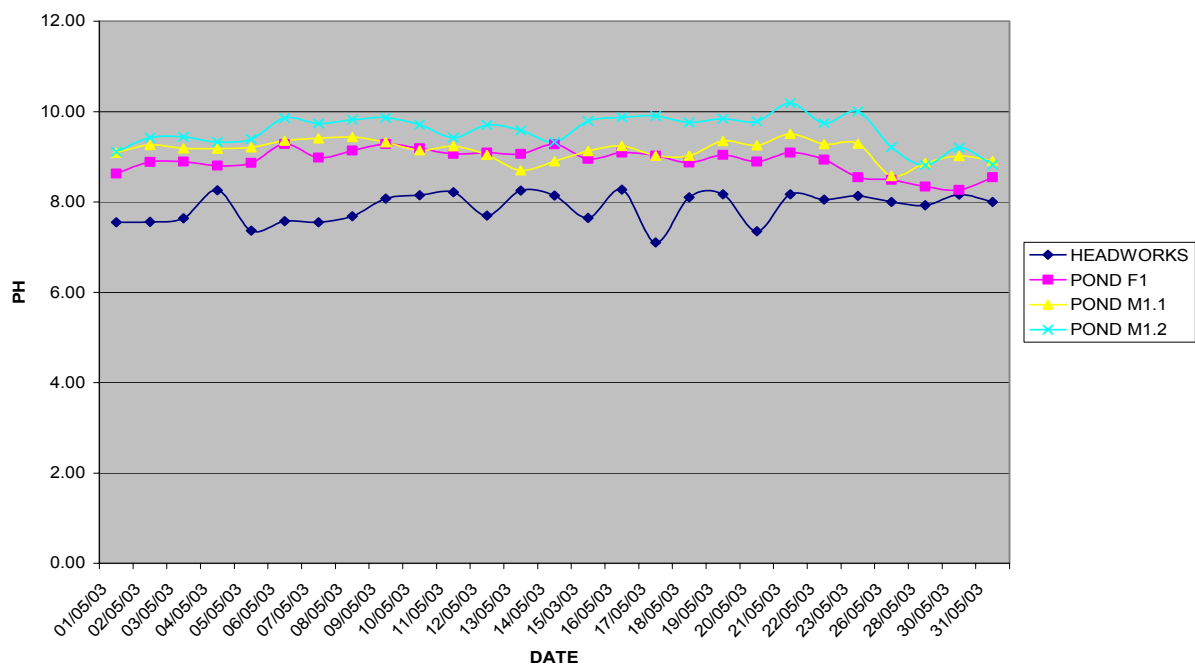
Table 4.3.2.2: <u>Dissolved Oxygen</u>

DATE	HEADWORK	POND F1	POND M1.1	POND M1.2
		DISSOLVED OXYGEN		
01/05/03	3.04	7.34	6.35	12.31
02/05/03	3.33	14.21	12.69	9.80
03/05/03	3.97	12.09	10.55	11.52
04/05/03	2.28	11.21	9.86	11.21
05/05/03	2.27	12.51	11.03	10.84
06/05/03	1.49	14.87	12.70	14.71
07/05/03	1.46	12.50	12.27	12.56
08/05/03	4.06	14.54	12.42	14.11
09/05/03	2.04	14.89	9.21	14.18
10/05/03	1.08	14.76	8.40	11.66
11/05/03	1.78	12.46	8.45	12.32
12/05/03	3.42	12.61	9.19	13.32
13/05/03	4.46	12.84	4.40	8.93
14/05/03	4.82	14.10	4.98	2.64
15/03/03	3.12	10.64	10.15	14.77
16/05/03	6.54	13.39	12.22	15.09
17/05/03	4.64	10.22	8.68	13.08
18/05/03	3.81	7.55	8.68	13.37
19/05/03	2.11	9.85	11.14	11.29
20/05/03	3.15	9.97	7.59	10.12
21/05/03	1.51	14.74	14.70	14.81
22/05/03	1.68	8.30	9.34	10.61
23/05/03	4.35	3.46	11.37	14.96
26/05/03	2.61	4.06	4.42	9.41
28/05/03	1.85	2.64	7.35	7.77
30/05/03	2.08	2.37	6.11	10.69
31/05/03	1.35	2.90	3.16	2.34
Mean	**2.90**	**10.41**	**9.16**	**11.42**
Median	**2.61**	**12.09**	**9.21**	**11.66**
Max	**6.54**	**14.89**	**14.70**	**15.09**
Min	**1.08**	**2.37**	**3.16**	**2.34**

Refer to CHART 4.3.2.2: **May's Variation of DO Across System**

Table 4.3.2.3: <u>pH</u>

		pH		
DATE	HEADWORK	POND F1	POND M1.1	POND M1.2
01/05/03	7.55	8.63	9.09	9.11
02/05/03	7.56	8.89	9.26	9.42
03/05/03	7.64	8.89	9.18	9.44
04/05/03	8.26	8.80	9.18	9.32
05/05/03	7.37	8.86	9.21	9.39
06/05/03	7.57	9.28	9.36	9.85
07/05/03	7.55	8.98	9.40	9.74
08/05/03	7.68	9.13	9.43	9.82
09/05/03	8.07	9.28	9.32	9.87
10/05/03	8.15	9.18	9.14	9.71
11/05/03	8.21	9.06	9.23	9.42
12/05/03	7.70	9.09	9.04	9.70
13/05/03	8.25	9.06	8.70	9.59
14/05/03	8.14	9.27	8.90	9.33
15/03/03	7.65	8.95	9.13	9.79
16/05/03	8.27	9.09	9.24	9.87
17/05/03	7.10	9.03	9.02	9.90
18/05/03	8.10	8.87	9.02	9.76
19/05/03	8.17	9.04	9.35	9.84
20/05/03	7.35	8.89	9.25	9.78
21/05/03	8.17	9.09	9.50	10.19
22/05/03	8.05	8.94	9.28	9.74
23/05/03	8.13	8.55	9.29	10.00
26/05/03	8.00	8.49	8.57	9.21
28/05/03	7.93	8.34	8.86	8.81
30/05/03	8.16	8.27	9.02	9.20
31/05/03	8.00	8.54	8.91	8.83
Mean	**7.88**	**8.91**	**9.14**	**9.58**
Median	**8.00**	**8.95**	**9.18**	**9.71**
Max	**8.27**	**9.28**	**9.50**	**10.19**
Min	**7.10**	**8.27**	**8.57**	**8.81**

Refer to CHART 4.3.2.3: **May's pH Variation Across System**

CHART 4.3.2.4: MAY'S CONDUCTIVITY VARIATION ACROSS SYSTEM
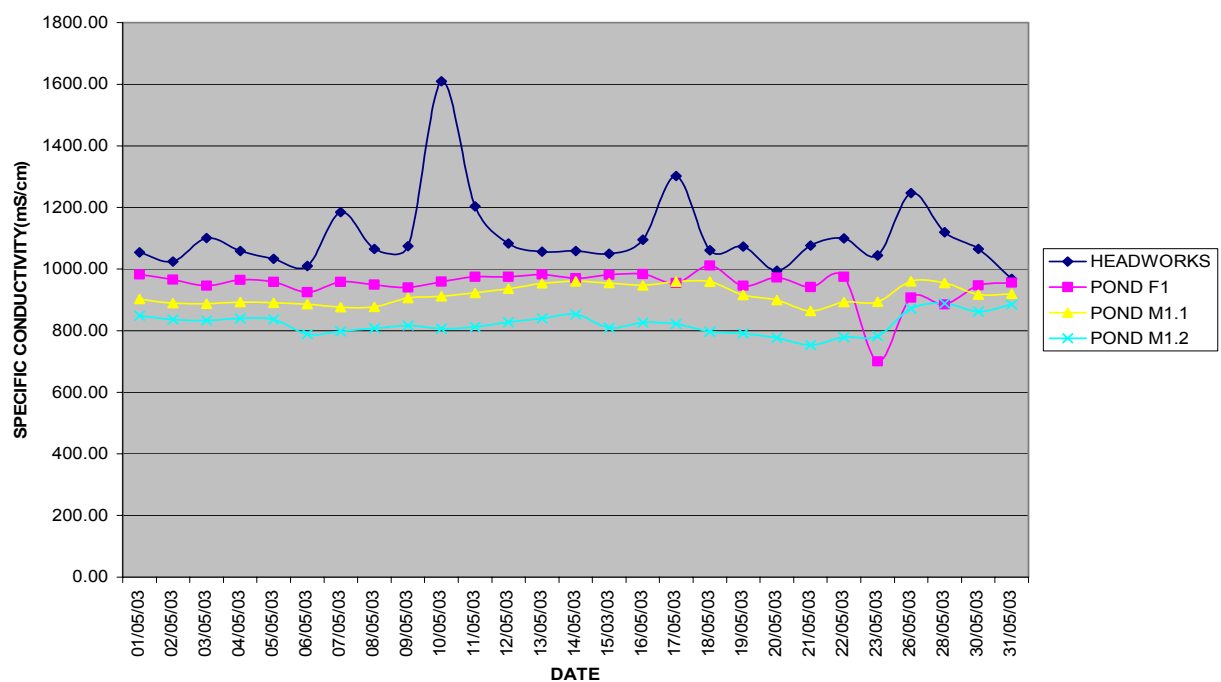
CHART 4.3.2.5: VARIATION OF PARAMETERS FOR MAY FOR HEADWORKS
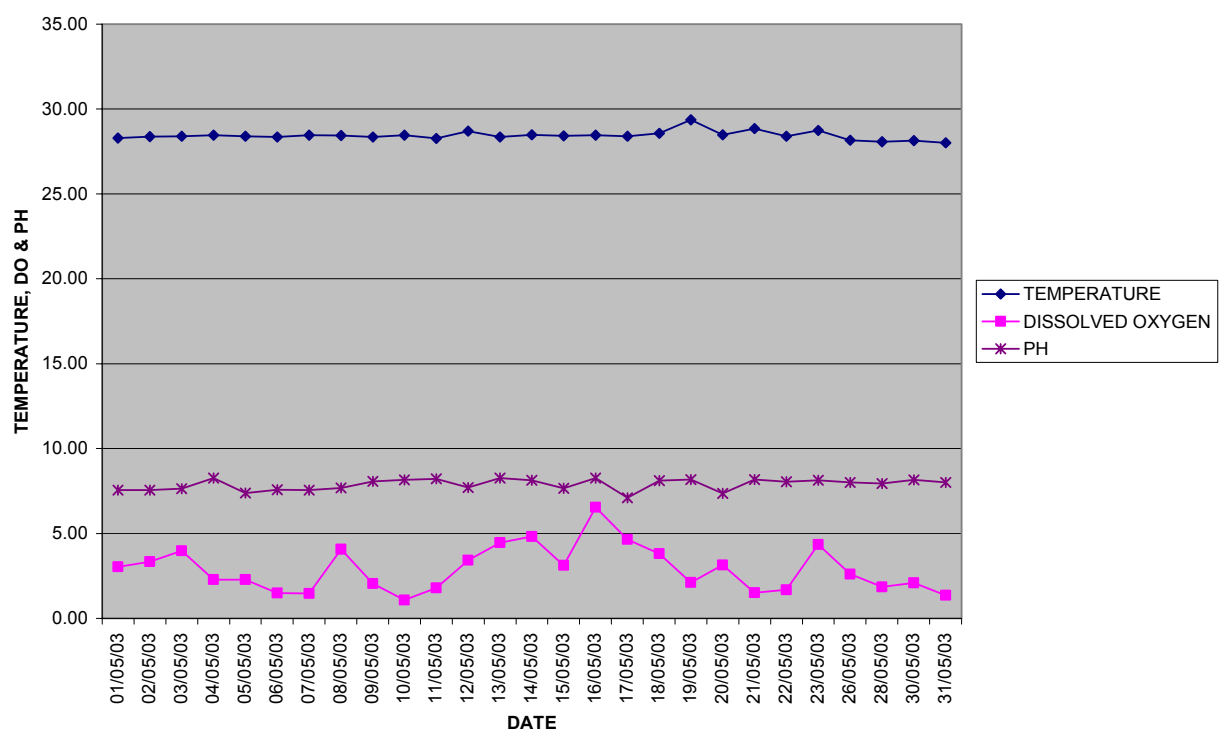
Table 4.3.2.4: <u>Specific Conductivity</u>

SPECIFIC CONDUCTIVITY				
DATE	**HEADWORK**	**POND F1**	**POND M1.1**	**POND M1.2**
01/05/03	1054.00	982.00	902.33	848.67
02/05/03	1025.00	965.33	889.33	836.33
03/05/03	1101.00	945.83	887.70	833.31
04/05/03	1059.00	964.39	893.12	839.44
05/05/03	1033.00	958.52	890.05	836.36
06/05/03	1010.00	924.67	886.67	788.67
07/05/03	1185.00	958.33	875.67	798.00
08/05/03	1065.00	949.67	877.00	807.33
09/05/03	1074.00	940.00	906.00	816.00
10/05/03	1610.00	958.67	912.00	807.00
11/05/03	1204.00	974.67	922.67	812.00
12/05/03	1083.00	974.33	936.33	827.33
13/05/03	1057.00	982.33	953.67	839.67
14/05/03	1059.00	970.67	960.67	852.67
15/03/03	1050.00	981.67	954.33	810.33
16/05/03	1095.00	983.67	947.00	826.00
17/05/03	1302.00	954.33	959.00	822.33
18/05/03	1061.00	1011.67	959.00	796.67
19/05/03	1073.00	946.00	916.33	791.00
20/05/03	995.00	972.33	899.33	777.00
21/05/03	1077.00	942.00	864.00	753.67
22/05/03	1100.00	974.33	892.67	778.67
23/05/03	1044.00	700.00	894.00	782.67
26/05/03	1247.00	907.56	960.67	872.00
28/05/03	1120.00	885.30	954.67	888.33
30/05/03	1065.00	947.06	917.33	862.00
31/05/03	968.00	955.33	919.67	885.00
Mean	**1104.30**	**948.54**	**915.97**	**821.79**
Median	**1065.00**	**958.52**	**912.00**	**822.33**
Max	**1610.00**	**1011.67**	**960.67**	**888.33**
Min	**968.00**	**700.00**	**864.00**	**753.67**

Refer to CHART 4.3.2.4**: May's Conductivity Variation Across System**

Table 4.3.2.5: <u>Headwork</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
01/05/03	28.28	3.04	1054.00	7.55
02/05/03	28.37	3.33	1025.00	7.56
03/05/03	28.40	3.97	1101.00	7.64
04/05/03	28.45	2.28	1059.00	8.26
05/05/03	28.39	2.27	1033.00	7.37
06/05/03	28.36	1.49	1010.00	7.57
07/05/03	28.47	1.46	1185.00	7.55
08/05/03	28.43	4.06	1065.00	7.68
09/05/03	28.36	2.04	1074.00	8.07
10/05/03	28.46	1.08	1610.00	8.15
11/05/03	28.27	1.78	1204.00	8.21
12/05/03	28.70	3.42	1083.00	7.70
13/05/03	28.35	4.46	1057.00	8.25
14/05/03	28.48	4.82	1059.00	8.14
15/05/03	28.41	3.12	1050.00	7.65
16/05/03	28.47	6.54	1095.00	8.27
17/05/03	28.39	4.64	1302.00	7.10
18/05/03	28.57	3.81	1061.00	8.10
19/05/03	29.37	2.11	1073.00	8.17
20/05/03	28.49	3.15	995.00	7.35
21/05/03	28.85	1.51	1077.00	8.17
22/05/03	28.40	1.68	1100.00	8.05
23/05/03	28.74	4.35	1044.00	8.13
26/05/03	28.16	2.61	1247.00	8.00
28/05/03	28.07	1.85	1120.00	7.93
30/05/03	28.13	2.08	1065.00	8.16
31/05/03	28.01	1.35	968.00	8.00
AVE	**28.44**	**2.90**	**1104.30**	**7.88**
MEDIAN	**28.40**	**2.61**	**1065.00**	**8.00**
MAX	**29.37**	**6.54**	**1610.00**	**8.27**
MIN	**28.01**	**1.08**	**968.00**	**7.10**

Refer to CHART 4.3.2.5: **Headwork: Variation of Parameters for May**

Table 4.3.2.6: <u>Pond F1</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
01/05/03	29.47	7.34	982.00	8.63
02/05/03	29.96	14.21	965.33	8.89
03/05/03	29.99	12.09	945.83	8.89
04/05/03	29.81	11.21	964.39	8.80
05/05/03	29.92	12.51	958.52	8.86
06/05/03	30.73	14.87	924.67	9.28
07/05/03	29.66	12.50	958.33	8.98
07/05/03	31.46	14.68	954.00	9.08
08/05/03	30.21	14.54	949.67	9.13
09/05/03	30.25	14.89	940.00	9.28
10/05/03	29.97	14.76	958.67	9.18
11/05/03	29.59	12.46	974.67	9.06
12/05/03	29.94	12.61	974.33	9.09
13/05/03	30.31	12.84	982.33	9.06
14/05/03	31.33	14.10	970.67	9.27
15/03/03	30.41	10.64	981.67	8.95
15/03/03	30.99	14.07	970.33	9.05
16/05/03	30.82	13.39	983.67	9.09
17/05/03	31.72	10.22	954.33	9.03
18/05/03	30.81	7.55	1011.67	8.87
19/05/03	30.82	9.85	946.00	9.04
20/05/03	30.23	9.97	972.33	8.89
21/05/03	31.33	14.74	942.00	9.09
22/05/03	30.12	8.30	974.33	8.94
23/05/03	29.39	3.46	700.00	8.55
23/05/03	28.84	0.42	1048.33	7.98
26/05/03	29.45	4.06	907.56	8.49
28/05/03	29.23	2.64	885.30	8.34
30/05/03	29.17	2.37	947.06	8.27
31/05/03	28.45	2.90	955.33	8.54
Mean	**30.15**	**10.34**	**952.78**	**8.89**
Median	**30.06**	**12.28**	**958.59**	**8.97**
Max	**31.72**	**14.89**	**1048.33**	**9.28**
Min	**28.45**	**0.42**	**700.00**	**7.98**

Refer to CHART 4.3.2.6: **F1: Variation of Parameters for May**

CHART 4.3.2.6: PARAMETER VARIATION FOR MAY FOR F1
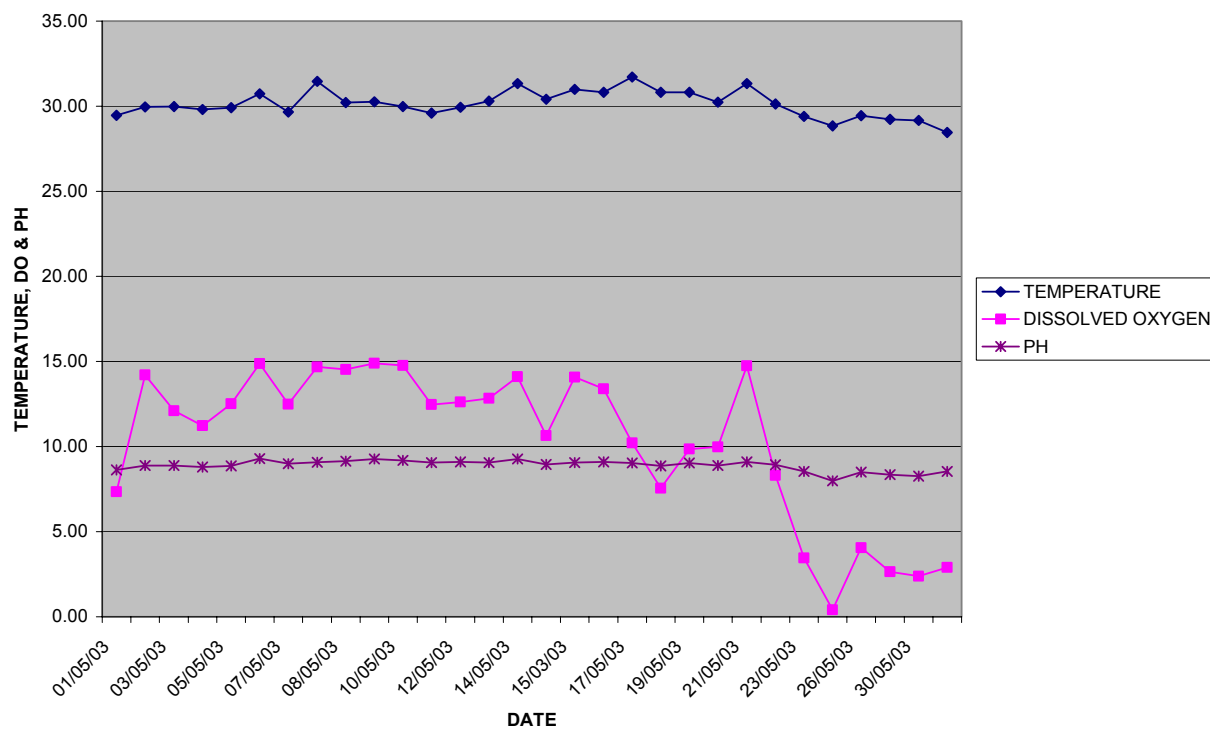
CHART 4.3.2.7: VARIATION OF PARAMETERS FOR MAY FOR M1.1
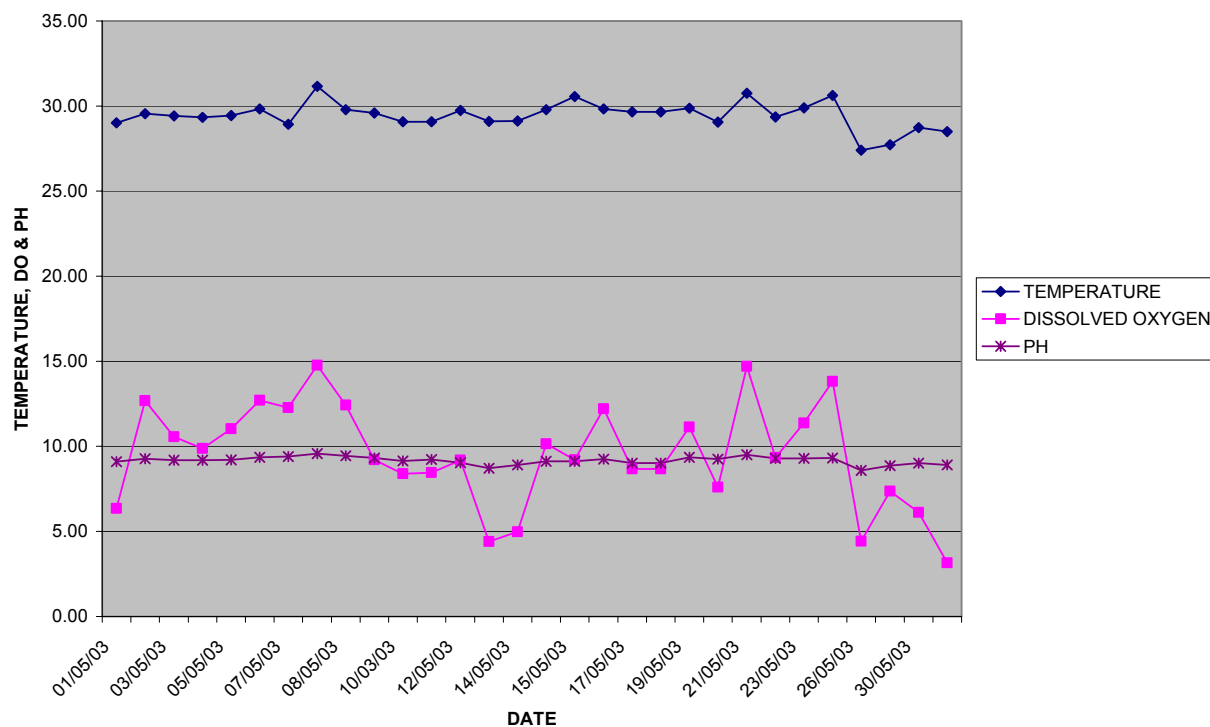
Table 4.3.2.7: <u>Pond M1.1</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
01/05/03	29.02	6.35	902.33	9.09
02/05/03	29.56	12.69	889.33	9.26
03/05/03	29.41	10.55	887.70	9.18
04/05/03	29.33	9.86	893.12	9.18
05/05/03	29.43	11.03	890.05	9.21
06/05/03	29.82	12.70	886.67	9.36
07/05/03	28.93	12.27	875.67	9.40
07/05/03	31.16	14.76	860.33	9.57
08/05/03	29.78	12.42	877.00	9.43
09/05/03	29.59	9.21	906.00	9.32
10/03/03	29.09	8.40	912.00	9.14
11/03/03	29.09	8.45	922.67	9.23
12/05/03	29.73	9.19	936.33	9.04
13/05/03	29.11	4.40	953.67	8.70
14/05/03	29.13	4.98	960.67	8.90
15/05/03	29.79	10.15	954.33	9.13
15/05/03	30.56	9.21	941.33	9.11
16/05/03	29.83	12.22	947.00	9.24
17/05/03	29.66	8.68	959.00	9.02
18/05/03	29.66	8.68	959.00	9.02
19/05/03	29.87	11.14	916.33	9.35
20/05/03	29.05	7.59	899.33	9.25
21/05/03	30.75	14.70	864.00	9.50
22/05/03	29.35	9.34	892.67	9.28
23/05/03	29.90	11.37	894.00	9.29
23/05/03	30.61	13.81	894.33	9.30
26/05/03	27.41	4.42	960.67	8.57
28/05/03	27.73	7.35	954.67	8.86
30/05/03	28.73	6.11	917.33	9.02
31/05/03	28.50	3.16	919.67	8.91
AVE	**29.45**	**9.51**	**914.24**	**9.16**
MEDIAN	**29.50**	**9.28**	**909.00**	**9.20**
MAX	**31.16**	**14.76**	**960.67**	**9.57**
MIN	**27.41**	**3.16**	**860.33**	**8.57**

Refer to CHART 4.3.2.7: **M1.1: Variation of Parameters for May**

Table 4.3.2.8: <u>Pond M1.2</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
01/05/03	28.90	12.31	848.67	9.11
02/05/03	29.60	9.80	836.33	9.42
03/05/03	29.68	11.52	833.31	9.44
04/05/03	29.39	11.21	839.44	9.32
05/05/03	29.56	10.84	836.36	9.39
06/05/03	30.04	14.71	788.67	9.85
07/05/03	29.34	12.56	798.00	9.74
07/05/03	31.10	14.78	783.33	9.97
08/05/03	29.67	14.11	807.33	9.82
09/05/03	29.74	14.18	816.00	9.87
10/05/03	29.12	11.66	807.00	9.71
11/05/03	29.04	12.32	812.00	9.42
12/05/03	29.69	13.32	827.33	9.70
13/05/03	29.43	8.93	839.67	9.59
14/05/03	28.62	2.64	852.67	9.33
15/05/03	30.00	14.77	810.33	9.79
15/05/03	30.89	14.83	826.67	9.77
16/05/03	29.89	15.09	826.00	9.87
17/05/03	30.51	13.08	822.33	9.90
18/05/03	29.93	13.37	796.67	9.76
19/05/03	29.87	11.29	791.00	9.84
20/05/03	29.50	10.12	777.00	9.78
21/05/03	30.98	14.81	753.67	10.19
22/05/03	29.40	10.61	778.67	9.74
23/05/03	30.51	14.96	782.67	10.00
23/05/03	29.30	6.17	845.00	9.40
26/05/03	27.35	9.41	872.00	9.21
28/05/03	27.69	7.77	888.33	8.81
30/05/03	28.86	10.69	862.00	9.20
31/05/03	28.16	2.34	885.00	8.83
AVE	**29.52**	**11.47**	**821.45**	**9.59**
MEDIAN	**29.58**	**11.99**	**824.17**	**9.73**
MAX	**31.10**	**15.09**	**888.33**	**10.19**
MIN	**27.35**	**2.34**	**753.67**	**8.81**

Refer to CHART 4.3.2.8: **M1.2: Variation of Parameters for May**

CHART 4.3.2.8: VARIATION OF PARAMETERS FOR MAY FOR M1.2
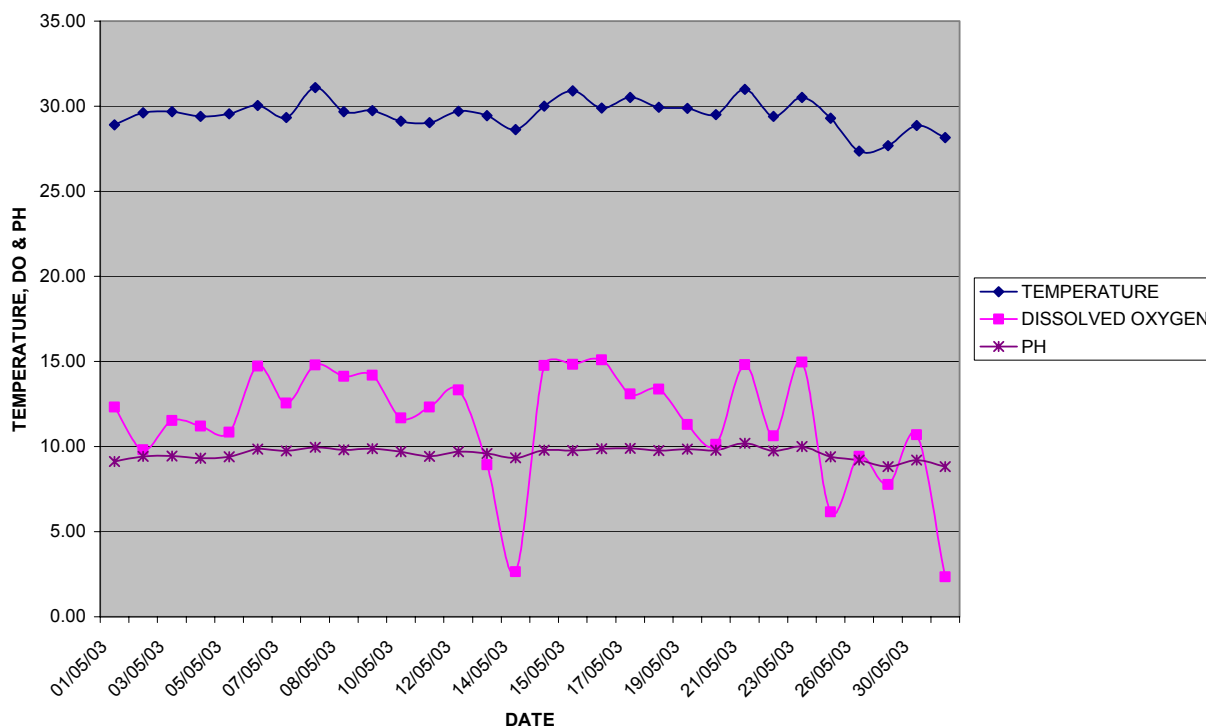
4.3.3   Physiochemical Parameters for June

June saw an increase in the greasy inflows at the Headwork and a subsequent persistence of floating algae and sludge in Pond F1. A grease trap audit was therefore conducted on the major food preparing establishments in and around the Montego Bay area and a report of the results is also included.

Also, initial dye tracing was embarked upon, where 24-hour readings were taken at 3-hour intervals. It was noticed that the effluent at Pond F1 became greasy and viscous at midnight after which floating sludge and algae formed. Apparently this is a normal occurrence in the pond's treatment cycle as the pond becomes anoxic during the nights. Due to the influx of grease, String one started overloading and management temporarily took the flow off it, causing dye tracing operations to be abandoned. Further dye tracing was then carried out in July.

Table 4.3.3.1: Temperature

TEMPERATURE				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
06/01/03	28.21	29.16	29.11	29.02
06/02/03	28.07	28.21	28.42	28.30
06/03/03	28.11	29.06	28.68	28.53
06/04/03	28.11	29.06	28.76	28.68
06/05/03	28.15	29.50	28.66	28.62
06/06/03	28.24	30.78	29.33	29.01
06/07/03	27.89	29.73	28.63	29.22
06/08/03	28.10	30.05	29.13	29.06
06/09/03	28.22	29.67	28.93	28.92
06/10/03	28.22	29.97	29.48	29.52
06/11/03	28.34	30.01	29.83	29.80
06/12/03	28.23	29.95	29.45	29.55
06/13/03	28.20	29.89	29.40	29.33
06/14/03	28.03	29.86	28.46	28.43
06/16/03	28.04	29.21	28.80	28.73
06/17/03	27.79	29.09	28.52	28.52
06/18/03	28.30	30.72	29.85	29.75
06/19/03	27.80	29.47	29.40	29.45
06/20/03	28.17	29.87	29.83	29.41
06/21/03	28.22	30.49	30.35	30.20
06/22/03	28.30	30.37	30.50	30.49
06/23/03	28.47	31.11	30.37	30.50
06/24/03	28.36	30.49	30.22	30.30
06/25/03	28.32	29.88	29.57	29.69
06/26/03	28.18	29.43	29.04	29.03
06/27/03	28.42	29.84	29.60	29.62
06/28/03	28.50	30.08	30.08	29.77
06/29/03	28.74	30.01	30.01	29.92
06/30/03	28.54	30.04	30.04	29.54
AVE	**28.22**	**29.83**	**29.39**	**29.34**
MEDIAN	**28.22**	**29.88**	**29.40**	**29.41**
MAX	**28.74**	**31.11**	**30.50**	**30.50**
MIN	**27.79**	**28.21**	**28.42**	**28.30**

Refer to CHART 4.3.3.1: **June's Temperature Variation Across System**

CHART 4.3.3.1: JUNE'S TEMPERATURE VARIATION ACROSS SYSTEM
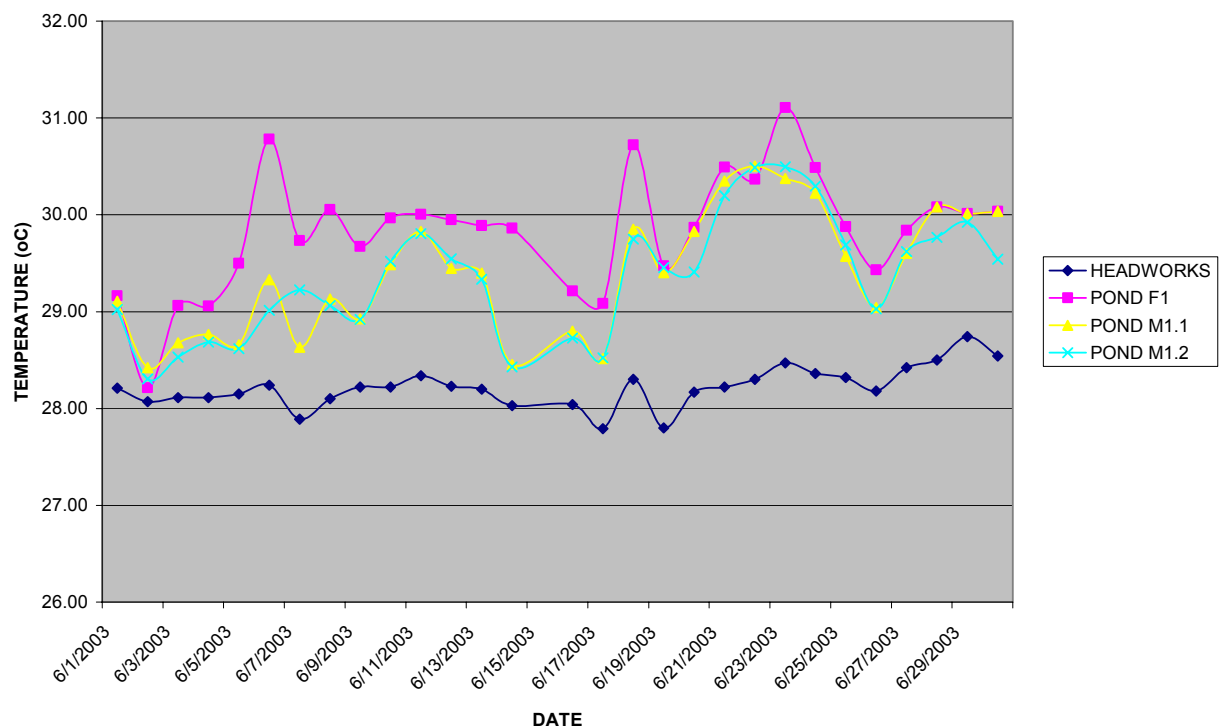
CHART 4.3.3.2: JUNE'S DISSOLVED OXYGEN VARIATION ACROSS SYSTEM
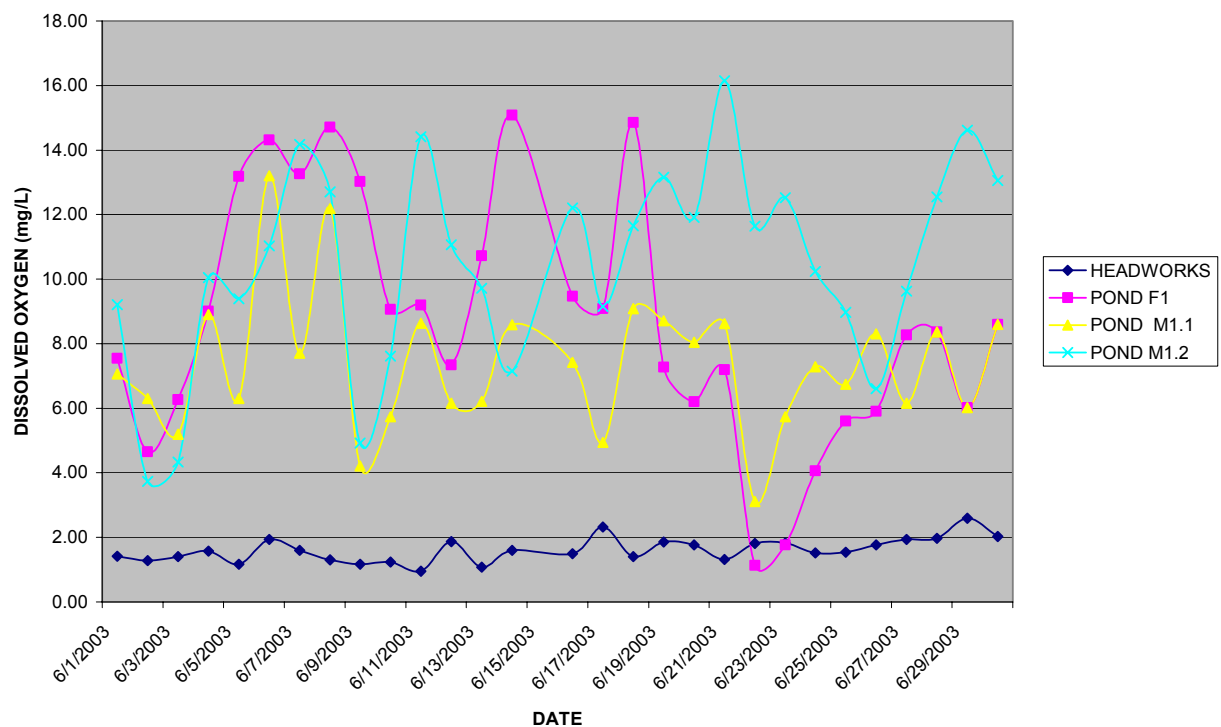
Table 4.3.3.2: <u>Dissolved Oxygen</u>

DISSOLVED OXYGEN				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
06/01/03	1.41	7.54	7.06	9.21
06/02/03	1.28	4.65	6.30	3.73
06/03/03	1.40	6.26	5.20	4.33
06/04/03	1.57	9.00	8.90	10.04
06/05/03	1.17	13.18	6.30	9.39
06/06/03	1.94	14.31	13.20	11.03
06/07/03	1.59	13.26	7.71	14.18
06/08/03	1.30	14.71	12.19	12.70
06/09/03	1.17	13.02	4.21	4.93
06/10/03	1.23	9.06	5.74	7.61
06/11/03	0.95	9.20	8.63	14.41
06/12/03	1.87	7.34	6.16	11.07
06/13/03	1.07	10.72	6.22	9.72
06/14/03	1.60	15.08	8.58	7.15
06/16/03	1.49	9.47	7.42	12.21
06/17/03	2.32	9.08	4.95	9.15
06/18/03	1.40	14.86	9.09	11.65
06/19/03	1.86	7.28	8.72	13.15
06/20/03	1.76	6.20	8.04	11.92
06/21/03	1.31	7.20	8.62	16.15
06/22/03	1.81	1.13	3.11	11.64
06/23/03	1.82	1.77	5.74	12.52
06/24/03	1.52	4.07	7.29	10.23
06/25/03	1.54	5.60	6.75	8.97
06/26/03	1.77	5.91	8.31	6.61
06/27/03	1.94	8.27	6.15	9.63
06/28/03	1.97	8.36	8.36	12.54
06/29/03	2.59	6.01	6.01	14.62
06/30/03	2.02	8.59	8.59	13.06
AVE	**1.61**	**8.66**	**7.36**	**10.47**
MEDIAN	**1.57**	**8.36**	**7.29**	**11.03**
MAX	**2.59**	**15.08**	**13.20**	**16.15**
MIN	**0.95**	**1.13**	**3.11**	**3.73**

Refer to CHART 4.3.3.2: **June's Variation of Dissolved Oxygen Across System**

Table 4.3.3.3: pH

pH				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
06/01/03	8.16	8.75	9.01	9.11
06/02/03	8.11	8.50	9.32	9.65
06/03/03	7.50	8.70	8.86	8.90
06/04/03	8.16	8.80	9.03	8.92
06/05/03	8.19	9.02	8.89	8.74
06/06/03	8.33	9.13	9.16	9.01
06/07/03	8.29	9.01	9.01	9.26
06/08/03	7.54	9.12	9.08	9.21
06/09/03	8.04	8.97	8.70	9.07
06/10/03	8.08	8.86	8.80	9.12
06/11/03	8.10	8.81	9.07	9.37
06/12/03	8.05	8.61	8.88	9.26
06/13/03	8.05	8.78	8.83	9.15
06/14/03	8.09	9.18	8.80	9.06
06/16/03	8.16	8.76	8.81	9.09
06/17/03	8.04	8.71	8.66	8.79
06/18/03	8.04	9.01	8.97	9.13
06/19/03	8.08	8.57	8.92	9.15
06/20/03	8.11	8.51	8.82	8.98
06/21/03	8.05	8.59	8.74	9.03
06/22/03	7.96	8.27	8.48	9.21
06/23/03	7.95	8.33	8.09	9.19
06/24/03	7.99	8.41	8.40	9.17
06/25/03	8.13	8.36	8.58	8.68
06/26/03	8.10	8.41	8.34	8.55
06/27/03	8.15	8.63	8.16	8.94
06/28/03	8.18	8.70	8.70	8.90
06/29/03	8.10	8.22	8.22	9.27
06/30/03	7.88	8.57	8.57	8.91
AVE	**8.06**	**8.70**	**8.76**	**9.06**
MEDIAN	**8.09**	**8.70**	**8.81**	**9.09**
MAX	**8.33**	**9.18**	**9.32**	**9.65**
MIN	**7.50**	**8.22**	**8.09**	**8.55**

Refer to CHART 4.3.3.3: **June's PH Variation Across System**

CHART 4.3.3.3: JUNE'S PH VARIATION ACROSS SYSTEM
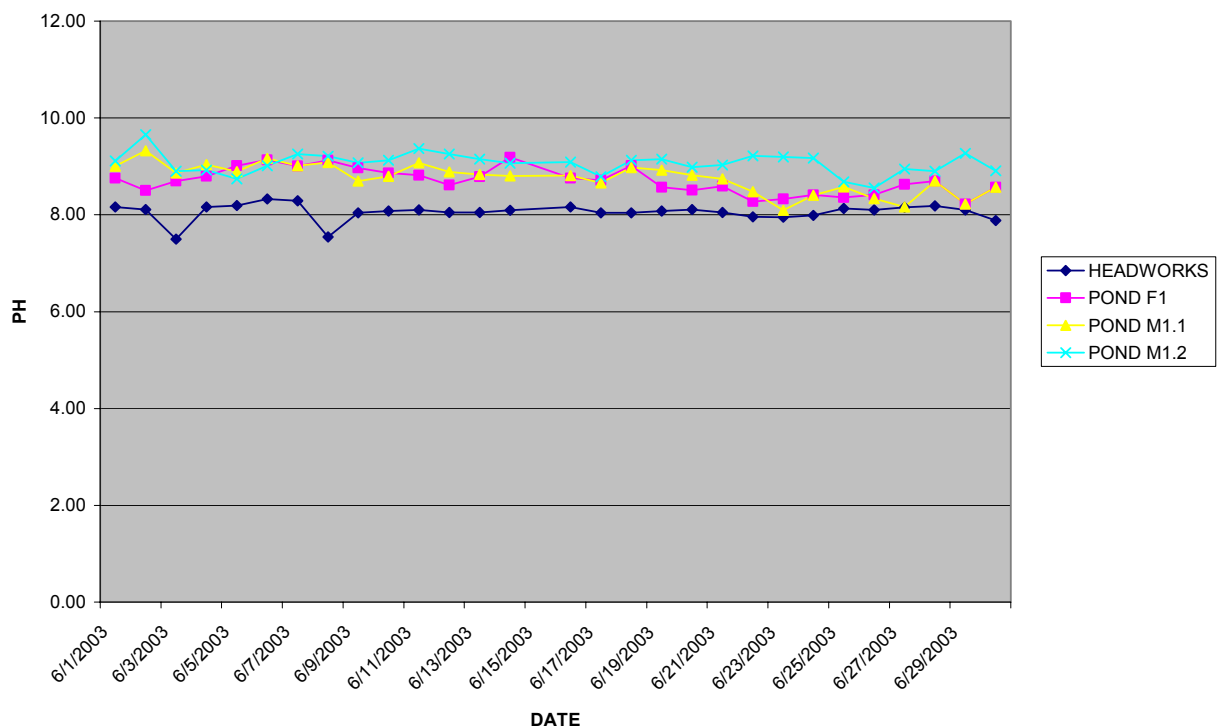
CHART 4.3.3.4: JUNE'S SPECIFIC CONDUCTIVITY ACROSS SYSTEM
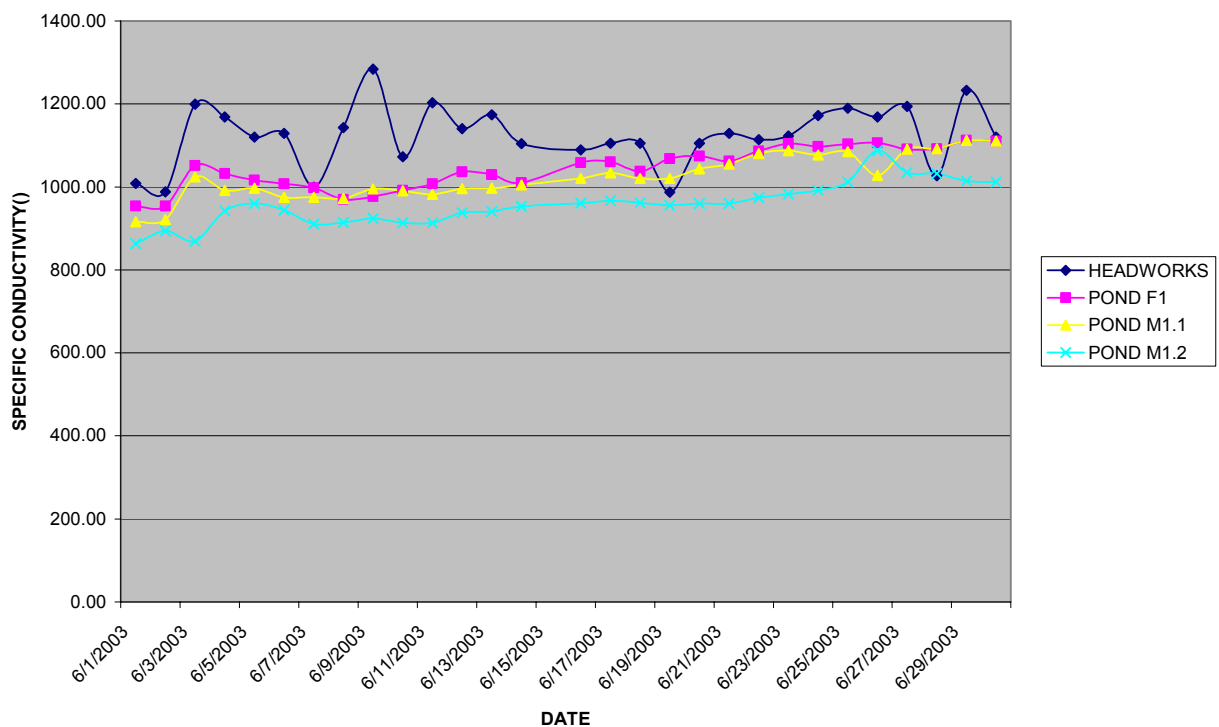
Table 4.3.3.4: Specific Conductivity

S/CONDUCTIVITY				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
06/01/03	1008.00	953.67	915.67	863.00
06/02/03	988.00	954.00	921.67	894.00
06/03/03	1199.00	1051.67	1024.33	869.67
06/04/03	1169.00	1032.00	992.00	942.00
06/05/03	1120.00	1016.00	996.67	960.00
06/06/03	1129.00	1007.33	975.00	944.00
06/07/03	1000.00	997.67	975.00	910.33
06/08/03	1143.00	970.00	972.67	914.67
06/09/03	1284.00	977.00	995.00	924.00
06/10/03	1073.00	992.00	991.00	913.67
06/11/03	1203.00	1007.67	982.00	913.00
06/12/03	1140.00	1036.67	996.33	937.67
06/13/03	1174.00	1029.67	997.33	940.33
06/14/03	1104.00	1010.00	1004.67	952.67
06/16/03	1089.00	1058.67	1021.00	960.67
06/17/03	1105.00	1060.00	1034.00	967.00
06/18/03	1105.00	1037.67	1021.00	961.67
06/19/03	987.00	1068.00	1020.33	955.33
06/20/03	1105.00	1074.00	1043.33	959.67
06/21/03	1129.00	1062.00	1055.33	960.33
06/22/03	1114.00	1086.33	1080.33	974.33
06/23/03	1123.00	1104.67	1088.00	983.00
06/24/03	1172.00	1097.33	1076.67	991.67
06/25/03	1190.00	1103.67	1085.33	1012.33
06/26/03	1169.00	1106.00	1028.00	1087.33
06/27/03	1194.00	1091.33	1091.00	1035.00
06/28/03	1027.00	1092.00	1092.00	1032.33
06/29/03	1233.00	1112.67	1112.67	1014.33
06/30/03	1120.00	1110.67	1110.67	1012.33
AVE	**1124.00**	**1044.84**	**1024.10**	**958.15**
MEDIAN	**1123.00**	**1051.67**	**1021.00**	**959.67**
MAX	**1284.00**	**1112.67**	**1112.67**	**1087.33**
MIN	**987.00**	**953.67**	**915.67**	**863.00**

Refer to CHART 4.3.3.4: **June's Conductivity Variation Across System**

Table 4.3.3.5: <u>Headwork</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	PH
06/01/03	28.21	1.41	1008.00	8.16
06/02/03	28.07	1.28	988.00	8.11
06/03/03	28.11	1.40	1199.00	7.50
06/04/03	28.11	1.57	1169.00	8.16
06/05/03	28.15	1.17	1120.00	8.19
06/06/03	28.24	1.94	1129.00	8.33
06/07/03	27.89	1.59	1000.00	8.29
06/08/03	28.10	1.30	1143.00	7.54
06/09/03	28.22	1.17	1284.00	8.04
06/10/03	28.22	1.23	1073.00	8.08
06/11/03	28.34	0.95	1203.00	8.10
06/12/03	28.23	1.87	1140.00	8.05
06/13/03	28.20	1.07	1174.00	8.05
06/14/03	28.03	1.60	1104.00	8.09
06/16/03	28.04	1.49	1089.00	8.16
06/17/03	27.79	2.32	1105.00	8.04
06/18/03	28.30	1.40	1105.00	8.04
06/19/03	27.80	1.86	987.00	8.08
06/20/03	28.17	1.76	1105.00	8.11
06/21/03	28.22	1.31	1129.00	8.05
06/22/03	28.30	1.81	1114.00	7.96
06/23/03	28.47	1.82	1123.00	7.95
06/24/03	28.36	1.52	1172.00	7.99
06/25/03	28.32	1.54	1190.00	8.13
06/26/03	28.18	1.77	1169.00	8.10
06/27/03	28.42	1.94	1194.00	8.15
06/28/03	28.50	1.97	1027.00	8.18
06/29/03	28.74	2.59	1233.00	8.10
06/30/03	28.54	2.02	1120.00	7.88
AVE	**28.22**	**1.61**	**1124.00**	**8.06**
MEDIAN	**28.22**	**1.57**	**1123.00**	**8.09**
MAX	**28.74**	**2.59**	**1284.00**	**8.33**
MIN	**27.79**	**0.95**	**987.00**	**7.50**

Refer to CHART 4.3.3.5: **Headwork: Variation of Parameters for June**

CHART 4.3.3.5: HEADWORK: VARIATION OF PARAMETERS FOR JUNE
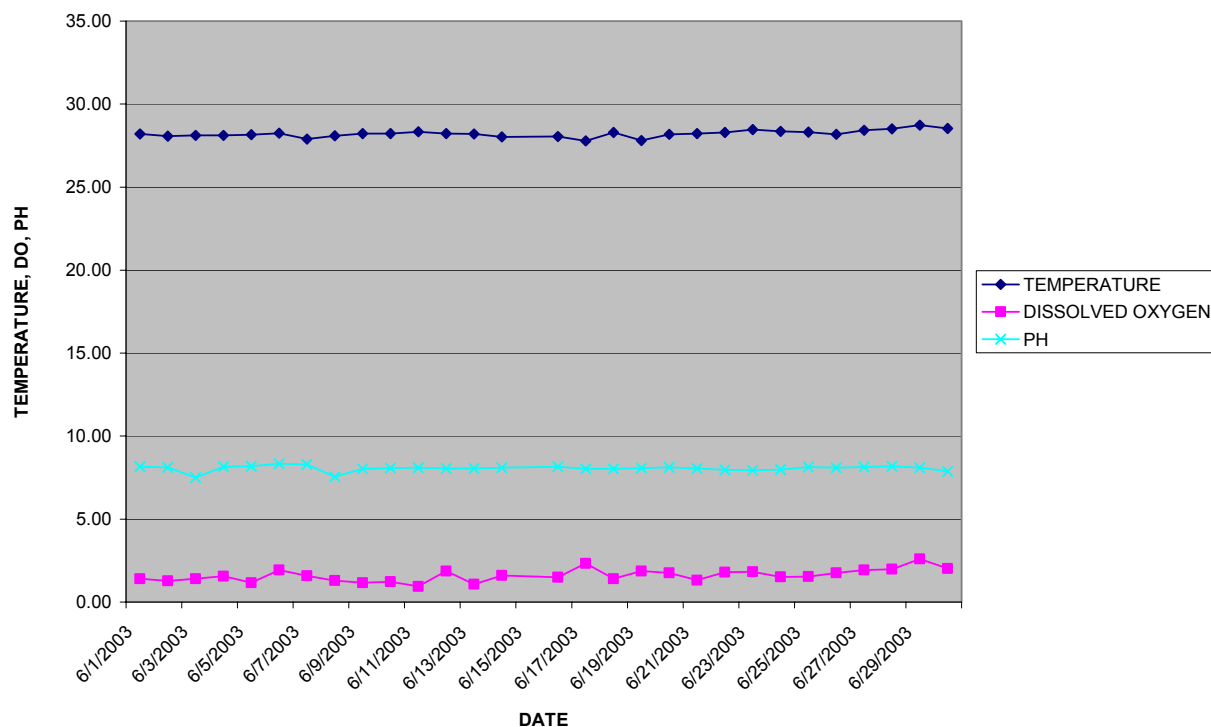
CHART 4.3.3.6: F1: VARIATION OF PARAMETERS FOR JUNE
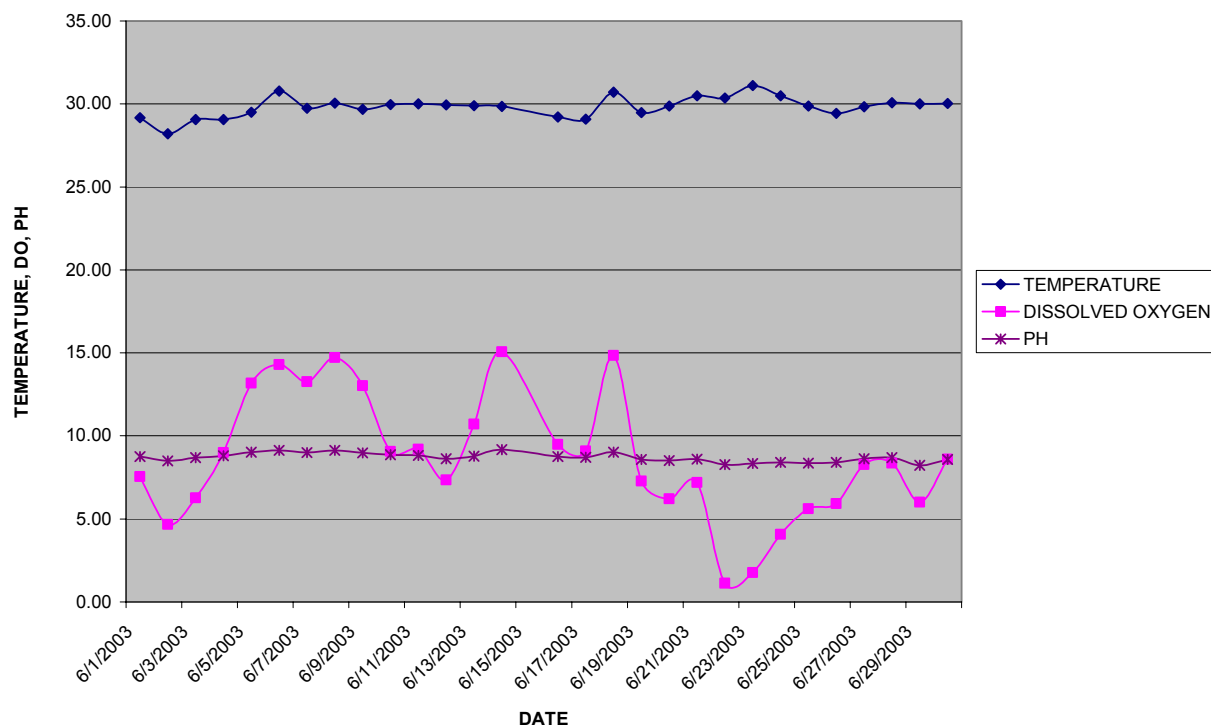
Table 4.3.3.6: Pond F1

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
06/01/03	29.16	7.54	953.67	8.75
06/02/03	28.21	4.65	954.00	8.50
06/03/03	29.06	6.26	1051.67	8.70
06/04/03	29.06	9.00	1032.00	8.80
06/05/03	29.50	13.18	1016.00	9.02
06/06/03	30.78	14.31	1007.33	9.13
06/07/03	29.73	13.26	997.67	9.01
06/08/03	30.05	14.71	970.00	9.12
06/09/03	29.67	13.02	977.00	8.97
06/10/03	29.97	9.06	992.00	8.86
06/11/03	30.01	9.20	1007.67	8.81
06/12/03	29.95	7.34	1036.67	8.61
06/13/03	29.89	10.72	1029.67	8.78
06/14/03	29.86	15.08	1010.00	9.18
06/16/03	29.21	9.47	1058.67	8.76
06/17/03	29.09	9.08	1060.00	8.71
06/18/03	30.72	14.86	1037.67	9.01
06/19/03	29.47	7.28	1068.00	8.57
06/20/03	29.87	6.20	1074.00	8.51
06/21/03	30.49	7.20	1062.00	8.59
06/22/03	30.37	1.13	1086.33	8.27
06/23/03	31.11	1.77	1104.67	8.33
06/24/03	30.49	4.07	1097.33	8.41
06/25/03	29.88	5.60	1103.67	8.36
06/26/03	29.43	5.91	1106.00	8.41
06/27/03	29.84	8.27	1091.33	8.63
06/28/03	30.08	8.36	1092.00	8.70
06/29/03	30.01	6.01	1112.67	8.22
06/30/03	30.04	8.59	1110.67	8.57
Mean	**29.83**	**8.66**	**1044.84**	**8.70**
Median	**29.88**	**8.36**	**1051.67**	**8.70**
Max	**31.11**	**15.08**	**1112.67**	**9.18**
Min	**28.21**	**1.13**	**953.67**	**8.22**

Refer to CHART 4.3.3.6: **F1: Variation of Parameters for June**

Table 4.3.3.7: Pond M1.1

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
06/01/03	29.11	7.06	915.67	9.01
06/02/03	28.42	6.30	921.67	9.32
06/03/03	28.68	5.20	1024.33	8.86
06/04/03	28.76	8.90	992.00	9.03
06/05/03	28.66	6.30	996.67	8.89
06/06/03	29.33	13.20	975.00	9.16
06/07/03	28.63	7.71	975.00	9.01
06/08/03	29.13	12.19	972.67	9.08
06/09/03	28.93	4.21	995.00	8.70
06/10/03	29.48	5.74	991.00	8.80
06/11/03	29.83	8.63	982.00	9.07
06/12/03	29.45	6.16	996.33	8.88
06/13/03	29.40	6.22	997.33	8.83
06/14/03	28.46	8.58	1004.67	8.80
06/16/03	28.80	7.42	1021.00	8.81
06/17/03	28.52	4.95	1034.00	8.66
06/18/03	29.85	9.09	1021.00	8.97
06/19/03	29.40	8.72	1020.33	8.92
06/20/03	29.83	8.04	1043.33	8.82
06/21/03	30.35	8.62	1055.33	8.74
06/22/03	30.50	3.11	1080.33	8.48
06/23/03	30.37	5.74	1088.00	8.09
06/24/03	30.22	7.29	1076.67	8.40
06/25/03	29.57	6.75	1085.33	8.58
06/26/03	29.04	8.31	1028.00	8.34
06/27/03	29.60	6.15	1091.00	8.16
06/28/03	30.08	8.36	1092.00	8.70
06/29/03	30.01	6.01	1112.67	8.22
06/30/03	30.04	8.59	1110.67	8.57
AVE	**29.39**	**7.36**	**1024.10**	**8.76**
MEDIAN	**29.40**	**7.29**	**1021.00**	**8.81**
MAX	**30.50**	**13.20**	**1112.67**	**9.32**
MIN	**28.42**	**3.11**	**915.67**	**8.09**

Refer to CHART 4.3.3.7: **M1.1: Variation of Parameters for June**

CHART 4.3.3.7: VARIATION OF PARAMETERS FOR JUNE AT M1.1

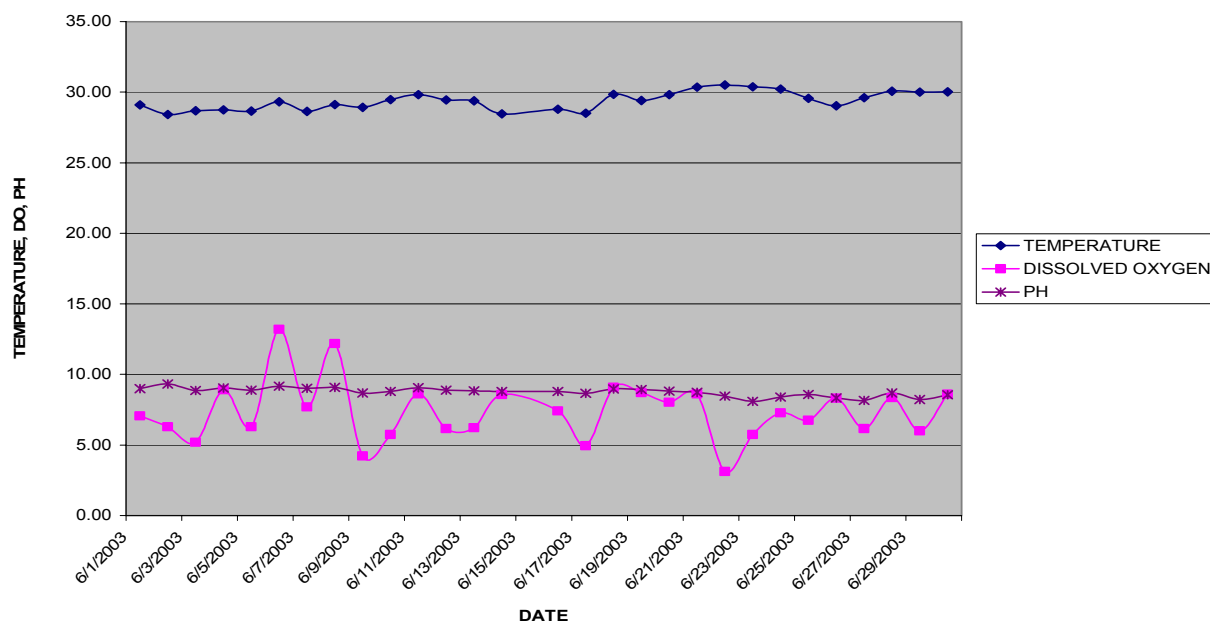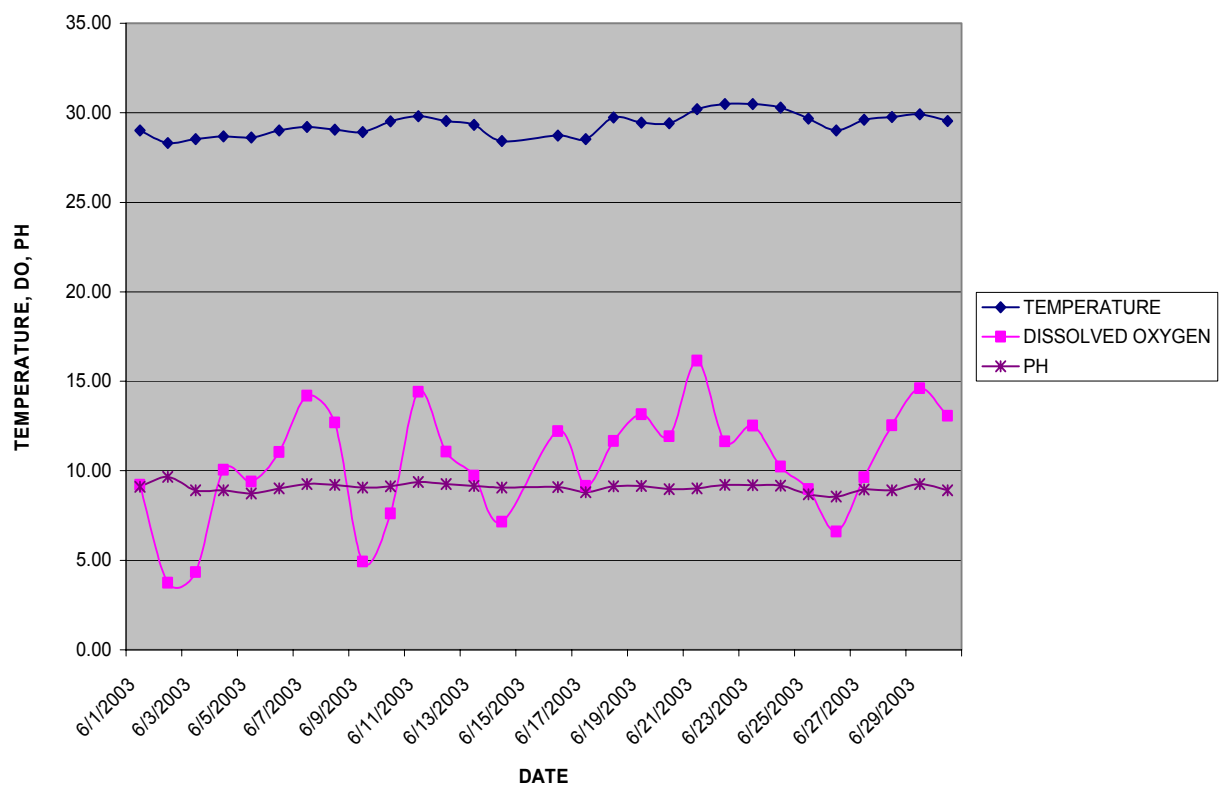**CHART 4.3.3.8: M1.2: VARIATION OF PARAMETER FOR JUNE**

Table 4.3.3.8: Pond M1.2

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
06/01/03	29.02	9.21	863.00	9.11
06/02/03	28.30	3.73	894.00	9.65
06/03/03	28.53	4.33	869.67	8.90
06/04/03	28.68	10.04	942.00	8.92
06/05/03	28.62	9.39	960.00	8.74
06/06/03	29.01	11.03	944.00	9.01
06/07/03	29.22	14.18	910.33	9.26
06/08/03	29.06	12.70	914.67	9.21
06/09/03	28.92	4.93	924.00	9.07
06/10/03	29.52	7.61	913.67	9.12
06/11/03	29.80	14.41	913.00	9.37
06/12/03	29.55	11.07	937.67	9.26
06/13/03	29.33	9.72	940.33	9.15
06/14/03	28.43	7.15	952.67	9.06
06/16/03	28.73	12.21	960.67	9.09
06/17/03	28.52	9.15	967.00	8.79
06/18/03	29.75	11.65	961.67	9.13
06/19/03	29.45	13.15	955.33	9.15
06/20/03	29.41	11.92	959.67	8.98
06/21/03	30.20	16.15	960.33	9.03
06/22/03	30.49	11.64	974.33	9.21
06/23/03	30.50	12.52	983.00	9.19
06/24/03	30.30	10.23	991.67	9.17
06/25/03	29.69	8.97	1012.33	8.68
06/26/03	29.03	6.61	1087.33	8.55
06/27/03	29.62	9.63	1035.00	8.94
06/28/03	29.77	12.54	1032.33	8.90
06/29/03	29.92	14.62	1014.33	9.27
06/30/03	29.54	13.06	1012.33	8.91
AVE	**29.34**	**10.47**	**958.15**	**9.06**
MEDIAN	**29.41**	**11.03**	**959.67**	**9.09**
MAX	**30.50**	**16.15**	**1087.33**	**9.65**
MIN	**28.30**	**3.73**	**863.00**	**8.55**

Refer to CHART 4.3.3.8: **M1.2: Variation of Parameters for June**

4.3.4   Physiochemical Parameters for July

Monitoring was only conducted for sixteen days in July because the battery in the YSI went dead. Tables 4.3.4.1 to 4.3.4.4 illustrate the variation of individual parameters across the system:

Table 4.3.4.1: Temperature

TEMPERATURE				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
07/01/03	28.87	29.83	29.87	29.54
07/02/03	28.57	29.14	29.63	31.03
07/03/03	28.85	29.39	28.76	28.55
07/04/03	28.40	28.99	28.74	30.27
07/05/03	28.30	30.72	27.82	29.61
07/06/03	28.20	29.05	28.73	29.02
07/07/03	28.16	29.29	29.26	29.11
07/08/03	28.30	29.40	29.29	29.04
07/09/03	26.77	30.39	29.62	29.35
07/10/03	28.41	28.71	28.39	28.02
07/11/03	29.08	29.39	28.92	29.10
07/12/03	28.44	30.23	29.54	29.46
07/13/03	28.40	29.93	29.22	29.92
07/14/03	28.41	30.42	29.39	29.52
07/15/03	28.74	30.73	30.39	27.29
07/16/03	28.16	29.91	29.58	29.25
AVE	**28.38**	**29.72**	**29.20**	**29.25**
MEDIAN	**28.40**	**29.61**	**29.28**	**29.30**
MAX	**29.08**	**30.73**	**30.39**	**31.03**
MIN	**26.77**	**28.71**	**27.82**	**27.29**

Refer to CHART 4.3.4.1: **July's Temperature Variation Across System**

CHART 4.3.4.1: JULY'S TEMPERATURE VARIATION ACROSS SYSTEM

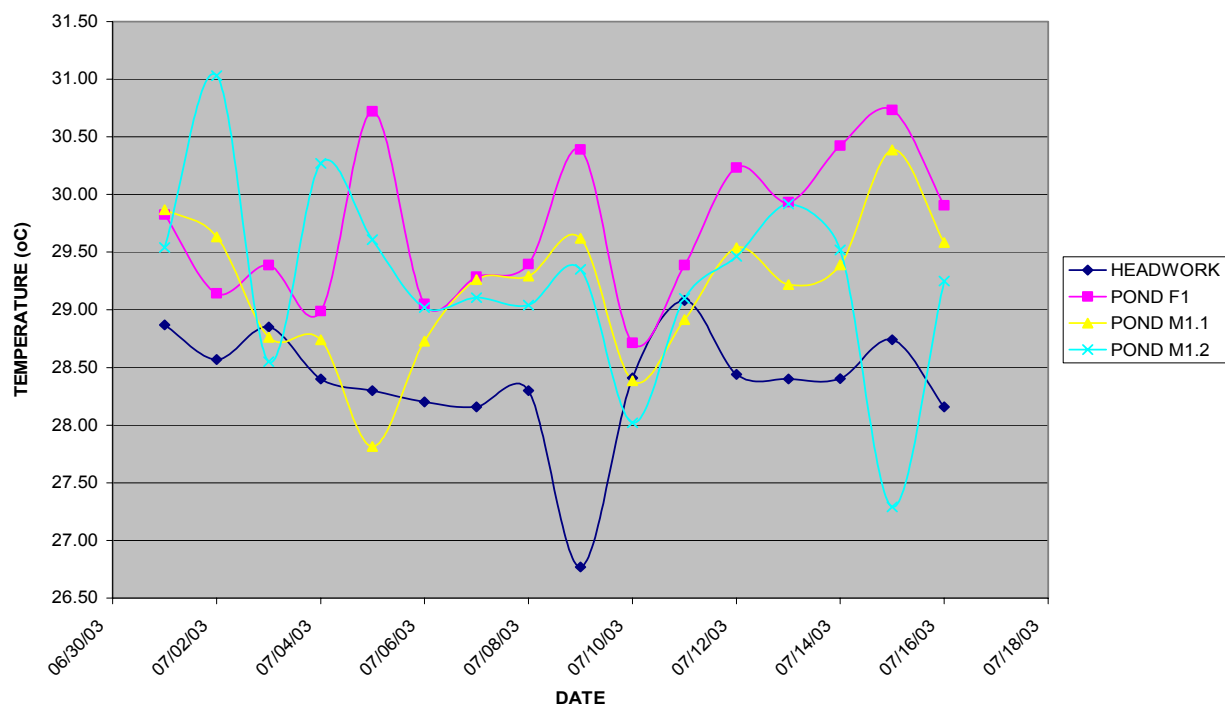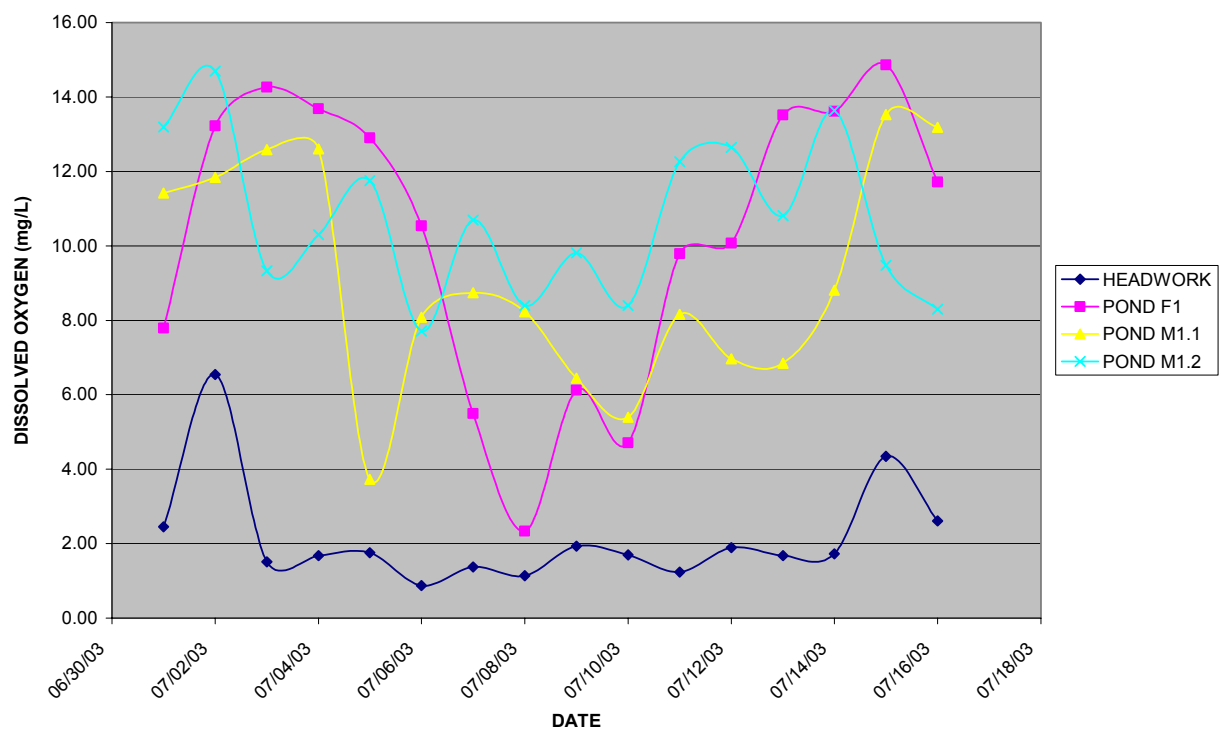**CHART 4.3.4.2: JULY'S VARIEATION OF DISSOLVED OXYGEN ACROSS SYSTEM**

Table 4.3.4.2: <u>Dissolved Oxygen</u>

DISSOLVED OXYGEN				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
07/01/03	2.45	7.79	11.42	13.19
07/02/03	6.54	13.22	11.84	14.70
07/03/03	1.51	14.26	12.59	9.33
07/04/03	1.68	13.69	12.61	10.30
07/05/03	1.76	12.90	3.72	11.75
07/06/03	0.87	10.54	8.09	7.71
07/07/03	1.37	5.49	8.74	10.69
07/08/03	1.14	2.33	8.23	8.40
07/09/03	1.93	6.12	6.45	9.81
07/10/03	1.70	4.71	5.40	8.40
07/11/03	1.24	9.79	8.16	12.27
07/12/03	1.89	10.08	6.96	12.65
07/13/03	1.68	13.52	6.85	10.81
07/14/03	1.73	13.61	8.81	13.64
07/15/03	4.35	14.86	13.53	9.48
07/16/03	2.61	11.71	13.18	8.30
AVE	**2.15**	**10.29**	**9.16**	**10.71**
MEDIAN	**1.72**	**11.13**	**8.49**	**10.50**
MAX	**6.54**	**14.86**	**13.53**	**14.70**
MIN	**0.87**	**2.33**	**3.72**	**7.71**

Refer to CHART 4.3.4.2: **July's Variation of Dissolved Oxygen Across System**
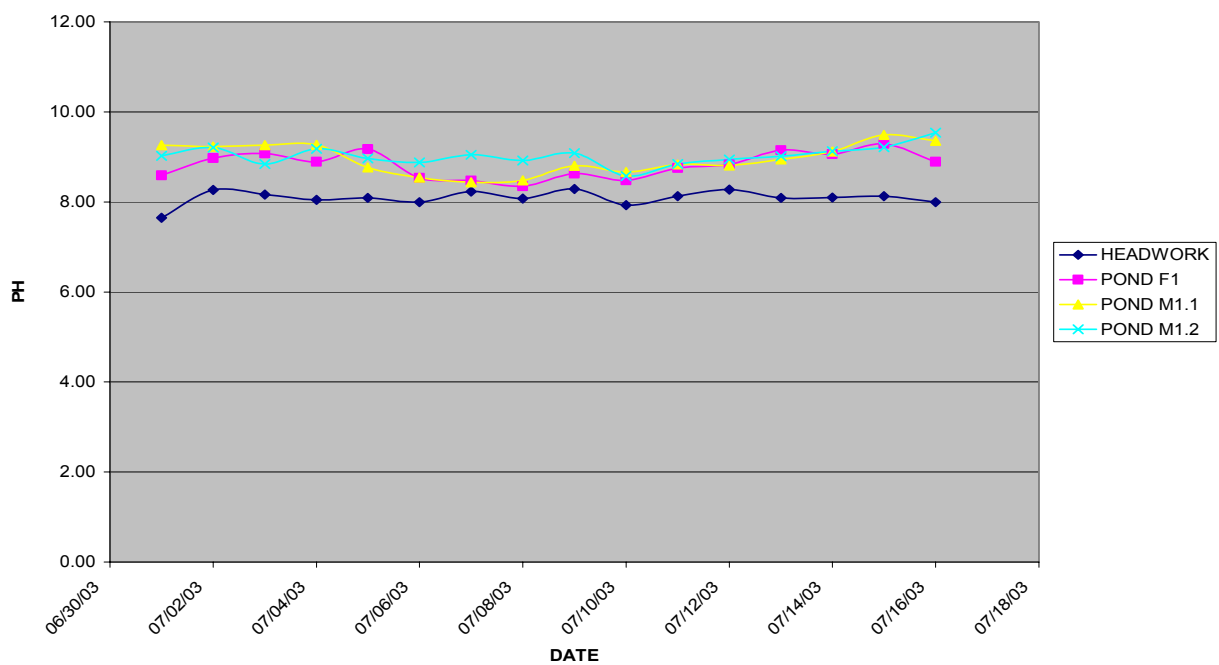
CHART 4.3.4.3: JULY'S PH VARIATION ACROOS SYSTEM

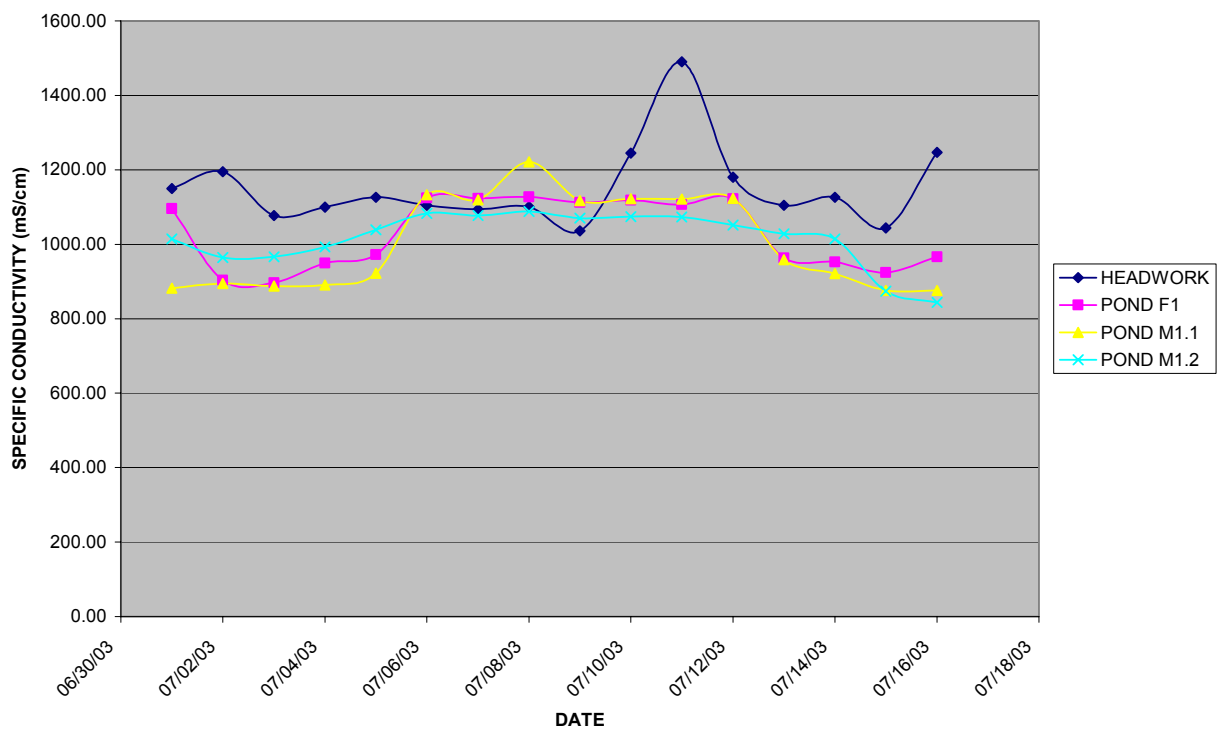**CHART 4.3.4.4: JULY'S CONDUCTIVITY VARIATION ACROSS SYSTEM**

Table 4.3.4.3: pH

DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
		pH		
07/01/03	7.65	8.59	9.26	9.03
07/02/03	8.27	8.98	9.23	9.21
07/03/03	8.17	9.08	9.26	8.84
07/04/03	8.05	8.90	9.27	9.18
07/05/03	8.09	9.17	8.77	8.97
07/06/03	8.00	8.53	8.54	8.88
07/07/03	8.23	8.48	8.44	9.05
07/08/03	8.08	8.35	8.48	8.92
07/09/03	8.29	8.63	8.80	9.08
07/10/03	7.93	8.49	8.67	8.58
07/11/03	8.13	8.76	8.83	8.84
07/12/03	8.28	8.83	8.82	8.95
07/13/03	8.09	9.15	8.95	9.02
07/14/03	8.10	9.07	9.12	9.13
07/15/03	8.13	9.29	9.49	9.22
07/16/03	8.00	8.89	9.36	9.54
AVE	**8.09**	**8.82**	**8.96**	**9.03**
MEDIAN	**8.09**	**8.86**	**8.89**	**9.03**
MAX	**8.29**	**9.29**	**9.49**	**9.54**
MIN	**7.65**	**8.35**	**8.44**	**8.58**

Refer to CHART 4.3.4.3: **July's pH Variation Across System**

Table 4.3.4.4: <u>Specific Conductivity</u>

SPECIFIC CONDUCTIVITY				
DATE	HEADWORKS	POND F1	POND M1.1	POND M1.2
07/01/03	1150.00	1095.67	882.33	1014.00
07/02/03	1195.00	903.67	894.33	964.00
07/03/03	1077.00	896.33	887.33	966.00
07/04/03	1100.00	949.67	890.67	993.00
07/05/03	1126.00	972.00	922.00	1039.00
07/06/03	1105.00	1124.33	1132.67	1082.67
07/07/03	1094.00	1123.33	1119.33	1077.33
07/08/03	1101.00	1127.33	1221.00	1088.00
07/09/03	1036.00	1112.67	1117.67	1070.67
07/10/03	1245.00	1118.33	1122.00	1074.67
07/11/03	1490.00	1106.33	1121.67	1073.67
07/12/03	1180.00	1122.67	1123.33	1051.67
07/13/03	1105.00	963.67	958.33	1028.00
07/14/03	1126.00	952.67	921.33	1014.00
07/15/03	1044.00	924.00	876.33	874.00
07/16/03	1247.00	966.67	875.67	844.00
AVE	**1151.31**	**1028.71**	**1004.12**	**1015.92**
MEDIAN	**1115.50**	**1033.83**	**940.17**	**1033.50**
MAX	**1490.00**	**1127.33**	**1221.00**	**1088.00**
MIN	**1036.00**	**896.33**	**875.67**	**844.00**

Refer to CHART 4.3.4.4**: July's Conductivity Variation Across System**

Table 4.3.4.5: Headwork

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
07/01/03	28.87	2.45	1150.00	7.65
07/02/03	28.57	6.54	1195.00	8.27
07/03/03	28.85	1.51	1077.00	8.17
07/04/03	28.40	1.68	1100.00	8.05
07/05/03	28.30	1.76	1126.00	8.09
07/06/03	28.20	0.87	1105.00	8.00
07/07/03	28.16	1.37	1094.00	8.23
07/08/03	28.30	1.14	1101.00	8.08
07/09/03	26.77	1.93	1036.00	8.29
07/10/03	28.41	1.70	1245.00	7.93
07/11/03	29.08	1.24	1490.00	8.13
07/12/03	28.44	1.89	1180.00	8.28
07/13/03	28.40	1.68	1105.00	8.09
07/14/03	28.41	1.73	1126.00	8.10
07/15/03	28.74	4.35	1044.00	8.13
07/16/03	28.16	2.61	1247.00	8.00
AVE	28.38	2.15	1151.31	8.09
MEDIAN	28.40	1.72	1115.50	8.09
MAX	29.08	6.54	1490.00	8.29
MIN	26.77	0.87	1036.00	7.65

Refer to CHART 4.3.4.5: **Headwork: Variation of Parameters for July**

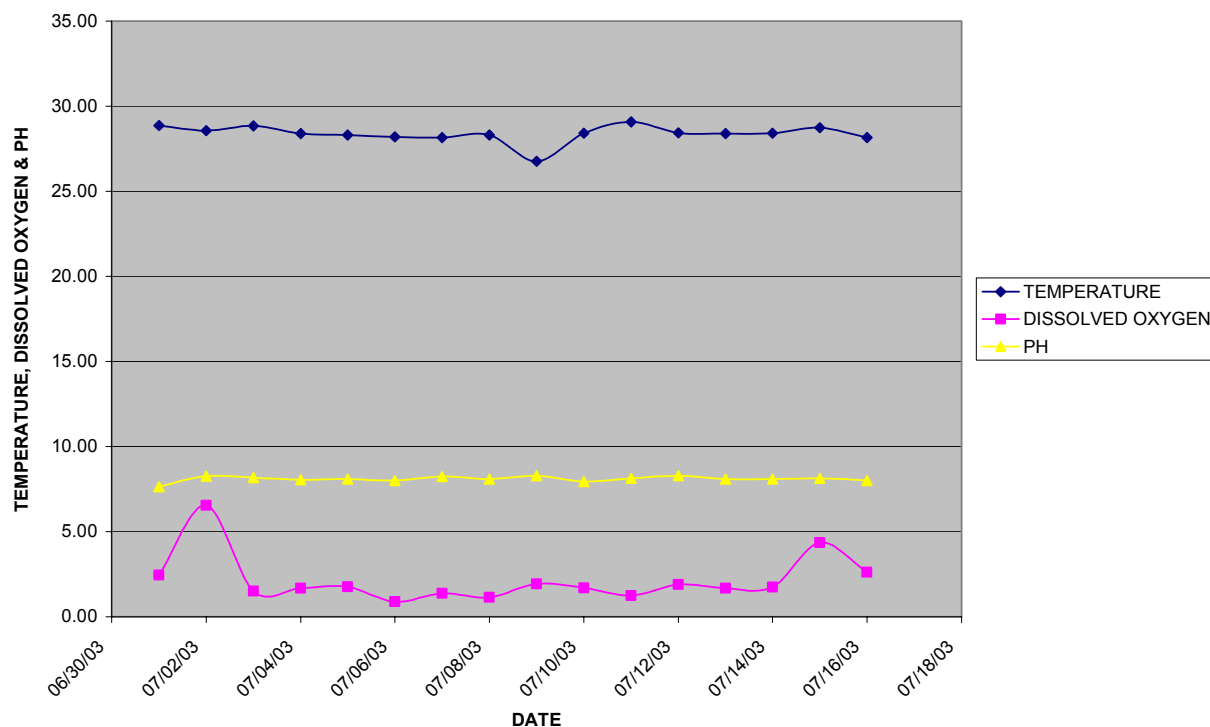**CHART 4.3.4.5: HEADWORK: VARIATION OF PARAMETERS FOR JUNE**
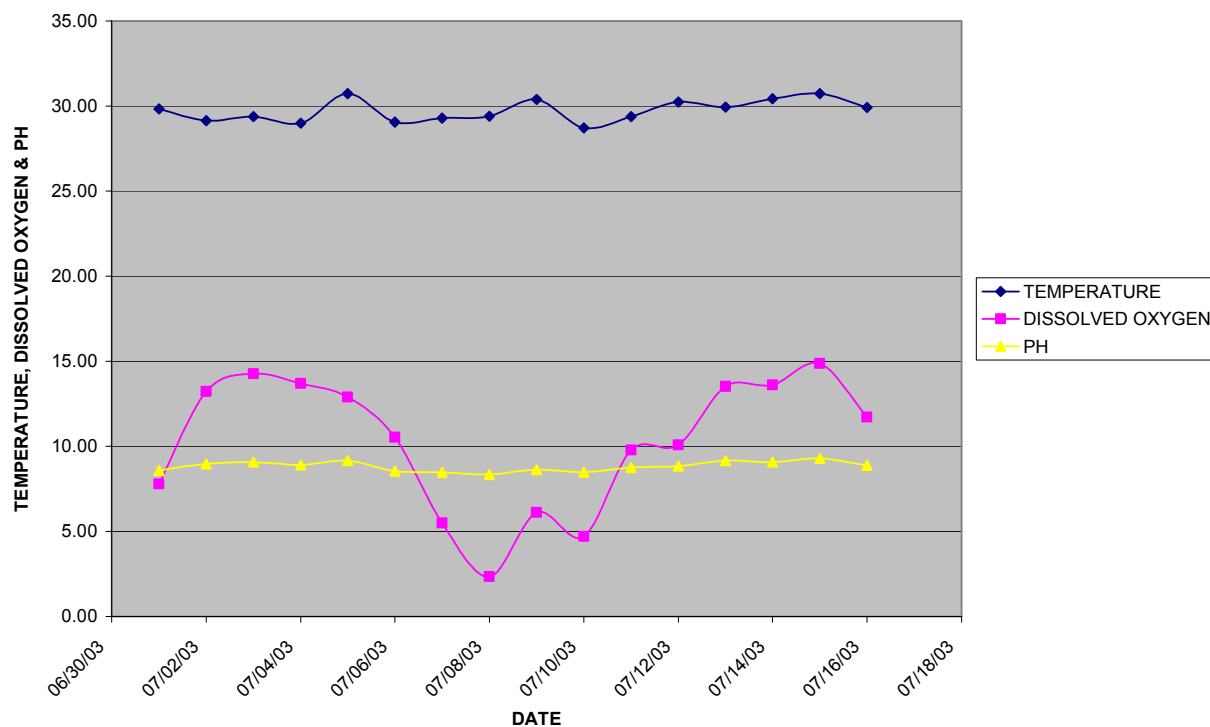

CHART 4.3.4.6: F1: VARIATION OF PARAMETERS FOR JULY

Table 4.3.4.6: <u>Pond F1</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
07/01/03	29.83	7.79	1095.67	8.59
07/02/03	29.14	13.22	903.67	8.98
07/03/03	29.39	14.26	896.33	9.08
07/04/03	28.99	13.69	949.67	8.90
07/05/03	30.72	12.90	972.00	9.17
07/06/03	29.05	10.54	1124.33	8.53
07/07/03	29.29	5.49	1123.33	8.48
07/08/03	29.40	2.33	1127.33	8.35
07/09/03	30.39	6.12	1112.67	8.63
07/10/03	28.71	4.71	1118.33	8.49
07/11/03	29.39	9.79	1106.33	8.76
07/12/03	30.23	10.08	1122.67	8.83
07/13/03	29.93	13.52	963.67	9.15
07/14/03	30.42	13.61	952.67	9.07
07/15/03	30.73	14.86	924.00	9.29
07/16/03	29.91	11.71	966.67	8.89
AVE	29.72	10.29	1028.71	8.82
MEDIAN	29.61	11.13	1033.83	8.86
MAX	30.73	14.86	1127.33	9.29
MIN	28.71	2.33	896.33	8.35

Refer to CHART 4.3.4.6: **F1: Variation of Parameters for July**

Table 4.3.4.7: <u>Pond M1.1</u>

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
07/01/03	29.87	11.42	882.33	9.26
07/02/03	29.63	11.84	894.33	9.23
07/03/03	28.76	12.59	887.33	9.26
07/04/03	28.74	12.61	890.67	9.27
07/05/03	27.82	3.72	922.00	8.77
07/06/03	28.73	8.09	1132.67	8.54
07/07/03	29.26	8.74	1119.33	8.44
07/08/03	29.29	8.23	1221.00	8.48
07/09/03	29.62	6.45	1117.67	8.80
07/10/03	28.39	5.40	1122.00	8.67
07/11/03	28.92	8.16	1121.67	8.83
07/12/03	29.54	6.96	1123.33	8.82
07/13/03	29.22	6.85	958.33	8.95
07/14/03	29.39	8.81	921.33	9.12
07/15/03	30.39	13.53	876.33	9.49
07/16/03	29.58	13.18	875.67	9.36
AVE	**29.20**	**9.16**	**1004.12**	**8.96**
MEDIAN	**29.28**	**8.49**	**940.17**	**8.89**
MAX	**30.39**	**13.53**	**1221.00**	**9.49**
MIN	**27.82**	**3.72**	**875.67**	**8.44**

Refer to CHART 4.3.4.7: **M1.1: Variation of Parameters for July**
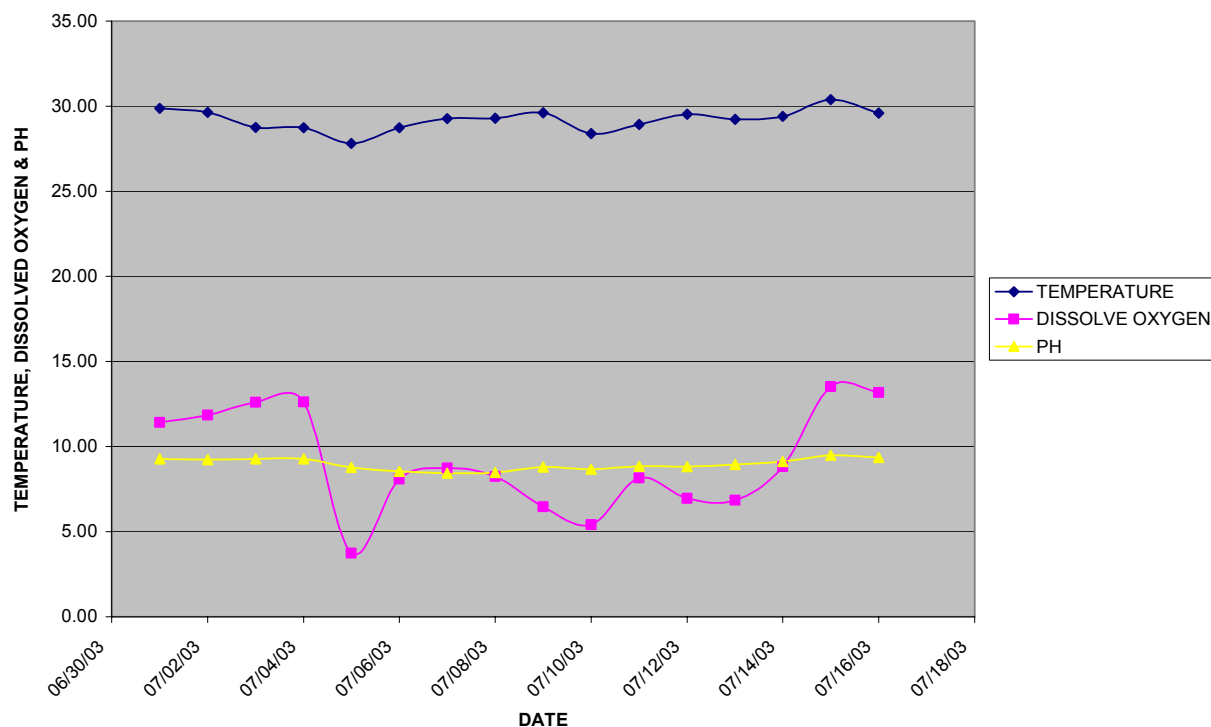
CHART 4.3.4.7: M1.1: VARIATION OF PARAMETER FOR JULY
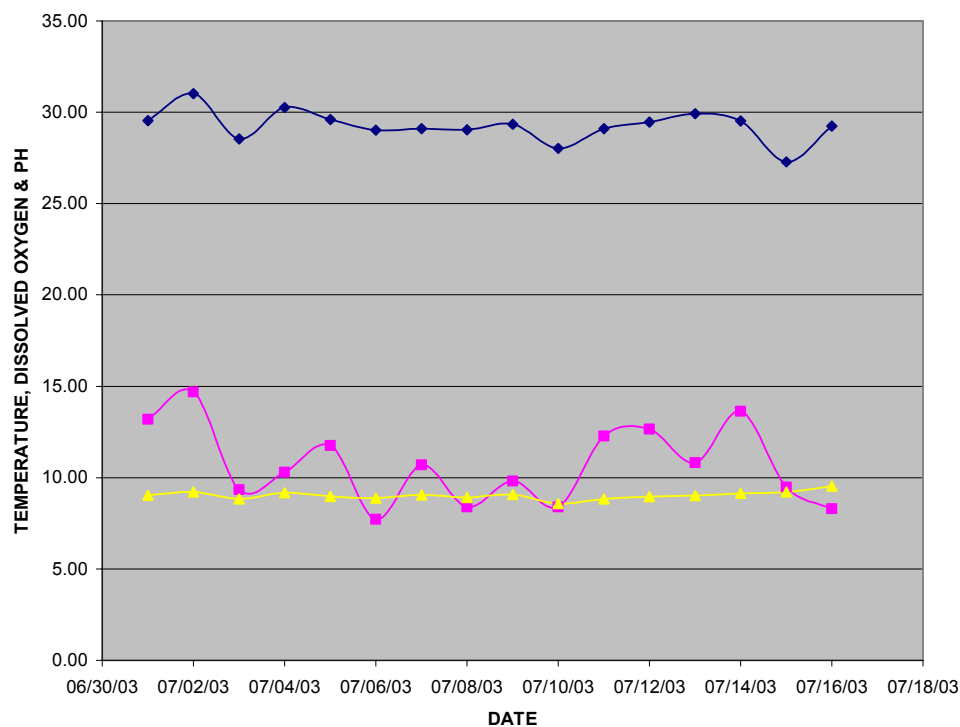

CHART 4.3.4.8: M1.2: VARIATION OF PARAMETER FOR JULY

Table 4.3.4.8: Pond M1.2

DATE	TEMPERATURE	DISSOLVED OXYGEN	S/CONDUCTIVITY	pH
07/01/03	29.54	13.19	1014.00	9.03
07/02/03	31.03	14.70	964.00	9.21
07/03/03	28.55	9.33	966.00	8.84
07/04/03	30.27	10.30	993.00	9.18
07/05/03	29.61	11.75	1039.00	8.97
07/06/03	29.02	7.71	1082.67	8.88
07/07/03	29.11	10.69	1077.33	9.05
07/08/03	29.04	8.40	1088.00	8.92
07/09/03	29.35	9.81	1070.67	9.08
07/10/03	28.02	8.40	1074.67	8.58
07/11/03	29.10	12.27	1073.67	8.84
07/12/03	29.46	12.65	1051.67	8.95
07/13/03	29.92	10.81	1028.00	9.02
07/14/03	29.52	13.64	1014.00	9.13
07/15/03	27.29	9.48	874.00	9.22
07/16/03	29.25	8.30	844.00	9.54
AVE	**29.25**	**10.71**	**1015.92**	**9.03**
MEDIAN	**29.30**	**10.50**	**1033.50**	**9.03**
MAX	**31.03**	**14.70**	**1088.00**	**9.54**
MIN	**27.29**	**7.71**	**844.00**	**8.58**

Refer to CHART 4.3.4.8: **M1.2: Variation of Parameters for July**

4.3.5   Summary of Results

Table 4.3.5.1: Simple Statistic of Physiochemical Parameters Across System

Parameter	Average	Standard Deviation	Median	Minimum	Maximum
Temperature	29.20	0.89	29.77	26.77	31.73
Dissolved Oxygen	8.03	4.68	8.40	0.41	16.15
S/Conductivity	998	119.5	983	700	1610
pH	8.76	0.60	8.86	7.08	10.19

Temperature showed little variation when compared to the other parameters, as seen from the standard deviation and averaged at about 29°C. The general trend is an increase in temperature from the Headwork to Pond F1 and then a decrease thereafter. F1 consistently showed the highest temperature in the system. The possible reason for this is the fact that it is at a higher elevation than the other ponds. This is further confirmed by the fact that the temperatures for M1.1 and M1.2, which are at the same elevation, hardly differed.

DO is highly variable, as can be seen from the standard deviation (more than one half the average) and the DO charts. Dissolved oxygen is lowest at the Headwork, highest in F1, decreases and then increases in Ponds M1.1 and M1.2 respectively. Dissolved oxygen is highly temperature dependent and normally shows an inverse relationship with temperature. The very low dissolve oxygen at the Headwork is within normal expectations as explained in Section 4.2.1 above.

pH values showed very little variation at the individual sampling points and over the String in general. As expected the Headwork had the lowest pH values. pH tended to increase as the water traveled across the ponds, with M1.2 showing the highest average pH. pH is a function of algal and bacterial activity. That is, the algae photosynthetic and bacterial activities use up or produce carbonate and bicarbonate ions resulting in variation of pH across the String.

The specific conductivity is highest at the Headwork and decreases as the water moved from Headwork to the final effluent, with M1.2 showing the lowest Conductivity. This as a result of the removal of ions and other solutes, such as organic matter, nutrients and inorganic ions from the water as it passes through the system.

4.3.6   Correlation Analysis of Physiochemical Parameters

Correlation analysis was conducted on all the depth averaged values for the four parameters collected at the four sampling points. The total number of points is 340, hence the central limit theory can be applied to the interpretation of the result and therefore the distribution of the sample mean is approximately normal. Correlation is a common statistic indicating the strength of a linear relationship that exists between two continuous variables. The two correlation procedures used in the analysis are Pearson's Correlation Coefficient and Spearman's Rank Correlation (Bhattacharyya and Johnson, 1977; Cody and Smith, 1997). Both methods are similar, however Spearman replaces the observations with their ranks, thus outliers are disregarded and the association between the variables need not be linear (Bhattacharyya and Johnson, 1977).

Table 4.3.6.1: Pearson Correlation Coefficients (p-value = 0.0001), N = 340

	Temperature	Dissolved Oxygen	S/Conductivity	pH
Temperature	1.00	0.65	-0.29	0.56
Dissolved Oxygen	0.65	1.00	-0.61	0.82
S/ Conductivity	-0.29	-0.61	1.00	-0.75
pH	0.56	0.82	-0.75	1.00

Table 4.3.6.2: Spearman Correlation Coefficients (p-value = 0.0001), N = 340

	Temperature	Dissolved Oxygen	S/Conductivity	pH
Temperature	1.00	0.66	-0.29	0.56
Dissolved Oxygen	0.66	1.00	-0.63	0.84
S/ Conductivity	-0.29	-0.63	1.00	-0.81
pH	0.56	0.84	0.81	1.00

Both methods had similar results, with Spearman showing small increases in both negative and positive correlations. From the analysis, there is a relatively strong positive correlation between Temperature and DO ($r^2 = 0.66$), pH and DO ($r^2 = 0.84$), and between Temperature and pH ($r^2 = 0.56$). Hence an increase in one parameter produces a subsequent increase in the other. Strong negative correlations were observed between pH and Conductivity ($r^2 = -0.81$) and DO and Conductivity ($r^2 = -0.63$), with a relatively small negative correlation between Conductivity and Temperature ($r^2 = -0.29$). An increase in Temperature produces a corresponding increase in algal photosynthetic activities, which increase the DO concentration,

resulting in an increase in pH. Thus, this explains the observed positive correlations between Temperature and DO, DO and pH and hence, Temperature and pH.

Strong negative correlations between pH and Conductivity and DO and Conductivity indicate that when one parameter increases the other subsequently decreases, these results are expected. However, one would expect that the relationship between Temperature and Conductivity would be positive and strongly correlated; instead a weak negative correlation is seen here. Plates 4.1 to 4.30 illustrate the correlation plots for the physiochemical parameters.
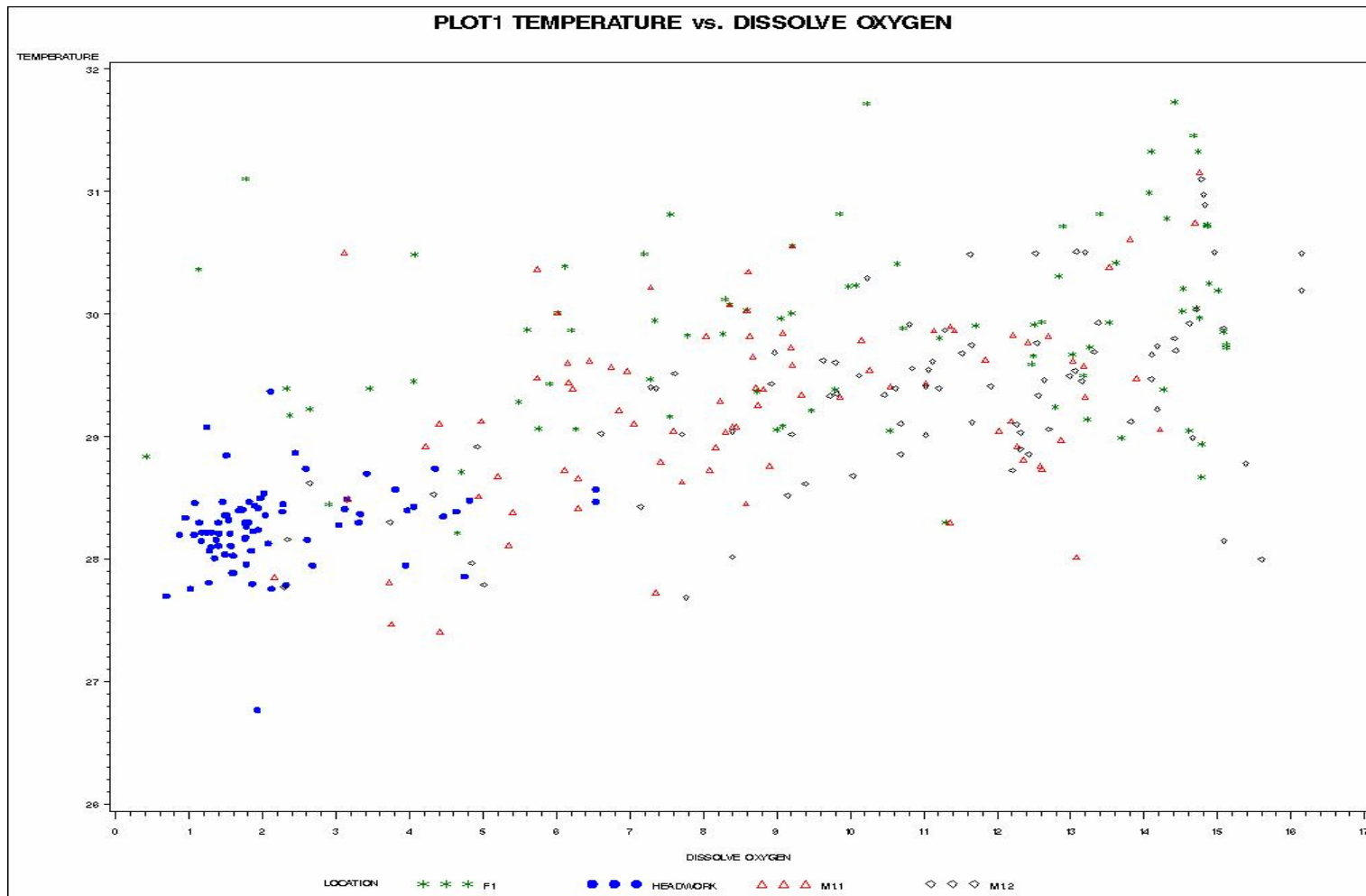
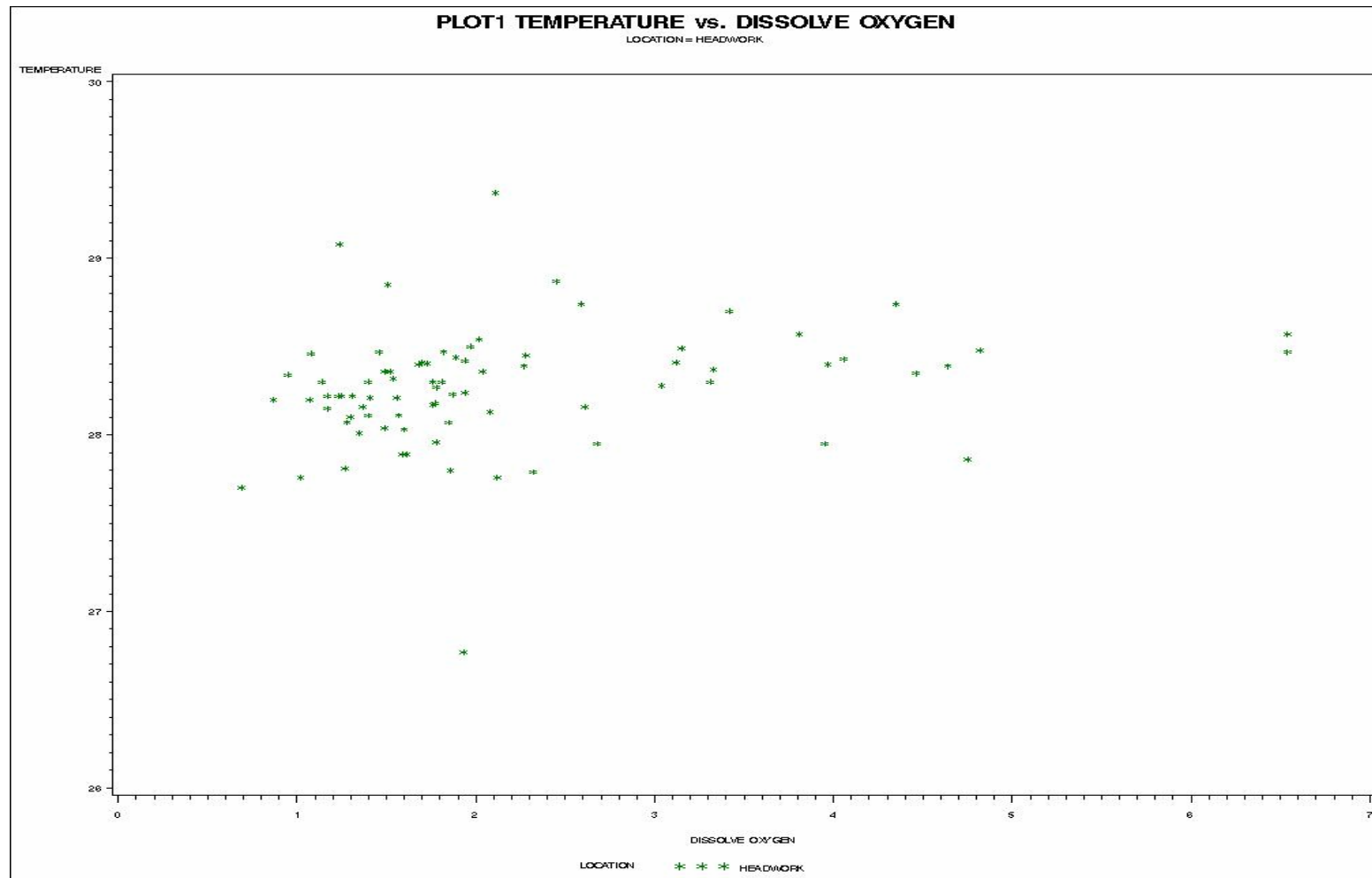**Plate 4.1: Correlation Plot for Temperature vs. Dissolved Oxygen for all Locations**

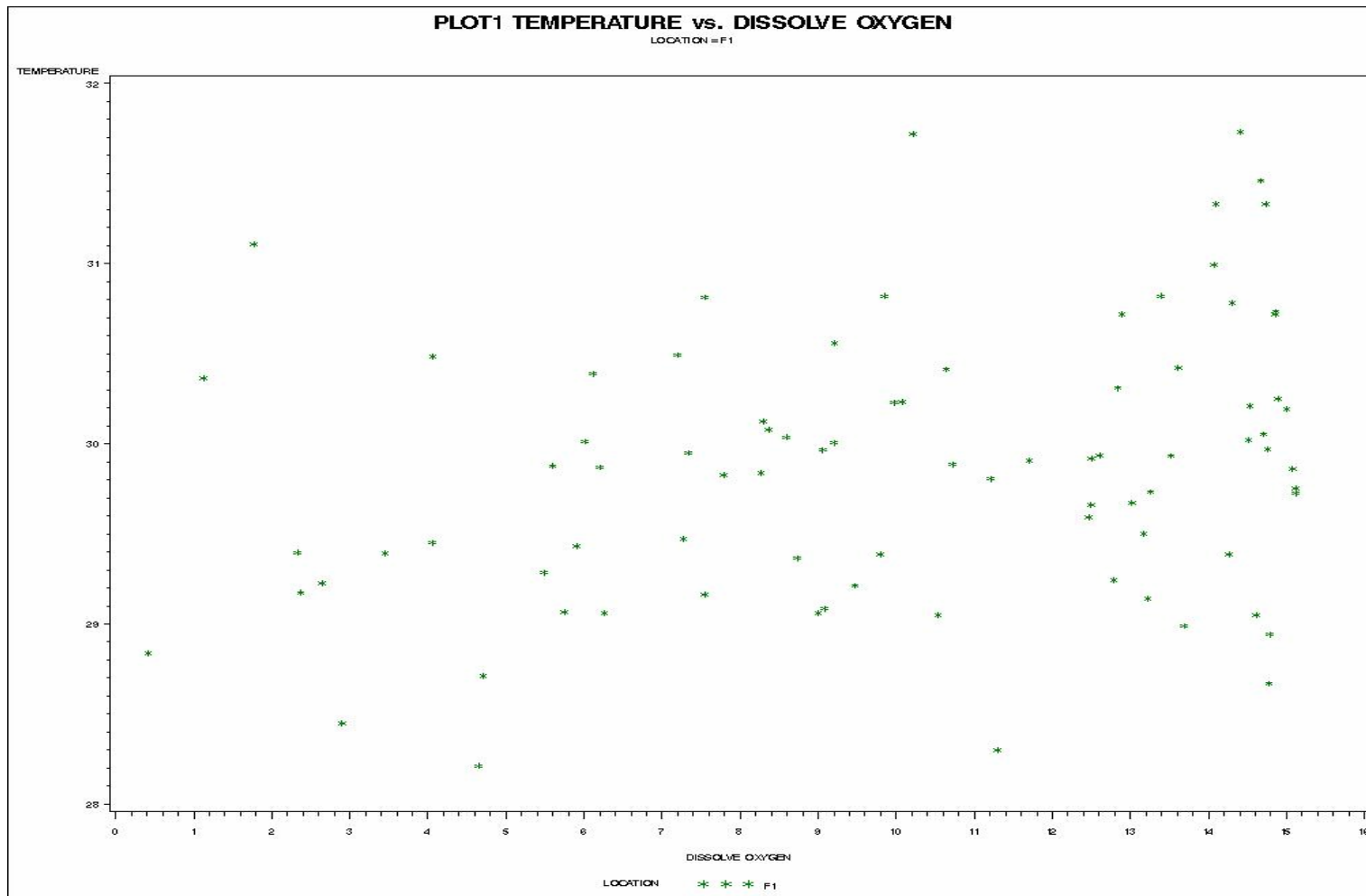**Plate 4.2: Correlation Plot for Temperature vs. Dissolved Oxygen for Headworks**

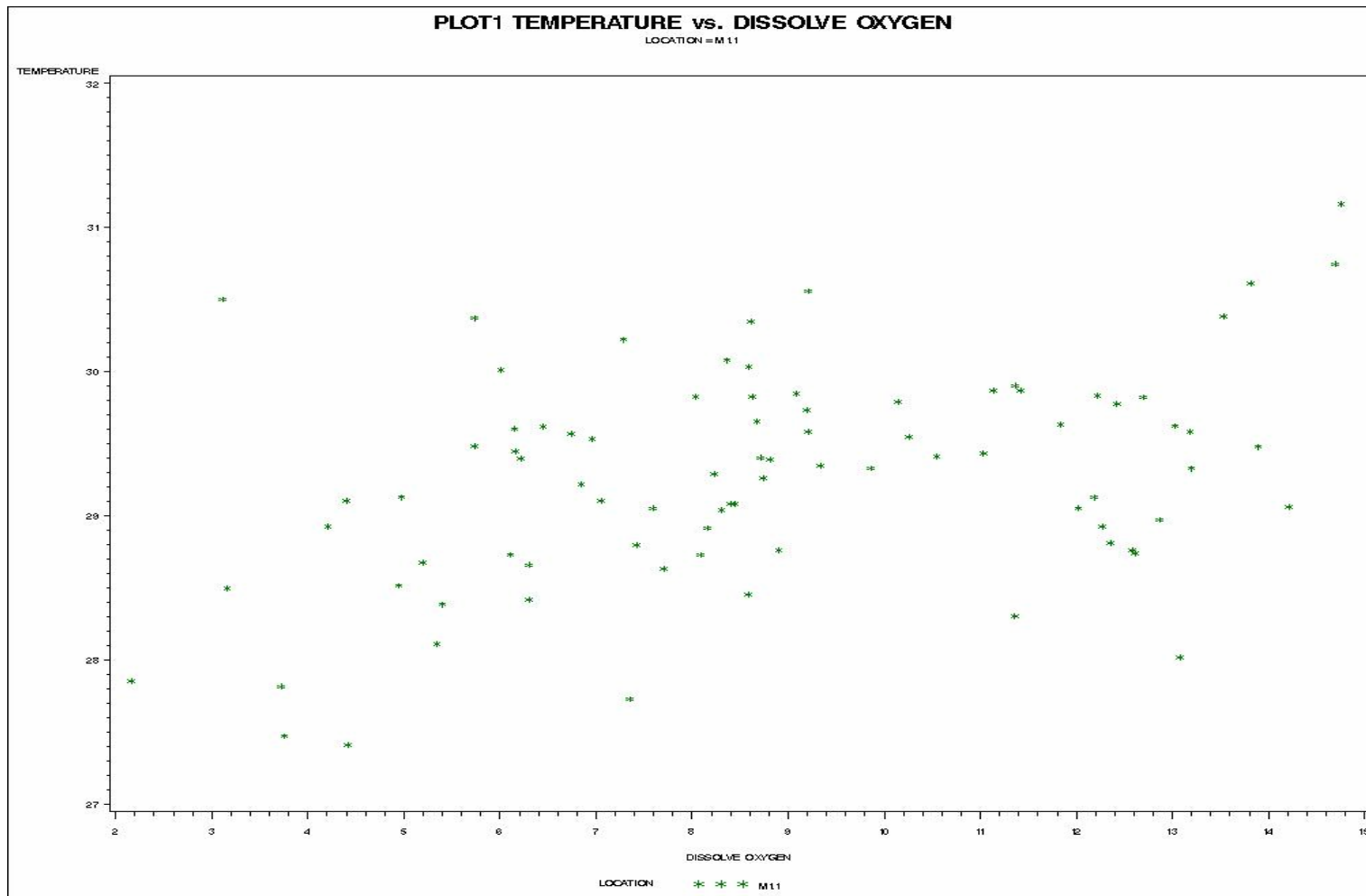**Plate 4.3: Correlation Plot for Temperature vs. Dissolved Oxygen for F1**

Plate 4.4: Correlation Plot for Temperature vs. Dissolved Oxygen for M1.1
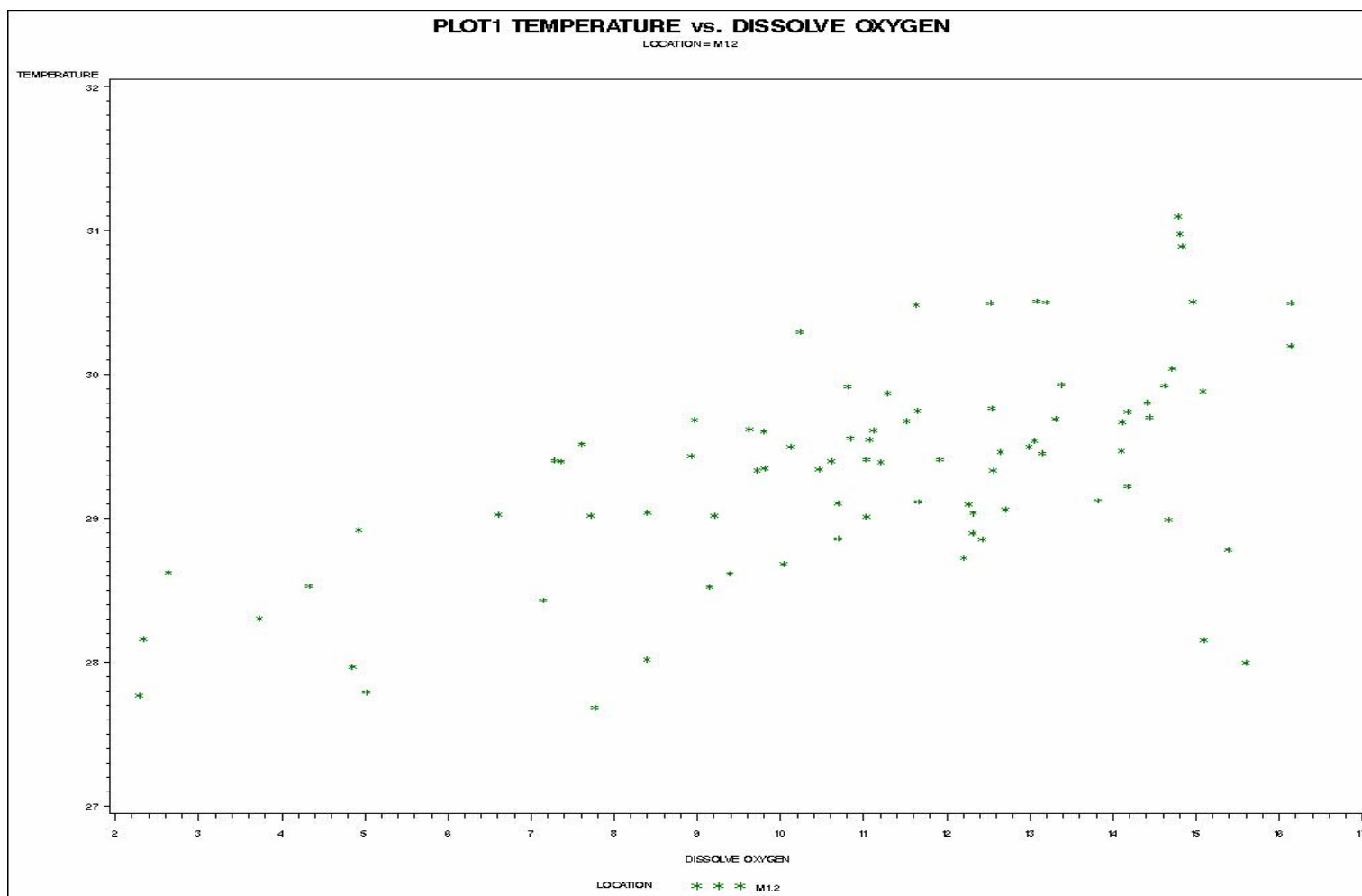
Plate 4.5: Correlation Plot for Temperature vs. Dissolved Oxygen for M1.2
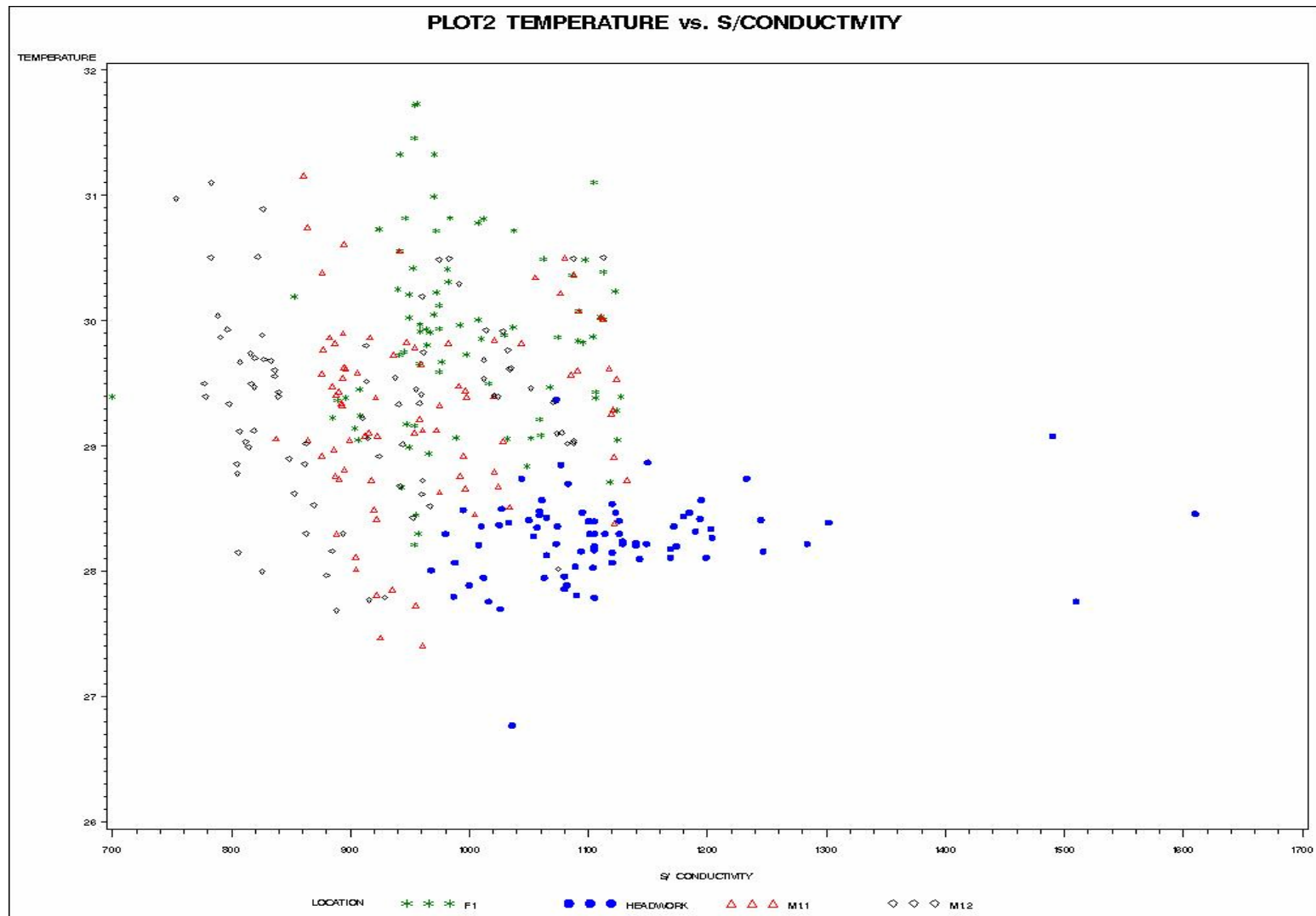
Plate 4.6: Correlation Plot for Temperature vs. Conductivity for All Locations

Plate 4.7: Correlation Plot for Temperature vs. Conductivity for Headworks
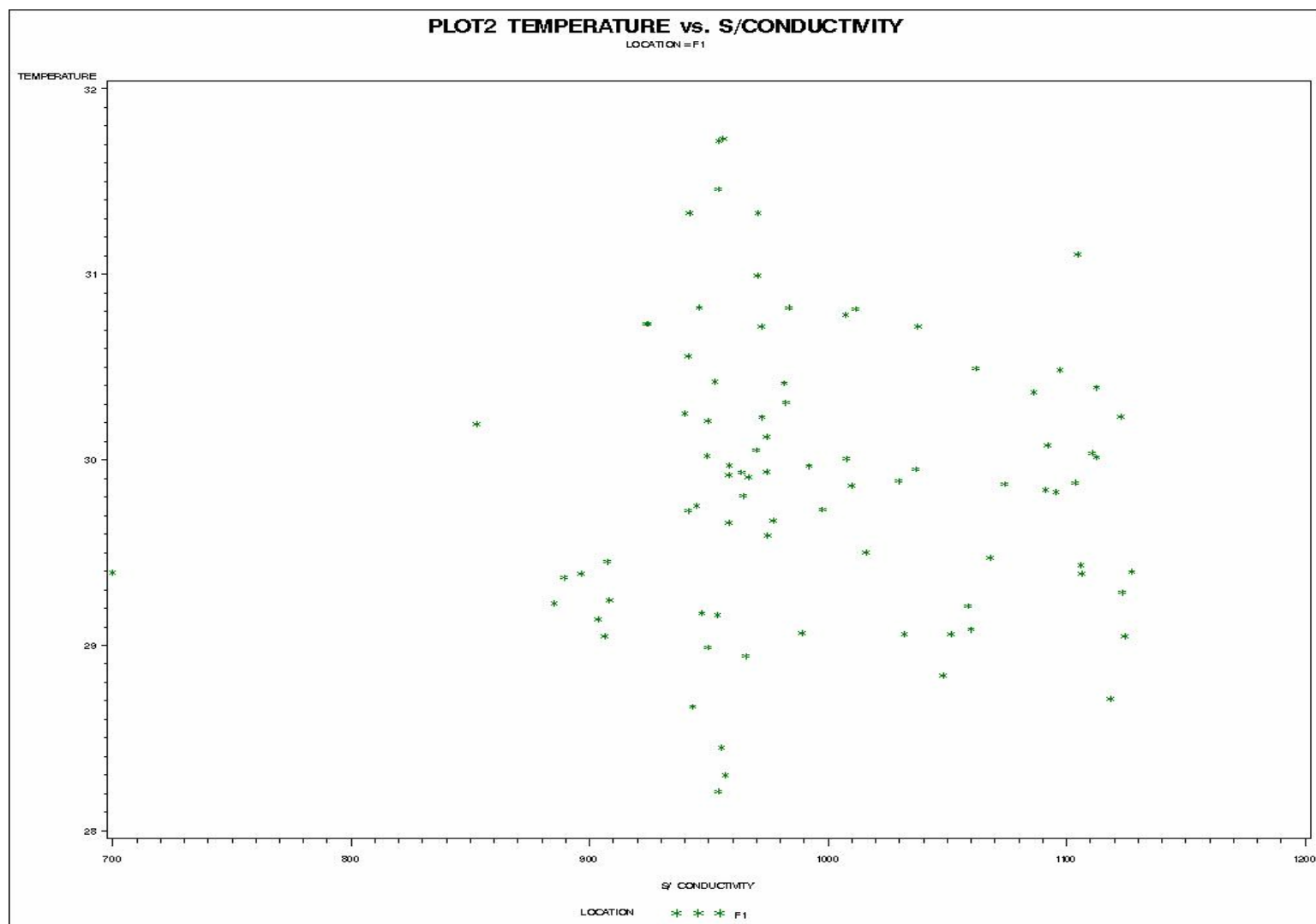
Plate 4.8: Correlation Plot for Temperature vs. Conductivity for F1
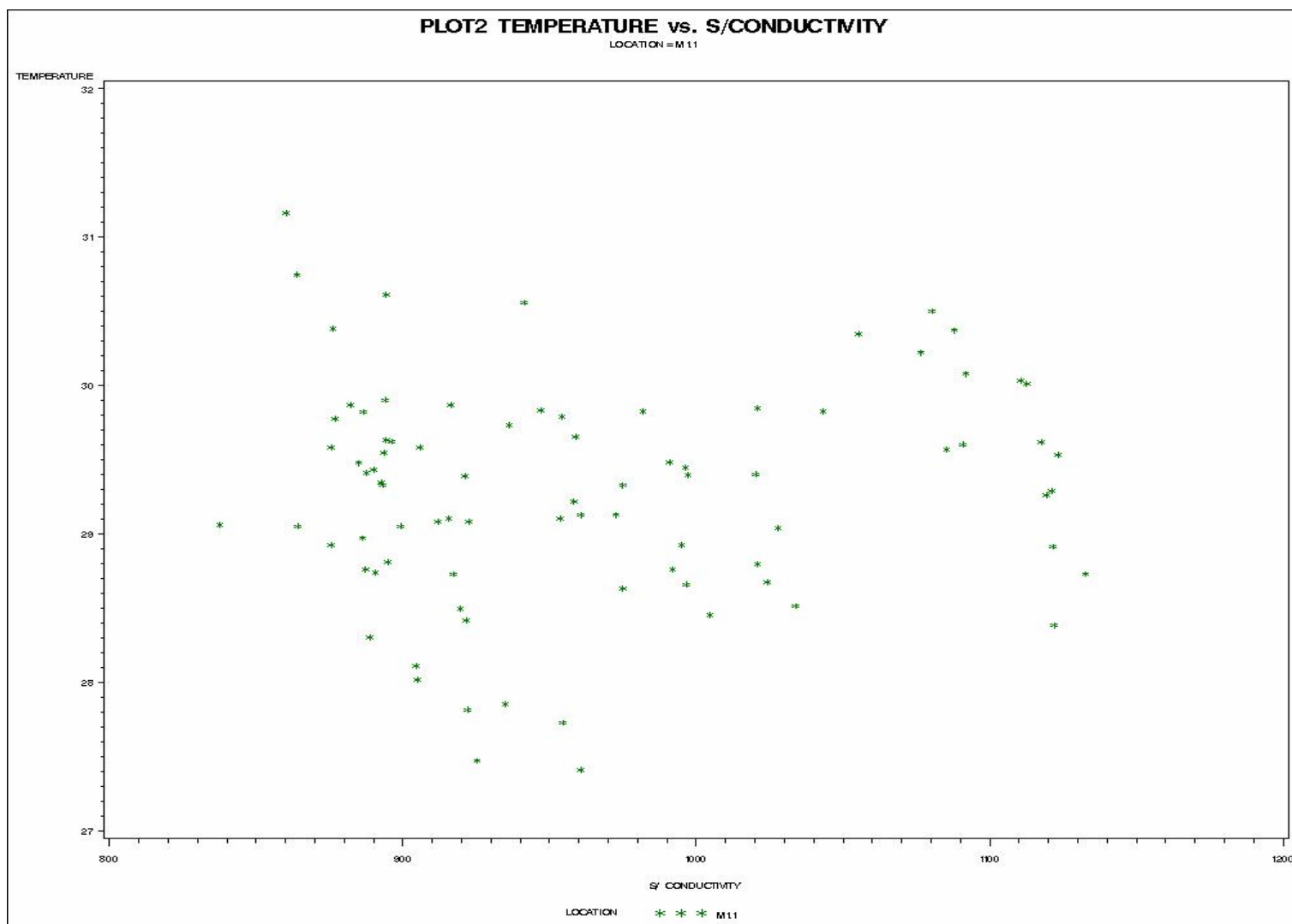
Plate 4.9: Correlation Plot for Temperature vs. Conductivity for M1.1
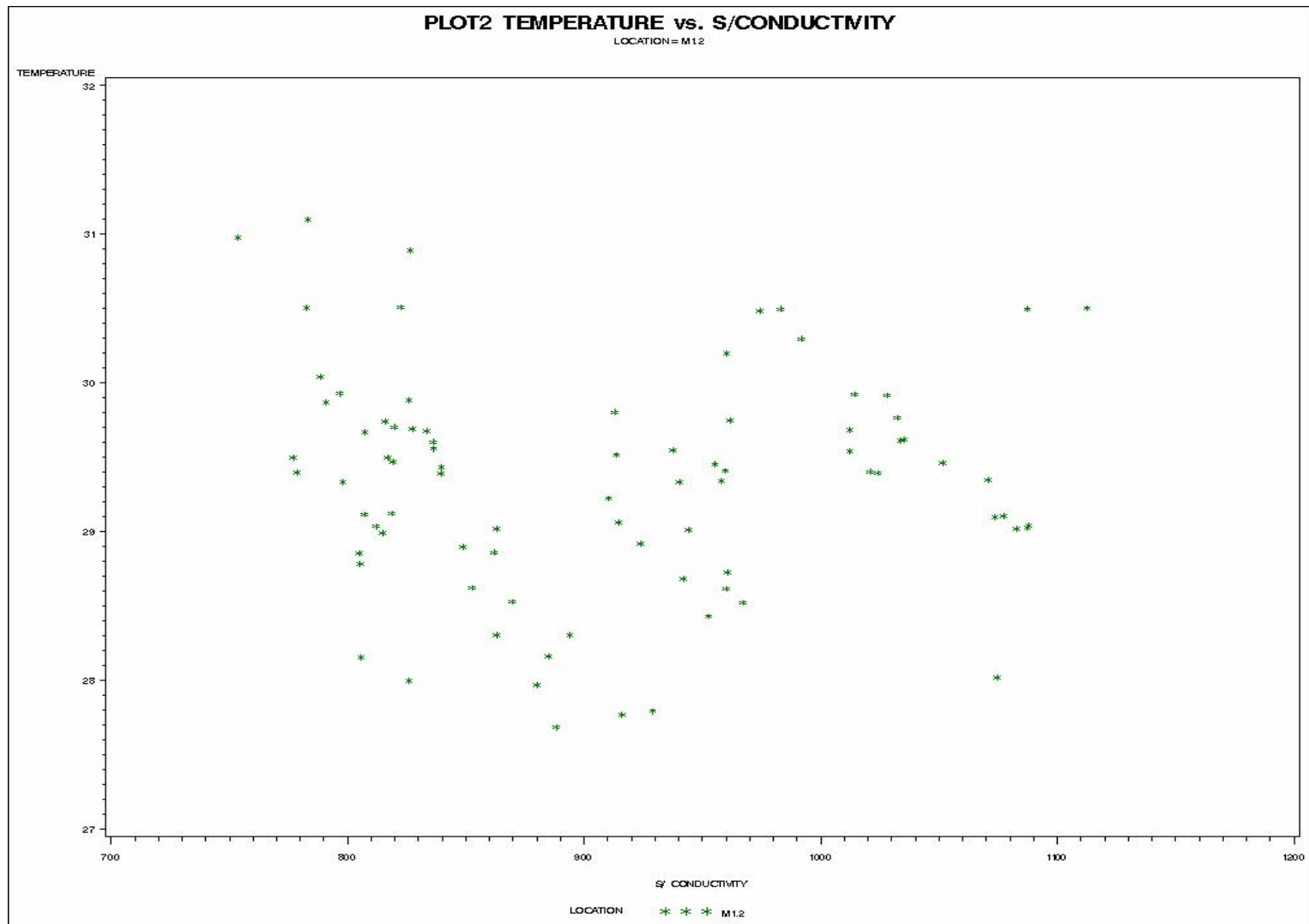
Plate 4.10: Correlation Plot for Temperature vs. Conductivity for M1.2

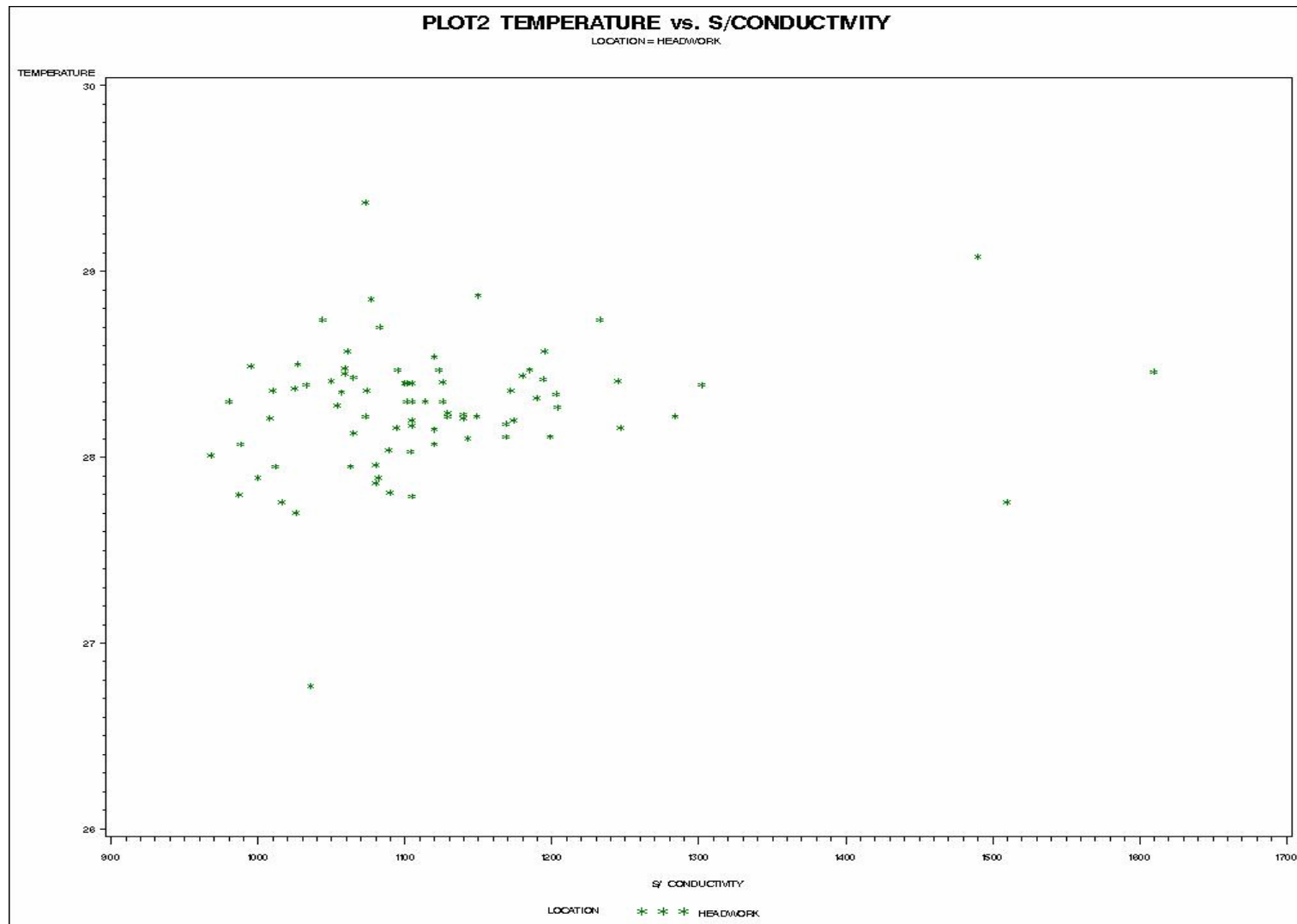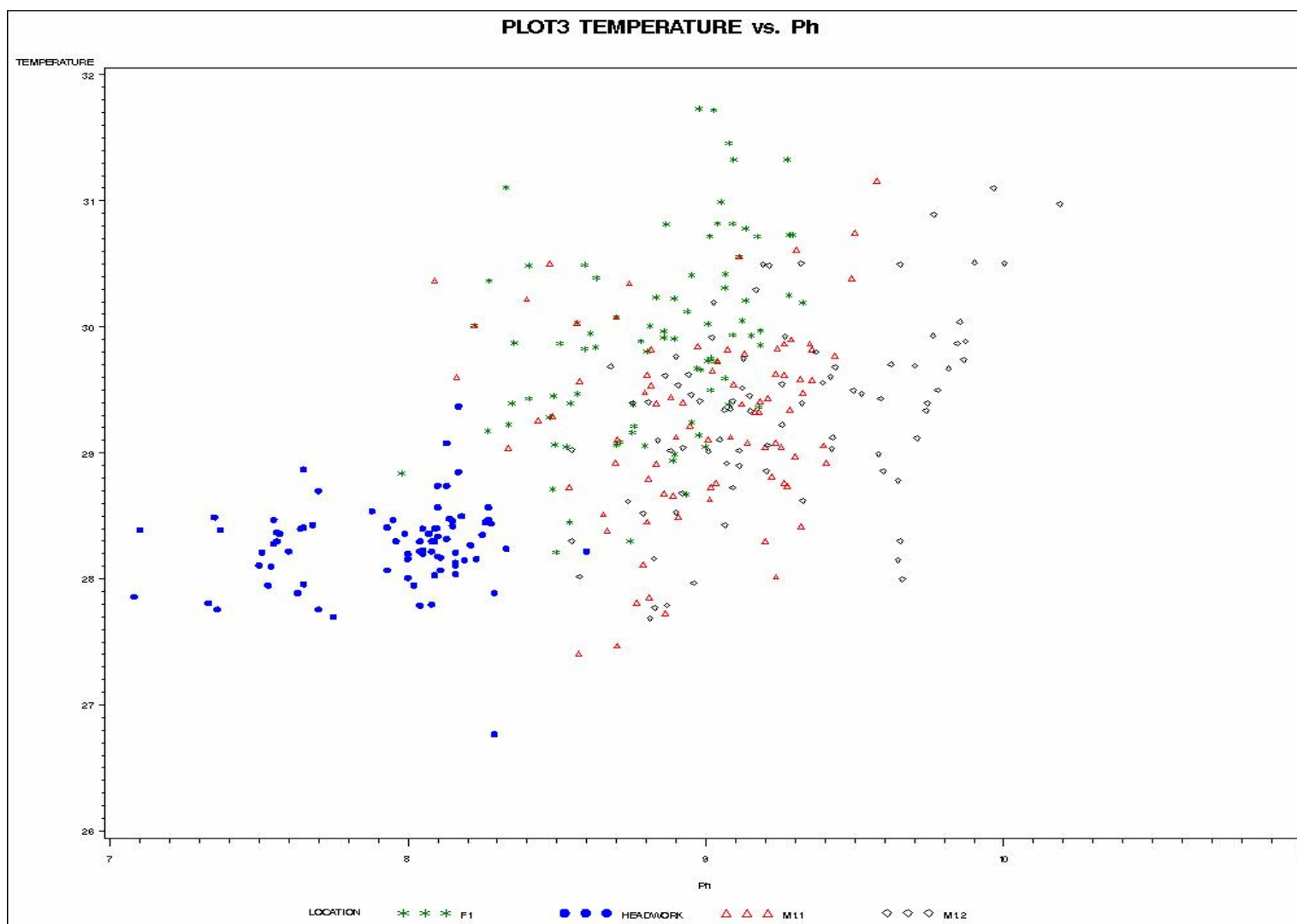**Plate 4.11: Correlation Plot for Temperature vs. pH for all Locations**
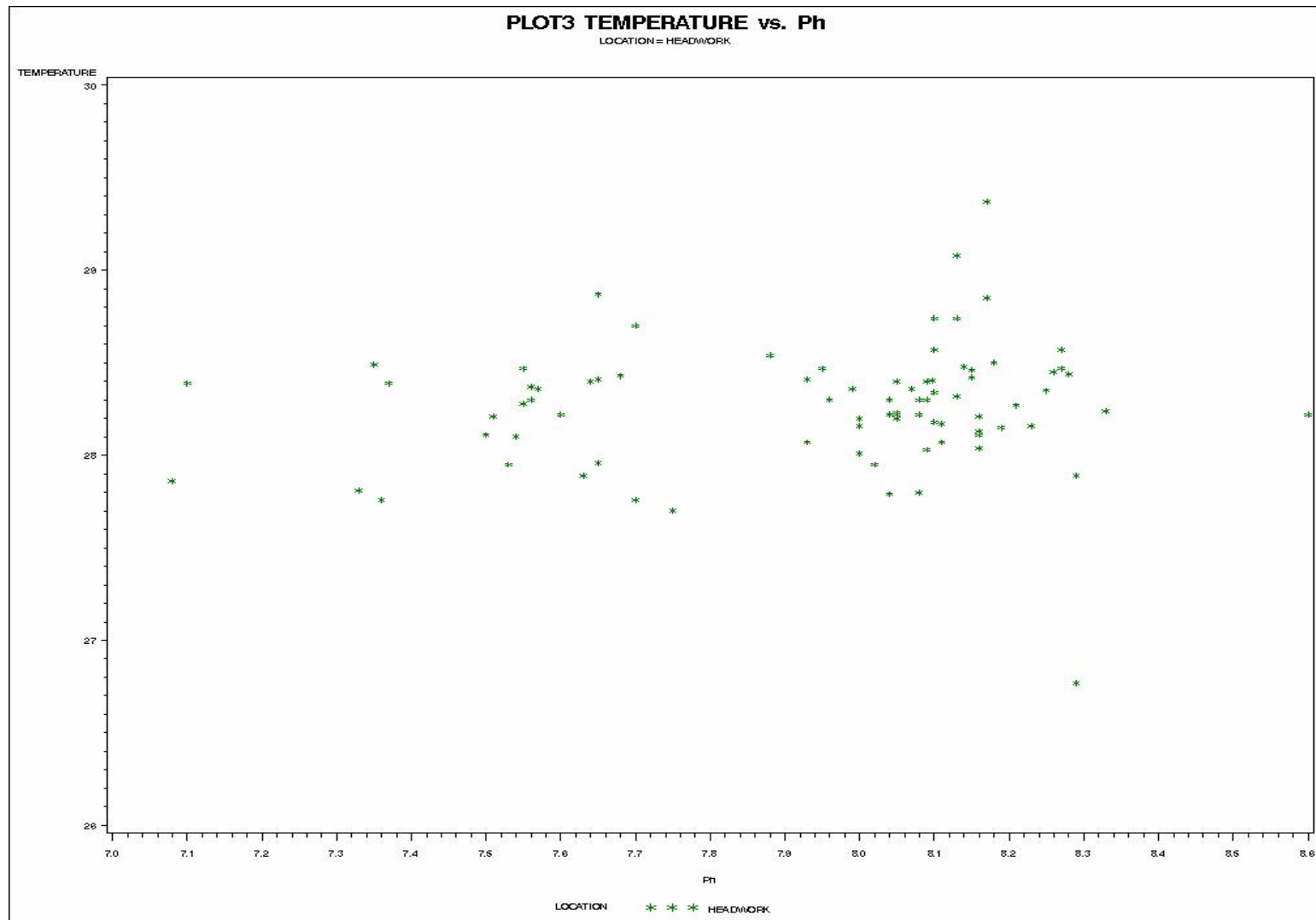
Plate 4.12: Correlation Plot for Temperature vs. pH for Headworks
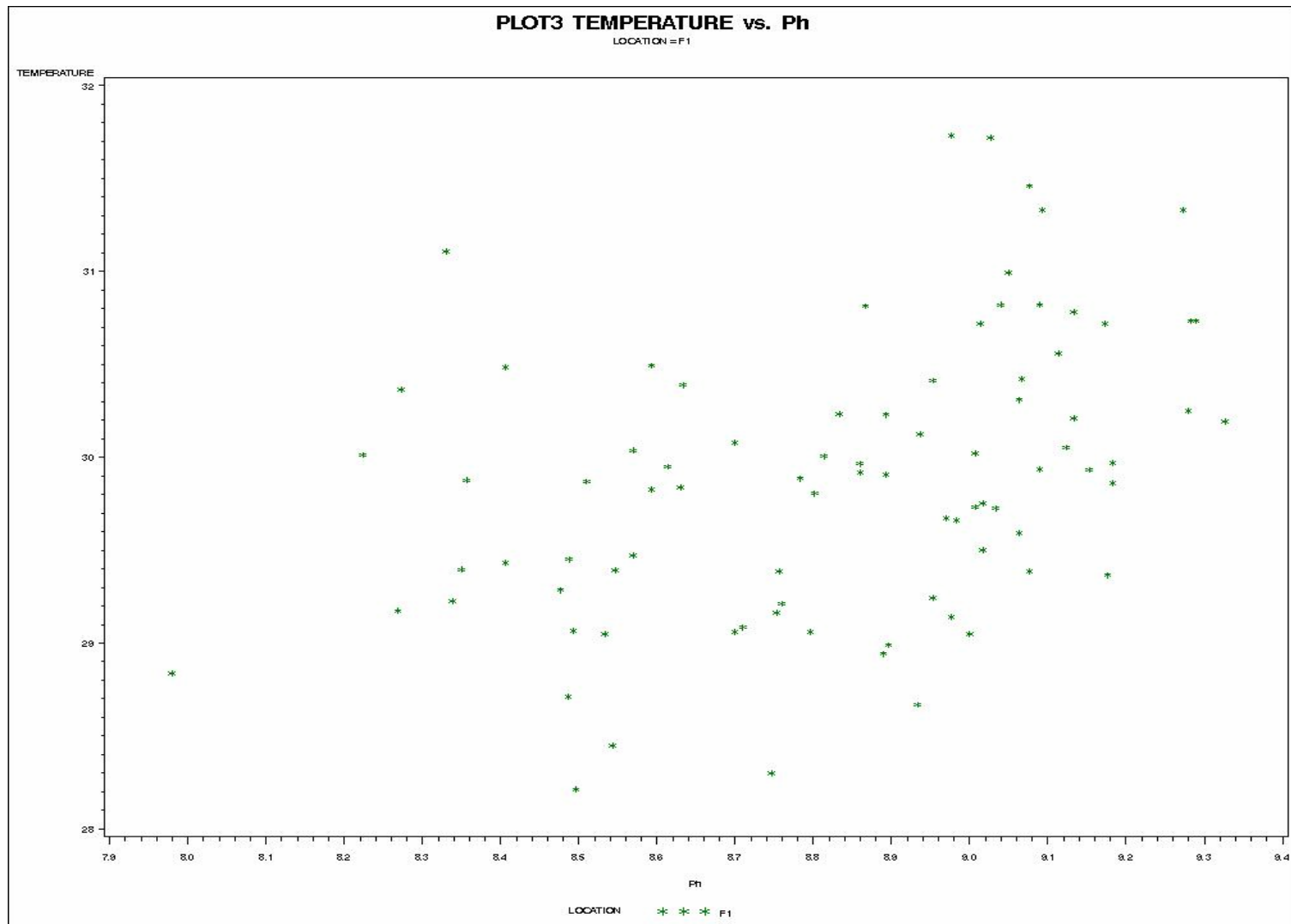
Plate 4.13: Correlation Plot for Temperature vs. pH for F1
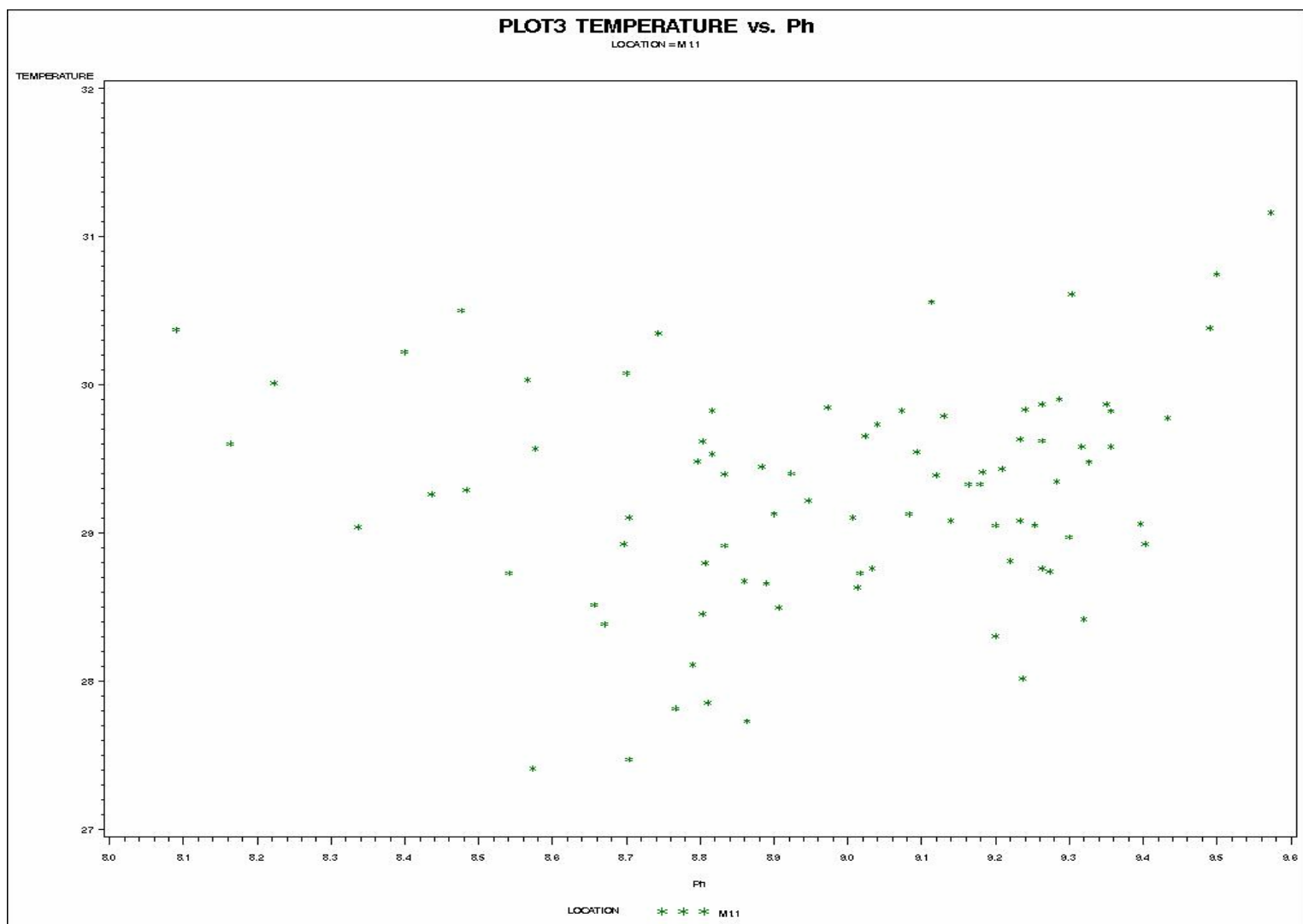
Plate 4.14: Correlation Plot for Temperature vs. pH for M1.1
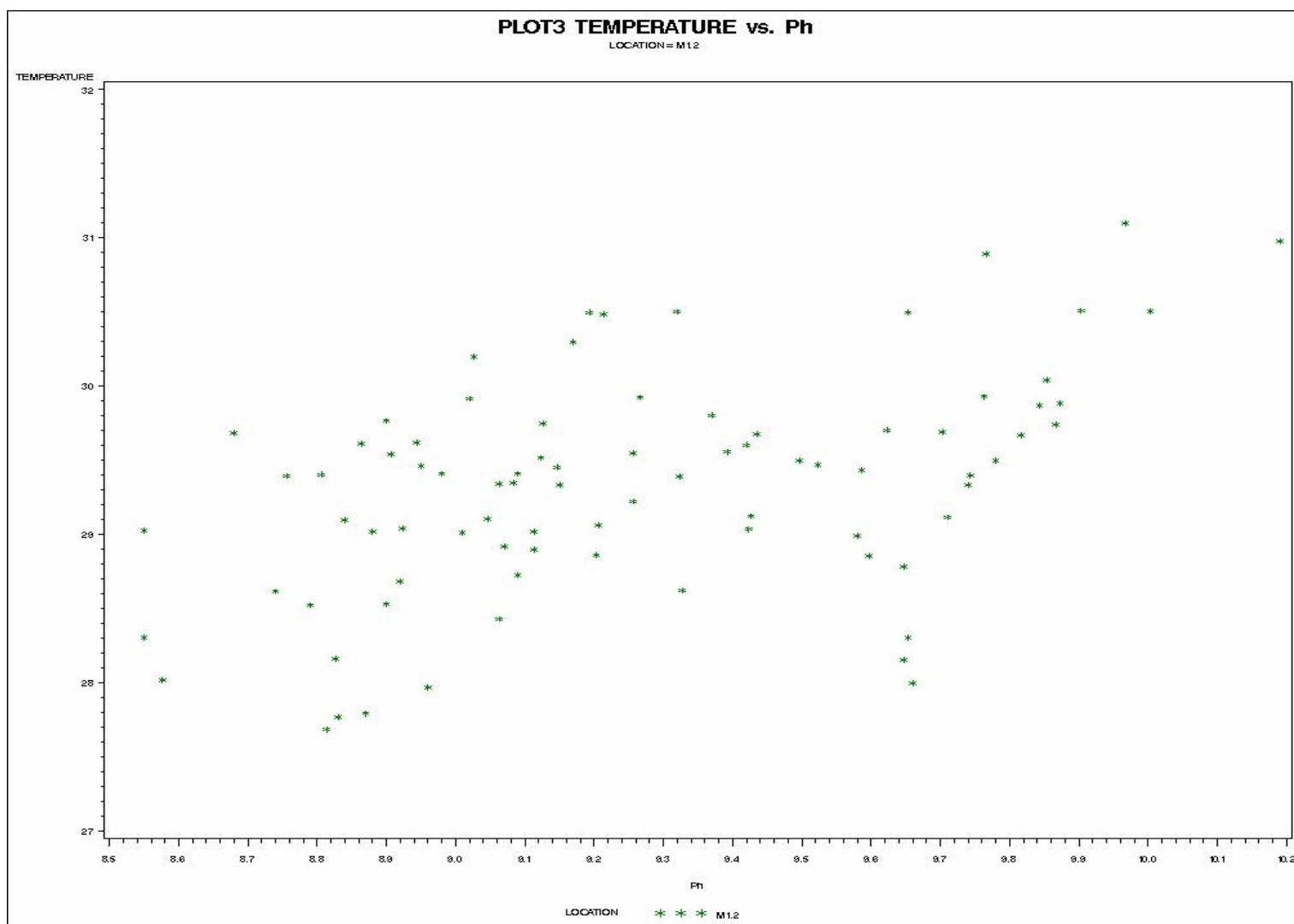
Plate 4.15: Correlation Plot for Temperature vs. pH for M1.2
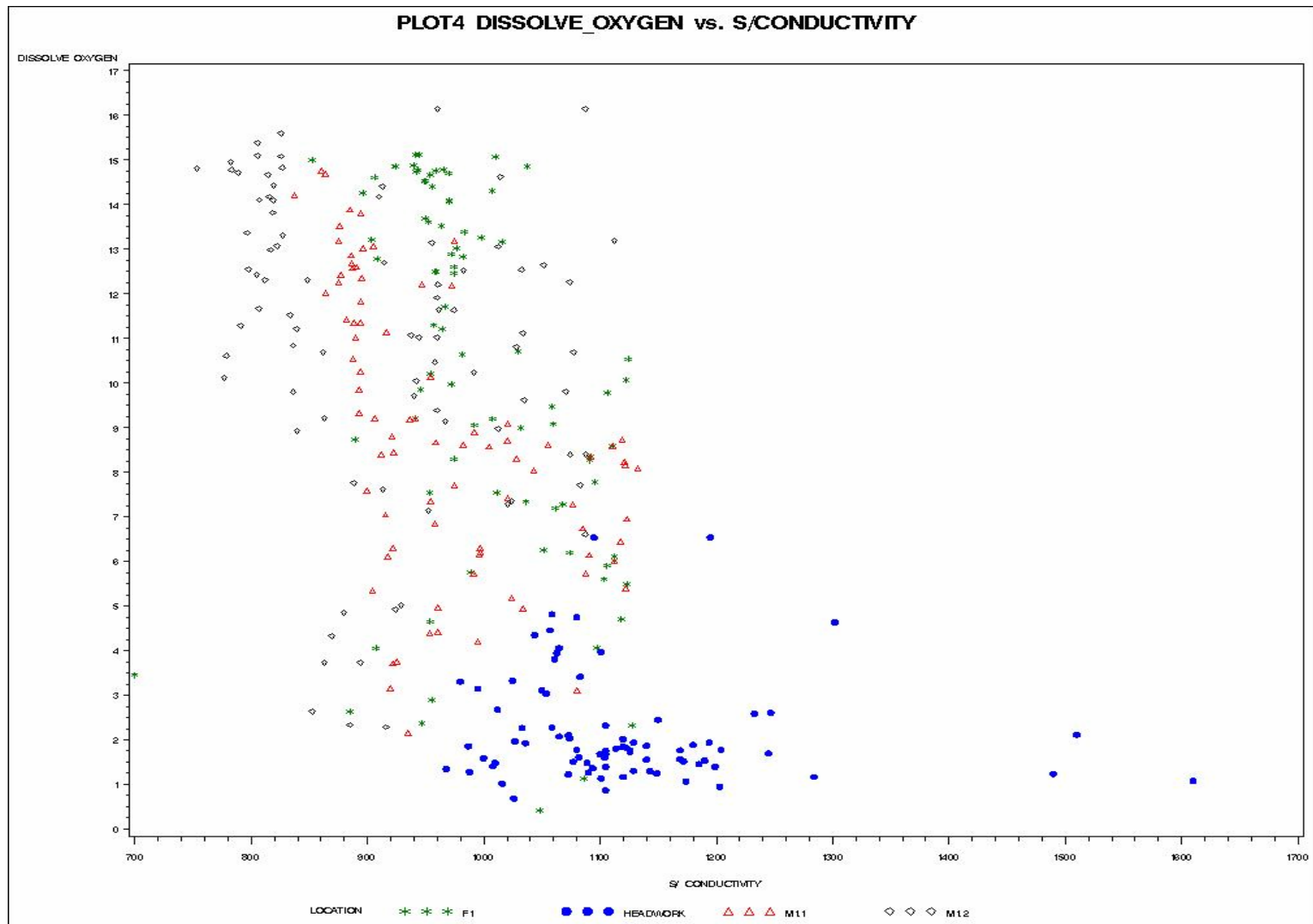
Plate 4.16: Correlation Plot for Dissolved Oxygen vs. Conductivity for all Locations
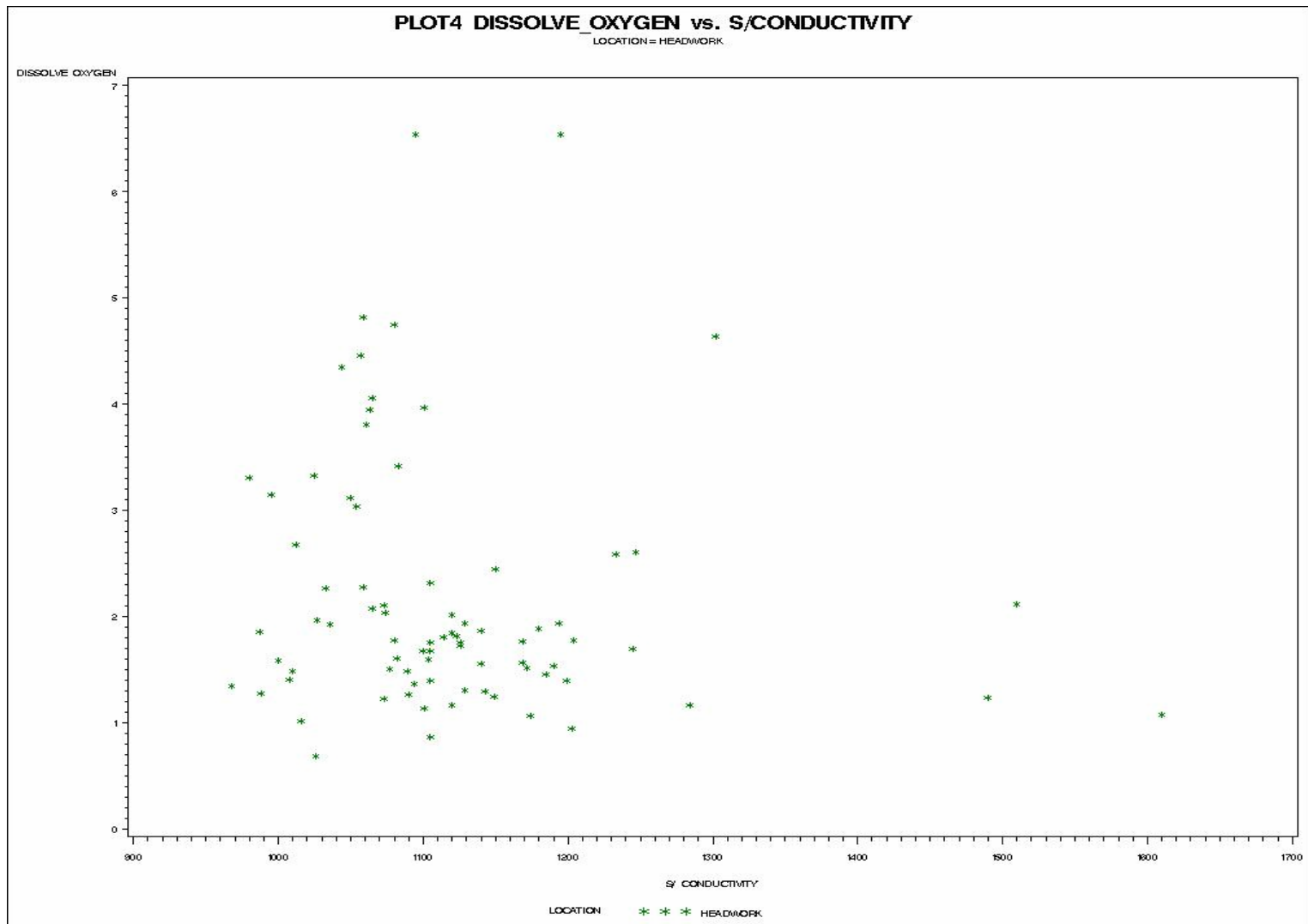
Plate 4.17: Correlation Plot for Dissolved Oxygen vs. Conductivity for Headworks
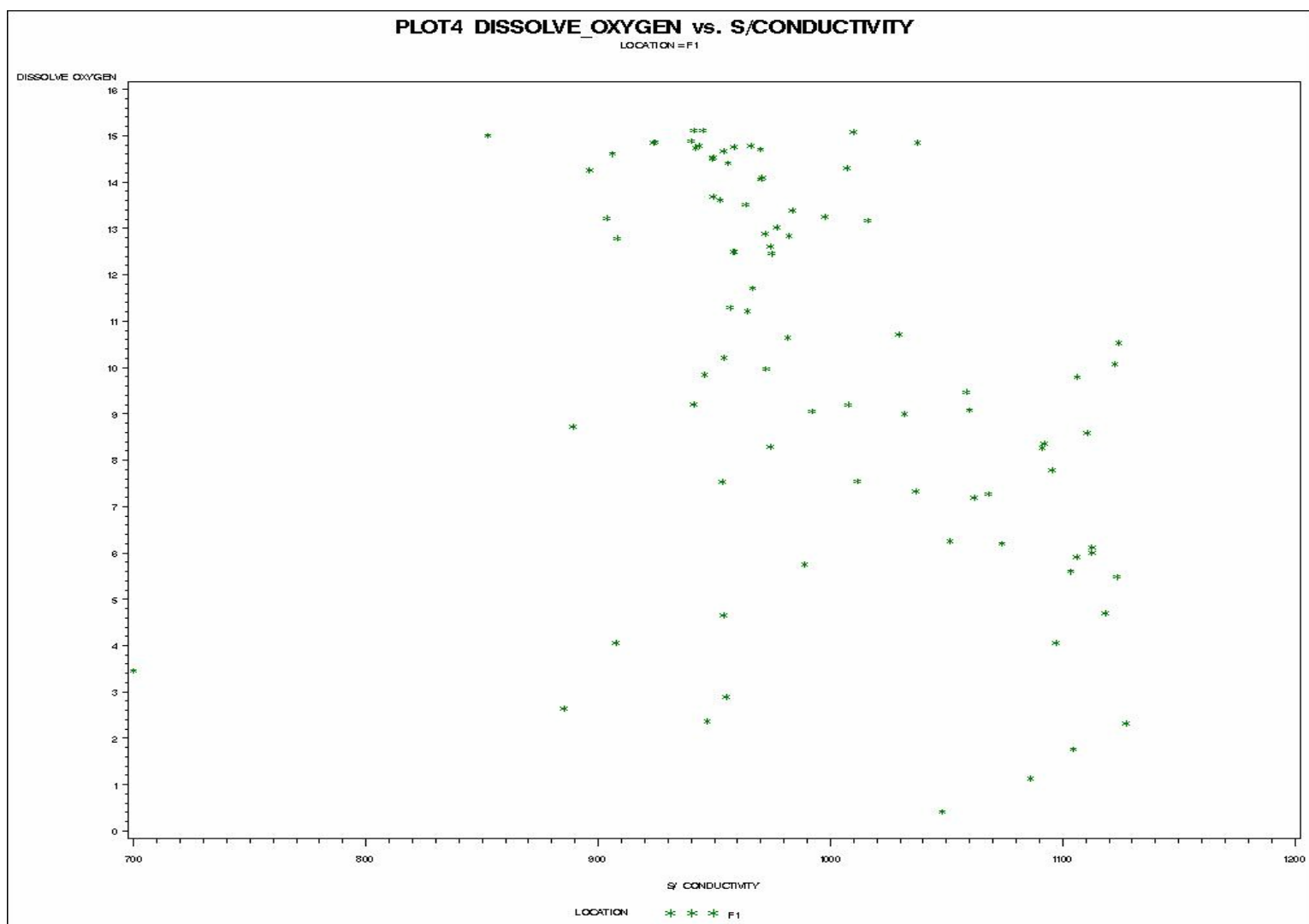
Plate 4.18: Correlation Plot for Dissolved Oxygen vs. Conductivity for F1
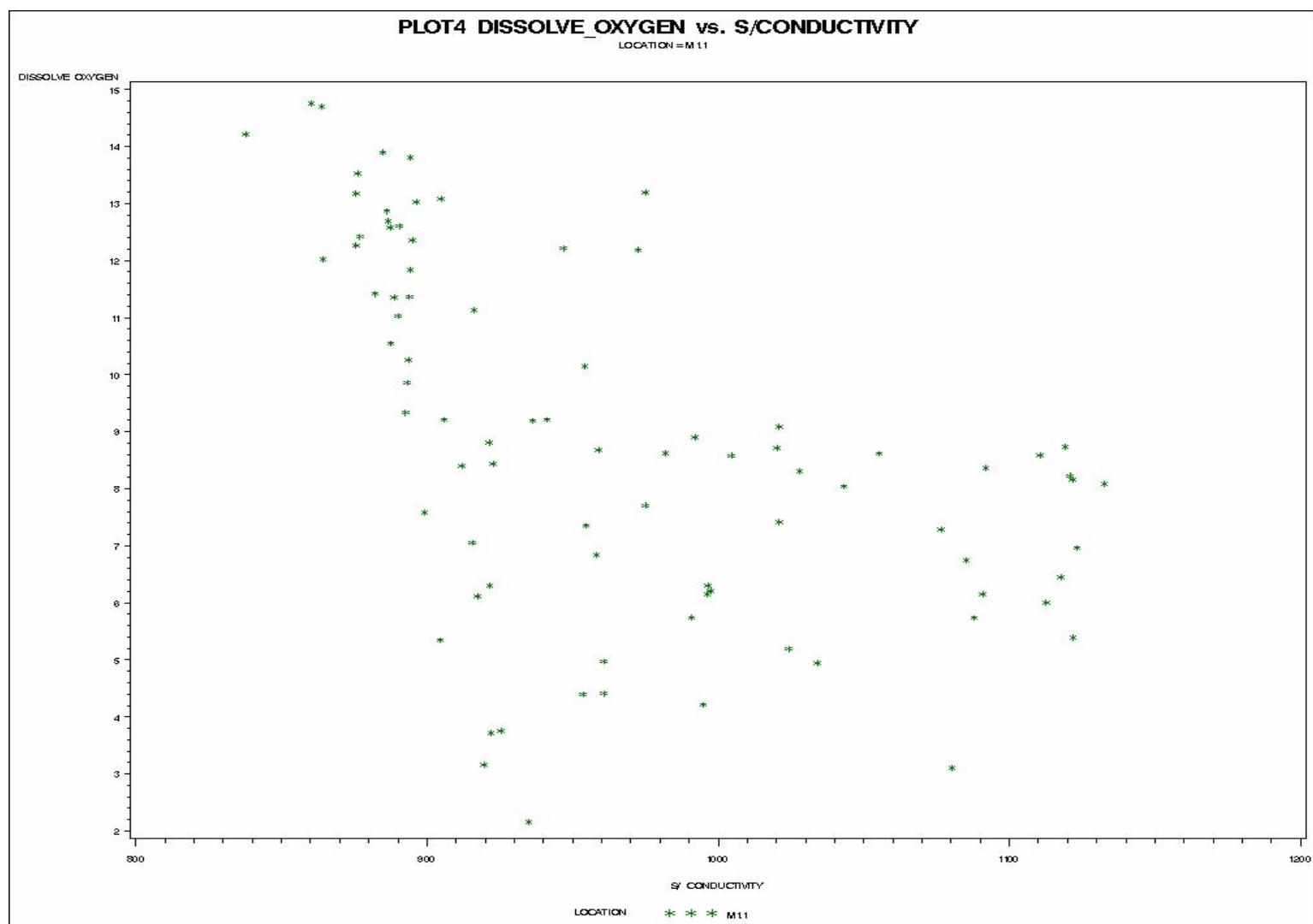
Plate 4.19: Correlation Plot for Dissolved Oxygen vs. Conductivity for M1.1
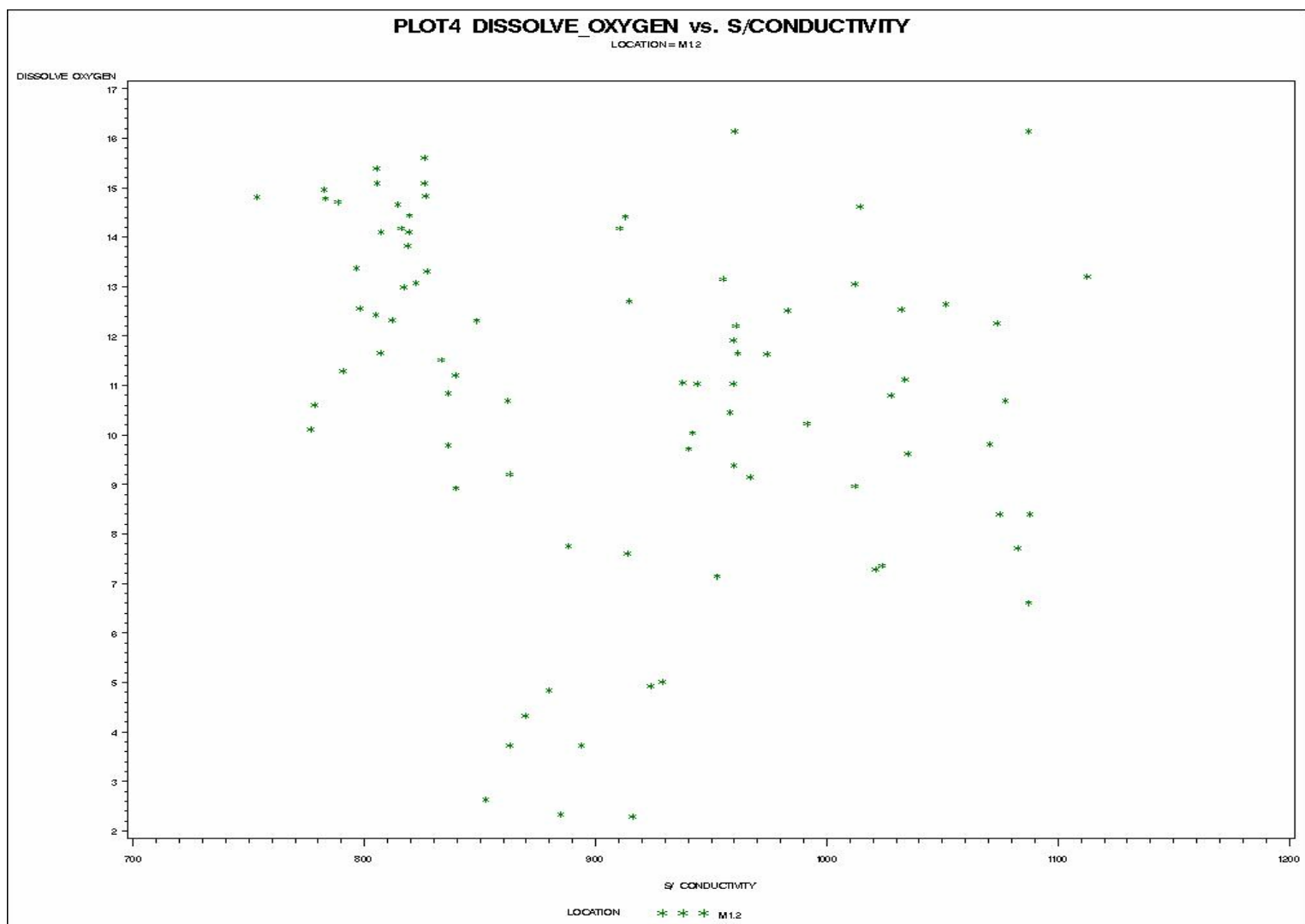
Plate 4.20: Correlation Plot for Dissolved Oxygen vs. Conductivity for M1.2
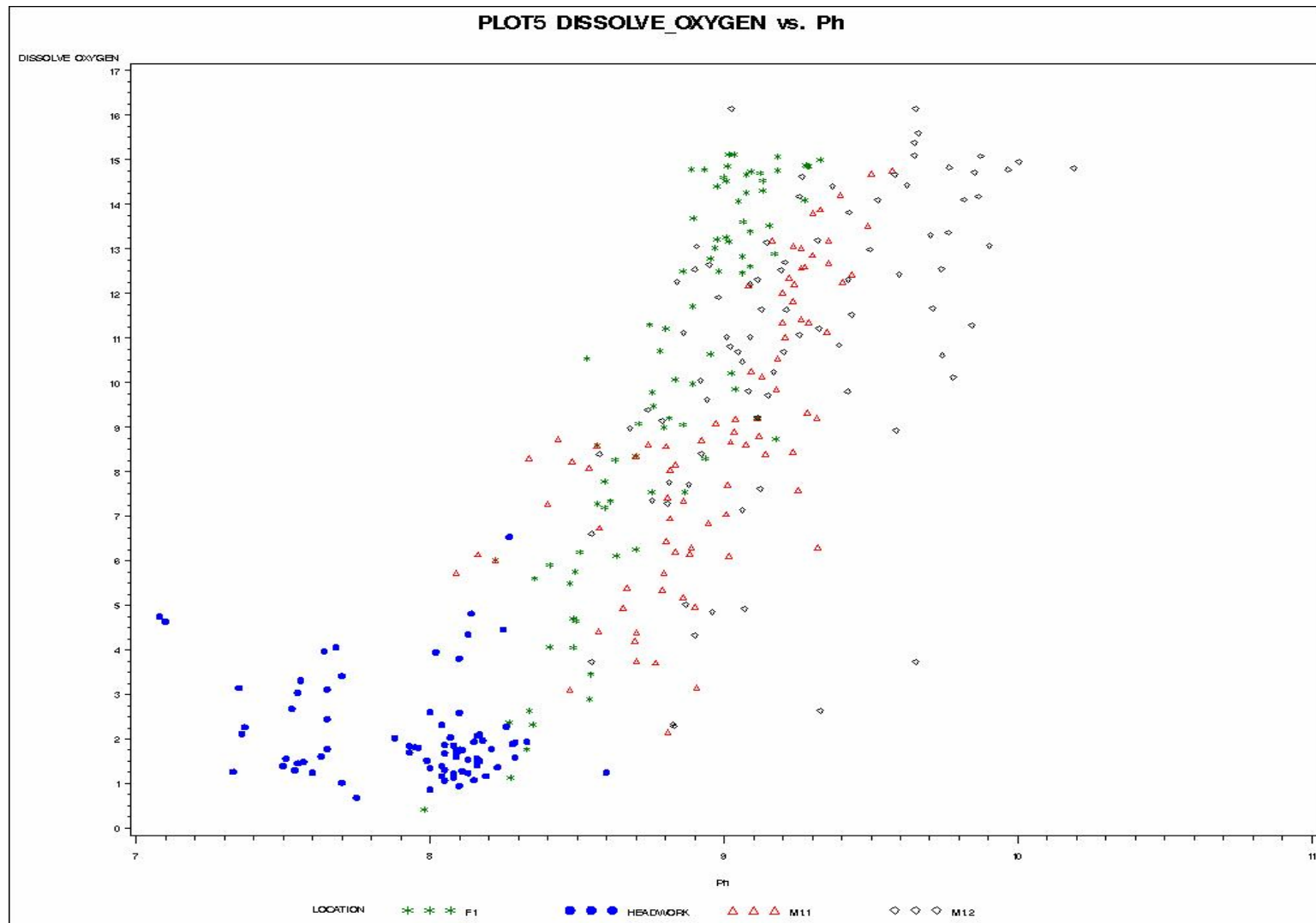
Plate 4.21: Correlation Plot for Dissolved Oxygen vs. pH for all Locations
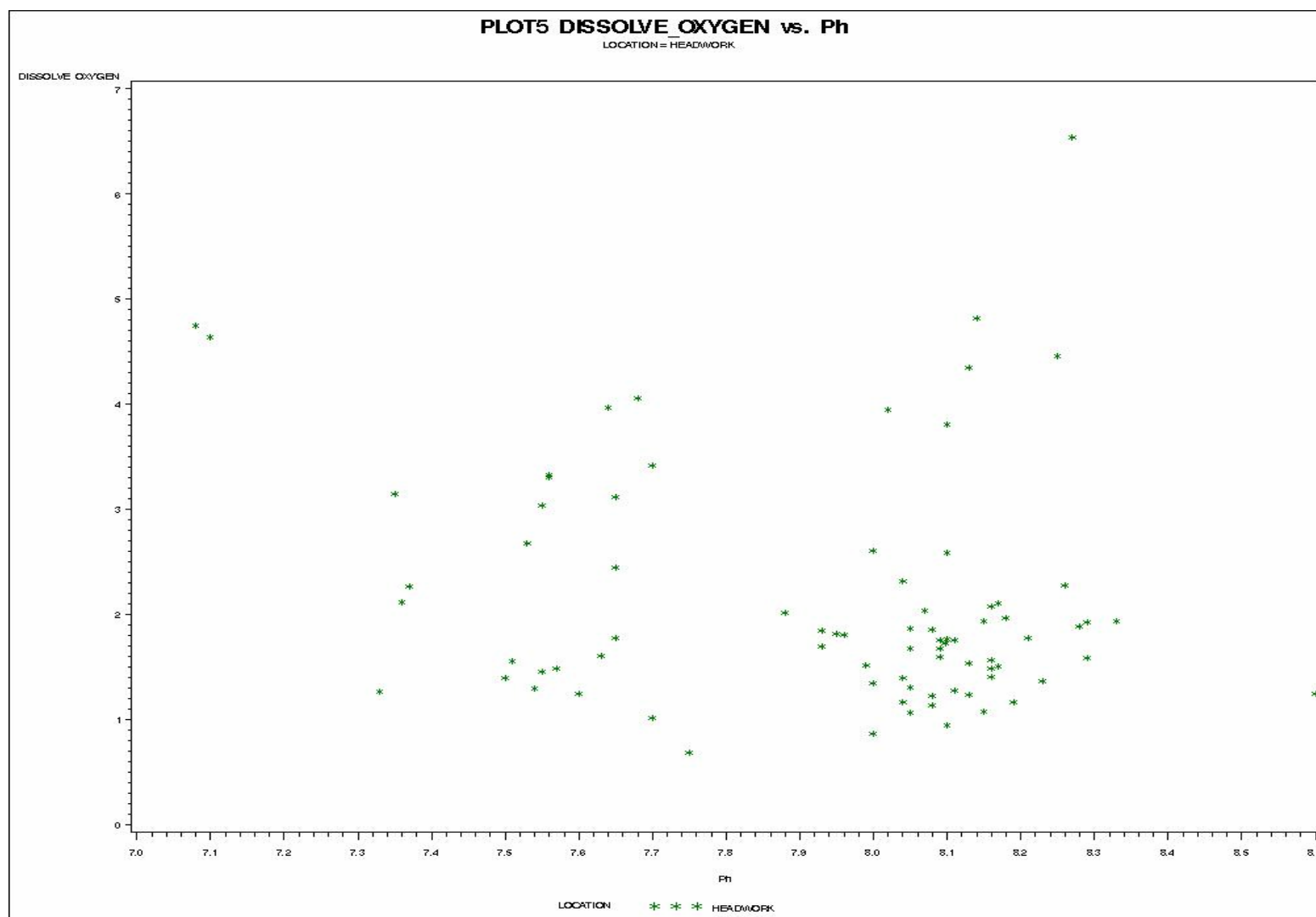
Plate 4.22: Correlation Plot for Dissolved Oxygen vs. pH for Headworks
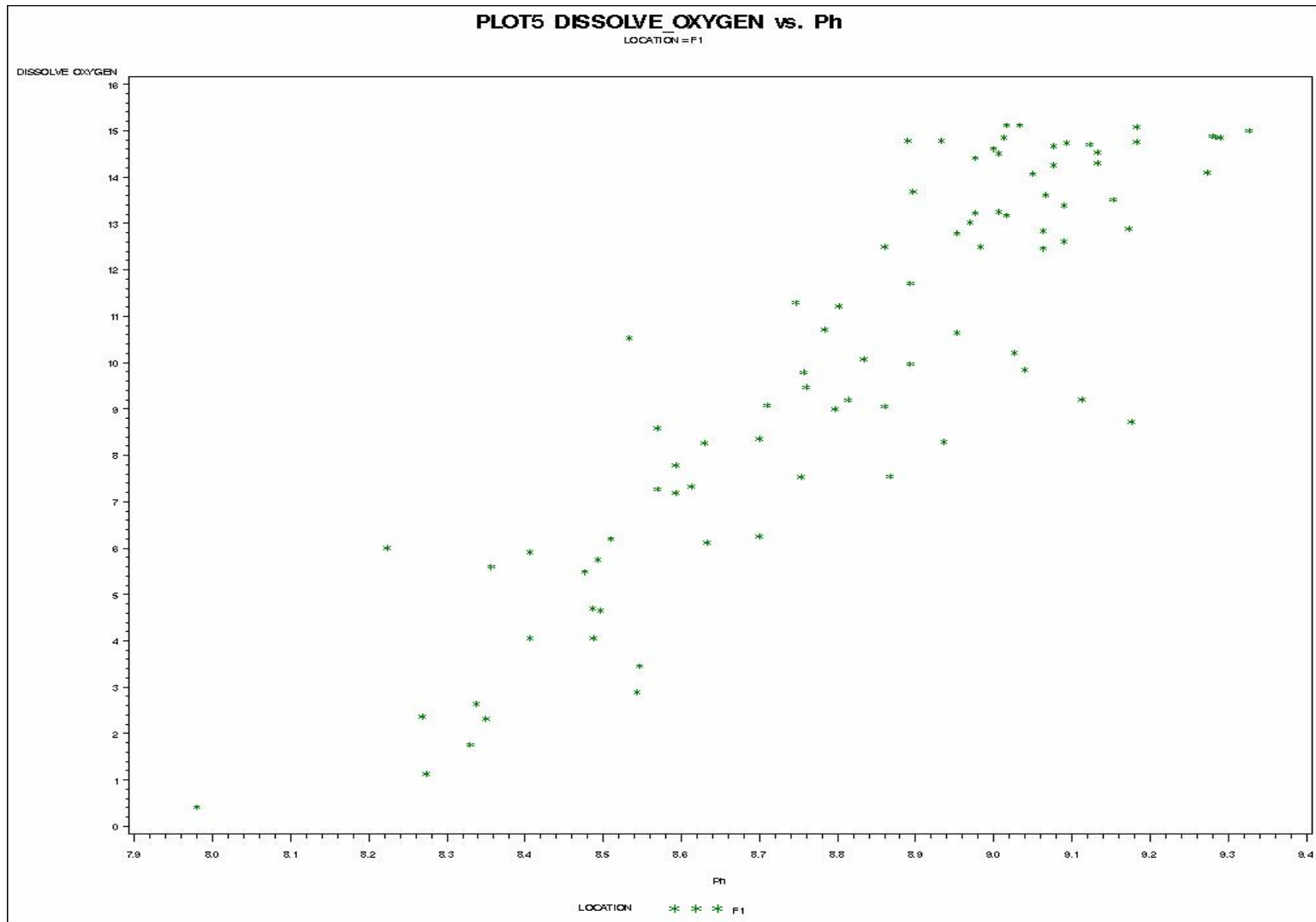
Plate 4.23: Correlation Plot for Dissolved Oxygen vs. pH for F1
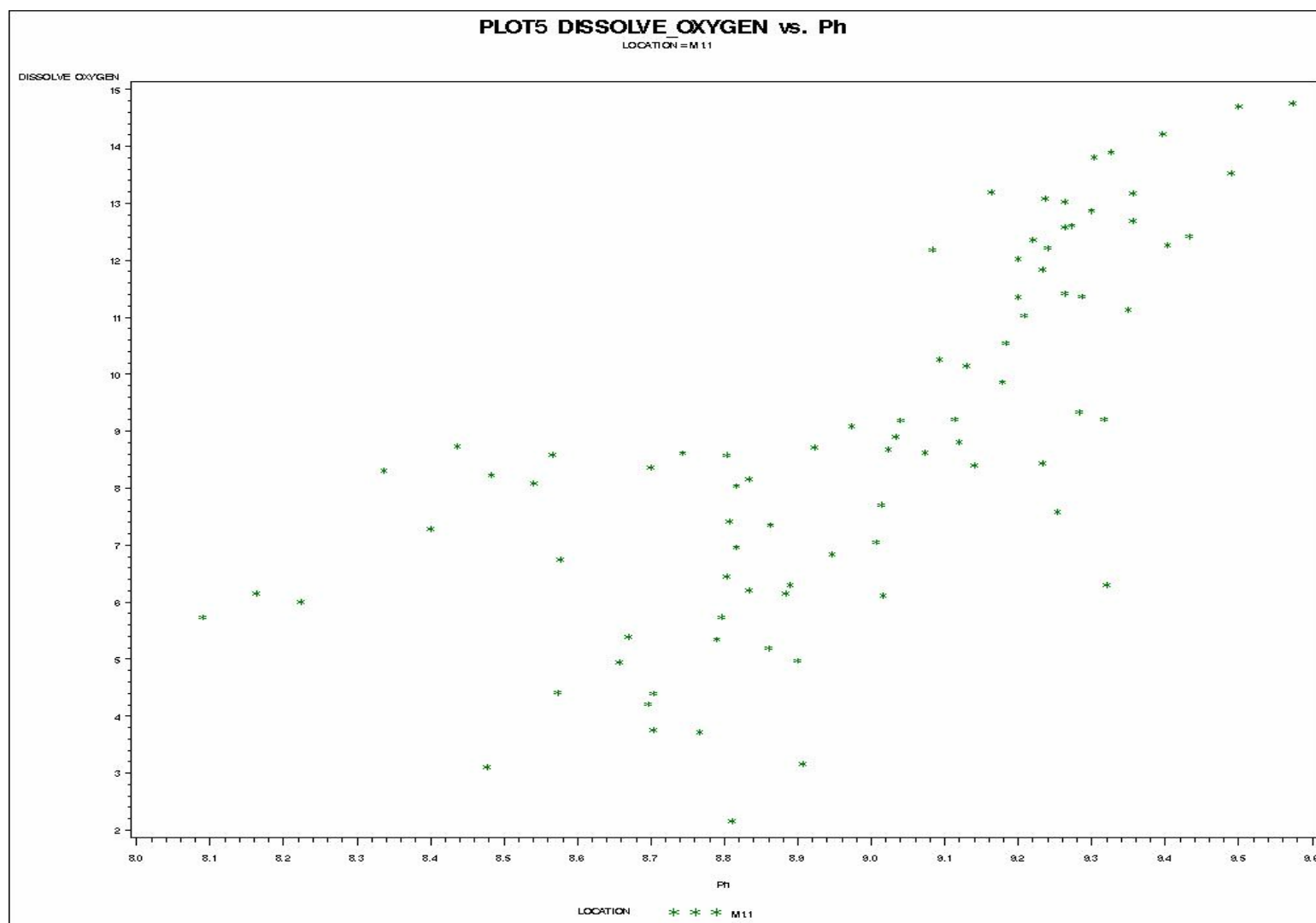
Plate 4.24: Correlation Plot for Dissolved Oxygen vs. pH for M1.1
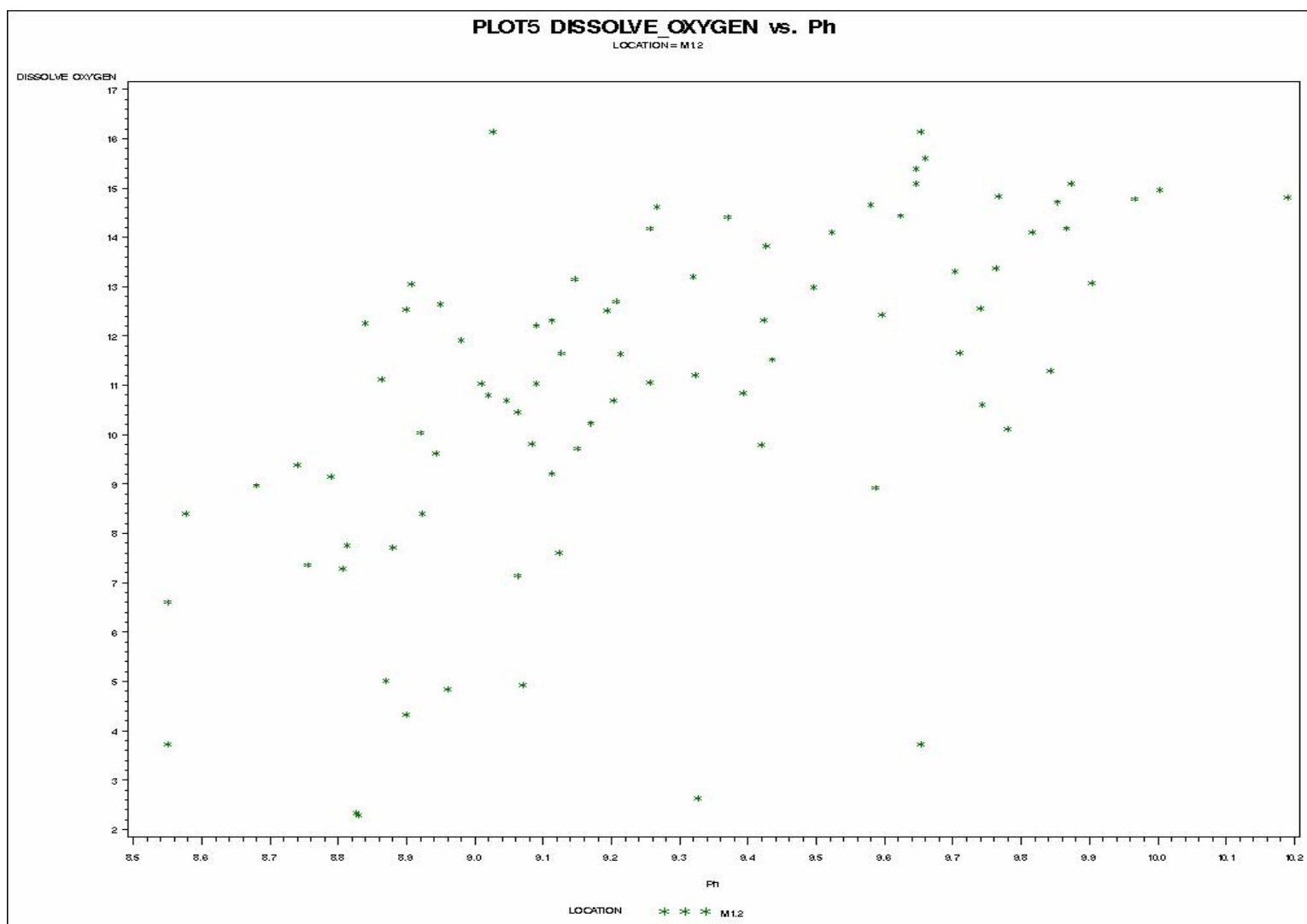
Plate 4.25: Correlation Plot for Dissolved Oxygen vs. pH for M1.2
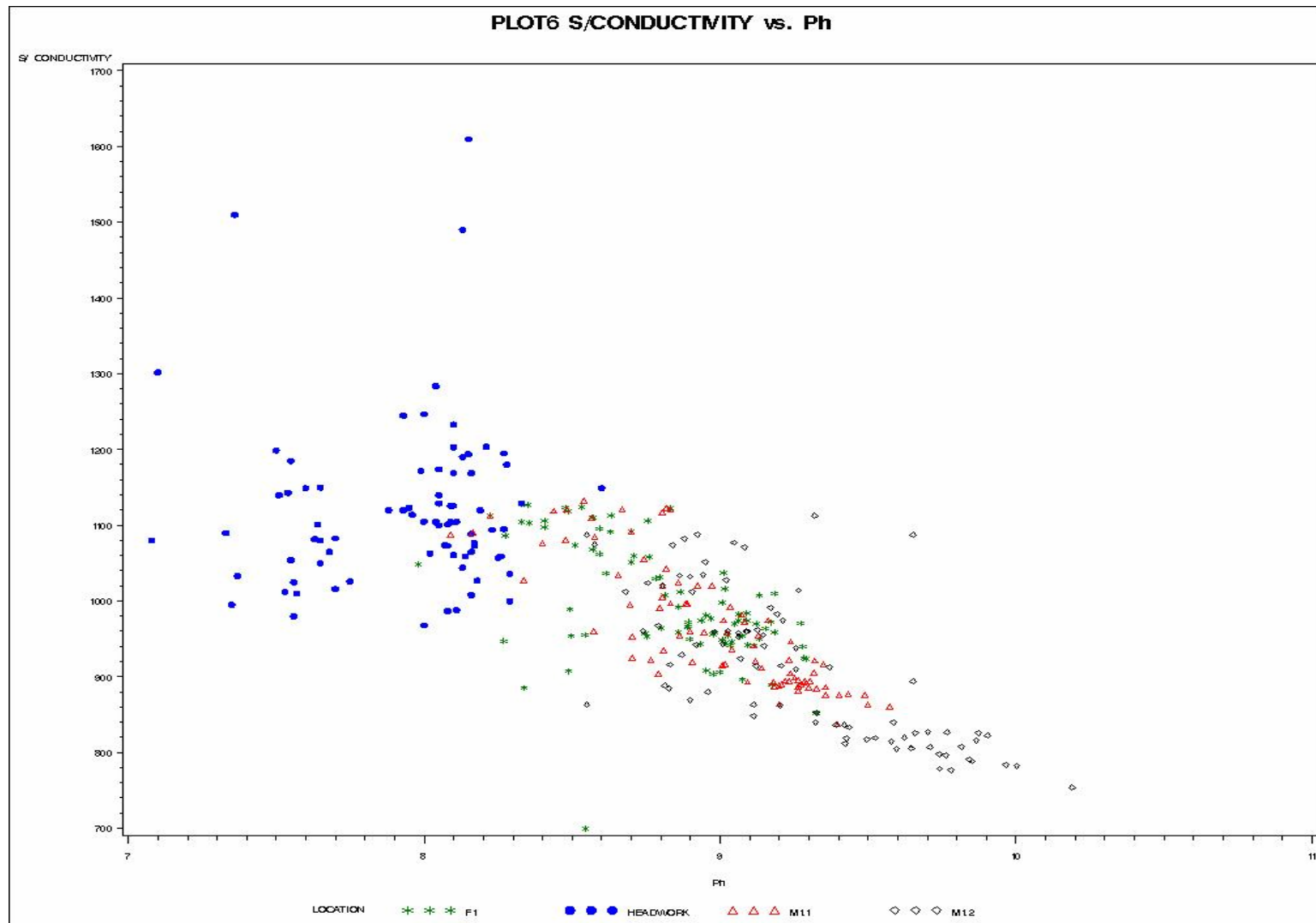
Plate 4.26: Correlation Plot for Conductivity vs. pH for all Locations
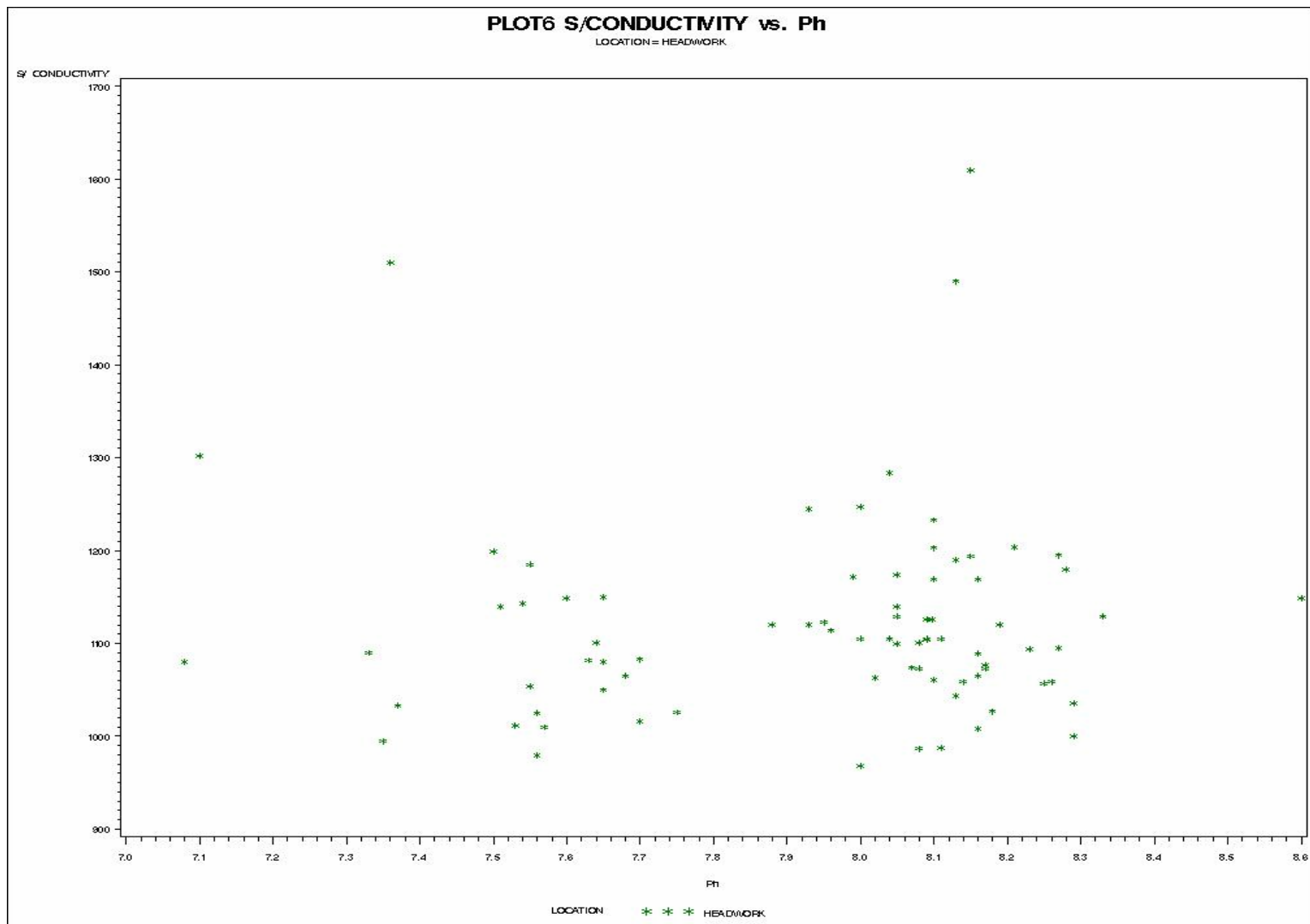
Plate 4.27: Correlation Plot for Conductivity vs. pH for Headworks
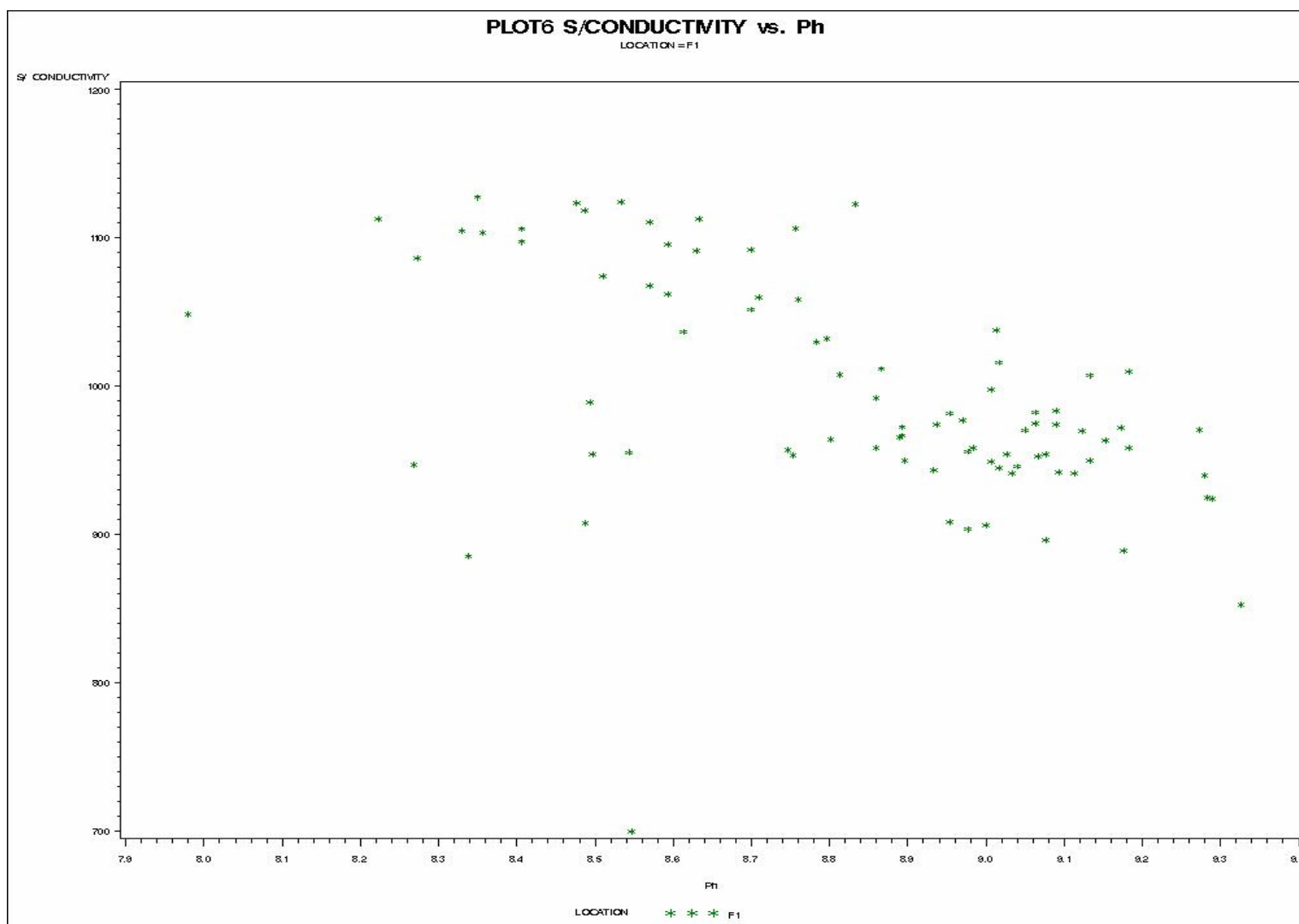
Plate 4.28: Correlation Plot for Conductivity vs. pH for F1
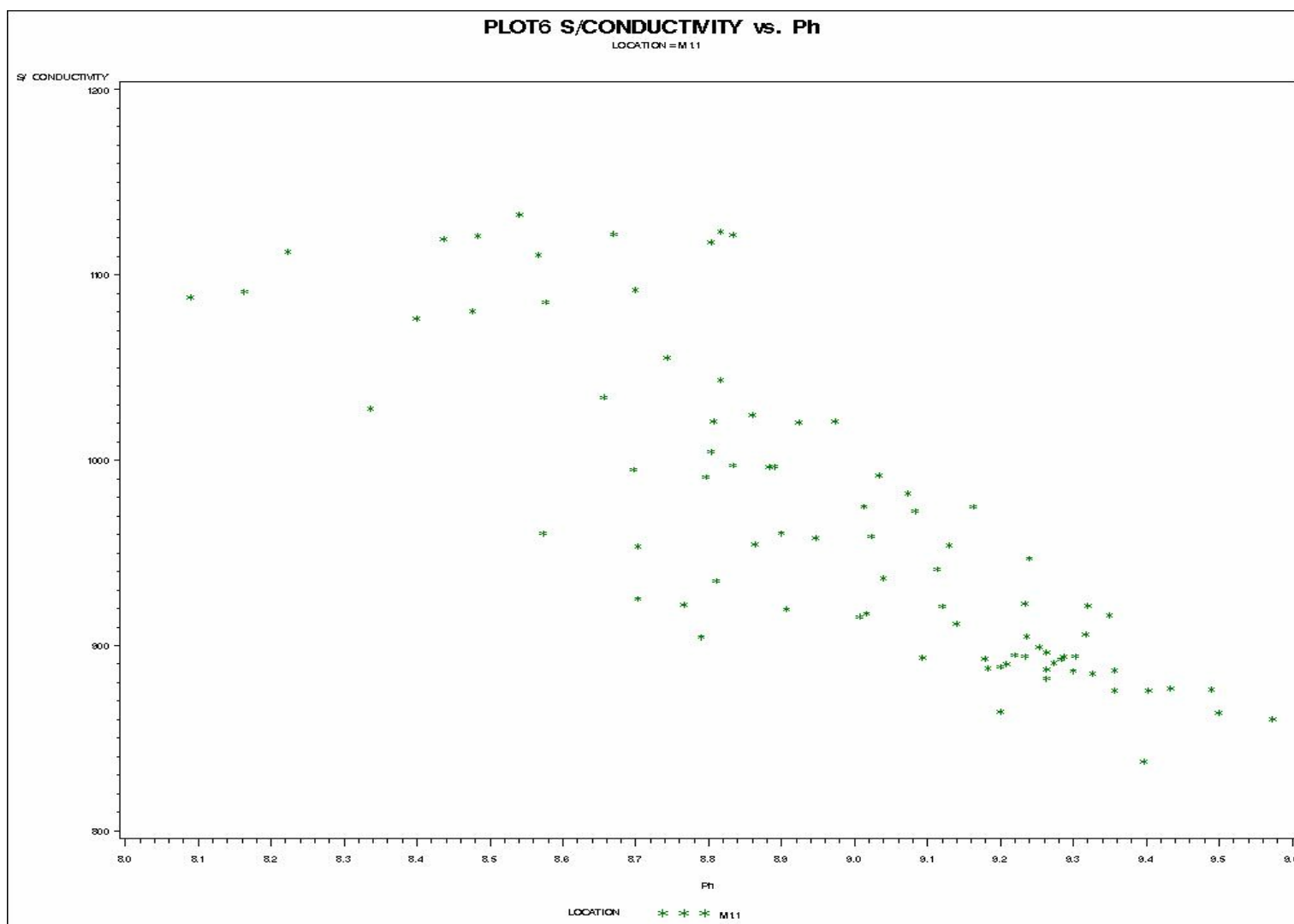
Plate 4.29: Correlation Plot for Conductivity vs. pH for M1.1
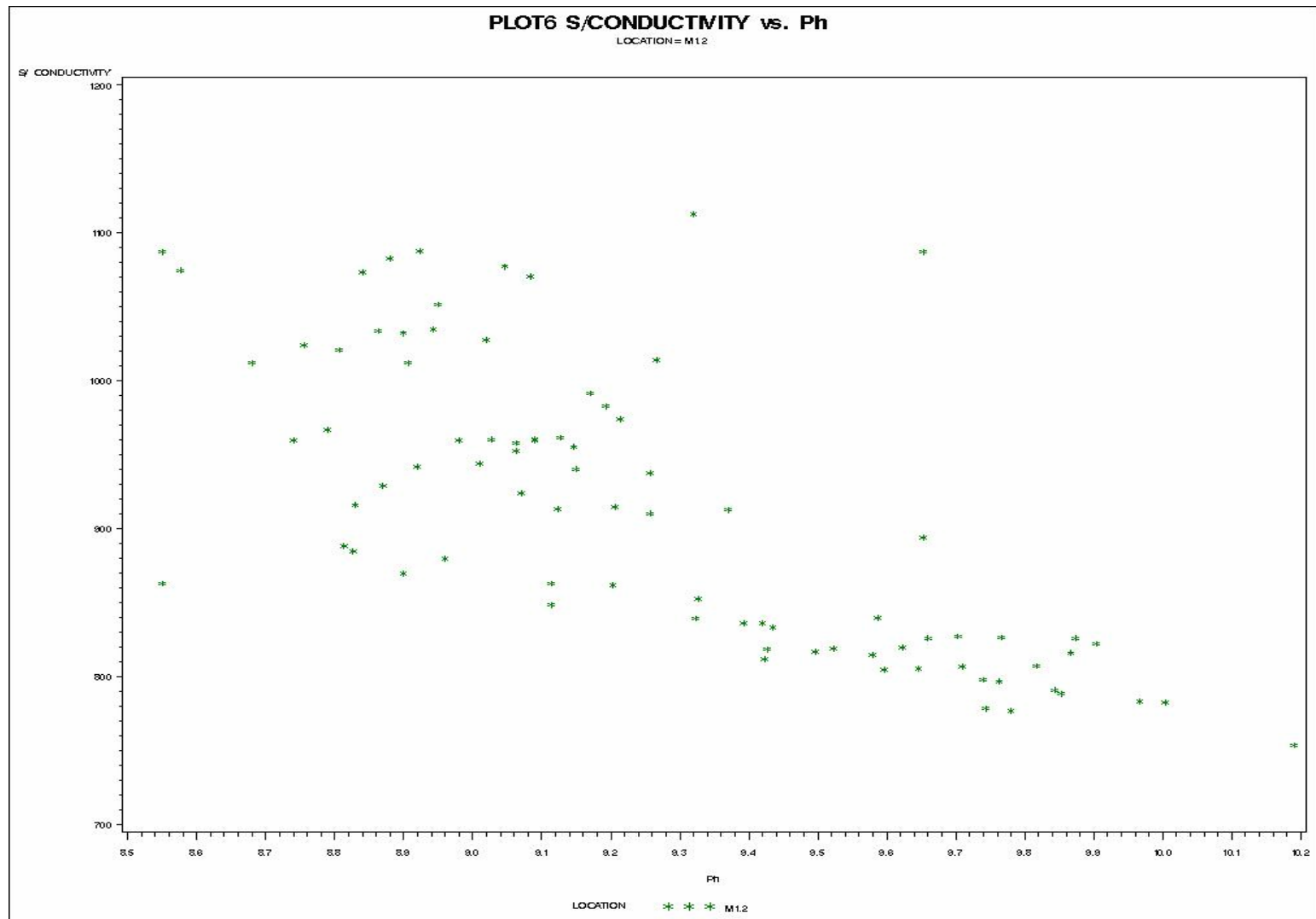
Plate 4.30: Correlation Plot for Conductivity vs. pH for M1.2

4.3.7   Chemical Parameters

4.3.7.1   Analysis of Headwork for BOD and TSS

Table 4.3.7.1: Flow Weighted BOD and TSS Results for Headwork, MAY 07, 2003

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS mg/L
5/7/2003	6:00 AM	7373	0			48	54
Wednesday	7:00 AM	7421	48	0.475247525	10	46	60
	8:00 AM	7476	55	0.544554455	11	36	46
	9:00 AM	7550	74	0.732673267	15	36	43
	10:00 AM	7617	67	0.663366337	13	36	60
	11:00 AM	7718	101	1	20	66	44
	12:00 PM	7804	86	0.851485149	17	69	74
	1:00 PM	7879	75	0.742574257	15	198	270
	2:00 PM	7940	61	0.603960396	12	129	143
	3:00 PM	8020	80	0.792079208	16	93	98
	4:00 PM	8103	83	0.821782178	16	111	148
	5:00 PM	8190	87	0.861386139	17	102	70
	6:00 PM	8277	87	0.861386139	17	78	370
				FLOW WEIGHTED RESULT		87	110
				AVERAGE		83.33333	118.8333
			m³	MGD			
		flow during sampling	904	1.9888			

Refer to **CHART 4.3.7.1**. FROM DAILY FLOW DATA: TOTAL FLOW FOR THE DAY = 3.3 MGD (12492 m³/d). THEREFORE 60% OF THE FLOW OCCURS DURING THE SAMPLING PERIOD.

CHART 4.3.7.1: FLOW WEIGHTED BOD AND TSS RESULTS, 5/7/03

Table 4.3.7.2: <u>Flow Weighted BOD and TSS Results for Headwork, MAY 15, 2003</u>

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS mg/L
5/15/2003	6:00 AM	6656	0			54	98
Thursday	7:00 AM	6712	56	0.538461538	11	76	65
	8:00 AM	6780	68	0.653846154	13	34	72
	9:00 AM	6862	82	0.788461538	16	48	63
	10:00 AM	6966	104	1	20	60	102
	11:00 AM	7032	66	0.634615385	13	60	88
	12:00 PM	7115	83	0.798076923	16	66	78
	1:00 PM	7191	76	0.730769231	15	72	80
	2:00 PM	7269	78	0.75	15	72	135
	3:00 PM	7348	79	0.759615385	15	75	100
	4:00 PM	7435	87	0.836538462	17	57	55
	5:00 PM	7503	68	0.653846154	13	66	122
	6:00 PM	7572	69	0.663461538	13	45	92
				FLOW WEIGHTED RESULT		**64**	**84**
				AVERAGE		**60.91667**	**87.66667**
			m³	**MGD**			
		Flow during sampling	**916**	**2.0152**			

Refer to **CHART 4.3.7.2.** FROM DAILY FLOW DATA: TOTAL FLOW FOR THE DAY = 3.73 MGD (14120 m³/d). THEREFORE 54% OF THE FLOW OCCURS DURING THE SAMPLING PERIOD.

CHART 4.3.7.2: FLOW WEIGHTED BOD AND TSS RESULTS, 5/15/03

Table 4.3.7.3: Flow Weighted BOD and TSS Results for Headwork, MAY 23, 2003

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS/ mg/L	
5/23/2003	6:00 AM	2019	0			72	135	
Friday	7:00 AM	2076	57	0.487179487	10	44	95	
heavy rain	8:00 AM	2149	73	0.623931624	12	46	60	
	9:00 AM	2218	69	0.58974359	12	60	50	
	10:00 AM	2297	79	0.675213675	14	39	85	
	11:00 AM	2376	79	0.675213675	14	69	205	
	12:00 PM	2458	82	0.700854701	14	87	107	
	1:00 PM	2539	81	0.692307692	14	90	160	
	2:00 PM	2656	117	1	20	96	85	
	3:00 PM	2743	87	0.743589744	15	72	95	
	4:00 PM	2813	70	0.598290598	12	135	280	
	5:00 PM	2876	63	0.538461538	11	102	140	
	6:00 PM	2938	62	0.52991453	11	114	190	
				FLOW WEIGHTED RESULT		96		
				AVERAGE			79.5	129.3333
			m³	MGD				
		flow during sampling	919	2.0218				

Refer to **CHART 4.3.7.3**. FROM DAILY FLOW DATA: TOTAL FLOW FOR THE DAY = 3.8 MGD (14385 m³/d). THEREFORE 53% OF THE FLOW OCCURS DURING THE SAMPLING PERIOD.

CHART 4.3.7.3: FLOW WEIGHTED BOD AND TSS RESULTS, 5/23/03

Table 4.3.7.4: <u>Flow Weighted BOD and TSS Results for Headwork, MAY 31, 2003</u>

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS mg/L
5/31/2003	6:00 AM	6261	0			34	37
Saturday	7:00 AM	6322	61	0.429577465	9	34	63
	8:00 AM	6402	80	0.563380282	11	32	80
	9:00 AM	6485	83	0.584507042	12	168	80
	10:00 AM	6571	86	0.605633803	12	70	47
	11:00 AM	6659	88	0.61971831	12	48	97
	12:00 PM	6775	116	0.816901408	16	87	130
	1:00 PM	6850	75	0.528169014	11	72	200
	2:00 PM	6934	84	0.591549296	12	102	250
	3:00 PM	7023	89	0.626760563	13	99	123
	4:00 PM	7134	111	0.781690141	16	87	80
	5:00 PM	7276	142	1	20	79	127
	6:00 PM	7400	124	0.873239437	17	99	340
				FLOW WEIGHTED RESULT		76.5	233
				AVERAGE		81.41667	134.75
			m^3	MGD			
		flow during sampling	1139	2.5058			

Refer to **CHART 4.3.7.4**. FROM DAILY FLOW READING THE TOTAL FLOW FOR TODAY = 4.87 MGD (18435 m^3/d). THEREFORE 52% OF THE FLOW OCCURS DURING SAMPLING

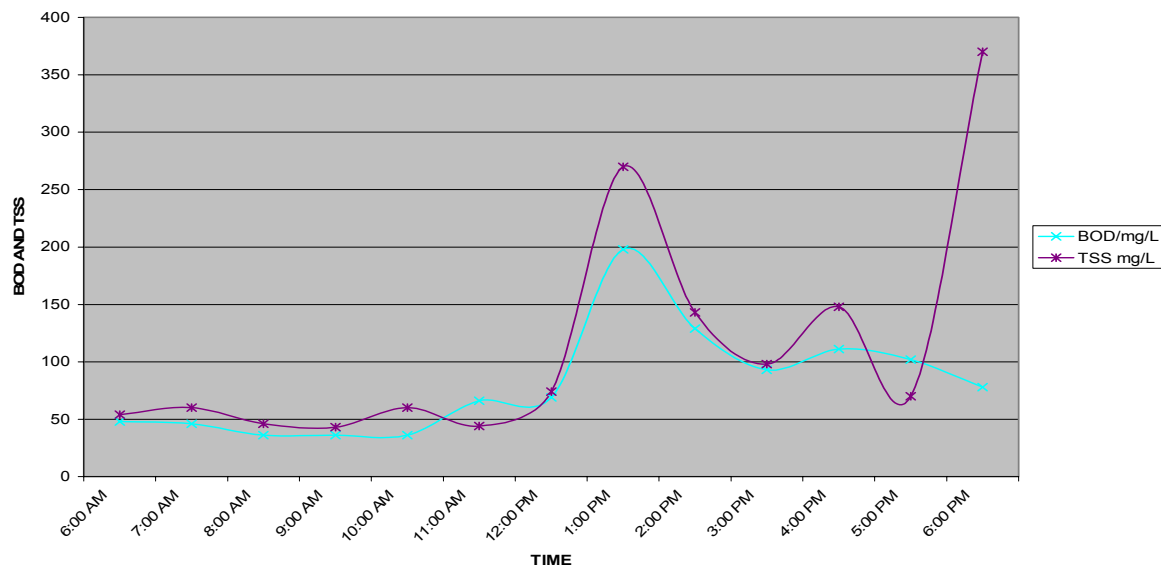**CHART 4.3.7.4: FLOW WEIGHTED BOD AND TSS RESULTS, 5/31/03**

Table 4.3.7.5: <u>Flow Weighted BOD and TSS Results for Headwork, JUNE 03, 2003</u>

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS mg/L
6/3/2003	6:00 AM	2277	0			40	41
Tuesday	7:00 AM	2333	56	0.518518519	10	40	53
	8:00 AM	2405	72	0.666666667	13	36	61
	9:00 AM	2488	83	0.768518519	15	42	66
	10:00 AM	2591	103	0.953703704	19	63	78
	11:00 AM	2696	105	0.972222222	19	63	108
	12:00 PM	2733	37	0.342592593	7	177	88
	1:00 PM	2828	95	0.87962963	18	73.5	66
	2:00 PM	2896	68	0.62962963	13	87	74
	3:00 PM	2982	86	0.796296296	16	69	94
	4:00 PM	3068	86	0.796296296	16	48	110
	5:00 PM	3176	108	1	20	156	134
	6:00 PM	3273	97	0.898148148	18	48	175
				FLOW WEIGHTED RESULT		174	94
				AVERAGE		75.20833	92.25
			M³	**MGD**			
		flow during sampling	**996**	**2.1912**			

Refer to **CHART 4.3.7.5**. FROM DAILY FLOW READING THE TOTAL FLOW FOR TODAY = 4.13 MGD (15634 m³/d). THEREFORE 53% OF THE FLOW OCCURS DURING SAMPLING
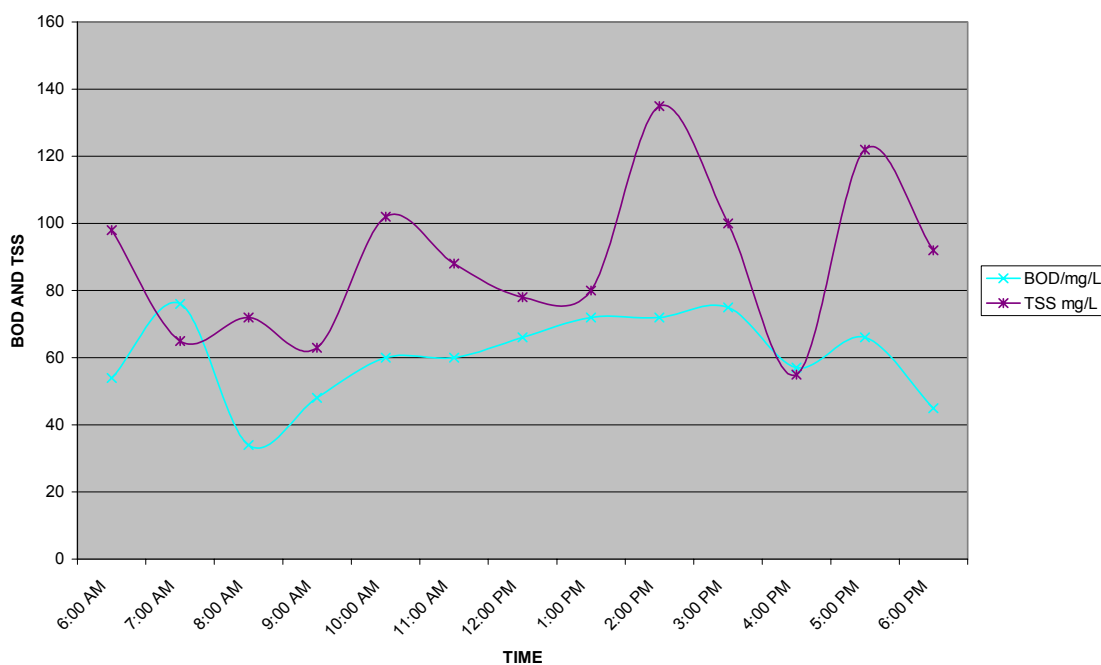
CHART 4.3.7.5: FLOW WEIGHTED BOD AND TSS RESULTS, 6-3-03

Table 4.3.7.6: <u>Flow Weighted BOD and TSS Results for Headwork, JUNE 08, 2003</u>

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS mg/L
6/8/2003	6:00 AM	3228	0			48	70
Sunday	7:00 AM	3300	72	0.666666667	13	46	63
	8:00 AM	3365	65	0.601851852	12	32	40
	9:00 AM	3449	84	0.777777778	16	30	53
	10:00 AM	3547	98	0.907407407	18	36	60
	11:00 AM	3634	87	0.805555556	16	48	70
	12:00 PM	3722	88	0.814814815	16	78	87
	1:00 PM	3804	82	0.759259259	15	60	70
	2:00 PM	3895	91	0.842592593	17	72	77
	3:00 PM	3971	76	0.703703704	14	78	67
	4:00 PM	4053	82	0.759259259	15	69	60
	5:00 PM	4131	78	0.722222222	14	57	57
	6:00 PM	4215	84	0.777777778	16	66	90
				FLOW WEIGHTED RESULT		103.5	50
				AVERAGE		56	66.16667
			m^3	MGD			
		flow during sampling	987	2.1714			

Refer to **CHART 4.3.7.6**. FROM DAILY FLOW READING THE TOTAL FLOW FOR TODAY = 4.48 MGD (16959 m^3/d). THEREFORE 48% OF THE FLOW OCCURS DURING SAMPLING

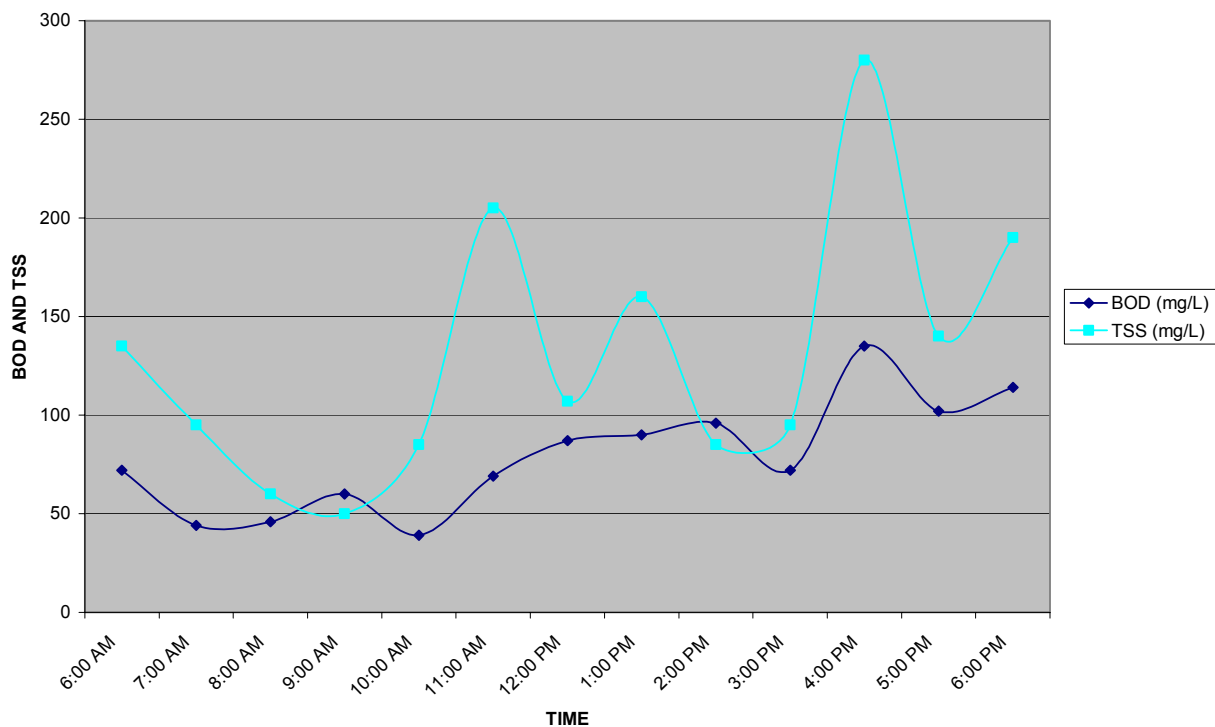**CHART 4.3.7.6: FLOW WEIGHTED BOD AND TSS RESULTS**
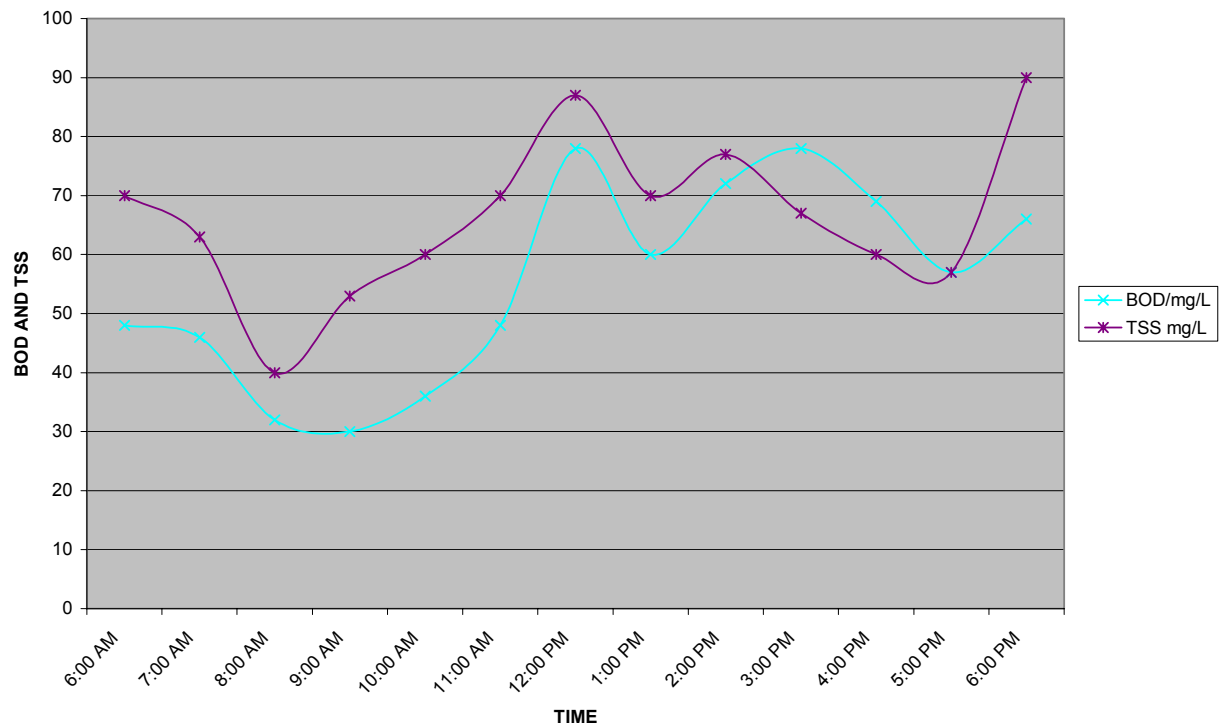
Table 4.3.7.7: <u>Flow Weighted BOD and TSS Results for Headwork, JUNE 16, 2003</u>

DATE	TIME	FLOW READING	DIFFERENCE	WEIGHTED FLOW	ANALYSIS VOLUME	BOD/mg/L	TSS mg/L
6/16/2003	6:00 AM	9107	0			28	42
Monday	7:00 AM	9176	69	0.420731707	8	50	64
	8:00 AM	9252	76	0.463414634	9	44	52
	9:00 AM	9346	94	0.573170732	11	51	125
	10:00 AM	9457	111	0.676829268	14	54	71
	11:00 AM	9548	91	0.554878049	11	33	77
	12:00 PM	9712	164	1	20	60	68
	1:00 PM	9730	18	0.109756098	2	111	108
	2:00 PM	9807	77	0.469512195	9	84	83
	3:00 PM	9885	78	0.475609756	10	93	107
	4:00 PM	9955	70	0.426829268	9	102	130
	5:00 PM	73	118	0.719512195	14	114	160
	6:00 PM	200	127	0.774390244	15	162	260
				FLOW WEIGHTED RESULT		**99**	**103**
				AVERAGE		**79.83333**	**108.75**
			m³	**MGD**			
		flow during sampling	**1093**	**2.4046**			

Refer to **CHART 4.3.7.7**. FROM DAILY FLOW READING THE TOTAL FLOW FOR TODAY = 4.58 MGD (17337 m³/d). THEREFORE 53% OF THE FLOW OCCURS DURING SAMPLING.
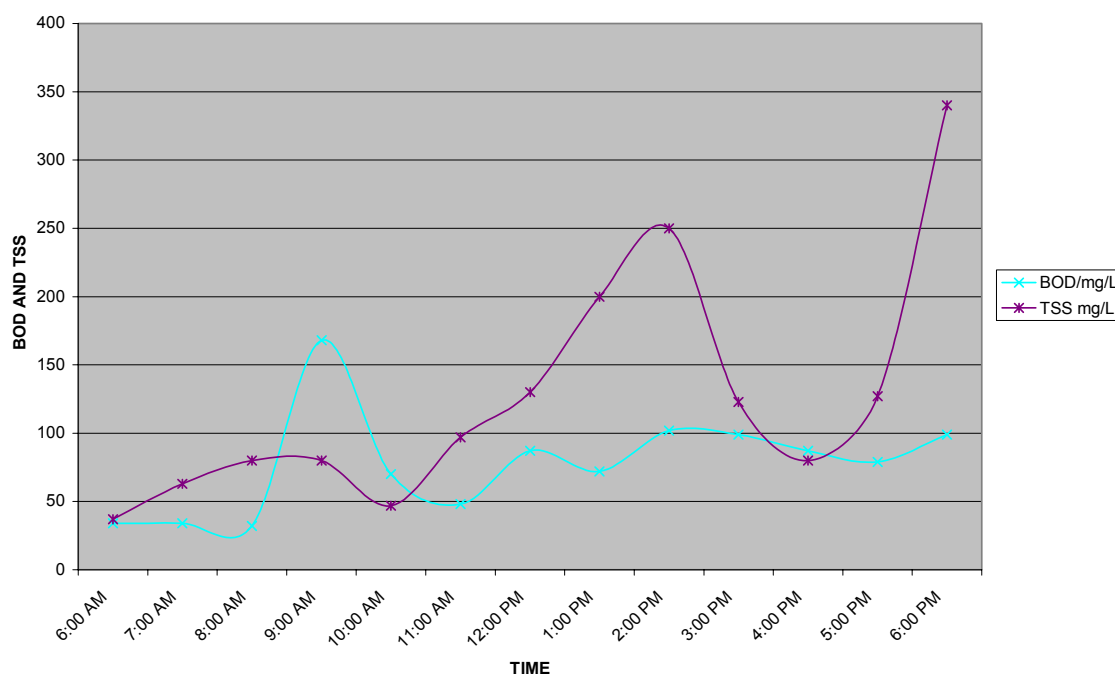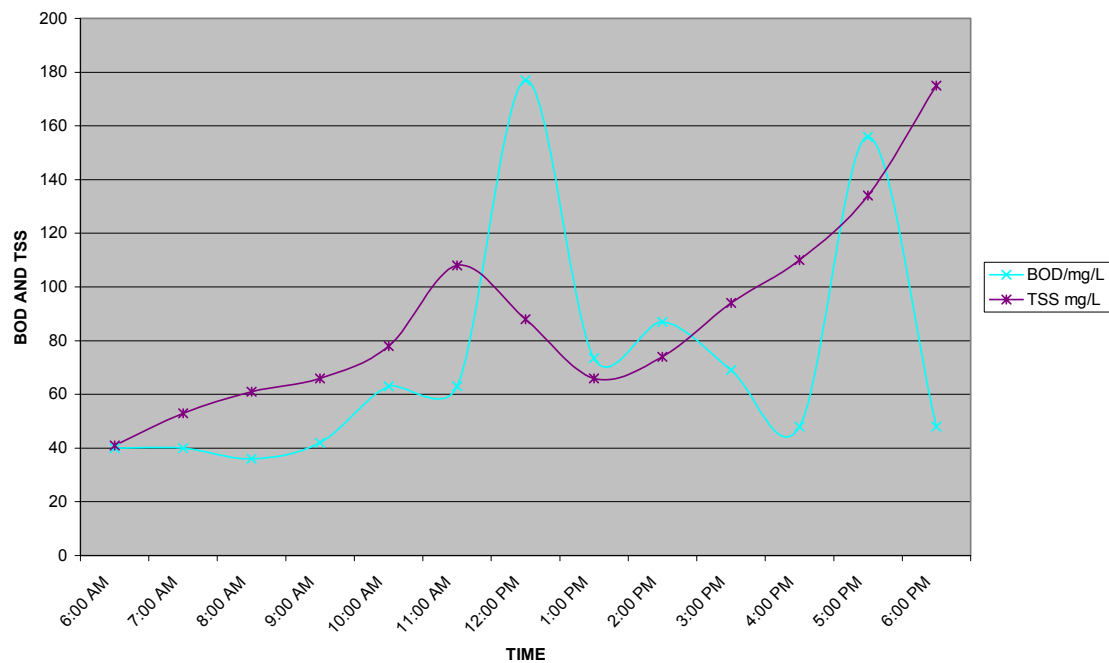
CHART 4.3.7.7: FLOW WEIGHTED BOD AND TSS RESULTS, 6/16/03
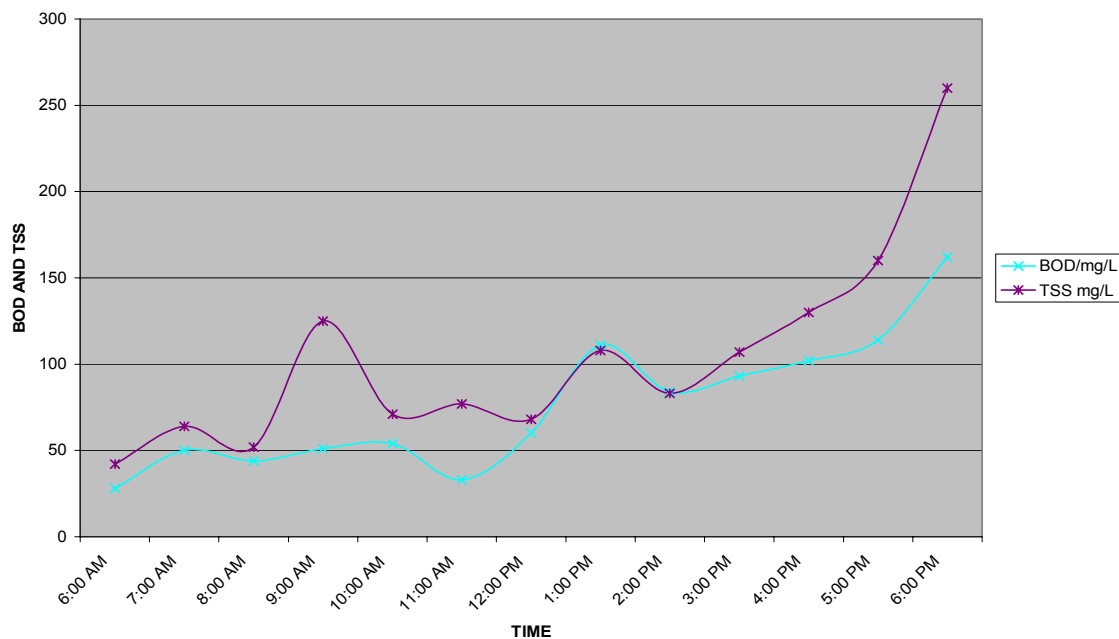
Over the entire sampling period, an average of 53% of the daily flow occurred during sampling. Therefore this was a well chosen sampling period, in that; extrapolation of data to daily averages is valid. In general, BOD started out low in morning and tended to reach maximum between 1200 – 1300 hours. After which time it decreased and then increased again between 1700 – 1800 hours (refer to **CHART 4.3.7.8**). TSS did not show a particular trend over the 12 hours of sampling. There seems to be no definite relationship between variation of BOD and TSS. However, in general, there is a tentative positive correlation, that is an increase in suspended solids saw an increase in BOD values.

Table 4.3.7.8: <u>Median BOD and TSS as a Function of Time</u>

TIME	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM
BOD	48	46	36	48	54	60	78	74	87	78	87	102	78
TSS	54	63	60	63	71	88	84	108	85	98	110	127	190

Refer to **CHART 4.3.7.8**.

CHART 4.3.7.8: COMPARISON OF MEDIAN BOD AND TSS
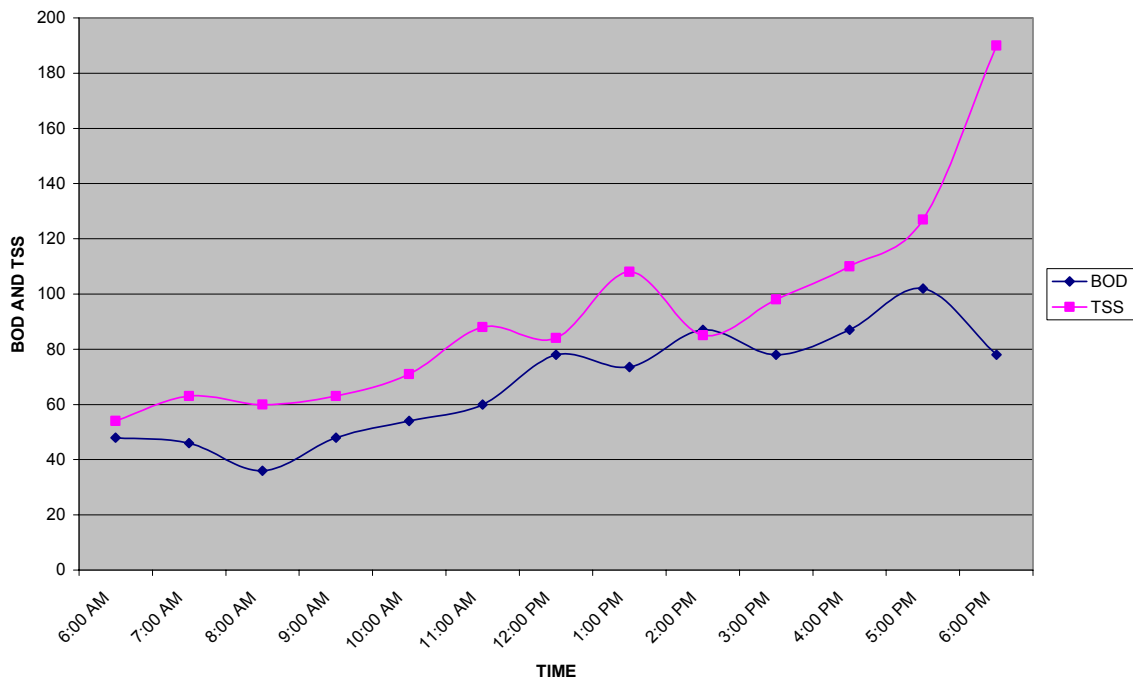
The general trend for BOD concentration is a decrease from 0600 – 0800 hours, after which the concentration increases until around 1200 hours. BOD concentration decreases and then increases again up to about 1700 hours. TSS concentration tends to follow the same general trend as the BOD.

Table 4.3.7.9: <u>Influent BOD Loading Rate</u>

Date	5/7/03	5/15/03	5/23/03	5/31/03	6/3/03	6/8/03	6/16/03
BOD Loading (kg/ha/d)	184	153	234	255	461	298	291

4.3.7.2 Analysis of BOD and TSS for F1

Table 4.3.7.10: Depth Weighted Average for F1 Mid-pond

Date	BOD	TSS
5/7/2003	35.27	125.00
5/15/2003	45.27	193.33
5/23/2003	25.77	96.67

Table 4.3.7.11: Depth Weighted Average for F1 Effluent

Date	BOD	TSS
5/7/2003	23.80	125.67
5/15/2003	38.50	245.67
5/23/2003	26.17	126.67
5/31/2003	37.25	221.00
6/3/2003	43.53	211.00
6/8/2003	42.27	150.00
6/16/2003	20.25	88.33

4.3.7.3 **Analysis of BOD and TSS for M1.1**

Table 4.3.7.12: Depth Weighted Average for M1.1 Mid-pond

Date	BOD	TSS
5/7/2003	29.53	121.67
5/15/2003	37.03	99.33
5/23/2003	44.28	171.00

Table 4.3.7.13: Depth Weighted Average for M1.1 Effluent

Date	BOD	TSS
5/7/2003	22.50	140.00
5/15/2003	34.77	120.00
5/23/2003	29.50	149.67
5/31/2003	22.25	105.33
6/3/2003	39.50	112.00
6/8/2003	38.77	145.00
6/16/2003	27.25	101.33

4.3.7.4 **Analysis of BOD and TSS for M1.2**

Table 4.3.7.14: Depth Weighted Average for M1.2 Mid-pond

Date	BOD	TSS
5/7/2003	26.53	141.67
5/15/2003	26.03	131.33
5/23/2003	25.25	113.33

Table 4.3.7.15: <u>Depth Weighted Average for M1.2 Effluent</u>

Date	BOD	TSS
5/7/2003	21.00	141.67
5/15/2003	32.50	161.00
5/23/2003	32.50	161.00
5/31/2003	32.77	131.00
6/3/2003	26.00	121.00
6/8/2003	40.50	168.67
6/16/2003	22.00	108.33

4.3.7.5 <u>Summary of Variation of BOD and TSS across String</u>

Table 4.3.7.16: <u>Variation of BOD across String</u>

Date	Headwork composite	F1-mid	F1-outlet	M1.1-mid	M1.1-outlet	M1.2-mid	M1.2-outlet
5/7/2003	87	35.27	23.80	29.53	22.50	26.53	21.00
5/15/2003	64	45.27	38.50	37.03	34.77	26.03	32.50
5/23/2003	96	25.77	26.17	44.28	29.50	25.25	32.50
5/31/2003	76.5		37.25		22.25		32.77
6/3/2003	174		43.53		39.50		26.00
6/8/2003	103.5		42.27		38.77		40.50
6/16/2003	99		20.25		27.25		22.00

Table 4.3.7.17: <u>Percentage BOD Removal within Ponds</u>

Date	Pond F1	Pond M1.1	Pond M1.2
5/7/2003	72	8	5
5/15/2003	39	10	6
5/23/2003	73	-15	-10
5/31/2003	52	41	-50
6/3/2003	75	7	35
6/8/2003	60	7	-5
6/16/2003	80	-35	19
	69	63	9
	68	61	-33
	68	49	-67

As much as eighty percent of the incoming BOD is removed in the first pond, Pond F1. This information further confirms the hypothesis and the explanations cited in Section 4.3.5 above; that higher algal activity occurs in the facultative pond and hence explained the seemingly abnormal DO levels even with the higher temperatures that occur in this pond. Further, Arthur (1983) indicated that algal concentration reduced as treatment progress and dissolved nutrient concentrations reduce.

Ponds M1.1 and M1.2 showed negative percentage removal on several occasions. This means that the effluent BOD is greater than the influent values and therefore there seemed to be little or no treatment. However, this is due to re-suspension of sludge. The pond system is located on an old cane field. As a result, there is a high organic matter content in the soil under the lining of the ponds, especially the last two ponds of String one. These decompose anaerobically, giving off gases and causing the lining to float and re-suspend the sludge. The operators made slits in the lining attached to the berms in order to create vents for the gases to escape and put sand bags on the lining inside the ponds to keep the lining from floating.

Table 4.3.7.18: <u>Variation of TSS across String</u>

Date	Headwork composite	F1-mid	F1-outlet	M1.1-mid	M1.1-outlet	M1.2-mid	M1.2-outlet
5/7/2003	110	125.00	125.67	121.67	140.00	141.67	141.67
5/15/2003	84	193.33	245.67	99.33	120.00	131.33	161.00
5/23/2003	-	96.67	126.67	171.00	149.67	113.33	161.00
5/31/2003	233		221.00		105.33		131.00
6/3/2003	94		211.00		112.00		121.00
6/8/2003	50		150.00		145.00		168.67
6/16/2003	103		88.33		101.33		108.33

From the result given in the Table 4.3.7.18 it would appear that the ponds do not remove solids. However, this is not the case. The solids in the pond influent and effluent differ in constituents and source. Influent solids originate from human waste and are the 0.06% component of domestic waste stream referred to in Section 2.2. These are usually about 70% organic matter and about 30% inorganic matter. These solids provide the food for the bacteria, create the oxygen demand on the ponds and are removed during treatment. Effluent solids mainly consist of algae. Algae in their symbiotic relationship with the bacteria produce oxygen and new algal cells. This is one of the main disadvantages of waste stabilization ponds, that is, their inability to meet their TSS effluent requirements without additional treatment to remove solids.

4.3.7.6   ANALYSIS OF NITROGEN REMOVAL ACROSS STRING

Table 4.3.7.19: Ammonia and Total Kjeldahl Nitrogen in Influent, May 23, 2003

Time	NH$_4$-N	TKN	Organic N.
6:00 AM	2.05	20.52	18.47
7:00 AM	0	18.46	18.46
8:00 AM	0	19.83	19.83
9:00 AM	0	13.67	13.67
10:00 AM	3.42	23.93	20.51
11:00 AM	-	-	-
12:00 PM	5.47	25.47	20
1:00 PM	7.18	12.31	5.13
2:00 PM	4.79	9.91	5.12
3:00 PM	6.50	16.75	10.25
4:00 PM	4.10	23.93	19.83
5:00 PM	5.47	22.56	17.09
6:00 PM	6.50	20.85	14.35
Average	**3.79**	**19.02**	**15.23**

Chart 4.3.7.19: Variation of Nitrogen with Time
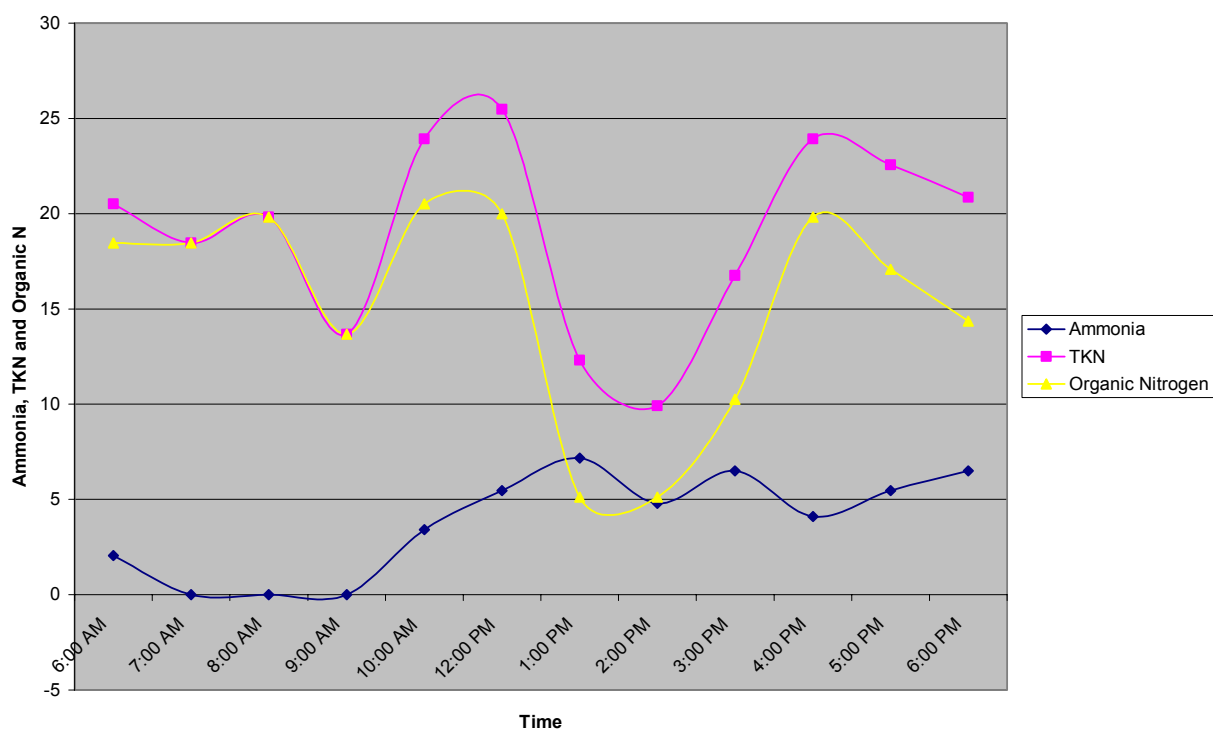
The main nitrogen species in wastewater are organic nitrogen and ammonia.
Ammonia and Total Kjeldahl Nitrogen (TKN) were measured for the samples collected.
TKN is the sum of organic and ammonical nitrogen. Thus column "Organic N." in Table
4.3.7.19 was computed by subtracting Ammonia values from TKN.

Table 4.3.7.20: <u>Ammonia and TKN Removal across String, May 23, 2003</u>

Parameter	Headwork	F1	M1.1	M1.2
NH_4-N	3.79	0	0	0
TKN	19.02	11.96	13.67	14.47

Table 4.3.7.21: <u>Ammonia and Total Kjeldahl Nitrogen in Influent, May 31, 2003</u>

Time	NH_4-N	TKN	Organic N.
6:00 AM	13.16	18.12	4.96
7:00 AM	11.28	14.36	3.08
8:00 AM	9.57	19.14	9.57
9:00 AM	10.26	19.49	9.23
10:00 AM	20.17	26.32	6.15
11:00 AM	16.07	25.98	6.16
12:00 PM	17.09	23.25	9.92
1:00 PM	15.72	25.64	7.86
2:00 PM	16.92	24.78	6.84
3:00 PM	19.14	25.98	9.57
4:00 PM	19.14	28.71	8.2
5:00 PM	20.51	28.71	10.59
6:00 PM	18.12	28.71	7.85
Average	**15.93**	**23.78**	**4.96**

Chart 4.3.7.21:Variation of Nitrogen with Time, 05/31/03
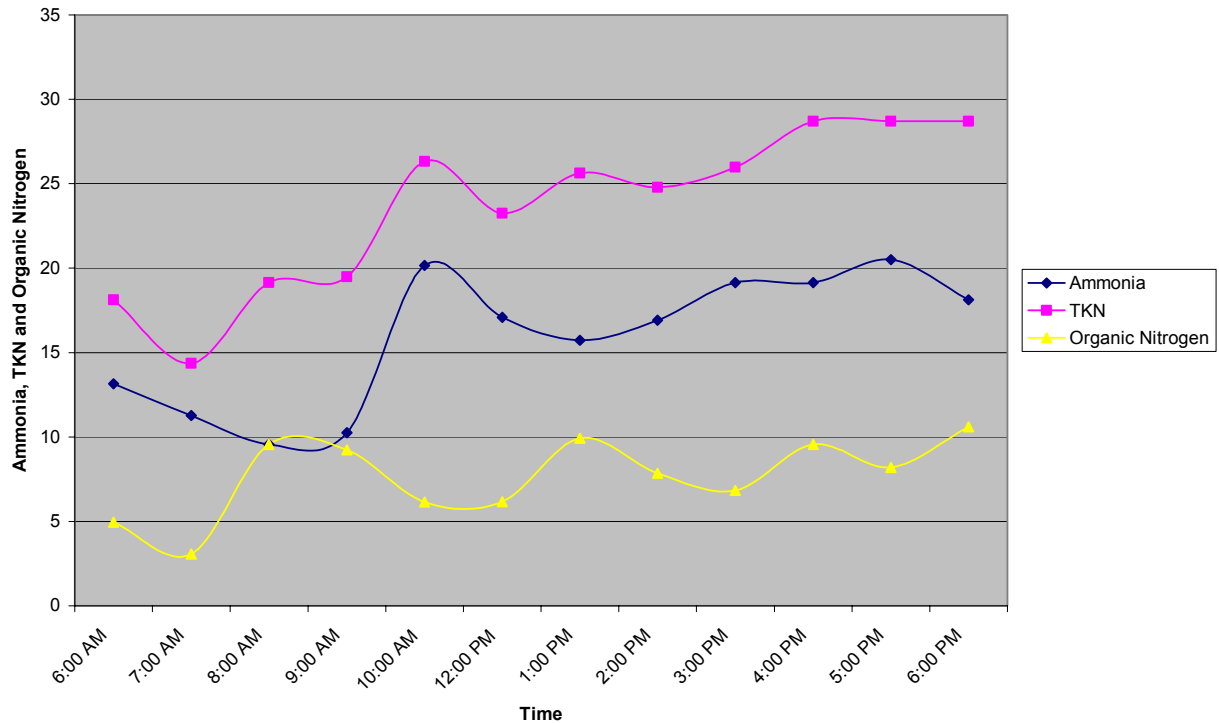
Table 4.3.7.22: <u>Ammonia and TKN Removal across String, May 31, 2003</u>

Parameter	Headwork	F1-mid	F1	M1.1-mid	M1.1	M1.2- mid	M1.2
NH_4-N	15.93	6.55	11.17	3.65	3.87	0.0	0.0
TKN	23.78	23.35	21.99	19.37	19.26	13.85	14.93

The above results agree with the findings of other researchers about the nitrogen composition of domestic wastewater. As stated in Section 2.7, ammonia accounts for 60% of nitrogen found in domestic wastewater, while 40% is organic nitrogen. The findings also agree with Kurosu (2001); Middlebrooks et. al. (1999); Pano and Middlebrooks (1982) and Soares, et al. (1996) about ammonia volatilization being the major removal pathway. Since, it was observed that the ammonia concentration

decreases without any significant decrease in organic nitrogen. Therefore, even though high concentrations of oxygen are available, nitrification of ammonia and organic nitrogen does not seem to be a major pathway. This conclusion is also based on the National Water Commission's monitoring program; nitrate concentration in the effluent has never exceeded 1.08mg/L in the effluent. From this it can be concluded, according to Kurosu (2001), that if nitrate concentration is significant then denitrification is the major pathway. Therefore, nitrification is not a major pathway unless denitrification is also taking place simultaneously. It should be noted that while these results might give some indication of the nitrogen removal process occurring within ponds, these are limited in scope because there simply is not enough trials to be able to deduce a particular trend. As stated in Section 2.7, the major ammonia species dominant at elevated pH is gaseous ammonia. Hence volatilization will take place. These results further indicate the re-suspension of sludge, this is seen where the values of TKN increased especially from Ponds M1.1 to M1.2.

4.3.7.7   <u>Summary of Results</u>

Table 4.3.7.23: <u>Simple Statistic of Chemical Parameters across System</u>

Parameter	Average	Standard Deviation	Minimum	Maximum
BOD	48.18	38.66	15.00	174.00
TSS	134.86	48.20	50.00	245.67
TKN	17.39	4.24	11.96	23.78

Table 4.3.7.24: <u>Pearson Correlation Coefficients (p-value = 0.0001)</u>

	BOD	TSS	TKN
BOD	1.00	-0.20	0.57
TSS	-0.20	1.00	0.74
TKN	0.57	0.74	1.00

Positive correlation exists between BOD and TKN (r^2 = 0.57) and TSS and TKN (r^2 = 0.74). While TSS and BOD (r^2 = -0.2) showed a negative correlation relationship. That is, a reduction in the TKN concentration shows a corresponding reduction in BOD and TSS concentrations. It would therefore be expected that TSS reduction would see a simultaneous decrease in BOD concentration. However, the results do not agree with this hypothesis.

4.4   <u>Phase 3: Determination of Dispersion Number and Retention Time</u>

Esen and Al-Shayji (1999) suggested the use of a least squares method to determine dispersion number 'd' and the reaction rate constant 'k' with Wehner-Wilhelm equation as the basic equation describing the pond performance. A full description of the pond system studied by the above mentioned authors can be found in Esen and Al-Shayji (1999), Esen et. al. (1992) and Puskas et. al. (1991). To develop this procedure, the authors used laboratory ponds of varying depth and flow rates.

The Wehner-Wilhelm equation for chemical reactors exhibiting first order kinetics and non-ideal mixing is given by:

$$\frac{C}{C_o} = \frac{4a\ell^{(1/2d)}}{(1+a)^2 * \ell^{(a/2d)} - (1-a)^2 * \ell^{(-a/2d)}} \qquad (2\text{-}11)$$

Where: C = effluent BOD or nitrogen concentration, mg/l

C_o = influent BOD or nitrogen concentration, mg/l

$$a = \sqrt{1 + 4Ktd}$$

Where: K = the first order reaction rate constant, d^{-1},

t = hydraulic retention time, d,

d = dimensionless dispersion number, where

$$d = \frac{H}{\upsilon * L} = \frac{Ht}{L^2} \qquad (2\text{-}12)$$

Where: H = axial or longitudinal dispersion coefficient, area per unit time,

ν = fluid velocity, m/s

L = length of travel path of a typical particle

Dispersion number 'd' measured in wastewater treatment ponds range from 0.1 to 2.0, with most values less than 1.0 (Reed, et al., 1995). Therefore, assuming' is less than 2 then equation 2-11 becomes

$$\frac{C}{C_o} = \frac{4a}{(1+a)^2} \ell xp^{\left(\frac{1-a}{2d}\right)} \qquad (4\text{-}1)$$

Since for $d \le 2$; $(1+a)^2 * \ell^{(a/2d)} \ggg (1-a)^2 * \ell^{(-a/2d)}$

The least squares method involves, making the Left Hand Side of the equation the dependent variable or observed values 'y' and the Right Hand Side of the equation the independent variable or computed values x and computing the theoretical retention time. The sum of squares of the difference between the observed and computed values S, is then used to compute d and k_T when S becomes minimum.

Let $y = \dfrac{C}{C_o}$ and $b = 4Kd$; therefore equation 4-1 can be rewritten as:

$$\frac{C}{C_o} = \frac{4a}{(1+a)^2}\, \ell xp^{\left(\frac{1-a}{2d}\right)}$$

$$\frac{C}{C_o} = \frac{4(1+4Kdt)^{1/2}}{(1+(1+4Kdt)^{1/2})^2}\, \ell xp^{\left(\frac{1-(1+4Kdt)^{1/2}}{2d}\right)}$$

$$y = \frac{4(1+bt)^{1/2}}{(1+(1+bt)^{1/2})^2}\, \ell xp^{\left(\frac{1-(1+bt)^{1/2}}{2d}\right)}$$

$$let\, \frac{4(1+bt)^{1/2}}{(1+(1+bt)^{1/2})^2} = f$$

$$\therefore y = f\, \ell xp^{\left(\frac{1-(1+bt)^{1/2}}{2d}\right)}$$

The aim is to minimize the error S, where S is given by

$$S = \sum_{i=1}^{n}\left(y - f\, \ell xp^{\left(\frac{1-(1+bt)^{1/2}}{2d}\right)} \right)^2 \quad \text{(4-2)}$$

'y' and $f\, \ell xp^{\left(\frac{1-(1+bt)^{1/2}}{2d}\right)}$ are the observed and computed ratio of effluent to influent BOD concentration where n = total number of observation for all the runs in an experiment. There exist values of 'b' and 'd' for which 'S' becomes minimum. 'b' and 'd' can be

determined by solving the following equations simultaneously (an ambitious and

complex venture):

$$\frac{\partial S}{\partial d} = 0 \quad and \quad \frac{\partial S}{\partial b} = 0 \quad (4\text{-}3)$$

The solution is thus obtained by assuming a value for b and then determine d from

$\frac{\partial S}{\partial d} = 0$. Both values are then used in equation 4-2 to compute S. $\frac{\partial S}{\partial d} = 0$ is determined

as follows:

$$let \ g = \left(\frac{1 - (1 + bt)^{1/2}}{2}\right)$$

$$\therefore S = \sum_{i=1}^{n}\left(y - f \, \ell x p^{\,g/d}\right)^2$$

$$\left(y - f \, \ell x p g \, / d\right)^2$$

$$= y^2 - 2y f \, \ell x p^{\,g/d} + f^2 \, \ell x p^{\,g/d}$$

$$for \ each \ run \ (1 - m) at \ a \ given \ retention \ time$$

$$\frac{\partial S}{\partial d} = 0 - 2y f g \, \ell x p^{\,g/d} + 2 f^2 g \, \ell x p^{\,g/d} = 0$$

$$- 2y f g \, \ell x p^{\,g/d} + 2 f^2 g \, \ell x p^{\,g/d} = 0$$

$$y f g \, \ell x p^{\,g/d} = f^2 g \, \ell x p^{\,g/d}$$
$$solving \ for \ d \ gives :$$

$$d = \frac{g}{Ln\left(\dfrac{yfg}{f^2 g}\right)}$$

Using the above equations and the least squares procedure in SAS, the K and d for the pond system was determined. The results obtained for this project was limited for use in this procedure, due to the fact that the depth remained constant and the influent flow rate could not be maintained. However, using the result and the theoretical retention time, it was found that with dispersion coefficient = 0.1, then the reaction rate k_T = 0.39 d^{-1}. This value is highly questionable, since the sample size is small and the relevant parameters were not varied as carried out in the literature.

Reed et. al. (1995) used a trial and error method with the Wehner-Wilhelm equation to determine the hydraulic retention time. The plug flow reaction rate constant equation (equation 2-8) is used to determine the rate constant for the dispersion equation (equation 2-11). The example listed below used the influent BOD concentration from the Headworks (C_o = 87mg/L), the effluent from Pond F1 (C = 23.8mg/L), the temperature (T = 29.66 ^{o}C) for the sampling done on May 7, 2003, the reaction rate constant at 20°C (K_{20} = 0.1d^{-1}) and the dispersion number (d=0.1), the retention time for Pond F1 is determined below.

1. Calculate k_T using equation 2-8

$$K_t = K_{20}(1.09)^{T-20} \qquad (2\text{-}8)$$

$$= 0.1*(1.09)^{29.66-20}$$

$$= 0.23 \ d^{-1}$$

2. Using an assumed value for the retention time (t = 5.6), and solve for "a"

$$a = \sqrt{1 + 4Ktd}$$

$$= (1 + 4*0.23*0.1*5.6)^{0.5}$$

$$= 1.23$$

3. Using the influent and effluent BOD concentrations calculate the LHS of the equation, and using the calculated a from 2 above calculate the RHS to determine if both are equal:

$$\frac{C}{C_o} = \frac{4a\ell^{(1/2d)}}{(1+a)^2 * \ell^{(a/2d)} - (1-a)^2 * \ell^{(-a/2d)}} \qquad (2\text{-}11)$$

$$\frac{C}{C_o} = \frac{23.8}{87} = 0.273563$$

$$= \frac{4*1.23*\ell^{(1/2*1.23)}}{(1+1.23)^2 * \ell^{(1.23/2*1.23)} - (1-1.23)^2 \ell^{(-1.23/2*1.23)}}$$

$$= 0.275976$$

These iterations were computed for all seven sampling results. The retention time t was varied until the C/C_o column approximately equal to the calculated C/C_o column. The average retention time, calculated from the resulting values was found to be 4.9 days and the results are presented in Table 4.4.1. The theoretical retention time for the May 7, 2003 can be calculated using the following equation:

$$t = \frac{V}{Q} = \frac{Area * depth}{Q}$$

$$= \frac{58958m^2 * 1.3m}{12492m^3 / d}$$

$$= 6.14d$$

Table 4.4.2 presents the result of a similar trial and error method as that in Table 4.4.1, but this time using the Plug flow equation. The average retention time for the dispersion flow, plug flow and the calculated theoretical retention time are found to be 3.67 days, 3.29 days and 5.04 days respectively. The calculated retention time was not found to approximately one half of the theoretical retention time as stated in the literature, this may be due to the presence of the baffles which lengthen the flow path

and increase the actual retention time. It is noted the retention time given by the plug flow equation is more conservative than the dispersion flow equation, this confirms the findings in the literature. That is, the dispersion flow equation assumes that some of the molecules are dispersed within the water column, hence the average age distribution of the molecules increases, while for plug flow there is no axial mixing hence the time is less.

Due to the re-suspension of sludge, the above approaches cannot be applied to Ponds M1.1 and M1.2, since the underlying assumption is that of a chemical reactor with no solid recirculation (Section 2.9). Therefore only the theoretical retention time will be calculated. The flow into Ponds M1.1. and M1.2 can be determined from the following equation for flow over a sharp edge weir:

$$Q = 0.66 * K * L * (2g)^{0.66} * H^{1.5}$$

Where: Q = water flow rate, m^3/s

L = width of weir, m

K = discharge coefficient ~ 0.62

g = $9.81 m/s^2$

H = height of water over weir measured behind the weir edge, m

NB. If the weir is narrower than the channel feeding it shorten L by 0.2H

For both ponds the weir was set to an upstream head of 1.3m with H = 0.2m. Therefore, the flow into the ponds is as follows (Roberson et. al. (1998)):

$$Q = 0.66 * 0.62 * (1.5 - 0.2 * 0.3) * (2 * 9.81)^{0.66} * 0.2^{1.5}$$
$$= 0.235 m^3 / s$$
$$= 20,304 m^3 / d$$

Theoretical retention time:

$$t_R = \frac{V}{Q} \qquad\qquad (3\text{-}3)$$

For Pond M1.1:

$$t_R = \frac{V}{Q}$$
$$= \frac{38363}{20304}$$
$$\approx 1.9d$$

For Pond M1.2:

$$t_R = \frac{V}{Q}$$
$$= \frac{35862}{20304}$$
$$\approx 1.8d$$

It should be noted that even this theoretical value may be incorrect, since currently the pond lining is floating and this causes a reduction in the pond volume.

Table 4.4.1: **Trial and Error Method for Retention Time Estimation (Wehner-Wilhelm)**

C	C$_O$	K$_{20}$	D	Q	T	k$_T$	t	a	C$_e$/C$_o$	CAL C$_e$/C$_o$
23.8	87	0.15	0.1	12492	29.66	0.344851	4.20	1.257	0.273563	0.273451
38.5	64	0.15	0.1	14119	30.41	0.367876	1.45	1.102	0.601563	0.600504
26.17	96	0.15	0.1	14384	29.39	0.336919	4.31	1.257	0.272604	0.272622
37.25	81	0.15	0.1	18435	28.45	0.310703	2.68	1.155	0.459877	0.459277
43.53	174	0.15	0.1	15633	29.06	0.327473	4.75	1.274	0.250172	0.250858
42.27	104	0.15	0.1	15633	30.05	0.356638	2.79	1.182	0.406442	0.398967
20.25	99	0.15	0.1	17337	29.21	0.331733	5.49	1.315	0.204545	0.203466
						Average	3.67			

Table 4.4.2: **Trial and Error Method for Retention Time Estimation (Plug Flow)**

C$_e$	C$_O$	K$_{20}$	Q	T	K$_t$	t	C$_e$/C$_o$	CAL C$_e$/C$_o$	Theoretical t
23.8	87	0.1	12492	29.66	0.229901	5.6	0.273563	0.275976	6.135607
38.5	64	0.1	14119	30.41	0.24525	2.05	0.601563	0.604857	5.428571
26.17	96	0.1	14384	29.39	0.224613	5.8	0.272604	0.271782	5.32856
37.25	81	0.1	18435	28.45	0.207135	3.8	0.459877	0.455157	4.157635
43.53	174	0.1	15633	29.06	0.218315	6.35	0.250172	0.249998	4.902834
42.27	104	0.1	15633	30.05	0.237759	3.8	0.406442	0.405156	4.902834
20.25	99	0.1	17337	29.21	0.221156	7.2	0.204545	0.203453	4.420949
					Average	4.94285714			5.03957

4.5   Grease Trap Audit Result

Of the one hundred food preparation establishment audited, 44 percent did not have grease traps. For those that had grease traps, the major problems were inadequate traps for the expected flow and the cleaning and maintenance of the traps. Most places were unsure as to what to do with the grease trap contents when the traps were cleaned. Therefore, there needs to be some sort of policy as to where and how grease trap contents should be disposed of. Also, there was no schedule as to when traps were inspected, cleaned and otherwise maintained. It is proposed the North Coast Wastewater District do follow up visits and require that a maintenance schedule be posted and make ready for inspection. Results of the actual audit are presented in Appendix 4.1.

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5   DISCUSSION AND CONCLUSION

5.1   Chapter Overview

The chapter starts by revisiting the objectives put forward in Chapter 1. The findings from monitoring and sampling for the physiochemical and chemical parameters are presented with corresponding discussions of these findings. The discussion continues with a statistical analysis of the parameters and a subsequent explanation of the results. The analysis for the hydraulic retention time is then presented, followed by the major challenges experienced since the ponds was been commissioned and also during this project. Recommendations that were used to deal with these issues during the project and for future situations are then presented. Finally, recommendations for future studies are listed and encouraged.

5.2   Objectives Revisited

The ability to reliably predict the fluid flow through a pond and relate these hydraulic characteristics to pond treatment performance will clearly be a very valuable tool to the design engineer and treatment system operation manager (Shilton, 2000). This means that once the retention time, removal and dispersion coefficient are determined then the appropriate flow equation (Plug, Complete mixed or Dispersed Flow) can be used to predict the degree of treatment of incoming pollutants. Based on this mandate the following objectives were presented in Section 1.4.

The specific objectives of the project are:

1. To design and perform dye tracing studies to determine the actual hydraulic retention time and dispersion coefficient. Therefore, the hydraulic flow regime present in the ponds can be ascertained.

2. To determine input and output concentrations of BOD and nitrogen in order to evaluate the treatment coefficient, which will describe the kinetics of the treatment mechanisms occurring in the pond.

3. Using the above information, the future treatment of incoming waste can be predicted.

5.3   Physiochemical and Chemical Parameters

The average and maximum temperatures over the String were 29.2 and 31.73 ^{o}C respectively. The general trend is an increase in temperature from the Headwork to Pond F1 and then a decrease thereafter. F1 consistently showed the highest temperature in the system. The possible reason for this is the fact that it is at a higher elevation than the other ponds. This is further confirmed by the fact that the temperatures for M1.1 and M1.2, which are at the same elevation, hardly differed. A higher temperature is theoretically indicative of a higher metabolic rate and hence more algae production and activity. That is, higher BOD reduction and subsequent variation in other temperature dependent parameters should confirm this hypothesis. This is confirmed by the fact that 50-80% of the incoming BOD is removed in F1 (Please refer to weekly sampling results located under Table 4.3.7.17).

The String experienced an average and maximum dissolved oxygen concentration of 8.03 and 16.15 mg/L. Dissolved oxygen is lowest at the Headwork,
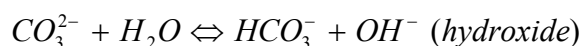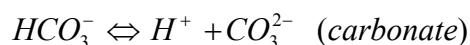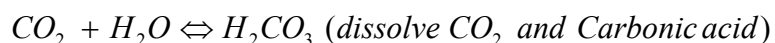
highest in F1, decreases and then increases in Ponds M1.1 and M1.2 respectively. Dissolved oxygen is highly temperature dependent and typically shows an inverse relationship. Thus, theoretically the pond with the higher temperature (F1) should have the lower oxygen concentration. However, this is not the case, since F1 had the higher oxygen concentration. This further confirms the above mentioned hypothesis of higher metabolic and algae activities occurring in F1. This seeming anomaly is easily explained. Dissolved oxygen is primarily provided by photosynthesis of the insitu algae population. Thus, higher algal metabolism which results from higher temperatures will result in a higher photosynthetic activity and thus higher dissolved oxygen. Notice that the inverse relationship is noticeably evident in the maturation pond (where the BOD loading is considerably reduced and therefore the algal activity along with it), that is, M1.1 with the relatively larger temperature had the smaller average dissolved oxygen. As seen from the literature, algal activity is a function of the BOD loading. Therefore, algal activity is not as dominant in the maturation ponds as the facultative pond, since up to 80% of the BOD is already removed. The very low dissolved oxygen at the Headwork is within normal expectations as explained in Section 4.2.1.

As expected the Headwork had the lowest pH values, with the String experiencing pH ranges of an average of 8.76 and a maximum of 10.19. pH tends to increase as the water travels across the ponds, with M1.2 showing the highest average pH. pH is a function of algal and bacterial activity. That is, the algae photosynthetic and bacterial activities use up or produce carbonate and bicarbonate ions resulting in variation of pH across the String.

The specific conductivity is highest at the Headwork and decreases as the water moved from Headwork to the final effluent, with M1.2 showing the lowest Conductivity. Average and maximum values observed over the sampling period are 998 and 1610 μS respectively. This as a result of the removal of ions and other solutes, such as organic matter, nutrients and inorganic ions from the water as it passes through the system.

5.4   Correlation Relationships of Physiochemical and Chemical Parameters

Of the many chemical characteristics of wastewater, the most important in terms of potential algal manipulation of water quality is the carbonate-bicarbonate alkalinity system (King, 1976). Therefore, the interaction among the physiochemical parameters are usually based on the existing equilibrium characteristics of this alkaline system. In ponds, the system is manipulated via the release or absorption of Carbon dioxide as illustrated by the following equations (Peavy, et. al., 1985):

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \; (dissolve \; CO_2 \; and \; Carbonic \; acid)$$
$$H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \; (bicarbonate)$$
$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-} \; (carbonate)$$
$$CO_3^{2-} + H_2O \Leftrightarrow HCO_3^- + OH^- \; (hydroxide)$$

In algae free natural systems the temperature-dissolved oxygen (DO) relationships are negatively correlated. That is, an increase in temperature would decrease the oxygen solubility in water, thus reducing the concentration of dissolved oxygen. However, in ponds where there is an abundance of algae, producing oxygen, an increase in temperature produces a subsequent increase in photosynthetic activity and a corresponding increase in oxygen concentration, hence the strong positive correlation observed in Section 4.3.6. The rate of oxygen production is greatest in mid

morning when free carbon dioxide is present at significantly higher levels than later in the day. It must be noted however, that during daylight, the carbon dioxide from bacterial respiration is important, but an even more important carbon source is the carbonate-bicarbonate system (King, 1976; Konig, 1987). Therefore, with carbon dioxide recharge to and the removal from the carbonate-bicarbonate system the pH of the system is modified.

When carbon dioxide is removed from the system the pH increases, that is, the ponds become more alkaline (Eckenfelder and O'Connor, 1961; Gray, 1989; Warren, 1971). The following equation illustrates this (Mudrack and Kunst, 1983):

$$Ca(HCO_3)_2 \xrightarrow{-CO_2} CaCO_3 + H_2O \xrightarrow{-CO_2} Ca(OH)_2$$
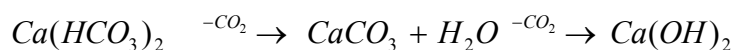
Hence, an increase in temperature produces a corresponding increase in algal photosynthetic activities, which increases the Carbon dioxide concentration removal from the system, resulting in an increase in pH. Thus, this explains the observed positive correlations between temperature and DO, DO and pH and hence, between temperature and pH.

However, algal activity is often self limiting by interacting feed-back mechanisms generated by rapid extraction of required materials by the algae from the water (King, 1976). That is, DO for example, will not linearly increase indefinitely with pH, since too high a pH causes inhibition of algal photosynthesis especially if there is a concurrent high ammonia concentration (Borowitzka, 1998). In addition, photosynthetic activity of the algae is further reduced because the amount of nitrogen required by the algae to fix a given amount of carbon increases with more alkaline pH. Further, reaction mechanisms have their limiting factors, for example, the conversion of carbonate to

bicarbonate is essentially completed at pH 8.3, while above pH 9 all the inorganic carbon is in the carbonate form and which is biologically unavailable to the algae for photosynthetic activities (Borowitzka, 1998; King, 1976; Peavy, et. al., 1985). The average pH observed in the Montego Bay system was 8.76.

From the correlation results there is a negative correlation between pH and conductivity. From section 4.3.5, it was observed that pH increased across the system while conductivity decreases. This could be that two mutually exclusive mechanisms are responsible for this. Namely, pH increases due to algal activity described above, while conductivity decreases due to removal of pollutants and the two are mutually exclusive and not necessarily related. However, with a correlation coefficient as high as r^2 = -0.81 this explanation seems unlikely. Hence a second explanation could be: conductivity is a function of the concentration of free ions in solution and the ability of those ions to move (please refer to section 3.2.2.4). Above pH 8, phosphates are precipitated out as calcium phosphate, and ammonium ion is volatilized out of solution (Konig, 1987; Gray, 1989). Further, as pH rises, the bicarbonate alkalinity shifts towards carbonate alkalinity form, the larger molecular weight cations begin to form insoluble carbonates and hydroxyphosphates complexes which settle out of solution (McKinney, 1976). Thus ions are taken out of solution and the result is a reduction in conductivity. This explanation also holds true for the negative correlation observed between DO and conductivity.

The relatively small and negative correlation between temperature and conductivity is surprising. It is usual that an increase in temperature causes the ions to be more mobile, and hence conductivity should be positively related to temperature. However, algal manipulation of the carbonate-bicarbonate system overrides this trend.

Positive correlation exists between BOD and TKN (r^2 = 0.57) and TSS and TKN (r^2 = 0.74), while TSS and BOD (r^2 = -0.2) showed a negative correlation relationship. These relationships are consistent with those found in literature. As implied above, bacteria require nitrogen for carbon assimilation. That is, with BOD removal, nitrogen is also subsequently removed, hence the positive relationship between BOD and TKN. TKN and TSS are also highly positively correlated. That is, TSS removal is concurrent with a subsequent reduction in TKN. As stated in Section 4.3.7.3, that there are different sources of TSS. It is most likely that this TSS is not from algal sources, but rather from incoming solids.

The relatively small negative correlation between BOD and TSS is surprising. That is, as the suspended solids are removed it is expected that the BOD would also reduce, resulting in a positive correlation. However, this is true for the incoming influent solids. However, the increase in algal solids with the decrease in BOD across the String, outweigh this trend, hence the relatively small negative correlation.

The designers of the Montego Bay pond system projected that the percentage BOD removal from the Facultative and the Maturation ponds are 80% and 33% respectively. It was found that percentage removal from the Facultative pond ranged from 39-80%. The Maturation ponds are currently recycling solids and so BOD values are not indicative of the removal processes occurring in the ponds. However, the positive BOD removal values ranged from 5% - 63%. It is therefore possible to tentatively predict that approximately 50% of the influent BOD organic loading will be removed by the Facultative pond while the removal efficiency of the maturation ponds is about 30%.

The major nitrogen pathway seemed to be ammonia volatilization, however due to the small sample size, the results obtained offer limited scope for extrapolation. The findings confirmed the observations in the literature, in that about 60% of the incoming nitrogen is in the form of ammonia, while the other 40% is organic or particulate nitrogen. The ponds were found to be very efficient at removing ammonia nitrogen, while about 30% of the incoming TKN is removed from the system.

5.5   Determination of Retention Time

One of the primary objectives of this thesis project was to determine the actual retention time of the ponds using the most accurate procedure available, dye tracing. However, when this did not work out, two analytical methods where undertaken. These procedures have as their underlying assumption; that the behavior of the ponds is similar to chemical reactors with no solid recycling. Due to the re-suspension occurring in the maturation ponds, these procedures cannot be applied to them and thus the theoretical retention time had to be calculated for them.

For the Facultative pond, it was found that the retention time was 3.67 and 4.9 days using the dispersion (with an assumed dispersion number of 0.1) and plug flow equations respectively. The theoretical retention time was found to be approximately 5 days. Using the least squares method it was found that the removal coefficient k_T was 0.39 d^{-1}. Thus, the "actual" retention time was not found to be half of the theoretical retention time as stated in the literature. This could be due to the presence of baffles. Pond M1.1 had a theoretical retention time of 1.9 days, while Pond M1.2 theoretical retention time was 1.8 days.

5.6 <u>Major Issues</u>

Since the ponds have been operational and while working on this project a number of challenges where encountered. In recent years the National Water Commission (NWC) has received numerous complaints from near by residents of Bogue Heights about odor from the treatment works. These complaints arose whenever an extensive algae mat developed and covered extensive portions of the facultative ponds. In response to these complaints, the NWC would channel flow to new strings (a string has three ponds in series) and skim the surface of the facultative ponds on a regular basis. This has resulted in additional and significant operational cost of up to US$ 40/truck. In addition even the best efforts of the operators have occasionally failed to prevent the rapid evolution of odors from the works as the algae mat forms.

In addition the effluent from the system has been assessed by the Natural Resources Conservation Authority (NRCA) and a requested for a reduction of the suspended solids concentrations was made. In summary, the major issues are as follows:

1. The Bogue Sewage Treatment Works, whilst operating well under its capacity, has failed on numerous occasions, being the source of numerous complaints arising from the generation of odor from the site.

2. The operational adjustments made by the National Water Commission (NWC) to alleviate the odor problem have resulted in additional costs.

3. High suspended solids concentrations in the final effluent of the waste stabilization pond system have raised concerns from the NRCA.

4. It was found that when all ponds or at least two Strings were operational, the system tended to fail, and odor evolved. Table 5.1 below shows the empirically determined time, after the initiation of flow in all three Strings that the ponds start failing.

Table 5.1: Showing Time to Failure (All Strings are Simultaneously Online)

Pond	Time to Failure
F1	Continuously
F2	2 Weeks
F3	1 Week

5. The location of the ponds was previously a cane field. As a result, there is high organic matter content in the soil under the pond linings especially of the Maturation Ponds. These decompose anaerobically, giving off gases and causing the lining to float and for settled sludge to be resuspended.

5.6.1 Solutions and Recommendations to Challenges

The odor problems arose when the ponds were failing and this normally occurred when more than one strings were receiving flow. Currently the system is receiving about a third of its designed capacity. Thus, only one string needs to be operational at this time. When two or more strings are online, the flow to each String is reduced and the hydraulic loading is not enough to push the flow, hence the pond stagnates and become anoxic and finally anaerobic. For the duration of this project, only String one was

operational. When it did fail, it was because the influx of greasy influent. The organic loading was reduced by adding fresh water from a near by water hydrant to the influent.

Waste stabilization pond systems are recognized to be a low cost and "appropriate" wastewater treatment technique. They are particularly suitable for small communities in developed countries and for developing countries. However, they have some serious drawbacks. A major limitation is the high concentration of total suspended solids in their effluent that is mainly due to large quantities of algal cells (Saidam, et. al., 1995). There is therefore a great need to overcome the apparent inability of ponds to produce superior effluent. However, direct harvesting of algae is costly and complicated procedure (Zhen-bin, et. al., 1993). Various researchers propose a number of solutions, a few of which are listed here. Suggestions include, rock filters, macrophytes and biological trickling filter. Arthur (1983) suggested a pebble bed clarifier or a horizontal rock filter which may be constructed in the pond adjacent to the outlet, which can reduce algal concentration by about 50%. O'Brien (1976) and Saidam, et. al. (1995) also recommended the use of rock filters but achieved a 60% removal with a capital increase in operating cost of about 5.4%. Meiring and Huyssteen (1990); Meiring and Oellermann (1995) suggested the use of biological trickling filters. While the use of sand filters was proposed by Somiya, et. al. (1987).

Floating and/or emergent macrophytes were used by Arthur (1983); Perdomo, et. al, (1999); Van der Steen et. al. 1998; and Zhen-bin, et. al.(1993). Macrophytes used included water lilies, water hyacinths, large duckweeds, water lettuce, and water peanuts. These compete with algae for light, nutrient and space, thus reducing algal concentrations. Also macrophytes excrete some organic matter from their rhizosphere

which injure and kill the algal cells. Zhen-bin, et. al. (1993) reported up to 70% removal success with macrophytes.

Snider (1976) suggested the use of Air flotation to remove the algae from the effluent. In this process, the presence of the suspended algae or alum-algae floc catalyzes the formation of small oxygen bubbles that results from a change in the oxygen partial pressure. The bubbles then attach themselves to the floc and rise to the surface. Algal flocculation with Aluminum Sulfate followed by flotation is also possible (Sandbank and Shelef, 1987). Finally, Arthur (1993) proposed that drawing the effluent off from below the algal rich surface layers remained the best method of reducing algal concentration. Although the outlet of the effluent ponds took from below the water surface, algal cells are found over almost the entire water column. Thus this would not be a viable option for this ponds system. The most economically and operationally viable option would be the use of macrophytes.

On both occasions when the samples were analyzed for nitrogen, the effluent total nitrogen concentration exceeded the lower limit of National Resource Conservation Agency (NRCA's) nitrogen standards (10mg/L). Horne (1995) suggested the use of Free-Surface Wetland to reduce nitrogen concentrations. However, the macrophytes suggested, could also be use to lower the nitrogen content in the effluent while simultaneously lowering the suspended solids concentration.

5.7   <u>**Recommendations for Future Studies**</u>

The equations used in this experiment assumed steady state conditions. Enzymic reactions does not of necessity approach a steady state, that is,

concentrations of the various substances which are present will oscillate continuously about particular values (Denbigh and Turner, 1984). Thus, with this in mind, preliminary analysis for COD should be carried out over at least twice the retention time on a daily basis to determine what this "particular value" is.

In order to facilitate correlation computations between physiochemical and chemical parameters, the sampling for chemical parameters should be done over the entire monitoring period with greater frequency. Since, over 53% of the flow occurred during the sampling period, this was as well chosen time and can be used in future studies.

For this experiment, the dye tracer studies had to be abandoned for a number of reasons. However, future dye tracing experiments should make use of an automatic sampler. Shilton and Harrison (2003) suggested using three liters of Rhodamine WT per 10 million liters of pond water. Therefore at least 66 liters of dye will be required for this system, with a safety factor put in to facilitate quenching by clothes brighteners. A suggestion is to put the dye at the inlet of each pond, so that the experimental period would be shortened.

5.8   On a Final Note

The retention times for F1, M1.1 and M1.2 were found to be 3.67, 1.9 and 1.8 days respectively. The removal coefficient was found to be 0.39 d-1, with BOD treatment efficiencies of 50-80% in the Facultative pond and 30% in the Maturation ponds. The major removal pathway for nitrogen removal seemed to be ammonia volatilization. Thus, the objectives revisited in Section 5.2 above are fulfilled. While the

system has suffered many set backs and have faced many unforeseen challenges, it is

basically operating at efficiencies projected by the designers.

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APPENDIX 3.1: PRELIMINARY TREATMENT WORKS

HEADWORKS
OUTLET

HEADWORKS
INLET

PLAN OF INLET WORKS
SCALE 1:100

BAR SCREENS
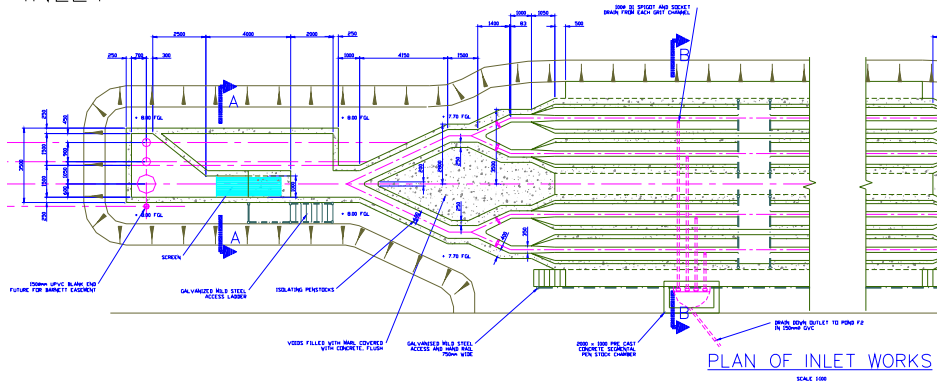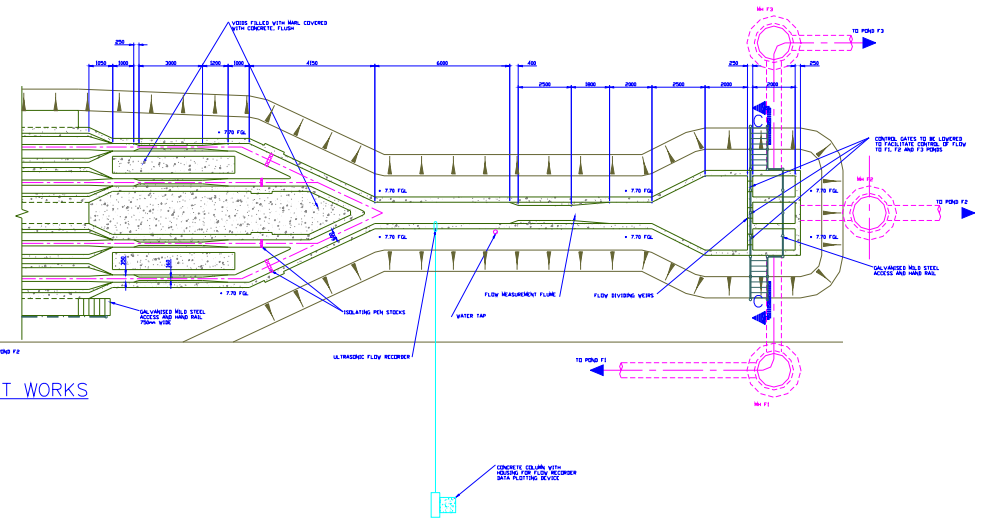
APPENDIX 3.2: WASTE STABILIZATION PONDS
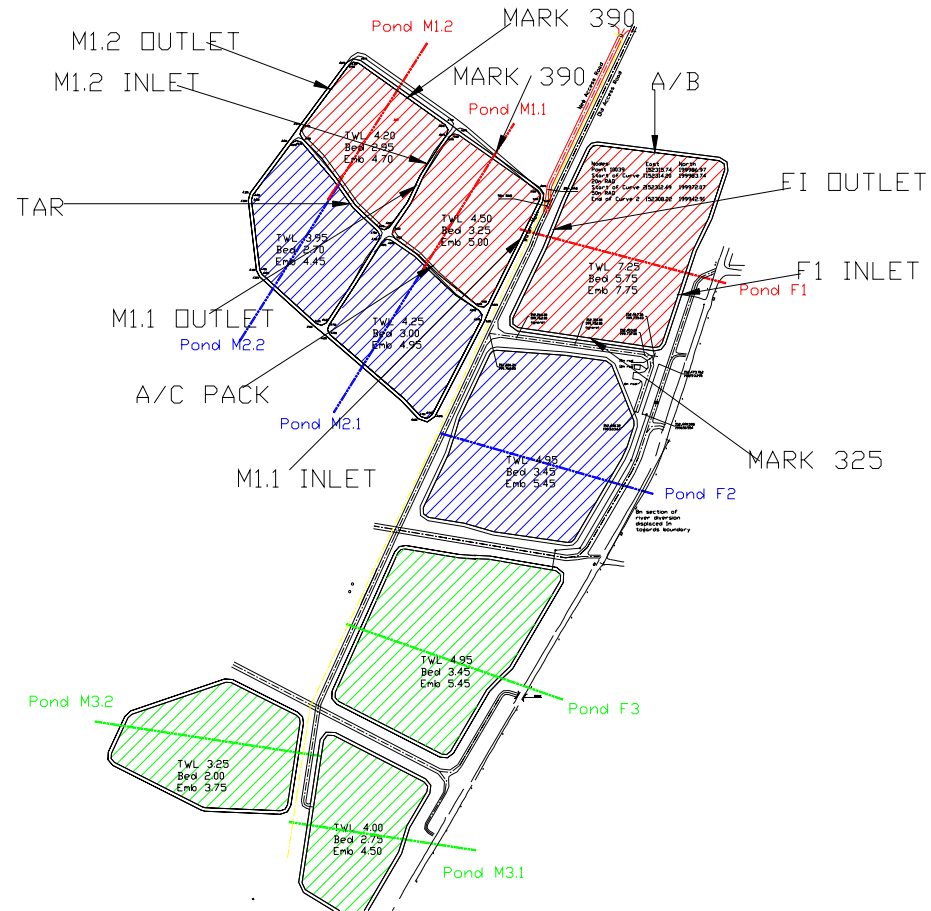
 APPENDIX 4.1: RESULTS OF GREASE TRAP AUDIT

Name of Facility	Contact Info	Address	G. Trap	Trap Dimensions			Maintenance	Comment
				Length (mm)	Width (mm)	Depth(mm)		
Pork-Knockers II Jerk Center/ Buccaneers	Tanya/ Owner: 971-3753	Kent Ave.	No	-	-	-	-	-
Sandals Inn	Oswald Campbell/ Patrick Rose (Steward/ Maintenance Manager): 952-4140	Kent Ave.	Yes	1600	1280	1520	Cleaned weekly, cesspool truck take away content	u-shaped inlet t slow flow into trap – good idea. However, outlet is at the same height as inlet to second chamber, should be higher
Montego Bay Beach Resort	Clinto Chin/ Kelvin Campbell (Maintenance Eng.): 952-4340	Gloucester Ave.	Yes	970	790	1170	Not maintained on a regular basis	Needs cleaning
Bullseye Steak and Seafood	Nadia Anderson (Ass. Manager)	Gloucester Ave.	No	-	-	-	-	-

Name of Facility	Contact Info	Address	G. Trap	Trap Dimensions			Maintenance	Comment
				Length (mm)	Width (mm)	Depth (mm)		
Breezes Resort	Winston Burke/ Peter Williams Sanitation Manager/ Electronic Eng 940-1150	Gloucester Ave	Yes	900	900	700	Cleaned weekly – 2-3 times depending on flow	Inlet needs to below water surface
Doctor's Cave Beach Hotel	Lennox McCleod/ Plumber	Gloucester Ave.	Yes	420	420	660	Not frequently	Insufficient for expected flows, poor design
Gloustershire Hotel	Veviene McDonald/ General Manager 952-4420	Gloucester Ave.	No	-	-	-	-	Takes grease from deep fryer and contracted to Ryco-Ja
Akbar/ The Garden	T.R. Praveen/ Manager: 940-4384	Gloucester Ave.	No	-	-	-	-	-
Coral Cliff	Mr. McDonald/ Mr. Ivey (Purchasing Manager/ Maintenance) : 952-4130-1	Gloucester Ave.	Yes	610	610	305	Checked every morning and cleaned as necessary	Grease from trap put with garbage. Capacity insufficient for expected flow
Burger King	Aretha Brown (District Operation Manager): 399-4259, 940-5015	Gloucester Ave.	Yes	3048	1423	1219	Inspected weekly and cleaned as necessary	Capacity 1200 gal
Pelican Restaurant	Glenroy Dixon (Maintenance Manager): 952-3171	Gloucester Ave.	Yes	610	610	914	Inspected daily cleaned as needed	Capacity insufficient for expected flow. Require baffle at inlet, outlet should be deeper

Name of Facility	Contact Info	Address	G. Trap	Trap Measurement			Maintenance	Comment
				Length	Width	Depth		
KFC	Denise Hall (Shift Supervisor): 971-5356	Howard Cooke Blvd	Yes	3448	2134	1538	Maintained once/month	Well designed
Pizza Hut	Charmaine Palmer (Manager): 971-5380	Same	As	Above	Same	As	Above	
McDonalds	Donovon Grignon (Manager): 940-6820	Baywest Center	Yes	330	254	254	Cleaned every day	insufficient for expected flows
KFC	J. Lennon/ Wesley Hall (Manager/ Supervisor): 953-6966	Bogue, Fairview Plaza	Yes	2743	2743	1473	Checked weekly, cesspooled when required or monthly	Well designed
Super Plus	Miss Hunt (meat department supervisor): 953-6987	Bogue, Fairview Plaza	No	-	-	-	-	Add degreasing agent to wastewater
Sunset Beach Resort and Spa	Nicolas Taylor/ Steve Brown (Operations Manager/Maintenance) :979-8800	Sunset Drive	Yes	770	770	500	Inspected at least every month	Water is siphoned off using floatation devise, grease is inadvertedly, pumped off too.

Name of Facility	Contact Info	Address	G. Trap	Trap Measurement			Maintenance	Comment
				Length	Width	Depth		
McDonalds	Angella Green/Depaul Willocks Manager – 979-7377	Westgate branch	Yes	3000	1200	1200	Cleaned every 2 months	Well designed, inlet pipe below water surface
Tastees	Mr. Strultz: maintenance manager – 971-0816	Upper Barnett street, clock tower	Yes	1950	750	2500	Cleaned every 3-4 weeks	Well designed, three compartment which makes for efficient grease trapping, needed cleaning
Juci Beef Patties	S. Brackett: supervisor – 979-9144	Upper Barnett Street Clock tower	No	-	-	-	-	Just bake already made patties, no cooking
St. James Bakery	Arlene Lue: manager - 952-2215	Barnett Street	No	-	-	-	-	The health department ask for it to be covered
Tastees	Clifton Gayle: supervisor – 979-9233	Lower Barnett street	No	-	-	-	-	-
Juci Beef Patties	T. Walker: team member: 971-5103	Lower Barnett street	No	-	-	-	-	No cooking, bake what is prepared in Clarendon
Wexford Hotel and Grill	George Black: Security – 952-2854	Gluocester Ave.	Yes	710	430	320	Cleaned every 2 weeks	Need cleaning, improper grease trap, not well designed.
China House	Ryan Lawrence: Scullian: 952-5440	Gluocester Ave	Yes	1500	900	600	Maintained every 2 days	The length is flow length, as there are 4 compartments that the water flow thru,

Name of Facility	Contact Info	Address	G. Trap	Trap Measurement			Maintenance	Comment
				Length	Width	Depth		
Dominoes	Jennifer Brown: manager – 979-2197	Gluocester Ave	No	-	-	-	-	-
Brewery	Frantz Irons: manager – 940-2613	Gluocester Ave	Yes	770	230	610	Not maintained	There is a hole in the bottom, into which the water escape, unsure of destination.
Ghanzhou Chinese restaurant	Lynford Robinson: maintenance – 952-6200	Gluocester Ave	Yes	600	600	280	Claim to clean every day	Needs cleaning, insufficient for expected flows, not well designed
Native Restaurant	Lawrence Rowe: waiter – 979-2769	Gluocester Ave	Yes	840	840	860	Cleaned as needed	Well designed, good size for expected flows
Pork pit	Uhma Williams	Gluocester Ave	No	-	-	-	-	Health department suggested a man hole that can be modified to a grease trap
Dragon Bay Chinese Restaurant	Irene Zhong: manager – 940-3708	Market Lane	No	-	-	-	-	-
Hilton's Bakery/Chester Fried Chicken	Marlene Chambers: manager – 979-1806	St. James Street	No	-	-		-	-
Dumbos Restaurant	Claudette Dixon: Supervisor – 952-6563	Harbour Street	No	-	-	-	-	-

Name of Facility	Contact Info	Address	G. Trap	Trap Measurement			Maintenance	Comment
				Length	Width	Depth		
McDonalds	Angella Green/Depaul Willocks Manager – 979-7377	Westgate branch	Yes	3000	1200	1200	Cleaned every 2 months	Well designed, inlet pipe below water surface
Tastees	Mr. Strultz: maintenance manager – 971-0816	Upper Barnett street, clock tower	Yes	1950	750	2500	Cleaned every 3-4 weeks	Well designed, three compartment which makes for efficient grease trapping, needed cleaning
Juci Beef Patties	S. Brackett: supervisor – 979-9144	Upper Barnett Street Clock tower	No	-	-	-	-	Just bake already made patties, no cooking
St. James Bakery	Arlene Lue: manager - 952-2215	Barnett Street	No	-	-	-	-	The health department ask for it to be covered
Tastees	Clifton Gayle: supervisor – 979-9233	Lower Barnett street	No	-	-	-	-	-
Juci Beef Patties	T. Walker: team member: 971-5103	Lower Barnett street	No	-	-	-	-	No cooking, bake what is prepared in Clarendon
Wexford Hotel and Grill	George Black: Security – 952-2854	Gluocester Ave.	Yes	710	430	320	Cleaned every 2 weeks	Need cleaning, improper grease trap, not well designed.

Name of Facility	Contact Info	Address	G. Trap	Trap Measurement			Maintenance	Comment
				Length	Width	Depth		
Burger King	Aretha Brown (District Operation Manager): 399-4259, 940-1307	St. James Street	Yes	900	900	600	Monthly	Inlet is above the water surface, needs 90° bend, very good size
Margaritaville	Andrew Downer: maintenance – 971-3136	Gloucester Ave	No	-	-	-	-	-
Island Grill	Gladie Daley: Supervisor – 952-3238	Center point plaza	Yes	2170	2500	1524	As necessary	Inlet below water surface, good size.
Butterflakes	Warren Chung: supervisor – 952-2314	Harbour Street	Yes	1220	1220	1220	Cleaned by vactor	Two chambers
China House	Ryan Lawrence: Scullian: 952-5440	Gloucester Ave	Yes	1500	900	600	Maintained every 2 days	The length is flow length, as there are 4 compartments that the water flow thru, well designed.
Tiger's Restaurant	Brigette Lindo: supervisor – 940-4816	28 St. James Street	yes	610	610	457	Cleaned every night	Inlet above water surface, 90° bend at outlet
New Creation Restaurant	Marcia Gardener; 971-2721	Barnett Street	Yes	520	520	300	Once per week	Inlet above water surface 90° outlet
Oriental Express	Mr. Lou Frank; 952-8866	Union Street	No	-	-	-	-	-
Vienese Pastry/Canton	Mr. Nam; 952-3711	Union Street	No	-	-	-	-	-

Name of Facility	Contact Info	Address	G. Trap	Trap Measurement			Maintenance	Comment
				Length	Width	Depth		
Captain's Bakery	Miss Wallace-Manager; 952- 1788	St. James Street	Yes	700	310	210		
Smokey Joe's Restaurant	Mr. Perkins: owner – 952-1155	St. James Street	No	-	-	-	-	-
Solomon's Bakery	Shirley Yon: manager – 952 - 2579	St. James Street	No	-	-	-	-	No washing of pans, pans are placed in oven and burned for cleaning process
Gonzo/Toby's Italian restaurant	M. Plumber: supervisor – 952 - 1890	Sunset Blvd.	No	-	-	-	-	Grease is sent out in garbage from grill. Small catchment off pot washing sink not a proper grease trap.
Gloriana hotel and Resturant	Eugene Minto: owner – 979-0069	Sunset Blvd.	Yes	660	400	300	Every week	Inlet below water surface.
Golden Delight Bakery and Restaurant	Karl McLean, 979-0237	25 Miram Way	No	-	-	-	-	-
Trailway Restaurant	Cheriffa Robinson, 979-2667	Dudley Kassin Drive	Yes	300	150	300	As needed	Inlet above water level, 90° outlet
Delli and Cherry Restaurant	Delbert James; 952-7635	13 Barnett Complex	Yes	300	300	760	Every three weeks	Inlet below water surface and 90° outlet
Cayote Ugly Sports Bar and Grill	Doreen Poyser; 971-4740	Barnett Complex	Yes	300	150	300	Every week	Inlet above water, 90° outlet

Name of Facility	Contact Info	Address	G. Trap	Trap Dimensions			Maintenance	Comment
				Length (mm)	Width (mm)	Depth(mm)		
Home style Restaurant and Snack	Margaret Mullings: Waitress – 952 -0225	Railway lane	No	-	-	-	-	-
Leaf of life Herbal and Health Food Restaurant	Lisa Allen: worker – 952-3169	Shop #8 Lane plaza – Railway lane	No	-	-	-	-	-
Time and Patience bakery depot	Caliesha Curtis: worker	Shop #2 Lane Plaza – Railway Lane	No	-	-	-	-	No baking done here, bakery depot
Saki Meat	Saki Chu: owner – 979 – 1529	Railway Lane	No	-	-	-	-	-
Time and Patience Bakery	Mr. Service: manager – 979-3660	2 Roosevelt Ave	No	-		-	-	Baking sheets are treated with chemical and then washed
Madourie Fast Food	Vanton Madourie: owner – 940-6518	Barnett street	No	-	-	-	-	-
Foreigners Fast Food	Errol Stewart: chef – 971 - 1901	Barnett street	Yes	550	550	610	1 per month	Inlet above water surface, 90° outlet

Name of Facility	Contact Info	Address	G. Trap	Trap Dimensions			Maintenance	Comment
				Length (mm)	Width (mm)	Depth(mm)		
Ol's Snack	Mr. Lawson; 979-0206	St. James Street	No	-	-	-	-	-
Eden II Healthfood store	Audrey Phips; 940-7122	72b Barnett Street	No	-	-	-	-	-
24-7 Restaurant	Jascinth Brown; Manager – 952-9726	St. James Street	No	-	-	-	-	-
Phoenix Restaurant	Derrick Warren – 971-9945	38 Barnett Street	Yes	450	420	300	When needed	Inlet above water surface 90° outlet
Sparkling Meat Mart and General Wholesale	Dwight Smith – 971-5310	30 Railway Lane	No	-	-	-	-	-
Arawak Meat Shop	Mauvet Coote – 979-7608	36 Railway Lane	No	-	-	-	-	-
Shorty Cook Shop	Lebert "shorty" Campbell: owner – 342-2553	Catherine Hall	No	-	-	-	-	-
Soft Spot Cook Shop	Devon Hamilton: owner – 361-6957	Catherine Hall	No	-		-	-	-