HYDROLOGIC AND CHEMICAL ANALYSIS OF SALT PONDS ON ST. JOHN, U.S. VIRGIN ISLANDS

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Abstract

In order to assess the impact of human development on salt ponds, this study investigated the relationships between the chemistry of salt ponds and the hydrology of the surrounding area. Aspects of pond health such as nutrient levels, sedimentation parameters, and water quality indicators were analyzed in conjunction with development metrics, watershed descriptions, and runoff characteristics. Salt ponds were determined to be composed primarily of evaporated seawater. This determination was based on the outputs of hydrologic modeling, which predicted minimal inputs due to surface runoff, plus the results of regression analyses, which showed significant correlation between nutrient levels and salinity (R^2=0.885) and minimal deviation of measured nutrient concentrations from those predicted by evaporation. In addition, the feasibility of groundwater seepage measurement was investigated, as this seepage could play a key role in determining the role that human development may play in salt pond chemistry. Southside Pond, which met all the criteria necessary for seepage meter deployment, was analyzed for groundwater inputs; however, the information collected showed no evidence of significant groundwater inputs.

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1 INTRODUCTION

1.1 Background

The United States Virgin Islands (USVI) are located approximately 1,000 miles east southeast of Miami, Florida (Smith et al., 2002). The USVI consist of three main islands: St. Croix, St. Thomas, and St. John. St. John is the smallest of the islands with dimensions of 9 miles in length and 3 miles in width. Approximately two-thirds of the island consists of the Virgin Islands National Park. Tourism supports the local economy with most of the tourists coming from North America by cruise ships to St. Thomas or St. John and by airplane to St. Thomas and ferrying over to St. John. The warm climate, pristine coastal waters, and duty free shopping are among the favorite attractions for these vacation destinations.

FIGURE 1
MAP OF CARIBBEAN

The climate of St. John is classified as subtropical with the winters being mild and dry, and summers warm and humid. Precipitation increases with altitude due to the moist air being forced up the slopes into the cooler air of the higher altitudes. Since the mountains are not very high as compared to other larger Caribbean islands, less rainfall is experienced on St. John, as much of the precipitation falls in the Caribbean Sea. Annual rainfall ranges from 40 to 60 inches (Colon-Dieppa et al., 1989). Rain occurs principally as brief intense tropical downpours. Longer and more severe rainfall occurs between August and November coinciding closely with the hurricane season (Smith et al., 2003). February or March is the driest month and September or October is the wettest. High evapotranspiration rates reduce the quantity of surface water (Jordan and Cosner, 1973).

The islands are composed of volcanic rock and have steep slopes and irregular coastlines. The steep hillsides, thin soil layers, and fractured igneous rock preclude natural catchment of rainfall as a means of groundwater replenishment (Smith el al., 2003). As a result, groundwater on the island of St. John is scarce. Surface runoff and groundwater recharge are low due to high rates of evapotranspiration. Runoff ranges from 2 to 8 percent of annual rainfall (Santiago-Rivera and Colon-Dieppa, 1986).

Since tourism became over half of the USVI's economy in the 1950s, development on the islands has expanded rapidly. Unfortunately, the growth in population and home building has not been accompanied by upgrades in the infrastructure of the island, particularly with regards to sewage and road maintenance. As such, human development on the USVI is taking a toll on the islands, and the pristine and sensitive marine environment, from which the islands derive much of their tourist industry, is endangered.

Salt ponds, so named due to their often hypersaline conditions, are an aspect of this marine environment that is threatened by human development. While deliberate destruction is the primary threat to salt ponds, more inconspicuous threats to their chemistry exist. In particular, the inadequate sewage and road infrastructure could potentially lead to nutrient loading and excessive sedimentation that could damage salt ponds.

1.2 Purpose

The purpose of this study was to assess the impact of human development on salt ponds by investigating the relationships between the chemistry of salt ponds and the hydrology of the surrounding area. Therefore, aspects of pond health such as nutrient levels, sedimentation parameters, and water quality indicators were analyzed in conjunction with development metrics, watershed descriptions, and runoff characteristics. In addition, the feasibility of groundwater seepage measurement was investigated, as this seepage could play a key role in determining the role that human development may play in salt pond chemistry.

In Chapter 2, we introduce the background of the formation, hydrology, ecology, and chemistry of salt ponds, which is followed in Chapter 3 by a description of the specific chemical parameters examined in this study. Chapter 4 discusses the hydrologic tools used to model the watersheds of concern, as well as various methods of measurement that were employed. The procedures followed to gather and analyze chemical and hydrologic data are enumerated in Chapter 5. The results from these procedures, and their importance for fulfilling the objectives of this study, are covered in Chapter 6, while Chapter 7 discusses the issues encountered during the study and recommendations for their resolution. Finally, Chapter 8 provides a summary of the major conclusions reached during this study and provides goals for future work.

2 BACKGROUND OF SALT PONDS

2.1 Salt Pond Formation

The primary theory describing the formation of salt ponds states that, as coral reefs in sheltered bays grow upwards, they eventually breach the water surface and create a berm (Jarecki, 1999). On this berm, mangrove trees and other vegetation can grow, until the bay is isolated from the neighboring seawater. Figure 2, a picture of Southside Pond on St. John, clearly displays a salt pond, the berm separating it from the ocean, and the neighboring bay. Other theories involve the gradual closing of lagoons and hurricane holes by longshore sediment transport and do not involve coral growth. A possible future salt pond forming by this mechanism is seen at John's Folly in St. John in Figure 3.

FIGURE 2
SOUTHSIDE POND

FIGURE 3
FORMING SALT POND AT JOHN'S FOLLY

2.2 Salt Pond Hydrology

As described above, salt ponds in general are hydrologically separated from the neighboring bay. Depending on the characteristics of the berm, though, some interchange with the ocean is still possible. The natural mechanisms for this interchange are seepage through the berm and overwash in some storm events. However, in many salt ponds the more relevant interchange mechanism is due to man-made openings to the sea to allow flushing.

In those ponds that are not opened to the sea, the hydrology is dominated by inflows from precipitation, surface runoff, and groundwater seepage, and outflows from evapotranspiration and, potentially, groundwater seepage.

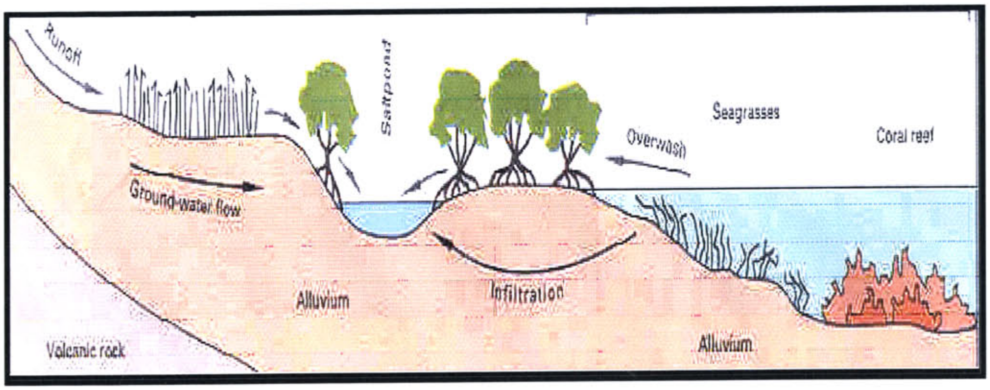

FIGURE 4
DEPICTION OF HYDROLOGY OF SALT POND
(Fretwell et al., 1996)

The runoff and groundwater seepage inflows to the salt ponds are potentially affected by human development in the surrounding area. With human development, the surrounding land changes from forest or grassland to a paved or dirt road with houses. The house is considered impervious and, in most cases in the continental United States, the runoff is infiltrated directly to groundwater. In the USVI, however, the roof catches the water for residential use, thus reducing the amount of runoff and erosion of the land. The roads built to access the development increase the runoff whether they are paved or not, since runoff increases when rainfall-holding grass and trees are replaced by poorly permeable roads. Pavement is nearly impervious and dirt roads, which are primarily Hydrologic Soil Group (HSG) D, are close to impervious. Hence, while the runoff may be reduced due to water catchments on house roofs, the potential also exists for increased runoff due to decreased cover and an increased number of roads.

2.3 Salt Pond Ecology

Salt ponds serve several valuable ecological functions in the USVI. First, salt ponds serve as a habitat for many indigenous as well as migratory species, some of which are endangered or threatened under the classifications developed in the Endangered Species Act (ESA) (Jarecki, 1999). Second, they act as a buffer between areas of human development and the sensitive reef ecosystems, as sediment and pollution carried by groundwater flow and surface runoff are filtered by salt ponds before they reach the reefs.

As salt ponds are dominated hydrologically by precipitation and evapotranspiration, their salinities can vary greatly throughout the dry and rainy seasons experienced in the USVI. Thus, the ecosystems present in salt ponds must be tolerant of drastic changes in salinity and also temperature. Because of the difficulty associated with surviving in the variability of salt ponds, only the hardiest species are able to live there.

Although species diversity may be lower than in other systems (Montgomery, 1996), salt ponds are some of the most biologically productive ecosystems in the world. Fish typically only live in salt ponds that have recently closed; in older salt ponds, the most typical representative groups of organisms that are able to survive in the ponds are various species of macroinvertebrates, bacteria, and phytoplankton (Maho, 2003). In addition, many salt ponds are inhabited by a variety of microbial species that make up a benthic microbial community.

All of these species, while resilient, may be vulnerable to the effects of human development on salt ponds.

2.4 Salt Pond Chemistry

As mentioned above, the most recognizable characteristic of salt pond chemistry is the widely varying concentration of salt. During the rainy season, some ponds can become hyposaline (less saline than seawater), while others remain hypersaline (more saline than seawater) throughout the year. In fact, some ponds reach salt concentrations high enough to crystallize minerals – calcite precipitates at ~75 ppt, gypsum at ~175 ppt, and sodium chloride at ~300 ppt. (Jarecki, 1999). The most recognizable of these crystallized minerals in salt ponds is gypsum, which forms a thin, brittle crust over the bottom of the pond.

Other aspects of salt pond chemistry also vary. The pH of salt ponds is generally between 7 and 9, but is highly dependent on the salinity of the pond and can change quickly in response to salinity variations. The temperature of salt ponds can fall to 20°C at night and then rise to 45°C during the daytime, often showing solar pond-like effects as increasing temperature with depth is supported by vertical salinity gradients. Dissolved oxygen follows its usual diurnal cycle, but also depends on salinity and temperature with inverse relationships (Jarecki, 1999).

Nutrient levels in salt ponds can also vary greatly, as they are dependent on a large range of factors. The evaporative flux of salt ponds can lead to higher salt concentrations than that of seawater due to the increased surface to volume ratio of ponds, leading to increased concentration of both salt and nutrient levels. The benthic microbial communities that reside at the bottom of salt ponds have the ability, in aerobic conditions, to take up ammonia (NH_4^+) from the water and release nitrate (NO_3^-), but also can become net nitrogen consumers if the nutrients are cycled within the benthic microbial communities (Jarecki, 1999). This can lead to decreased nutrient levels for the rest of the salt pond community. In addition, nutrient levels in salt ponds are potentially affected by human development. Population growth in the USVI has not been accompanied by improvements in the sewage infrastructure, so salt ponds are bearing a greater nutrient load from the greater number of septic tanks in use.

3 BACKGROUND OF NUTRIENT AND WATER QUALITY CHEMISTRY

3.1 Necessity of Nutrients

Similar to humans' needs for nutrients in food, aquatic life depends on nutrients; however, it is a critical balance – excessive nutrients, which can lead to excessive growth, can have disastrous effects on aquatic ecosystems. This is due primarily to eutrophication, a process that results from accumulation of nutrients in water bodies. Eutrophication is a natural process, but is often accelerated by the nutrient loading that occurs as a result of human activity. It is marked by increased algal growth, which leads to increased algal death. When these algae decompose, oxygen is consumed, leading to decreased dissolved oxygen levels available for the rest of the ecosystem.

The two main nutrients of concern are nitrogen and phosphorus. Nitrogen is essential for growth in cells, as it is a necessary component of protein synthesis, and also plays an important role in chlorophyll and therefore photosynthesis. Phosphorus is also an important factor in photosynthesis.

3.2 Nitrogen

Due to its biological role as an essential component of proteins, nitrogen is required by all organisms for growth. In its inorganic state, it is most commonly found as ammonia (NH_3), nitrite (NO_2^-), or nitrate (NO_3^-).

- **Ammonia –** The least stable form of nitrogen in water, ammonia is easily converted to nitrate under aerobic conditions. Under anaerobic conditions, it can also be transformed into nitrogen gas (N_2), but this is less of a concern in salt ponds. Ammonia is found in two forms in water: the ammonium ion (NH_4^+) and dissolved ammonia gas (NH_3). The prevalent species depends highly on pH. The most common measurement methods for ammonia are based on either spectrophotometry or acid/base titration.

- **Nitrite –** Also unstable in water, nitrite is quickly converted to nitrate by bacteria known as *nitrobacter*. Nitrite is also commonly measured by spectrophotometry.

- **Nitrate** – The most prevalent inorganic form of nitrogen found in water, nitrate is highly soluble in both surface waters and groundwater. Hence, it is easily transported. Nitrate feeds many forms of aquatic life, from phytoplankton to plants, and is also measured by spectrophotometry.

Surface waters can accumulate inorganic nitrogen in a variety of ways. Atmospheric deposition of nitrogen gas and the decomposition of the proteins present in both plants and animals give rise to ammonia, which is converted to nitrite and then nitrate. However, of greater concern for this study are the human processes that lead to increased nitrogen loading in salt ponds. The most prominent human sources of nitrogen are wastewater and septic system effluent. The urea and proteins in human waste decompose to form ammonia, nitrite, and nitrate. (This is also the case for animal waste; hence, agriculture can lead to nitrogen loading.) In addition, cleaning products which enter effluent streams due to their use in bathrooms and kitchens are often rich in ammonia, which is then converted to nitrite and nitrate. Other sources of nitrogen are fertilizers, which contain nitrate and ammonia. The ammonia in these fertilizers is commonly converted to nitrate in soil, which can then dissolve in and be transported by groundwater.

3.3 Phosphorus

Also crucial for biological processes, phosphorus is an element commonly found in rocks, soils, and organic material. While often biologically bound with plankton and other organisms, phosphorus also exists in inorganic forms. The most common inorganic form of phosphorus is phosphate (PO_4^-), which can exist as orthophosphates or polyphosphates. Orthophosphates are commonly known as "reactive phosphorus" and are taken up by organisms. Phosphorus sorbs easily to soil particles and is used by plants, so concentrations are often low in surface waters.

Human sources of phosphorus are similar to nitrogen. Wastewater and septic system effluents contain human wastes and food residues, which contain phosphorus due to its essential role in metabolism. Detergents often contain phosphates, which also enter the effluent streams. Some fertilizers and many pesticides contain phosphates as well.

3.4 Water Quality Indicators

Appropriate indicators for judging the chemical health of salt ponds are temperature, salinity, dissolved oxygen, and pH, for the following reasons:

- **Temperature** – Biological activity and growth are strongly influenced by temperature, as are aquatic chemical processes. Fluctuations in temperature can potentially result in disturbances in the biochemical cycles present in salt ponds, an effect that can easily be observed in dissolved oxygen concentrations. As temperature increases, water becomes saturated with oxygen at a lower concentration, which may be insufficient to sustain life. Natural variation in temperature is expected, but human influence can also play a role if effluent from a municipal or industrial process is put into a pond. However, no salt ponds in this study were affected by thermal effluents.

- **Salinity** – The species composition of the ecosystems present in salt ponds is highly dependent on salinity. As some ponds have extreme salt concentrations, low levels of biodiversity can be found, which renders these ecosystems very vulnerable to sudden changes. Again, salinity shows a high degree of natural variation, as the salt concentration is dependent on evaporation and precipitation. However, human impact on salinity levels can often be observed in those ponds that have been opened to the ocean, allowing for flushing by seawater and therefore lower salinity levels.

- **Dissolved Oxygen** – The organisms present in salt ponds depend on the oxygen that is dissolved in the water surrounding them. As many of these organisms take oxygen from the water by diffusion processes, variations in concentration can have a significant impact on biological processes. Dissolved oxygen levels follow a diurnal cycle, rising during the day and falling during the night. However, the concentration of dissolved oxygen is also susceptible to human activity by a number of mechanisms. Especially relevant in the salt ponds of St. John are inputs of nutrients, which lead to increased biological growth and oxygen consumption, and the deposition of organic matter such as tree leaves or domestic wastewater which, when decomposing, take up oxygen.

- **pH** – While extreme levels of pH will obviously render life difficult for the ecosystems of salt ponds, minor fluctuations can also impact aquatic chemical processes. For example, the form that nutrients take upon entering a pond and their subsequent availability for life depends on the pH of the pond water.

4 BACKGROUND OF HYDROLOGIC MODELING AND MEASUREMENT

4.1 Geographic Information Systems (GIS)

GIS is a valuable technology for capturing, interpreting, and displaying environmental information. The GIS dataset can be used as a public education tool, facilitating an understanding of alternative development costs and benefits and aiding the process of public decision making. In this project, the GIS software used, Arcview 3.2, was extremely useful in enabling the delineation of watersheds, the determination of coverage types, and the construction of maps, all of which were essential for the hydrologic modeling performed.

GIS datasets often include digital elevation models, or DEMs. A DEM is a digital representation of topography (USGS, 1987). The model is based on the scale of the original data and is commonly found as a raster dataset, which is a grid of x and y (and z) coordinates on a display space. DEM data can be used to perform different tasks; in this project, DEMs were particularly useful for modeling the hydrologic behavior of watersheds on St. John.

The hydrologic functions of GIS use the topographic form of a drainage basin to model the drainage network and associated drainage divides. One function, "Flow Direction," calculates the direction that surface water will flow using the relative elevation of neighboring cells, as higher cells discharge to lower cells. Watershed boundaries can then be delineated by locating the lowest cell, which is deemed the "source cell," and then determining all the cells that flow into this cell. All of these cells comprise the watershed.

Common errors in a DEM, which must be fixed before hydrologic functions are used, are called "sinks" when a very low elevation relative to the surrounding cells is entered, or "spires" when a very high elevation relative to the surrounding cells is entered. The DEM can be fixed by a "Fill" function, which looks for sinks and fills them in or finds spires and removes them. Sinks can cause problems when using the hydrologic modeling functions in GIS software.

All aspects of the GIS dataset need to be in a consistent reference frame, called a projection, in order to be used together. A projection is a mathematical transformation by which latitude and longitude of each point on the earth's surface are converted into corresponding projected coordinates in a flat map reference frame (McDonnell, 1991). The criteria for a map projection are specification of an earth datum, projection method, and set of projection parameters. The two common earth data for the United States are the North American Datum of 1927 (NAD 27) and the North American Datum of 1983 (NAD 83). The most common cylindrical projection is the Transverse Mercator projection. It forms the basis for the Universe Transverse Mercator (UTM) coordinate system that is widely used for the United States. The projection of each component of the GIS dataset is described in the accompanying metadata file, and GIS software can be used to transform all the components into the same projection.

4.2 HydroCAD

The HydroCAD Stormwater Modeling System computer program by Applied Microcomputer Systems is used to develop stormwater runoff rates and volumes using the Soil Conservation Services hydrologic methods (HydroCAD, 2001; USDA, 1986). The HydroCAD software is a hydrograph generation and routing program based on TR-20 and TR-55 (HydroCAD, 2001). It outputs the volume (liters) and rate (mm^3/second) of runoff based on inputs of the area of the watershed and characteristics of the land including vegetative coverage, slope, soil type, and impervious area. These runoff characteristics are important when considering the effects of development on salt ponds, as nutrient loading and sedimentation potentially depend on the magnitude and rate of runoff.

4.2.1 TR-20 AND TR-55 INTRODUCTION

The Computer Program for Project Formulation Hydrology (TR-20) is a physically based watershed-scale runoff event model (USDA, 1986). It computes direct runoff and develops hydrographs resulting from any synthesized rainstorm event or natural rainstorm. Developed hydrographs are routed through stream and valley reaches as well as through reservoirs and are combined from tributaries with those on the mainstem stream. Branching flow (diversions) and baseflow can also be accommodated. Unlike TR-55, which was developed for manual use, the calculations in TR-20 are far too complex and numerous to be of practical use without appropriate computer software. While the TR-20 program remains the benchmark for runoff calculations using the Soil Conservation Service (SCS) methods, it has limitations as a practical engineering tool. The program was written in FORTRAN and employs input forms dating from its punched-card ancestry. Thus, TR-20 takes considerable time to master and use. Also, TR-20 does not provide any procedures for calculating time of concentration (TC), deriving stage-storage tables, or calculating stage-discharge relationships for hydraulic devices. All such calculations must be performed by other means and the final results entered into TR-20.

TR-55 is perhaps the most widely used approach to hydrology in the United States (USDA, 1986). TR-55 was developed by the National Resources Conservation Service (NRCS, formerly known as SCS) to estimate runoff from storm rainfall for small watersheds. NRCS uses the runoff curve number (CN) method (see chapters 4 through 10 of NEH-4, SCS 1972). The CN value depends on the watershed's soil and cover conditions, which the model represents as hydrologic soil group, cover type, treatment, and hydrologic condition. Chapter 2 of the TR-55 manual discusses the effect of urban development on CN and explains how to use CN to estimate runoff. Since the initial publication predated the widespread use of personal computers, TR-55 was designed primarily as a set of manual worksheets. A TR-55 computer program is now available, following closely on the manual calculations of TR-55. TR-55 utilizes the SCS runoff equation to predict the peak rate of runoff as well as the total volume. TR-55 also provides a simplified "tabular method" for the generation of complete runoff hydrographs. The tabular method is a simplified technique based on calculations performed with TR-20. TR-55 specifically recommends the use of more precise tools, such as TR-20, if the assumptions of TR-55 are not met. TR-55 presents simplified procedures for estimating runoff and peak discharges in small watersheds. While this TR gives special emphasis to urban and urbanizing watersheds, the procedures apply to any small watershed in which certain limitations are met. These limitations include NRCS type distributions (discussed below), 10 subwatersheds, minimum 0.1 hour and maximum 10-hour time of concentrations (TC's) (USDA, 1986).

4.2.2 TR-20 AND TR-55 METHODOLOGY

The theory behind TR-20 and TR-55 and how they estimate stormwater discharge volume, velocity, and time of concentration incorporates the assumption that there exists an initial abstraction before stormwater runoff. The initial abstraction, I, consists of water retained in surface depressions, captured by vegetation, and lost to infiltration and evaporation. Runoff begins only after this initial abstraction is exceeded (USDA, 1986). S (Storage) is the potential maximum retention of stormwater once runoff has started. The empirical relationship determined by the USDA through multiple studies of small watersheds is:

$$I = 0.2S \tag{1}$$

where both I and S are in units of inches.

Storage and initial abstraction also depend on land coverage and percent impervious. CN is the mean curve number for a watershed and is representative of the runoff potential. The CN values were determined by NRCS by performing studies on watersheds with a single land-soil cover. The range for CN values is 0 to 100 where 0 is no runoff and 100 is 100% runoff. The SCS method relates storage to the CN value according to this equation:

$$S = \left(\frac{1000}{CN}\right) - 10 \tag{2}$$

Next, Q (the amount of stormwater rainfall inches) can be determined.

$$Q = \left(\frac{(P-I)^2}{(P-I+S)}\right) \tag{3}$$

where P is the rainfall in units of inches.

If you were to substitute 0.2S for I, the equation would be:

$$Q = \left(\frac{(P-0.2S)^2}{(P+0.8S)}\right) \tag{4}$$

To determine V (velocity in feet/sec) of the stormwater:

$$V = \left(\frac{1.49}{n}\right) R^{\frac{2}{3}} \times Sl^{0.5} \tag{5}$$

where: n is the Manning roughness coefficient,
R is the hydraulic radius (area of flow (ft^2)/wetted perimeter (ft)),
Sl is the slope (ft/ft).

The National Resource Conservation Service (NRCS) methodology incorporates rainfall observations in the form of standard rainfall storm events for different parts of the United States. By studying the Weather Bureau's Rainfall Frequency Atlases, the NRCS determined that four "mass curves" could be used to represent all rainfalls within the United States (HydroCAD, 2002). The mass curve is a dimensionless distribution of rainfall over time, which indicates the fraction of the rainfall event that occurs at a given time within a 24-hour precipitation event. Separating the IDF data into individual 30-minute increments of storm duration within the 24-hour storm period develops mass curves. The largest 30-minute increments are placed at the middle (12-hour point) of the hypothetical storm. The second largest increment is placed next to the largest and so on until the entire 24-hour curve is developed. The benefit of the NRCS method is that the curve contains depth information for all events up to 24 hours. This results in a storm that builds steadily in intensity, reaching a peak at 12 hours, when the intensity recedes until the 24-hour point is reached. This synthetic distribution develops peak rates for storms varying in duration and intensity. The NRCS distribution provides a cumulative rainfall at any point in time and allows volume dependent routing runoff calculations to occur.

4.2.3 HYDROCAD METHODOLOGY

The calculations performed by HydroCAD were the primary descriptor of runoff used in this study, and provided valuable information regarding the relationships between nutrient loading, sedimentation, and runoff. HydroCAD is based largely on the NRCS methodology and incorporates the Curve Number method of computing runoff as well as the standard NRCS design rainstorms.

The HydroCAD software has the capacity to describe shallow concentrated flow. The "NEH-4 Upland Method" included in the HydroCAD software is applicable for conditions that occur in the headwaters of a watershed up to 2,000 acres. The NEH-4 Upland Method allows the time of concentration (TC) to reflect ground conditions such as overland flow, grassed waterways, paved areas, and upland gullies. This results in a model that more accurately reflects the ground surface, for shallow concentrated flow conditions, than TR-55, which is limited to distinguishing only paved and unpaved surfaces. The mathematical procedure for calculating TC and the runoff accuracy is within 1% of TR-20. Soils are classified into one of four hydrologic soil groups (HSGs) in order to give a general indication of the infiltration rate for the soil type. The HSGs, which are A, B, C, and D, range from soils that have high infiltration rates and low runoff potential (A soils) to soils that have very low infiltration rates and high runoff potential (D soils).

Drainage subcatchment areas are areas that act as relatively small watersheds for a specific site. These areas can be located either entirely on a site or may include adjacent areas (areas that may have an influence on the drainage patters for that site) (HydroCAD, 2001). There are a number of factors that determine what areas are included as drainage subcatchments in the drainage calculations for a site. These factors include the general topography of the land and abutting property uses. The points or areas where these subcatchments discharge their stormwater runoff are usually described as the design point or points.

4.3 Seepage Meters

Seepage meters are inexpensive instruments used to measure seepage flux in lakes and estuaries (Lee, 1977; Lee, 1978). This flux is an important parameter in this study, as groundwater seepage into salt ponds could potentially carry nutrients into the ambient water. A common seepage meter construction technique is to cut off approximately ten inches from the top of a 55-gallon metal drum, leaving an open end and a closed end—see Figure 5. A vent hole is cut in the closed end of the drum and fitted with a plastic tube that serves as both a vent for gas and a connection for the measurement bag. The seepage meter is utilized by putting the open end of the drum in the sediment of a pond bottom. An adequate seal is required, therefore, it is necessary to push the seepage meter about 10 centimeters into the sediment or until the closed end is about 2 centimeters above the sediment. The vent hole is slightly elevated to allow gas to escape. The amount of water collected within a measured time period gives the flux of water through the pond bottom. The basis is the Darcy Equation,

$$Q = A \times \left(\frac{dh}{dl} \right) \times K \tag{6}$$

where: Q is the flux of groundwater (volume/unit time),
A is the area through which the flux occurs,
dh/dl is the hydraulic gradient,
and K is the hydraulic conductivity (length/time).

Information on the direction and rate of groundwater can be determined in the matter of a few hours of testing. Figure 5 is a schematic of a seepage meter. For convenience purposes, plastic quick connections were installed on the tube from the vent hole on the seepage meter and also on the seepage meter bag. Also, there was a shutoff on the tube for the seepage meter bag to prevent spilling while the seepage meter bags were removed and replaced or being weighed.

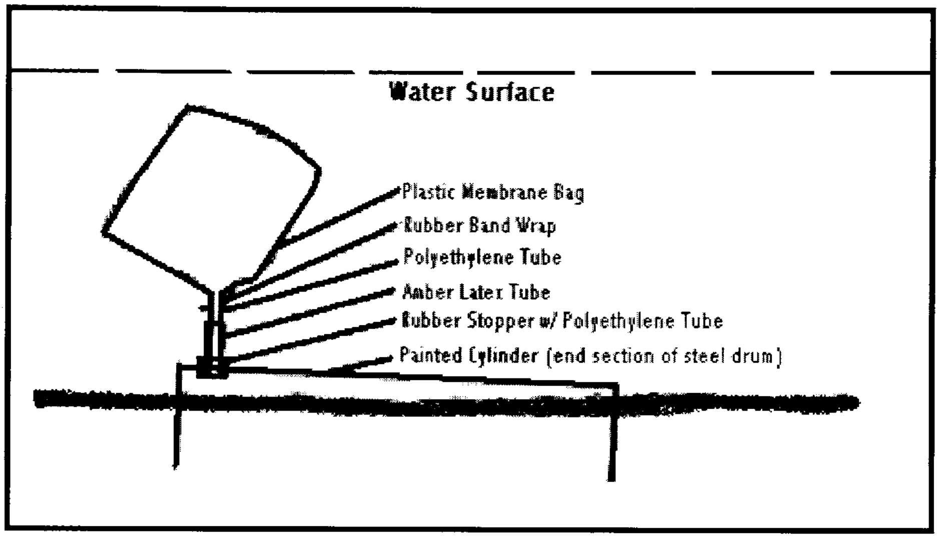

FIGURE 5
SEEPAGE METER SCHEMATIC
(Lee, 1978)

4.4 Mini-Piezometers

Mini-piezometers can be used to measure hydraulic head (Lee, 1977; Lee, 1978) – see Figure 6. The piezometer consists of a polyethylene tube with a perforated tip, which is protected from sediment influx by some netting or fiberglass cloth. It is installed in 1.7-centimeter internal diameter steel pipe that is driven in by a hammer. The plastic tube is inserted and held in place as the pipe is pulled out. The translucent tube shows the head differential with respect to water surface. After a static level is obtained for the water levels in the tubes, *dh*, the differential head is read off of a meter stick. *dh/dl*, the vertical hydraulic gradient, is then determined by using the depth of the piezometer screen below the sediment-water interface as *dl*. The hydraulic conductivity of the sediment can be determined by either a falling head test or a constant head test. For a falling head test, the piezometer tube is filled with water. Then, the water level is recorded at set time intervals throughout the test. A stopwatch and marked intervals on the tubing are essential to the process. A constant head test is performed by attaching a plastic bag filled with a known volume of water to the plastic tube. The change in volume of water over a period of time is recorded. The equation (Lee, 1978) used is

$$K = q \times \ln\left[\left(\frac{ml}{D}\right) + \left(1 + \left(\frac{mL}{D}\right)^2\right)^{0.5}\right] \times (2 - LH)^{-1} \qquad (7)$$

where: D is the intake diameter (cm),
L is the intake length (cm),
H is the constant piezometric head (cm),
q is the flow of water (cm^3/s), t is time (seconds),
m is the transformation ratio, $(K_h/K_v)^{0.5}$ assumed to equal 1.

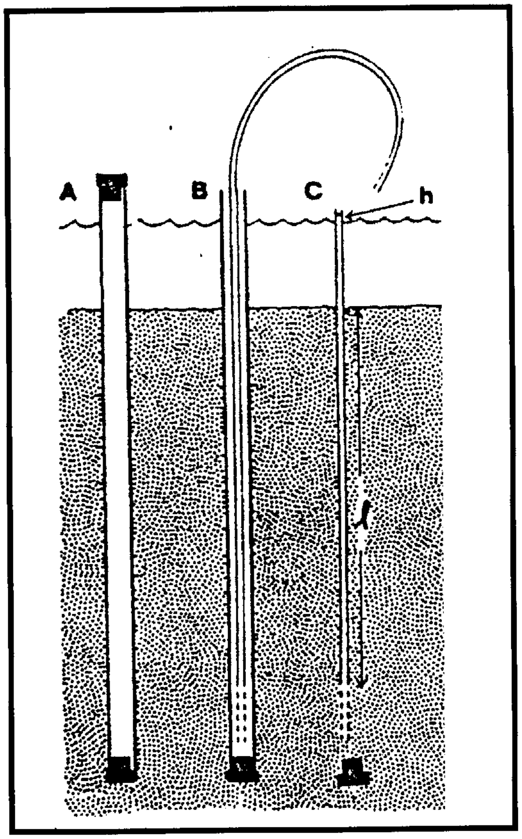

FIGURE 6
MINI-PIEZOMETER SCHEMATIC
General features and method of installation of a mini-piezometer.
A, casing driven into sediment
B, plastic tube with screened tip inserted in casing
C, plastic tube is a piezometer and indicates differential
head with respect to surface water
(Lee, 1978)

5 METHODS AND EQUIPMENT

In order to investigate possible relationships between salt pond chemistry and the hydrology of the surrounding area, the ambient water of ten ponds (shown in Figure 7) was sampled for nutrient levels, sedimentation parameters, and various water quality indicators. In addition, the watersheds that are hydrologically linked to each of the ponds sampled were modeled using GIS and HydroCAD, and all the data collected were analyzed using the statistical software package Stata.

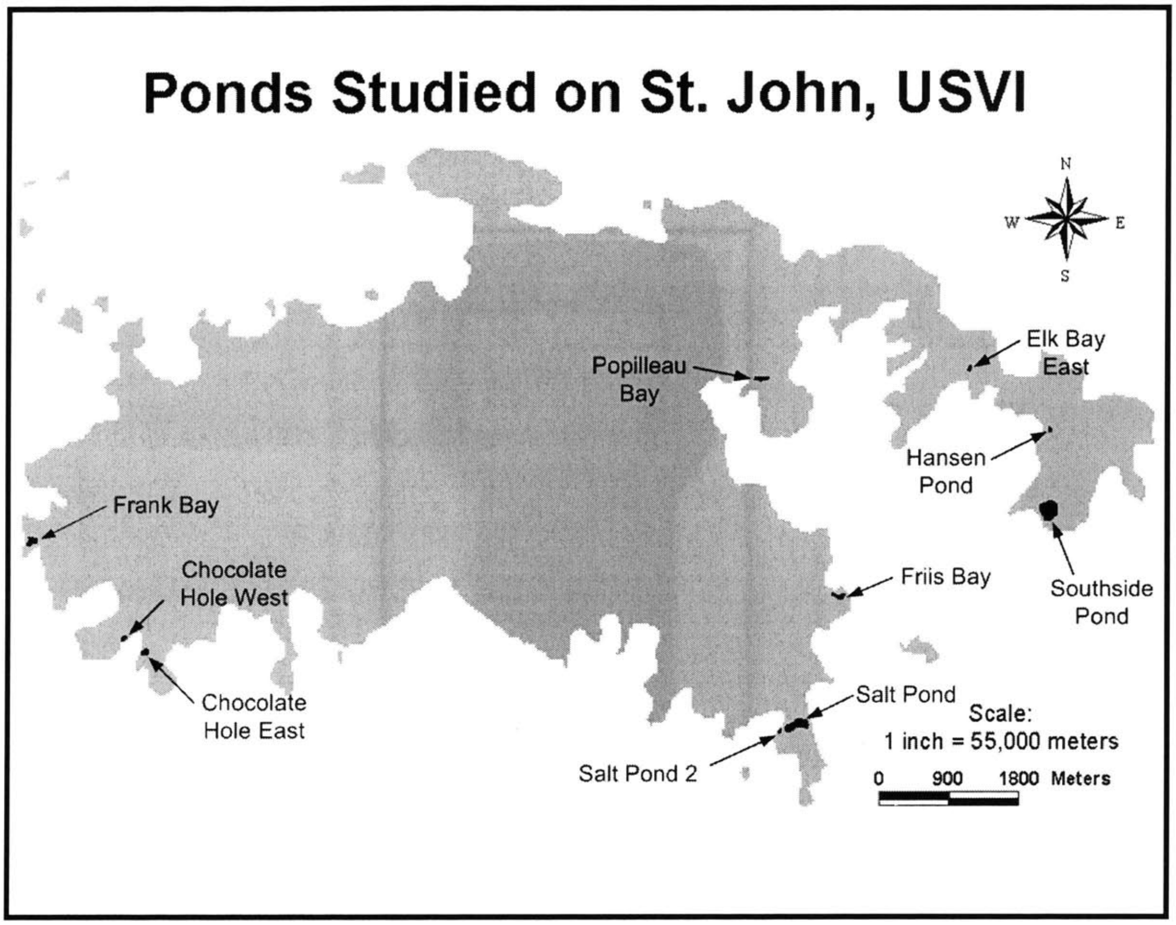

FIGURE 7
MAP OF PONDS STUDIED ON ST. JOHN

5.1 Water Quality Indicators

The following water quality indicators were measured: temperature, salinity, dissolved oxygen, and pH. A YSI600XLM multiparameter sonde was used in conjunction with a YSI600MDS handheld display:

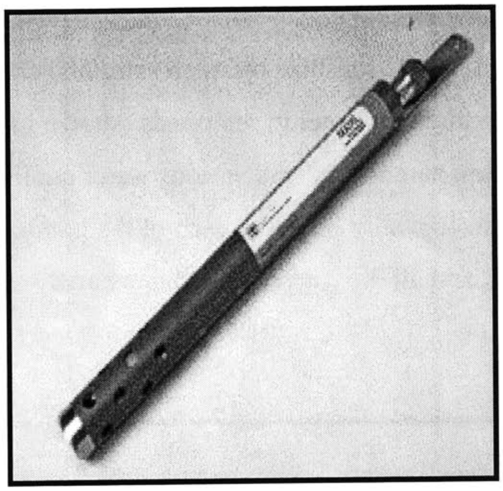

FIGURE 8
YSI600XLM MULTIPARAMETER SONDE

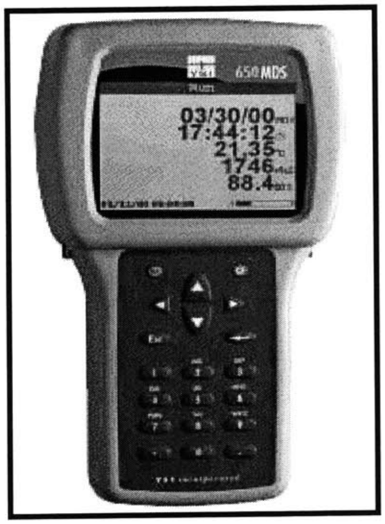

FIGURE 9
YSI600MDS HANDHELD DISPLAY

The YSI technology uses a variety of probes to make the necessary measurements, all of which were calibrated at the facility from which the equipment was rented. These probes are:

- Temperature – The resistance of a thermistor of sintered metallic oxide, which changes predictably with temperature variation, is used to calculate temperature.

- Conductivity – This probe consists of a cell with four nickel electrodes, two of which are driven by a current and two of which measure voltage drop. This voltage drop is then converted to a conductivity value, which, when combined with the recorded temperature, is used to calculate salinity according to the algorithms found in Standard Methods for the Examination of Water and Wastewater (APHA, 1999).

- pH – In order to determine hydrogen ion concentration, a combination electrode is employed, which consists of a proton-selective glass reservoir filled with buffer at pH~7 and another Ag/AgCl electrode that utilizes gelled electrolyte. A silver wire coated with AgCl is immersed in the buffer reservoir, and when protons interact with the glass of the reservoir, a potential gradient across the glass is established. Since the hydrogen ion concentration of the buffer inside the glass reservoir is constant, the potential difference is then used to calculate the pH of the sample.

- Dissolved Oxygen – Three electrodes are used in the measurement of dissolved oxygen concentration: cathode, anode, and reference electrode. The electrodes are pulsed between on (polarized) and off (depolarized), creating a voltage sufficiently negative to cause oxygen to be reduced to hydroxide at the cathode and silver to be oxidized to silver chloride at the anode. The current measured in this process is used to calculate the oxygen concentration.

Measurements were taken by inserting the sonde into the pond water, allowing enough time for equilibration, and then recording the output of the digital handheld display. In all ponds deep enough, the sonde was inserted 6-12" into the water to avoid measuring surface water that may not have been representative of the ambient conditions in the pond due to incomplete mixing. In extremely shallow ponds, the sonde was submerged as deeply as possible.

Samples were taken from a boat in all ponds that were deep enough to accommodate the boat. In those shallow ponds where the boat could not stay off of the bottom, all possible precautions were taken while wading to avoid mixing the water and stirring up sediments. Samples were also taken from the front of the boat and in front of foot traffic to further guard against interference from disturbed sediment.

In some instances, the salinity level in the ponds being sampled was greater than 85 ppt, which is greater than the upper measurement limit of the YSI equipment. A handheld refractometer was used in these cases to measure the salinity level.

In order to determine whether there was any spatial variation in the ponds, samples were taken from various points, and in one deep pond (Frank Bay Pond), vertical profiling was performed using the 8-foot communication cable to deploy the sonde to greater depths.

5.2 Sedimentation Characteristics

The sedimentation characteristics measured were the concentration of total suspended solids (TSS) and turbidity. In order to measure TSS, a volume of water was taken from the lake in a 1L Nalgene sample bottle. The sample was shaken to ensure homogeneity and then a known volume (usually 200-400 ml) was pulled through a filter using a syringe attached to a Millipore filtration device. The filters used were pre-tared (pre-weighed), and after filtration, they were wrapped in aluminum foil and placed on ice until they could be transported to a freezer. (This wrapping procedure, however, was found to be flawed, as the foil used was found to have corroded during transportation.)

The filters were later thawed, baked in an oven for 24 hours to remove all water, and allowed to cool in a dessicator. The mass of each filter was then measured using an electronic balance, and the initial tared weight subtracted to yield the mass of solids implanted on the filter. This mass, when divided by the volume of water filtered, yielded the concentration of TSS.

Analysis of turbidity was done using a Hach 2100P turbidimeter shown in Figure 10. From the same sample taken for TSS analysis, a small volume was used to first rinse and then fill the turbidimeter cell. The cell was then cleaned and wiped with a silicone oil to ensure clear transmission through the cell wall, and the sample then scanned.

FIGURE 10
HACH 2100P PORTABLE TURBIDIMETER

The turbidimeter used in this study operates on the nephelometric principles of turbidity measurement. A tungsten filament lamp is used to generate light, which passes through the cell and is scattered by the particles present in the sample. The intensity of the light is then measured by two detectors, one at 90° from the incident beam and one directly behind the sample cell. A diagram of this process is shown in Figure 11. The ratio of the signals from these two detectors is used to calculate the turbidity of the sample, which is presented on the digital display screen in standard (nephelometric) turbidity units. This output was recorded.

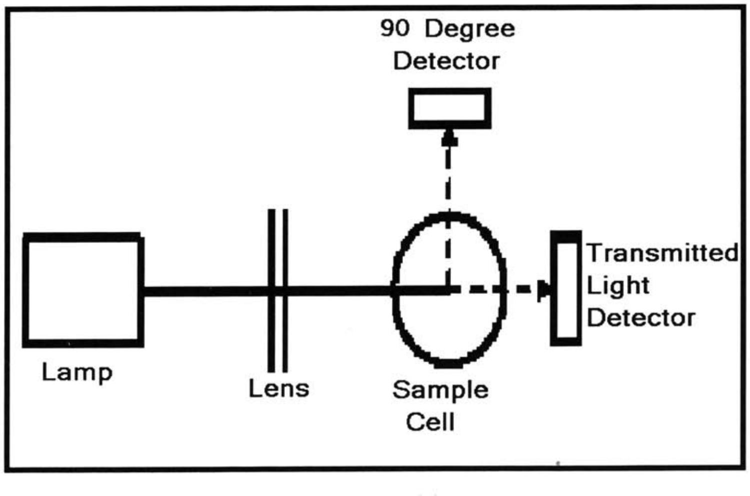

FIGURE 11
DIAGRAM OF TURBIDIMETER OPERATION

5.3 Nutrient Levels

Water samples for nutrient analysis were taken from the same representative points in each pond and put on ice until they could be analyzed in the lab. Each sample was filtered to remove particles and then diluted to a salinity level of 35 ppt, which is the level at which the spectrophotometer used in the analysis was calibrated.

Measurement of nitrate, nitrite, ammonia, and phosphate concentrations was done using a Hach DR2000 portable spectrophotometer (shown in Figure 12). The spectrophotometer works much like the turbidimeter, with several important differences. First, the wavelength of the incident light can be set in the spectrophotometer, allowing for scanning for the presence of specific chemicals. Second, there is no 90° light detector; rather, the intensity of the incident light beam is compared to that of the resultant beam in order to generate the concentration by an imbedded algorithm. In order to calculate the concentration of the nutrient of interest, a standard Hach chemical reagent (the exact composition of which is proprietary information) is added to a sample, which begins a reaction that causes a color change. The intensity of the color, which is related to the concentration of the nutrient, is then measured by the spectrophotometer, and the concentration calculated.

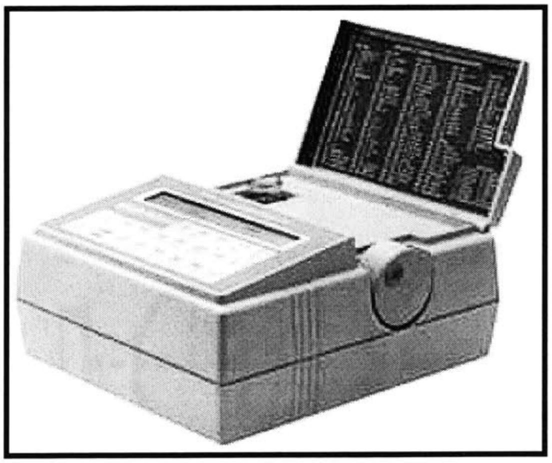

FIGURE 12
HACH DR2000 PORTABLE SPECTROPHOTOMETER

The methods used for the measurement of each nutrient are detailed below.

- **Nitrate** – The instrument was first blanked by scanning a 25 ml vial filled with the filtered and diluted sample at 500 nm. To another 25 ml aliquot, a Hach NitraVer 5 Nitrate Reagent Powder Pillow was added. Five minutes were then allowed for reaction, after which this reacted sample was scanned at 500 nm. The instrument then reported a concentration of nitrate as nitrogen (NO_3^--N), which was recorded.

Calibration for this instrument was performed using a Nitrate Standard Solution, which was diluted to five gradations of nitrate concentration. Salt (NaCl) was added to each of these standards to achieve 35 ppt salinity, and then they were reacted with NitraVer 5 and scanned after a blank. The calibration curve generated from the result of scanning these five standards can be found in Appendix A – Calibration Curves.

- **Nitrite** – A 25 ml aliquot of the filtered and diluted sample was scanned at 507 nm to generate the blank. To a separate 25 ml aliquot, a Hach NitriVer 3 Nitrite Reagent Powder Pillow was added, and 15 minutes allowed for reaction. After this period, the reacted sample was scanned at 507 nm and the resultant concentration of nitrite as nitrogen (NO_2^--N) recorded. Calibration for this procedure was carried out in the same fashion as that for nitrate.

- **Ammonia** – In this analysis, samples taken from the ponds (after filtration and dilution) were compared to distilled water. To 25 ml of each, a Hach Ammonia Salicylate Reagent Powder Pillow was added, and three minutes allowed for the reaction. At the end of this period, a Hach Ammonia Cyanurate Reagent Powder Pillow was added to both the pond sample and the distilled water sample, and a 15-minute reaction period carried out. The distilled water sample was then run as a blank at 655 nm, followed by scanning of the pond water sample.

  Calibration for this test was carried out in a similar fashion. Standard solutions of five different ammonia concentrations were prepared at 35 ppt salinity, reacted with both reagents, blanked against distilled water that was also reacted, and then scanned to generate the calibration curve found in Appendix A – Calibration Curves.

- **Phosphate** – The procedure for phosphate analysis is very similar to that for nitrate analysis. To a 25 ml aliquot of filtered and diluted pond water sample, the contents of a Hach PhosVer 3 Phosphate Powder Pillow were added and two minutes allowed for reaction. A sample cell was filled with unreacted, filtered, diluted pond water and scanned at 890 nm to generate the blank, after which the reacted sample was scanned. Calibration procedures for this test were identical to those for nitrate, and the calibration curve can be found in Appendix A – Calibration Curves.

5.4 Formation of Development Matrix

The level of development surrounding each pond was quantified using a development matrix. This matrix was formulated by using a set of parameters to describe the area surrounding each pond and then determining the relative development of each pond with respect to those parameters. The parameters included are:

- Number of surrounding houses
- Proximity of surrounding houses
- Predominant sewage treatment methods
- Presence of agriculture or livestock
- Slope of surrounding land
- Number of surrounding roads and paths
- Proximity of surrounding roads and paths
- Condition of roads and paths (dirt or paved)

The first five parameters attempt to encompass the contribution of residences to the nutrient loading of each pond, while the final four attempt to quantify the potential for sediment erosion and runoff. Each category had two to three levels of increasing development, and ponds that were more developed were given increasingly higher scores for that category. The final score was calculated by summing the scores for all of the categories. The framework for the matrix can be found in Appendix E – Development Matrix.

5.5 Modeling

5.5.1 GIS

A GIS dataset for the island of St. John, which provided a background for the hydrologic analysis of St. John, was collected. It includes a soil survey, hydrologic unit code (HUC) 14 watershed boundaries, subwatershed boundaries of the HUC 14 watersheds, and an aerial photograph of St. John. Multiple attempts were made to put all of the data into the same projection. Following the assembly of the GIS dataset, hydrologic watershed modeling was implemented to determine the watersheds tributary to the ponds being studied. Several methods were used to determine the size of the watersheds hydrologically connected to each pond.

First, the watershed tool imbedded in the Spatial Analyst extension of ArcView 3.2 software was used. This tool shows the cells that drain to the cell the user selects. Thus, for a pond that consists of multiple cells, multiple points are necessary which produces watersheds that overlie one another. The process takes multiple iterations to determine the watershed for the whole pond. Second, since some of the smaller ponds are actually smaller than the 30-meter cell size of the DEM, the watershed tool could not be used. For these ponds, ArcView drawing tools were used to virtually trace the watershed boundaries and measure the traced area.

5.5.2 PLANIMETER

In order to check the watershed areas output by GIS hydrologic modeling, a planimeter was used in conjunction with United States Geological Survey (USGS) contour maps. Watershed areas for each pond were determined using visual inspection of the contours on the USGS quad and drawing watershed boundaries by hand. These areas were compared to those obtained in GIS by drawing a polygon using the DEM (with contours added). Next, the area was measured using a planimeter, a drafting instrument used to measure the area of a graphically represented planar region. The planimeter is used to trace the outlined watershed, and the result is a digital output of the area. The accuracy of the planimeter is dependent on a steady hand and hand-eye coordination, but it also allows for visual inspection because the watershed can be reviewed and fixed. A picture of the instrument is shown in Figure 13. The area measure with the planimeter was averaged over several trials, since the measure is inherently approximate due to the scale of USGS Quads (1”:2000’). A much smaller scale plan is often used with this type of analysis.

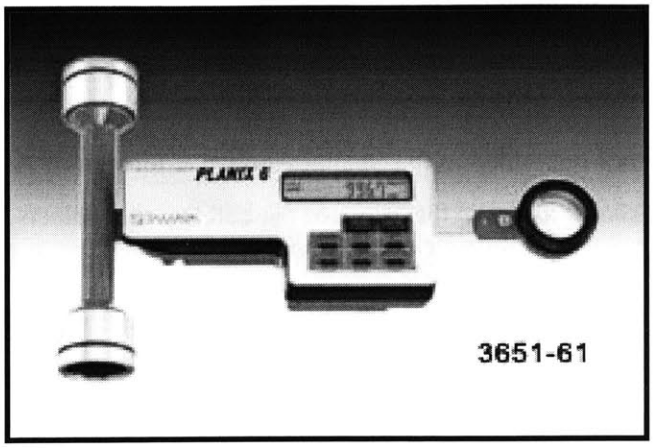

FIGURE 13
ELECTRONIC PLANIMETER
Planix 6 Roller-type electronic planimeter

5.5.3 HYDROCAD

HydroCAD was utilized to calculate the amount of flow expected during certain rain events. The rate of flow and total volume of flow were outputs determined by the model. To determine the amount of runoff, the watershed area was input. Within each watershed, the amount of roof, impervious road, dirt road, and other coverage (trees, brush) were determined. The pond area was given by the Wetlands Inventory theme, a component of the GIS dataset, and checked by drawing a polygon. In most cases, the type of coverage is determined by a site visit; however, not all the areas could be traversed for this determination. Hence, aerial photos were used (see Appendix B for GIS maps).

In order to deal with the issue of residential water catchments, the roof areas were subtracted directly from the watershed. This is a conservative estimate since it is likely that in more severe rainfall events some water is not caught by the roof. An average single family home in the Virgin Islands has a footprint of approximately 1,600 square feet, approximately 150 sq. m (Smith et al., 2003). Table 2 lists the watershed areas and soil descriptions for the HydroCAD implementation as determined from the soils map of the GIS dataset (see Appendix B for Soils Map).

The results of the HydroCAD model are tabulated in the Results section and in Appendix D.

5.6 Groundwater Sampling

5.6.1 SEEPAGE METERS

FIGURE 14
SEEPAGE METERS

The first test implemented to assess the feasibility of seepage meters was a visual inspection of the pond sediments. Due to accumulation of sediments from rainfall runoff, salt ponds typically have unconsolidated soils that present problems for seepage meters, which require sandy sediments for optimal results. Most of the salt ponds located on St. John have bottom sediments that are not suitable for implementation of seepage meters due to consolidated pieces of sediment or the bacterial mat that would become lodged in the plastic connection to the bag, thus preventing flow. Also, the mats are of such a substance that they may either seal the seepage meters, preventing inflow and outflow, or fail under the weight of the meters. In addition, the sediments in salt ponds were often a soft soil that would be unable to support the weight of the meters. Before experiments were started, the bottom sediments were checked by walking on them to see if they were suitable.

The depth of water was also critical with 30 centimeters of depth required for installation of the meters. Tests on one salt pond, Southside Pond, were performed. This pond has a bacterial mat and sediments which are durable enough to hold up during experiments and water deep enough to submerge the meters.

The first task in seepage meter installation was to walk around the pond to determine where the seepage meters could be implemented. While implementation of seepage meters on both sides of the berm would yield information about the connectivity (flux) between the pond and the ocean, the area proximate to the berm was rocky, preventing use of the seepage meters.

Therefore, a number of other locations were surveyed, where groundwater inputs to the pond from the surrounding watershed were believed to exist. Two locations from this set were selected, based on ease of conducting the experiments. The salt pond was observed on two different sides – the north and west – and tests performed for five days, including overnight on the north side.

The first row of seepage meters was placed such that the depth of water was sufficient for the seepage meter bag to float above the seepage meter. The rest of the rows and columns were organized to be approximately equidistant from the first row provided there were no obstructions (rocks or sticks in the sediment). The seepage meters were then set into the bacterial mat until the prongs on the sides were just visible. Next, a stopper was put into the hole on top of the seepage meter, and the seepage meter was allowed to equilibrate with the pond water. The plastic connection from the top of the meter was left open during equilibration.

While equilibrating, the seepage meter bags were partially filled with a set amount of liquid (which depended on the size of the bag and the length of the test). The bags' weights were measured and then any air was degassed so that it could not prevent the hydraulic connection between the groundwater and water in the bag. The bags were numbered, carried out to their correspondingly numbered seepage meter, and clipped onto the polyethylene tube connection, and then the nozzle was turned on. The tests were run for a predetermined amount of time, and while the test ran, the next set of bags were filled and weighed. Then, the bags were swapped by turning the shutoff off, taking off the old bag and replacing with the new one, and then turning the nozzle on the new bag on. The old bags were weighed and the result recorded.

YSI600XLM multiparameter sonde measurements of salinity, DO, and other parameters for both the pond and water in the seepage meter bags were taken. After the seepage meter bags had been weighed, the water was poured into a container with a depth greater than 6". The sonde was inserted into the water in this container and allowed to equilibrate. Then, the output of the digital handheld display was recorded.

5.6.2 MINI-PIEZOMETERS

FIGURE 15
INSTALLATION OF MINI-PIEZOMETERS
(Southside Pond, St. John, USVI)

Mini-piezometers were utilized at Southside Pond in an attempt to determine the hydraulic conductivity of the surrounding sediments. In addition, the mini-piezometers were used for groundwater sampling. The piezometer was hammered to a depth at which the screen intersected the water table. Then, the water was drawn using polyethylene tubing and collected in falcon tubes for chemical analysis.

5.7 Data Analysis Using Stata

Data analysis for this study was carried out using the statistical software package Stata (Stata Corporation, 2002). Both simple linear and multivariate regressions were run using Stata's "regress" command. Simple linear regressions are run by using one dependent variable and one predictor variable to predict the relationship between the two. An example of a simple linear regression would be analysis of the dependence of nitrate levels on salinity.

Multivariate regressions also use one dependent variable, but have a number of predictor variables.

In order to document how Stata regression results are interpreted, the important parameters from a Stata output are annotated in Table X.

TABLE 1
EXAMPLE STATA OUTPUT

Regression
R^2: 0.1266
Adjusted R^2: 0.072
Degrees of Freedom: 17
Prob > F: 0.1474

Independent Variables	Coeff	t	P>|t|
Salinity	0.011863	1.52	0.147

The results shown above have the following meanings:

- Prob(F) > – Using the F-value documented above in an F-test, this parameter illustrates the confidence limit associated with the question of whether the set of predictor variables can predict the dependent variables. If the Prob(F) value is less than an alpha value (such as $\alpha=0.05$ for the 95% confidence limit), it can be said that the group of independent variables can be used to reliably predict the dependent variable. However, this test does not address the relative ability of one predictor over another to control the dependent variable.
- R-squared – The value shown here, 0.8896, states that 88.96% of the variance associated with the dependent variable is accounted for by the predictors. This is a measure of the strength of association, but again, cannot be used to address the relative association of individual predictors with the dependent variable.
- Adj R-squared – As predictor variables are added to the model, some of the variance of the dependent variable will be associated with these new variables by chance. The value of R-squared is thus adjusted to eliminate these chance contributions.
- Coeff – The numbers in this column represent the coefficients associated with each of the predictor variables in the model (_cons is the constant). These values are used to predict the dependent variable in the following fashion:

Nitrate= -0.2424074 + .0371464*salinity + 9.00e-6*shedarea + 0.0001139*tc +...

An interesting point derived from these values is the contribution that each predictor variable can have on the dependent variable. For example, if all values are held constant except salinity, an increase of one unit in salinity would result in an increase in the nitrate level of 0.0371464. However, this is only the case if the coefficients are shown to be significantly different than zero.

- t – Calculated by dividing the coefficient of each predictor variable by its standard error, these values are used in the Student's t-test to determine whether or not the coefficients calculated for the model are significantly different from zero.
- P>|t| - Similar to the F-test described above, this value is compared to a prescribed alpha value that describes a confidence level. When P is less than alpha, the coefficient is statistically shown to be different than zero at the confidence interval described by alpha.

The regressions performed using Stata were the primary mechanism by which both chemical and hydrologic data were analyzed. Thus, relationships among nutrient levels, sedimentation parameters, watershed properties, and runoff characteristics were investigated in order to link the chemistry of salt ponds to the hydrology of the surrounding area.

The first aspect of the output that was considered was the result of the F-test in order to determine whether the models developed by Stata could be considered statistically significant. Those regressions whose probability for this test was outside of the 95% confidence limits were discarded, for the model failed to reliably describe the system.

Following this screening, the R^2 and adjusted R^2 values were examined to determine whether or not the models could account for the variance in the dependent variable. While no regressions were discarded based on this parameter, closer attention was paid to those whose R^2 was closer to 1. In addition, those regressions that had larger discrepancies between R^2 and adjusted R^2 values, which suggests that more of the association shown between the model and the dependent variable is due to chance, were viewed with caution.

P>|t| values were the next aspects of the regression to be analyzed. Predictors whose probabilities were less than the alpha value for the 95% confidence interval (α=0.05) were then analyzed further; since their coefficients were more likely to be different than zero, these predictors were more likely to have a direct effect on the magnitude of the independent variable.

Finally, the coefficients of these predictors were compared to the magnitudes of the predictors themselves to determine the extent of the effect that a change in the predictor would have on the dependent variable.

6 DATA AND RESULTS

The results presented in this section appear in the order in which they were obtained and utilized. The GIS and planimeter results were obtained first, and provided valuable information regarding the delineation of watersheds and subwatersheds, descriptions of the soil present, and the types of coverage. This information was then utilized in HydroCAD models to produce results describing watershed properties and runoff characteristics. These results, in conjunction with the chemical health parameters and development metrics, were analyzed using Stata to explore the relationships between the chemistry of salt ponds and the hydrology of the surrounding area. Finally, the information gathered using seepage meters illustrates the potential complexity of groundwater-salt pond interaction. This information also indicates the feasibility of groundwater seepage measurement, which may be an important part of future studies for salt pond analysis.

6.1 GIS Results

The data for the GIS dataset were downloaded from several different Internet sites. The site <http://www.gisdatadepot.com/catalog/VI/> was especially helpful, as was the USGS website. The data were collected and then the metadata read to determine the projection and other important aspects of the data. Then, it was attempted to put all of the data in the same projection, UTM with a datum of NAD83, using the ArcView 3.2 program. After the data were projected, the data were compared to determine if they were compatible. Unfortunately, some of the data did not match; especially important was the fact that the soil map and the DEM were off by over a hundred meters. In order to overcome this discrepancy, simultaneous visual inspection of both contour and soil maps was necessary to analyze watersheds. The results of the GIS data collection and map making are presented in Appendix B. The data were essential for the HydroCAD analysis. Watershed areas, soil areas and classifications, pond areas, and many other important data were determined using the GIS data. Following the removal of sinks and spires using the "Fill" function, the watersheds were determined by adding contours to the DEM and visually determining the surface area that would run off to the pond.

The soil map was downloaded off the USDA-NRCS website <http://www.ftw.nrcs.usda.gov /ssur_data.html>, which contains the Soil Survey Geographic Database (SSURGO), a soil survey for many areas within the US. The soil map is made to provide information about the soils and their properties; specifically, a description of the soils, their location, and their suitability, limitations, and management for specified uses (USDA, 1998). The work is undertaken by soil scientists who dug many holes to study the soil profile (the sequence of natural layers, or horizons in a soil). They also observe the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. The profile contains information from the surface down into the unconsolidated material.

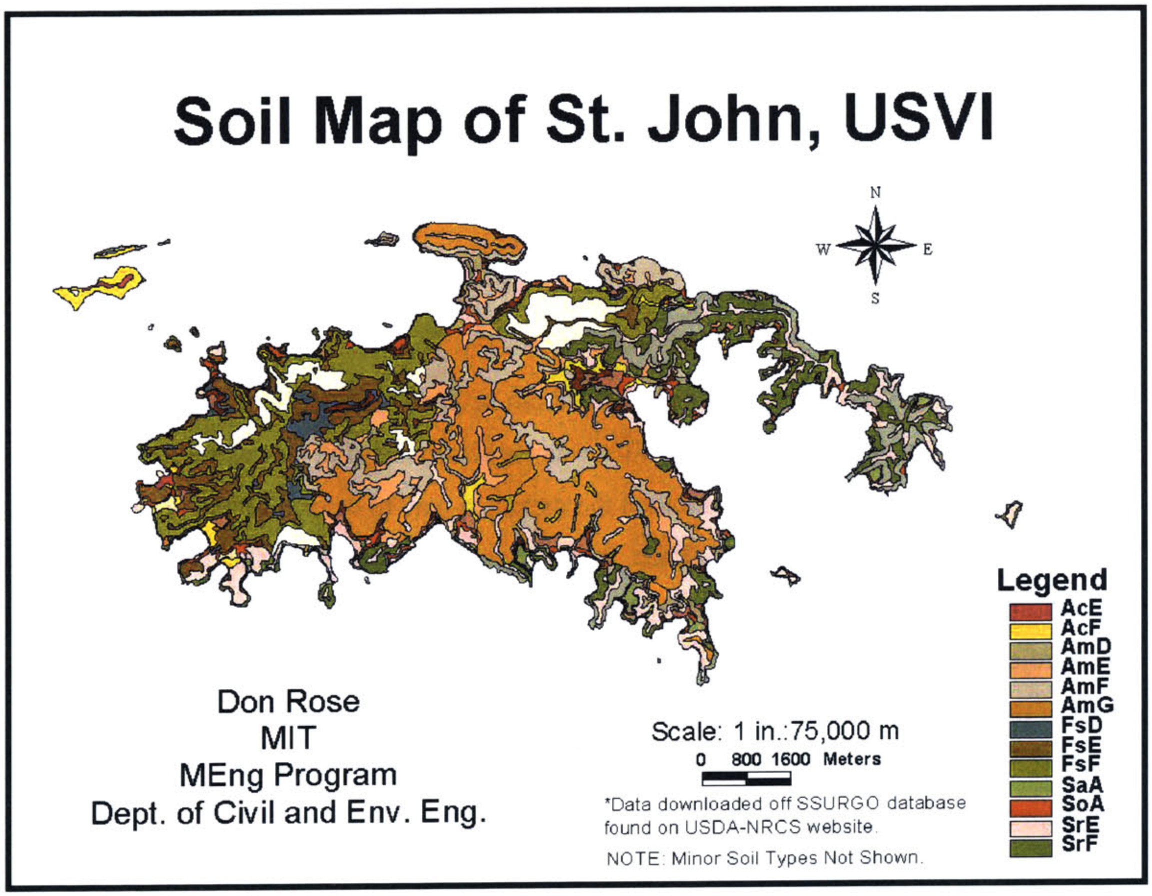

FIGURE 16
SOIL MAP

AcE - Annaberg-Cramer complex, 20 to 40 percent slopes, extremely stony
AcF - Annaberg-Cramer complex, 40 to 60 percent slopes, extremely stony
AmD - Annaberg-Maho Bay complex, 12 to 20 percent slopes, extremely stony
AmE - Annaberg-Maho Bay complex, 20 to 40 percent slopes, extremely stony
AmF - Annaberg-Maho Bay complex, 40 to 60 percent slopes, extremely stony
AmG - Annaberg-Maho Bay complex, 60 to 90 percent slopes, extremely stony
FsD - Fredriksdal-Susannaberg complex, 12 to 20 percent slopes, extremely stony
FsE - Fredriksdal-Susannaberg complex, 20 to 40 percent slopes, extremely stony
FsF - Fredriksdal-Susannaberg complex, 40 to 60 percent slopes, extremely stony|
SaA - Salt flats, ponded
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded|
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes
SrF - Southgate-Rock outcrop complex, 40 to 60 percent slopes

A mosaic aerial photograph of St. John was downloaded from the website <http://biogeo.nos.noaa.gov/products/benthic/data/mosaic/zip/stjohn.zip>. The aerial photograph was published by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. The map is a mosaic of several aerial photos and provides a full map of St. John and information regarding the coverage surrounding salt ponds. Figure 17 shows a smaller version of the map contained in Appendix B.

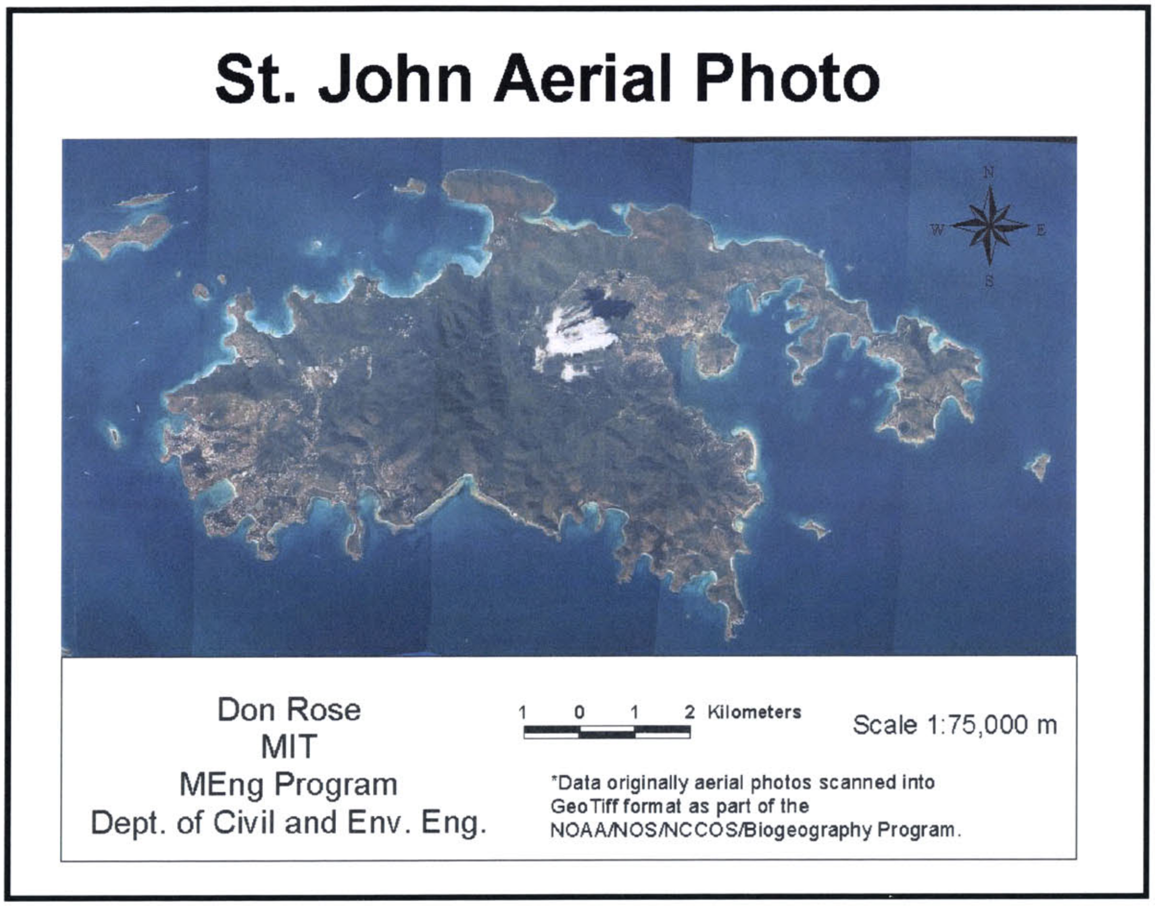

FIGURE 17
AERIAL PHOTOGRAPHIC MAP

The subwatersheds presented in the Subwatershed Map (Figure 18) are the result of an adaptation by the Island Resources Foundation of the CH2M Hill "Sediment Reduction Watershed Study." These watersheds are more useful than the USGS HUC 14 watersheds for determining runoff and eventual discharge points, and were used for a comparison of the drawn watersheds. However, they are not applicable for hydrologic analysis of smaller ponds.

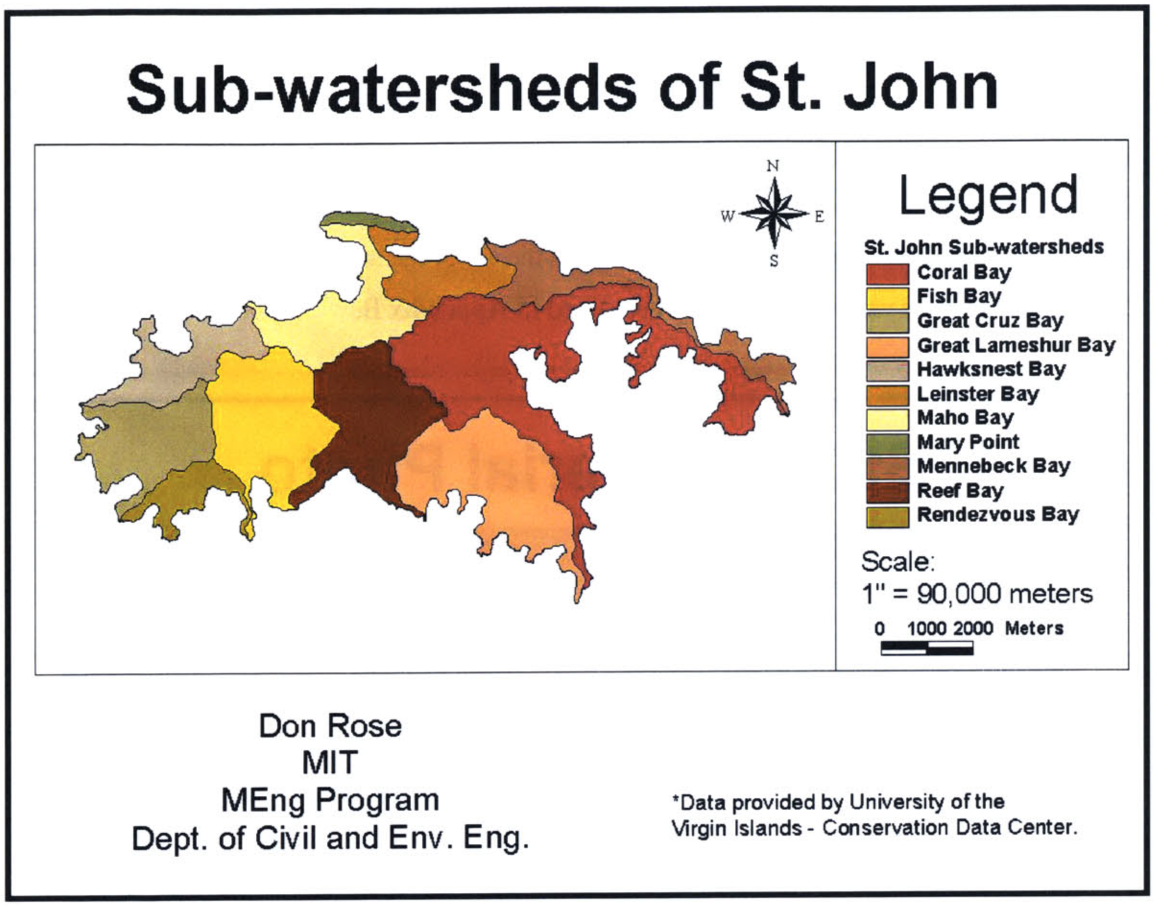

FIGURE 18
SUB-WATERSHED BOUNDARIES

The ground surface elevation contour map (Figure 19) was produced by adding contours to the DEM using ArcView 3.2 Spatial Analyst. The contours were used for delineation of the watersheds for the ponds. The flow path of runoff is determined by the slope and direction of land with the pond as the ultimate discharge point.

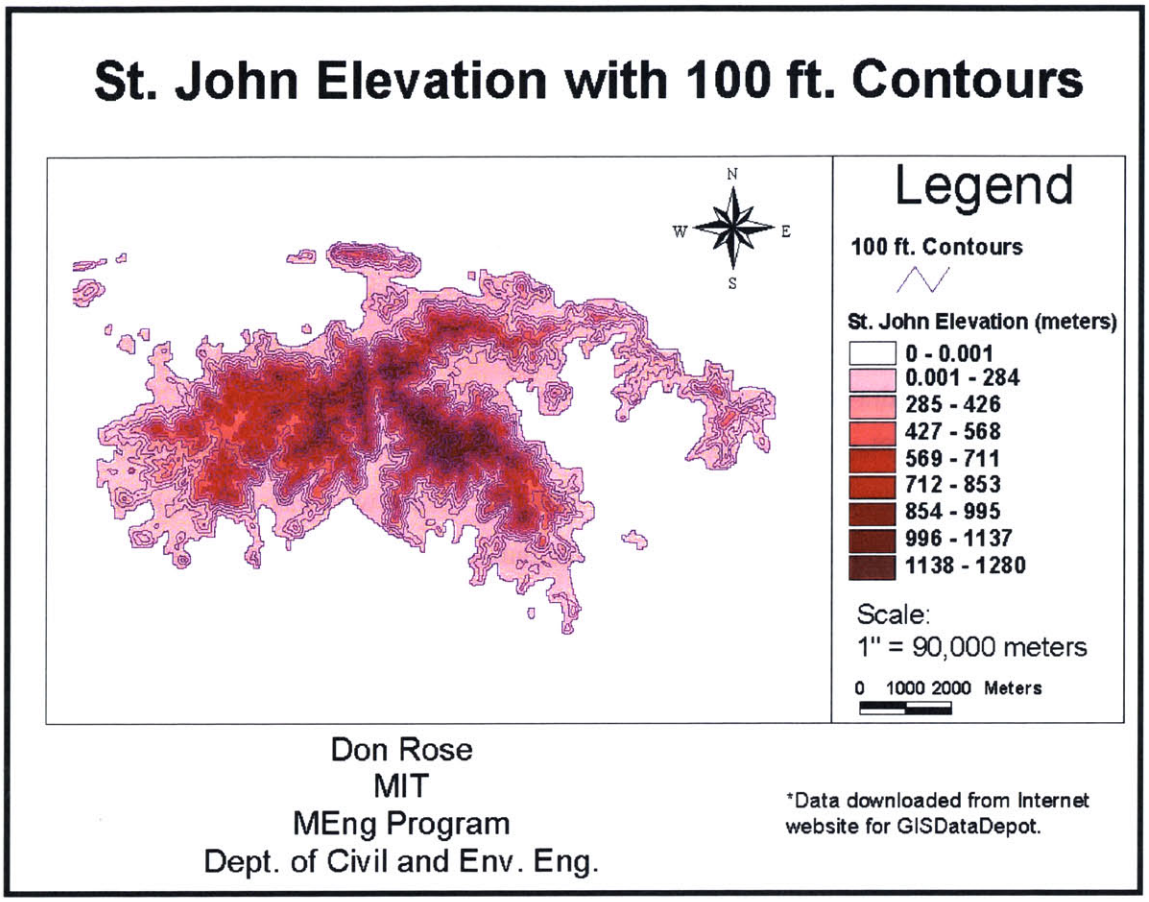

FIGURE 19
ELEVATION MAP WITH 100-FOOT CONTOURS

The pond map (Figure 7) was produced by downloading an outline of St. John as well as the wetland areas prepared by the U.S. Fish and Wildlife Service from the GISdatadepot website <http://data.geocomm.com/>. The wetland areas were compared to a pond list and map provided in Stengel (1998). The ponds were selected and renamed. The rest of the wetland areas were deleted from the GIS database.

The main problem encountered while gathering GIS data for St. John was the variety of projections used. As stated earlier, the data can be expressed via a specific datum which can be altered in order to make the data uniform. When specific pieces of data were reprojected so as to put them into the UTM projection with a NAD 83 datum, the map features did not match up. This prevented using specific map coverages together. This was especially problematic when drawing the watersheds because the DEM did not match the soil map. Therefore the soils were approximated using visual inspection. Unfortunately, the originator of the data causes these problems and they cannot be fixed easily. Nevertheless, the results from GIS data manipulation were crucial for developing hydrologic models in HydroCAD.

6.2 Planimeter Results

The planimeter results are based on visual inspection of the contours to determine the surface area that would erode to the pond in a storm event. The GIS watershed map allowed greater manipulation because it allowed changes in the contour interval. Therefore, a more exact watershed could be drawn. On the USGS maps, there is a limitation due to the 20-foot contours provided. Planimetry was performed because it provided a second method to check the results of the watersheds drawn using the GIS data. There were cases, though, when the pond was not shown on the USGS maps, and the only method of determining the watershed was by using the GIS method.

6.3 Averaging Procedure

The areas determined by planimetering the hand-drawn watersheds on the USGS maps were averaged with the watershed areas determined using visual inspection on a GIS map with contours. This procedure was applied because it was deemed that averages would make the result more representative. The planimeter results may have been affected by the map scale (1":2000'), since very small errors in hand movement can greatly alter the area measurement, as well as the drawn boundaries of the watersheds. The GIS maps, which allow for manipulation of contour intervals, were used to draw a more accurate watershed, but the resolution of the GIS sometimes caused calculation problems. By averaging the results, the error inherent in the measurement techniques was diluted. Table 2 contains the USGS (planimetered), GIS, and averaged results. In most cases, the planimeter and GIS results were not very far off. In cases where the watershed could not be planimetered due to lack of data on the USGS contour maps (Friis Bay, Salt Pond 2, and Poppilleau Bay), the GIS result was used.

TABLE 2
WATERSHED AREA RESULTS
(Area in Square Meters)

Pond Name	USGS	GIS	Averaged
Chocolate Hole East	38,900	36,700	37,800
Chocolate Hole West	20,000	18,600	19,300
Elk Bay East	51,800	53,300	52,600
Frank Bay	45,100	42,300	43,700
Friis Bay	*	56,400	56,400
Hansen Pond	55,700	55,700	55,700
Popilleau Bay	*	369,000	369,000
Salt Pond	100,800	90,900	95,900
Salt Pond 2	*	14,700	14,700
Southside Pond	224,600	218,100	221,400

6.4 HydroCAD Results

A HydroCAD model was prepared for the watershed of each pond. The data necessary to formulate HydroCAD models, as described in the methods section, include watershed area, house area, impervious area, land coverage, soil type, and the lengths and slopes necessary to calculate time of concentration (TC). Table 3 contains these parameters for each pond. HydroCAD then returned outputs that can be grouped into two categories: watershed description and runoff characteristics. These outputs are tabulated in Tables 3 and 4. For watershed description, HydroCAD provided information regarding the area contributing to each pond (which does not include the pond itself nor the house area), the weighted curve number, and the time of concentration. In addition, a manual calculation was performed to determine the percentage of area surrounding each pond that could be considered "natural," or undeveloped. As can easily be seen, Frank Bay is located within least natural watershed due to the number of buildings and roads surrounding it.

TABLE 3
HYDROCAD WATERSHED DESCRIPTION INPUT

Pond Name	Pond Area (sq. m)	Watershed Area (sq. m.)	House Area (sq. m.)	Impervious Area (sq. m.)	Dirt Road (sq. m.)	Soil Type*	TC Length (m)	Slope (m/m)
Choc. Hole E.	4,965	37,790	446	836	0	D	170	0.32
Choc. Hole W.	2,438	19,300	743	836	0	D	268	0.30
Elk Bay East	1,740	52,550	0	0	0	D	180 155	0.12 0.43
Frank Bay	8,643	43,710	2,230	7,440	0	D	135	0.20
Friis Bay	6,108	56,400	1,740	451	0	D	900	0.20
Hansen Pond	1,505	55,690	2,230	0	267	D	500	0.24
Popilleau Bay	5,766	369,000	2,970	4,175	0	C, D	230 108 490	0.50 0.23 0.05
Salt Pond	26,521	95,850	0	0	0	D	60 150	0.20 0.01
Salt Pond 2	1,086	14,700	0	0	0	D	145	0.19
Southside	40,494	221,370	149	0	0	D	263 105	0.39 0.015

* Soil type refers to Hydrologic Soil Group A, B, C, or D.

TABLE 4
HYDROCAD WATERSHED DESCRIPTION OUTPUT
(CN = Curve number, TC = Time of concentration)

Pond Name	Area (sq. m)	Weighted CN	TC (min.)	Percent Natural
Chocolate Hole East	32,379	68	1.6	96.1
Chocolate Hole West	16,789	72	2.7	90.6
Elk Bay East	50,810	70	4.1	100
Frank Bay	32,837	73	1.6	72.4
Friis Bay	48,101	63	11	95.6
Hansen Pond	54,835	73	5.6	95.4
Popilleau Bay	360,264	72	15	98
Salt Pond	69,329	72	5.8	100
Salt Pond 2	13,614	72	1.1	100
Southside Pond	180,727	72	7	99.9

* Watershed area excludes pond area and house roofs.

When the HydroCAD models were completed, the initial attempt was to calculate runoff characteristics based on the average rainfall for each month. For this amount of rainfall, HydroCAD predicted zero runoff. This is consistent with our observations in the field; storm events that occurred while performing experiments on the island were not sufficient to produce runoff to the ponds. This was further confirmed by visual inspection while on the island, as no ponds were seen to experience runoff during the experimentation period.

(During one particularly intense rain event, runoff was seen at a water gut, but this was not located near a pond.) It was determined that based on the input parameters to the model, the minimum rainfall event resulting in runoff ranged between 19 mm (approximately 0.75 inches) and 30 mm (approximately 1.18 inches) depending on the pond (see Table 5). Therefore, rainfall data from the National Climatic Data Center (NCDC) Hourly Precipitation CD's produced by EarthInfo, Inc were used to determine how many rain events that were greater than these minimum values occur in the historic rainfall record. These results are presented in Table 5. The rainfall record was for the station located at the Caneel Bay Plantation for the period of 1978 to 1995.

TABLE 5
RUNOFF CHARACTERISTICS BY POND

Pond Name	Storm Depth Required for Runoff (mm)	Average Annual Number of Storms	Runoff Rate (mm^3/sec)	Runoff Volume (Liters)
Chocolate Hole East	24	6.72	11,200	0.002
Chocolate Hole West	20	9.83	27,700	0.01
Elk Bay East	22	8.44	58,600	0.024
Frank Bay	19	9.83	49,700	0.016
Friis Bay	30	5.28	14,200	0.009
Hansen Pond	19	9.83	58,900	0.026
Popilleau Bay	20	9.83	252,000	0.217
Salt Pond	20	9.83	90,000	0.042
Salt Pond 2	20	9.83	24,000	0.008
Southside Pond	20	9.83	216,000	0.109

6.5 Stata Regression Results

The watershed description and runoff characteristics output by HydroCAD were coupled with the chemical health parameters and development metrics shown in Table 6. This data set was then analyzed using multivariate regressions in Stata to discern the relationships between salt pond chemistry and the hydrology of the surrounding area.

The results from the many regressions that were run can be found in Appendix I - Stata Regression Results. Based on the methods described in Section 5.7, Data Analysis Using Stata, the outputs from the statistical software package Stata were analyzed using a screening procedure to examine the relationships between the variables measured. In particular, the data analysis was carried out to determine whether nutrient levels and sedimentation parameters are associated with development, and what effect development may have on the chemical health of ponds.

TABLE 6
AVERAGE CHEMICAL PARAMETERS AND DEVELOPMENT
METRICS FOR PONDS SAMPLED

Pond Name	Temp. (° C)	Salinity (ppt)	DO (%)	DO (mg/L)	pH	Turbidity (NTU)	TSS (mg/L)	NO_3^- (mg/L as N)	PO_4^- (mg/L as P)	Development Matrix
Frank Bay	27.44	72.13	68.11	3.63	8.44	8.39	0.00013	2.38	0.40	17
Choc. Hole W.	33.93	69.47	109.43	5.24	8.27	4.86	0.00007	2.60	N/A	11
Choc. Hole E.	28.66	33.58	60.37	3.87	8.12	9.55	0.00011	1.33	N/A	10
Popilleau Bay	30.10	36.50	109.60	6.67	8.65	13.42	0.00008	1.01	N/A	15
Elk Bay Pond	29.54	58.54	84.10	4.69	8.21	14.73	0.00012	2.00	N/A	6
Hanson Bay	31.10	31.00	52.27	3.29	8.10	52.00	0.00015	0.67	N/A	6
Friis Bay	25.82	62.97	38.80	2.59	8.95	5.97	0.00014	2.40	N/A	14
Salt Pond	28.77	227.15	45.76	1.56	7.67	2.58	0.00048	9.07	1.69	9
Salt Pond 2	24.71	59.97	53.70	3.16	8.83	N/A	0.00022	2.00	0.53	9
Southside Pond	27.64	105.00	39.88	1.81	8.19	3.55	0.00019	3.90	0.69	15

6.5.1 SPATIAL AND TEMPORAL VARIABILITY WITHIN PONDS

It was expected that temperature and dissolved oxygen would vary with time within a pond. However, the first regression run, which included temperature, dissolved oxygen, and time points for all ponds, did not find time to be a significant predictor of temperature or dissolved oxygen. Therefore, separate regressions were run on Frank Bay Pond and Southside Pond, which were the only ponds that were visited more than once and at different times during the day. Frank Bay was visited on several different days at different times during the day, while one full day at Southside Pond yielded several samples at different times during the day. The results of these regressions were more in concordance with what was expected. Temperature was found to be predicted by time to a high confidence level, while dissolved oxygen was predicted by both time and temperature within each of these ponds.

Another area of concern was whether spatial variability of nutrient levels within ponds could be attributed to development. Therefore, samples were taken from points around the pond to try and find whether "hotspots" existed; most sampling runs consisted of one sample from the middle of a pond, one from near the berm, and then a final sample taken from the water closest to the most heavily developed area. However, no significant variations were seen in any of the ponds to suggest that the water near developed areas had higher nutrient concentrations. This is presumably due to mixing in the very shallow ponds; pond depths range from a few centimeters to, at most, two meters.

In order to determine whether the shallowness of the ponds would result in a well-mixed system, a depth profile of temperature and salinity was measured at one of the deeper ponds, Frank Bay Pond. This test showed almost no variation with depth of either temperature or salinity, which suggests that the pond was well mixed. This result, when coupled with the lack of spatial variability of nutrient concentrations within ponds, suggests that all salt ponds, due to their lack of depth and small surface area, are well mixed. This is an important result, especially in the case of Chocolate Hole East. Since this pond is open to the ocean and well mixed, the assumption that the nitrate concentration in the pond is the same as that in the neighboring bay, which is important for a later calculation, is justified.

6.5.2 PHOSPHATE CONCENTRATIONS

The first point of interest from the Stata regressions output is that all regressions run using phosphate concentration as a dependent variable result in a high value for the F-test, an indicator that the model developed is insignificant and the predictor variables cannot accurately determine the dependent variable. In other words, phosphate concentrations in the salt ponds cannot be shown to be related to any of the other parameters measured, since the Prob>F values are higher than acceptable confidence intervals (Table 7).

TABLE 7
STATA OUTPUT OF REGRESSIONS INVOLVING PHOSPHATE

Dependent Variable: Phosphate

Regression 1
R^2: 0.5311
Adjusted R^2: -1.3447
Degrees of Freedom: 10
Prob > F: 0.9205

Independent Variables	Coeff	t	P>|t|
DO	-0.0462882	-0.43	0.711
Temperature	-1.50705	-0.18	0.871
Salinity	-0.1880685	-0.02	0.987
pH	7.069773	0.05	0.967
Time	0.0113387	0.26	0.819
Turbidity	-0.2083186	-0.07	0.952

TSS	10077.77	0.3	0.791
Watershed Area	0.0000196	0.01	0.993
Slope	Dropped		
TC	Dropped		

Regression 2
R^2: 0.1266
Adjusted R^2: 0.072
Degrees of Freedom: 17
Prob > F: 0.1474

Independent Variables	Coeff	t	P>|t|
Salinity	0.011863	1.52	0.147

Several potential reasons exist for this failure of the regression analysis. The first is that phosphate tests were added midway through the study. This leads to both a decrease in the total number of observations as well as a decreased number of ponds sampled. Hence, the broader relationships between variables that require extensive data to be discerned remain invisible. Another potential explanation for the lack of significance seen in the phosphate concentrations is the failure of the sampling method. The Hach spectrophotometric method for orthophosphate has been criticized for its accuracy (Murcott, 2003), and also has a high likelihood of failure due to salt interference.

Sampling methods and statistics aside, there also exist biogeochemical explanations for the lack of statistical significance associated with phosphate concentrations. These phosphate concentrations reflect orthophosphate, or reactive phosphate, which is the concentration of phosphate that is readily bioavailable. A more applicable concentration to measure for the purpose of regression analysis would be total phosphorus, which would include not only the reactive, bioavailable phosphorus but also the phosphorus that is already biologically bound. The four ponds sampled for phosphate concentrations exhibit variations in their ecology, and since these variations were not included in the regression analysis, the effect that they might have on the concentrations of bioavailable phosphate is undetermined. Therefore, in order to remove the effect of biology from the regression analysis of phosphate concentrations and their association with development, total phosphorus would be a more appropriate measure. In addition, the independent variables used in the regressions to predict phosphate concentrations are more readily in the water column, while phosphate tends to sorb to sediments. This may have affected the ability of the independent variables to predict phosphate.

6.5.3 NITRATE CONCENTRATIONS

In contrast, regression analyses that include nitrate concentrations show F-tests that are significant at very high confidence levels. In addition, the adjusted R^2 values prove that the models account for at least 83% of the variance seen in nitrate concentrations. In addition, since nitrate levels were measured in every pond sampled throughout the study, a larger number of observations exist.

From these regressions, several variables were shown by their t-tests to be particularly significant. It is difficult to compare t-values across models, but the probability test associated with the t-value shows how likely the effect of each predictor variable is to be nonzero within the model. With this in mind, salinity was shown in every nitrate regression to be a statistically significant variable at high confidence levels.

TABLE 8
STATA OUTPUT OF REGRESSIONS INVOLVING NITRATE

Dependent Variable: Nitrate

Regression 1
R^2: 0..8944
Adjusted R^2: 0.8389
Degrees of Freedom: 29
Prob > F: 0

Independent Variables	Coeff	t	P>|t|
Temperature	-0.0323171	-0.15	0.88
Salinity	0.0408693	2.39	0.028
pH	0.4221056	0.23	0.822
Turbidity	0.0068833	0.17	0.866
TSS	7446.041	2.1	0.049
Watershed Area	0.0000196	0.01	0.993

Regression 2
R^2: 0..8944
Adjusted R^2: 0.8389
Degrees of Freedom: 29
Prob > F: 0

Independent Variables	Coeff	t	P>|t|
Salinity	0.0371464	9.03	0
Watershed Area	0.000009	1.04	0.305
House Area	-0.00000843	-1.1	0.279
Impervious Area	-0.0000465	-0.89	0.378

The association between nitrate concentrations and salinity levels can also be seen graphically, as in Figure 20. From the equation for the trendline shown in Figure 20, 88.5% of the variance seen in nitrate concentrations can be predicted by salinity levels. (This value, however, is unadjusted; therefore, some of the variance is predicted solely by chance.) In addition, the coefficient for salinity in this model, β=0.0409, shows that for a one unit (ppt) increase in salinity levels, an increase of 0.0409 units (mg/L as N) in nitrate concentration will be seen. These values from the single variable regression performed by Excel are consistent with those reported by Stata's multivariate regressions. Unadjusted R^2 values reported by Stata range between 88.5% and 89.9%, while coefficients range between β=0.0343 and β=0.0409.

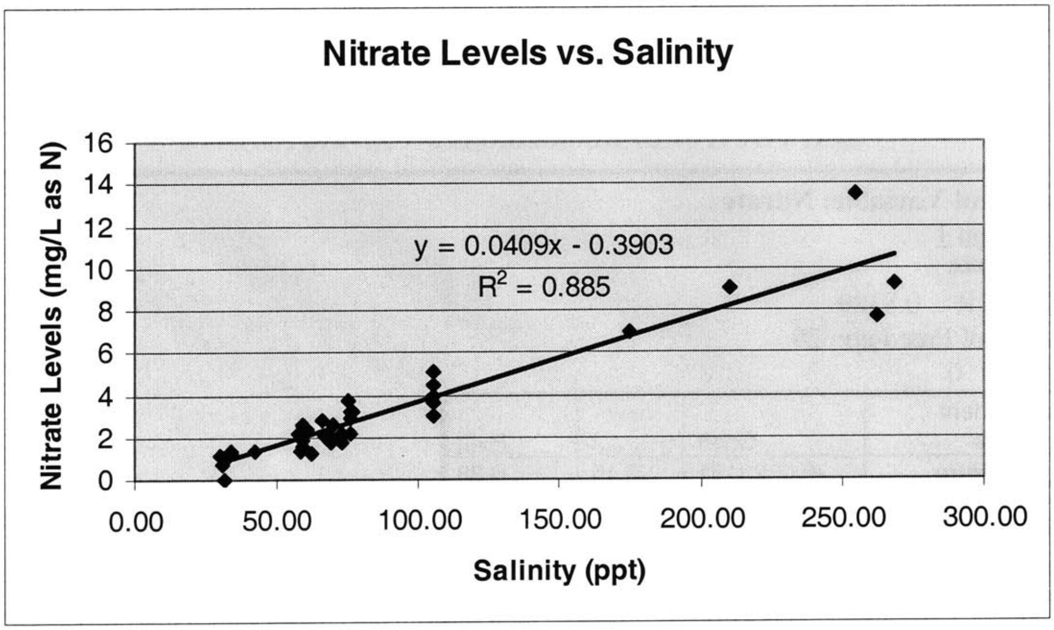

FIGURE 20
PLOT OF NITRATE LEVELS VS. SALINITY

Other variables that show significant t-test results when included in nitrate regression analyses are TSS, watershed area, and house area. In the case of TSS, however, the coefficient ranges between β=3958 and β=7446. This suggests that for a one unit increase (mg/L) of TSS, an increase of approximately 5000 nitrate units (mg/L as N) would be seen. This is obviously an artifact of the sampling results. Watershed and house area have more reliable coefficients (β=0.000074 and β=-0.0000645, respectively), but these coefficients also suggest that large increases in watershed and house areas would have to occur before any appreciable change in nitrate concentration could be seen.

Nitrate concentrations were not shown to be significantly associated with any other factor of development, as can be seen from the P>|t| values shown in Appendix I.

6.5.4 NITRATE DEVIATIONS FROM EXPECTED EVAPORATIVE VALUES

The linear relationship between nitrate and salinity levels suggests that concentration by evaporation is the main mechanism leading to elevated nutrient concentrations. In order to verify this suggestion, a plot was constructed by calculating the nitrate concentration that would result from evaporation. These calculations were performed by obtaining the salinity and concentration of nitrate in the ambient ocean water surrounding St. John (36.47 ppt and 0.214 mg/L as N, respectively) from the National Oceanic and Atmospheric Administration (NOAA, 2001) and then calculating new concentrations as water is removed by evaporation. The plot constructed using these values is exhibited in Figure 21.

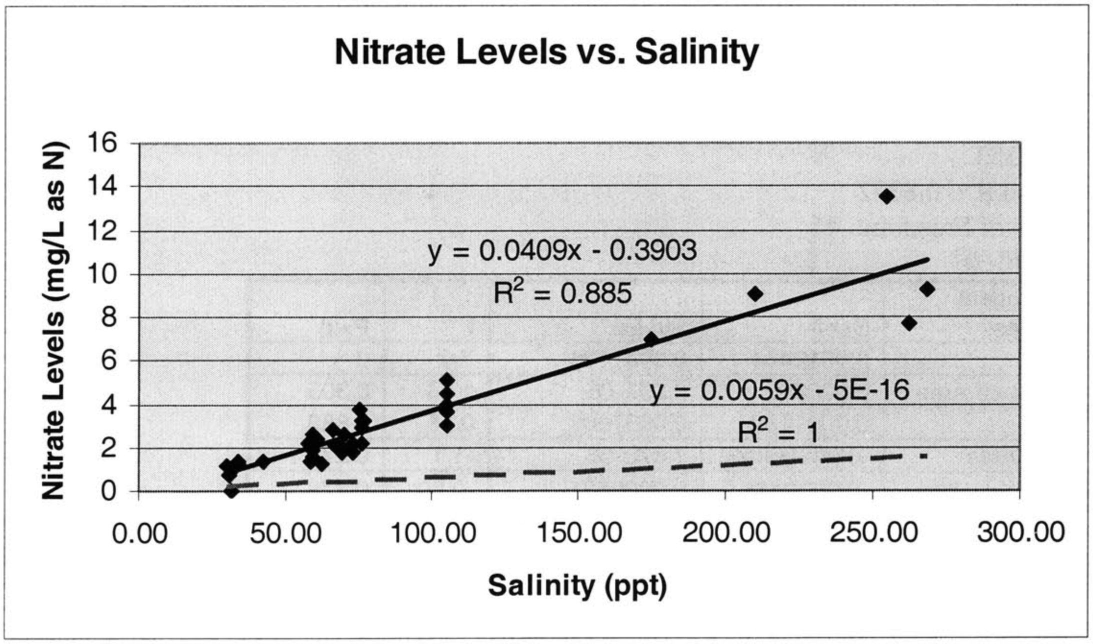

FIGURE 21
DEVIATION OF NITRATE LEVELS FROM EXPECTED EVAPORATIVE VALUES AS CALCULATED FROM NOAA CONCENTRATION
(solid line represents measured values; dashed line represents calculated values)

The dashed line in Figure 21 represents the nitrate concentrations expected from evaporation, while the solid line is a linear regression of the measured salinities and nitrate concentrations. As can easily be seen, the deviations from expected values also increase with salinity. Hence, regressions were run in Stata to determine if the increased deviations were associated with development; if ponds in highly developed areas had nitrate concentrations that were even higher than expected from evaporation, regression analysis should show an association. However, this analysis of nitrate deviations had similar results to that of nitrate. All regressions with F-test results that proved the model to be significant showed salinity to be the only significant predictor of nitrate deviation. Other variables with t-test results that are significant are watershed area and house area; however, again their coefficients are so small that large changes in these parameters would have minimal effects on nitrate deviation. In addition, the adjusted R^2 value for the model including only watershed area and house area is only R^2=0.5589, showing that this model fails to account for approximately 45% of the variance seen in nitrate deviation values.

TABLE 9
STATA OUTPUT OF REGRESSIONS INVOLVING NITRATE DEVIATIONS (NOAA)

Dependent Variable: Nitrate Deviation from Expected Value (NOAA)

Regression 1
R^2: 0.8553
Adjusted R^2: 0.8372
Degrees of Freedom: 45
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	0.0312464	0.0041136	7.6	0
Watershed Area	0.000009	8.65E-06	1.04	0.305
TC	0.0001139	0.0007668	0.15	0.883
House Area	-0.00000843	7.67E-06	-1.1	0.279
Impervious Area	-0.0000465	0.0000521	-0.89	0.378

Regression 2
R^2: 0.5589
Adjusted R^2: 0.5785
Degrees of Freedom: 45
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Watershed Area	0.0000637	8.33E-06	7.64	0
House Area	-0.0000555	7.33E-06	-7.57	0

Regression 3

R^2: 0.8493
Adjusted R^2: 0.8458
Degrees of Freedom: 45
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	0.0350106	0.0022237	15.74	0

The magnitude of the deviations from the expected concentration of nitrate suggests that the starting value provided by NOAA may be inaccurate. Several reasons for this are possible. First, there may be spatial differences in salinity and nitrate concentration in the ocean surrounding St. John. This could be due to differences in ecology (coral reefs, which are extremely productive ecosystems, are often found near shore). Second, temporal variations may be large, especially on a seasonal timescale. Finally, the difference in measurements may be an artifact of sampling, as NOAA's measurement techniques are unknown.

For these reasons, another starting value was used. Chocolate Hole East, which is a pond that has been opened to the surrounding bay to allow for flushing, showed salinity readings (average 33.58 ppt) which were extremely close to the surrounding bay water (34.52 ppt). The close salinity values suggest that the bay water has thoroughly mixed into the pond. If the average nitrate concentration in the pond is assumed to be the same as that in the bay, the same evaporation calculations can be run to generate a range of nitrate concentrations at differing salinities corresponding to those that would be found if evaporation took place. These calculations were performed, and a graph was generated – see Figure 22.

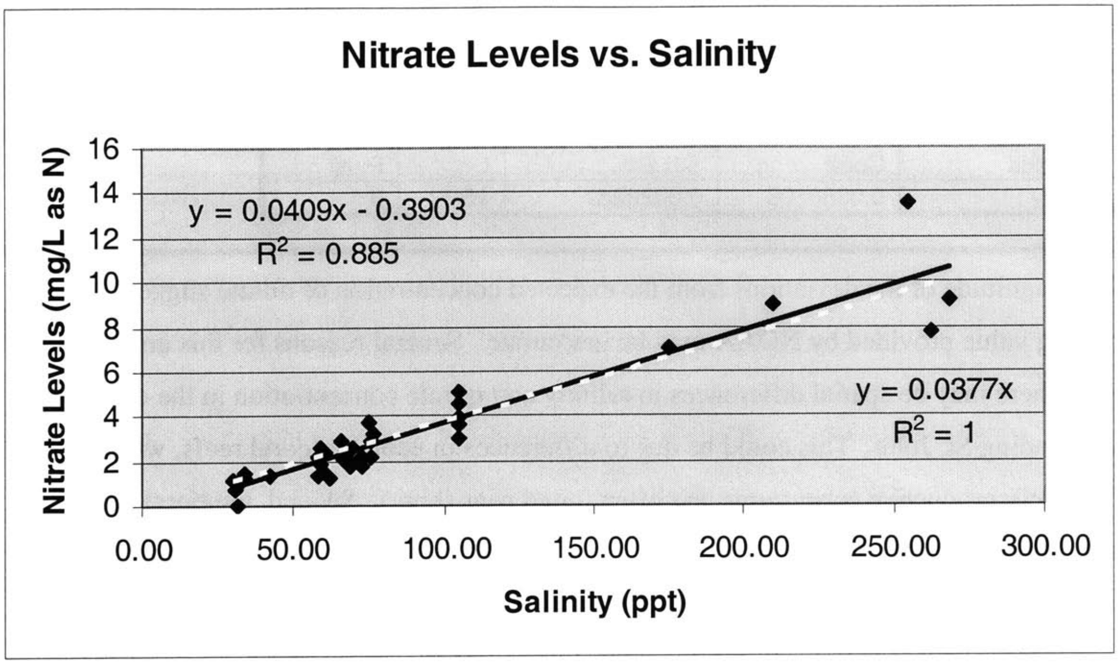

FIGURE 22
DEVIATION OF NITRATE LEVELS FROM EXPECTED EVAPORATIVE VALUES AS CALCULATED FROM CHOCOLATE HOLE EAST NITRATE CONCENTRATIONS
(solid line represents measured values; dashed line represents calculated values)

Again, the dashed lines represent the expected evaporative nitrate concentrations, while the solid line is a linear regression of the measured salinities and nitrate concentrations. The lines are so close in this figure that another graph was made, this time forcing both lines through the origin. Figure 23 shows that the measured values of nitrate correspond very closely with those values expected at varying salinity levels, as their slopes only differ by 0.001. Despite this minimal difference, the deviations from expected values were still analyzed to search for possible relationships with development. No significant correlations were found, as all regression runs resulted in F-tests and R^2 values that were insignificant.

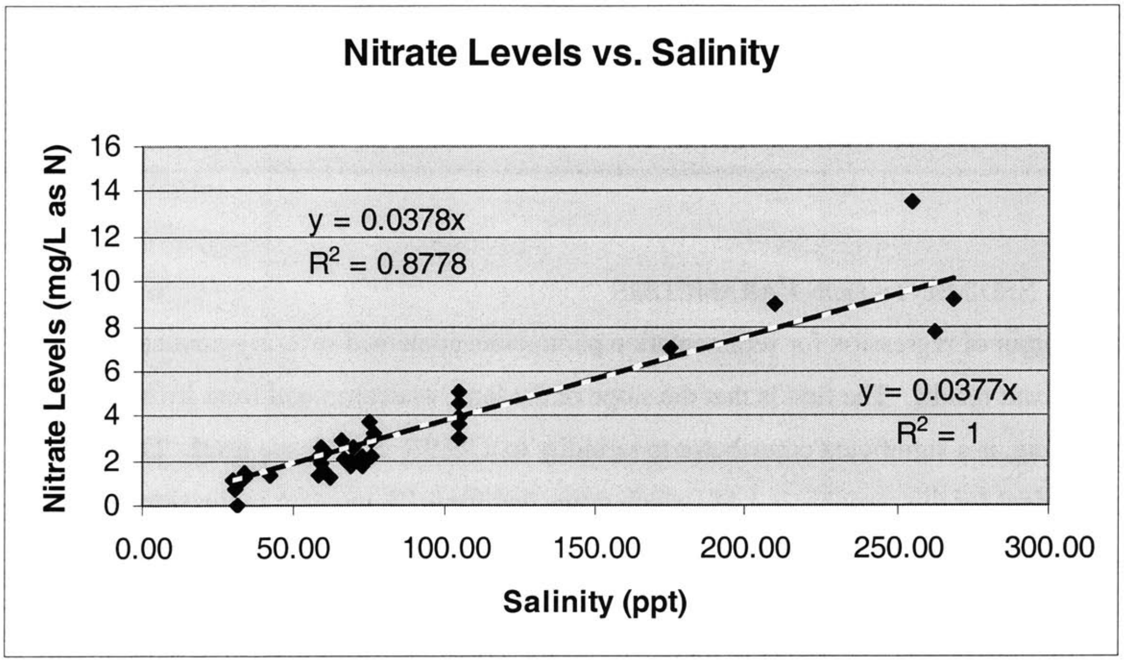

FIGURE 23

DEVIATION OF NITRATE LEVELS FROM EXPECTED EVAPORATIVE VALUES AS CALCULATED FROM CHOCOLATE HOLE EAST NITRATE CONCENTRATIONS

(solid line represents measured values; dashed line represents calculated values, trendlines forced through origin.)

TABLE 10

STATA OUTPUT OF REGRESSIONS INVOLVING NITRATE DEVIATIONS (CHOCOLATE HOLE EAST)

Dependent Variable: Nitrate Deviation from Expected Value (CHE)

Regression 1

R^2: 0.0834

Adjusted R^2: -0.0311

Degrees of Freedom: 46

Prob > F: 0.6064

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	-0.0005483	0.004115	-0.13	0.895
Shedarea	8.96E-06	8.66E-06	1.03	0.307
TC	0.0001095	0.000767	0.14	0.887
House Area	-8.39E-06	7.67E-06	-1.09	0.281
Impervious Area	-0.0000465	0.0000521	-0.89	0.377

Regression 2

R^2: 0.0451

Adjusted R^2: 0.0234

Degrees of Freedom: 46

Prob > F: 0.1564

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	3.21E-03	2.22E-03	1.44	0.156

6.5.5 SEDIMENTATION PARAMETERS

The output of regression for sedimentation parameters contained several statistically significant results. The first is that the slope of the land, as determined from hydrologic modeling, is a significant contributor to turbidity to a 99.9% confidence level. The coefficient for this variable is 1.58, which states that for a 1% increase in the slope of land, turbidity is likely to increase by 1.58 NTU.

Another interesting result is that, while turbidity is significantly associated with the score each pond received from both the full development matrix and the subset associated with only roads, the coefficients have opposing signs: an increase in development as defined by the full development matrix would result in a decrease in turbidity, while an increase in development as defined by the roads subset increases turbidity. Due to this apparent discrepancy, the parameter associated with the full development matrix was removed from the dataset and the regression run again. The result of this regression was found to be statistically insignificant by an F-test, which suggests that neither of the development matrix parameters are statistically significant predictors of turbidity.

TABLE 11
STATA OUTPUT OF REGRESSIONS INVOLVING TURBIDITY

Dependent Variable: Turbidity

Regression 1

R^2: 0.8258

Adjusted R^2: .7595

Degrees of Freedom: 29

Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
TSS	27864.57	18185.89	1.53	0.14
Dev Mat	-12.20656	1.54361	-7.91	0
Dev Mat Roads	26.25947	4.230475	6.21	0
Watershed Area	-0.0000168	0.0000751	-0.22	0.825
Slope	158.1497	40.10126	3.94	0.001
TC	0.0733523	0.0116215	6.31	0
House Area	-0.0000812	0.0000761	-1.07	0.298

Impervious Area	0.0020761	0.0008091	2.57	0.018

The output from Stata showed no significant association of the sedimentation parameter TSS with any factor of development or chemical health. This is most likely due to poor sample handling procedures; the foil seal around the filter paper used in TSS filtration was seen to be corroded in many of the samples. Given the analysis methodology (Section 5.2), bits of corroded foil were likely weighed as TSS mass, thus biasing the TSS measurements.

TABLE 12
STATA OUTPUT OF REGRESSIONS INVOLVING TSS

Dependent Variable: TSS

Regression 1
R^2: 0.7196
Adjusted R^2: 0.6128
Degrees of Freedom: 29
Prob > F: 0.0002

Independent Variables	Coeff	Std Err	t	P>|t|
Turbidity	0.00000361	2.36E-06	1.53	0.14
Dev Mat	0.000039	0.000034	1.15	0.263
Dev Mat Roads	-0.0000613	0.0000799	-0.77	0.452
Watershed Area	-3.89E-10	8.51E-10	-0.46	0.653
Slope	-0.0015964	0.0004911	-3.25	0.004
TC	-0.000000388	2.09E-07	-1.86	0.077
House Area	6.81E-10	8.77E-10	0.78	0.446
Impervious Area	-3.39E-08	7.52E-09	-4.51	0

6.6 Seepage Meter Results

All salt ponds that were sampled for chemistry were surveyed for the feasibility of implementing seepage meters. The most important criteria for choosing a site, as mentioned above were the sediments, pond depth, and lack of obstructions (rocks or roots). A few ponds were not deep enough for utilization of the meters. Also, many of the ponds were surrounded by mangroves (indigenous trees which are found along the shores of the salt ponds). The roots of these trees proved to be impediments for seepage meter use.

Based on these criteria, Southside Pond, located on the eastern part of St. John, was selected for seepage meter testing during the salt pond survey. The seepage meter deployment locations are portrayed in Figure 24. As stated in Section 5.6.1, the location of the first row of meters was dependent upon the depth of water. The other rows and columns were placed approximately equidistant for ease in analysis. The seepage meters were put into two or three rows in an attempt to determine a flow pattern.

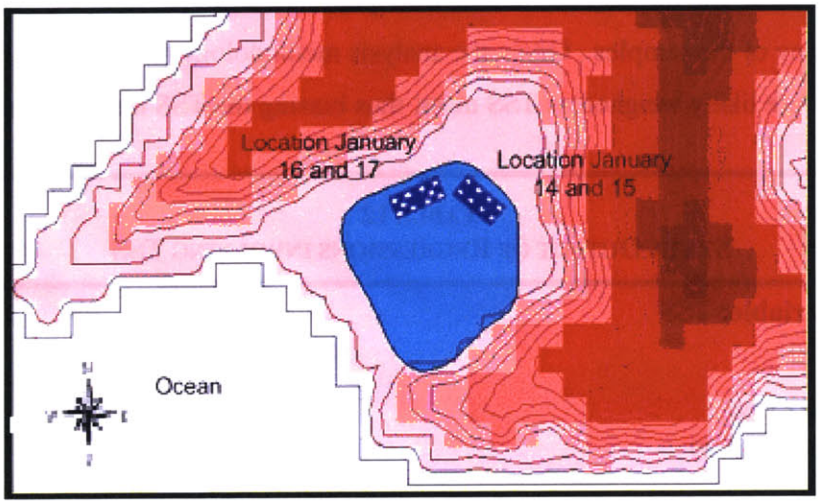

FIGURE 24
SOUTHSIDE POND SEEPAGE METER DEPLOYMENT MAP

The bacterial mat at Southside Pond, while usually strong enough to withstand foot traffic, sometimes failed under increased pressure. It was unclear if the bacterial mat impeded flow to the seepage meters from the groundwater. Therefore, a soil column was taken from the soil surrounding the salt pond in order to characterize the soil. This column is shown in Figure 25, and based on the information obtained from this test, it is believed that the seepage meters did cut through the mat and made a connection to the soil below.

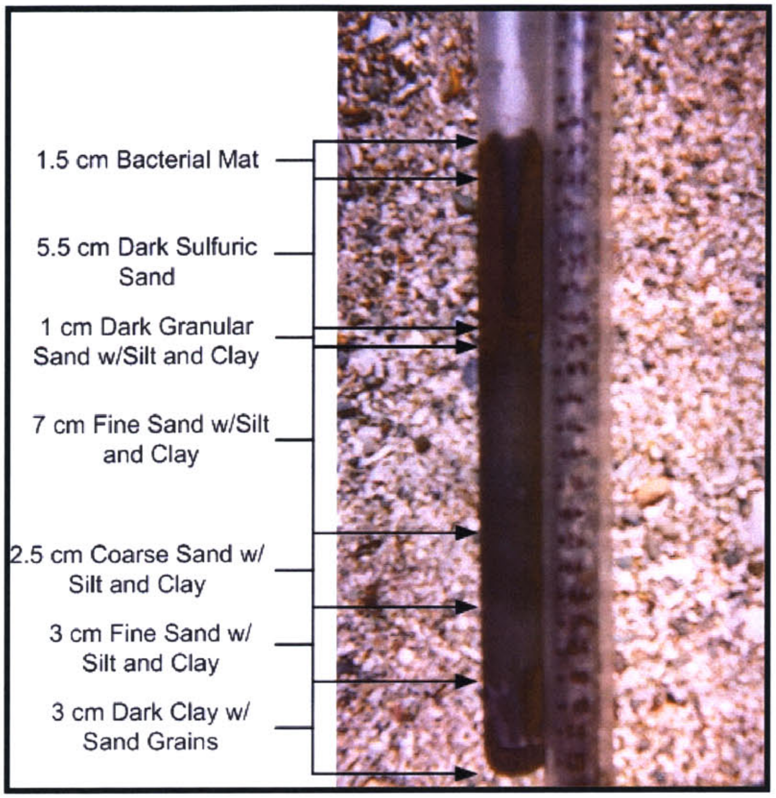

FIGURE 25
SOIL COLUMN FROM SOUTHSIDE POND
(Markings to the right of the core are in 1 centimeter intervals)

Figures 26 and 27 show the results from the seepage meter implementation at two separate locations in Southside Pond. The location for January 14th and 15th was on the far end of the pond from the berm. The slope of the land near this deployment location was less steep than the other sides (excluding the berm), but grew steeper near the northern side of the deployment. At this location, a pattern of groundwater flow was seen. While almost all of the meters at this location lost water from their bags, a behavior known as downwelling, those closest to the steeper northern slope showed higher rates of downwelling. This contradicts the hypothesis formulated when the location was chosen, which theorized that there would be upwelling from the groundwater coming off the slope.

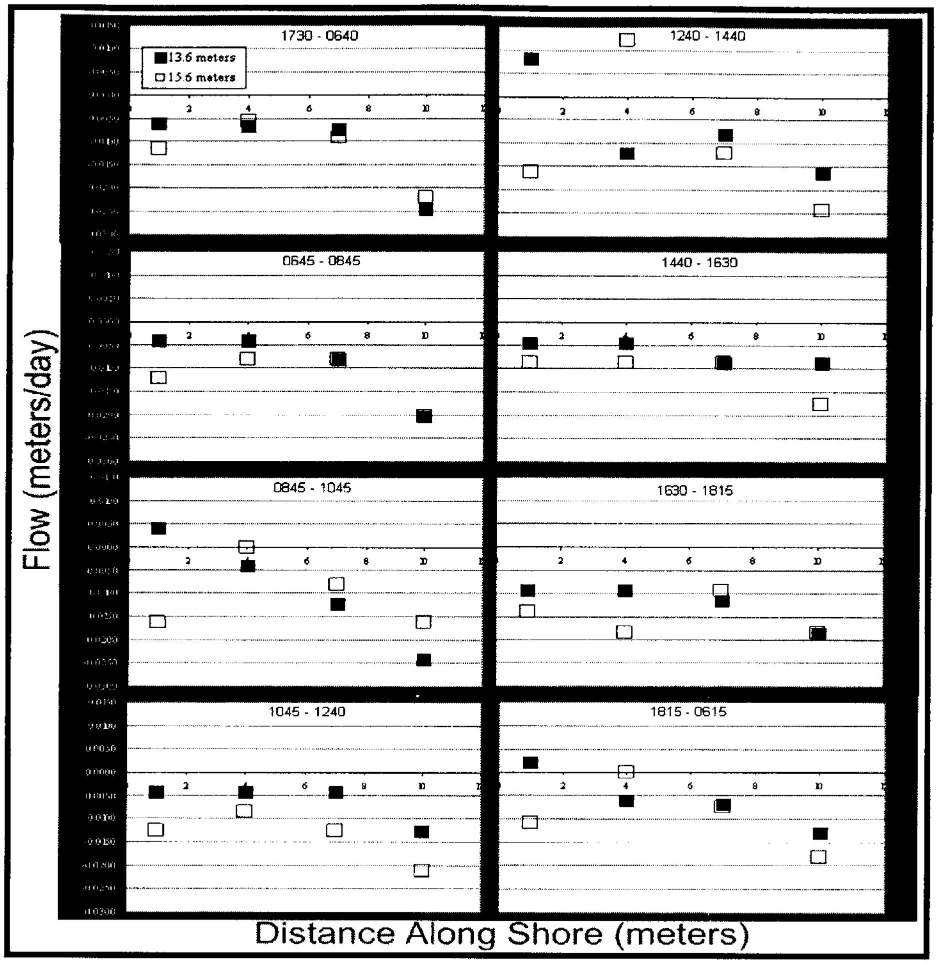

FIGURE 26
SEEPAGE METER RESULTS FOR JANUARY 14TH AND 15TH

Several possible explanations exist for this increased downwelling. The first is related to the hydrology of the surrounding area – if the slope of the land is too steep, groundwater recharge from runoff may be negligible. Therefore, there may be less groundwater discharge in some areas, which might lead to greater rates of downwelling. Another possible explanation is related to the geology of the area. As bedrock on the USVI is often very close to the ground surface, it is possible that the soil around those meters that showed lower rates of downwelling is less hydraulically conductive. Finally, it is possible that no hydrologic connection to the underlying groundwater exists due to a short circuit in the seepage meter system. If the circulation in the system were such that a connection exists between only the seepage meter bag and the immediate porewater beneath the meter, flow might never reach groundwater.

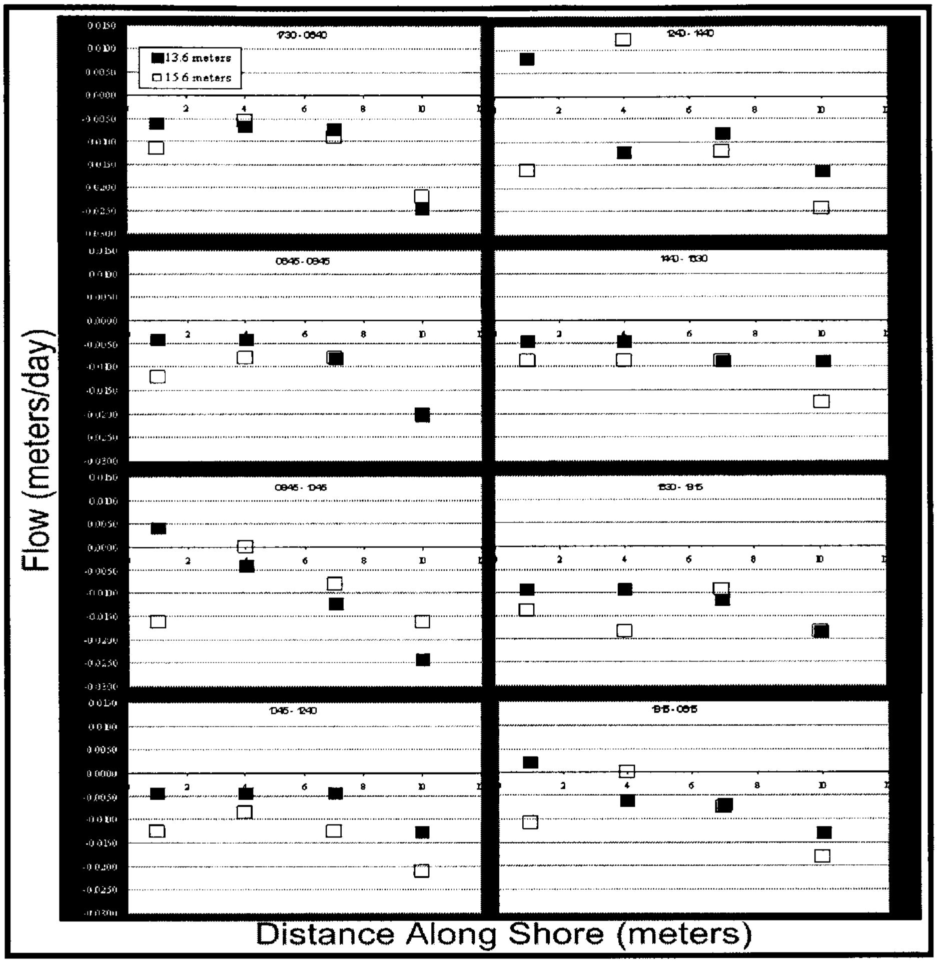

FIGURE 27
SEEPAGE METER RESULTS FOR JANUARY 16^{TH} AND 17^{TH}

The location for January 16th and 17th, in contrast, showed more consistent evidence of flow into the seepage meter bags, otherwise known as upwelling. Downwelling did occur in those meters furthest from the berm, but it appeared that there was a hinge point around the third column. Thus, the closer to the berm, the greater the upwelling of the seepage meter. Again, several possible explanations for this behavior exist. One is that septic effluent from the buildings on the northwestern slope of the pond was discharged along this slope and caused some gradient to the pond. Another is that there is a hydrologic connection between the pond and the neighboring bay that results in seawater infiltration to the pond.

6.7 Mini-Piezometer Results

Piezometers were generally unsuccessful in acquiring useful data due to inherent difficulties in installing the piezometers in the fine sediments of the salt pond. The impediments were the sediments (silty clays), which prevented water from entering or leaving the well-point screens due to smearing on the screen. If given pumps and other equipment for complete piezometer development, piezometers would provide a viable method for sampling groundwater and also for performing falling head tests (this is discussed further in Section 7.1: Well Development).

7 RECOMMENDATIONS

7.1 Well Development

One of the problems encountered when trying to implement mini-piezometers was lack of well development. Well development is described as the act of cleaning out the clay and silt introduced during the drilling process as well as the finer part of the aquifer directly around the well screen prior to testing. Effective well development results in increases in the rate of water movement from the aquifer into the well and stabilization of the aquifer to prevent sand pumping, thereby producing better quality water and increasing the service life of the pump cylinder and well (Schreurs, 198?). It also removes organic and inorganic material which may inhibit effective well disinfection (if the well is to be used as a drinking water supply).

Development should continue until the discharge water is clear. This is difficult because fines from the well and adjacent aquifer have to be removed after the screen has been installed. The time required for development depends on the nature of the water bearing layer, the thickness of screen slots relative to aquifer particle size, and the type of equipment and degree of development desired. Large amounts of development energy are required to remove drilling fluid (if used) containing clay additives (Driscoll, 1986); well development may be completed in 1 hour, but up to 10 hours may be required (Brush, 1979).

Well development methods are all based on establishing velocities of flow greater than those produced by the expected rate of pumping from the completed well. Ideally, this is combined with vigorous reversal of flow (surging) to prevent sand grains from bridging against each other (Schreurs, 198?). Movement in only one direction, as when pumping from the well, does not produce the proper development effect - sand grains can "bridge" voids around the screen. Agitation from pumping during normal pump use may cause these bridges to break down over time and sand to be pumped. This sand will act like sandpaper in the pump cylinder and will cause the cup leather to wear-out and the pump to fail within a few days or weeks. There are a number of techniques which can be used to develop newly constructed wells.

In cases like Southside Pond, where the piezometer installation is made in formations that have low hydraulic conductivity or where sediments may smear the well screen, none of the typical well development methods (bailing, mechanical surging, pumping, backwashing and hydraulic jetting) may be found to be completely satisfactory. Adding water to the well for flushing should only be done when no better options are available. In some fine-grained deposits vigorous development can be detrimental to the well. If vigorous development is attempted in such wells, the turbidity of water removed from the well may actually increase many times over. In some fine-grained formation materials, well development may not measurably improve formation hydraulic conductivity.

This project would be greatly aided by additional well-development equipment (i.e. pumps). More sophisticated piezometer equipment would also be beneficial. If given the proper equipment, the piezometers would provide a viable method for sampling groundwater and also for performing falling head tests to determine the hydraulic conductivity of the soils. This would aid in also determining the groundwater flow to the ponds.

7.2 GIS Data

GIS datasets are a powerful way of expressing data that can be shared by many. It is essential that data be expressed in the proper projections, and that the metadata describe the projection as well as other attributes of the data. Despite the fact that most of the data used in this study was downloaded from reputable services like USGS, much of the data did not match up. Consultation with a GIS data specialist who has encountered these problems as well as use of advanced tools like ArcInfo would be suggested to deal with such problems.

The data that have been collected should be put into one projection. This would be a great resource for the persons interested in the environmental characteristics of St. John, since data that are in the same projection and are properly described by attached metadata files would allow future users to more easily manipulate the data. However, the accumulation of these data is beyond the scope of this project.

7.3 Seepage Meters

Based on the surrounding area, it was hypothesized that groundwater inputs to Southside Pond would be easy to measure. Seepage meters were implemented in a manner designed to collect groundwater upwelling into the pond near shore. However, it was found that the connection between groundwater and pond water at Southside Pond was extremely complex and could not be adequately described by the limited number of seepage meters transported to

St. John. This is due to the fact that only small portions of the pond could be studied at once, and time limitations prevented the numerous deployments necessary for determination of the flow pattern. In addition, the seepage meters transported to St. John had to be deployed approximately ten meters from shore in order to meet depth constraints. This prevented measurement of seepage closer to shore, where groundwater inputs may be significant. Therefore, other methods of groundwater seepage flux measurement should be considered. One possibility would be the measurement of horizontal salinity gradients in the area surrounding the pond. If fresh water were flowing into the pond, flux could be quantified by the precise measurement of these salinity gradients. Another issue associated with the short time available for seepage meter implementation was the lack of rainfall during the experimentation period. A longer study would provide more information regarding the response of seepage flux to rainfall.

Finally, the bacterial mat found at Southside Pond was unique to Southside. The obvious physical characteristics of the gelatinous mat were noted, but further study could provide more information on flow through the mat. A possible future experiment which could provide important information on the flow characteristics of the bacterial mat would require cutting out an area of mat and comparing the flow through the mat to the flow through the sediments without a mat.

7.4 Chemical Sampling

The exploration of possible relationships among nutrient levels, sedimentation parameters, development metrics, and runoff characteristics could be aided in a number of ways. First, sampling of phosphate concentrations in salt ponds could be increased to provide a greater number of observations for statistical analysis, as one of the primary limitations in analyses involving phosphate was the small number of ponds sampled. Phosphorus could also be measured in terms of total phosphorus, which may be a more appropriate parameter than the reactive phosphorus concentrations measured in this study.

Another aspect of nutrient chemistry that could be explored in greater detail is the concentration of nitrate by the evaporative mechanism. Measurement of the evaporative flux at different salt pond locations on the island could reveal important information regarding the concentration of nutrients, while sampling of nitrate concentrations in the neighboring bay would provide a more accurate starting point for the calculation of expected evaporative concentrations. In addition, much like phosphorus, nitrogen could be measured as Total Kjeldahl Nitrogen, which would account for both inorganic forms of nitrogen and ammonia.

The sedimentation parameters employed in this study would be greatly enhanced by better handling of TSS samples. As the salt pond water is often extremely saline and can corrode foil, other storage and transport methods should be used.

The development metrics used in this study could also be examined and potentially altered. While efforts were made to include all the parameters that may affect salt pond chemistry, several rankings had to be estimated based on a lack of information (i.e. sewage treatment mechanisms). In addition, other parameters could be included to more thoroughly describe the general aspects of development included in this study.

8 CONCLUSIONS

Following completion of this study, several valuable conclusions have been reached. The first deals with the collection and assembly of the various data used in this study. The GIS dataset that has been assembled contains a number of important components: soil maps, watershed boundaries, subwatershed boundaries, digital elevation models, aerial photos, and elevation maps. These components provided necessary inputs for the hydrologic models developed in this study, but may also be used to fulfill various needs beyond the scope of this project. The manipulation carried forth to put all data into the same projection (where possible), translate some components to correspond more closely with others, and fix errors within the dataset (e.g. sinks and spires) has resulted in the formation of a more complete and accurate GIS dataset for St. John than was previously publicly available. This dataset could potentially have a number of uses for other projects; examples include assessing the potentially impacted areas of development or assisting in planning erosion control measures, which may require information about slope, soil type, and coverage.

The inputs and outputs of the hydrologic modeling also contain information that may be useful in other projects beyond this work. In this study, the delineation of watershed boundaries was critical, as these were parameters used in the regression analysis to explore possible linkages between the chemistry of salt ponds and the hydrology of the surrounding area. However, these boundaries may also be helpful in the future; if development increases substantially, these watershed boundaries may be used, as mentioned above, to aid in determining potentially impacted areas. The rainfall data amassed from various sources and analyzed provided details on the magnitude of storm needed to cause runoff in the watersheds tributary to the ponds studied, as well as the likelihood of these storms occurring. This information may also be useful in the erosion control measures mentioned above, particularly in those ponds with smaller storms needed to cause runoff.

Finally, the collection of the water quality data presented in this paper may be useful for other studies. Due to the fact that experimentation was carried out in January, these data may not be representative of other months; however, they would provide an interesting supplement if further experimentation were to be carried out during the rainy season. The comparison between data collected in January and data collected in August may yield interesting results regarding the seasonal behavior of salt ponds. In addition, the development metrics developed in this study and the scoring procedure used to describe each pond provide a good base for future work, which could expand on the parameters chosen for this development matrix.

Analysis of the data collected during this study has yielded at least one interesting conclusion regarding the composition of salt ponds. As the nutrient levels measured in the salt ponds closely resemble those expected from evaporation of seawater, the water in salt ponds is shown to be composed primarily of evaporated seawater. This result is strengthened by the hydrologic modeling, which shows no runoff reaching the ponds, except in the case of infrequent large storms. Also, while the results of seepage meter experimentation in Southside Pond cannot be extended to all ponds without a more thorough characterization of the ponds' sediments and surrounding geology, the lack of measurable groundwater inputs in this pond suggest that groundwater may play a minimal role in the hydrologic budget of salt ponds during the dry season.

In addition, the various metrics used to describe development in this study did not correlate with nutrient concentrations measured in salt ponds. While the aforementioned refinement of the metrics used could result in increased correlation, other aspects of this study could be furthered to more thoroughly explore this possible relationship. First, the implementation of mini-piezometers (with adequate well development) on the berm and near highly developed areas may provide more information regarding the relative magnitudes of any groundwater flow. Performing these tests during the rainy season would also provide a basis for comparison of groundwater flux during each of the seasons.

However, the lack of information regarding groundwater flux to the ponds suggests that the development of a full hydrologic budget could be the most useful extension of this report. There are six terms in the hydrologic budget for salt ponds: flux through the berm, groundwater inputs, surface runoff, overwash in severe storm events, precipitation, and evaporation. The observations made during the experimentation period on St. John suggest that overwash would be a minimal input for most ponds due to the height and width of the berm, as well as the infrequency of severe storm events. Precipitation records are readily accessible, and have been amassed for this report. Similarly, surface runoff has been shown by the models developed in this study to occur infrequently, suggesting that its effect in the hydrologic budget may be minimal. However, the remaining three terms require further study to be described. The measurement of groundwater inputs to salt ponds and of seawater flux through the berm, and the information that these measurements may provide, has been discussed thoroughly above as a valuable extension of this study. Similarly, variations in evaporative flux, both between ponds and over time, should be investigated, as evaporation has been shown by the analyses carried forth in this study to be an important aspect of the hydrology of salt ponds.

The conclusions developed in this study have illuminated several interesting aspects of salt pond composition, as well as the relationships between their chemistry and the hydrology of the surrounding area. However, the data collected in this study will also serve as valuable resources for future work, which may shed more light on the complex nature of these ponds.

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SOURCES OF GIS INFO INCLUDE THE FOLLOWING:
<http://edc.usgs.gov/glis/hyper/guide/1_dgr_demfig/states/VI.html>
<http://www.maproom.psu.edu/dcw/>
<http://edc.usgs.gov/>
<http://www.irf.org/irinfgis.html>
<http://www.nps.gov/gis/park_gisdata/virginislands/vi.htm>
<http://www.gisdatadepot.com/catalog/VI/>
<http://www.epa.gov/region02/gis/data/geographicdata.htm#usvi>
<http://freegis.org/geo-data.en.html>
<http://www.ftw.nrcs.usda.gov/ssur_data.html>
<http://biogeo.nos.noaa.gov/products/benthic/data/mosaic/zip/stjohn.zip>

APPENDIX A: CALIBRATION CURVES

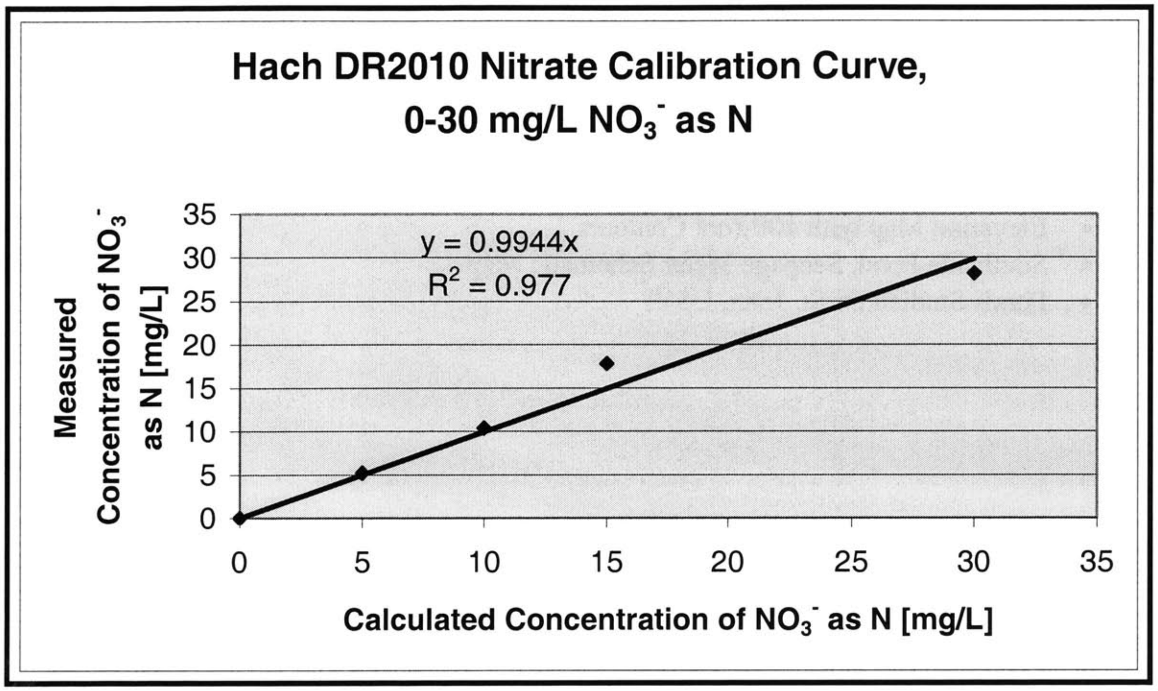


FIGURE 28
NITRATE CALIBRATION CURVE

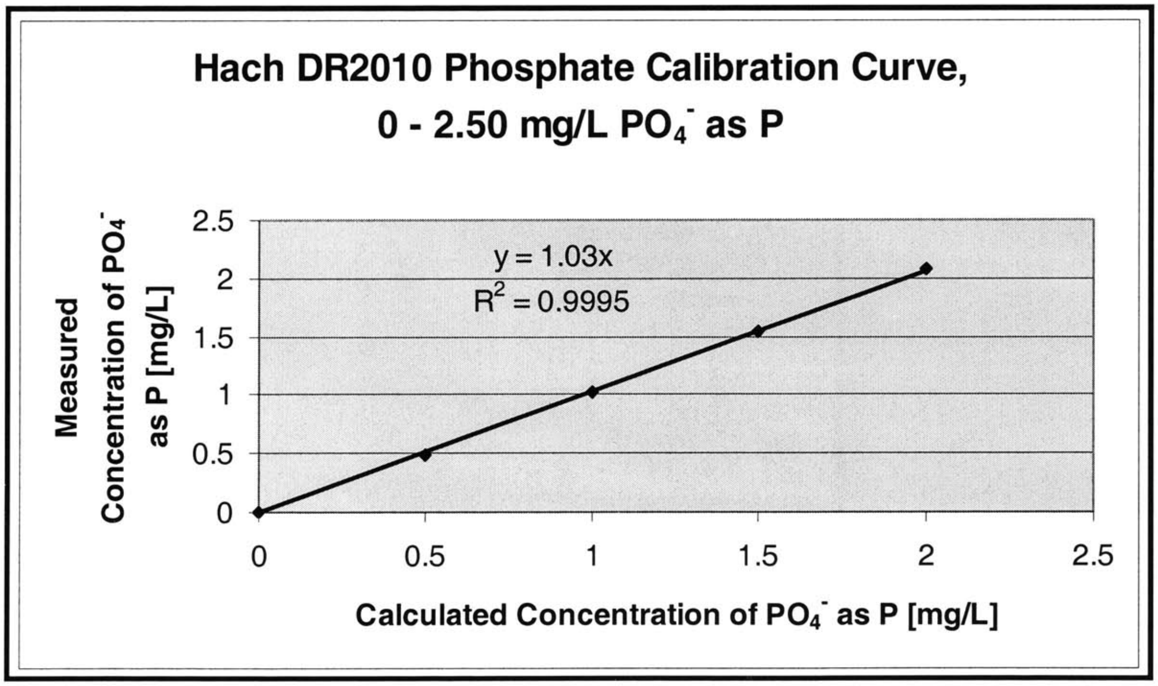


FIGURE 29
PHOSPHATE CALIBRATION CURVE

APPENDIX B: GIS MAPS

Maps presented in this Appendix include:

- Aerial Photograph
- USGS HUC 14 Watersheds
- Sub-Watershed Map
- Soil Map of St. John
- Elevation Map with 100-foot Contours
- Southside Pond, Seepage Meter Schematic Map
- Ponds Studied on St. John, USVI

St. John Aerial Photo

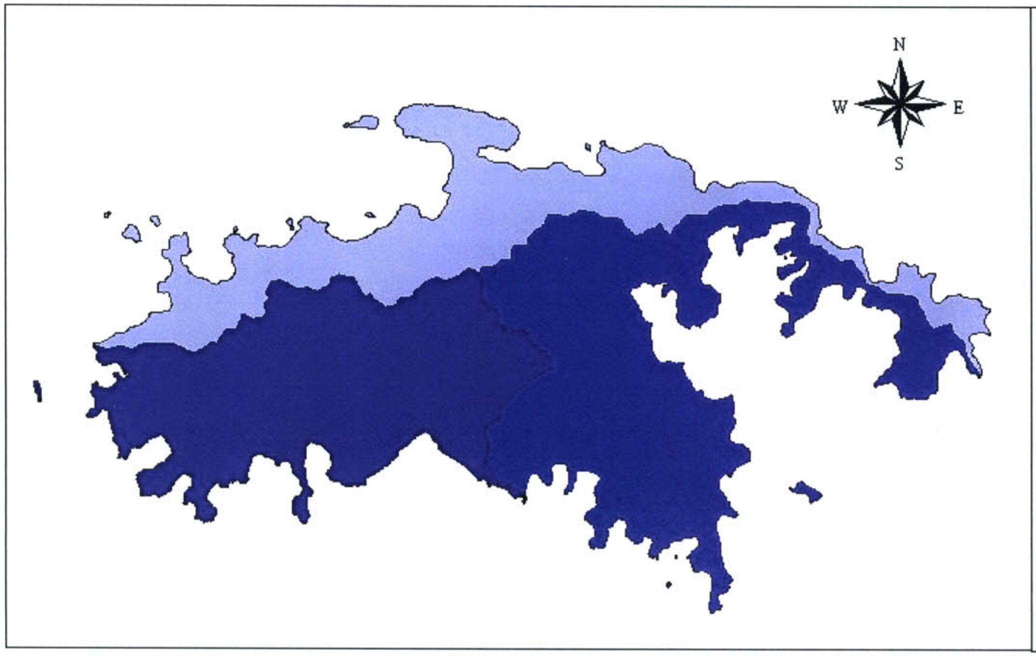
Don Rose
MIT
MEng Program
Dept. of Civil and Env. Eng.

1 0 1 2 Kilometers

Scale 1:75,000 m

*Data originally aerial photos scanned into GeoTiff format as part of the NOAA/NOS/NCCOS/Biogeography Program.

USGS HUC 14 Watersheds



Legend

St. John Watersheds

- ▨ 21020001020010
- ▨ 21020001020020
- ▨ 21020001020030

Scale:
1" = 90,000 meters

0 1000 2000 Meters

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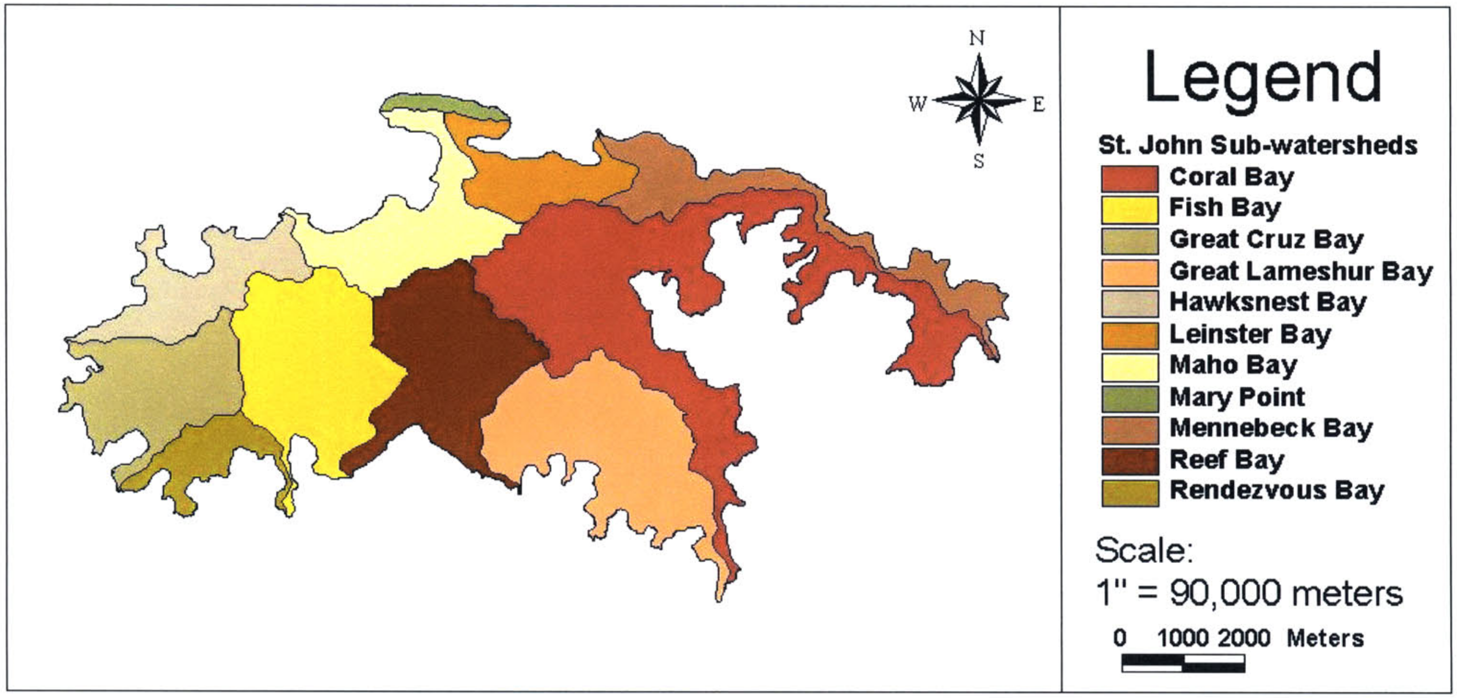
*Data provided by U.S. Geological Survey and the USDA Natural Resources Conservation Service. Hydrologic Unit Boundaries for the U.S. Virgin Islands by Marilyn Santiago, Luis Santiago-Rivera and Orlando Ramos-Ginés.

Sub-watersheds of St. John



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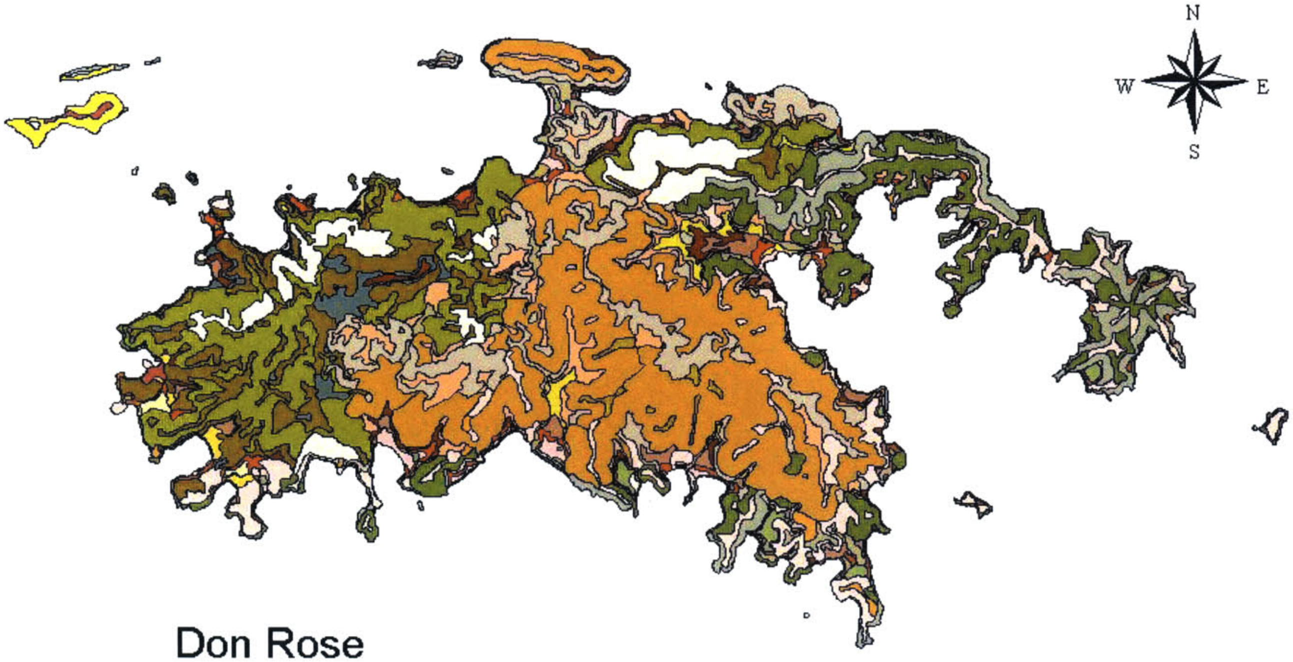
*Data provided by University of the Virgin Islands - Conservation Data Center.

Soil Map of St. John, USVI



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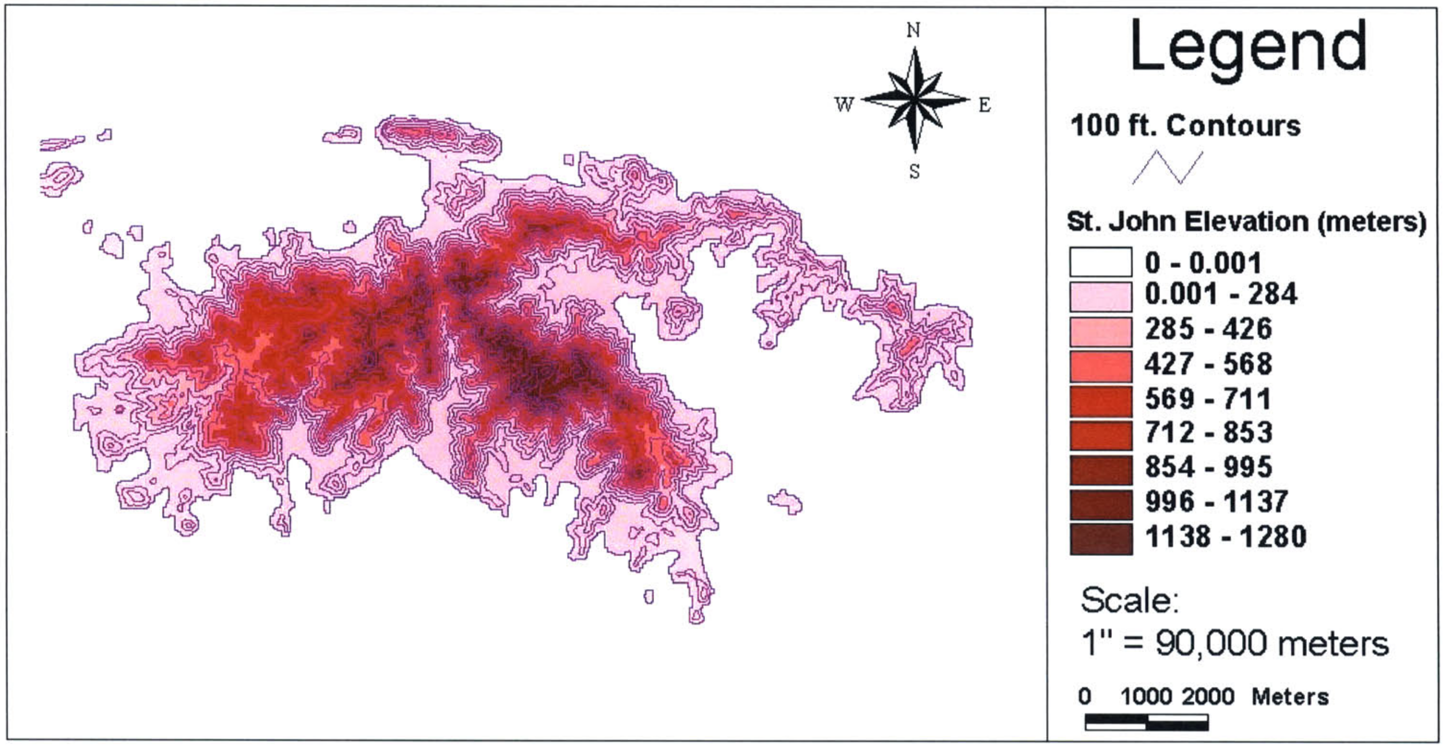
Scale 1 in.:75,000 m

0 1000 2000 Meters

Data downloaded off SSURGO database found on USDA-NRCS website.

St. John Elevation with 100 ft. Contours



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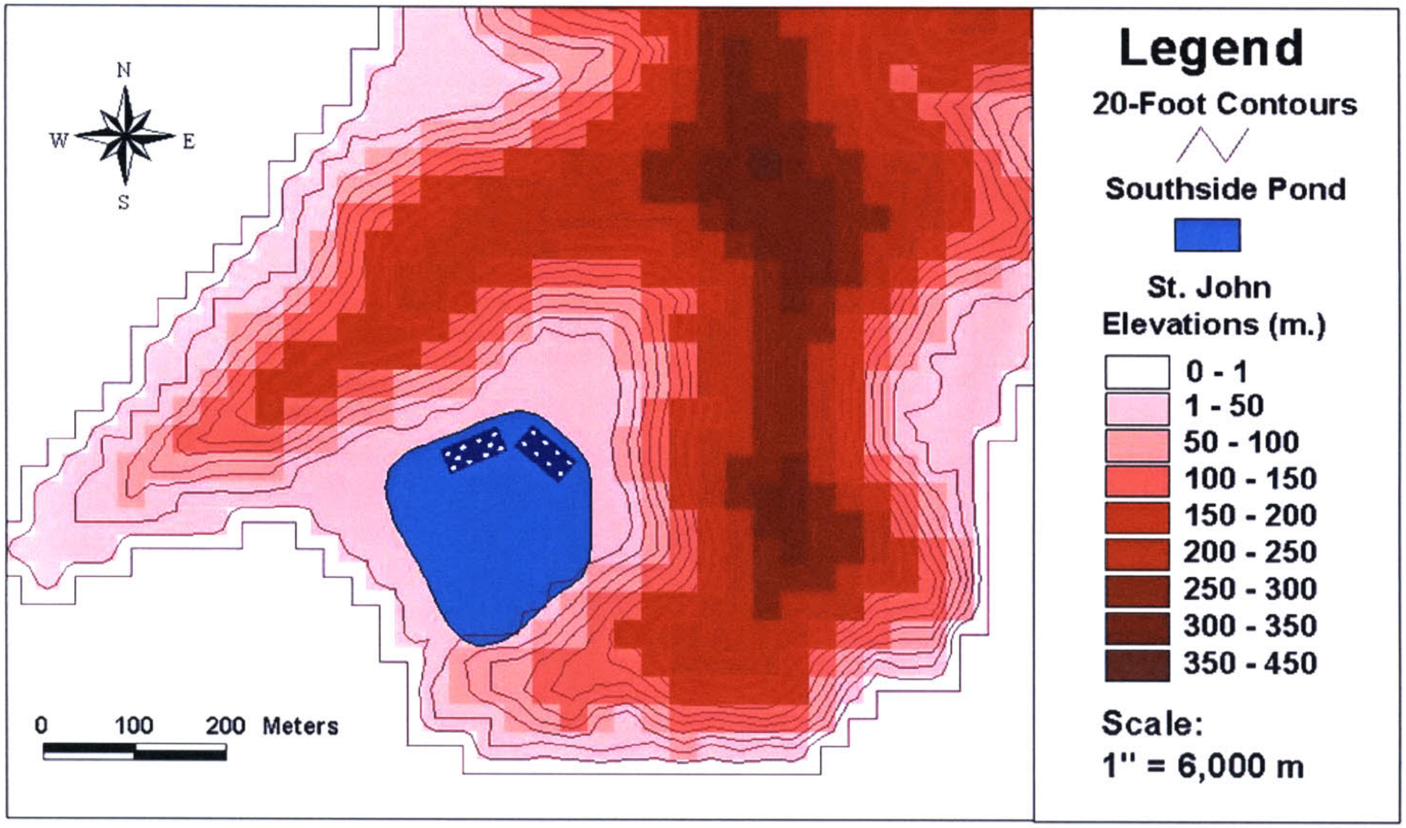
*Data downloaded from Internet website for GISDataDepot.

Southside Pond, St. John, USVI



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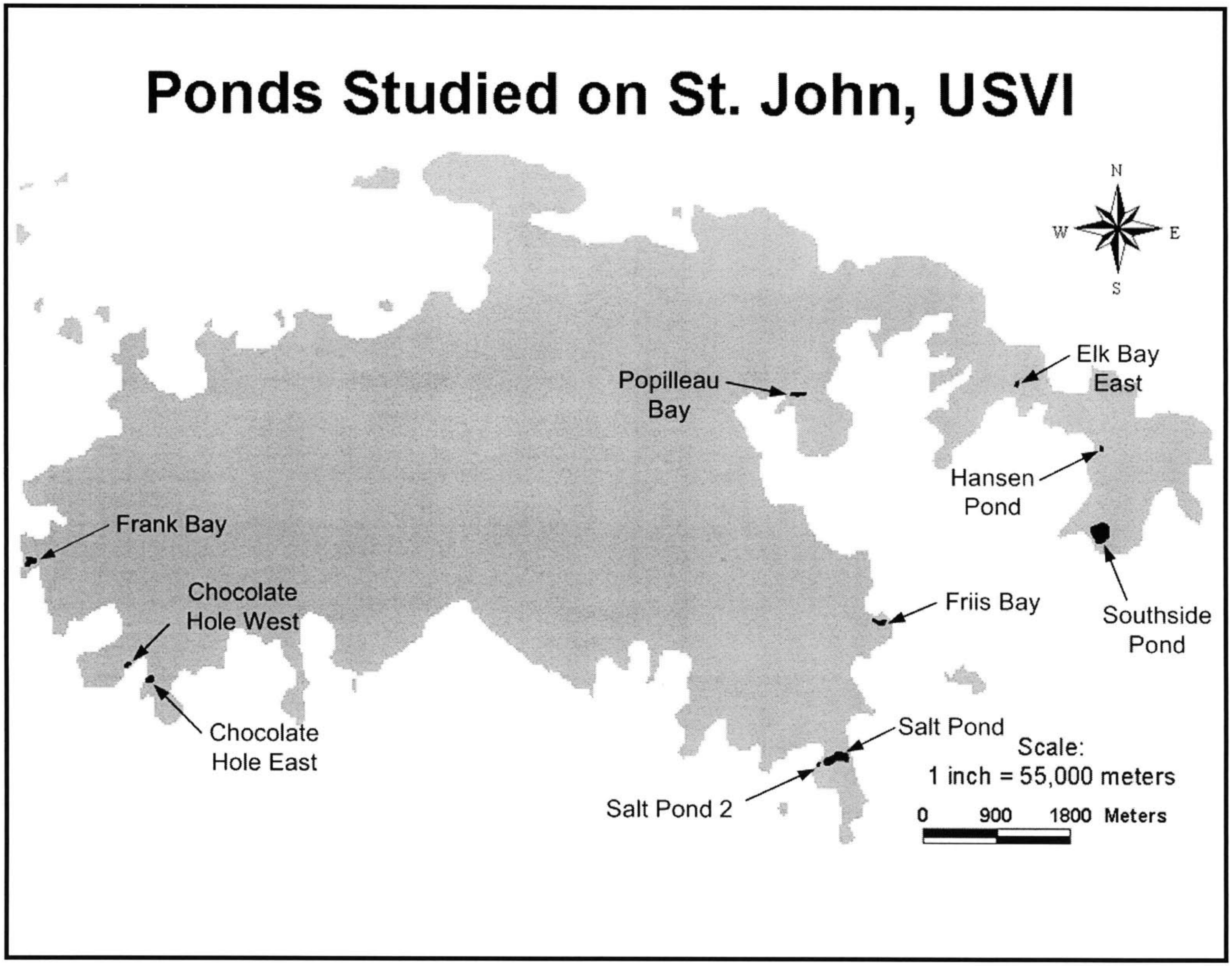
Ponds Studied on St. John, USVI
N
W
E
S
Popilleau Bay
Elk Bay East
Hansen Pond
Frank Bay
Chocolate Hole West
Chocolate Hole East
Friis Bay
Southside Pond
Salt Pond
Salt Pond 2
Scale:
1 inch = 55,000 meters
0
900
1800
Meters

APPENDIX C: RAINFALL EVENTS

TABLE 13
NUMBER OF RAIN EVENTS GREATER THAN 19 AND 20 MM

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0	0	0	0	0	0	0	0	0	0	1	0	1
79	0	0	2	0	8	2	1	1	5	2	3	0	24
80	0	0	1	3	2	0	0	2	0	1	1	0	10
81	1	0	0	2	0	0	0	0	2	1	0	0	6
82	0	2	0	2	4	1	0	0	1	2	3	1	16
83	0	0	0	2	0	1	3	4	0	0	1	2	13
84	2	0	1	1	0	1	0	1	0	1	0	0	7
85	0	0	0	0	1	0	0	1	0	1	1	0	4
86	0	0	0	2	6	0	1	1	1	0	2	0	13
87	0	0	0	0	4	2	0	1	0	2	4	0	13
88	0	0	0	0	0	0	0	2	1	1	1	1	6
89	0	0	1	2	1	2	1	3	6	0	0	1	17
90	0	0	0	1	0	0	0	1	2	2	1	1	8
91	0	1	0	0	1	0	0	1	2	0	2	0	7
92	1	0	0	0	4	0	0	0	1	1	0	0	7
93	0	2	0	1	1	2	0	0	2	1	2	0	11
94	0	0	0	1	0	0	0	1	1	0	0	1	4
95	1	0	0	0	1	0	2	1	4	0	0	1	10
Total	5	5	5	17	33	11	8	20	28	15	22	8	177
Avg	0.28	0.28	0.28	0.94	1.83	0.61	0.44	1.11	1.56	0.83	1.22	0.44	9.83

TABLE 14
NUMBER OF RAIN EVENTS GREATER THAN 21 AND 22 MM

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0	0	0	0	0	0	0	0	0	0	1	0	1
79	0	0	1	0	7	2	1	1	5	1	3	0	21
80	0	0	0	3	2	0	0	2	0	2	2	1	12
81	1	0	0	2	0	0	0	0	2	1	0	0	6
82	0	2	0	0	3	1	0	0	1	1	2	1	11
83	0	0	0	2	1	1	2	3	0	0	1	2	12
84	2	0	1	0	0	2	0	1	0	1	0	0	7
85	0	0	0	0	1	0	0	1	0	1	1	0	4
86	0	0	0	2	5	0	1	1	0	0	2	0	11
87	0	0	0	0	4	2	0	1	0	0	3	0	10
88	0	0	0	0	0	0	0	2	1	0	1	1	5
89	0	0	1	0	0	2	1	3	5	0	0	1	13
90	0	0	0	1	0	0	0	1	1	2	2	1	8
91	0	1	0	0	1	0	0	1	1	0	2	0	6
92	1	0	0	0	3	0	0	0	1	1	0	0	6
93	0	1	0	1	0	2	0	0	2	1	2	0	9
94	0	0	0	1	0	0	0	1	1	0	0	1	4
95	0	0	0	0	0	0	2	0	3	0	0	1	6
Total	4	4	3	12	27	12	7	18	23	11	22	9	152
Avg	0.22	0.22	0.17	0.67	1.50	0.67	0.39	1.00	1.28	0.61	1.22	0.50	8.44

TABLE 15
NUMBER OF RAIN EVENTS GREATER THAN 23, 24, AND 25 MM

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0	0	0	0	0	0	0	0	0	0	1	0	1
79	0	0	0	0	5	1	1	1	4	0	3	0	15
80	0	0	0	3	2	0	0	2	0	2	1	1	11
81	1	0	0	2	0	0	0	0	2	0	0	0	5
82	0	0	0	0	3	1	0	0	1	1	2	0	8
83	0	0	0	2	1	1	1	3	0	0	1	1	10
84	1	0	0	0	0	2	0	1	0	1	0	0	5
85	0	0	0	0	1	0	0	0	0	1	1	0	3
86	0	0	0	2	4	0	0	1	0	0	2	0	9
87	0	0	0	0	3	2	0	0	0	0	1	0	6
88	0	0	0	0	0	0	0	2	1	0	0	0	3
89	0	0	1	0	0	2	0	3	5	0	0	1	12
90	0	0	0	1	0	0	0	1	1	2	1	0	6
91	0	1	0	0	1	0	0	1	1	0	2	0	6
92	1	0	0	0	3	0	0	0	1	1	0	0	6
93	0	0	0	1	0	2	0	0	1	1	1	0	6
94	0	0	0	1	0	0	0	1	1	0	0	1	4
95	0	0	0	0	0	0	1	0	3	0	0	1	5
Total	3	1	1	12	23	11	3	16	21	9	16	5	121
Avg	0.17	0.06	0.06	0.67	1.28	0.61	0.17	0.89	1.17	0.50	0.89	0.28	6.72

Table 16
Number of Rain Events Greater than 26 and 27 mm

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	4	1	1	1	3	0	3	0	13
80	0	0	0	3	2	0	0	2	0	1	1	1	10
81	1	0	0	2	0	0	0	0	1	0	0	0	4
82	0	0	0	0	3	1	0	0	1	1	2	0	8
83	0	0	0	1	1	1	0	3	0	0	1	0	7
84	0	0	0	0	0	2	0	1	0	1	0	0	4
85	0	0	0	0	1	0	0	0	0	1	1	0	3
86	0	0	0	2	4	0	0	1	0	0	2	0	9
87	0	0	0	0	1	2	0	0	0	0	1	0	4
88	0	0	0	0	0	0	0	2	1	0	0	0	3
89	0	0	1	0	0	2	0	2	5	0	0	1	11
90	0	0	0	1	0	0	0	1	1	1	0	0	4
91	0	1	0	0	1	0	0	1	1	0	1	0	5
92	1	0	0	0	3	0	0	0	1	1	0	0	6
93	0	0	0	1	0	2	0	0	1	1	1	0	6
94	0	0	0	1	0	0	0	1	1	0	0	1	4
95	0	0	0	0	0	0	1	0	3	0	0	1	5
Total	2	1	1	11	20	11	2	15	19	7	13	4	106
Avg	0.11	0.06	0.06	0.61	1.11	0.61	0.11	0.83	1.06	0.39	0.72	0.22	5.89

Table 17
Number of Rain Events Greater than 28, 29, and 30 mm

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
78	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	4	1	1	1	4	0	2	0	13
80	0	0	0	2	2	0	0	1	0	0	0	0	5
81	1	0	0	1	0	0	0	0	1	0	0	0	3
82	0	0	0	0	3	0	0	0	1	1	1	0	6
83	0	0	0	1	1	0	0	3	0	0	1	0	6
84	0	0	0	0	0	2	0	1	0	1	0	0	4
85	0	0	0	0	1	0	0	0	0	1	1	0	3
86	0	0	0	2	4	0	0	1	0	0	2	0	9
87	0	0	0	0	0	2	0	0	0	0	1	0	3
88	0	0	0	0	0	0	0	2	1	0	0	0	3
89	0	0	1	0	0	1	0	2	5	0	0	1	10
90	0	0	0	1	0	0	0	1	1	1	0	0	4
91	0	1	0	0	1	0	0	1	1	0	1	0	5
92	1	0	0	0	3	0	0	0	1	1	0	0	6
93	0	0	0	1	0	2	0	0	1	1	1	0	6
94	0	0	0	1	0	0	0	1	1	0	0	1	4
95	0	0	0	0	0	0	1	0	3	0	0	1	5
Total	2	1	1	9	19	8	2	14	20	6	10	3	95
Avg	0.11	0.06	0.06	0.50	1.06	0.44	0.11	0.78	1.11	0.33	0.56	0.17	5.28

APPENDIX D: HYDROCAD IN/OUTPUT

HydroCAD Input by Pond

Chocolate Hole East:
Pond Area: 4,965sq. m
Watershed Area: 38,880 sq m (USGS); 36,700 sq. m. (GIS), 37,790 sq. m. (avg.)
House Area: 446 sq. m
Impervious Area: 836 sq. m
SaA - salt flats ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes

TC: Length 170 m., Slope 32%
Notes: 3 houses within watershed, cover appears to be very good, lots of trees some impervious driveways, road 1.67 m (18 feet wide) and about 500 meters in length. All soils are HSG D.

Chocolate Hole West:
Pond Area: 2,438 sq. m
Watershed Area: 20,000 sq. m (USGS); 18,600 sq. m. (GIS); 19,300 sq. m. (avg.)
House Area: 743 sq. m
Impervious Area: 836 sq. m
FsE - Fredriksdal-Susannaberg complex, 20 to 40 percent slopes, extremely stony
SaA - salt flats ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes

TC: Length 268 m., Slope 30%
Notes: 5 houses within the watershed, cover appears to be good, lots of trees some impervious road 1.67 meters (18 feet wide) and about 500 meters in length. All soils are HSG D.

Elk Bay East:
Pond Area: 1,740 sq. m
Watershed Area: 51,840 sq. m (USGS), 53,260 sq. m. (GIS); 52,550 sq. m. (avg.)
SaA - salt flats ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrF - Southgate-Rock outcrop complex, 40 to 60 percent slopes

TC: Length 180 m., Slope 12%, Length 155 m, Slope 43%
Notes: No houses. Good cover. No roads. All soils are HSG D.

Frank Bay:
Pond Area: 8,643 sq. m
Watershed Area: 45,120 sq. m (USGS); 42,300 sq. m. (GIS); 43,710 sq. m. (avg.)
House Area: 2,230 sq. m
Impervious Area: 7,440 sq. m
FsE - Fredriksdal-Susannaberg complex, 20 to 40 percent slopes, extremely stony
SaA - Salt flats, ponded (actually pond)

SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes

TC: Length 135 m., Slope 20%
Notes: About 15 houses in the watershed. Lots of impervious area within the watershed. Cover is only ok. All soils are HSG D.

Friis Bay:
Pond Area: 6,108 sq. m
Watershed Area: could not do using USGS; 56,400 sq. m. (GIS)
House Area: 1,740 sq. m
Impervious Area: 451 sq. m
CbB - Cinnamon Bay loam, 0 to 5 percent slopes, occasionally flooded
SaA - Salt flats, ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes
SrF - Southgate-Rock outcrop complex, 40 to 60 percent slopes
VsC - Victory-Southgate complex, 2 to 12 percent slopes, very stony
VsE - Victory-Southgate complex, 20 to 40 percent slopes, very stony
VsF - Victory-Southgate complex, 40 to 70 percent slopes, very stony

TC: Length 900 m., Slope 20%
Notes: About 7 houses in the watershed. The impervious road is 1.67 meters (18 feet) wide and about 270 meters in length. Approximately 13,500 sq. m. of CbB, which is HSG B. VsC, VsD, are VsE are assumed HSG D (Victory HSG B, Southgate D). Cover is good with areas of thick underbrush. All soils are HSG D.

Hansen Pond:
Pond Area: 1,505 sq. m
Watershed Area: 55,680 sq. m (USGS); 55,700 sq. m. (GIS); 55,690 sq. m. (avg.)
House Area: 2,230 sq. m
Impervious Area: 0 sq. m
Dirt Road: 267 sq. m
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes
SrF - Southgate-Rock outcrop complex, 40 to 60 percent slopes
SrG - Southgate-Rock outcrop complex, 60 to 90 percent slopes

TC: Length 500 m., Slope 24%
Notes: Road beside the pond. Cover is good. Appears to be 3 small houses within the watershed. About 160 meters of road (appears to be dirt) tributary. Road in front may drain to pond, difficult to tell from aerial photo. All soils are HSG D.

Poppilleau Bay:
Pond Area: 5,766 sq. m
Watershed Area: could not do using USGS; 369,000 sq. m. (GIS)
House Area: 2,970 sq. m
Impervious Area: 4,175 sq. m
Dirt Road: 0 sq. m
CgC – Cinnamon Bay gravelly loam, 5 to 12 percent slopes, occasionally flooded

SBA – Sandy Point and Sugar Beach soils, 0 to 2 percent slopes, frequently flooded
SoA – Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE – Southgate-Rock outcrop complex, 20 to 40 percent slopes
SrF – Southgate-Rock outcrop complex, 40 to 60 percent slopes
VsC – Victory-Southgate complex, 2 to 12 percent slopes, very stony
VsD – Victory-Southgate complex, 12 to 20 percent slopes, very stony
VsE – Victory-Southgate complex, 20 to 40 percent slopes, very stony

TC: Length 230 m., Slope 50%, Length 108 m, Slope 23%, Length 490 m., Slope 5%
Notes: Approximately 20 houses in watershed. The are 14,324 sq. m of CgC, which is HSG B. VsC, VsD, are VsE are assumed HSG D (Victory HSG B, Southgate D). Approximately impervious road 1.67 meters (18 feet) wide and about 2,500 meters in length.

Salt Pond:
Pond Area: 26,521sq. m
Watershed Area: 100,800 sq. m (USGS); 90, 900 sq. m. (GIS); 95,850 sq. m. (avg.)
House Area: 0 sq. m
Impervious Area: 0 sq. m
SaA - Salt flats, ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrD - Southgate-Rock outcrop complex, 12 to 20 percent slopes
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes
VsC - Victory-Southgate complex, 2 to 12 percent slopes, very stony

TC: Length 60 m., Slope 20%, Length 150 m, Slope 1%
Notes: No houses or impervious areas. Soils are all HSG D except VsE (Victory HSG B, Southgate D).

Salt Pond 2
Pond Area: 1,086 sq. m
Watershed Area: could not do by USGS; 14,700 sq. m. (GIS)
House Area: 0 sq. m
Impervious Area: 0 sq. m
SaA - Salt flats, ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes

TC: Length 145 m., Slope 19%
Notes: No houses or impervious areas. Soils are all HSG D.

Southside Pond:
Pond Area: 40,494sq. m
Watershed Area: 224,640 sq. m (USGS); 218,100 sq. m. (GIS); 221,370 sq. m. (avg.)
House Area: 148.5 sq. m
Impervious Area: 0 sq. m
SaA - Salt flats, ponded (actually pond)
SoA - Solitude gravelly fine sandy loam, 0 to 2 percent slopes, frequently flooded
SrE - Southgate-Rock outcrop complex, 20 to 40 percent slopes
SrF - Southgate-Rock outcrop complex, 40 to 60 percent slopes
SrG - Southgate-Rock outcrop complex, 60 to 90 percent slopes

VsE - Victory-Southgate complex, 20 to 40 percent slopes, very stony

TC: Length 263 m., Slope 39%, Length 105 m, Slope 1.5%
Notes: Appears to be 1 house tributary. Lots of small brushy trees, cactus, dense; some exposed soil. Soils are HSG D except VsE (Victory HSG B, Southgate D).

HydroCAD Output

TABLE 18
HYDROCAD OUTPUT FOR GIVEN RAINFALL DEPTHS

Rainfall (mm)	Chocolate Hole East		Chocolate Hole West		Elk Bay East	
	Rate (mm^3/s)	Vol. (L)	Rate	Volume	Rate	Vol.
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	27,700	0.01	0	0
21	0	0	212,000	0.26	0	0
22	0	0	380,000	0.84	58,600	0.02
23	0	0	577,000	1.73	590,000	0.70
24	11,200	0	785,000	2.94	1,170,000	2.27
25	315,000	0.32	1,060,000	4.44	1,720,000	4.73
26	663,000	1.17	1,410,000	6.23	2,330,000	8.03
27	1,040,000	2.53	1,910,000	8.31	2,990,000	12.2
28	1,420,000	4.39	2,480,000	10.7	3,990,000	17.1
29	1,820,000	6.74	3,410,000	13.3	5,160,000	22.9
30	2,310,000	9.57	4,560,000	16.2	6,760,000	29.4
31	2,970,000	12.9	6,290,000	19.3	8,620,000	36.6
32	3,780,000	16.6	8,050,000	22.7	11,400,000	44.6
33	4,810,000	20.8	11,400,000	26.3	14,700,000	53.3
34	6,050,000	25.5	15,000,000	30.1	18,900,000	62.7
35	7,850,000	30.5	19,200,000	34.2	25,300,000	72.8
36	9,930,000	36.0	23,700,000	38.5	31,700,000	83.6
37	12,800,000	41.9	28,700,000	43.0	38,800,000	95
38	17,900,000	48.1	34,000,000	47.8	46,700,000	107
39	22,900,000	54.8	39,800,000	52.7	55,700,000	120
40	28,400,000	61.8	45,900,000	57.8	72,100,000	133

TABLE 19
HYDROCAD OUTPUT FOR GIVEN RAINFALL DEPTHS

Rainfall (mm)	Frank Bay		Friis Bay		Friis Bay	
	Rate	Vol.	Rate	Vol.	Rate	Vol.
18	0	0	0	0	0	0
19	49,700	0.02	0	0	58,900	0.03
20	372,000	0.51	0	0	611,000	0.85
21	740,000	1.67	0	0	1,240,000	2.79
22	1,130,000	3.49	0	0	1,870,000	5.82
23	1,540,000	5.93	0	0	2,560,000	9.91
24	2,120,000	8.99	0	0	3,520,000	15.0
25	2,860,000	12.6	0	0	4,740,000	21.1
26	3,900,000	16.9	0	0	6,470,000	28.2
27	5,290,000	21.7	0	0	8,540,000	36.2
28	7,250,000	27.0	0	0	11,700,000	45.1
29	9,940,000	32.9	0	0	15,500,000	54.9
30	14,900,000	39.2	14,200	0.01	20,600,000	65.5
31	20,200,000	46.1	401,000	0.43	26,400,000	77.0
32	25,900,000	53.5	913,000	1.49	35,500,000	89.3
33	32,100,000	61.3	1,460,000	3.16	44,600,000	102
34	38,800,000	69.6	2,000,000	5.44	54,700,000	116
35	46,100,000	78.3	2,580,000	8.31	65,900,000	131
36	53,900,000	87.5	3,190,000	11.8	78,100,000	146
37	62,500,000	97.1	3,830,000	15.8	91,400,000	162
38	72,100,000	107	4,760,000	20.4	106,000,000	179
39	89,400,000	118	5,770,000	25.5	121,000,000	196
40	104,000,000	128	6,860,000	31.2	137,000,000	214

TABLE 20
HYDROCAD OUTPUT FOR GIVEN RAINFALL DEPTHS

Rainfall (mm)	Popilleau Bay		Salt Pond		Salt Pond 2		Southside	
	Rate	Vol.	Rate	Vol.	Rate	Vol.	Rate	Vol.
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	252,000	0.22	90,000	0.04	24,000	0.04	24,000	0.01
21	3,530,000	5.58	790,000	1.07	160,000	1.07	160,000	0.21
22	7,530,000	18.0	1,600,000	3.50	314,000	3.50	314,000	0.68
23	11,900,000	37.2	2,400,000	7.20	471,000	7.20	471,000	1.41
24	16,500,000	63.0	3,200,000	12.0	639,000	12.0	639,000	2.38
25	22,200,000	95.3	4,400,000	18.0	860,000	18.0	860,000	3.60
26	29,800,000	134	5,800,000	26.0	1,140,000	26.0	1,140,000	5.06
27	38,700,000	178	7,800,000	34.0	1,550,000	34.0	1,550,000	6.74
28	50,800,000	229	10,200,000	44.0	2,040,000	44.0	2,040,000	8.65
29	64,800,000	285	13,700,000	55.0	2,780,000	55.0	2,780,000	10.8
30	81,900,000	347	18,100,000	67.0	3,750,000	67.0	3,750,000	13.1
31	103,000,000	414	23,400,000	80.0	5,610,000	80.0	5,610,000	15.6
32	127,000,000	487	30,500,000	94.0	7,480,000	94.0	7,480,000	18.4
33	156,000,000	564	38,200,000	109	9,460,000	109	9,460,000	21.3
34	187,000,000	647	50,300,000	125	11,600,000	125	11,600,000	24.4
35	223,000,000	734	62,200,000	141	13,900,000	141	13,900,000	27.7
36	264,000,000	827	75,400,000	159	16,500,000	159	16,500,000	31.2
37	308,000,000	923	89,900,000	178	21,500,000	178	21,500,000	34.9
38	356,000,000	1020	106,000,000	197	26,500,000	197	26,500,000	38.7
39	407,000,000	1130	123,000,000	218	32,200,000	218	32,200,000	42.7
40	461,000,000	1240	141,000,000	239	38,400,000	239	38,400,000	46.9

APPENDIX E: DEVELOPMENT MATRIX

Pond Name	Number of Surrounding Houses			Proximity of Houses			Slope of Surrounding Land			Predominant Apparent Sewage Treatment		
	1 to 5	5 to 10	10 +	100' +	50' - 100'	0 - 50'	Flat	Slight	Steep	Septic	Leach Field	None
Frank Bay			3			3		2		1		
Choc. Hole W.	1				2				3	1		
Choc. Hole E.	1				2			2		1		
Popilleau Bay	1				2		1				2	
Elk Bay				1			1					
Hanson Bay							1					
Friis Bay	1				2			2				3
Salt Pond	1			1				2		1		
Salt Pond 2	1			1				2		1		
Southside Pond		2		2					3			3

Pond Name	Number of Surrounding Roads/Paths			Proximity of Roads/Paths			Are Nearby Roads/Paths Paved?		Agriculture or Livestock Present?	
	0	1	2 or more	100' +	50' - 100'	0 - 50'	Yes	No	No	Yes
Frank Bay			3			3	1		1	
Choc. Hole W.	1			1			1		1	
Choc. Hole E.	1			1			1		1	
Popilleau Bay			3			3	1			2
Elk Bay	1			1			1		1	
Hanson Bay	1				2		1		1	
Friis Bay		2		1			1			2
Salt Pond	1			1				2		
Salt Pond 2	1			1				2		
Southside Pond		2		1				2		

Pond Name	Total Score	Development - Nutrients	Development - Roads
Frank Bay	17	10	9
Choc. Hole W.	11	8	6
Choc. Hole E.	10	7	5
Popilleau Bay	15	8	8
Elk Bay	6	3	4
Hanson Bay	6	2	5
Friis Bay	14	10	6
Salt Pond	9	5	6
Salt Pond 2	9	5	6
Southside Pond	15	10	8

APPENDIX F: CHEMICAL HEALTH DATA

Pond Name	Temp [deg C]	Salinity [ppt]	DO [%]	DO [mg/L]	pH	Turbidity [NTU]	TSS [mg/L]	Nitrate as N [mg/L]	Phosphate as P [mg/L]
Frank Bay	27.48	61.80	100.60	5.66	8.23	9.12	0.00013	1.2	
Frank Bay	28.19	69.14	102.70	5.45	8.35		0.00016	2.0	
Frank Bay	27.70	68.87	91.00	4.87	8.34	7.77		1.8	
Choc. Hole E.	28.90	33.63	62.80	4.00	8.06	10.40	0.00013	1.2	
Choc. Hole E.	28.58	33.62	58.70	3.77	8.07	8.69		1.4	
Choc. Hole E.	28.49	33.50	59.60	3.83	8.23		0.00008	1.4	
Choc. Hole W.	36.20	75.60	172.00	7.80	8.39	4.50	0.00010	2.9	
Choc. Hole W.	33.70	66.90	99.70	4.95	8.25	5.22	0.00004	2.1	
Choc. Hole W.	31.90	65.90	56.60	2.96	8.18			2.9	
Popilleau Bay	31.10	42.10	131.80	7.78	8.66	12.00	0.00007	1.3	
Popilleau Bay	29.10	30.90	87.40	5.55	8.64	14.83	0.00009	0.7	
Elk Bay	29.85	58.42	97.90	5.41	8.27	13.50	0.00012	1.4	
Elk Bay	29.21	58.85	82.70	4.60	8.22	16.00	0.00011	1.9	
Elk Bay	29.25	57.82	79.90	4.60	8.22	14.70	0.00013	2.2	
Elk Bay	29.83	59.07	75.90	4.16	8.12			2.6	
Frank Bay	26.89	72.64	40.10	2.13	8.37	10.30	0.00011	1.8	
Frank Bay	27.50	73.00	47.90	2.57	8.48	6.56	0.00011	2.2	
Frank Bay	29.20	75.60	64.20	3.26	8.66	5.35	0.00021	2.2	
Hanson Bay	31.25	30.15	54.60	3.48	8.12		0.00009	1.1	
Hanson Bay	31.06	31.16	51.00	3.20	8.09	40.50		0.0	
Hanson Bay	30.98	31.70	51.20	3.18	8.09	63.50	0.00022	0.9	
Friis Bay	25.65	70.00	45.50	3.67	8.96		0.00014	2.6	
Friis Bay	25.85	59.01	35.00	2.02	8.88	5.39	0.00017	2.2	
Friis Bay	25.95	59.91	35.90	2.07	9.01	6.54	0.00012	2.4	
Salt Pond	31.49	254.55	66.00	2.00	7.67	3.07	0.00050	13.5	
Salt Pond	30.88	262.50	42.20	1.51	7.68	1.96	0.00019	7.7	
Salt Pond	30.96	268.33	42.90	1.56	7.68	2.72	0.00049	9.2	
Southside	27.30	105.00	60.90	2.78	8.21	1.59	0.00021	3.0	0.12
Southside	27.22	105.00	42.30	1.94	8.19	1.07	0.00022	3.6	0.93
Southside	27.18	105.00	35.40	1.63	8.20	0.79	0.00023	3.9	4.65
Southside	27.20	105.00	29.40	1.35	8.21		0.00017	3.9	0.33
Southside	27.27	105.00	28.70	1.31	8.22		0.00020	3.0	0.48
Southside	27.24	105.00	29.30	1.34	8.22		0.00016	3.9	0.06
Southside	27.66	105.00	41.60	1.90	8.18	1.93	0.00019	4.5	0.06
Southside	27.37	105.00	37.40	1.71	8.18	1.03	0.00012	3.9	0.12
Southside	27.70	105.00	38.00	1.74	8.19	1.00	0.00020	5.1	0.03
Southside	28.54	105.00	40.30	1.82	8.18	8.18	0.00019	3.6	
Southside	28.40	105.00	41.00	1.85	8.17	8.17	0.00021	3.9	0.15
Southside	28.60	105.00	54.20	2.40	8.18	8.18	0.00019	4.5	0.81
Frank Bay	26.92	76.34	40.10	2.09	8.55	8.78	0.00011	3.3	0.3
Frank Bay	26.73	76.50	69.30	3.61	8.56	8.76	0.00011	3.3	0.625
Frank Bay	26.35	75.31	57.10	3.04	8.45	10.40	0.00010	3.8	0.275
Salt Pond	26.55	175.00	50.30	1.73	7.68		0.00051	7.0	0.2
Salt Pond	26.29	210.00	32.00	1.12	7.65		0.00063	9.0	3.18
Salt Pond 2	24.93	60.56	57.30	3.35	8.85		0.00020	2.4	0.256
Salt Pond 2	24.48	59.38	50.10	2.97	8.81		0.00023	1.6	0.8

APPENDIX G: SEEPAGE METER DATA & RESULTS

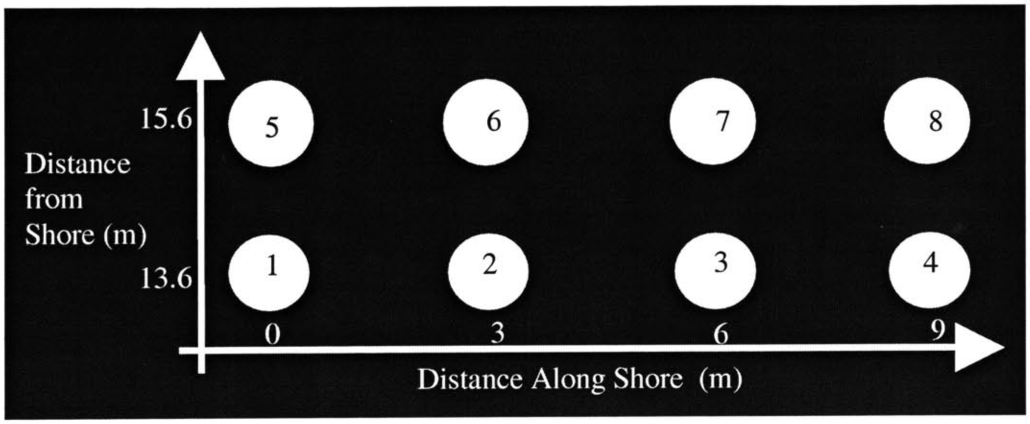

FIGURE 30
SEEPAGE METER SCHEMATIC
(January 14th and 15th, Southside Pond)

TABLE 22
SEEPAGE METER RESULTS
(January 14th and 15th, Southside Pond)

Deployment 1:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	13:27	14:57	5.6	5.5	-0.1	1.50	-0.07	-0.0606	-6.06E-05	-1.45E-03	-5.39E-03
2	13:27	14:57	6.1	5.9	-0.2	1.50	-0.13	-0.1212	-1.21E-04	-2.91E-03	-1.08E-02
3	13:27	14:57	6.2	6.1	-0.1	1.50	-0.07	-0.0606	-6.06E-05	-1.45E-03	-5.39E-03
4	13:27	14:57	5.4	5.1	-0.3	1.50	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02
Deployment 2:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	14:57	16:27	2.2	2.2	0.0	1.50	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
2	14:57	16:27	2.2	2.0	-0.2	1.50	-0.13	-0.1212	-1.21E-04	-2.91E-03	-1.08E-02
3	14:57	16:27	2.3	2.2	-0.1	1.50	-0.07	-0.0606	-6.06E-05	-1.45E-03	-5.39E-03
4	14:57	16:27	2.4	2.1	-0.3	1.50	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02
Deployment 3:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	17:30	6:40	7.2	6.2	-1.0	13.17	-0.08	-0.0690	-6.90E-05	-1.66E-03	-6.14E-03
2	17:30	6:40	7.1	6.0	-1.1	13.17	-0.08	-0.0759	-7.59E-05	-1.82E-03	-6.75E-03
3	17:30	6:40	6.6	5.4	-1.2	13.17	-0.09	-0.0829	-8.29E-05	-1.99E-03	-7.36E-03
4	17:30	6:40	7.7	3.7	-4.0	13.17	-0.30	-0.2762	-2.76E-04	-6.63E-03	-2.45E-02
5	17:30	6:40	5.6	3.7	-1.9	13.17	-0.14	-0.1312	-1.31E-04	-3.15E-03	-1.17E-02
6	17:30	6:40	7.2	6.3	-0.9	13.17	-0.07	-0.0621	-6.21E-05	-1.49E-03	-5.52E-03
7	17:30	6:40	7.6	6.1	-1.5	13.17	-0.11	-0.1036	-1.04E-04	-2.49E-03	-9.21E-03
8	17:30	6:40	7.8	4.2	-3.6	13.17	-0.27	-0.2486	-2.49E-04	-5.97E-03	-2.21E-02

Deployment 4:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	6:45	8:45	3.7	3.6	-0.1	2.00	-0.05	-0.0455	-4.55E-05	-1.09E-03	-4.04E-03
2	6:45	8:45	3.7	3.6	-0.1	2.00	-0.05	-0.0455	-4.55E-05	-1.09E-03	-4.04E-03
3	6:45	8:45	3.8	3.6	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
4	6:45	8:45	3.7	3.2	-0.5	2.00	-0.25	-0.2273	-2.27E-04	-5.45E-03	-2.02E-02
5	6:45	8:45	3.7	3.4	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
6	6:45	8:45	3.8	3.6	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
7	6:45	8:45	3.8	3.6	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
8	6:45	8:45	3.7	3.2	-0.5	2.00	-0.25	-0.2273	-2.27E-04	-5.45E-03	-2.02E-02

Deployment 5:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	8:45	10:45	4.6	4.7	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
2	8:45	10:45	4.5	4.4	-0.1	2.00	-0.05	-0.0455	-4.55E-05	-1.09E-03	-4.04E-03
3	8:45	10:45	4.7	4.4	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
4	8:45	10:45	5.6	5.0	-0.6	2.00	-0.30	-0.2727	-2.73E-04	-6.55E-03	-2.42E-02
5	8:45	10:45	4.4	4.0	-0.4	2.00	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02
6	8:45	10:45	4.6	4.6	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
7	8:45	10:45	4.4	4.2	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
8	8:45	10:45	4.4	4.0	-0.4	2.00	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02

Deployment 6:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	10:45	12:40	4.4	4.3	-0.1	1.92	-0.05	-0.0474	-4.74E-05	-1.14E-03	-4.22E-03
2	10:45	12:40	4.2	4.1	-0.1	1.92	-0.05	-0.0474	-4.74E-05	-1.14E-03	-4.22E-03
3	10:45	12:40	4.4	4.3	-0.1	1.92	-0.05	-0.0474	-4.74E-05	-1.14E-03	-4.22E-03
4	10:45	12:40	4.1	3.8	-0.3	1.92	-0.16	-0.1423	-1.42E-04	-3.42E-03	-1.26E-02
5	10:45	12:40	4.4	4.1	-0.3	1.92	-0.16	-0.1423	-1.42E-04	-3.42E-03	-1.26E-02
6	10:45	12:40	4.3	4.1	-0.2	1.92	-0.10	-0.0949	-9.49E-05	-2.28E-03	-8.43E-03
7	10:45	12:40	4.4	4.1	-0.3	1.92	-0.16	-0.1423	-1.42E-04	-3.42E-03	-1.26E-02
8	10:45	12:40	4.2	3.7	-0.5	1.92	-0.26	-0.2372	-2.37E-04	-5.69E-03	-2.11E-02

Deployment 7:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	12:40	14:40	4.5	4.7	0.2	2.00	0.10	0.0909	9.09E-05	2.18E-03	8.08E-03
2	12:40	14:40	4.4	4.1	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
3	12:40	14:40	4.6	4.4	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
4	12:40	14:40	4.6	4.2	-0.4	2.00	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02
5	12:40	14:40	4.4	4.0	-0.4	2.00	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02
6	12:40	14:40	4.4	4.7	0.3	2.00	0.15	0.1364	1.36E-04	3.27E-03	1.21E-02
7	12:40	14:40	4.4	4.1	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
8	12:40	14:40	4.6	4.0	-0.6	2.00	-0.30	-0.2727	-2.73E-04	-6.55E-03	-2.42E-02

Deployment 8:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	14:40	16:30	4.3	4.2	-0.1	1.83	-0.05	-0.0496	-4.96E-05	-1.19E-03	-4.41E-03
2	14:40	16:30	4.4	4.3	-0.1	1.83	-0.05	-0.0496	-4.96E-05	-1.19E-03	-4.41E-03
3	14:40	16:30	4.4	4.2	-0.2	1.83	-0.11	-0.0992	-9.92E-05	-2.38E-03	-8.82E-03
4	14:40	16:30	4.2	4.0	-0.2	1.83	-0.11	-0.0992	-9.92E-05	-2.38E-03	-8.82E-03
5	14:40	16:30	4.2	4.0	-0.2	1.83	-0.11	-0.0992	-9.92E-05	-2.38E-03	-8.82E-03
6	14:40	16:30	4.3	4.1	-0.2	1.83	-0.11	-0.0992	-9.92E-05	-2.38E-03	-8.82E-03
7	14:40	16:30	4.5	4.3	-0.2	1.83	-0.11	-0.0992	-9.92E-05	-2.38E-03	-8.82E-03
8	14:40	16:30	4.3	3.9	-0.4	1.83	-0.22	-0.1983	-1.98E-04	-4.76E-03	-1.76E-02

Deployment 9:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	16:30	18:15	4.5	4.3	-0.2	1.75	-0.11	-0.1039	-1.04E-04	-2.49E-03	-9.24E-03
2	16:30	18:15	4.3	4.1	-0.2	1.75	-0.11	-0.1039	-1.04E-04	-2.49E-03	-9.24E-03
3	16:30	18:15	4.8	4.6	-0.3	1.75	-0.14	-0.1299	-1.30E-04	-3.12E-03	-1.15E-02
4	16:30	18:15	4.4	4.0	-0.4	1.75	-0.23	-0.2078	-2.08E-04	-4.99E-03	-1.85E-02
5	16:30	18:15	4.3	4.0	-0.3	1.75	-0.17	-0.1558	-1.56E-04	-3.74E-03	-1.39E-02
6	16:30	18:15	4.5	4.1	-0.4	1.75	-0.23	-0.2078	-2.08E-04	-4.99E-03	-1.85E-02
7	16:30	18:15	4.2	4.0	-0.2	1.75	-0.11	-0.1039	-1.04E-04	-2.49E-03	-9.24E-03
8	16:30	18:15	4.3	3.9	-0.4	1.75	-0.23	-0.2078	-2.08E-04	-4.99E-03	-1.85E-02

Deployment 10:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	18:15	6:15	7.6	7.9	0.3	12.00	0.03	0.0227	2.27E-05	5.45E-04	2.02E-03
2	18:15	6:15	7.0	6.1	-0.9	12.00	-0.08	-0.0682	-6.82E-05	-1.64E-03	-6.06E-03
3	18:15	6:15	6.8	5.8	-1.0	12.00	-0.08	-0.0758	-7.58E-05	-1.82E-03	-6.73E-03
4	18:15	6:15	7.0	5.1	-1.9	12.00	-0.16	-0.1439	-1.44E-04	-3.45E-03	-1.28E-02
5	18:15	6:15	6.7	5.1	-1.6	12.00	-0.13	-0.1212	-1.21E-04	-2.91E-03	-1.08E-02
6	18:15	6:15	7.0	7.0	0.0	12.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
7	18:15	6:15	6.6	5.5	-1.1	12.00	-0.09	-0.0833	-8.33E-05	-2.00E-03	-7.41E-03
8	18:15	6:15	6.5	3.8	-2.7	12.00	-0.23	-0.2045	-2.05E-04	-4.91E-03	-1.82E-02

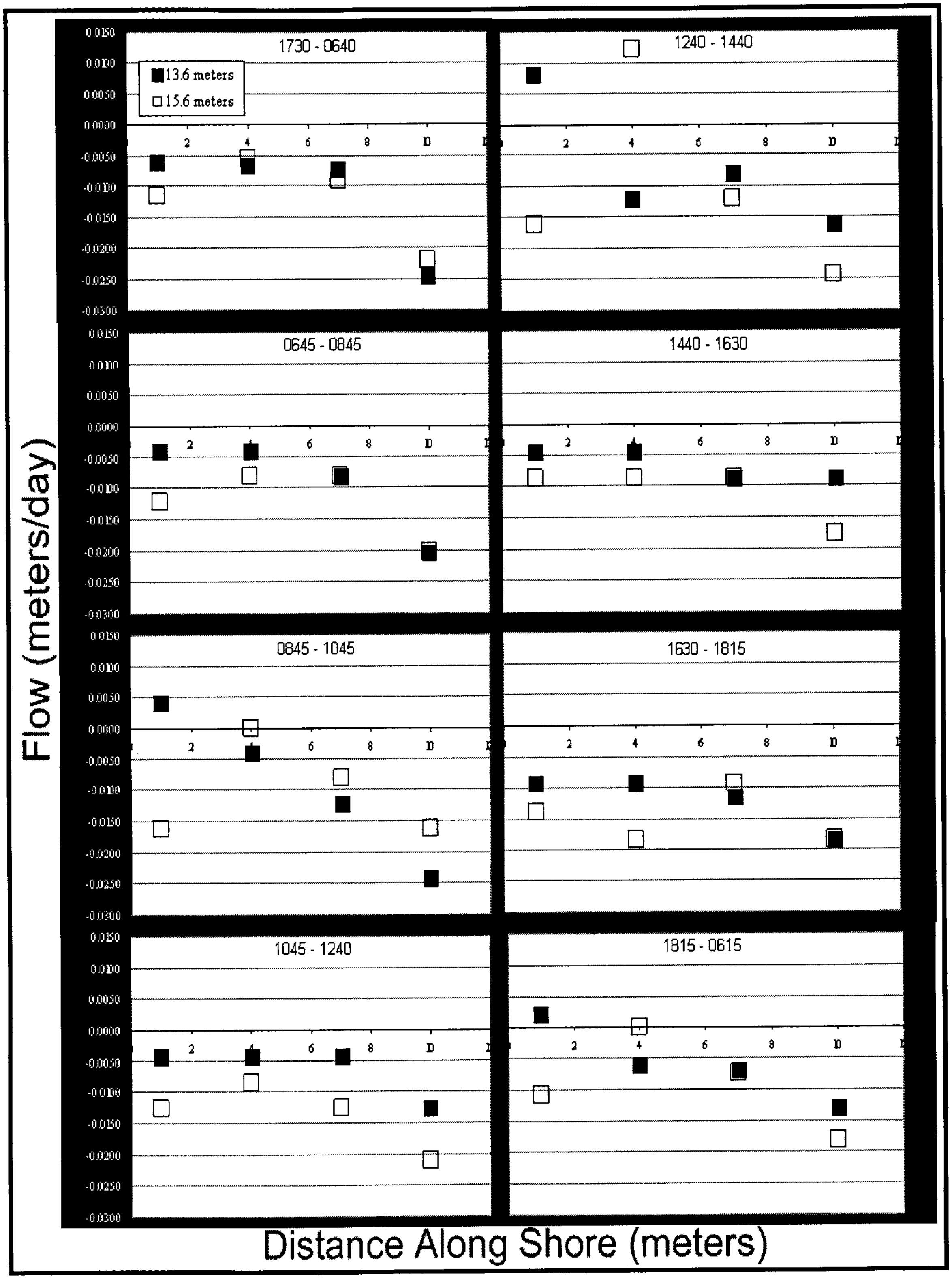

FIGURE 31
SEEPAGE METER FLOW RESULTS
(January 14th and 15th, Southside Pond)

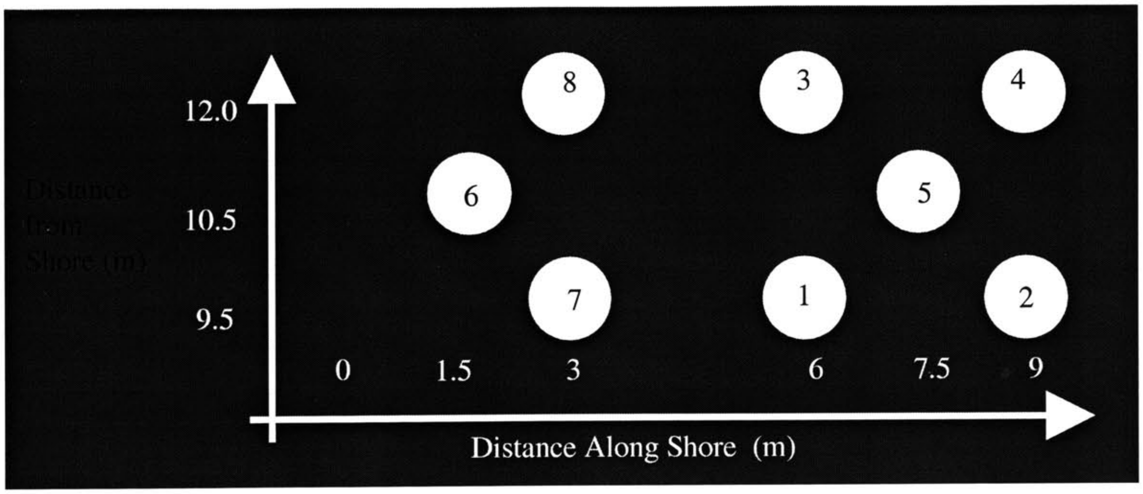

FIGURE 32
SEEPAGE METER SCHEMATIC
(January 16th, Southside Pond)

TABLE 23
SEEPAGE METER RESULTS
(January 16th, Southside Pond)

Deployment 1:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	11:20	13:20	3.2	3.6	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
2	11:20	13:20	3.4	3.8	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
3	11:20	13:20	3.5	3.6	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
4	11:20	13:20	3.4	3.9	0.5	2.00	0.25	0.2273	2.27E-04	5.45E-03	2.02E-02
5	11:20	13:20	3.6	4.0	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
6	11:20	13:20	3.3	3.1	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
7	11:20	13:20	3.7	3.7	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
8	11:20	13:20	3.1	3.1	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
Deployment 2:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	13:20	15:20	4.3	4.8	0.5	2.00	0.25	0.2273	2.27E-04	5.45E-03	2.02E-02
2	13:20	15:20	4.4	5.2	0.8	2.00	0.40	0.3636	3.64E-04	8.73E-03	3.23E-02
3	13:20	15:20	5.9	6.2	0.3	2.00	0.15	0.1364	1.36E-04	3.27E-03	1.21E-02
4	13:20	15:20	4.9	6.0	1.1	2.00	0.55	0.5000	5.00E-04	1.20E-02	4.44E-02
5	13:20	15:20	5.2	7.1	1.9	2.00	0.95	0.8636	8.64E-04	2.07E-02	7.68E-02
6	13:20	15:20	5.5	5.2	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
7	13:20	15:20	5.6	5.7	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
8	13:20	15:20	4.7	4.8	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03

Deployment 3:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	15:20	17:20	2.2	2.6	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
2	15:20	17:20	2.0	2.7	0.7	2.00	0.35	0.3182	3.18E-04	7.64E-03	2.83E-02
3	15:20	17:20	2.2	2.6	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
4	15:20	17:20	2.3	3.3	1.0	2.00	0.50	0.4545	4.55E-04	1.09E-02	4.04E-02
5	15:20	17:20	2.5	3.8	1.3	2.00	0.65	0.5909	5.91E-04	1.42E-02	5.25E-02
6	15:20	17:20	3.0	3.0	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
7	15:20	17:20	2.4	2.5	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
8	15:20	17:20	2.1	2.2	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03

Deployment 4:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	17:20	6:50	2.3	2.7	0.4	13.50	0.03	0.0269	2.69E-05	6.46E-04	2.39E-03
2	17:20	6:50	2.5	6.4	3.9	13.50	0.29	0.2626	2.63E-04	6.30E-03	2.33E-02
3	17:20	6:50	2.2	3.6	1.4	13.50	0.10	0.0943	9.43E-05	2.26E-03	8.38E-03
4	17:20	6:50	2.6	8.9	6.3	13.50	0.47	0.4242	4.24E-04	1.02E-02	3.77E-02
5	17:20	6:50	2.3	11.2	8.9	13.50	0.66	0.5993	5.99E-04	1.44E-02	5.33E-02
6	17:20	6:50	5.7	2.5	-3.2	13.50	-0.24	-0.2155	-2.15E-04	-5.17E-03	-1.92E-02
7	17:20	6:50	2.3	2.2	-0.1	13.50	-0.01	-0.0067	-6.73E-06	-1.62E-04	-5.99E-04
8	17:20	6:50	2.5	2.0	-0.5	13.50	-0.04	-0.0337	-3.37E-05	-8.08E-04	-2.99E-03

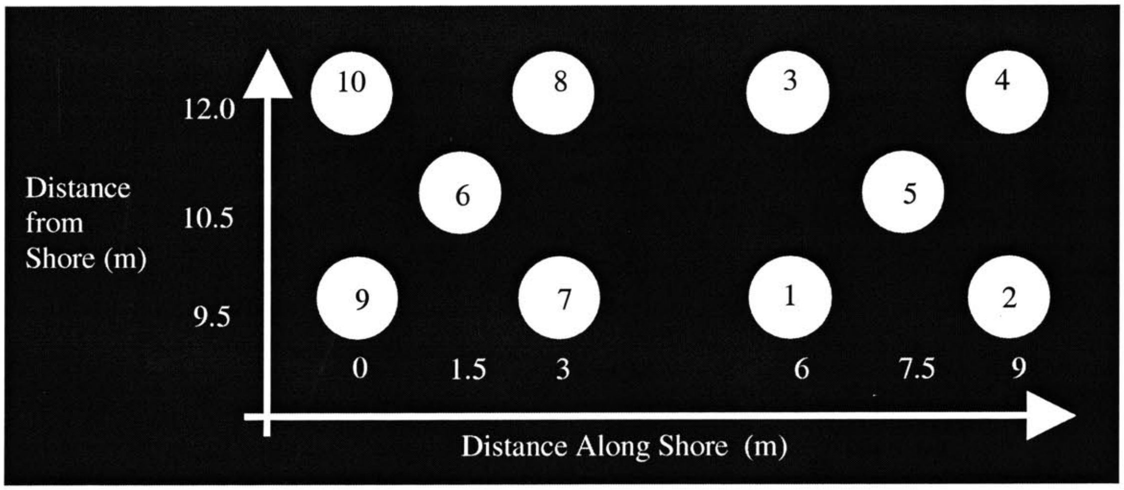

TABLE 24
SEEPAGE METER RESULTS
(January 17th, Southside Pond)

Deployment 1:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	7:30	9:30	3.0	3.4	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
2	7:30	9:30	3.0	3.8	0.8	2.00	0.40	0.3636	3.64E-04	8.73E-03	3.23E-02
3	7:30	9:30	3.1	3.7	0.6	2.00	0.30	0.2727	2.73E-04	6.55E-03	2.42E-02
4	7:30	9:30	3.0	4.0	1.0	2.00	0.50	0.4545	4.55E-04	1.09E-02	4.04E-02
5	7:30	9:30	3.0	3.8	0.8	2.00	0.40	0.3636	3.64E-04	8.73E-03	3.23E-02
6	7:30	9:30	3.1	2.8	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
7	7:30	9:30	3.1	3.2	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
8	7:30	9:30	3.2	3.3	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
9	7:30	9:30	4.3	4.1	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
10	7:30	9:30	4.1	3.7	-0.4	2.00	-0.20	-0.1818	-1.82E-04	-4.36E-03	-1.62E-02
Deployment 2:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	9:30	11:30	3.4	4.0	0.6	2.00	0.30	0.2727	2.73E-04	6.55E-03	2.42E-02
2	9:30	11:30	3.4	5.3	1.9	2.00	0.95	0.8636	8.64E-04	2.07E-02	7.68E-02
3	9:30	11:30	3.5	4.5	1.0	2.00	0.50	0.4545	4.55E-04	1.09E-02	4.04E-02
4	9:30	11:30	3.4	4.3	0.9	2.00	0.45	0.4091	4.09E-04	9.82E-03	3.64E-02
5	9:30	11:30	3.5	5.0	1.5	2.00	0.75	0.6818	6.82E-04	1.64E-02	6.06E-02
6	9:30	11:30	3.6	3.6	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
7	9:30	X				2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
8	9:30	X				2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
9	9:30	11:30	4.7	4.4	-0.3	2.00	-0.15	-0.1364	-1.36E-04	-3.27E-03	-1.21E-02
10	9:30	11:30	4.7	4.5	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
Deployment 3:											
bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	11:30	1:30	3.7	4.1	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
2	11:30	1:30	3.3	3.5	0.2	2.00	0.10	0.0909	9.09E-05	2.18E-03	8.08E-03
3	11:30	1:30	3.7	4.2	0.5	2.00	0.25	0.2273	2.27E-04	5.45E-03	2.02E-02
4	11:30	1:30	3.3	4.4	1.1	2.00	0.55	0.5000	5.00E-04	1.20E-02	4.44E-02
5	11:30	1:30	3.2	3.4	0.2	2.00	0.10	0.0909	9.09E-05	2.18E-03	8.08E-03
6	11:30	1:30	3.8	3.8	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
7	9:30	1:30	3.5	3.9	0.4	4.00	0.10	0.0909	9.09E-05	2.18E-03	8.08E-03
8	9:30	1:30	3.2	3.6	0.4	4.00	0.10	0.0909	9.09E-05	2.18E-03	8.08E-03
9	11:30	1:30	3.7	3.5	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
10	11:30	1:30	4.0	3.9	-0.1	2.00	-0.05	-0.0455	-4.55E-05	-1.09E-03	-4.04E-03

Deployment 4:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	1:30	3:30	3.3	3.8	0.5	2.00	0.25	0.2273	2.27E-04	5.45E-03	2.02E-02
2	1:30	3:30	3.3	4.2	0.9	2.00	0.45	0.4091	4.09E-04	9.82E-03	3.64E-02
3	1:30	3:30	3.5	4.6	1.1	2.00	0.55	0.5000	5.00E-04	1.20E-02	4.44E-02
4	1:30	3:30	3.5	5.1	1.6	2.00	0.80	0.7273	7.27E-04	1.75E-02	6.46E-02
5	1:30	3:30	3.3	6.0	2.7	2.00	1.35	1.2273	1.23E-03	2.95E-02	1.09E-01
6	1:30	3:30	4.6	4.7	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
7	1:30	X			0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
8	1:30	X			0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
9	1:30	3:30	3.4	3.3	-0.1	2.00	-0.05	-0.0455	-4.55E-05	-1.09E-03	-4.04E-03
10	1:30	3:30	3.5	3.3	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03

Deployment 5:

bag/ meter #	time on	time off	(kg) on	(kg) off	Δ (kg)	Δ time (hr)	kg/hr	L/hr	m^3/hr	m^3/d	m/d
1	3:30	5:30	3.4	3.5	0.1	2.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
2	3:30	5:30	3.4	3.4	0.0	2.00	0.00	0.0000	0.00E+00	0.00E+00	0.00E+00
3	3:30	5:30	3.3	3.7	0.4	2.00	0.20	0.1818	1.82E-04	4.36E-03	1.62E-02
4	3:30	5:30	3.7	4.7	1.0	2.00	0.50	0.4545	4.55E-04	1.09E-02	4.04E-02
5	3:30	5:30	3.7	4.4	0.7	2.00	0.35	0.3182	3.18E-04	7.64E-03	2.83E-02
6	3:30	5:30	3.5	3.3	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
7	1:30	5:30	3.4	3.7	0.3	4.00	0.08	0.0682	6.82E-05	1.64E-03	6.06E-03
8	1:30	5:30	3.4	3.6	0.2	4.00	0.05	0.0455	4.55E-05	1.09E-03	4.04E-03
9	3:30	5:30	3.5	3.3	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03
10	3:30	5:30	3.5	3.3	-0.2	2.00	-0.10	-0.0909	-9.09E-05	-2.18E-03	-8.08E-03

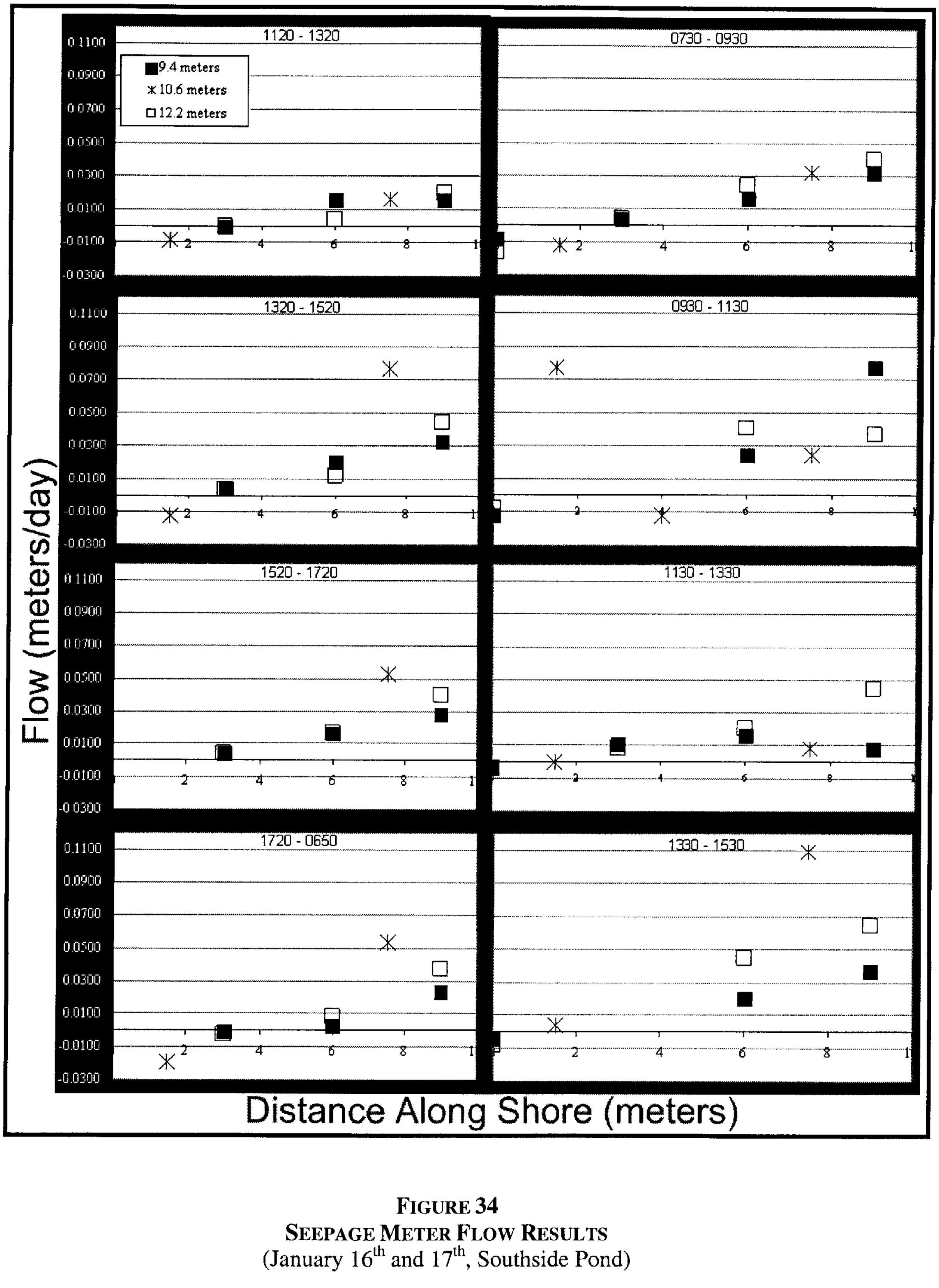

FIGURE 34
SEEPAGE METER FLOW RESULTS
(January 16th and 17th, Southside Pond)

APPENDIX H: SOIL INFORMATION

TABLE 25
RAINFALL, TEMPERATURE, AND POTENTIAL EVAPOTRANSPIRATION
Soil Survey of the United States Virgin Islands (USDA, 1998)

Month	Mean Total Rainfall (inches)	Mean Air Temperature (degrees F)	Potential Evapo-transpiration (inches)
January	2.60	76.2	3.89
February	1.84	76.2	3.67
March	2.09	76.9	4.45
April	2.89	78.0	4.96
May	4.55	79.4	5.94
June	2.96	81.0	6.27
July	3.19	82.0	6.55
August	4.57	82.0	6.40
September	5.67	81.0	5.85
October	5.82	80.4	5.69
November	6.08	78.8	4.90
December	3.76	76.9	4.27

TABLE 26
CLASSIFICATION OF SOILS
Soil Survey of the United States Virgin Islands (USDA 1998)

Soil name	Family or Higher Taxonomic Class
Cramer	Clayey, mixed, active, isohyperthermic, shallow Typic Haplustolls
Dorothea	Fine, vermiculitic, isohyperthermic Typic Haplustalfs
Fredriksdal	Clayey-skeletal, vermiculitic, isohyperthermic Lithic Haplustolls
Jaucas	Carbonatic, isohyperthermic Typic Ustipsamments
Solitude	Fine-loamy, mixed, superactive, nonacid, isohyperthermic Aeric Tropaquepts
Southgate	Loamy-skeletal, mixed, active, isohyperthermic Lithic Ustropepts
Susannaberg	Clayey, vermiculitic, isohyperthermic, shallow Typic Haplustolls
Victory	Loamy-skeletal, mixed, superactive, isohyperthermic Typic Ustropepts

Soil Survey

(USGS Soil Survey)

The soils described below are the ones which were encountered when modeling the watersheds using HydroCAD.

Soil Characteristics:

Cramer soils

Surface layer: 0 to 9 inches, dark reddish brown gravelly clay loam
Subsoil: 9 to 14 inches, dark red gravelly clay
14 to 19 inches, dark reddish brown gravelly clay
Bedrock: 19 to 32 inches, weathered igneous bedrock
32 to 60 inches, unweathered igneous bedrock

Dorothea soils

Surface layer: 0 to 6 inches, dark brown clay loam
Subsoil: 6 to 11 inches, brown clay loam
11 to 19 inches, yellowish brown clay
19 to 30 inches, strong brown clay loam
Substratum: 30 to 60 inches, strong brown saprolite

Fredriksdal soils

Surface layer: 0 to 7 inches, dark reddish brown very gravelly clay loam
Subsoil: 7 to 12 inches, reddish brown very gravelly clay loam
Bedrock: 12 to 16 inches, weathered igneous bedrock
16 to 60 inches, unweathered igneous bedrock

Jaucas soils

Surface layer: 0 to 6 inches, grayish brown sand
Substratum: 6 to 16 inches, light brownish gray sand
16 to 26 inches, pale brown sand
26 to 60 inches, very pale brown sand

SaA - Salt flats, ponded

This map unit consists of unvegetated areas of saline flats, saline marshes, and salt ponds. The areas are prone to ponding and flooding resulting from gut flow, marine tides, and marine storm surges. The soils are very deep, poorly drained and very poorly drained, strongly saline, and frequently ponded for very long periods. An onsite investigation is required to determine the suitability or potential of the map unit for any use.

Solitude

Surface layer: 0 to 6 inches, light olive brown gravelly fine sandy loam
Subsoil: 6 to 10 inches, light olive brown gravelly fine sandy loam
10 to 28 inches, grayish brown fine sandy loam
28 to 57 inches, grayish brown gravelly loam
57 to 61 inches, light olive brown gravelly fine sandy loam

Southgate soils
Surface layer: 0 to 5 inches, brown gravelly loam
Subsoil: 5 to 10 inches, brown very gravelly loam
Bedrock: 10 to 17 inches, weathered igneous bedrock
17 to 60 inches, unweathered igneous bedrock

Susannaberg soils
Surface layer: 0 to 2 inches, very dark brown clay loam
Subsoil: 2 to 9 inches, very dark brown clay
9 to 15 inches, dark brown gravelly clay loam
Bedrock: 15 to 21 inches, weathered igneous bedrock
21 to 60 inches, unweathered igneous bedrock

Victory soils
Surface layer: 0 to 6 inches, brown loam
Subsurface layer: 6 to 11 inches, dark yellowish brown loam
Subsoil: 11 to 14 inches, dark yellowish brown very gravelly loam
14 to 20 inches, brown very gravelly loam
Substratum: 20 to 33 inches, very pale brown very gravelly loam
Bedrock: 33 to 50 inches, weathered igneous bedrock
50 to 60 inches, unweathered igneous bedrock

APPENDIX I: STATA REGRESSION RESULTS

Dependent Variable: Phosphate

Regression 1

R^2: 0.5311

Adjusted R^2: -1.3447

Degrees of Freedom: 10

Prob > F: 0.9205

Independent Variables	Coeff	Std Err	t	P>|t|
DO	-0.0462882	0.1082388	-0.43	0.711
Temperature	-1.50705	8.205608	-0.18	0.871
Salinity	-0.1880685	10.40689	-0.02	0.987
pH	7.069773	152.9841	0.05	0.967
Time	0.0113387	0.0434663	0.26	0.819
Turbidity	-0.2083186	3.060218	-0.07	0.952
TSS	10077.77	33304.46	0.3	0.791
Watershed Area	0.0000196	0.0020427	0.01	0.993
Slope	Dropped			
TC	Dropped			

Regression 2

R^2: 0.1266

Adjusted R^2: 0.072

Degrees of Freedom: 17

Prob > F: 0.1474

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	0.011863	0.0077915	1.52	0.147

Dependent Variable: Nitrate

Regression 1

R^2: 0..8944

Adjusted R^2: 0.8389

Degrees of Freedom: 29

Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
DO	0.0099863	0.0159785	0.62	0.539
Temperature	-0.0323171	0.2109087	-0.15	0.88
Salinity	0.0408693	0.0171251	2.39	0.028
pH	0.4221056	1.852242	0.23	0.822
Time	-0.0016156	0.0023101	-0.7	0.493
Turbidity	0.0068833	0.0401985	0.17	0.866
TSS	7446.041	3541.179	2.1	0.049
Watershed Area	0.0000196	0.0020427	0.01	0.993
Slope	Dropped			
TC	Dropped			

Regression 2

R^2: 0.8944

Adjusted R^2: 0.8389

Degrees of Freedom: 29
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	0.0371464	0.0041136	9.03	0
Watershed Area	0.000009	8.65E-06	1.04	0.305
TC	0.0001139	0.0007668	0.15	0.883
House Area	-0.00000843	7.67E-06	-1.1	0.279
Impervious Area	-0.0000465	0.0000521	-0.89	0.378

Dependent Variable: Nitrate Deviation from Expected Value (NOAA)

Regression 1
R^2: 0.8553
Adjusted R^2: 0.8372
Degrees of Freedom: 45
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	0.0312464	0.0041136	7.6	0
Watershed Area	0.000009	8.65E-06	1.04	0.305
TC	0.0001139	0.0007668	0.15	0.883
House Area	-0.00000843	7.67E-06	-1.1	0.279
Impervious Area	-0.0000465	0.0000521	-0.89	0.378

Regression 2
R^2: 0.5589
Adjusted R^2: 0.5785
Degrees of Freedom: 45
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Watershed Area	0.0000637	8.33E-06	7.64	0
House Area	-0.0000555	7.33E-06	-7.57	0

Regression 3
R^2: 0.8493
Adjusted R^2: 0.8458
Degrees of Freedom: 45
Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	0.0350106	0.0022237	15.74	0

Dependent Variable: Nitrate Deviation from Expected Value (CHE)

Regression 1
R^2: 0.0834
Adjusted R^2: -0.0311
Degrees of Freedom: 46
Prob > F: 0.6064

Independent Variables	Coeff	Std Err	t	P>|t|
salinity	-0.0005483	0.004115	-0.13	0.895
Shedarea	8.96E-06	8.66E-06	1.03	0.307
TC	0.0001095	0.000767	0.14	0.887

House Area	-8.39E-06	7.67E-06	-1.09	0.281
Impervious Area	-0.0000465	0.0000521	-0.89	0.377

Regression 2

R^2: 0.0451

Adjusted R^2: 0.0234

Degrees of Freedom: 46

Prob > F: 0.1564

Independent Variables	Coeff	Std Err	t	P>|t|
Salinity	3.21E-03	2.22E-03	1.44	0.156

Dependent Variable: Turbidity

Regression 1

R^2: 0.8258

Adjusted R^2: .7595

Degrees of Freedom: 29

Prob > F: 0

Independent Variables	Coeff	Std Err	t	P>|t|
TSS	27864.57	18185.89	1.53	0.14
Dev Mat	-12.20656	1.54361	-7.91	0
Dev Mat Roads	26.25947	4.230475	6.21	0
Watershed Area	-0.0000168	0.0000751	-0.22	0.825
Slope	158.1497	40.10126	3.94	0.001
TC	0.0733523	0.0116215	6.31	0
House Area	-0.0000812	0.0000761	-1.07	0.298
Impervious Area	0.0020761	0.0008091	2.57	0.018

Dependent Variable: TSS

Regression 1

R^2: 0.7196

Adjusted R^2: 0.6128

Degrees of Freedom: 29

Prob > F: 0.0002

Independent Variables	Coeff	Std Err	t	P>|t|
Turbidity	0.00000361	2.36E-06	1.53	0.14
Dev Mat	0.000039	0.000034	1.15	0.263
Dev Mat Roads	-0.0000613	0.0000799	-0.77	0.452
Watershed Area	-3.89E-10	8.51E-10	-0.46	0.653
Slope	-0.0015964	0.0004911	-3.25	0.004
TC	-0.000000388	2.09E-07	-1.86	0.077
House Area	6.81E-10	8.77E-10	0.78	0.446
Impervious Area	-3.39E-08	7.52E-09	-4.51	0

APPENDIX J: DATA ANALYSIS USING STATA

Data analysis for this study was carried out using the statistical software package Stata (Stata Corporation, 2002). Both simple linear and multivariate regressions were run using Stata's "regress" command. Simple linear regressions are run by using one dependent variable and one predictor variable to predict the relationship between the two. An example of a simple linear regression would be analysis of the dependence of nitrate levels on salinity. Multivariate regressions also use one dependent variable, but have a number of predictor variables.

In order to document how Stata regression results are interpreted, an example output is annotated:

TABLE 27
ANNOTATED STATA OUTPUT

```
. . regress nitrate salinity shedarea tc housearea impervarea;

Source          SS         df         MS              Number of obs =       46
-------------------------------------------------     F(  5,     40) =    64.46
Model      254.235467      5      50.8470935          Prob > F      =   0.0000
Residual   31.5518101      40     .788795252          R-squared     =   0.8896
-------------------------------------------------     Adj R-squared =   0.8758
Total      285.787277      45     6.35082839          Root MSE      =   .88814

------------------------------------------------------------------------------
nitrate |       Coef.    Std. Err.       t     P>|t|      [95% Conf. Interval]
-------------+----------------------------------------------------------------
salinity |    .0371464    .0041136     9.03    0.000      .0288325    .0454603
shedarea |    9.00e-06    8.65e-06     1.04    0.305     -8.49e-06    .0000265
tc |          .0001139    .0007668     0.15    0.883     -.0014358    .0016636
housearea |  -8.43e-06    7.67e-06    -1.10    0.279     -.0000239    7.08e-06
impervarea | -.0000465    .0000521    -0.89    0.378     -.0001517    .0000588
_cons |      -.2424074    .4387687    -0.55    0.584     -1.129192    .6443772
------------------------------------------------------------------------------
```

The results shown above have the following meanings:

- SS – The numbers in this column represent the Sum of Squares, and are partitioned between the Model and the Residual:
  - SSTotal: The total variability around the mean. $\Sigma(Y - Ybar)^2$.
  - SSResidual: The sum of squared errors in prediction. $\Sigma(Y - Ypredicted)^2$.
  - SSModel: The improvement in prediction by using the predicted value of Y instead of the mean of Y.

- df – The degrees of freedom associated with the sources of variance. Since this regression has five predictors (salinity, shedarea, tc, housearea, and impervarea), the model has five degrees of freedom. Also, since there are N=46 observations, the total degrees of freedom is N-1=45.
- MS – The mean square values shown here are computed by MS=SS/df, and are computed to assist with the F-test to determine whether the predictors are statistically significant.
- Number of Obs – This is the total number of sample points used in the analysis.
- F(x,y) – This value represents the mean square of the model divided by the mean square of the residual, $F(x,y) = MS_x/MS_y$.
- Prob(F) > - Using the F-value documented above in an F-test, this parameter illustrates the confidence limit associated with the question of whether the set of predictor variables can predict the dependent variables. If the Prob(F) value is less than an alpha value (such as $\alpha=0.05$ for the 95% confidence limit), it can be said that the group of independent variables can be used to reliably predict the dependent variable. However, this test does not address the relative ability of one predictor over another to control the dependent variable.
- R-squared – The value shown here, 0.8896, states that 88.96% of the variance associated with the dependent variable is accounted for by the predictors. This is a measure of the strength of association, but again, cannot be used to address the relative association of individual predictors with the dependent variable.
- Adj R-squared – As predictor variables are added to the model, some of the variance of the dependent variable will be associated with these new variables by chance. The value of R-squared is thus adjusted to eliminate these chance contributions.
- Root MSE – This is the standard deviation of the error term, also known as the root mean squared error.
- Coeff – The numbers in this column represent the coefficients associated with each of the predictor variables in the model (_cons is the constant). These values are used to predict the dependent variable in the following fashion:

$$\text{Nitrate}= -0.2424074 + .0371464*\text{salinity} + 9.00e\text{-}6*\text{shedarea} + 0.0001139*\text{tc} + \ldots$$

An interesting point derived from these values is the contribution that each predictor variable can have on the dependent variable. For example, if all values are held constant except salinity, an increase of one unit in salinity would result in an increase in the nitrate level of 0.0371464. However, this is only the case if the coefficients are shown to be significantly different than zero.

- Std Err – These are the standard errors associated with the coefficients, and are used to generate t values in the next column.
- t – Calculated by dividing the coefficient of each predictor variable by its standard error, these values are used in the Student's t-test to determine whether or not the coefficients calculated for the model are significantly different from zero.
- P>|t| - Similar to the F-test described above, this value is compared to a prescribed alpha value that describes a confidence level. When P is less than alpha, the coefficient is statistically shown to be different than zero at the confidence interval described by alpha.
- 95% Conf Interval – These numbers represent a range of possible values for the coefficient, which is 95% likely to fall in this range.

The regressions performed using Stata were the primary mechanism by which both chemical and hydrologic data were analyzed. Thus, relationships among nutrient levels, sedimentation parameters, watershed properties, and runoff characteristics were investigated in order to link the chemistry of salt ponds to the hydrology of the surrounding area. The following text contains outputs from all Stata regressions.

Regression 1: All Ponds

```
------------------------------------------------------------------------------
       log:  C:\ProjectStata\project13aprilgeneral.log
  log type:  text
 opened on:   3 May 2003, 18:40:09

. use C:\ProjectStata\project.dta;

. regress do temperature salinity ph time;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  4,    41) =   10.22
       Model |  18601.7627     4  4650.44067           Prob > F      =  0.0000
    Residual |  18653.4706    41  454.962697           R-squared     =  0.4993
-------------+------------------------------           Adj R-squared =  0.4505
       Total |  37255.2333    45  827.894072           Root MSE      =   21.33

------------------------------------------------------------------------------
          do |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 temperature |   8.788281   1.896251     4.63   0.000     4.958725    12.61784
    salinity |  -.0645709   .0726814    -0.89   0.380     -.211354    .0822121
          ph |   27.79276   13.88015     2.00   0.052    -.2387765    55.82429
        time |   .0020776   .0199987     0.10   0.918    -.0383107    .0424659
       _cons |  -416.9775    143.712    -2.90   0.006    -707.2099   -126.7452
------------------------------------------------------------------------------
```

```
. regress ph temperature salinity time;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  3,    42) =   14.50
       Model |  2.44656562     3  .815521874           Prob > F      =  0.0000
    Residual |    2.361497    42  .056226119           R-squared     =  0.5088
-------------+------------------------------           Adj R-squared =  0.4738
       Total |  4.80806262    45  .106845836           Root MSE      =  .23712

------------------------------------------------------------------------------
          ph |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 temperature |  -.0433975   .0199884    -2.17   0.036    -.0837359   -.0030592
    salinity |  -.0034054   .0006138    -5.55   0.000    -.0046441   -.0021668
        time |  -.0000925   .0002219    -0.42   0.679    -.0005402    .0003552
       _cons |   9.925499   .4547429    21.83   0.000     9.007791    10.84321
------------------------------------------------------------------------------

. regress turbidity tss devmatroads shedarea slope tc housearea impervarea;

      Source |       SS       df       MS              Number of obs =      30
-------------+------------------------------           F(  7,    22) =    1.39
       Model |  1131.31635     7  161.616622           Prob > F      =  0.2571
    Residual |  2550.56946    22  115.934975           R-squared     =  0.3073
-------------+------------------------------           Adj R-squared =  0.0868
       Total |  3681.88581    29   126.96158           Root MSE      =  10.767

------------------------------------------------------------------------------
   turbidity |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         tss |   37288.72   35360.51     1.05   0.303    -36044.48    110621.9
 devmatroads |  -5.695558   2.439716    -2.33   0.029    -10.75522   -.6358963
    shedarea |  -.0000918   .0001452    -0.63   0.534    -.0003928    .0002093
       slope |   .2774175   .7122738     0.39   0.701    -1.199748    1.754583
          tc |    .005847   .0153663     0.38   0.707    -.0260208    .0377147
   housearea |   .0001046   .0001411     0.74   0.466    -.0001879    .0003972
  impervarea |   .0028361   .0015654     1.81   0.084    -.0004103    .0060825
       _cons |   29.10723   27.72306     1.05   0.305    -28.38688    86.60135
------------------------------------------------------------------------------

. regress tss turbidity devmatroads shedarea slope tc housearea impervarea;

      Source |       SS       df       MS              Number of obs =      30
-------------+------------------------------           F(  7,    22) =    7.40
       Model |  2.0790e-07     7  2.9700e-08           Prob > F      =  0.0001
    Residual |  8.8260e-08    22  4.0118e-09           R-squared     =  0.7020
-------------+------------------------------           Adj R-squared =  0.6072
       Total |  2.9616e-07    29  1.0212e-08           Root MSE      =  6.3e-05

------------------------------------------------------------------------------
         tss |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   turbidity |   1.29e-06   1.22e-06     1.05   0.303    -1.25e-06    3.83e-06
 devmatroads |    .000029   .0000148     1.96   0.063    -1.66e-06    .0000597
    shedarea |  -3.92e-10   8.58e-10    -0.46   0.652    -2.17e-09    1.39e-09
       slope |  -.0000118   3.36e-06    -3.52   0.002    -.0000188   -4.85e-06
          tc |  -1.68e-07   8.33e-08    -2.02   0.056    -3.41e-07    4.48e-09
   housearea |   3.58e-10   8.37e-10     0.43   0.673    -1.38e-09    2.09e-09
  impervarea |  -3.14e-08   7.25e-09    -4.33   0.000    -4.65e-08   -1.64e-08
       _cons |   .0003582   .0001487     2.41   0.025     .0000499    .0006665
------------------------------------------------------------------------------

. regress nitrate do temperature salinity ph time turbidity tss shedarea slope tc;

      Source |       SS       df       MS              Number of obs =      30
-------------+------------------------------           F( 10,    19) =   16.10
       Model |  184.668823    10  18.4668823           Prob > F      =  0.0000
    Residual |  21.7960473    19  1.14716039           R-squared     =  0.8944
```

```
-------------+------------------------------           Adj R-squared =  0.8389
       Total |  206.46487    29  7.11947828            Root MSE      =  1.0711

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          do |   .0099863   .0159785     0.62   0.539    -.0234571    .0434298
 temperature |  -.0323171   .2109087    -0.15   0.880    -.4737541    .4091198
    salinity |   .0408693   .0171251     2.39   0.028      .005026    .0767126
          ph |   .4221057   1.852242     0.23   0.822    -3.454681    4.298892
        time |  -.0016156   .0023101    -0.70   0.493    -.0064507    .0032196
   turbidity |   .0068833   .0401985     0.17   0.866    -.0772531    .0910197
         tss |   7446.041   3541.179     2.10   0.049     34.26786    14857.81
    shedarea |  -3.85e-07   2.72e-06    -0.14   0.889    -6.08e-06    5.31e-06
       slope |   .0555232    .079283     0.70   0.492     -.110418    .2214645
          tc |   .0004311   .0017803     0.24   0.811    -.0032951    .0041572
       _cons |  -4.386452   17.44873    -0.25   0.804    -40.90706    32.13416
------------------------------------------------------------------------------

. regress phosphate do temperature salinity ph time turbidity tss shedarea slope
tc;

      Source |       SS       df       MS              Number of obs =      11
-------------+------------------------------           F(  8,     2) =    0.28
       Model | 9.47148888     8  1.18393611            Prob > F      =  0.9205
    Residual |  8.3636164     2   4.1818082            R-squared     =  0.5311
-------------+------------------------------           Adj R-squared = -1.3447
       Total | 17.8351053    10  1.78351053            Root MSE      =  2.0449

------------------------------------------------------------------------------
   phosphate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          do |  -.0462882   .1082388    -0.43   0.711     -.512002    .4194256
 temperature |   -1.50705   8.205608    -0.18   0.871    -36.81293    33.79883
    salinity |  -.1880685   10.40689    -0.02   0.987    -44.96531    44.58917
          ph |   7.069773   152.9841     0.05   0.967    -651.1678    665.3073
        time |   .0113387   .0434663     0.26   0.819    -.1756818    .1983593
   turbidity |  -.2083186   3.060218    -0.07   0.952    -13.37537    12.95874
         tss |   10077.77   33304.46     0.30   0.791    -133219.8    153375.3
    shedarea |   .0000196   .0020427     0.01   0.993    -.0087693    .0088086
       slope |  (dropped)
          tc |  (dropped)
       _cons |  -12.98855   619.8936    -0.02   0.985    -2680.176    2654.198
------------------------------------------------------------------------------

. regress nitrate salinity tss;

      Source |       SS       df       MS              Number of obs =      41
-------------+------------------------------           F(  2,    38) =  169.28
       Model | 240.553408     2  120.276704            Prob > F      =  0.0000
    Residual | 26.9990129    38  .710500339            R-squared     =  0.8991
-------------+------------------------------           Adj R-squared =  0.8938
       Total | 267.552421    40  6.68881053            Root MSE      =  .84291

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |   .0343872    .003526     9.75   0.000     .0272491    .0415253
         tss |   3958.669   1676.984     2.36   0.023     563.7924    7353.546
       _cons |  -.5232057   .2546025    -2.05   0.047    -1.038621   -.0077899
------------------------------------------------------------------------------

. regress nitrate salinity shedarea tc housearea impervarea;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  5,    40) =   64.46
       Model | 254.235467     5  50.8470935            Prob > F      =  0.0000
    Residual | 31.5518101    40  .788795252            R-squared     =  0.8896
```

```
-------------+------------------------------           Adj R-squared =  0.8758
       Total |  285.787277    45  6.35082839           Root MSE      =  .88814

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |   .0371464   .0041136     9.03   0.000      .0288325    .0454603
   shedarea  |   9.00e-06   8.65e-06     1.04   0.305     -8.49e-06    .0000265
          tc |   .0001139   .0007668     0.15   0.883     -.0014358    .0016636
   housearea |  -8.43e-06   7.67e-06    -1.10   0.279     -.0000239    7.08e-06
 impervarea  |  -.0000465   .0000521    -0.89   0.378     -.0001517    .0000588
       _cons |  -.2424074   .4387687    -0.55   0.584     -1.129192    .6443772
------------------------------------------------------------------------------

. regress nitratedev salinity shedarea tc housearea impervarea;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  5,    40) =   47.30
       Model |  186.547929     5  37.3095858           Prob > F      =  0.0000
    Residual |  31.5520466    40  .788801166           R-squared     =  0.8553
-------------+------------------------------           Adj R-squared =  0.8372
       Total |  218.099976    45  4.84666613           Root MSE      =  .88814

------------------------------------------------------------------------------
  nitratedev |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |   .0312464   .0041136     7.60   0.000      .0229324    .0395604
    shedarea |   9.00e-06   8.65e-06     1.04   0.305     -8.49e-06    .0000265
          tc |   .0001139   .0007668     0.15   0.883     -.0014358    .0016636
   housearea |  -8.43e-06   7.67e-06    -1.10   0.279     -.0000239    7.08e-06
  impervarea |  -.0000465   .0000521    -0.89   0.378     -.0001517    .0000588
       _cons |  -.2424077   .4387704    -0.55   0.584     -1.129196    .6443803
------------------------------------------------------------------------------

. regress nitrate shedarea housearea;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  2,    43) =   31.74
       Model |  170.369474     2  85.1847371           Prob > F      =  0.0000
    Residual |  115.417803    43  2.68413496           R-squared     =  0.5961
-------------+------------------------------           Adj R-squared =  0.5774
       Total |  285.787277    45  6.35082839           Root MSE      =  1.6383

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    shedarea |    .000074   9.34e-06     7.93   0.000      .0000552    .0000928
   housearea |  -.0000645   8.22e-06    -7.84   0.000      -.000081   -.0000479
       _cons |   .9161815   .4442488     2.06   0.045      .0202684    1.812095
------------------------------------------------------------------------------

. regress nitratedev shedarea housearea;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  2,    43) =   29.51
       Model |  126.178101     2  63.0890503           Prob > F      =  0.0000
    Residual |  91.9218752    43  2.13771803           R-squared     =  0.5785
-------------+------------------------------           Adj R-squared =  0.5589
       Total |  218.099976    45  4.84666613           Root MSE      =  1.4621

------------------------------------------------------------------------------
  nitratedev |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    shedarea |   .0000637   8.33e-06     7.64   0.000      .0000469    .0000805
   housearea |  -.0000555   7.33e-06    -7.57   0.000     -.0000703   -.0000407
       _cons |   .7199884   .3964599     1.82   0.076     -.0795492    1.519526
------------------------------------------------------------------------------
```

```
. regress nitrate devmat devmatroads devmatnutrients;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  3,    42) =    4.14
       Model |  65.2356338     3  21.7452113           Prob > F      =  0.0117
    Residual |  220.551644    42  5.25122961           R-squared     =  0.2283
-------------+------------------------------           Adj R-squared =  0.1731
       Total |  285.787277    45  6.35082839           Root MSE      =  2.2916

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      devmat |  -2.315556   .6777162    -3.42   0.001    -3.683243   -.9478697
 devmatroads |   2.923793   .8506634     3.44   0.001     1.207085    4.640501
devmatnutr~s |   1.590176   .5598651     2.84   0.007     .4603225    2.720029
       _cons |   -.288338   1.741741    -0.17   0.869    -3.803314    3.226638
------------------------------------------------------------------------------

. regress nitratedev devmat devmatroads devmatnutrients;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  3,    42) =    3.92
       Model |   47.694113     3  15.8980377           Prob > F      =  0.0149
    Residual |  170.405863    42  4.05728245           R-squared     =  0.2187
-------------+------------------------------           Adj R-squared =  0.1629
       Total |  218.099976    45  4.84666613           Root MSE      =  2.0143

------------------------------------------------------------------------------
  nitratedev |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      devmat |  -1.988633   .5957102    -3.34   0.002    -3.190825   -.7864413
 devmatroads |   2.489241   .7477301     3.33   0.002     .9802607    3.998222
devmatnutr~s |   1.376093   .4921194     2.80   0.008     .3829556     2.36923
       _cons |  -.2441096   1.530984    -0.16   0.874    -3.333761    2.845542
------------------------------------------------------------------------------

. regress nitrate devmatroads devmatnutrients;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  2,    43) =    0.30
       Model |  3.93344898     2  1.96672449           Prob > F      =  0.7423
    Residual |  281.853828    43  6.55474019           R-squared     =  0.0138
-------------+------------------------------           Adj R-squared = -0.0321
       Total |  285.787277    45  6.35082839           Root MSE      =  2.5602

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 devmatroads |   .3074128   .4138895     0.74   0.462    -.5272749    1.142101
devmatnutr~s |  -.1769542   .2394913    -0.74   0.464    -.6599344    .3060259
       _cons |   2.497374   1.719578     1.45   0.154    -.9704851    5.965233
------------------------------------------------------------------------------

. regress nitratedev devmatroads devmatnutrients;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  2,    43) =    0.25
       Model |  2.47994517     2  1.23997258           Prob > F      =  0.7820
    Residual |  215.620031    43  5.01441932           R-squared     =  0.0114
-------------+------------------------------           Adj R-squared = -0.0346
       Total |  218.099976    45  4.84666613           Root MSE      =  2.2393

------------------------------------------------------------------------------
  nitratedev |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 devmatroads |   .2422564    .362007     0.67   0.507    -.4878004    .9723131
devmatnutr~s |   -.141544   .2094702    -0.68   0.503    -.5639809    .2808929
       _cons |     2.1483   1.504023     1.43   0.160    -.8848511    5.181451
```

```
------------------------------------------------------------------------------

. regress nitrate salinity;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  1,    44) =  338.47
       Model |  252.909587     1  252.909587           Prob > F      =  0.0000
    Residual |  32.8776909    44  .747220247           R-squared     =  0.8850
-------------+------------------------------           Adj R-squared =  0.8823
       Total |  285.787277    45  6.35082839           Root MSE      =  .86442

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |   .0409106   .0022237    18.40   0.000      .036429    .0453921
       _cons |  -.3903119   .2355507    -1.66   0.105    -.8650332    .0844093
------------------------------------------------------------------------------

. regress nitratedev salinity;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  1,    44) =  247.88
       Model |  185.222045     1  185.222045           Prob > F      =  0.0000
    Residual |  32.8779308    44  .747225701           R-squared     =  0.8493
-------------+------------------------------           Adj R-squared =  0.8458
       Total |  218.099976    45  4.84666613           Root MSE      =  .86442

------------------------------------------------------------------------------
  nitratedev |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |   .0350106   .0022237    15.74   0.000      .030529    .0394922
       _cons |  -.3903123   .2355516    -1.66   0.105    -.8650353    .0844107
------------------------------------------------------------------------------

. regress phosphate salinity;

      Source |       SS       df       MS              Number of obs =      18
-------------+------------------------------           F(  1,    16) =    2.32
       Model |  3.16590765     1  3.16590765           Prob > F      =  0.1474
    Residual |  21.8506252    16  1.36566407           R-squared     =  0.1266
-------------+------------------------------           Adj R-squared =  0.0720
       Total |  25.0165328    17  1.47156075           Root MSE      =  1.1686

------------------------------------------------------------------------------
   phosphate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |    .011863   .0077915     1.52   0.147    -.0046541    .0283802
       _cons |  -.5012496    .862445    -0.58   0.569    -2.329551    1.327052
------------------------------------------------------------------------------

. regress chenitratedev shedarea housearea;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  2,    43) =    1.36
       Model |   2.0467347     2  1.02336735           Prob > F      =  0.2679
    Residual |  32.3999617    43  .753487482           R-squared     =  0.0594
-------------+------------------------------           Adj R-squared =  0.0157
       Total |  34.4466964    45  .765482142           Root MSE      =  .86804

------------------------------------------------------------------------------
chenitrate~v |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    shedarea |   7.97e-06   4.95e-06     1.61   0.114    -2.00e-06     .0000179
   housearea |  -7.16e-06   4.35e-06    -1.64   0.107    -.0000159     1.62e-06
       _cons |  -.3384215    .235376    -1.44   0.158    -.8131024     .1362593
------------------------------------------------------------------------------

. regress chenitratedev devmatroads devmatnutrients;
```

```
      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  2,    43) =    0.29
       Model |  .460583452     2  .230291726           Prob > F      =  0.7487
    Residual |   33.986113    43   .79037472           R-squared     =  0.0134
-------------+------------------------------           Adj R-squared = -0.0325
       Total |  34.4466964    45  .765482142           Root MSE      =  .88903

------------------------------------------------------------------------------
chenitrate~v |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 devmatroads |  -.1093505    .143722    -0.76   0.451    -.3991935    .1804925
devmatnutr~s |   .0495802   .0831627     0.60   0.554    -.1181333    .2172937
       _cons |   .2659286   .5971186     0.45   0.658    -.9382758    1.470133
------------------------------------------------------------------------------

. regress chenitratedev salinity shedarea tc housearea impervarea;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  5,    40) =    0.73
       Model |  2.87422481     5  .574844962           Prob > F      =  0.6064
    Residual |  31.5724716    40   .78931179           R-squared     =  0.0834
-------------+------------------------------           Adj R-squared = -0.0311
       Total |  34.4466964    45  .765482142           Root MSE      =  .88843

------------------------------------------------------------------------------
chenitrate~v |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |  -.0005483    .004115    -0.13   0.895     -.008865    .0077683
    shedarea |   8.96e-06   8.66e-06     1.03   0.307    -8.54e-06    .0000265
          tc |   .0001095    .000767     0.14   0.887    -.0014407    .0016597
   housearea |  -8.39e-06   7.67e-06    -1.09   0.281    -.0000239    7.12e-06
  impervarea |  -.0000465   .0000521    -0.89   0.377    -.0001518    .0000587
       _cons |  -.2419513   .4389123    -0.55   0.585    -1.129026    .6451236
------------------------------------------------------------------------------

. regress chenitratedev salinity;

      Source |       SS       df       MS              Number of obs =      46
-------------+------------------------------           F(  1,    44) =    2.08
       Model |  1.55452618     1  1.55452618           Prob > F      =  0.1564
    Residual |  32.8921702    44  .747549323           R-squared     =  0.0451
-------------+------------------------------           Adj R-squared =  0.0234
       Total |  34.4466964    45  .765482142           Root MSE      =  .86461

------------------------------------------------------------------------------
chenitrate~v |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    salinity |   .0032074   .0022242     1.44   0.156    -.0012752      .00769
       _cons |  -.3918068   .2356026    -1.66   0.103    -.8666326     .083019
------------------------------------------------------------------------------

.
end of do-file

. exit, clear
```

Regression 2: Southside Pond

```
------------------------------------------------------------------------------
log:  C:\ProjectStata\project13aprilsouthside.log
  log type:  text
 opened on:  17 Apr 2003, 14:14:59

. use C:\ProjectStata\project.dta;

. keep if pond=="Frank Bay";
(37 observations deleted)

. regress do temperature salinity ph time;

      Source |       SS       df       MS              Number of obs =       9
-------------+------------------------------           F(  4,     4) =    7.50
       Model |  4316.1438     4  1079.03595            Prob > F      =  0.0383
    Residual |  575.364954    4  143.841239            R-squared     =  0.8824
-------------+------------------------------           Adj R-squared =  0.7647
       Total |  4891.50875    8  611.438594            Root MSE      =  11.993

------------------------------------------------------------------------------
          do |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 temperature |  -4.571521   8.642068    -0.53   0.625    -28.56575    19.42271
    salinity |  -1.900612   2.859993    -0.66   0.543    -9.841226    6.040002
          ph |   124.4793   110.5642     1.13   0.323    -182.4961    431.4548
        time |   .2856803   .0940362     3.04   0.038     .0245939    .5467667
       _cons |  -996.5271   654.8091    -1.52   0.203    -2814.569    821.5145
------------------------------------------------------------------------------

. regress ph temperature salinity;

      Source |       SS       df       MS              Number of obs =       9
-------------+------------------------------           F(  2,     6) =   27.87
       Model |  .129645339     2   .06482267           Prob > F      =  0.0009
    Residual |  .013954807     6  .002325801           R-squared     =  0.9028
-------------+------------------------------           Adj R-squared =  0.8704
       Total |  .143600146     8  .017950018           Root MSE      =  .04823

------------------------------------------------------------------------------
          ph |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 temperature |   .0568707   .0200608     2.83   0.030     .0077836    .1059577
    salinity |    .026355   .0035998     7.32   0.000     .0175465    .0351635
       _cons |   4.981731   .6521426     7.64   0.000     3.385995    6.577466
------------------------------------------------------------------------------

. regress nitrate do temperature turbidity;

      Source |       SS       df       MS              Number of obs =       8
-------------+------------------------------           F(  3,     4) =    1.18
       Model |  2.57950697     3  .859835655           Prob > F      =  0.4229
    Residual |  2.92018049     4  .730045123           R-squared     =  0.4690
-------------+------------------------------           Adj R-squared =  0.0708
       Total |  5.49968746     7  .785669637           Root MSE      =  .85443

------------------------------------------------------------------------------
     nitrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          do |   -.011465    .015485    -0.74   0.500    -.0544582    .0315283
 temperature |  -.9617579   .7942639    -1.21   0.293    -3.166988    1.243472
   turbidity |  -.3065709   .3843246    -0.80   0.470    -1.373627    .7604853
       _cons |   32.03211   24.25754     1.32   0.257    -35.31763    99.38184
------------------------------------------------------------------------------

.
end of do-file
. exit, clear
```