DEVELOPMENT OF A DAILY-BALANCE COMPUTER MODEL FOR ESTIMATING HYDRAULIC AND ELECTRICAL CONDUCTIVITY FOR SINGLE-STAGE ANAEROBIC SWINE LAGOONS

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NOMENCLATURE

$V_{(d)}$	Volume at the end of the day, ft^3
$V_{(d-1)}$	Volume at the beginning of day, ft^3
V_{in}	Volume entering into the lagoon, ft^3
V_{out}	Volume leaving the lagoon, ft^3
MW	Volume of manure and wastewater, ft^3
R	Volume of rain falling directly on the lagoon surface, ft^3
R_o	Volume of runoff, ft^3
E_l	Volume of evaporation from lagoon surface, ft^3
I	Volume of irrigated effluent, ft^3
R_c	Volume of recycle liquids, ft^3
S_p	Volume of seepage, ft^3
W	Lagoon top width, ft
L	Lagoon top length, ft
s	Lagoon sidewalls slopes, ft ft^{-1}
d	Lagoon total depth, ft
$h_{(d-1)}$	Lagoon operating level at start of the day, ft
$h_{(d)}$	Lagoon operating level at the end of the day, ft
S_a	Lagoon surface area, ft^2
P	Total daily precipitation, ft
R_a	Roof area, ft^2
C	Concrete area, ft^2
D	Soil or dirt area, ft^2

G	Grass area, ft^2
SWA_t	Total inner sidewalls area, ft^2
SWA_w	Wetted sidewalls area, ft^2
L_L	Length of the lagoon at operational liquid level, ft
W_W	Width of the lagoon at operational liquid level, ft
SD	Depth above the operational liquid level, ft
R_{sw}	Sidewalls runoff area, ft^2
Q	Rainfall excess, ft
S	Maximum soil water retention after runoff begins, ft
CN	Curve number
$CN_{I\ to\ III}$	Curve numbers for antecedent conditions I, II, and III.
M_v	Manure volume, ft^3
L_t	Liquid transport volume, ft^3
D_v	Waterer or drinking channel volume, ft^3
O_v	Other volumes, ft^3
N_a	Number of animals
A_a	Type of animals
f_a	Manure produced, ft^3
n	Number of pits or flush tanks of a given volume
P_v	Volume used to recharge pits, ft^3
F_r	Frequency between recharges, days
F_v	Flush tank volume, ft^3
F_d	Number of flushes per day
WW_v	Washwater volume, ft^3
F_c	Frequency of cleaning, days
N_c	Number of channels
R_c	Flow rate of water used per channel, $ft^3\,hr^{-1}$

$H_{c, m, dr}$	Operational hours for drinking channels, misters, and drippers, hr day^{-1}
B_r	Measured volume at the beginning of the channel, ft^3
F_d	Total amount of dry feed consumed daily, lbs day^{-1}
MI	Number of misters
R_w	Flow rate of water per mister or dripper after evaporation have been subtracted, ft^3 hr^{-1}
D	Number of drippers
S_w	Leaks and spillage volume, ft
PP_r	Fraction of pit volume recycled
PF_r	Fraction of flush volume recycled
v	Specific discharge rate, cm sec^{-1}
k	Hydraulic conductivity, cm sec^{-1}
d	Thickness of the liner material, ft
W_a	Wetted area at the operational liquid level, ft^2
B_a	Lagoon bottom area, ft^2
E	Evaporation rate from an open water surface, mm day^{-1}
Δ	Gradient of the saturated vapor pressure curve, Pa $°C^{-1}$
γ	Psychrometric constant, Pa $°C^{-1}$
R_n	Net radiation, MJ m^{-2} d^{-1}
G_w	Sensible heat exchange from the water, MJ m^{-2} d^{-1}
l_v	Latent heat of vaporization, J/kg
ρ_w	Water density taken as a constant value of 997 kg/m^3
k	von Karman's constant (k = 0.4)
ρ_a	Air density, kg m^3
p	Atmospheric pressure, kPa
u_2	Wind velocity measured at height z_2 m s^{-1}

z_0	Roughness height, cm
e_{as}	Saturated vapor pressure, Pa
e_a	Actual vapor pressure, Pa
T_c	Air temperature, °C
C_p	Specific heat of moist air at constant pressure, J kg^{-1} K^{-1}
α	Albedo number
R_s	Solar radiation, MJ m^{-2} d^{-1}
R_b	Net long-wave or thermal radiation for cloudy days, MJ m^{-2} d^{-1}
R_{bo}	Net outgoing long-wave radiation on a clear day, MJ m^{-2} d^{-1}
R_{so}	Solar radiation on a cloudless day, MJ m^{-1} d^{-1}
ε	Net emissivity of the surface
σ	Stefan-Bolzmann constant (4.903×10^{-9} MJ m^{-2} d^{-1} K^{-4})
T_k	Air temperature, °K
R_h	Relative humidity
EC	Electrical conductivity, dS m^{-1} or mg l^{-1}
$EC_{(d)}$	Mass of EC in the supernatant at the end of the day, lbs
$EC_{(d-1)}$	Mass of EC at the beginning of the day, lbs
EC_{in}	Mass of EC entering into the lagoon, lbs
EC_{out}	Mass of EC leaving the lagoon, lbs
EC_m	Mass of EC carryover in the manure, lbs
EC_{fw}	Mass of EC from freshwater, lbs
X_i	Mass of cation *i* entering with feed, lbs
ig	Ration ingredient (feedstuffs)
A_a	Type of animal
P_i	Percent of cation *i* in the dry feed
N_a	Number of animals
S_i	Soluble mass of cations flowing into the lagoon (lbs)

γ_i	Percent of feed cations in the excreted waste, %
σ_i	Soluble fraction of cations in lagoon supernatant, %
C_i	Soluble cation concentration, mg L^{-1}
EC_i	Supernatant EC, dS m^{-1}

CHAPTER 1

INTRODUCTION

1. 1 Statement of the Problem

As the result of the increase in swine production industry in Oklahoma during the 1990s, the number of complaints about odor emissions from swine operations began making news. Farmers aware of this situation have been asking for new treatment processes or modifications to existing systems that can easily be implemented in the facility to control odor emissions while minimizing operational cost. Researchers have reported that collecting and storing liquid manure, as in pit-recharge and lagoon systems, reduces levels of ammonia and hydrogen sulfide gas from the facility if the liquids are properly handled. Therefore, farmers should become familiar with the handling of liquids throughout the facility, and how changes to the actual liquid operation can improve the performance of the lagoon as a treatment system while recycling nutrients to the soil and minimizing odor emissions.

Poor liquid handling in the farm increases odor emissions from buildings and lagoon treatment systems and increases salt levels in the lagoon. Higher levels of salts cause detrimental effects in the performance of lagoons as treatment systems and in the soil and plant interface when lagoon effluent is irrigated for nutrient recycling. Increased salt levels above those recommended for anaerobic lagoons affect biological activity of anaerobic microorganisms which function to break down organic matter, resulting in the accumulation of partially digested organic matter and the emission of foul-smelling gases.

Lagoon design standards set by MWPS (1985), USDA-SCS (1992), and ASAE (1994), recommend that operators maintain lagoon liquid level between a maximum operational level (MOL) and a minimum drawdown level (MDL) for good performance. The treatment performance of the lagoon will be affected if the liquid level drops below the MDL resulting in less available volume to dilute incoming waste and a smaller volume than the design capacity. On the other hand, liquid level above MOL reduces the storm storage capacity which is designed to prevent liquids from overflowing during unexpected rainfall events.

The quantity of fresh water used for pits or flushtanks recharge can be greatly reduced and frequent irrigation can be minimized by recycling lagoon effluent. Although this practice reduces the operational cost involved in irrigation, the prolonged exposure of the lagoon to recycled effluent may adversely affect the biological activity in the lagoon, increase the rate of salts accumulation, and possibly lead toward buildup of crystalline materials in pumps and pipes of the recycle system (Westerman et al., 1985; Georgacakis and Samantouros, 1986).

Liquid handling practices are affected by variation in climatic conditions, especially rainfall and evaporation. Lagoons located in the eastern portion of Oklahoma are exposed to higher net rainfall minus evaporation; therefore, they are more likely to overflow without periodic irrigation. In the Oklahoma Panhandle, where negative net rainfall minus evaporation prevails, farmers have to add fresh water to compensate evaporation losses and to maintain lower salt concentrations.

To assist farmers with the problem of liquid handling, a computer program has been developed to balance materials flowing into and out of a single stage lagoon and estimate lagoon performance based on salt level.

1. 2 Objectives

The overall goal of this research was to develop a user-friendly mass-balance computer program that combines facility operation data and weather data to predict liquid level and effluent electrical conductivity. The computer program provides a step-by-step mode of inputting data that allows farmers to develop the best strategy of liquid. Good liquid management maximizes the performance of the lagoon as a treatment system and effluent storage structure. The specific objectives of this research were:

1. To develop and test a hydraulic model to predict, on a daily basis, the liquid level for a single cell lagoon.
2. To incorporate an electrical conductivity model of the lagoon supernatant into the hydraulic model.
3. To calibrate both models using the Oklahoma State University's Swine Research Center and historical weather data from the Mesonet station located in Stillwater, Oklahoma.
4. To validate both models using operational information from three facilities located in eastern, central and western Oklahoma.

1. 3 Scope of the Study

The model integrates all possible modes of liquid operation and waste collection found on swine production facilities in Oklahoma (Chapter 3). It is expected that farmers will use this program as a tool; therefore, the interactive language displayed in the program is self-explanatory to avoid misunderstanding data input and interpretation. Moreover, all inputs and outputs, except electrical conductivity, were expressed in the English system so farmers will be more familiar with the program environment.

Actual operational data from all the facilities involved in this research were used for calibration and validation of the model. This information was acquired from the four facility managers. Also, historical weather data from Mesonet stations were used in conjunction with on-site rain gage measurements. Uncertainty in the model output will always be present, but the magnitude is lowered if actual operational and weather data are used for the simulation. The simulation periods tested during the research were established by the availability of observed liquid levels, irrigation data, and electrical conductivity measurements.

CHAPTER 2

REVIEW OF LITERATURE

2. 1 Lagoon Mass Balance

Anaerobic lagoons are natural ecosystems. Their liquid storage capacity is constantly changing due to: the environment (e.g., rainfall and evaporation), the introduction of liquids from operational units, recycling of effluent, and application of effluent to soil as final receiver. In order to develop a liquid balance on treatment lagoons, all possible sources of material entering and leaving the systems should be considered. Casey (1995) described the increase in anaerobic lagoon volume due to manure loading, rainfall, and runoff and the reduction of volume by evaporation, seepage, and discharge.

The importance of developing liquid mass balance in lagoons is to provide operational alternatives for proper handling of excess or deficiency of liquids without affecting the lagoon performance. Anaerobic lagoon design standards have determined that the operational liquid levels should always be maintained within the effluent or storage zone (MWPS, 1985; USDA-SCS, 1992; ASAE, 1994). The upper and bottom sections of this zone are classified as the maximum operational level and minimum drawdown level, respectively. It is a potential pollution risk to allow liquid level to rise above the maximum operation level during any period because the excess of rainfall on top of the lagoon can overflow and contaminate receiving areas. On the other hand, if the liquid level falls below the minimum drawdown level, lagoons will not have enough available liquid volume to dilute incoming waste and to maintain a sufficient residence time (solid and hydraulic residence time) in the lagoon to achieve efficient treatment. In places where the net rainfall minus evaporation is negative all year around, it is more likely to find liquid levels below the maximum operation level. Special attention should be paid to the liquid operation in these lagoons. It may be necessary to add fresh water in order to maintain salt concentration within the recommended levels. Higher levels of inorganic salts affect the biological activity of anaerobic microorganisms in anaerobic lagoons (Georgacakis and Samantouros, 1986).

Lagoons have become an attractive treatment system for hog production primarily because they have a lower capital and operational cost than mechanical treatment systems. Lagoons allow the storage of nutrients in the treated and minimize the use of freshwater by recycling effluent for the storage pits and the flushing tanks. Booram et al. (1975) studied the convenience of using recycling effluent as the driving force for swine manure handling and transportation. They concluded that the use of hydraulic manure-transport system to recycle treated wastewater has reduced both the labor and the volume of liquid that must be discharged from the system. Others researchers have reported that if irrigation is the primary objective for lagoon storage, adequate fresh water volume must be periodically added to avoid accumulation of nutrients and inorganic salts which could injure crop production (Stewart and Meek, 1977; Sutton et al., 1982).

Anaerobic lagoon liquid level and effluent nutrient characteristics depend on the amount of wastewater entering into the lagoon. Inflow volume is a function of the type of hog production unit, type of waste collection and handling system, frequency and amount of washwater per cleaning event, water addition from spillage, recycling, irrigation, and climatic conditions, especially rainfall and evaporation (Sutton et al., 1980; Nordstedt and Baldwin, 1984; Payne et al., 1985; and Westerman, 1990). Excess liquids and nutrients in lagoons can be estimated by applying a mass balance on the material flowing in and out of the lagoon. Overcash et al. (1978) estimated the excess of liquids in swine lagoon by determining the wastewater and rainfall input to the lagoon minus the average Class A pan evaporation data. Casey (1995) used a computer program to determine long term nutrient composition on swine lagoons based on a mass balance approach and empirically derived relationships. Both investigations reported that rainfall and evaporation had a significant impact on lagoon performance.

Two climatic conditions of concern in terms of liquid operation are rainfall and evaporation. Observation of the historic weather pattern for a specific location can help farmers obtain better understanding of what should be the operational liquid level. Normal variation of the water balance during the year requires that lagoon water level to be lowered in the fall to provide storage for winter and spring rains (Barth et al. 1990). Humenik et al. (1980) concluded that lagoons overflow in high moisture regions and possibly can have periodic discharges regardless of geoclimatic location and waste management practices. In regions where evaporation exceeds rainfall in a series of dry years, lagoons should be partly drawn down and refilled to dilute excess concentrations of nutrients and minerals (USDA-SCS, 1992).

2. 2 Evaporation from Water Surface

Evaporation is a significant component in the hydraulic balance when a large quantity of water evaporates from the lagoon surface to the atmosphere. Evaporation from water surfaces has been widely studied since the early part of the 20th century. Thanks to the development of instrumentation to measure physical weather phenomena, a number of different approaches to estimate evaporation has been developed using measurable meteorological data. One of the classic works in this area was conducted by Penman (1948) in which he introduced an empirical equation to estimate evaporation combining both aerodynamic and energy factors from standard meteorological data. Many investigators, including Penman, continued to expand the theory of the combination equation since 1950 with emphasis on the aerodynamic aspect. A modification of the original combined equation replaces the linear vapor transfer with a more theoretical vapor transfer function (Jensen 1990). The combination equation of estimating potential evaporation from meteorological data is the most accurate method when all the required data are available and the assumptions are satisfied (Chow, 1988). The required climatological data for combined equation includes net radiation, air temperature, humidity, and wind speed (Jensen 1990).

Evaporation from anaerobic lagoons should be compared with lake evaporation instead of pan evaporation because the large surface area and liquid volume of the lagoon stores absorbed radiation as heat over extended time periods. Heat absorbed during daytime in a Class A pan is lost during night. Farnsworth et al. (1982) explained the relationship between pan evaporation, free water surface evaporation, and lake evaporation. Pan evaporation is the observed evaporation rate at a standard National

Weather Service (NWS) Class A pan installation. Free water surface (FWS) evaporation was defined as "evaporation from a thin film of water having no appreciable heat storage". FWS is considered to be approximately equivalent to potential evaporation from a shallow water surface. Lake evaporation may differ significantly from FWS evaporation during a given month because of changes in heat storage in the water body. It is generally thought that on an annual basis the FWS evaporation and the lake evaporation are about the same.

A simple method to estimate lake evaporation is to multiply Class A pan evaporation by a factor of 0.70, but this factor varies with seasons and locations (Farnsworth et al., 1982). The Class A pan evaporation values tend to overestimate the total amount of evaporation and distort the seasonal distribution of large water bodies due to differences in thermal characteristics (ASCE, 1996). When the water in the pan is warmer than the air, the coefficient is greater than 0.70, and vice versa. During winter, when snow and ice cover the water surface in the pan, the tendency for most locations is to use lower coefficients that those for summer months (Jones, 1991).

An alternative to reduce variations in evaporation values from Class A pans and wastewater holding ponds was studied by Pratt et al. (1975). The results from their investigation indicated an average coefficient between the floating pan and the lined pond of 0.98 and between the land pan and the pond of 0.73. The close relationship between evaporation from the pond and from the floating pan also indicated that the physical properties of the liquids in the pond and the freshwater in the floating pan possessed similar evaporation characteristics. Based on this finding, similar values of the albedo number for water can be applied to treatment lagoons. Approximate mean albedo values for deep water are between 0.04 - 0.08 (Brutsaert, 1982).

Most evaporation equations that use an energy balance assume that temperature of the water is constant in time and that the change in stored heat is only the change in the internal energy of the water evaporated. However, the value of heat storage over the entire period may be significant, especially for periods of 30 days or longer. The exclusion of energy storage limits the application of the combined method to daily time intervals or longer, and to situations not involving large heat storage capacity, such as a large lake possesses (Chow, 1988).

For evaporation over very large areas, energy balance considerations largely govern the evaporation rate (Chow, 1988). The magnitude of heat stored in the lagoon is insignificant during short periods (e.g., 24 hrs.) but is notable during longer periods (e.g., seasons of the year). In moderate climates such as Oklahoma's, heat is stored in lagoons during spring and is released during fall and winter months. In order to estimate evaporation on a daily basis using the combined equation, the energy storage factor from the energy balance must be adjusted based on reported ratios of energy storage (G_w) and net radiation (R_n). The seasonal lag in water bodies can be expected to produce higher ratios of G_w/R_n in spring than in fall months with equivalent solar or net radiation amounts (ASCE, 1996).

Lake evaporation in Oklahoma generally increases from southeast to northwest across the state. This variation in evaporation is attributed to the differences in climatic regions from humid in the extreme east to dry in the Panhandle. The average annual lake evaporation ranges from 48 inches in the eastern section to as high as 68 inches in the

Panhandle region. The pan coefficients for the conversion to lake evaporation range from 0.69 in the Panhandle to around 0.73 along the eastern border.

2. 3 Lagoon Seepage

The liquid fall rate from earthen basins is also related to the potential removal of liquid through the lagoon sidewalls and bottom floor to underground soils, as well as evaporation. Initial liquid removal by seepage varies because of physical characteristics and properties of the soil liner, type of liquid waste, and biological transformation of the organic matter in lagoons. Many investigators have concluded that microbial action and/or fine organic material generally clogs soil pores in the soil barrier of lagoons making then effectively "self-sealing" (Barrington and Jutras, 1983). These fine materials, under the hydraulic pressure of the liquid manure will penetrate into the soil macropores causing reduced hydraulic conductivity and in turn reduced seepage (Ghaly et al., 1988).

Barrington and Jutras (1985) determined that when the soil bottom and sidewalls of manure storage ponds and lagoons have a moderate to fine-textured soil (such as silt clay loam or clay), the final permeability coefficient is usually on the order of magnitude of 10^{-6} to 10^{-7} cm/sec. Moreover, the hydraulic conductivity can decrease up to 10^{-10} cm/sec depending on the level of construction quality (Hootkany et al., 1994).

2. 4 Sources of Inorganic Salts

Manure is the major source of inorganic salts in lagoons. Inorganic salts are generally fed to hogs in quantities higher than the daily minimum value. While this practice may not harm the animals, it has a serious consequence on the manure handling system. Researchers have identified three operational problems caused by higher levels of inorganic salts in lagoons. These problems are the crystalline struvite (magnesium ammonium phosphate $MgNH_4PO_4$-$6H_2O$) buildup in pumps and pipes, reduction in biological activity in the lagoon, and salt buildup in irrigated soils. Although the addition of fresh water for the dilution of high levels of salts in lagoons has been suggested by many researchers and lagoon designers, an equally effective solution is to control the excess of salt added in the hog diet. However, letting the lagoon liquids evaporate over long periods results in an increase in salts concentration regardless of the salt loading level from manure.

The functions of dietary minerals are extremely diverse. Rea et al. (1990) indicated that at least 20 inorganic elements are required in the swine diet. These include sodium, potassium, calcium, magnesium, phosphorus, chlorine, sulfur, iron, zinc, copper, manganese, iodine, and selenium. There are other minerals required by pigs in very small amounts for which the dietary essentiality has not been demonstrated (NRC, 1979).

Recommended dietary levels of minerals for pigs vary from farrowing sows to finish hog. The differences are primarily due to the animal's diet, age, usage, and productivity (Rea et al., 1990). Levels of inorganic minerals are based on the minimum requirement to achieve production performance. However, these recommended levels are sometimes altered by the producer, whose primary goal is to maximize the conversion of feed into meat products in a short time and to produce large numbers of healthy pigs.

Swine production is an industry which produces a large volume of concentrated waste that contains high levels of mineral salts, heavy metals, and antibiotics (Overcash et al., 1978). The use of high levels of dietary feed containing inorganic cations must be considered both in terms of the swine uptake efficiency and the further presence of these cations in lagoon supernatant and land as terminal receiver. Researchers have found that the excess amounts of inorganic elements in diets which are not retained in the animal body are excreted in the urine and feces (Sutton et al. 1976; Golz and Crenshaw, 1991). Therefore, the environmental impact of these cations can be repressed by controlling the excess given in the formulated rations.

Although hog diets contain significant amounts of inorganic salts, only those that represent a potential hazard to lagoons and crops will be considered in this discussion. These are: sodium, calcium, potassium, and magnesium.

Sodium is the most important extracellular cation in the swine body. Sodium is routinely added as a sodium chloride (NaCl) supplement. Recommended levels for boars, pregnant females, and lactating females are between 0.25 % to 0.50 % (5 to 10 lbs per ton of feed) (NRC, 1979). Hagsten and Perry (1976) showed that sodium excretion increased when salt levels above 0.14% (2.8 lbs per ton of feed) were added to swine growing-finishing diets. Similar results were also found by Sutton et al. (1976) in which the waste from pigs fed with 0.5% salt contained higher sodium levels than waste from pigs fed with 0.2% salt.

Potassium is an important mineral involved in electrolyte balance and neuromuscular function and serves as a monovalent cation to balance anions intracellularly, much as sodium functions extracellularly. The daily potassium requirements to farrowing-finishing pigs range between 0.17 % to 0.30 %, much less than the percent available in a diet containing only soybean meal or rice (NRC, 1979).

Calcium is of major importance for skeletal development and for many other physiological functions like blood clotting and muscle contraction (NRC, 1979). For maximum performance, an optimum daily dietary level of calcium between 0.75 % to 0.90 % is suggested for bred, gilts, lactating sows, and young and adult boars. Most natural ingredients commonly used to prepare swine diets are almost devoid of calcium. Corn-soybean meal diets and sorghum grain-soybean meal diets must therefore be supplemented with calcium. Luce et al. (1990) reported that the standard sources supplying supplemental calcium in swine diets are limestone ($CaCO_3$) and dicalcium phosphate ($CaHPO_4$) with 38 % and 20 % respectively.

Magnesium requirements for swine are around 0.04% (NRC, 1979). Grain and soybean meal ingredients generally contain up to 0.42% of magnesium, sufficient to prevent deficiency signs. The magnesium will always be present in excess in the feed since the amount of these ingredients is formulated as an energy and protein source but not as a mineral source. Jones et al. (1990) mentioned that higher levels of these cations are commonly found since the rations are usually over-fortified as insurance against variations in feeds and requirements.

Excretions of excess inorganic salts can alter microbiological activity during waste treatment and subsequently have an adverse environmental effect if accumulated on land over a long term. The fraction of these excreted cations depends on several factors that include the animal physiology as well as the presence or absence of some minerals that can interact to alter the excretion or retention of other minerals. The percentages of inorganic salts carried over in the feces and urine from feed input have been determined by using a mass balance analysis of the material fed and wastewater flows from a large growing unit (Overcash et al., 1978), and by analyzing the composition of feed intake and excreted portion (Meyer et al., 1950; Mayo et al., 1959; Hansard et al., 1961; Hagsten et al., 1976; and Golz and Crenshaw, 1991). The percentages of feed sodium, calcium, potassium, and magnesium carried over into manure are given in Table 2.1.

Table 2. 1. Percent of feed cations excreted in manure.

Cations	Percent excreted, %	
Na^+	66[1]	60 - 81[2]
Ca^{2+}	55[1]	40 - 74[3]
K^+	60[1]	55 - 60[4]
Mg^{2+}	74[1]	60 - 75[5]

[1] Overcash et al, (1978).

[2] Golz and Crenshaw, (1991) and Meyer et al. (1950).

[3] Hansard et al. (1961).

[4] Golz and Crenshaw, (1991) and Overcash et al. (1978).

[5] Mayo et al. (1959).

Increasing attention has been taken toward modification of existing cation-anion balance in diets to increase retention of certain minerals. Golz and Crenshaw (1991) found that excessive levels of chloride or sulfate ion in diets increased the potassium requirement, thus lowering its amount excreted. The amount of sodium carryover in the feces and urine was approximately 60 % for NaCl levels between 0.2 % and 0.5% (Golz and Crenshaw, 1991) and 81% or higher when NaCl content is above 0.8 % (Meyer et al, 1950). Approximately sixty percent of K^{+} intake was found in manure (Golz and Crenshaw, 1991 and Overcash et al., 1978). Hansard et al. (1961) reported that the total fecal calcium excretion increased with increasing calcium levels (0.70 to 1.2 % calcium intake), weight, and age. Levels of potassium and magnesium ranged from 0.5 % to 0.65 % and 0.40 % to 0.50 %, respectively.

An estimate of the excreted quantity of these cations in fresh feces and urine, based on the total live weight, is given by ASAE (1994) standards. Variations from actual values are possible due to the differences in the feedstuffs used and the level of minerals in formulating the diets.

Not all the cations entering the lagoon remain in the supernatant. The sludge layer contains a significant portion of the chemical and physical elements commonly used to describe the lagoon performance (Fulhage, 1980). Many authors have described the distribution of cations in anaerobic lagoons (Booram et al., 1975; Overcash et al., 1978; Fulhage, 1980; Barth and Kroes, 1985). The mean fraction of cations distributed in the liquid layer of a mature lagoon is given in Table 2.2. This table shows that sodium and potassium are more strongly associated with the liquid layer than magnesium and calcium. The distribution of cations in the sludge or liquid depends on parent compound solubility and the tendency of ionized cations to form chelates with organic matter. Soluble salt content is influenced by dilution of the organic waste with water (Steward and Meek, 1977). Salts with low solubility will release less ions into solution at higher effluent electrolyte concentrations. Special attention should be paid toward materials in solution because they are the most toxic to biological activity.

Table 2. 2. Percent of base cations entering a lagoon found in the liquid portion.

Cations	Overcash[1] %	Fulhage[2] %	Barth and Kroes[3], %	Average %	Standard Deviation, %
Na^+	76	60	50	62	13
Ca^{2+}	20	38	28	29	9
K^+	76	77	50	68	15
Mg^{2+}	64	40	52	52	12

[1] Overcash et al. (1978).
[2] Fulhage, (1980).
[3] Barth and Kroes, (1985).

Values reported by Overcash et al. (1978) were used in the model due to the similarities in the type of operation used in Oklahoma. The similarity included the type of waste collection system, feedstuff composition, and lagoon sizing.

2. 5 Cation Effect on Biological Activity

It is desired to avoid the toxicity of salts in lagoons to achieve higher treatment efficiencies and to maximize the nutrient uptake by plants without affecting the soil-plant interface. Methods to control salt toxicity include solids separation and the addition of fresh water to dilute the concentration of salts. Most swine facilities do not use solids separation because of the required labor and capital cost; therefore, it is assumed the total daily mass of earth-metal salts such as sodium, potassium, calcium or magnesium excreted by hogs will be collected and transported to the lagoon.

Most of the cations that are present in swine waste can be tolerated by anaerobic lagoons at certain concentrations. While anions are always present with cations in lagoons, it is the cations which normally contribute to the toxicity problem (Georgacakis and Sievers, 1979). The concentration of sodium, potassium, calcium, and magnesium that may be stimulatory or inhibitory to the biological activity of methane-forming bacteria in anaerobic digestion processes and their order of toxicity have been intensively investigated by McCarty and McKinney (1961), Kugelman and McCarty (1964), and Kugelman and McCarty (1965). The methane bacteria exhibited the same basic response to the presence of cations as all other organisms. In most organisms, divalent cations were found to be significantly more toxic than monovalent cations; however, the relative toxicity of divalent versus monovalent cations to methane producing organisms was rather unusual. Results from these investigations can be applied to anaerobic lagoons where the complete conversion of digested solids depends on this group of bacteria.

McCarty (1964) described the effect of salt additions on anaerobic digester systems in this manner: initially, small additions of salt stimulate bacterial activity, with the stimulation peaking from a fraction of 1.0 mg/L for heavy metal salts to over 100 mg/L for sodium or calcium salts. A further increase in salt concentration beyond the optimum level causes a decrease in bacterial activity until the rate of reaction equals that of the original environment before salts were added. Further increases in salt concentration beyond this point result in a continuing decrease in activity due to increasing toxicity. Table 2.3 shows the concentration effect of base cations on bacterial activity in anaerobic digestion.

Table 2. 3. Stimulatory and inhibitory concentrations of base cations on digester performance.

Cation	Stimulatory mg/L	Moderate Inhibitory, mg/L	Strongly Inhibitory, mg/L
Na^+	100 - 200	3,500 - 5,500	8,000
K^+	200 - 400	2,500 - 4,500	12,000
Ca^{2+}	100 - 200	2,500 - 4,500	8,000
Mg^{2+}	75 - 150	1,000 - 1,500	3,000

[1] Mc Carty, 1964.

The toxic effects of these cations, however, vary widely from organism to organism, and certain species can tolerate much higher concentrations than others. Cations play an important role in the metabolism of all organisms. They possess a nutritional function by virtue of the fact that many cations serve as metallic activators for a wide variety of enzymes. Kugelman and McCarty (1965) studied the cation toxicity on methane producing organisms and their stimulation in anaerobic waste treatment. They have found that when the concentration of the cation increases from zero, more enzymes are activated and the reaction rate increases. However, all the enzymes are activated eventually and the excess cation then reacts with an enzyme for which it is not the metallic activator. This results in a decrease in the reaction rate.

Another important aspect found is that when combinations of these cations are present in solution, the nature of the effect becomes more complex as some of the cations act antagonistically, reducing the toxicity of other cations, while other act synergistically, increasing the toxicity of the other cations (McCarty and McKinney, 1961; Kugelman and McCarty, 1965; Georgacakis and Sievers, 1979).

It is clear than an effort must be made to adjust the cation concentrations in an anaerobic lagoon as much as possible toward the optimum concentration for each cation. With knowledge of the concentration of these cations an evaluation of the lagoon can be made and corrective measures be taken. This implies periodic collection of samples from the lagoon supernatant for laboratory analyses. Further research has shown that electrical conductivity measurements from lagoon supernatant can be used as a field tool in measuring the effect of salt accumulation on biological activity in livestock lagoons (Georgacakis and Sievers, 1979 and Georgacakis and Samantouros, 1986).

2. 6 Electrical Conductivity and Lagoon Performance

Ideally, it is desirable to know the individual solute concentrations in the lagoon supernatant, as well as the lagoon performance and effluent suitability for irrigation, without need for collection of samples or laboratory analyses. To date, such determination is possible by relating biological, physical, and chemical characteristics of anaerobic lagoons with electrical conductivity (EC) or conductivity measurements (Stewart and Meek, 1977, Fulhage et al., 1978, and Payne et al., 1985).

In anaerobic lagoons and other water or wastewater sources, electrical conductivity is related to the concentration of total dissolved salts. The concentration of salts in swine waste that is readily dissolved depends on several physiological factors of the animal and the amount and composition of the feed. Excess salt in the feed is excreted by animals and contributes to the dissolved salts in the lagoon; therefore, the greater the excess of salts in the animals' diet, the greater the lagoon supernatant EC.

Measurements of conductivity are used as a convenient method to estimate the performance of the lagoon in terms of biological activity and the amount of nutrients available for land application. EC is a parameter which can be determined quickly and easily in the field.

EC measurements may be used to estimate nutrient composition. Fulhage et al. (1978) has found that a conductivity meter could be used to evaluate nitrogen concentration for swine and dairy lagoons in Missouri. Sutton et al. (1980) showed good correlation between EC and each of three parameters: TKN, ammonium nitrogen (NH_4-N), and COD. Similar results were also found by Payne et al. (1985) and Westerman et al. (1990) in which EC measurements from lagoon supernatant were correlated with total nitrogen, ammonia, potassium, and phosphorous.

Work by Georgacakis and Sievers (1979) showed an excellent correlation between EC and gas production in anaerobic digesters. They showed that EC values between 4 and 8 dS/m were considered optimum for anaerobic digestion. EC in this range was shown to stimulate bacterial activity with a peak stimulation occurring at an EC value of 6.5 dS/m. EC between 10 and 13 dS/m caused a large reduction in digestion efficiency. EC levels higher than 13 dS/m rapidly increased toxicity, resulting in a 90 percent inhibition of gas production at 33 dS/m.

The application of effluent to irrigated land adds an additional source of salt beside that from the irrigation water. Guidelines on lagoon effluent application have been developed to assure that soil EC does not accumulate excess salt from manure. High soil salinity interferes with the ability of the plant to absorb water from the soil and to exchange plant nutrients. Slight limitation for effluent application exists to soil EC below

8 dS/m. Above values of 8 dS/m, plant growth is affected except for all but the most tolerant crops (USDA-SCS, 1992). Salt accumulation occurs most often when a moisture deficit is predominant. Under these conditions, farmers must add fresh water to dilute the concentration of salt in the lagoon and irrigate more frequently to disperse salt build up and avoid plant injury. If lagoon effluent is not diluted with fresh water, farmers must reduce the application rate so rainfall can dissipate the high concentration of salts in the soil.

CHAPTER 3

METHODOLOGY

3. 1 Description of the Model

This model was developed on a daily time step to simulate lagoon elevation, volume, surface area, and supernatant conductivity. The program uses historical Mesonet data to determine volume of rainfall and runoff entering the lagoon and evaporation leaving the lagoon. Operational data supplied by the farmer includes lagoon dimensions, all possible sources of liquid from the operational units, and how the liquids are handled through the facility.

Many empirical relationships were combined in the model to estimate lagoon evaporation, runoff, and seepage. Some equations were developed to calculate lagoon volume, surface area, elevation, inner lagoon walls area, and electrical conductivity loading. A complete description of the development of the hydraulic and electrical conductivity balance follows.

Mass-Balance Analysis

The fundamental approach used to determine the change in liquid storage occurring in the lagoon is a mass-balance analysis. The change in storage is equal to the mass flow entering minus the mass flow leaving the lagoon:

$$\Delta S = input - output \tag{3.1}$$

Consider the lagoon shown in Figure 3.1. An envelope is drawn to show the system boundary established so that all the flows of mass into and out of the system can be identified. Mass flow into the lagoon can be identified as manure, wastewater, and rainfall. Outputs are identified as evaporation, irrigation, and seepage.

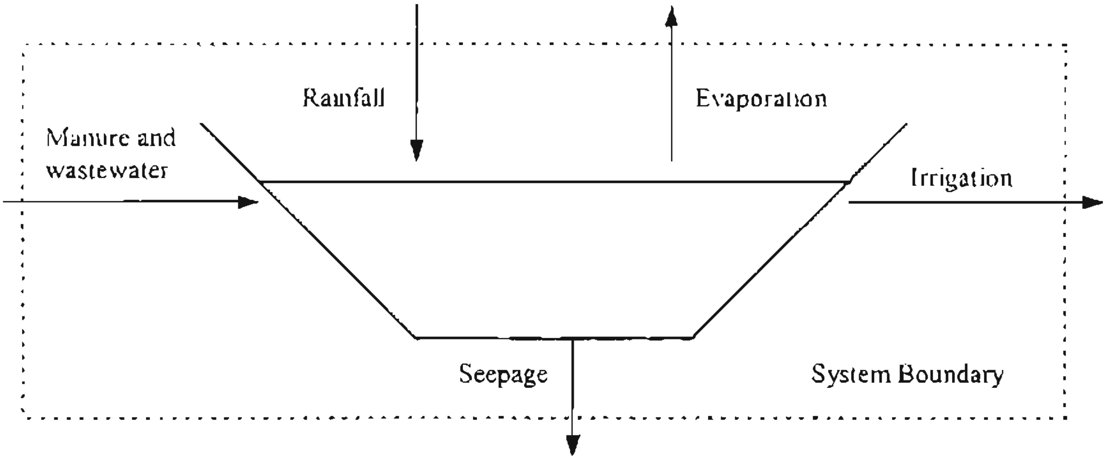


Figure 3. 1. Sketch of a lagoon for the application of mass-balance analysis.

Incoming manure and wastewater volume is determined from the number of animals in the facility and the capacity of the waste collection system and other liquid handling systems. Other information related to operational procedure such as irrigation and recycling is obtained from record books or by personal communication with facility managers. Rainfall entering and evaporation leaving the lagoon is determined from the Mesonet data. EC balance is determined once the lagoon liquid volume is estimated because the addition or removal of liquids will change the composition of EC in the lagoon.

3. 2 Hydraulic Balance

Liquid Data Analysis

Volume of manure and wastewater entering into the lagoon depends on the type and size of unit operation as well as the type of liquid waste handling system. It is important to become familiar with all possible sources of liquids flowing into the lagoon because they will determine the total load of wastewater.

Many complex liquid pathways must be taken into account to model both the hydraulic and salt (EC) balance in the lagoon. Possible input sources of wastewater from different types of hog production facilities using single cell lagoons for waste treatment and storage are illustrated in Figure 3.2.

Not all the waste generated inside the building enters the lagoon. The volume of manure from the operational units changes if a solids separation process precedes the lagoon. If the manure is exposed to solar radiation, the volume of manure will be reduced by evaporation. Also, evaporation may reduce the volume of wastewater from drippers and misters before it drains into the underfloor pits or gutters. Therefore, the model users should subtract these losses from the total calculated volume, otherwise the model will overestimate the actual lagoon elevation.

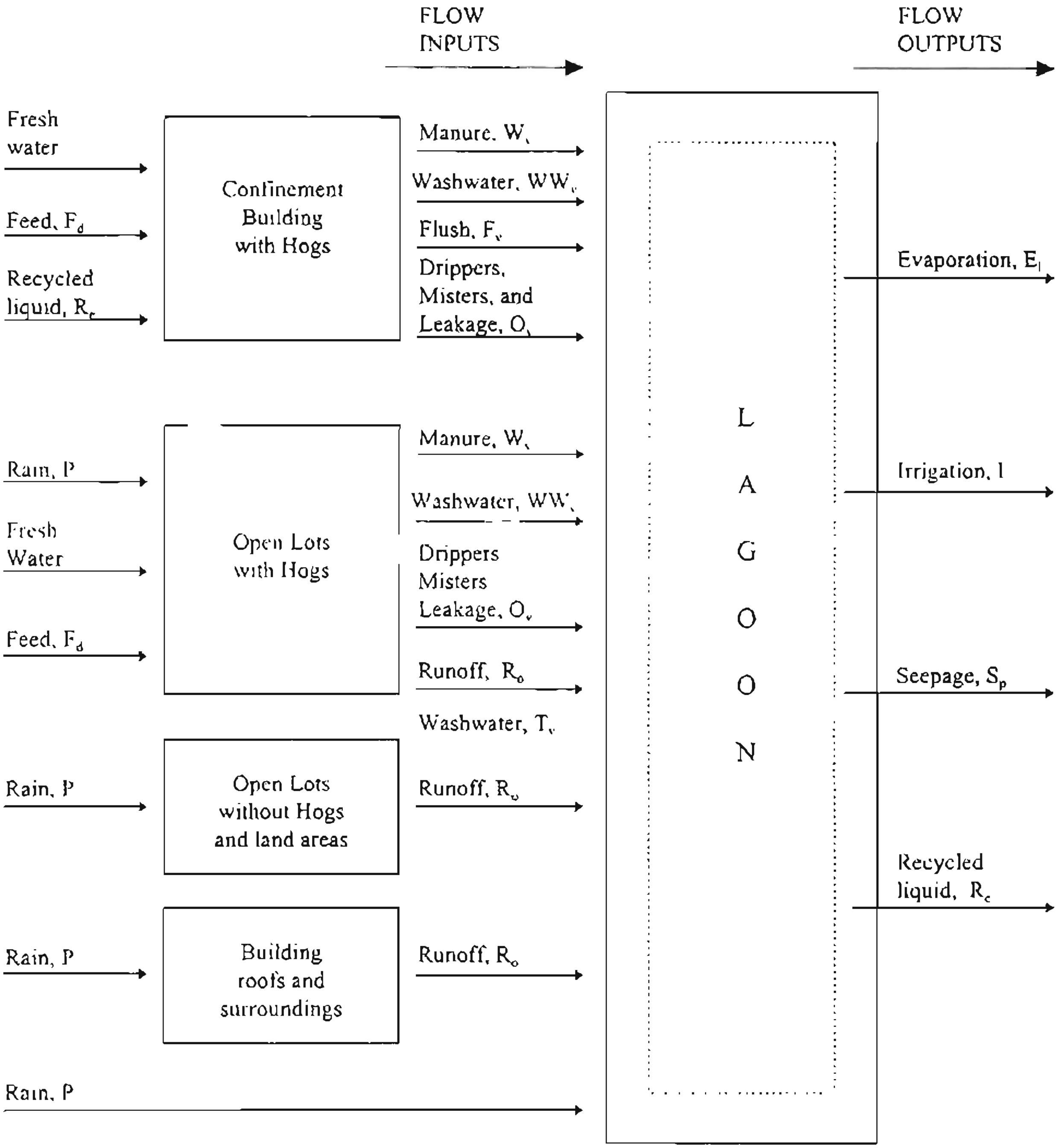


Figure 3. 2. Mass flow of liquids for hog farms with single-stage lagoon.

A model based on a mass balance approach (Equation 3.1) was used to determine volume into and out of the lagoon on a daily time step. This relation can be shown mathematically as:

$$V_{(d)} = V_{(d-1)} + V_{in} - V_{out} \tag{3.2}$$

where $V_{(d)}$ is the volume at the end of the day (ft^3), $V_{(d-1)}$ is the volume at the beginning of the day (ft^3), V_{in} is the volume entering into the lagoon (ft^3), and V_{out} is the volume leaving the lagoon (ft^3).

The volume flowing into the lagoon is divided into the following components:

$$V_{in} = MW + R + R_o \tag{3.3}$$

where MW is the volume of manure and wastewater (ft^3), R is the volume of rain falling directly on the lagoon surface (ft^3), and R_o is the volume of runoff (ft^3).

Likewise, the volume leaving the lagoon is divided as follows:

$$V_{out} = E_l + I + R_c + S_p \tag{3.4}$$

where E_l is the volume of evaporation (ft^3), I is the volume of irrigation (ft^3), R_c is the volume of recycled liquid (ft^3), and S_p is the volume of seepage (ft^3).

The model uses the equation for a rectangular lagoon to solve for the water level at any time using the following procedure:

$$V_i = w*l*h + s*h^2(w+l) + \frac{4}{3}s^2h^3 \tag{3.5}$$

$$w = W - 2s*d \tag{3.6}$$

$$l = L - 2s*d \tag{3.7}$$

$$\Delta V = V_{(d)} - V_i \tag{3.8}$$

$$h_i = h_{(d-1)} + h_{(d-1)}\left({\Delta V}/{V_{(d)}} \right) \tag{3.9}$$

$$\Delta h = ABS(h_i - h_{(d-1)}) \tag{3.10}$$

where W is the lagoon top width (ft), L is the lagoon top length (ft), s is the lagoon side-walls slopes (ft/ft), d is the lagoon total depth (ft), $h_{(d-1)}$ is the lagoon operating level at start of the day (ft), and $h_{(d)}$ is the lagoon operating level at the end of the day (ft).

Volume of the lagoon at the end of the day $V_{(d)}$ is given in Equation 3.2. This volume is compared with the volume at the beginning of the day $V_{(d-1)}$ and the difference between the two volumes is used to calculate h_i (Equation 3.9). Thus, the value of h_i is substituted in Equation 3.5 to get a new estimate of $V_{(d)}$ called V_i. When ΔV (now $V_{(d)}$ - V_i) is very small, h is equal to h_i. This procedure (Equations 3.5 to 3.10) is repeated until Δh (Equation 3.10) is less than 0.0001 ft (h and h_i are statistically identical).

Once the lagoon level has been determined, lagoon surface area, S_a, is calculated using the equation,

$$S_a = w*l + 2s*h(w+l) + 4s^2h^2 \tag{3.11}$$

Daily Hydraulic Input

a) Rainfall

The rainfall volume, R, is the total amount of rainfall falling on the lagoon surface and is calculated from,

$$R = P * S_a \tag{3.12}$$

where P is the total daily precipitation (ft). Daily precipitation data are obtained from the nearest Mesonet station or on-site rain gage.

b) Runoff

Rainfall may also enter lagoons as runoff from the freeboard area of the lagoon sidewalls, building roofs, and land areas draining into the lagoon. Runoff from the sidewalls and land areas is estimated using the Soil Conservation Service curve number method (Schwab et al. 1981). The land areas are divided into soil, grass, and concrete areas. Rainfall falling on roofs is assumed to flow directly to the lagoon. Daily runoff was calculated using Equations 3.13 through 3.17:

$$R_u = R_a * P + C * Q + D * Q + G * Q + R_{sw} * Q \tag{3.13}$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}, P > 0.2S \tag{3.14}$$

$$S = \frac{83.33}{CN} - 0.8333 \tag{3.15}$$

$$SWA_t = \left[(L+W)2d\sqrt{s^2+1}\right] + 4\left[sd\sqrt{d^2+(sd)^2}\right] \qquad (3.16)$$

$$SWA_w = \left[(L_L+W_W)2h\sqrt{s^2+1}\right] + 4\left[sh\sqrt{h^2+(sh)^2}\right] \qquad (3.17)$$

$$L_L = L-(2s*SD) \qquad (3.18)$$

$$W_W = W-(2s*SD) \qquad (3.19)$$

$$SD = d-h \qquad (3.20)$$

$$R_{sw} = SWA_T - SWA_w \qquad (3.21)$$

where R_a is the roof area (ft^2), C is the concrete area (ft^2), D is the dirt or soil area (ft^2), G is the grass area (ft^2), Q is the rainfall excess (ft), S is the maximum soil water retention after runoff begins (ft), CN is the curve number varying from 0 to 100, SWA_t is the total sidewalls area (ft^2), SWA_w is the wetted sidewalls area (ft^2), L_L is the length of the lagoon at operational level (ft), W_W is the width of the lagoon at operational level (ft), SD is the depth above the operational liquid level (ft), R_{sw} is the sidewalls runoff area (ft^2). A runoff curve number of 93, 88, and 85 was selected for the lagoon sidewalls, dirt and grass areas, respectively.

The CN is not constant; it might change because of abstraction from rainfall dependent on the antecedent conditions that exist at the time a rainstorm occurs (Haan et al., 1994). Three curves numbers have been defined based on 5-day antecedent rainfall. The selected curve numbers is for antecedent condition II which is the average value from sample rain and runoff data. Table 3.1 gives the condition number for 5-day antecedent rainfall for dormant and growing seasons (Schwab, 1981).

Table 3. 1. CN for 5-day antecedent rainfall (in.)

Dormant Season	Growing Season	Curve Number for Condition
< 0.51	< 1.42	I
0.51 - 1.10	1.42 - 2.08	II
> 1.10	> 2.08	III

Curve numbers for antecedent conditions I and III can be estimated using the following equations taken from Haan et al. (1994),

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \tag{3.22}$$

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}} \tag{3.23}$$

where CN_I, CN_{II}, and CN_{III} are the curve numbers for antecedent conditions I, II, and III, respectively.

c) Manure and Wastewater Volume

The total volume of manure and wastewater is broken into manure volume (M_v), liquid transport volume (L_t), waterer or drinking channel volume (D_c), and other volumes (O_v), all with units of ft^3.

$$MW = M_v + L_t + D_c + O_v \tag{3.24}$$

Daily manure volume is calculated by the number of animals and the volume of manure generated according to their classification. Data on the volume of waste from different types and sizes of hogs are summarized in Table 3.2. Waste produced includes both fresh feces and urine (Hamilton et al. 1997).

Table 3. 2. Volume of waste produced per animal.

Animal (A_a)	Volume of waste per animal (f_a) (ft^3/day)
Boar (*B*)	0.13
Gilt (*G*)	0.13
Gestating and Sow (*GS*)	0.13
Sow and Litter (*SL*)	0.41
Nursery (*N*)	0.06
Growers (*GR*)	0.10
Finisher 125-175 (F_{175})	0.13
Finisher 175 - 250 (F_{250})	0.15

The total manure volume for any farm with different types of animals is calculated using the following equation,

$$M_v = \sum \left(N_a * A_a * f_a \right) \tag{3.25}$$

where N_a is the number of animals, A_a is the type of animal, and f_a is the manure produced (Table 3.2).

d) Liquid Transport Volume

The transport volume is the daily volume of liquids required to flush gutters, recharge pits, and clean floors. Farmers do not use a specific amount of cleaning water every day; therefore, an average volume was calculated from the frequency of cleaning, time spent cleaning and the flow rate of cleaning equipment. The frequency of cleaning and flushing should be known in order to calculate the daily transport volume.

$$L_t = \sum_n \frac{P_v}{F_f} + \sum_n F_v * F_d + \frac{WW_v}{F_c} \tag{3.26}$$

where L_t is the transportation volume (ft^3), n is the number of pits or flushtanks of a given volume, P_v is the volume used to recharge pits (ft^3), F_r is the frequency between recharges (days), F_v is the flush tank volume (ft^3), F_d is the number of flushes per day, WW_v is the washwater volume (ft^3), and F_c is the frequency of cleaning (days).

e) Waterer or Drinking Channels Volume

Some facilities use drinking channels instead of automatic waterers. Drinking channels are automatically controlled by timers. The mode of operation is per cycles of fifteen or thirty minutes every two or one and a half hours. With this information the operator can calculate the total hours per day that drinking channels are in operation.

$$D_c = N_c * R_c * H_d \tag{3.27}$$

where N_c is the number of channels, R_c is the rate of water used per channel (ft^3/hr), and H_d is the hours used per day (hr/day). It is recommended to measure R_c at the end of the channel. If the flow rate is measured at the beginning of channel (e.g. distribution line), the amount consumed by the animal must be subtracted using the following equation,

$$R_c = B_f - F_d * 0.056 \tag{3.28}$$

where, B_f is the measured volume at the beginning of the channel (ft^3) and F_d is the amount of dry feed consumed daily (lbs/day). According to NRC (1979), pigs drink approximately 0.056 cubic feet of water per pound of dry feed consumed.

f) Other Volume

This includes the volume of water used for evaporative cooling through misters and drippers, water lost through broken pipes, and other sources of wasted water.

$$O_v = \left(MI * R_w * H_{mi}\right) + \left(D * R_w * H_{dr}\right) + S_w \tag{3.29}$$

where MI is the number of misters, R_w is the rate of water used per mister or dripper after evaporation has been subtracted (ft^3/hr), D is the number of drippers, H_{mi} and H_{dr} are the hours used per day of misters and drippers, respectively (hr/day), and S_w is the leaks and spillage volume (ft^3). Wastewater evaporation from the misters is higher than drippers because the surface area covered is larger in the misters.

Daily Hydraulic Output

a) Irrigation Volume

Treated wastewater from lagoon supernatant is periodically removed for irrigation of adjacent land. The irrigation volume, I, removed at any time is entered directly into Equation 3.4 to calculate the new volume and depth of the lagoon. The irrigation frequency and volume data were obtained directly from the farmer.

b) Recycled Liquids

Farmers often recycle the treated effluent back to the facility through the flushing system to reduce fresh water usage and to decrease the total volume of lagoon storage. The model uses the following reasoning to calculate recycle volume:

$$R_c = P_v * PP_r + F_c * PF_r \tag{3.30}$$

where R_c is the recycle volume (ft^3), PP_r is the fraction of pit volume recycled, and PF_r is the fraction of flush volume recycled.

c) Seepage

Lagoon seepage is determined following Darcy's Law. Darcy (1856), found that the flow of water through a porous media, such as soil, is related to the head loss across the porous media. USDA-NRCS (1993) uses the following equation to calculate specific discharge rate from earthen lagoons:

$$v = k\frac{h + d}{d} \tag{3.31}$$

where v is the specific discharge rate (cm/sec), k is the hydraulic conductivity (cm/sec), and d is the thickness of the liner material (ft). The model uses a default value for d of 1.5 because this is the minimum recommended thickness for soil liners construction for lagoon treatment systems.

The seepage of the lagoon is calculated by multiplying the cross-sectional area of the flow by the specific discharge rate. The cross-sectional area is determined from the wetted area at the lagoon operational level. Lagoon seepage is calculated using the following equation,

$$S_p = W_a * v \tag{3.32}$$

$$W_a = \left[(L_L + W_W)2h\sqrt{s^2 + 1}\right] + 4\left[sh\sqrt{h^2 + (sh)^2}\right] + B_a \tag{3.33}$$

$$B_a = w * l \tag{3.34}$$

where W_a is the wetted area at the operational level of the lagoon (ft^2) and B_a is the lagoon bottom area (ft^2).

d) Evaporation

Anaerobic lagoon evaporation was estimated by the combined aerodynamic and energy balance method developed by Penman (1948). This method combined components to account for a supply of radiation energy and a mechanism required to remove the vapor away from the immediate proximity of the evaporation surface. The original equation uses an empirical lineal equation for wind, which in practice accounts for the ability to transport vapor away from the surface. Researchers have adapted a more theoretical vapor transfer function based on a wet surface with zero resistance to vapor transfer (Jensen et al., 1991). The resulting equation to estimate evaporation from a water surface is:

$$E = \frac{\Delta}{\Delta + \gamma}\left(\frac{R_n - G}{l_v \rho_w}\right) + \frac{\gamma}{\Delta + \gamma}\left(\frac{0.622 k^2 \rho_a u_2}{p \rho_w \left[ln\left(\frac{z_2}{z_0}\right)\right]^2}\right)\left(e_{as} - e_a\right) \tag{3.35}$$

where E is the evaporation rate from an open water surface (mm/day), Δ is the gradient of the saturated vapor pressure curve (Pa/°C), γ is the psychrometric constant (Pa/°C), R_n is the net radiation (MJ/m^2d), G is the sensible heat exchange from the water (MJ/m^2d), l_v is the latent heat of vaporization (J/kg), ρ_w is the water density taken as a constant value of 997 kg/m^3, k is the von Karman's constant (k = 0.4), ρ_a is the air density (1.19 kg/m^3), p is the atmospheric pressure (101.3 kPa), u_2 is the wind velocity measured at height z_2 (m/s), z_0 is the roughness height (0.003 cm)(Brutsaert, 1982), e_{as} is the saturated vapor pressure (Pa), and e_a is the actual vapor pressure (Pa).

The slope of the saturation vapor pressure curve, Δ, is usually calculated at the mean daily temperature (Chow, 1988).

$$\Delta = \frac{4098 e_{as}}{\left(237.3 + T_a\right)^2} \tag{3.36}$$

where T_c is the air temperature in °C.

The psychrometric constant, γ, represents a balance between the sensible heat gained from air flowing past a wet bulb thermometer and the sensible heat transformed into latent heat (Chow, 1988),

$$\gamma = \frac{C_p p}{0.622 l_v} \tag{3.37}$$

where C_p is the specific heat of moist air at constant pressure (C_p = 1005 J/kg K).

The latent heat transfer is the dominant cause of internal energy change for water (Jensen et al., 1990). The latent heat of vaporization varies slightly with temperature changes according to,

$$l_v = 2.501x10^6 - 2370T_c \tag{3.38}$$

i. Energy Balance Method

Energy balance considerations largely govern the evaporation rate from large open water surface areas (Chow, 1988; Jensen et al. 1990; Jones, 1991). The main source of heat energy is the solar radiation (R_s) which supplies the energy input for the latent heat of vaporization to an open water surface. The source of heat energy in the water is the net radiation (R_n) which requires measurements or estimates of both incoming and reflected short wave radiation and net long-wave radiation (e.g. incoming and outgoing solar radiation) (Jensen, 1991). When solar radiation strikes on the water surface, it is either reflected or absorbed. The portion of the incoming radiation that is reflected back by the water surface into the atmosphere is measured by the albedo (α) with values ranging between 0 and 1. Part of the solar radiation that is absorbed by the water surface is emitted back as long-wave radiation.

It is possible to estimate R_n from R_s since R_n is the net input of radiation at the surface, that is, the difference between short-wave and long-wave components of the radiation,

$$R_n = (1-\alpha)R_s - R_b \tag{3.39}$$

where $(1-\alpha)R_s$ is the radiation absorbed by the water and R_b is the radiation emitted (MJ/m^{2}d). Measurements of albedo number for deep waters was used in the model to calculate R_n. Albedo values for deep water range between 0.04 to 0.08 (Brutsaert, 1982). A default albedo number of 0.05 was chosen for the model.

The net long-wave radiation for clear skies or for partly cloudy conditions can be adjusted from solar radiation data as shown in the following equation (Jensen et al., 1990).

$$R_b = \left[a\frac{R_s}{R_{so}} + b \right] R_{bo} \tag{3.40}$$

where R_b is the net long-wave or thermal radiation for cloudy conditions (MJ/m^{2}d), R_{bo} is the net outgoing long-wave radiation on a clear day (MJ/m^{2}d), the coefficients a and b are given in Table 3.3, and R_{so} is the solar radiation on a cloudless day (MJ/m^{2}d).

Table 3. 3. Coefficients for net long-wave radiation.

Region	a	b
humid area	1.0	0
arid area	1.2	-0.2
semi-humid area	1.1	-0.1

The coefficients a and b are determined for the climate of the region of interest. This set of values for each region was considered in the model since the climatic conditions in Oklahoma vary from the humid southeast to the dry northwest Panhandle. Jensen et al. (1990) recommends these coefficient values for these three types of climatic conditions. Estimates of R_{so} by month and latitude are given in Table 3.4.

Table 3. 4. Mean solar radiation for cloudless skies (R_{so}) for Oklahoma.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
14.95	19.55	24.58	29.31	32.11	33.49	32.95	30.14	25.25	20.52	15.91	13.52

The net outgoing long-wave radiation on a clear day can be estimated by the Stefan-Boltzmann law,

$$R_{bo} = \epsilon \sigma T_k^4 \qquad (3.41)$$

where ε is the net emissivity of the surface, σ is the Stefan-Bolzmann constant (4.903 x 10^{-9} MJ m^{-2} $d^{-1}K^{-4}$), and T_k is the temperature in degrees Kelvin.

The net emissivity, ε, was calculated using the Idso-Jackson equation (Jensen et al., 1990),

$$\varepsilon = -0.02 + 0.261 \exp\left[-7.77x10^{-4}\left(T_r\right)^2\right] \tag{3.42}$$

Values of energy storage are usually neglected when dealing with smaller periods of time but may be significant over longer periods. It is expected that G will regularly change due to changes in net radiation. Therefore, the energy storage in the lagoon can be approximate during each month by the following expression,

$$G_w = R_n * f_{es} \tag{3.43}$$

where G is the energy storage (MJ/m^{2}d) and f_{es} is the energy storage factor ($0 < f_{es} < 0.5$). Values for f_{es} were adjusted during the model calibration (Chapter 4) and the results are given in Table 3.5.

Table 3. 5. Adjusted f_{se} for lagoon evaporation.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
0.40	0.38	0.36	0.32	0.30	0.24	0.12	0.10	0.05	0.01	0.05	0.30

ii. Aerodynamic Method

The second factor controlling the evaporation rate from an open water surface is the ability to transport vapor away from the surface (Chow, 1988; Jensen, 1991). The transport rate is governed by the humidity gradient in the air near the surface and the wind speed across the surface (Penman, 1948). The saturation vapor pressure, e_{as}, is the maximum moisture content the air can hold for a given air temperature. Over a water surface, the saturation vapor pressure is related to the air temperature (Penman, 1948). A convenient expression for estimating saturation vapor pressure (e_{as}) is (Chow, 1988):

$$e_{as} = 611\exp\left(\frac{17.27T_r}{237.3 + T_r}\right) \tag{3.44}$$

The actual vapor pressure (e_a) is calculated from relative humidity data. The relative humidity (R_h) is the ratio of the actual vapor pressure to its saturation value at a given air temperature.

$$e_a = R_h * e_{as} \tag{3.45}$$

The required climatic data for the evaporation equation obtained from Mesonet stations includes solar radiation (R_s) , air temperature (T_c), relative humidity (R_h), and wind speed (u_2). Evaporation losses from the lagoon surface are calculated by multiplying evaporation obtained from Equation 3.35 times the lagoon surface area, S_a.

$$E_l = E * S_a * t_l \tag{3.46}$$

where E_l is the volume of liquid evaporated from the lagoon (ft^3) and t_c is a conversion factor equal to 3281×10^{-6}.

3. 3 Electrical Conductivity Balance

A daily time step model was developed to balance the electrical conductivity measurements in the lagoon supernatant. Total EC was treated in the same manner as a single inorganic salt in order to calculate the mass flowing into the lagoon; thus, the units of EC (dS/m) were substituted with mg/L.

$$EC_{(d)} = EC_{(d-1)} + EC_{in} - EC_{out} \tag{3.47}$$

where $EC_{(d)}$ is the mass of EC in the supernatant during the day (lbs.), $EC_{(d-1)}$ is the mass of EC at the beginning of the day (lbs.), EC_{in} is the mass of EC entering into the lagoon (lbs.), and EC_{out} is the mass of EC leaving the lagoon (lbs.).

Daily EC Input

The mass of EC that enters to the lagoon is a function of the soluble inorganic salts from the manure (EC_m) and the contribution from fresh water (Ec_{fw}):

$$EC_{in} = EC_m + EC_{fw} \tag{3.48}$$

The first step in developing EC_m was to correlate the EC of the lagoon supernatant with inorganic salts in the feed found as soluble in the supernatant. The cations making up these inorganic salts are sodium, calcium, potassium, and magnesium. A regression equation was developed from the correlation analysis to estimate the EC_m loading to the lagoon.

Supernatant samples from the lagoons at the OSU Swine Research Center and at the validation sites were analyzed for sodium, calcium, potassium, magnesium, and EC (Table F.1). A statistical analysis was performed to determine the correlation between the four cations and the supernatant EC. Among the four cations, potassium had the greatest correlation with EC, followed by sodium, magnesium, and calcium. All possible combinations were analyzed to determine any significant difference among them. The coefficient of determination (r^2) in Table F.2 indicates that higher correlation with EC exists when two and three cations were combined ($r^2 = 0.94$). The regression equations of the combinations with the highest r^2 are given in Table 3.6. The selection of the equation for estimating EC loading depends on the availability of the feedstuff composition required to estimate the soluble portion of these cations in the lagoon supernatant.

Table 3. 6. Regression equation of EC versus soluble cations (mg/L).

Equation for EC estimation	r^2	Equation No.
$-6.15 + (C_a*0.07) + (M_g*-0.013) + (K*0.01) + (Na*0.01)$	0.94	3.49
$-6.93 + (C_a*0.07) + (Na*0.013) + (K*0.01)$	0.94	3.50
$-5.35 + (C_a*0.06) + (M_g*-0.017) + (K*0.01)$	0.94	3.51
$-6.22 + (C_a*0.06) + (K*0.01)$	0.93	3.52
$-6.94 + (C_a*0.08) + (M_g*-0.01) + (Na*0.03)$	0.91	3.53
$-7.62 + (C_a*0.08) + (Na*0.01)$	0.91	3.54

The total mass of Na^+, K^+, Ca^{+2} and Mg^{+2} entering into the lagoon can be estimated if the composition of the feedstuffs in the diets, the number of animals, and the pounds of feed consumed are known. If X_i is any of the four cations, then the daily mass of cations entering the lagoon can be calculated using the following equation:

$$X_i = \sum_{ig}^{A_a} F_d * P_i * N_a \tag{3.55}$$

where X_i is the mass of cation *i* in feed (lbs), *ig* is the type of ingredient, A_a is the type of animal, F is the daily dry feed intake per animal (lbs/day), P_i is the percent of cation *i* in the dry feed, and N_a is the number of animals.

The percent of cation *i* in the dry feed, P_i, of only those feedstuffs used in the diets involved in this research are given in Table 3.7. For a complete list of ingredients please refer to NRC (1979) or Feedstuffs (1994).

Table 3. 7. Inorganic salt content in feed ingredients.

Ingredients	International Food Number	Ca^{2+} %	Na^+ %	K^+ %	Mg^{2+} %
Bio-phos		16	0.05	0.06	0.5
Calcium Carbonate		38	0.06	0.06	0.5
Dicalcium phosphate		20	0.08	0.07	0.6
Corn Yellow	4-02-935	0.01	0.03	0.33	0.15
Corn-ground	4-02-849	0.04	0.01	0.45	0.13
Soybean meal 48%	5-04-612	0.2	0.04	1.9	0.27
Rice bran	4-26-201	0.1	0.07	1.35	0.95
Wheat middlings	4-05-205	0.15	0.6	0.6	0.29
Fish Meal	5-02-009	5	0.34	0.72	0.14
Whey, dried	4-01-182	0.87	2.5	1.2	0.13

The soluble mass of *i* that flows into the lagoon, S_i, is estimated from literature-based values.

$$S_i = X_i * \gamma_i * \sigma_i \tag{3.56}$$

where γ_i is the percent of feed cations excreted in the waste and σ_i is the soluble fraction of individual cation in lagoon supernatant. Values of γ_i and σ_i are given in Tables 2.1 and 2.2, respectively.

The soluble cation concentration (C_i) used in the selected regression equation from Table 3.6 is calculated as follows,

$$C_i = \frac{S_i t}{MW} \tag{3.57}$$

where C_i has units of mg/L and *t* is a scaling factor equal to 15,993 mg/l.

The mass of EC that enters to the lagoon and remains in the supernatant is estimated by,

$$EC_m = \frac{EC * M_v}{t} \tag{3.58}$$

where EC_m is the mass carryover from the waste (lbs/day) and EC is the result from the selected regression equation (mg/l).

The mass of EC_{fw} can be estimated by measuring the EC of fresh water, which takes into account the soluble salts. Therefore, the soluble mass entering to lagoon is calculated as follows:

$$EC_{fw} = \frac{EC_w * (L_t + D_r + O_v)}{t} \tag{3.59}$$

where EC_w has actual units of dS/m, but is input as mg/L.

The supernatant EC, EC_s, is calculated using the volume of the lagoon and the EC at the end of the day:

$$EC_l = \frac{EC_{(d)}t}{V_{(d)}} \tag{3.60}$$

where EC_l has units of dS/m.

Daily EC Outputs

The sole method of EC output considered by the model is removal through irrigation. The removal of EC through pumpdown of the lagoon liquid fraction is given by,

$$EC_{out} = \frac{I * EC_l}{t} \tag{3.61}$$

CHAPTER 4

MODEL CALIBRATION

4. 1 Description of the Calibration Site

The model was developed and calibrated using operational and management information, and lagoon characteristics of the OSU Swine Research Center located in Stillwater, Oklahoma. The facility is primary used by OSU's College of Veterinary and the Animal Science Department to conduct physiological and nutritional studies. Throughout the years the facility has undergone numerous physical changes caused by an increase in the number of hogs produced. This increase caused an expansion in the number of buildings and in the size of a single-stage anaerobic lagoon. Manure and wastewater generated in the operational units of the facility are collected in several different types of waste collection systems which include pits, gutters and scraped floors. From the collection systems the manure and liquids are transported by gravity to the lagoon. Lagoon effluent was not recycled or land applied during the research period (summer 1996 to summer 1997). A more detailed description of the facility is given in Appendix A.

Several advantages of using this facility for the model calibration were: the easy access to operational information from the facility manager, routine inspection of the waste handling systems, periodic observation of lagoon liquid level, electrical conductivity measurements, and rain gage data, and the vicinity of the Mesonet Station located at the OSU Agronomy Farm less than one mile north of the swine barn.

Unit Size and Waste Collection Management

There are a total of five operational units including three confined and two semi-confined buildings. A total of 370 confined animals are located in the nursery, farrowing and growing units, and 416 semi-confined animals are located in two finishing floors (Figure A.1). An additional 200 gestation sows are housed on pasture which runoff is diverted from the lagoon. Only waste generated in the confined and semi-confined units is considered in the model calibration. Additional volume sources are the runoff from a small soil area and from the semi-confined unit.

Different building sizes and waste collection methods are used in the confined unit. Each unit was carefully inspected with the facility manager to gather information on the number of animals and the operation and management of the wastewater throughout the system. An overall inspection of the research farm was conducted on June 2, 1996. The number of animals by type and the daily amount of manure produced are given in Table A.1.

The nursery unit has four rooms with an average population of 168 pigs weighing 35 pounds. Manure and wastewater are collected in two under-slat-floor pits per room. The top dimensions of the pits are 4.92 feet wide by 28 feet long with a longitudinal bottom slope of 0.4% (Figure A.2). The pits' concrete bottom is sloped toward a small deep gutter. A free board of two inches is left between the alley floor and the maximum accumulated manure and wastewater level.

Only three rooms are used on the average. The fourth room is left idle for disinfection before receiving the weaning pigs. The pits used in this facility are "pull-plug" types which require the operator to manually drain the pits. The frequency of pulling the plugs and recharging the pits with fresh water is every one and a half weeks. Water used to clean the alleys and wasted feed are collected in the pits.

An on-line water meter was installed before the distribution of water to the nursery rooms to determine the amount of fresh water used to recharge the pits and to clean the floors. Meter readings were taken from January 14, 1997 to July 18, 1997 (Table A.2). During 186 days the volume of fresh water used to recharge the pits and clean the floors was 47,120 gallons, thus the daily usage was 34 ft^3. The recharged volume was calculated from the top pit dimensions and a half inch of water added after drainage. Since there are two pits per room, the pit capacity for recharged liquids and for accumulated wastewater is 33 ft^3 and 69 ft^3, respectively.

The farrowing unit has two narrow rooms with a maximum number of 25 sows and litters. Manure and wastewater are collected on the sloped floor with a long gutter in the south side. The gutter allows the continuous drainage of urine to the lagoon. The concrete floor is periodically scraped and it is entirely cleaned with hose water every month.

The growing building houses up to 200 hogs. Manure and wastewater are collected in slatted floor gutters. Two gutters on each side of the building are automatically flushed twice per day with fresh water. A fiber glass flush tank with capacity of 840 gallons is used to flush each gutter. Flush water is collected in a small sump located at the discharge end of the flushing gutter. From the sump the waste drains by gravity to the lagoon. Daily volume of flushwater required to clean the gutters is 224 ft^3.

There are two finishing units located nearly the lagoon with a total capacity of 410 finishing hogs. The southwest unit (#5 in Figure A.1) is larger with a total area of 4,782 ft^2 and a total of 238 hogs weighing more than 175 lbs. The unit located in the southeast is smaller with a total concrete area of 1,216 ft^2. It houses 172 hog weighing between 125 to 175 lbs. The southwest and southeast units will henceforth be known as finishing 1 and finishing 2, respectively. Waste from these semi-confined open concrete lots is manually scraped and washed with a water hose full opened twice per week. Other sources of wastewater from these units includes liquids from the misters and runoff from the concrete floor and building roof. Manure and wastewater are collected in a gutter located in the lower end of the concrete floor, from which they are transported by gravity to the lagoon.

The daily volume of waste produced in finishing 1 and 2 may be lower than that given by Hamilton et al. (1997) for finishing hogs. When the manure is accumulated in the concrete floor and exposed to outdoor environmental conditions, ambient factors such as solar radiation and wind will considerately change the manure composition, especially the moisture content. Researchers have found that the percent of moisture in manure is about 92 percent on an as-is basis but much lower when the manure is exposed to sunny conditions. Therefore, a conservative factor of one third was applied to the manure volume factor for finisher hogs in Table A.1.

Wastewater Loading

The sources of wastewater found during the inspection were the liquids from the misters and washout water used to clean the units. Drinking water in all units is controlled by automatic waterers which minimizes the amount of wasted freshwater. The flow rate of each water hose located in every unit was measured with a five-gallon bucket. The frequency of cleaning and the operational timing of the mister was obtained form the facility manager.

There are 29 misters in the finishing units that normally work during summer or when the air temperature reaches 85 °F. The timing and operation of the misters is manually controlled and operated up to five hours per day. The pipe that supplies water to the misters is connected to the same water hose used for cleaning, but the flow rate is controlled to avoid excess of wasted water. However, several misters in both units are broken, producing a larger volume of wastewater. Five misters from each unit were selected to determine the average flow rate. The average flow rate including both units was 5.7 gallons per hour. Thus, the daily volume of water from the misters is 110.2 ft^3.

Some amount of water is evaporated from the concrete floor before it reaches the lagoon. Based on an average evaporation value during summer of 0.20 inches and an effective wet area of 4,000 ft^2, the amount of wasted water that enters to the lagoon is reduced to 77 ft^3 or 30 % of the previous amount.

Washout water was determined from the frequency of cleaning and the hose water flow rate when full opened. The information regarding the frequency of cleaning and the time spend cleaning was provided by the facility manager. The average flow rate in each unit and washout volume is given in Table A.3.

According to Table A.3, a total of 62 ft^3 of fresh water is used daily to hose down waste from the concrete floors. A large amount of water is used to clean the nursery and the finishing I units. Washout water from the nursery room was determined by subtracting the pit recharge fresh water to the average wasted volume from Table A.2. The frequency of cleaning the farrowing and finishing units are once every month for 8 hours and twice per day for one hour, respectively. A summary of all the daily wastewater loading for the unit operations is given in Table 4.1.

Table 4.1. Manure and wastewater volume inputs for OSU Swine lagoon.

Manure Volume			
Animal	*No of each*	*Vol. Waste (ft^3/day-hd)*	*Total (ft^3/day)*
Boar	5	0.13	0.65
Sow + Litter	22	0.41	9.02
Nursery	168	0.06	10.1
Grower 50 - 125 lbs	181	0.10	18.1
Finisher 125 - 175 lbs	172	0.04	7.45
Finisher 175 + lbs	238	0.05	12.0
		Total manure volume	57.3
Flushwater			
Tank	*Vol. of tank*	*Frequency of Flush*	*Total (ft^3/day)*
1	840 gal.	2 days	224
Pit Recharge Water			
Tank	*Vol. of tank*	*Frequency of Pulling*	*Total (ft^3/day)*
1	33 ft^3	10.5 days	3.14
2	33 ft^3	10.5 days	3.14
3	33 ft^3	10.5 days	3.14
		Total pit recharge volume	9.42
Washout Water			
Unit			*Total (ft^3/day)*
Farrowing			9
Nursery			25
Finisher 125 - 175 lbs			7
Finisher 175 + lbs			21
		Total washout water	62
Misters			
No. of misters	*Water use*	*Frequency (hr/day)*	*Total (ft^3/day)*
29	4 gal/hr	5	77
Total Manure and Wastewater Loading			**430 ft^3/day**

Lagoon Survey

The purposes of the lagoon survey were to determine the actual top dimensions of the lagoon, the lagoon's depth and sludge depth. To accomplish this task, it was required to use several tools and instruments including surveying equipment, a sidewinder (lagoon sampler), a T-probe (depth), and a boat. The surveying equipment, lagoon sampler and the boat were available at the OSU Biosystems and Agricultural Engineering Laboratory. The T-probe was built in the laboratory.

The survey equipment used during the research was taken from the Biosystems Engineering Shop. The sidewinder, built 14 years ago, was used to take representative samples of one liter of sludge or supernatant from any desired depth in the lagoon. The sidewinder sampler functioned in excellent fashion taking discrete samples of supernatant and sludge (Hamilton and Rosser, 1994). The T-probe with scale of a hundredth of a foot was built with angular aluminum of 0.5 inches to each side and a longitudinal distance of 25 ft. The T-probe was built in three sections to allow handling during the transportation to the facility and on the boat. The sidewinder mechanism and T-probe are based on a design developed at Clemson University to study sludge characterization of different lagoons (Barth and Kroes, 1985).

A 10-foot aluminum boat was used to collect depth data and supernatant samples. A wood base was built and installed on the back of the boat to support the sidewinder. Two snap links were installed in one side of the boat, one located in the front and the other one in the back. The snap links were used to slide through a 3/8-inche rope to facilitate the linear movement across the lagoon. A wing nut was installed in the middle of the boat to tighten the rope and maintain the boat's position more stable during sampling. The rope was marked every ten feet to record the location of the samples and the depth measurements. When the boat was in operation, the person in the back of the boat operated the T-probe and the sidewinder while the other person recorded data and balanced the boat.

The single-cell anaerobic lagoon consists of two lagoons connected together by removing the bank between them, resulting in an "L" shaped lagoon as illustrated in Figure A.1. The first single-cell lagoon was excavated in early 1940 and had top dimensions of 190 feet wide by 190 feet long by 13.5 feet deep with a 3:1 (horizontal : vertical) side slope. Over the years the facility increased its operation, thus loading rate increased to a point which exceeded the lagoon capacity. In 1992, a new lagoon was built adjacent to the existing lagoon. The new lagoon area has a top width of 301 feet and length of 185 feet with side slopes of 3:1. The original lagoon with an surface area of 0.72 acres was expanded to 2 acres, with an effluent storage capacity of 48 acre-in.

The lagoon was surveyed on May 17, 1996. The top dimensions of the lagoon are given in Figure A.3. The bench mark was located in the southeast corner of the finishing 1 unit. The elevation survey data of the lagoon and an illustration of the areas surveyed are given in Table A.4 and Figures A.4 and A.5. The lowest point of the lagoon embankment is located in the northeast side of the lagoon and has a height of 13.5 ft from the bottom of the lagoon. Different areas around the top of the embankment were surveyed to determine the total depth of the lagoon which is 15.30 ft.

The lagoon was divided into five transects to determine the lagoon and sludge depth every 10 feet from offshore and to measure the electrical conductivity of the supernatant (Figure A.4). These transects were located at 0 + 50 ft, 1 + 00 ft, 1 + 75 ft, 2

+ 75 ft, and 3 + 25 ft from the east side of the lagoon. The measured elevation data of each transect are given in Tables A.5 to A.9 and are summarized in Table A.10.

A finding during the survey was the presence of a small dam of approximately 4.02 ft high between the existing and new lagoon (Figure A.5). Apparently the west bank of the existing lagoon was not completely removed during the construction. Therefore, if the water level drops below 4.02 ft, the lagoon top will exhibit two separate rectangular lagoons with different dimensions.

According to Table A.10, between 3.20 ft to 3.12 ft of sludge thickness was measured in the first two transects of the original lagoon. Since both outfalls are located in this section, the dam will retain most of the incoming solids, allowing small amounts of lighter particles to be deposited on the bottom of new lagoon. These two sides of the lagoon will henceforth be known as the sludge and clear sides.

A second lagoon survey was performed on May 26, 1997 to determine the new sludge depth and to measure the electrical conductivity. Two transects, one in the sludge side and one in the clear side, were located at 0 + 66 ft and 2 + 54 ft from the east bank. Depth measurement and average values are given in Tables A.11 to A.13. The sludge thickness in the sludge side was higher than the previous measurement. A summary of the sludge thickness for 1996 and 1997 is presented in Table A.14. During 375 days of operation the sludge thickness increased 1.11 ft and 0.17 ft in the sludge and clear side, respectively.

Sludge volume from the lagoon bottom flat and side slopes was calculated from a modification of Equations 4.5 and 4.7. The average sludge thickness value from the side slopes and from the bottom was used to calculate the total volume of sludge. Side slopes sludge thickness data are given in Table A.15. An effective side slope depth of 7 ft and 8 ft was used to determine the side slope area where sludge is accumulated. Not much sludge was accumulated on the side banks of the clear side. The calculated sludge volume on both sides during the research period was 35,304 ft^3 as given in Table A.16.

The sludge accumulation rate was calculated based on 375 days of operation and a daily total solids production of 593.08 lbs TS (Table A.1). Based on this information the accumulation rate is calculated as 0.1587 ft^3/lb TS-d. This value is much higher compared with the average accumulation rate of 0.0486 ft^3/lb TS-d found by Barth and Kroes (1985) for swine operations. One factor that could have led to this higher rate of sludge accumulation is the runoff loading from the dirt or soil area (Figure A.1.).

4. 2 Development of Equations for the Hydraulic Balance

Several equations were specially developed for this lagoon because of the unique shape and fixed dimensions. Two details were considered to develop the equations: a) The presence of a small dam between the existing and the new lagoon, which yields less available storage for liquids and the presence of two lagoons if the water level is below 4.02 ft and b) A fixed runoff area above the lowest embankment. The developed equations were used to calculate the lagoon volume, surface area, and sidewalls area. The following is a description of how these equations were developed.

Lagoon Volume and Surface Area

The lagoon was divided into three areas to determine the surface area and the total volume (Figure A.6). The dotted lines divided the lagoon bottom into three rectangular sections. The dam was not included in the equation that calculate the overall volume capacity.

Equations 3.6 and 3.7 were used to calculate the bottom dimensions with two side slopes. For single side slope the following equations were used:

$$l = L - s * d \tag{4.1}$$

$$w = W - s * d \tag{4.2}$$

The area of the three rectangular bottom sections are given in Table A.17. These equations were developed using a total lagoon depth of 15.30 feet. The surface area of the lagoon was determined by summing the area of each rectangular section from Table A.17, resulting the following equation:

$$SA_{ol} = 42324 + 3066h + 45h^2 \tag{4.3}$$

where SA_{ol} is the surface area of the lagoon (ft^2). The integration of this equation gives the total lagoon volume of the lagoon without the dam.

$$VOL_{ol} = 42324h + 1533h^2 + 15h^3 \tag{4.4}$$

where VOL_{ol} is the volume of the lagoon (ft^3).

To estimate the volume of the dam, the lagoon was divided into the existing and the new lagoon resulting two rectangular sections, as illustrated in Figure A.7. Table A.18 shows the surface area equation developed for the two rectangular sections. Both equations were combined and integrated to determine the volume of the lagoon at 4.02 ft high.

$$VOL_{I\&II} = 34688h + 1506h^2 + 24h^3 \tag{4.5}$$

where $VOL_{I\&II}$ is the volume of both lagoons (ft^3).

The volume occupied by the dam was estimated by subtracting Equation 4.5 to 4.4 at h equals to 4.02 ft, resulting a volume of 30,549 ft^3 (195,891 ft^3 - 165,342 ft^3). Therefore, the equation used in the model to calculated the actual volume of the lagoon at any depth above 4.02 ft is:

$$VOL_I = (42324h + 1533h^2 + 15h^3) - 30549 \tag{4.6}$$

Plots of the volume and surface area of the lagoon versus depth (Equations 4.3 and 4.6) are given in Figures A.8 and A.9. A minimum of one foot of freeboard, one foot of a 25-yr, 10 days storm and 0.5 ft of runoff depth is included above the maximum operating level. The maximum volume capacity and surface area of the lagoon at 13.5 ft is 857,120 ft^3 (236 acre-in) and 90,000 ft^2 (2 acres), respectively. The actual treatment volume of the lagoon is 83 acre-in, which is 57 % over the minimum recommended treatment volume. This reduction was determined using the NRCS design standards of

2.75 lbs. VS/1000 ft^3-d for volumetric loading rate for "reduce odor" lagoons in Stillwater, Oklahoma.

Sidewalls Area

Equations 3.16 and 3.17 were modified to estimate the sidewalls area. The modification included the number of sidewalls of the lagoon which for this L-shaped lagoon is six instead of four sides.

$$SWA = ((6.32 * h)(W_1 + W_2 + L_2 - (18 * h))) + (3 * h * ((h^2 + (3 * h)^2)^{0.5}))6 \tag{4.7}$$

$$W_1 = 169.2 - (6 * SD) \tag{4.8}$$

$$W_2 = 249.2 - (6 * SD) \tag{4.9}$$

$$L_2 = 244.2 - (6 * SD) \tag{4.10}$$

$$SD = 13.5 - h \tag{4.11}$$

The seepage area was calculated by adding the bottom flat area of the lagoon (42,324 ft^2) to Equation 4.7.

Runoff Area

The lagoon receive runoff volume from four areas. These areas are the roof and the concrete floor from the two finishing units (Figure A.1), the soil area located between the finishing units, and the lagoon sidewalls above 13.5 ft. Runoff from the roof and the concrete floor is collected in a deep gutter which drains to the lagoon. Runoff from the dirt area drains into the cleanout pipe of the main drain line located underground (Figure A.1). All these areas were carefully measured before inputted in the model (Table A.19).

The fixed runoff area of the bank sides above 13.5 ft was determined by modifying the Equation 4.7:

$$SWA = ((6.32 * h)(W_n + W_s + L_s - (18 * h))) + (3 * h * ((h^2 + (3 * h)^2)^{0.5}))6 \quad (4.12)$$

where W_n, W_s, and L_s are the dimensions of the lagoon at a height of 15.30 ft and 13.50 (Table A.20). The difference between both areas is the estimated runoff from the sidewalls area.

4. 3 Hydraulic Balance - Calibration Overview, Adjusted Parameters, Process, and Results

Calibration Overview

The hydraulic model requires two different types of inputs: operational information and weather data. Operational information was subdivided into three areas: manure and flushwater volume, washout water, and lagoon information. The weather data were used to determine the rainfall and runoff entering and evaporation leaving the lagoon. Operational information was carefully analyzed before running the model.

Given the number of animals per unit, the model calculates the total volume of manure generated daily in the facility. The flushwater volume and washout water determine how much fresh water was used as the mechanism for manure transportation to the lagoon and for cleaning. Researchers have found that for most unit operations in which flush tanks or pits are used for waste handling, the ratio between excreted manure total solids and wastewater total solids before entering into the lagoon is approximately 10:1. According to Table 4.1 the influent total solids concentration is slightly above 1% during daily operation, but this will not affect the treatment performance since the lagoon treatment volume is sufficiently large to dilute incoming waste.

Weather Variables

Weather data used for the model calibration were obtained from the Oklahoma Mesonetwork (Mesonet) which is an extensive network of automated weather stations deployed across the state of Oklahoma (Brock et al., 1995). The Mesonet weather stations collect continuous readings, summarized every five minutes and reported at 15-minute intervals to the Oklahoma Climatological Survey located at the University of Oklahoma. Data are analyzed to provide average daily values of a variety of weather parameters for the dissemination to users via a computer bulletin-board system and over the Internet. A list of the weather variables used in the hydraulic model is given in Table 4.2.

Table 4.2. Weather variables used in the model.

Variable	Symbol	Height of measurement	Units
Air Temperature	T_c	1.5 m	°F
Humidity	R_h	1.5 m	
Wind	u_2	0.5 m	mph
Precipitation	R	2 m	inche
Solar radiation	R_s	2 m	$MJ\ m^{-2}$

All weather data were available during the period of the research. Although the Mesonet provides precipitation data, a plastic rain gage was installed on the lagoon bank but no significant statistical differences were found between both gages; therefore, only precipitation data from the Mesonet was used for the model calibration. The daily weather data was converted into a database format which is used by the computer model as input weather data. This database contains weather data from 1994 to 1997 for all the sites involved in this research. A computer program using Basic language was used for the development of the weather database file.

Adjustable Parameters

The following parameters were adjusted during the calibration process: 1) the energy storage factor of the evaporation equation, 2) the hydraulic conductivity of the seepage equation, and 3) the SCS curve number for the runoff potential. The model was calibrated against the lagoon liquid level observations. A predicted liquid level between ± 2 inches of the observed liquid level was used as baseline for the calibration process.

a. Evaporation Equation

Evaporation from the lagoon surface cannot be directly measured but can be estimated if sufficient weather data from the location are available. The equation used for estimating lagoon evaporation was the combined aerodynamic and energy balance method developed by Penman (1948). Numerous researchers have modified the original combined equation because it requires too many variables, most of which are weather dependent. However, the combination method gives reliable evaporation estimates when all the required data are available (Chow, 1988).

Although the combination method has many parameters, most of their values were taken from literature or calculated as described in Chapter 3. The incorporation of the energy storage factor (f_{es}) into the energy equation was considered the most important parameter to adjust in the evaporation equation. A factor value in the range of 0 to 0.50 was given to each month based on the energy gain or loss from the lagoon surroundings. A description of how this factor was obtained is described in the model calibration procedure.

b. Runoff - SCS Curve Number

The most important parameter when determining the runoff volume is the SCS curve number assigned which leads to the runoff potential from a predetermined area. All the areas in the farm susceptible to runoff were measured or estimated previous to running the model. A runoff curve number (CN) of 95 was selected for the inner lagoon sidewalls, soil, and grass areas. A CN of 100 % was used for the roof and concrete areas. The final SCS curve numbers assigned to each area were determined in the model calibration procedure.

c. Seepage Equation

The hydraulic conductivity was the last variable in the model adjusted. During the calibration process, values in the range of 10^{-6} to 10^{-9} cm/sec were tested. It was assumed that the hydraulic conductivity had reached a lower value due to the years in operation, and that remained constant during the simulation period; therefore, a constant hydraulic conductivity within the above range was used for model calibration.

Calibration Process

The first adjusted parameter in the model was the energy storage factor, because it only required the weather database and the observed Class A evaporation pan data. In order to conduct this calibration it was not required to run the program. This procedure was accomplished using a spreadsheet.

Pan evaporation data were obtained from Climatological Data for Oklahoma (NOAA, 1995 and 1996) for the weather observing site located at the OSU Agronomy farm. Equation 3.35 was used to estimate the evaporation during the summer 1995 and 1996 with energy storage set to zero. The results were compared with the observed pan evaporation data times a factor of 0.70 for lake evaporation. In both years the results from the evaporation equation overestimated the lake evaporation. Thus, f_{sc} was increased until the estimated evaporation was comparable to the lake evaporation (r^2 = 0.95). Then adjusted f_{se} was incorporated into the hydraulic model to adjust other variables.

The second parameter of the hydraulic model adjusted was the SCS curve number. The facility operational data and lagoon information were input into the model to calculate the lagoon elevation between rainfall events. It was run for the same period used to adjust the f_{sc} but with the default CN for each area. The model was run during rainfall event no longer than three days to compare the peaks caused by predicted and observed rainfall events. The results of the first run, which includes several rainfall events, gave higher peaks for all the events, thus the CN was too high. CN for areas contributing more to runoff was decreased. The model was run again, and the results were compared. This procedure was repeated several times until the predicted peak was close to the observed data. The final CN, used in the model are given in Table 4.3.

Table 4.3. Adjusted SCS curve number.

Runoff Area	Adjusted CN	Expected CN[1]
Roof and concrete	90	95 - 100
Soil	87	70 - 91[2]
Lagoon Sidewall	85	79 - 95[3]

[1] Schwab et al. (1981).

[2] Hydrologic soil group D

[3] Hydrologic soil group C

The roof and concrete CN were below the expected. The adjusted CN for these areas was attributed due the fact that the drainage pipe located at the end of the concrete floor gets clogged very quickly with rainfall intensity greater than one inch; therefore, some runoff may not enter to the lagoon. The inner lagoon sidewalls CN was set to 85. This CN could be as a result of the prevailing grass cover on top of the bank and sidewalls and the variation of bank slope and height.

The last variable adjusted in the model was the hydraulic conductivity of the lagoon seepage equation. The model was run for the same period used to adjust f_{se} and CN and the results were compared with the weekly observed data. Hydraulic conductivities in the order of magnitude of 10^{-6} and 10^{-7} cm/sec were initially used but both values overestimated the lagoon seepage; therefore, the predicted liquid levels were below the observed data. A final adjusted hydraulic conductivity value of 1.51×10^{-8} cm/sec successfully predicted water levels.

The final step involved in the calibration was to apply the adjusted CN and the hydraulic conductivity values in the model to determine the energy storage factor of the remaining months. The model was run using the same input data, and the results were compared with the lagoon elevation data. Continuous changes to the remaining energy storage factor were made and the program was run until reasonably good matches between observed and predicted data were found.

Calibration Results

Once the above factors were calibrated, the hydraulic model was run from the period May 15, 1996 to October 2, 1997 and the results were compared with the observed liquid elevation data given in Table A.21 and Figure A.10. The model predictions compare very well with the observed liquid level data as illustrated in Figure 4.1. The prediction follows the trend of the observations throughout the simulation period. Figures 4.2 and 4.3 illustrates a one-to-one plot of the predicted versus observed lagoon elevation data and a residual plot, respectively. A statistical analysis of the results is presented in Tables 4.4 and 4.5. Comparison of the mean and standard deviation between the observed and predicted were very similar. The regression analysis indicated that model prediction compares well with the observed data with r^2 value of 0.99 and a slope value close to one. There is a 95 % confidence that the intercept and slope of the regression does not contain zero. Therefore, the model explained a significant amount of the variation in the predicted liquid elevation. Moreover, according to Table 4.4, the mean error after 504 days of operation was very small (-0.01 ft) which indicated how well the model performed once calibrated.

All the peaks in Figure 4.1 were caused by the volume of rainfall on top of the lagoon and runoff. There is a slight deviation on the prediction curve after October 1997 which was due to an increase in runoff area. This conclusion was made after a physical inspection of the farm. The area between the Finishing 2 and the sow unit was also draining into the cleanout pipe. This new source of runoff was caused by the channeling left by tractor tires on wetted soil.

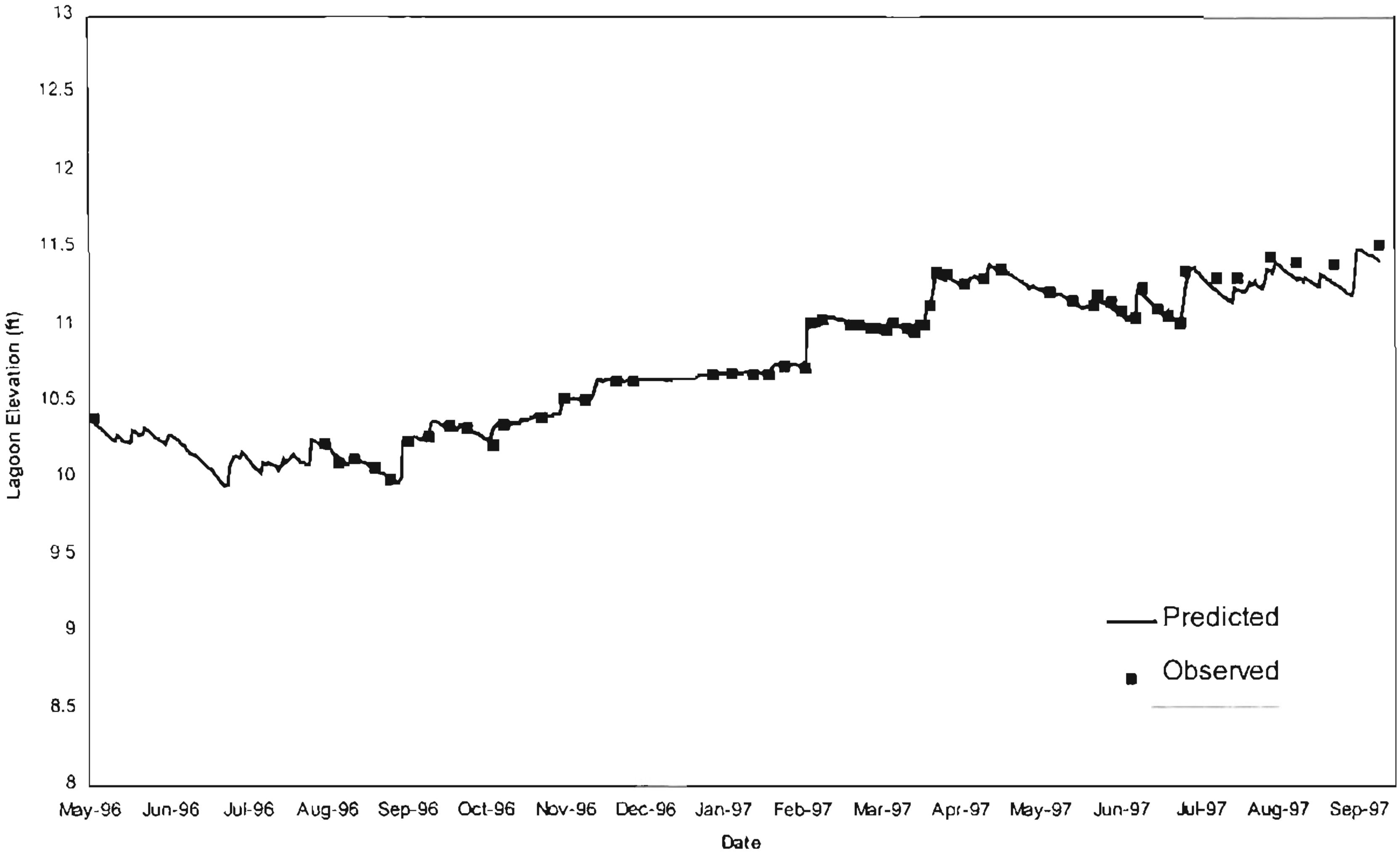


Figure 4. 1. Observed and predicted lagoon elevation for the OSU swine lagoon from May 15, 1996 to October 2, 1997.

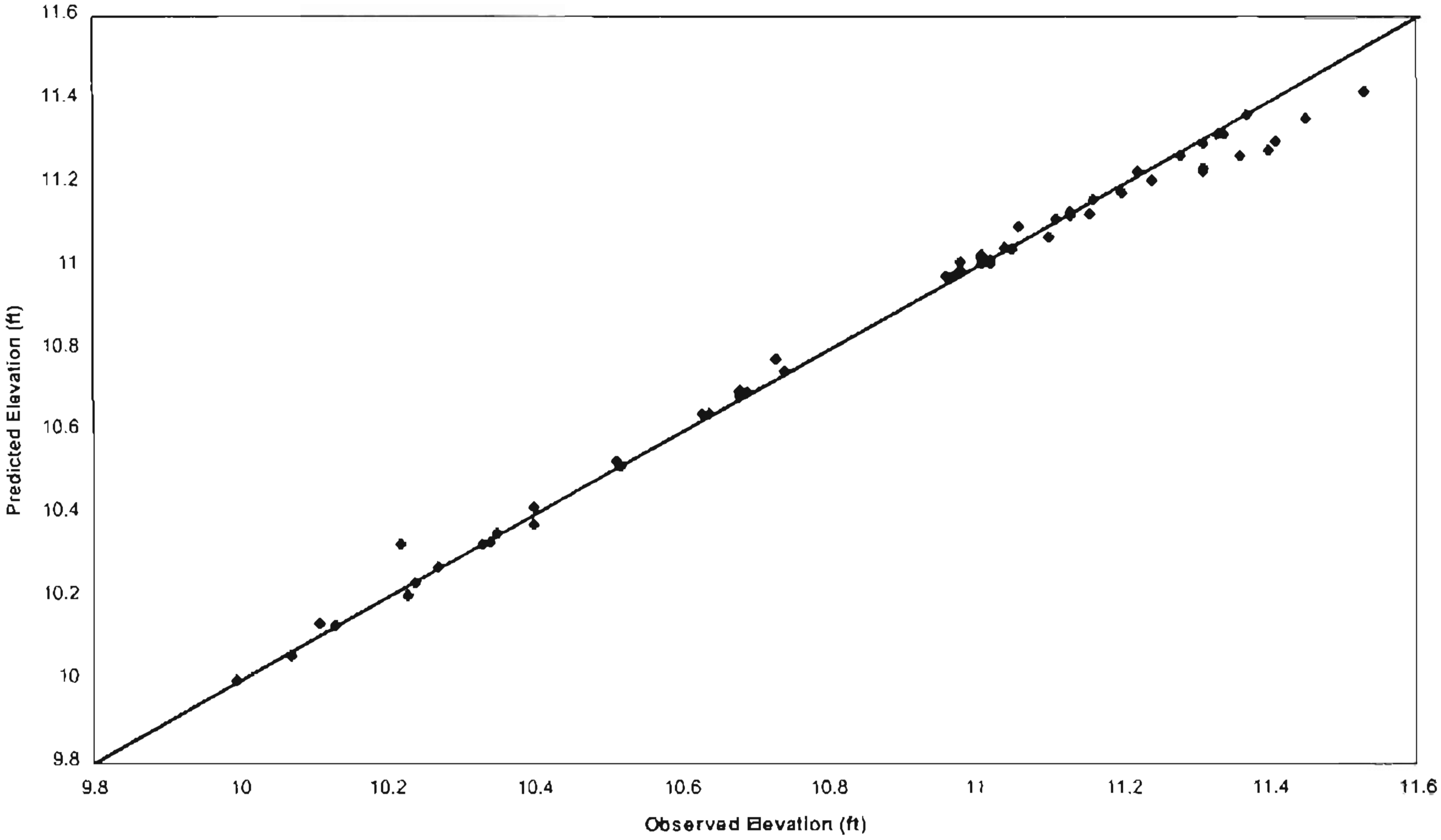


Figure 4. 2. Comparison of predicted and observed lagoon elevation data for the OSU swine lagoon from May 15, 1996 to October 2, 1997

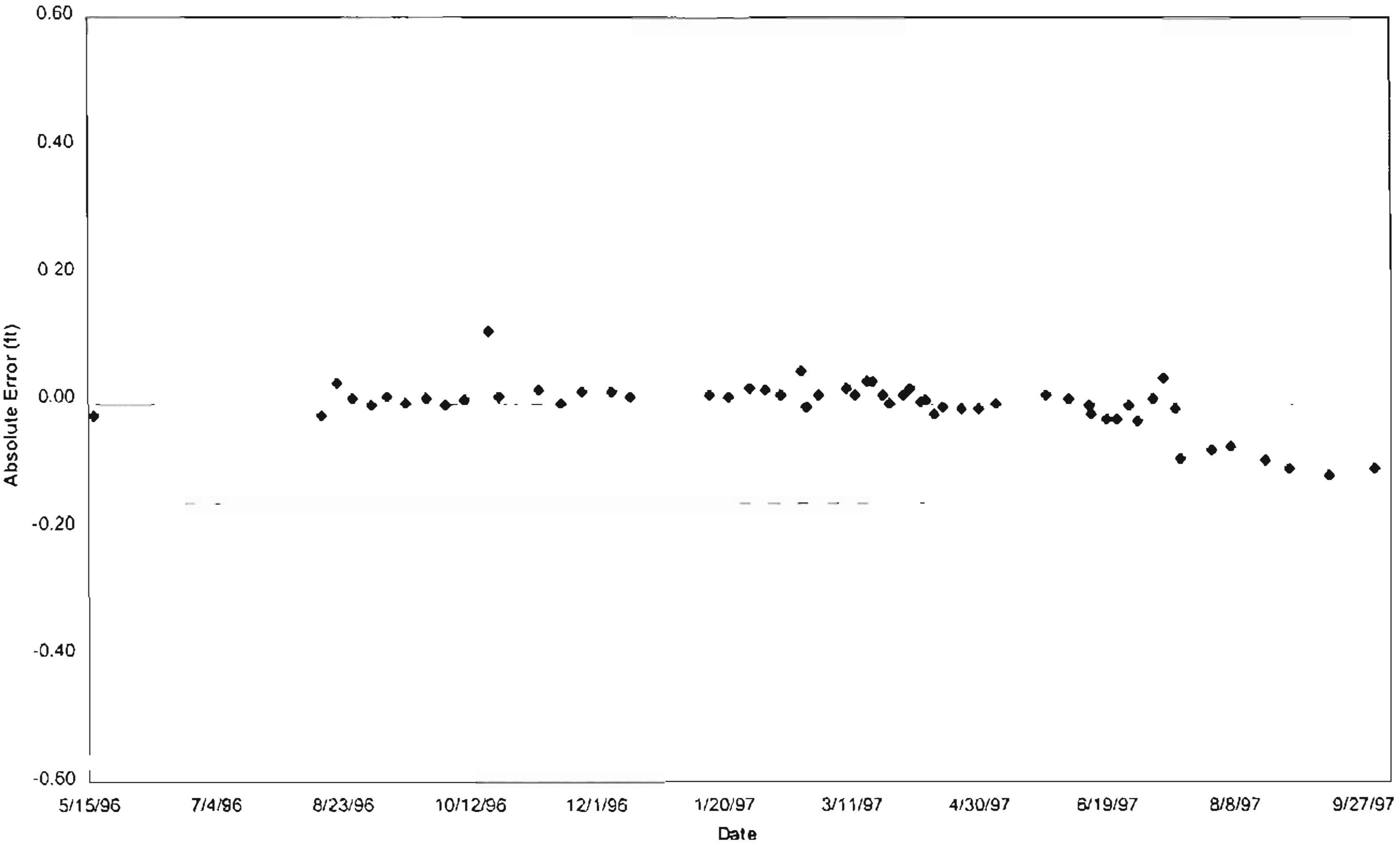


Figure 4. 3. Residual plot of the lagoon elevation data for the OSU swine lagoon from May 15, 1996 to October 2, 1997.

Table 4.4. Statistical analysis of the observed and predicted elevation for the OSU swine lagoon.

	Predicted ft	Observed ft	Absolute Error, ft
Observations	58	58	58
Minimum	10.00	10.00	-0.12
Maximum	11.42	11.53	0.11
Range	1.42	1.54	0.23
Mean	10.86	10.87	-0.01
Variance	0.16	0.18	0.00
Std. Deviation	0.40	0.42	0.04
Std. Error	0.05	0.06	0.01
Median	11.01	11.01	0.00

Table 4. 5. Regression statistics and significance of the model for the OSU swine lagoon.

	Results	$\lvert t_{cal} \rvert$	$t_{0.975,56}$
r^2	0.99		
Std. Error	0.03		
Intercept	0.53	4.60	2.0
Slope	0.95	-4.70	2.0
Corr. Coef., r	1.0	89.0	2.0

4. 4 Electrical Conductivity Balance - Calibration Overview, Adjusted Parameters, Process, and Results

Calibration Overview

During the lagoon survey, the EC of the supernatant was measured in different areas of the lagoon and at different depths beneath the surface (Tables A.22 and A.23). EC measurements were higher in the deeper portion of the lagoon compared with those in the upper portion. However, the lagoon supernatant showed uniform EC values at vertical and horizontal positions. Similar distribution of EC and inorganic salts in the lagoon supernatant were reported by Sutton et al. (1980); Overcash et al. (1978); Georgacakis and Sievers (1979). A representative 500 mL supernatant sample was periodically collected at 10 feet offshore and 0.5 feet deep beneath the surface at different locations around the lagoon (Figure A.11). An expandable plastic rod with an attached plastic bottle at the end was used to collect supernatant samples. Each sample was analyzed at the lagoon bank with a YSI Model 31 Portable Conductivity Bridge for EC, conductivity, temperature, and salinity measurements. Tables A.24 and A.25 give the EC measurements at different locations and the average data, respectively.

The measurements of EC indicated no significant variation around the lagoon except for the area immediately surrounding the outfall. The average EC values given in Table A.25 were used for comparison with the model output.

Adjusted Parameters

The percent of feed cations in the waste and the percent of cations in the lagoon supernatant were considered the most important parameters in the development of the EC balance. These parameters were not analyzed for any of the facilities involved in this research, thus literature values were used for model estimation (Tables 2.1 and 2.2). For the calibration, values of γ_i and σ_i reported by Overcash et al. (1978) were considered the most appropriate in estimating soluble mass of inorganic salts in the lagoon supernatant. A justification for the application in the model of these values was that the comparison of the feedstuff and the amount fed in both facilities were very close, especially the percent of NaCl and calcium used in formulating the ration. Therefore, it was assumed that this facility may have a similar response in the percent of cations carried over in the waste and the percent available in the supernatant. This assumption does not necessary means that γ_i and σ_i reported by Overcash et al. (1978) are correct.

Calibration Process

The facility manager provided the ration information for each unit as described in Table A.26. The Equations 3.50 and 3.51 were used to determine the mass of calcium, sodium, potassium, and magnesium available in the feed and the soluble mass that enters to the lagoon, respectively. The results obtained from the calculations are described in Table G.1 and summarized in Table 4.6.

Table 4.6. Daily mass of cations at different stages in the swine operation (lbs/day).

Stage	Ca^{2+}	Na^+	K^+	Mg^{2+}
Feed (X_i)	19.07	6.02	21.55	6.15
Waste ($X_i\gamma_i$)	10.45	3.97	12.92	4.55
Soluble (S_i)	9.09	3.02	9.82	2.91

The soluble cations mass from Table 4.6 was substituted in Equation 3.57 to calculate the concentration of cation *i* that is used in Equation 3.49. The mass of EC from the feed that enters to the lagoon was calculated using Equation 3.58, resulting in 0.012 lbs per day.

The fresh water used to clean and to recharge pits and flush tank was another contribution of the supernatant EC. The EC in the facility was measured as 0.539 dS/m, thus 0.539 mg/L was daily added to the lagoon. The mass of EC from the freshwater was determined using Equation 3.59. Two EC mass loadings were calculated due to the additional wastewater from the misters. The mass of EC inputted in the model was 0.025 lbs and 0.022 lbs, with and without the misters wastewater volume, respectively.

Calibration Results

Electrical conductivity predictions for the lagoon supernatant were compared against the EC measurements taken from September 4, 1996 to October 2, 1997 (Table A.25). Time-series trends of the predicted EC were in good agreement with the observed EC, except for some minor deviations during winter and summer months (Figure 4.5). A one-to-one plot of the observed and predicted supernatant EC and residual plot are given in Figures 4.5 and 4.6, respectively. The cycle trends on the residual error plot were caused by physical and biological factors not considered in the EC balance. The statistical analysis given in Tables 4.7 and 4.8 showed that the model predicted significant amount of the observed EC. The model prediction closely followed the observed pattern as shown Figure 4.7, with the observed and predicted slope of -0.0007 and -0.0012, respectively. Moreover, the average relative error during the 394 days of the simulation was -0.15 dS/m; therefore, the model predicts the lagoon supernatant EC very well.

The predicted did not follow the same trend of the observed data because there are physical, chemical, and biological factors involved on the lagoon environment which contribute with the supernatant EC that were not considered in the EC balance. Some of these factors are, besides the hydraulic component, the temperature effect on the rate of biological activity in the lagoon systems. Sutton et al. (1980) reported that nutrient and solids concentration in lagoon supernatant varied with the season of the year for one swine and one dairy lagoon with total Kjeldahl nitrogen and ammonia nitrogen being higher in the spring and the summer months. They also reported that during the four years of the investigation, ammonium-N and EC followed the same trend. Westerman et al. (1990) showed a cyclic trend of NH_3-N in two swine lagoons and in two poultry lagoons and they concluded that the variation is due to temperature effects on the lagoon biological activity.

The predicted EC followed the same trend as the observed EC measurements until late fall when the temperature of the lagoon went down to 2 °C (Figure 4.6). Since mid January to mid February, the lagoon surface was approximately 90 percent covered by ice. This decreased in lagoon temperature reduced the activity of both acid and methane forming bacteria. However, the methane forming are more sensitive to lower temperatures than acid forming. At lower temperature, the acid former bacteria can continue releasing fatty acids which lower the pH and hold more NH_4^+ in solution, resulting in a increase of the supernatant EC.

Raising the liquid temperature during spring and summer month increased the NH_3 level and dropped the liquid EC. The effect of NH_3 on lagoon EC were not evaluated in this research due to the dynamic conditions required for the simulation (biological activity, temperature, etc.). Humenik and Overcash (1976) developed a steady-state equation for continuous loading to predict NH_3 losses from swine lagoons on the basis of TKN concentrations and the interfacial area between the lagoon and the atmosphere. They also reported deviation from observed and predicted values due to differences in liquid temperature and probably due to wind conditions.

The effect of the lagoon liquid temperature during spring and fall months produce sludge turn-over which increase the total solid content in the liquid portion. This phenomena could also produce a rise in the supernatant EC.

As expected, the EC balance responded very well during rainfall events as illustrated in Figure 4.7. The predicted EC shown several drops as a result of the rainfall and runoff volume entering into the lagoon Similar drops were observed in the measured EC after nearly all rainfall events. Although inorganic salts are continually been added to the lagoon, its concentration in the liquid portion may goes down when moisture excess prevail. No effect of irrigation on the EC was noticed because the lagoon effluent was not pumped out during the observed period. The lower EC measurements observed in the lagoon could be attributed for three reasons: (a) The swine were receiving a high forage diet with minimal mineral supplements. An average of 0.30 percent salt is being added to the diets which is close to 0.20 percent, the minimum recommended for the swine nutrition (Rea et al. 1990), (b) The use of fresh waster for recharging the pits and flushing the gutters and the large volume of rainfall on top of the lagoon serves as a means of keeping the inorganic salt concentration diluted and the EC value under the minimum recommended for good lagoon performance, and (c) The capacity of the treatment volume (83 acre-in) is very large, thus it provides large dilution to the incoming waste.

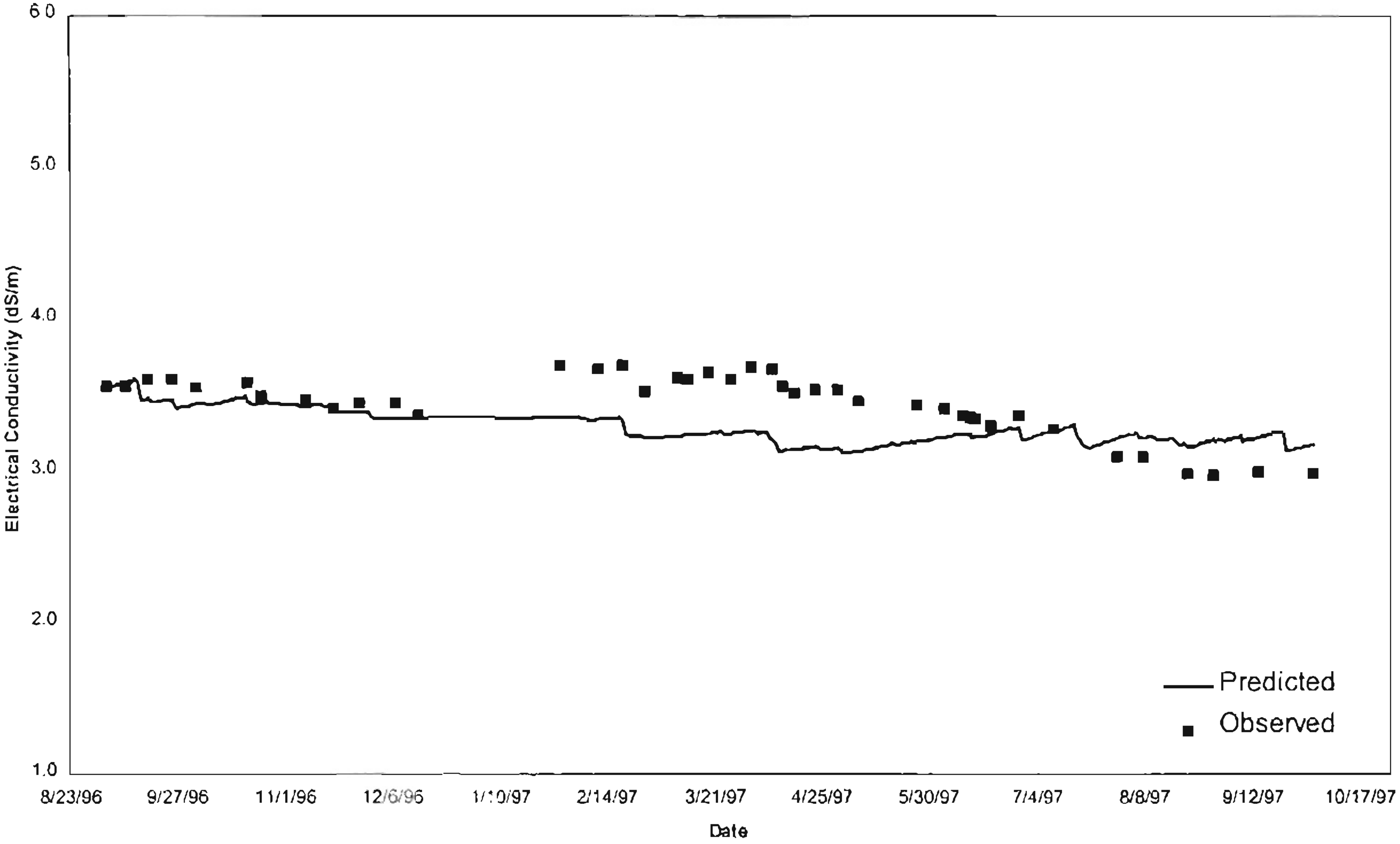


Figure 4. 4. Electrical conductivity of the lagoon supernatant (@ 0.5 ft beneath the surface) for September 4, 1996 through October 2, 1997.

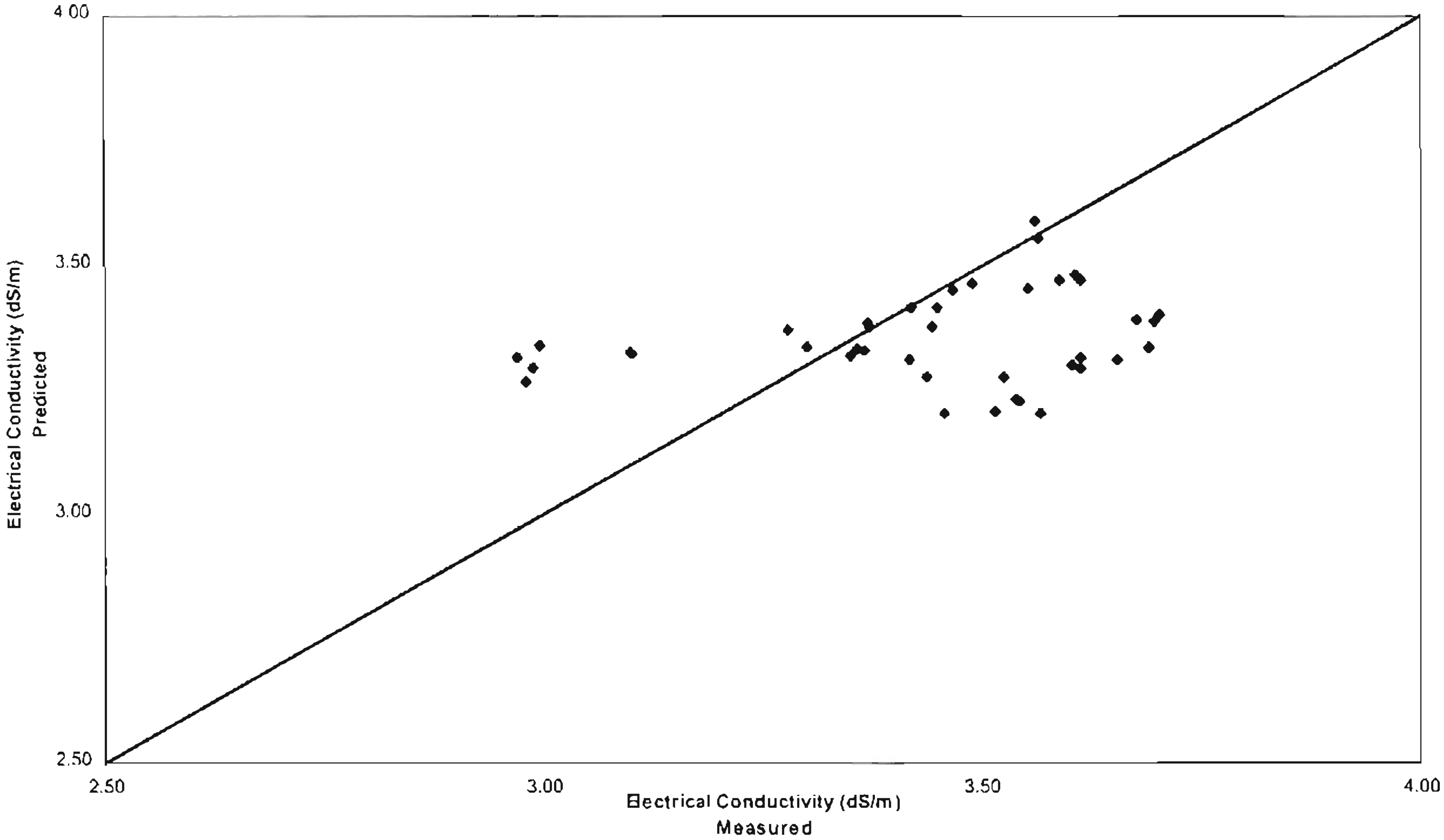


Figure 4. 5. Comparison of predicted and observed EC for September 4, 1996 through October 2, 1997.

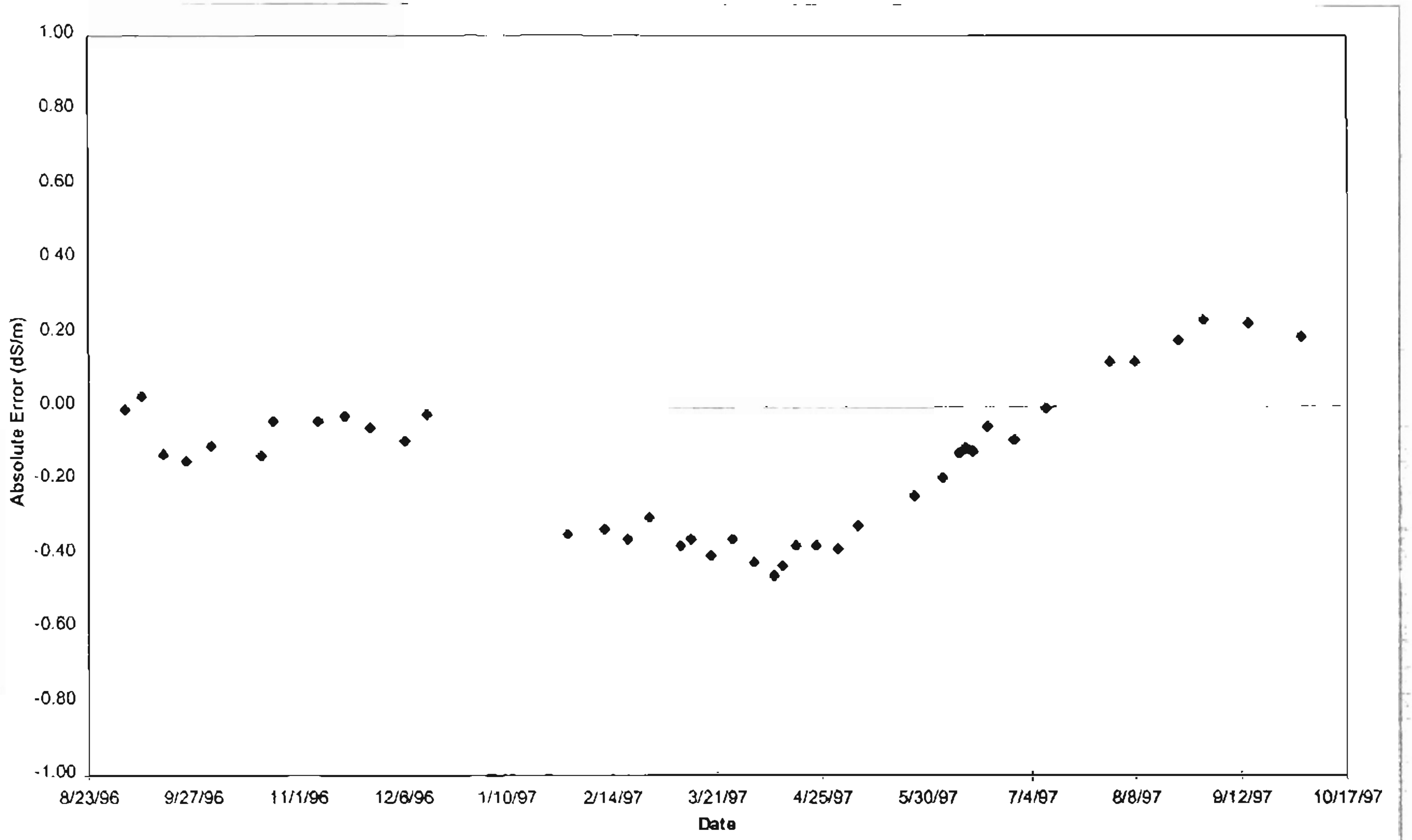


Figure 4. 6. Residual plot of the OSU swine lagoon supernatant EC from September 4, 1996 through October 2, 1997.

Table 4.7. Statistical analysis of the observed and predicted supernatant EC for the OSU swine lagoon.

	Predicted ft	Observed ft	Absolute Error, ft
Observations	41	41	41
Minimum	3.13	2.97	-0.46
Maximum	3.59	3.70	0.24
Range	0.46	0.73	0.70
Mean	3.29	3.45	-0.15
Variance	0.01	0.04	0.04
Std. Deviation	0.12	0.21	0.20
Std. Error	0.02	0.03	0.03
Median	3.25	3.49	-0.13

Table 4. 8. Regression statistics and significance of the supernatant EC model in the OSU swine lagoon.

	Results	$\lvert t_{cal} \rvert$	$t_{0.975,39}$
r^2	0.12		
Std. Error	0.11		
Intercept	2.61	8.92	2.02
Slope	0.20	-9.46	2.02
Corr. Coef., r	0.35	2.34	2.02

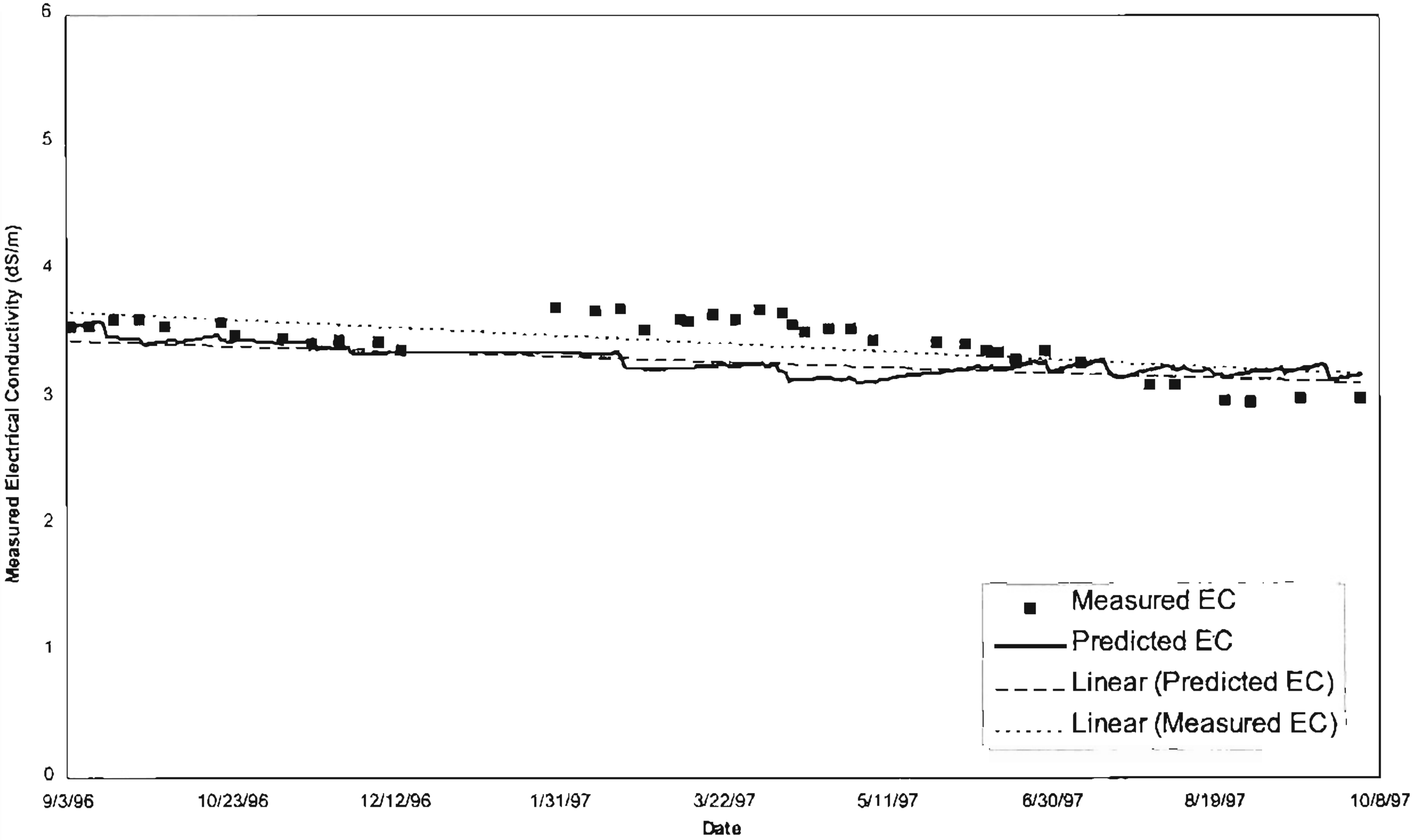


Figure 4. 7. Comparison of predicted and observed slopes of the EC model for the OSU swine lagoon.

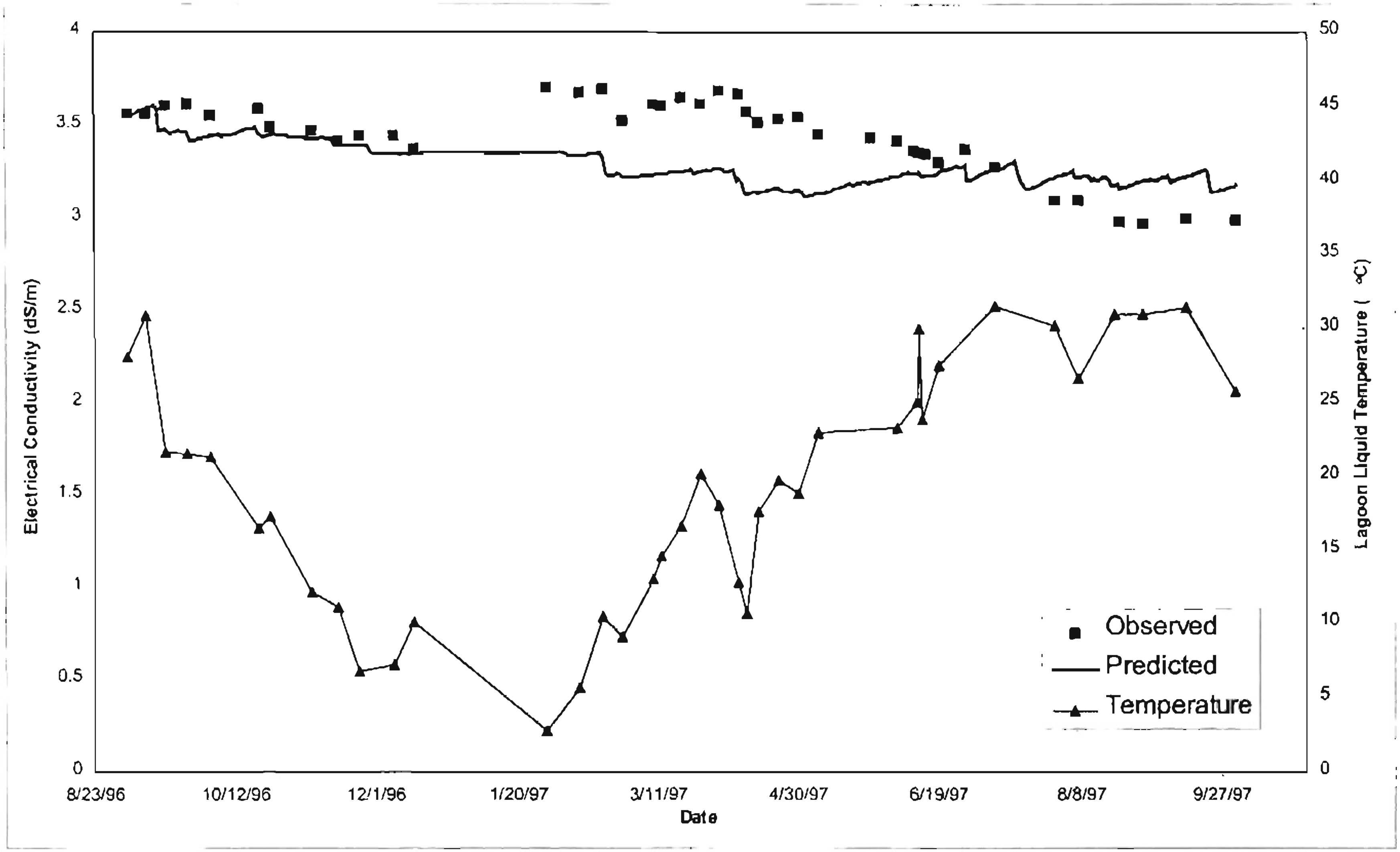


Figure 4. 8. Temperature effect on predicted and observed EC in the OSU swine lagoon.

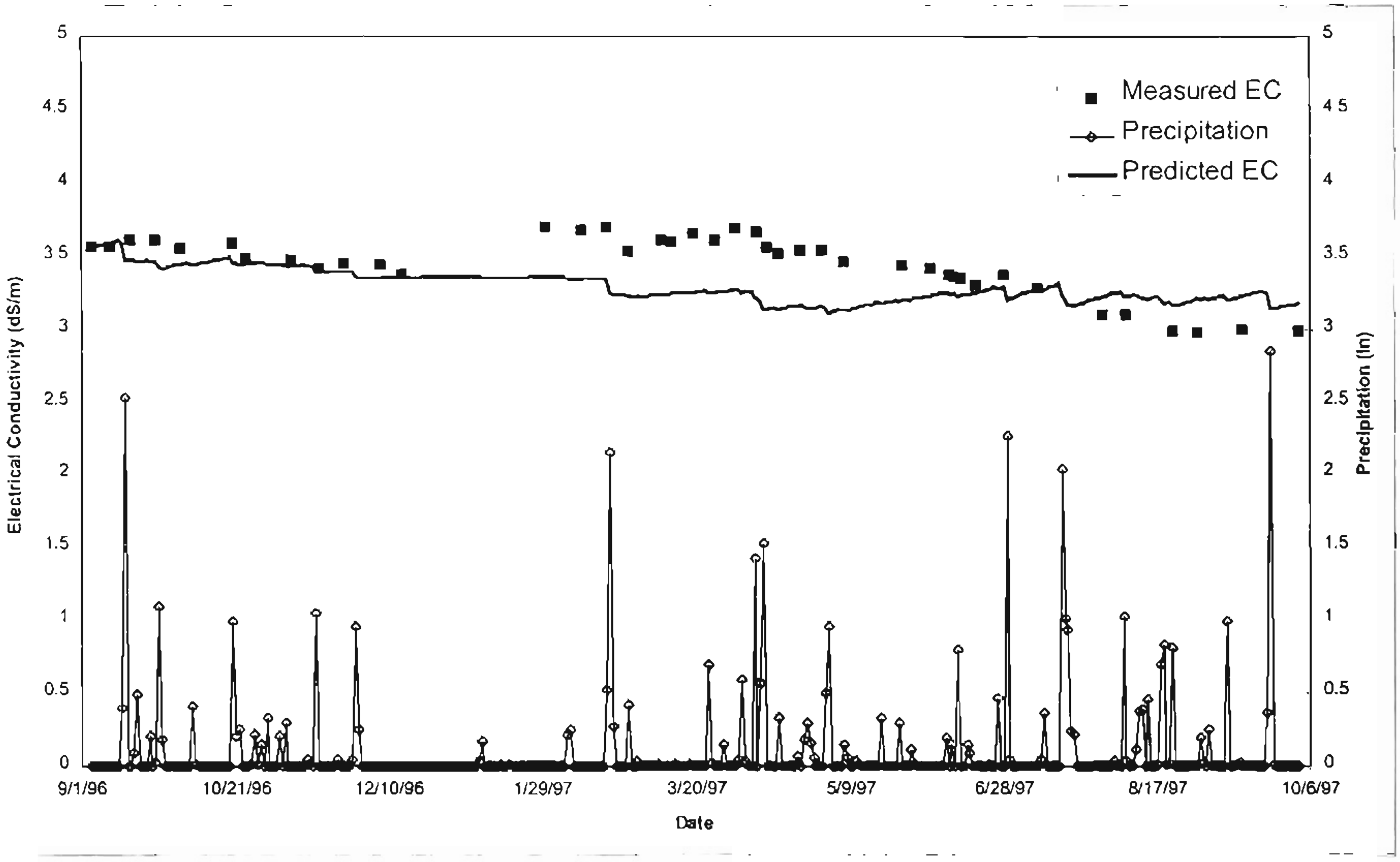


Figure 4. 9. Rainfall effect on predicted and observed EC in the OSU swine lagoon.

CHAPTER 5

MODEL VALIDATION

5. 1 Overview of the Validation Sites

Due to the variation in climatic conditions in the state of Oklahoma, three facilities with similar operational characteristics were selected to validate the hydraulic and the EC model. Two of the facilities are 600-sow breeding farms located in Shawnee, Pottawatomie County and Poteau, LeFlore County; central and southeastern region of the state, respectively. The other facility is a 2,000 sow-breeding farm located at Goodwell, Texas County, in the northwestern region of the state (Figure 5.1). The validation sites exhibit considerable variation in the weather pattern, especially the net rainfall minus evaporation (Figure 5.2), and the handling of wastewater throughout the lagoon system.

Several visits to the facilities were performed to survey the lagoons, to measure the supernatant EC, to collect supernatant samples, and to interview the manager to gather operational information required for the model input. The lagoon survey was performed to determine the lagoon top dimensions, depth, and sludge thickness. Additional information given by the facility managers included the daily amount of feed consumed and the composition of dietary ration.

The validation of the model was performed using data from the facilities located at Shawnee and Poteau. These two facilities were physically inspected to determine all possible sources of wastewater contributing to the lagoon volume. Flow rate from the misters and the drippers were measured at different points in each units to estimate the volume of wasted freshwater. Not enough operational data were obtained from the facility located at Goodwell. Physical inspections to this facility were not permissible due to a strict animal disease control program.

Lagoons supernatants from all the sites were sampled and analyzed for Na^+, K^+, Ca^{+2}, Mg^{+2}, and EC. Analyses of elemental ions were performed at OSU's Soil, Water & Forage Analytical Laboratory following the procedure outlined in Standard Methods (APHA, 1990). The EC was measured by a YSI Model 31 Conductivity Bridge.

Weather data from the nearest Mesonet station was used to determine rainfall and evaporation. However, the historical rainfall data from the Mesonet was substituted with on-site rainfall records.

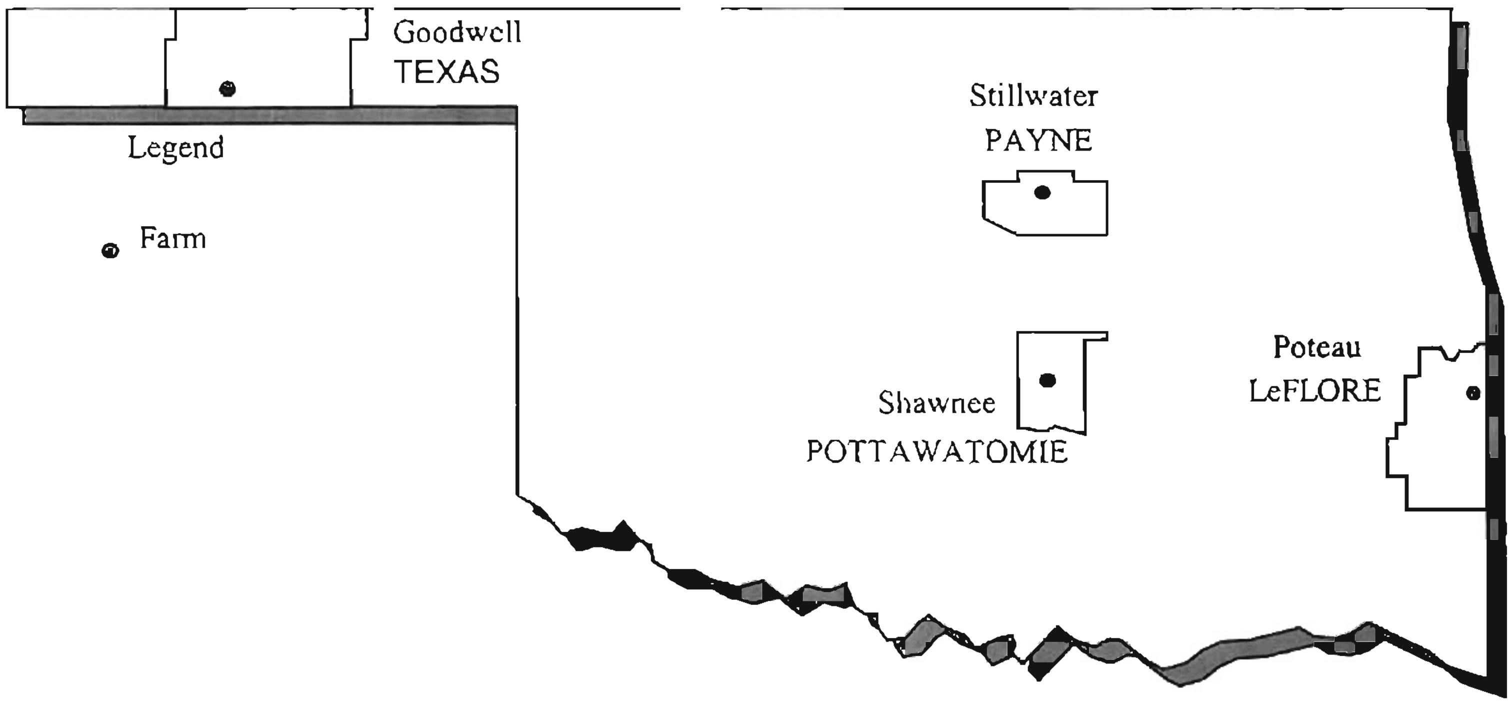


Figure 5. 1. Location of swine farms used to validated the model.

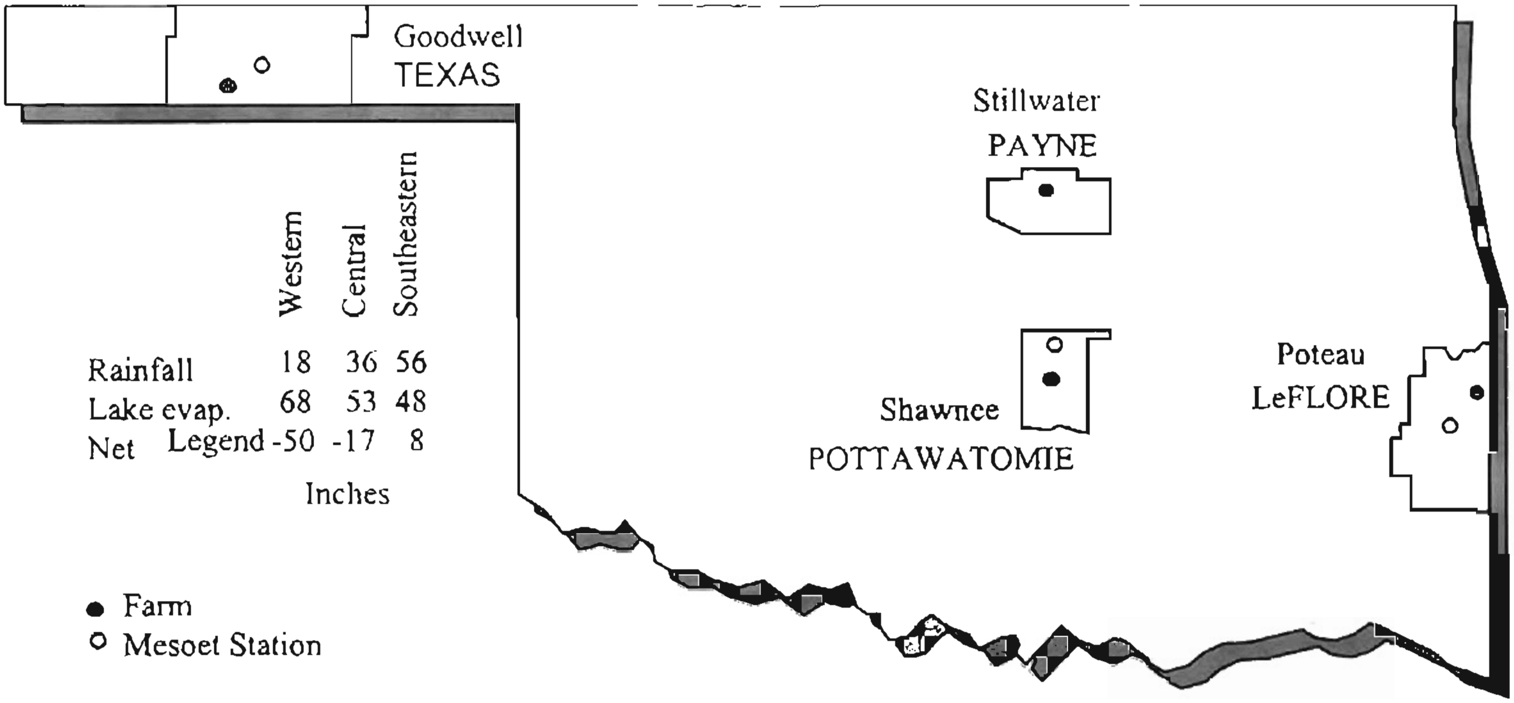


Figure 5. 2. Variation in rainfall minus evaporation in Oklahoma.

5. 2 Description of the Facility Located at Poteau

This farm is a 600-sow breeding facility that has been in operation since February 1995. The facility is located at Poteau, in the southeast portion of Oklahoma, where the net rainfall minus evaporation is 8 inches. The confined 300-lbs animals are kept inside two partially enclosed buildings, the breeding and gestation (B&G) and farrowing (Figure B.1). Waste generated in each unit is collected in under slotted floor gutters which are periodically flushed by gravity to a single stage anaerobic lagoon. The flush tanks are recharged with recycle lagoon effluent. The facility was designed to recycle effluent all year around, thus minimize the utilization of freshwater. A deep well is used to supply drinking water and hose washing. The well is located approximately 500 feet away from the lagoon.

Unit Size and Waste Collection Operation

The facility manager maintains a steady number of animals in the B&G and farrowing units. The dimensions of the breeding and gestation unit are 36 ft wide by 250 ft long. This unit has the larger number of animals, 430 animals including boars, gilts, and gestation sows. The dimensions of the farrowing unit are 42 ft wide by 130 ft long. The number of animals in this unit are 84 sows with litters.

Manure and wastewater generated in both buildings are collected in slatted floor gutters flushed every hour. The frequency of flushing the gutters is automatically controlled to be in series. The flushing tanks are located in a upper section along the roof and are recharged with lagoon effluent. A suction pump located close to the outfall from the breeding and gestation building is used to recharge the tanks. An schematic of the recycling pump and return line are illustrated in Figure B.1. The number of animals by their type and the amount of manure daily generated at the farm are given in Table B.1.

Wastewater Loading

The sources of wastewater are the washout water and wasted water from the misters and drinking channels. All potential runoff areas are diverted from the lagoon. The average flow rate from the water hose located behind the storage room was 13.11 gallons per min. Also, the flow was measured at different water hoses inside the B&G building to determine the volume of water used for the drinking channels.

There is a total of 514 misters in the farm, 430 are located in the breeding and gestation units and 84 in the farrowing unit. The operation of the mister is automatically controlled by a thermostat and timers. The misters are activated when the air temperature inside the buildings reaches 85 °F. They are set to operate for 30 seconds in a cycle of 20 minutes for 8 hours. The misters flow rate was 5 galls/hr. Therefore, the calculated daily volume of water was 68.26 ft^3.

Not all the water from the misters drains into the lagoon, some amount is evaporated in the concrete floor and drinking gutters. In order to estimate how much wastewater is evaporated daily, the effective wet area of the floor was measured as 5.5 ft^2 per stall. The estimated wetted area in both buildings is 2,835 ft^2. According to the pan evaporation data for this region, the average summer water surface evaporation is 0.20 inches. Thus the evaporation will carry approximately a 70 percent of the water from the buildings floor.

A water pressure pump with an average flow rate of 3.5 galls/min and 250 psi is used to wash down the floors. The facility manager indicated that it takes approximately 20 hours per week to clean and disinfect the buildings resulting in a calculated daily volume of washout water equal to 80 ft^3.

The operation of the drinking channels is automatically controlled by timers. There are four drinking channels in the B&G building. The operational schedule is given in Table B.2. This type of waterer generates a large volume of wasted water which will end up in the lagoon causing periodic removal of lagoon effluent for land application. Automatic nipples are used in the farrowing unit.

The amount of wasted water was determined by measuring the flow rate at the beginning of the channel and subtracting the amount of water consumed by the animals. Equation 3.28 was used to estimate the volume of water consumed. According to the manager, the animals in the breeding and gestation unit are daily fed with 5.5 pounds of dry feed, so, the daily amount of water consumed in this unit is 147.2 ft^3.

The average flow rate at one channel was measured as 4.61 gals./min. Based on the flow rate and the operational time, the calculated total volume of fresh water daily supplied for drinking is 479.44 ft^3. Therefore, the estimated daily amount of wasted water from the drinking channels is 332 ft^3 or 3.2 gals/min-channel.

The daily total volume of manure and wastewater that flows into the lagoon is 523.61 ft^3. A summary of the manure and wastewater volume produced as well as the model input are given in Table 5.1.

Table 5. 1. Manure and wastewater volume inputs, Poteau farm.

Manure Volume			
Animal		*No of each*	*Total (ft^3/day)*
Boars		12	0.65
Gilts		25	3.25
Gestation Sows		393	51.5
Sows & Litter		84	34.4
		Total manure volume	90
Drinking Channels			
Channel	*Flow Rate (gal/min)*	*Operational Time (min)*	*Total (ft^3/day)*
4	3.2	195	333
Washout Water			
Washout vol. (gal)		*Frequency (days)*	*Total (ft^3/day)*
4,200		7	80
Misters			
No. of misters	*Water use (gal/hr)*	*Frequency (hr/day)*	*Total (ft^3/day)*
514	0.04	8	20.6
Total Manure and Wastewater Loading			**524 ft^3/day**

Lagoon Survey

The lagoon was survey for the first time in May 23, 1996. The dimensions of the lagoon from top of the bank are 140 feet wide by 190 feet long with a side slope of 3:1. A bench mark was located at the northwest corner of the (B&G) unit. Table B.3 gives the elevation data measured at different locations around the top of the embankment and at the water level. The locations given in Table B.3 are illustrated in Figure B.2.

Supernatant samples and depth measurements were taken at two equally distant transects (0 + 70 and 1 + 40) located along the side of lagoon, as illustrated in Figure B.2. The required depth data was measured every ten feet across the side with the T-probe device. Depth data at the two transects and the sludge thickness values are given in Table B.4 and B.5. The average sludge thickness and sludge depth were calculated from the measured depth at the bottom flat area of the lagoon. Table B.6 gives the average values for each transect. Sludge accumulation was measured higher in the first transect than the second transect. The bottom region near both outfalls tends to accumulate more solids but it decreases as you move farther.

In May 13, 1997 the lagoon was surveyed again to determine the new sludge depth and to measure the electrical conductivity. The transects were set at the same locations and the measurements were taken at ten feet from shore. Electrical conductivity measurements were taken at 60 ft offshore of the second transect. Depth and sludge thickness data for both location are given in Tables B.7 and B.8. The average sludge thickness and sludge depth are given in Table B.9.

Table B.10 gives the percent of sludge increase in the bottom flat area during 356 days of operation. The difference in sludge accumulation between 0 + 70 and 1 + 40 in

1996 were higher than 1997 which indicates that during the second survey the sludge depth was more uniform. The overall sludge accumulation increased 78 percent in 356 days of operation.

In both surveys, an appreciable amount of sludge was measured in the side slopes of the lagoon. This accumulation could be caused by the mixing effect produced due to the location of the outfalls and recycling suction line. Sludge accumulation values from the side slopes where determined from thirty feet offshore and the results are given in Table B.11.

The sludge volume produced was calculated by adding the sludge volume in the side slopes and the volume in the bottom flat portion. The average thickness value for each year was used to estimate the volume. The effective sidewall sludge depth was 8.5 feet and 9.0 feet for 1996 and 1997, respectively. The total sludge volume accumulated during 356 days of operation is given in Table B.12.

The rate of sludge accumulation in the lagoon was estimated based on the total sludge volume accumulated during 356 days and since the farm started in operation February 1995 (833 days). Given a total solid production of 542.77 lbs/day (Table B.1), the calculated accumulation rate for both periods are 0.0871 ft^3/lb TS-d and 0.0372 ft^3/lbTS-d, respectively.

Lagoon Liquid Zones and Stages Curves

The volume capacity and surface area of the lagoon are plotted in Figures B.3 and B.4. These plots were determined using the lagoon dimensions and Equations 3.5 and 3.11. The maximum volume capacity and surface area at 11.125 ft (spillway) are 183,387

ft^3 (50.52 acre-in) and 25,863 ft^2 (0.60 acres), respectively. Based on the NRCS (1994) design standard, the volumetric loading rate for this anaerobic lagoon is 5.8 lbs. VS/1000 ft^3-day. The actual volumetric loading rate at the minimum drawdown level is 4.66 lbs. VS /1000 ft^3, thus the lagoon has a suitable performance base on the organic loading, provided sludge does not accumulate. The actual treatment volume is 82,038 ft^3, which is slightly higher (0.15 %) than that recommended by the NRCS.

5. 3 Description of the Facility Located at Shawnee

This farm is a total confinement 600-sow breeding operation located at Shawnee, Oklahoma, where the net rainfall minus evaporation is -17 inches. The facility started in operation in July 1994. There are three operational buildings for farrowing, breeding, and gestation sows (Figure C.1). Manure and wastewater in these buildings are collected in storage pits beneath slotted floors which drain by gravity to a single-cell anaerobic lagoon. The pits are manually recharged with either recycled lagoon effluent or fresh water. Fresh water is pumped out from a well located near the facility. Lagoon effluent is periodically irrigated onto adjacent fields.

Unit Size and Waste Collection Management

The production units contain three partially enclosed buildings which: farrowing, the gestation, and the breeding units with a total animal capacity of 120, 300, and 210, respectively. The population of animals in the farms remains steady all year round. The number of animals by type and the daily amount of manure produced are given in Table C.1.

The dimensions of the farrowing unit are 42 feet wide by 226 feet long. This unit is divided into eight separates rooms each having crates for 15 sows and litters. All rooms shares three underfloor liquid manure storage pits which are separated by a feed and sow concrete allays. These pits are 7 feet wide with a longitudinal distance of 226 feet. A layout of the "pull plug" type pit with the dimensions is given in Figures C.2.

The G&B units have the same dimensions which are 42 feet long and 159 feet wide. The number of animals in the breeding unit is shared by boars, gilts and gestation sows. The generated manure in each unit is collected in two underfloor storage pits separated by a concrete allays. These pits are 10 feet wide and have and a longitudinal distance of 159 feet. All pits have a longitudinal bottom slope of 0.5 % toward the overflow outlet. The effective underfloor storage pit capacity for recharged liquids and for accumulated wastewater is given Table C.2.

The minimum volume of fresh water or recycled effluent required to recharge all the pits is 12,957 ft^3, based on the dimension in Figure C.2. When all the pits are recharged with the lagoon effluent, the lagoon liquid level drops approximately 5 inches. However, if all the pits are drained when they are at full capacity (20,361 ft^3), the lagoon liquid level increases approximately 8 inches.

The pit recharge frequency is every 21 days during spring, summer, and fall months, and every 7 days during winter months. The farmer continuously changed the operation of liquid through the lagoon. The change in operation was controlled by the liquid level. During the research period, the operator used freshwater and recycle lagoon effluent to recharge the pit and changed the frequency of recharging the pits. However, the facility always recycle during winter months to reduce emissions of odors from the pits. The calculated pit recharge volume to the lagoon is 617 ft^3.

Wastewater Loading

It was found during the first visit to the farm, that the only sources of wastewater inside the buildings are the washout water and the drippers wastewater. Drinking water in each building is supplied by automatic waterers, thus minimize the amount of spilled water that enters into the pit. The information concerning the frequency of cleaning the building as well as the operational timing of the drippers was obtained from the facility manager.

The hose water flow rate was measured at the water hose located between the farrowing and gestation building. The calculated average flow rate at the faucet was 13 gal/min. However, a water pressure pump that provides a lower flow rate is used for hose cleaning.

The number of drippers in the G&B are 300 and 210, respectively. No drippers or misters are used in the farrowing unit. The 510 drippers starts working when the air temperatures inside the buildings reaches 88 °F. The excess of water from the drippers is collected inside the feed gutters where it is partially evaporated or is drank by the animal. The remains of the water drained from the sloped feed gutter to the pit.

The drippers are manually set to operate for 2 minutes in a 10 minutes cycle that lasts eight hours. This means that the drippers works for a total of 96 minutes per day.

The average flow rate from the drippers was calculated as 0.55 gal/hr. The flow rate was determined by collecting in a 100 mL beaker the water of several drippers at different areas across the building. The daily volume of water from the drippers was calculated as 60.36 ft^3 from which approximately 40 % is removed from the gutters by evaporation before it enter the pits.

The buildings are hose cleaned with a water pressure pump that has a flow rate of 3.6 gallons per minute and 250 psi. The frequency of cleaning and time spend varies from the farrowing unit to the breeding and gestation units. In the farrowing building the operator spends 4 hours per room and cleans 2 rooms per week. In the gestation and breeding units the operator estimates a water usage of 100 gal per week. The daily volume of washout water is calculated as 36.72 ft^3. A summary of all the daily lagoon wastewater loading is given in Table 5.2.

Table 5. 2. Manure and wastewater volume inputs, Shawnee farm.

Manure Volume			
Animal		*No of each*	*Total (ft^3/day)*
Boars		6	0.78
Gilts		15	1.95
Gestation Sows		480	62
Sows & Litters		120	49
		Total manure volume	114
Pit Recharge Water			
Pit	*Volume of Pit (ft^3)*	*Frequency (days)*	*Total (ft^3/day)*
1	5,537	21	264
2	3,710	21	177
3	3,710	21	177
		Total pit recharge volume	618
Washout Water			
Washout vol. (gal)		*Frequency (days)*	*Total (ft^3/day)*
1928		7	37
Drippers			
No. of misters	*Water use (gal/hr)*	*Frequency (hr/day)*	*Total (ft^3/day)*
510	0.066	8	35
Total Manure and Wastewater Loading			**804 ft^3/day**

Lagoon Survey

The survey of the lagoon was performed during the first visit to the farm in May 21, 1996. The top lagoon dimensions are 150 ft wide by 240 ft long with a 3:1 side slope. The bench mark was located at the southwest corner of the farrowing unit. The elevation survey data of the lagoon bank are given in Table C.3 and Figure C.3.

Two equally distant transects were used to determine the lagoon depth and the sludge thickness and to measure the electrical conductivity of the supernatant at different depths. The first transect was located near the outfall at 0 + 80 feet. The second transect was located at 1 + 60 feet. Depth measurements from each transect were collected at 10 ft from the bank shore. The data from both transects are given in Tables C.4 and C.5. Table C.6 gives the average sludge thickness and lagoon depth from the bottom flat area. As it is shown in Table C.6 the sludge accumulation was higher in the bottom area near the inlet pipe and it decreases as you move further toward the opposite side.

In May 15, 1997 the sludge depth was measured again to determine the sludge accumulation rate and the electrical conductivity. Electrical conductivity were measured at 60 ft from the offshore of the second transect. The transects were situated in the same locations, along the side bank of the lagoon. Depth measurements from both transects and average values at the bottom flat area are given from Tables C.7 to C.9.

Sludge volume increased 171 % since May 21, 1996 to May 15, 1997 or during 360 days of operation. Although the accumulated sludge near the outfall were measured higher, the difference toward the opposite side was considerately reduced by 20 % as it is shown in Table C.10. This indicates that the sludge accumulation at the bottom of the lagoon was more uniform during 1997 than 1996 survey.

The average sludge thickness in the lagoon side slope was determined using the depth measurements from each transect at 10 feet and 20 feet from both offshore. The average sludge accumulation values in the lagoon side slope for both years are given in Table C.11. Sludge deposits were also found higher near the outfall than in the opposite side slopes.

The average thickness value for both areas was used to determine the total sludge volume in the lagoon. An effective depth of 5.25 ft and 6.35 ft for 1996 and 1997, respectively, were used to determine the overall lagoon side slope area covered by the sludge. The total sludge volume accumulated in the lagoon during 360 days of operation is given in Table C.12.

The sludge accumulation rate was estimated base on 360 days and 1,036 days (since July 1994) of operation. According to Table C.1, the daily total solid production is 689 lbs TS/day, therefore, the accumulation rate for 360 days and 1,036 days are 0.09 ft^3/lb TS d and 0.03 ft^3/lb TS d.

Lagoon Liquid Zones and Stages Curves

Figures C.4 and C.5 have a plot of the volume capacity and surface area of the lagoon that were determined using the lagoon dimensions and the Equations 3.5 and 3.11. The maximum volume capacity and surface area at 9.25 ft (spillway) are 224,411 ft^3 (61.62 acre-in) and 33,244 ft^2 (0.76 acres), respectively. Based on the NRCS (1994) design standard, the volumetric loading rate for this anaerobic lagoon is 5.7 lbs. VS/1000 ft^3-day. The actual volumetric loading rate at the minimum drawdown level is 3.85 lbs. VS /1000 ft^3-day or 32 % lower than the recommended. Base on the actual organic loading rate the lagoon should be able to perform very well. The actual treatment volume is 105,270 ft^3, which is slightly lower (0.50 %) than that recommended by the NRCS.

5. 4 Description of the Facility Located at Goodwell

This farm is a totally confined 2000-sow breeding facility that has been in operation since January 1994. The facility is located in southern portion of Goodwell, Texas County, Oklahoma. The year average rainfall minus evaporation in the Panhandle is -57 inches. The anaerobic lagoon receives wastewater from three operational units, two breeding and gestation units and one farrowing unit (Figure D.1). Manure and wastewater from these buildings are collected in storage pits under slotted floors. Wastewater flushed from the pits drains by gravity to a single-cell anaerobic lagoon. No recycle lagoon effluent is used to recharge the pits. Lagoon effluent is pumped for irrigation to nearby croplands every month.

A steady number of animals in maintain in the operational units. According to the facility manager, in the last inventory they were 2,450 hogs, 1,081 head in each G&B and 288 head in the farrowing unit. The distribution of animals by type and the daily amount of manure produced are given in Table D.1. A summary of the manure volume is given in Table 5.3.

All three units have the same dimensions, 60 ft wide by 429 ft long with a longitudinal bottom slope of 0 %. Each building has two under floor pits similar to those used in the facility at Shawnee (Figure C.2) but here the pits have a "pull plug" in each opposite end. Information about the dimensions of the pits or the recharge liquid level was not given by the operator. This facility also use drinking channels but the information regardless their operation and flow rate were not provided. Same situation happened with the washout water. No misters or drippers cooling system is used in the buildings. Other information gathered from the facility manager is given in Appendix D.

The lagoon was surveyed to determine liquid level and sludge depth (Table D.2). Only one transept was necessary to determine sludge depth. The lagoon has a triangular shape with side slope of 3:1 and a total depth of 12.8 ft. The lagoon top dimensions are given in Figure D.1. One supernatant sample was collected at 4 feet beneath the surface. The lagoon volume and the surface area are plotted in Figures D.2 and D.3. These plots were determined by dividing Equations 3.5 and 3.11 by two. The maximum volume capacity and surface area at 10.8 ft are 1,169,145 ft^3 (322 acre-in) and 123,690 ft^2 (2.84 acre).

Table 5. 3. Daily manure volume.

Type	# of pigs	Manure Volume ft^3/day
Boars	50	6.5
Gilts	100	13
Gestation Sow	2,012	262
Sows & Litters	288	118
Total	2,450	400

5. 5 Validation Process and Results

Validation Process

The validation of the model was performed once the hydraulic and EC model were tested and calibrated at the OSU Swine Research Center. The calibrated factors in the evaporation and seepage equations were not changed during the validation procedure. The only source of runoff is from the lagoon sidewalls. The curve number was adjusted to 93 for the validation sites because the lagoon inner sidewalls were mostly covered by a layer of clay and poorly covered with grass. Input data was carefully analyzed prior to running both models. Weather data from the nearest Mesonet station was used (Figure 5.2), but significant distant from the facility was noticeable which can increase model uncertainty. For this reason, recorded on-site rainfall data were used in the validation sites instead of Mesonet precipitation data. The time period used to validate the model was limited by the availability of recorded liquid level or irrigation data for each site. The predicted lagoon liquid level and the EC were compared to the observed and measured data.

Table 5. 4. Distance from the validation sites to the nearest Mesonet station.

Validation Sites	Mesonet Stations	Approximate Distance (miles)
Poteau	Wister	8
Shawnee	Shawnee	9
Goodwell	Goodwell	5

Validation Results - Hydraulic Balance

a) Poteau Farm

The simulation was performed from November 11, 1996 through September 22, 1997 and the results were compared with the observed elevation data (Table B.13). The on-site rainfall data obtained from the facility manager is given in Table B.14. The model prediction compares well with the observed data as shown in Figure 5.3. The drops in the predicted and observed lagoon elevation are caused by the removal of lagoon effluent for land irrigation. During the simulation period the facility operator irrigated ten times for a total volume of 155,881 ft^3 (Table B.15). The computer program allows the users to modify the input data and make changes to the liquid operation when the simulation is running. Simulation was readjusted to start at the producers water level after irrigation (Table B.15). After the irrigation, the predicted followed the same trend as the observed elevation data, except for the period between March 3, 1997 to April 17, 1997. Predicted versus observed elevation and residual plots are shown in Figures 5.4 and 5.5. The dotted lines in the residual plot indicates that most of the predicted values were within ± 2 in. The associated statistical parameters are presented in Tables 5.5 and 5.6. The higher coefficient of determination and slope and the similarity between the average and the median are further evidence of the excellent performance of the hydraulic model. The intercept is not significant different from zero and the slope is not significant different from one. The regression equation explains a significant amount of the variation in the predicted liquid level.

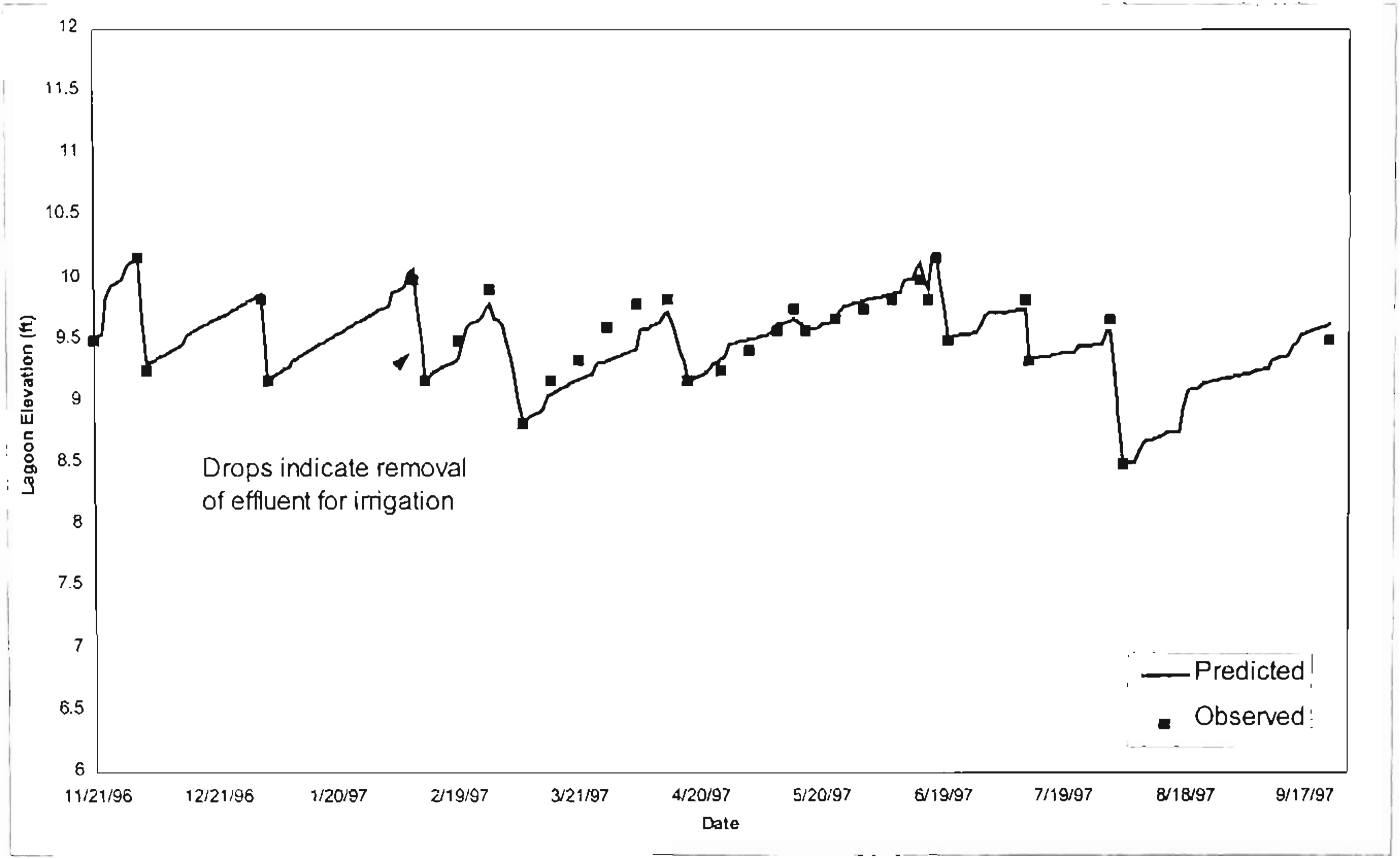


Figure 5. 3. Observed and predicted lagoon elevation for the facility located in Poteau from November 11, 1996 to September 22, 1997.

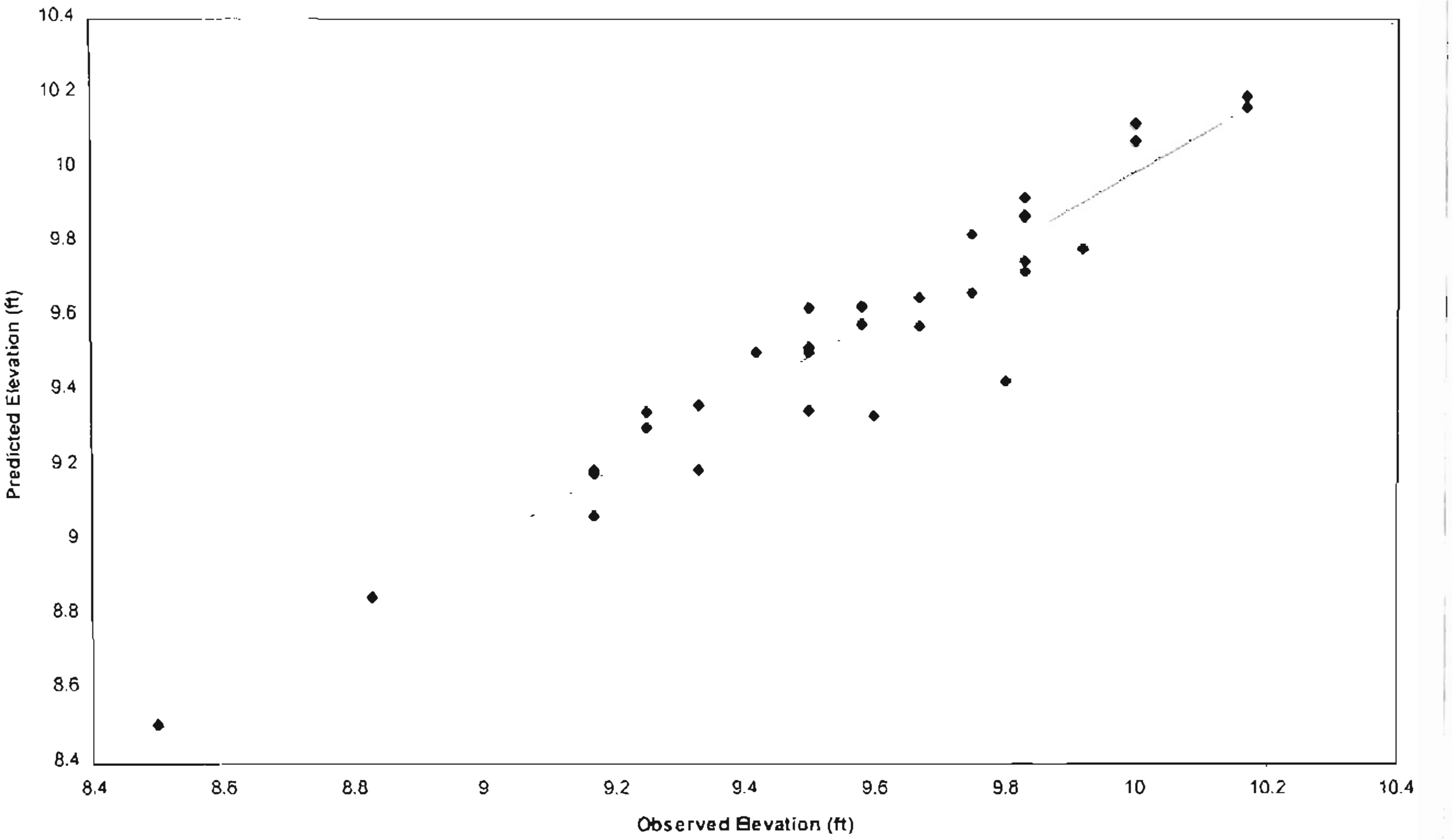


Figure 5. 4. Comparison of predicted and observed lagoon elevation for the facility located in Poteau.

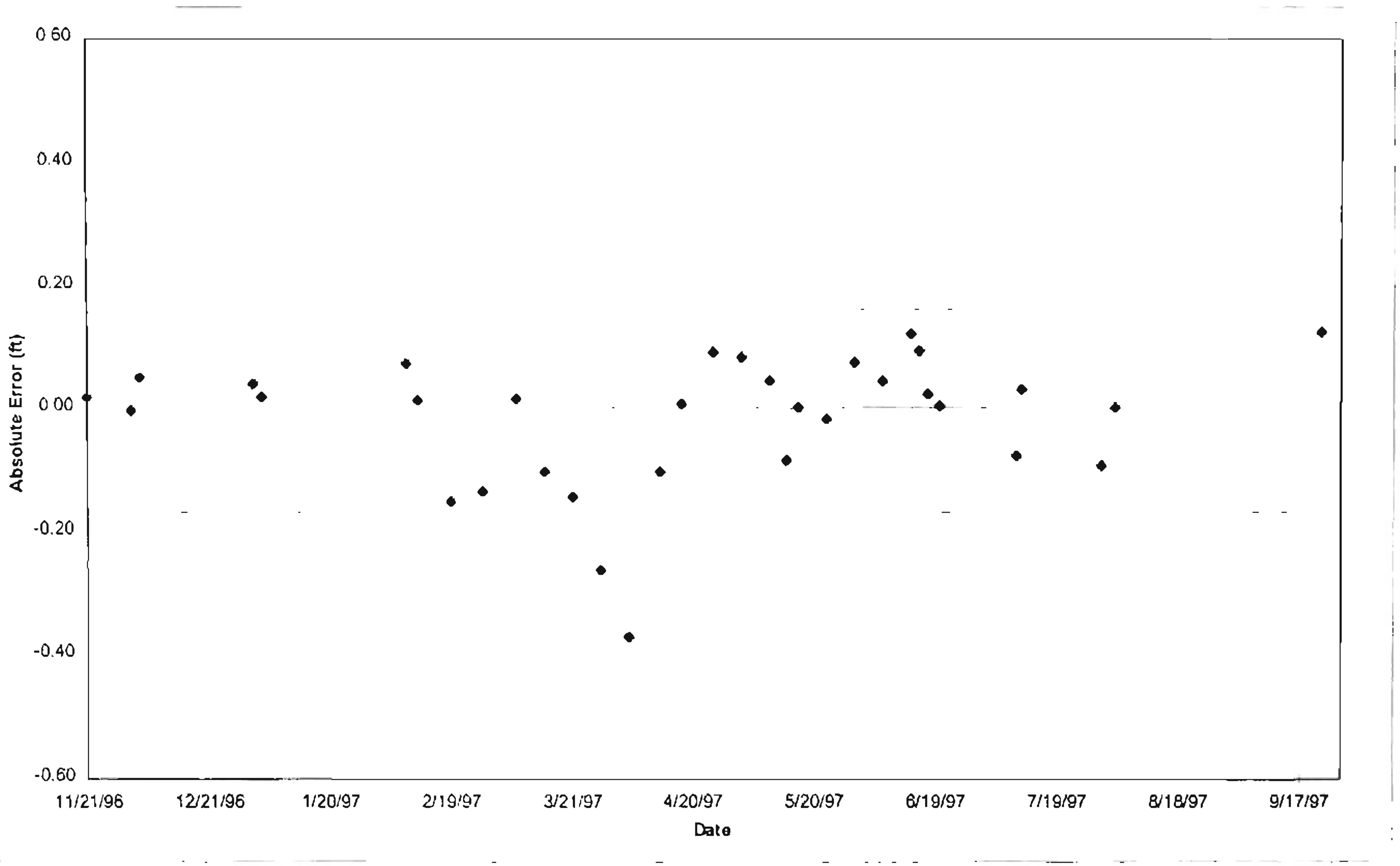


Figure 5. 5. Residual plot of the hydraulic balance for the facility located in Poteau from November 11, 1996 to September 22, 1997.

Table 5.5. Statistical analysis of the observed and predicted elevation for the facility located in Poteau.

	Predicted ft	Observed ft	Absolute Error, ft
Observations	33	33	33
Minimum	8.50	8.50	-0.37
Maximum	10.20	10.17	0.13
Range	1.69	1.67	0.50
Mean	9.54	9.56	-0.02
Variance	0.14	0.14	0.01
Std. Deviation	0.38	0.37	0.11
Std. Error	0.07	0.06	0.02
Median	9.58	9.58	0.02

Table 5. 6. Regression statistics and significance of the hydraulic model of the facility located in Poteau.

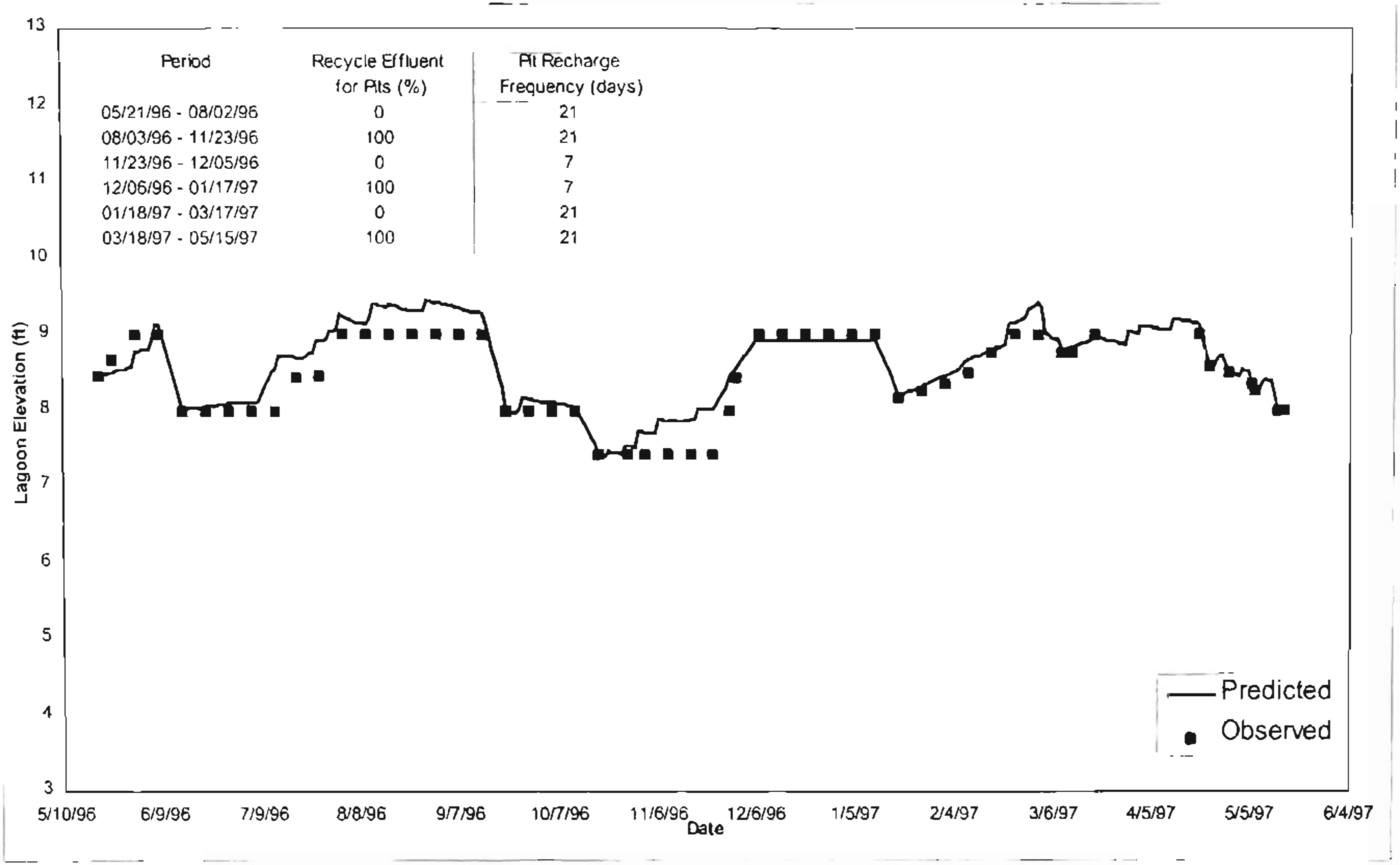
	Results	$\lvert t_{cal} \rvert$	$t_{0.975,31}$
r^2	0.92		
Std. Error	0.11		
Intercept	0.16	0.32	2.04
Slope	0.98	-0.38	2.04
Corr. Coef., r	0.96	18.53	2.04

b) Shawnee Farm

The model was run for the period starting in May 21, 1996 to May 15, 1997 and the results were compared with the observed elevation data given in Table C.13. Liquid operation in the production units and in the lagoon were continually changed during the research period. These changes included the frequency of pit recharge and the addition of fresh water or recycle lagoon effluent to the pits (Table C.14). According to the facility manager, the recycle rotation is determined by how close the liquid level is from the maximum operation level. In winter the manager prefers to recharge the pits more often (every 7 days) to reduce odors emission from the underfloor pits. All the changes in the liquid operation were inputted in the model according to the dates presented in Table C.14. Irrigation dates and volume pumped during the research period are given in Table C.15.

The results of the simulation are plotted in Figure 5.6. Simulation was stopped and reset at the producer provided water level after irrigation. The simulated liquid level properly matched the lagoon liquid level observations, although during some periods the predicted was a little off from the observed. Further investigation of the observed elevation and the rainfall data revealed that there were some errors associated to the recorded elevation data. The facility manager record a constant value of 9 feet when the liquid level was above the maximum operation level. This explained why the predicted elevation was higher from August 08 to November 22, 1997. During December 1996 to early January 1997 he also recorded a constant liquid level of 9 feet. Here the predicted elevation remained steady because no significant rainfall events were recorded and because the evaporation was very small. Other error were found when comparison of the rainfall events and the observed elevation for the periods of 06/15/96 to 07/13/96, 09/21/96 to 10/12/97, and 10/19/96 to 11/23/96 in which he recorded 8 ft, 8 ft, and 7.42 ft respectively. During these three periods the lagoon received significant amount of rainfall that would caused an increase in the lagoon elevation as it is shown in the simulation result. On-site rainfall data used during the simulation is given in Table C.16.

In general, the predicted observation followed the same trend as the observed data. The one-to-one plot and residual error are illustrated in Figure 5.7 and 5.8. The statistical analysis of the predicted, observed, the absolute error are given in Table 5.7. A regression analysis is given in Table 5.8. The low coefficient of determination and the differences between the average and the median of the observed and predicted elevation are caused by errors in the recorded liquid level data rather than the model prediction. However the mean error was very small (0.13 ft). The intercept of the regression line is statistically significant and the slope is not significant different from one. In general the regression line was significant.



Period	Recycle Effluent for Pits (%)	Pit Recharge Frequency (days)
05/21/96 - 08/02/96	0	21
08/03/96 - 11/23/96	100	21
11/23/96 - 12/05/96	0	7
12/06/96 - 01/17/97	100	7
01/18/97 - 03/17/97	0	21
03/18/97 - 05/15/97	100	21

Figure 5. 6. Observed and predicted lagoon elevation for the facility located in Shawnee from May 21, 1996 to May 15, 1997.

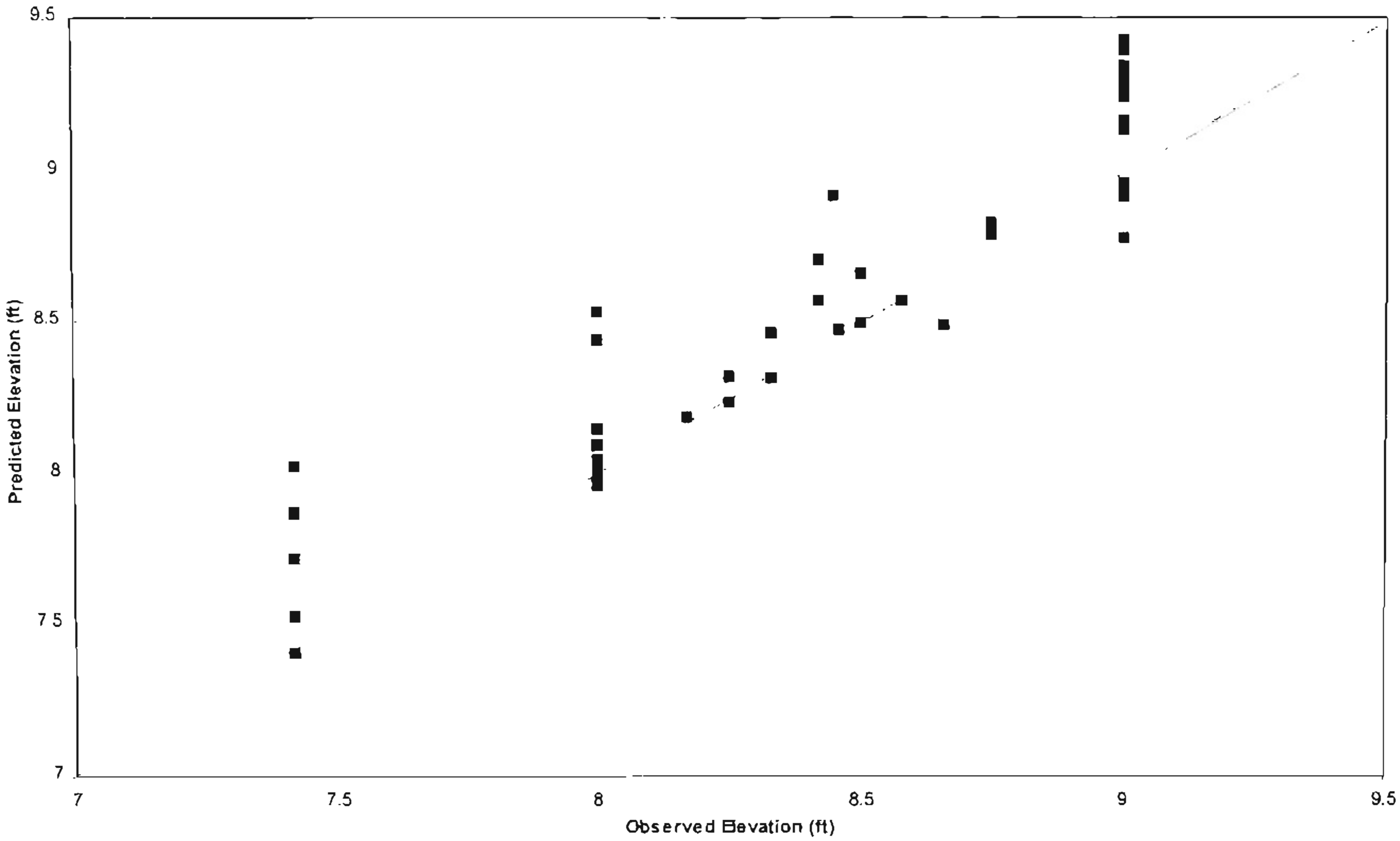


Figure 5. 7. Comparison of predicted and observed lagoon elevation data for the facility located in Shawnee.

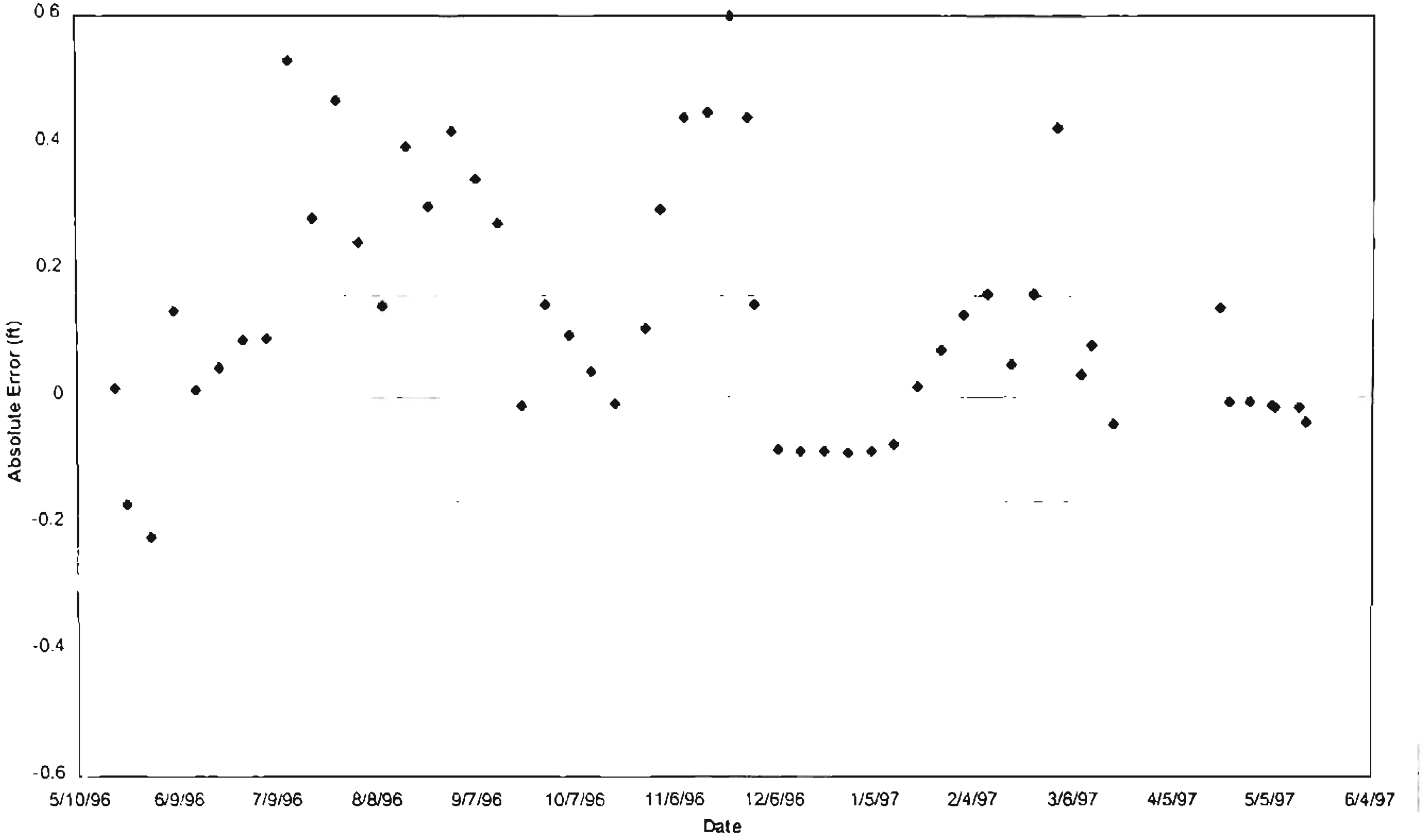


Figure 5. 8. Residual plot of the hydraulic balance for the facility located in Shawnee from May 21, 1996 to May 15, 1997

Table 5. 7. Statistical analysis of the observed and predicted elevation for the facility located in Shawnee.

	Predicted ft	Observed ft	Absolute Error, ft
Observations	53	53	53
Minimum	7.41	7.42	-0.22
Maximum	9.42	9.00	0.60
Range	2.02	1.58	0.82
Mean	8.56	8.44	0.13
Variance	0.28	0.29	0.04
Std. Deviation	0.53	0.54	0.19
Std. Error	0.07	0.07	0.03
Median	8.57	8.46	0.09

Table 5. 8. Regression statistics and significance of the hydraulic model of the facility located in Shawnee.

	Results	$\lvert t_{cal} \rvert$	$t_{0.975,51}$
r^2	0.87		
Std. Error	0.19		
Intercept	0.85	2.04	2.01
Slope	0.91	-1.74	2.01
Corr. Coef., r	0.93	18.64	2.01

c) Goodwell Farm

In order to validate the model, precise input data most be used otherwise errors from estimates will be reflected in the output as it is show in the sensitivity analysis (Chapter 7). Although the manager provided some operational data (Appendix D), these were not enough for a good validation. Because of the number of animals and buildings size, this facility could generated a wastewater volume of more that 4,000 ft^3. An estimate of inputs with this order magnitude is more likely to offset both simulations. Therefore, the model was not validated for the Panhandle region. However, it is expected to obtain all the required data and the authorization to inspect the facility during the summer of 1998.

Validation Results - Electrical Conductivity

a) Poteau Farm

Two types of rations are prepared for the B&G and the farrowing units. According to the facility manager, the amount of feed consumed per head in each unit is 5 lbs and 10 lbs., respectively. The total amount of feed supplied per unit is summarized in Table B.16. Values of calcium and sodium used in formulating the diets were supplied by the producer (Table B.17). Values from Tables B.16 and B.17 were used in Equations 3.51 and 3.52 to determine the total mass of these cations carryover in the waste and the soluble mass that enters to the lagoon (Table 5.9).

Table 5. 9. Daily mass of cations at different stages (lbs./day).

Stage	Ca^{2+}	Na^{2+}
Feed (X_i)	34.1	24.1
Waste ($X_i y_i$)	25.2	21.1
Soluble (S_i)	5.03	16.1

Mass of cations carryover in the waste was estimated using the fraction of higher dosage in diets and aged swine (Table 2.1). The concentration of EC that flows into the lagoon was estimated by substituting the soluble mass values given in Table 5.9 into the Equation 3.54, resulting an input concentration of 28 mg/L and a mass loading rate of 0.1582 lbs./day.

Wastewater from hose cleaning, drinking channels, and misters increases the mass of EC loading. EC of the well water was measured as 0.638 dS/m which causes a contribution of 0.0173 lbs. and 0.0165 lbs per day. The variation in the loading is caused by the operation of the misters.

EC simulation was run from November 11, 1996 to September 22, 1997 and the predicted EC values were compared with the EC measured at the lagoon supernatant (Table B.18). The model underestimates the observed EC measurements (Figure 5.9); however, the predicted values follow the same positive trend as the observed data. Statistical analysis (Table 5.10) indicated a mean error of -0.71 dS/m. The drops in the predicted plot, are caused by the dilution effect due to rainfall and the removal of EC by irrigation. A comparison of the EC loading of this facility versus OSU's Swine Research facility result in a higher EC loading due to the large sodium content in the diets. However, the frequent irrigation and the large volume of wasted drinking water provide enough dilution to maintain the EC levels within the recommended level.

Replacing the drinking channels with automatic waterers will reduce the volume of freshwater pumped from the well, the daily liquid loading to the lagoon, and the frequency of irrigation. These changes may also increase the EC loading by a factor of three, resulting in a higher EC values in the lagoon supernatant (assuming 100 % recycle). Recharging the flush tanks with fresh water will reduce the supernatant EC but it will generate large consumption of freshwater and wastewater volume and more frequent irrigation schedule. If salts levels increase in this lagoon, the only economical solution for the farmer is to feed the animal with diets having lower salt content. Rea et al. (1990) recommended that 0.25 to 0.50 percent salt be added to diets of boars, pregnant females, and lactating females.

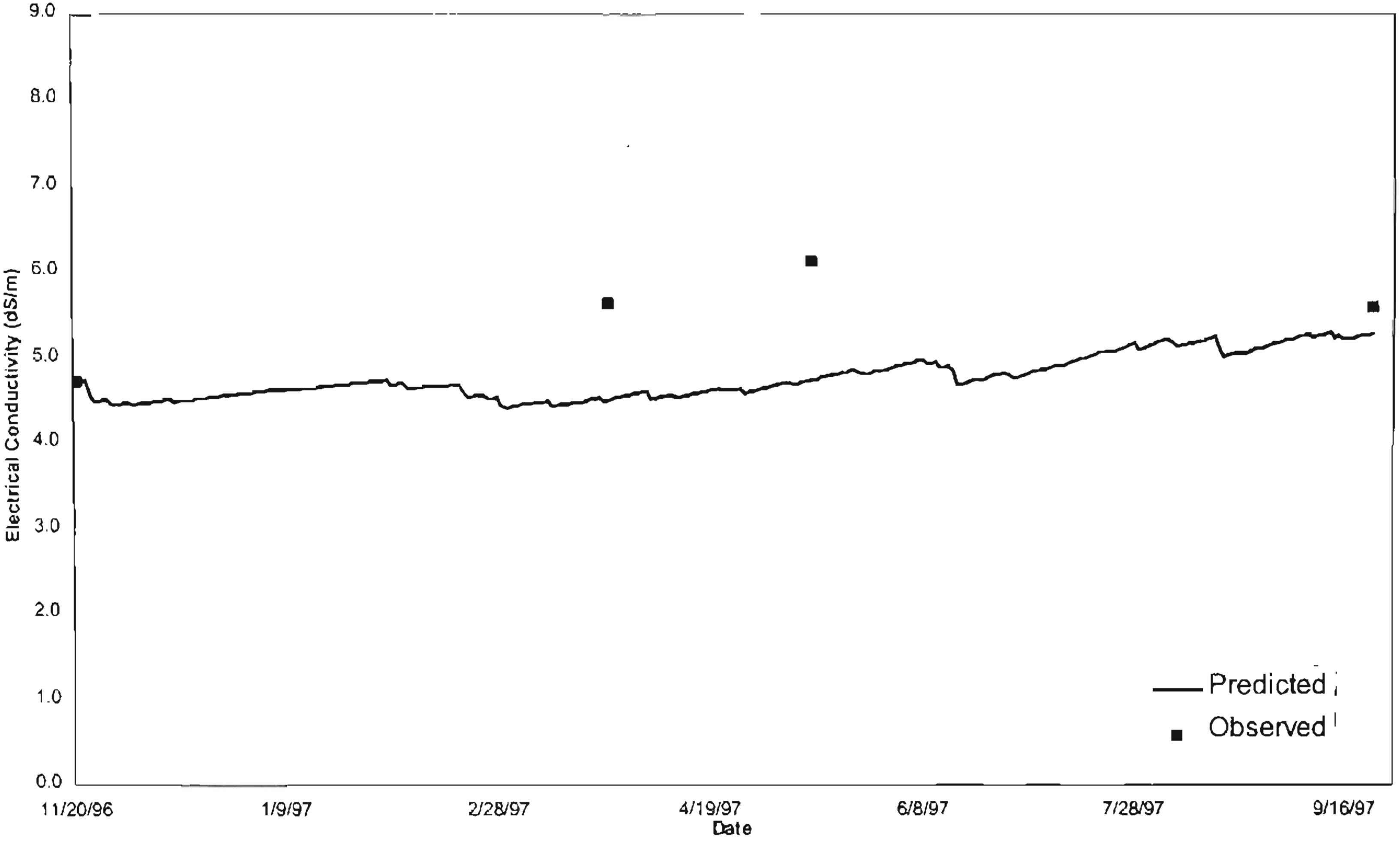


Figure 5. 9. Observed and Predicted supernatant EC for the facility located in Poteau from November 11, 1996 to September 22, 1997.

Table 5. 10. Statistical analysis of the observed and predicted supernatant EC for the facility located in Poteau.

	Predicted dS/m	Observed dS/m	Absolute Error, dS/m
Observations	4	4	4
Minimum	4.51	4.73	-1.39
Maximum	5.28	6.13	0.00
Range	0.77	1.40	1.39
Mean	4.82	5.52	-0.71
Variance	0.11	0.34	0.43
Std. Deviation	0.33	0.58	0.66
Std. Error	0.16	0.29	0.33
Median	4.74	5.62	-0.72

b) Shawnee Farm

The producer did not provide the values of the composition of feedstuff. The same percent of calcium and sodium used in Poteau were applied here because this facility has similar production operation. The amount fed at a daily level was the only information obtained from the facility manager (Table C.17). Table 5.11 summarize the amount of salts in the feed, carryover in the waste, and the soluble portion that flows into the lagoon. A similar procedure used in the previous farm to estimate mass of EC loading was applied here. The resulting concentration of EC was 24 mg/L or a daily mass of 0.1711 lbs.

During the first visit to the facility the EC from the well was measured as 0.88 dS/m. The contribution of the EC from the freshwater and the total loading to the lagoon is summarized in Table 5.12. The variation in EC loading is caused by the variation in the liquid handling through the system.

The simulation was performed for May 21, 1996 through May 15, 1997. The results were compared with the observed EC measurements from the lagoon supernatant (Table C.18). The predicted EC follows a closed pattern of the observed (Figure 5.10). An statistic analysis is given in Table 5.13. Mean error was smaller (-0.17 dS/m) that for Poteau (-0.71 dS/m). During the three recycle periods (Table C.14) the simulated EC showed a higher positive slope in comparison with periods of no recycle or when the pit were recharged with freshwater. The drops in the predicted plot were caused by the removal of EC through irrigation, rainfall and the use of freshwater to recharge the pits. These changes in the liquid operation allows the supernatant EC to be maintained within the recommended level. However, the observed EC measurements are getting closer to 8 dS/m, which is the maximum level recommended for optimal biological activity (Georgacakis and Samantouros, 1986).

Table 5. 11. Daily mass of cations at different stages (lbs./day).

Stage	Ca^{2+}	Na^{2+}
Feed (X_i)	49	33
Waste ($X_i\gamma_i$)	36.3	26.7
Soluble (S_i)	7.25	20.3

Table 5. 12. Mass of EC from freshwater and from total loading.

Sources	Freshwater EC, lbs./day	Total EC, lbs./day
pit, washout water, and drippers	0.03	0.21
pit and washout water	0.03	0.20
washout water and drippers	0.004	0.18
washout water	0.003	0.17

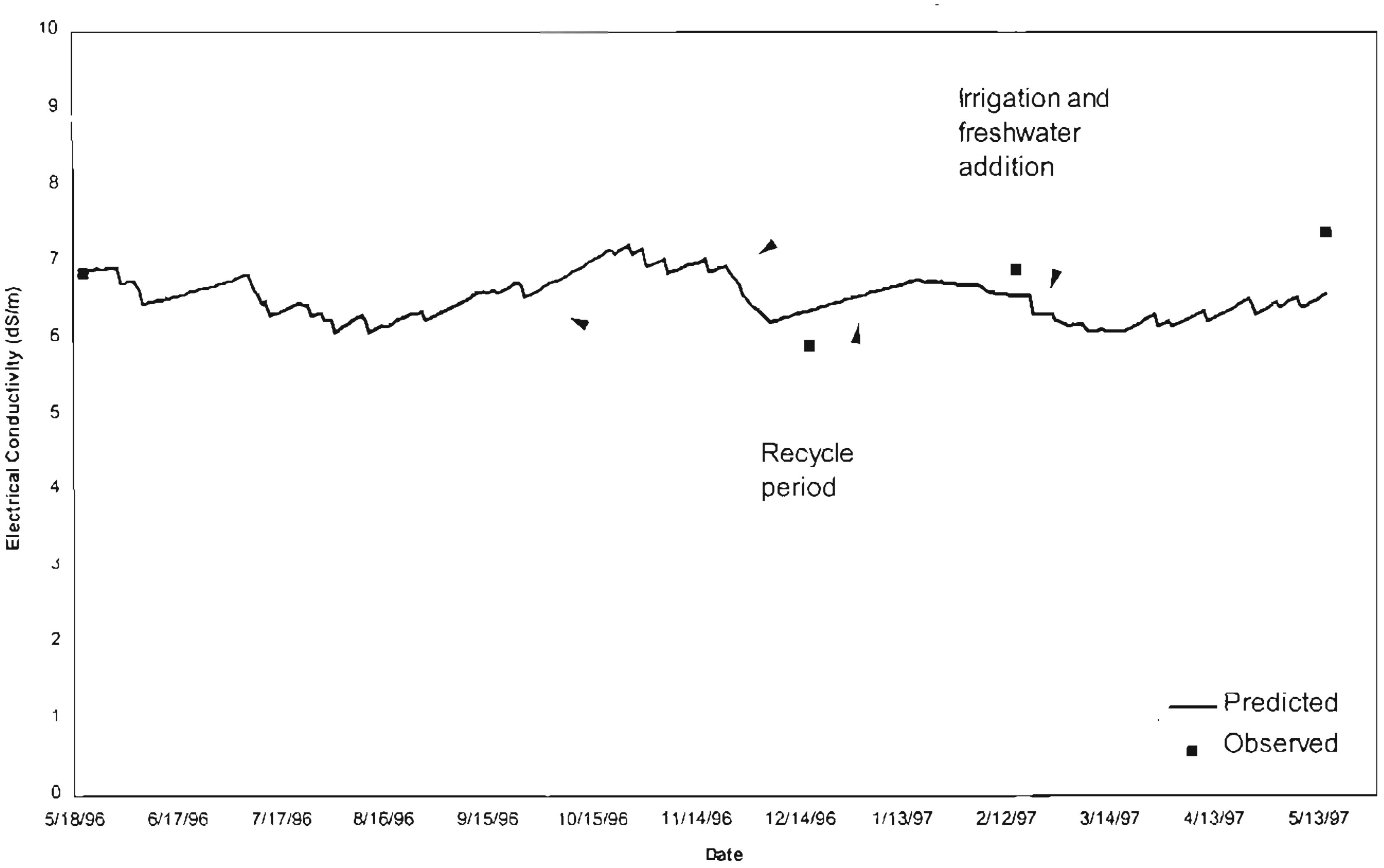


Figure 5. 10. Observed and predicted supernatant EC for the facility located in Shawnee from May 21, 1996 to May 15, 1997.

Table 5. 13. Statistical analysis of the observed and predicted supernatant EC for the facility located in Shawnee.

	Predicted dS/m	Observed dS/m	Absolute Error, dS/m
Observations	4	4	4
Minimum	6.37	5.90	-0.81
Maximum	6.87	7.40	0.47
Range	0.51	1.50	1.27
Mean	6.60	6.77	-0.17
Variance	0.04	0.39	0.29
Std. Deviation	0.21	0.63	0.54
Std. Error	0.10	0.31	0.27
Median	6.58	6.89	-0.16

CHAPTER 6

SENSITIVITY ANALYSIS

6. 1 Overview

A sensitivity analysis was performed to identify which model components processes and parameters have the greatest impact on the model output. This analysis determines parameters in the model that require particular attention during actual data collection to reduce model uncertainty, and parameters that can be less precisely estimated without affecting the performance of the model.

Different methods have been developed for the application of sensitivity analysis to hydrologic models. Haan et al. (1995) described two types of sensitivity analysis which are defined as:

$$S_a = \frac{\partial \cdot O}{\partial \cdot P} \tag{6.1}$$

$$S_r = \frac{\partial \cdot O}{\partial \cdot P} \frac{P}{O} \tag{6.2}$$

where S_a is the absolute sensitivity coefficient, S_r is the relative sensitivity coefficient, O is the output of interest, and P the particular input parameter. S_a gives the absolute change in O for a unit change in P while S_r gives the % change in O for a 1 % change in P.

The absolute sensitivity can not be ranked on the basis of sensitivity because it has units of input and output. Because parameters tested (input) are more likely to have different units, the resulting absolute sensitivity will also have different units which make it difficult to compare sensitivities among parameters. This problem can be overcome by the application of relative sensitivity which is dimensionless and can be compared across parameters. Parameters can be ranked, with the highest S_r showing the greatest impact on the model output.

When applying this methodology to hydrologic model, it is impossible to solve $\partial O/\partial P$ directly. Relative sensitivity can be numerically approximated as:

$$S_r = \frac{P}{O}\frac{(O_2 - O_1)}{(P_2 - P_1)} \tag{6.3}$$

where P and O are the base values of inputs and outputs, respectively. The base values are changed by a constant "percent change" to obtain P_1, P_2 and their corresponding O_1, and O_2. This approximation assumes that the model response is linear in the range of interest.

6. 2 Hydraulic Balance - Sensitivity Procedure and Results

Sensitivity Procedure

The sensitivity analysis was performed using 14 parameters including facility operational and weather data, and internal parameters required by the model (some of which were adjusted during the calibration process). The output considered was the lagoon liquid level.

The OSU's Swine Research Center was selected for the sensitivity analysis. The model was run from May 15, 1997 to July 31, 1997 using the same input data and the same adjusted variable values obtained from the model calibration. Results from this run will henceforth be known as the base values because they are used as baseline condition for comparison purpose. A constant percent change of ±10 % was applied to each parameters from the baseline condition during each run while keeping the other parameters unchanged. The baseline (0 %) and ±10 % estimates of each parameters are given in Table 6.1. A ±10 % was applied to the daily weather data.

Table 6. 1. Parameters used in the sensitivity analysis of the hydraulic balance.

Parameter	Baseline, 0 %	-10 %	+ 10 %
Volume of manure and washout water (MW)	430	387	473
Lagoon total depth (d)	15.3	13.8	16.8
Hydraulic conductivity (k)	1.50×10^{-8}	1.36×10^{-8}	1.66×10^{-8}
Runoff (maximum soil water retention, S)	1.11	1.00	1.22
Albedo (α)	0.05	0.045	0.055
Precipitation (P)	Daily Mesonet data	P - 10 %	P + 10 %
Wind (u_2)	Daily Mesonet data	u_2 - 10 %	u_2 + 10 %
Temperature (T_c)	Daily Mesonet data	T_c - 10 %	T_c + 10 %
Relative humidity (R_h)	Daily Mesonet data	R_h - 10 %	R_h + 10 %
Solar Radiation (R_s)	Daily Mesonet data	R_s - 10 %	R_s + 10 %
Evaporation (E)	Daily estimated	E - 10 %	E + 10 %
Mean solar radiation for cloudless skies (R_{so})	Table E.1	R_{so} - 10 %	R_{so} + 10 %
Energy storage factor (f_{se})	Table E.2	f_{se} - 10 %	f_{se} + 10 %
Lagoon surface area, S_a (Figures E.1 and E.2)	97,800	79,218	118,338

Sensitivity Results

Results from the relative sensitivity are given in Table 6.2 and with time-series plots for visual comparison (Figures 6.1 to 6.16). The effect of the ±10 % change on the lagoon liquid level after a period of six months and one year is given in Table 6.3. Since the model simulates lagoon elevation in a daily-time-step procedure, any erroneous data inputted during the run will offset the predicted plot.

The effect of the ±10 % change of each parameter were analyzed only with respect to the lagoon liquid level. Among the model components evaporation has the greatest effect on the performance of the model followed by precipitation, volume of manure and washout water, and seepage (Table 6.2). Evaporation was three times more sensitive than wastewater inputs. However, the parameter with the highest impact on the model output is the solar radiation.

The lagoon evaporation is the most important component in the lagoon liquid balance and the one which requires more data for estimation. Therefore, it is more likely to obtain uncertainty on the model output throughout the evaporation component than any other components in the hydraulic model. As show in Figure 6.1, the sensitivity of the model output caused by evaporation is reflected just after few days from the starting date and the difference from the baseline progressively increased (-10%) or decreased (+10%) during the run. Higher estimate of the evaporation will increase the volume of evaporation losses from the lagoon surface, thus decrease the effluent storage volume.

Among the four weather data used to estimate evaporation, solar radiation showed the greatest offset followed by relative humidity, air temperature, and wind speed. Solar radiation caused approximately a difference of 2.39 inches of liquid depth after 6 months of operation (46 acre-in volume) (Figure 6.2). The sensitivity of the other three weather parameters is illustrated in Figures 6.3 to 6.5 and Table 6.2. Because most Mesonet weather stations are distant from swine operation (Table 5.4), it is more likely to input uncertain weather data to the model. There exists a variability in space and time in these weather parameters. However, for the validation sites, it was assumed that evaporation parameters were spatially homogenous within a radius of 20 miles from the Mesonet station. This assumption was tested in the validation sites, in which the model prediction were within 1 % of the observed data in most of the time.

The sensitivity of the model to the other internal parameters in the evaporation equation are given in Figures 6.6 to 6.8. The model is slightly affected by measurements on the mean solar radiation for cloudless skies. Insignificant sensitivity is found with the albedo number. The energy storage has little sensitivity on the model performance.

The effect of precipitation on the lagoon level is remarkable as shown in Figure 6.9 and Table 6.2. After six months the difference in liquid depth was 2.27 inches. The estimates on precipitation will change the runoff volume and the rainfall volume on top of the lagoon. The peaks in water level are caused by precipitation and runoff. However, a comparison of the peaks height reflected a higher peak in Figure 6.9 than in the others plots.

Insignificant variation were found between historic Mesonet precipitation data and observed rain gauge at the calibration site. This condition did not apply to the validation sites. It was not assumed that precipitation was spatially homogeneous for the validation sites. Therefore, on-site rain gages were used to record precipitation data for the model validation.

It is important to mention that the sensitivity on the model output may vary from other facilities with smaller or larger operational size. Nevertheless, the order of sensitivity of weather parameters and internal evaporation parameter on the performance of the model will remain the same from a baseline condition.

A ± 10 % on the manure and washout volume also caused a significant change in the liquid level after 6 months. This change would be larger if the lagoon surface area is smaller. The actual loading of manure and washout volume to the lagoon will increase the daily liquid level by 0.06 inches. This small contribution drastically changed the model output as illustrated in Figure 6.10. After six months of operation, the model over or under estimated an average of 1.05 inches of lagoon depth or 2 acre-in of lagoon volume.

As expected, +10 % of CN had a significant effect on the lagoon elevation whereas the maximum soil water retention (S) parameter had negligible effect (Figures 6.11 and 6.12). The low relative sensitivity is as a result of the small area susceptible to runoff compared to the 2-acre size lagoon. The runoff area only accounts to 18 % of the lagoon surface area.

The analysis shows the model is not sensitive to the hydraulic conductivity, at least within the ± 10 % range (Figure 6.13). Because it is difficult to physically measure hydraulic conductivity within 10 %, the sensitivity was tested based on a plus or minus one and two orders of magnitude change in hydraulic conductivity (Figure 6.14). The model is highly sensitive when the k value is increased up to two orders of magnitude. When k is equal to 10^{-7} cm/sec, the model underestimate actual liquid level by 3.33 ft after six months (Table 6.3). Higher estimate of k will increase seepage rate from 26 ft^3/day (baseline) up to 1,300 ft^3/day (10^{-6} cm/sec).

The lagoon surface area significantly affected the model output as illustrated in Figure 6.15. Larger surface area increases evaporation losses, volume of rainfall on top of the lagoon, seepage area, sidewalls runoff, and decreases or makes insignificant the changes in lagoon elevation due to manure and washout volume. Thus, when lagoon dimensions are overestimated the liquid level will be underestimated.

Based on these analyses, all data inputted in the model were excellent since the adjustment of the energy storage factor made a large difference in being able to predict lagoon level.

Table 6. 2. Relative sensitivity of the hydraulic balance parameters.

Parameters	Relative Sensitivity
Hydraulic conductivity (k)	0.01
Volume of manure and washout water (MW)	0.17
Precipitation (P)	0.35
Evaporation (E)	0.41
Solar Radiation (R_s)	0.32
Temperature (T_c)	0.17
Relative humidity (R_h)	0.19
Mean solar radiation for cloudless skies (R_{so})	0.11
Wind (u_2)	0.08
Energy storage factor (f_{se})	0.09
Albedo (α)	0.02
Runoff	
maximum soil water retention, S	0.02
CN	0.11
Lagoon dimensions (L x W)	0.21

Table 6. 3. Results of ± 10 % parameter estimates on liquid level elevation (in) after six months and one year.

	After six months		After one year	
Parameters	-10 %	+ 10 %	-10 %	+ 10 %
Hydraulic conductivity (k)	0.07	0.07	0.14	0.14
Volume of manure and washout water (MW)	1.07	1.05	1.94	1.91
Precipitation (P)	2.27	2.25	3.66	3.79
Evaporation (E)	2.99	3.01	4.20	4.21
Solar Radiation (R_s)	2.39	2.40	3.26	3.07
Temperature (T_c)	1.95	2.21	3.01	3.04
Relative humidity (R_h)	1.24	1.23	1.98	2.18
Mean solar radiation for cloudless skies (R_{so})	0.82	0.68	1.28	1.06
Wind (u_2)	0.51	0.51	1.02	0.98
Energy storage factor (f_{se})	0.41	0.41	0.75	0.78
Albedo (α)	0.16	0.16	0.23	0.23
Runoff maximum soil water retention, S)	0.09	0.07	0.13	0.11
CN	0.27	1.13	0.38	1.81
Lagoon dimensions (L x W)	2.93	2.29	5.28	4.10

Table 6. 4. Differences in liquid level caused by hydraulic conductivity from base value 1.5×10^{-8} cm/sec.

Hydraulic Conductivity cm/sec	After six months (in)	After one year (in)
1×10^{-6}	- 40	- 69
1×10^{-7}	- 4	- 8
1×10^{-8}	+ 0.2	+ 0.5
1×10^{-9}	+ 0.7	- 1

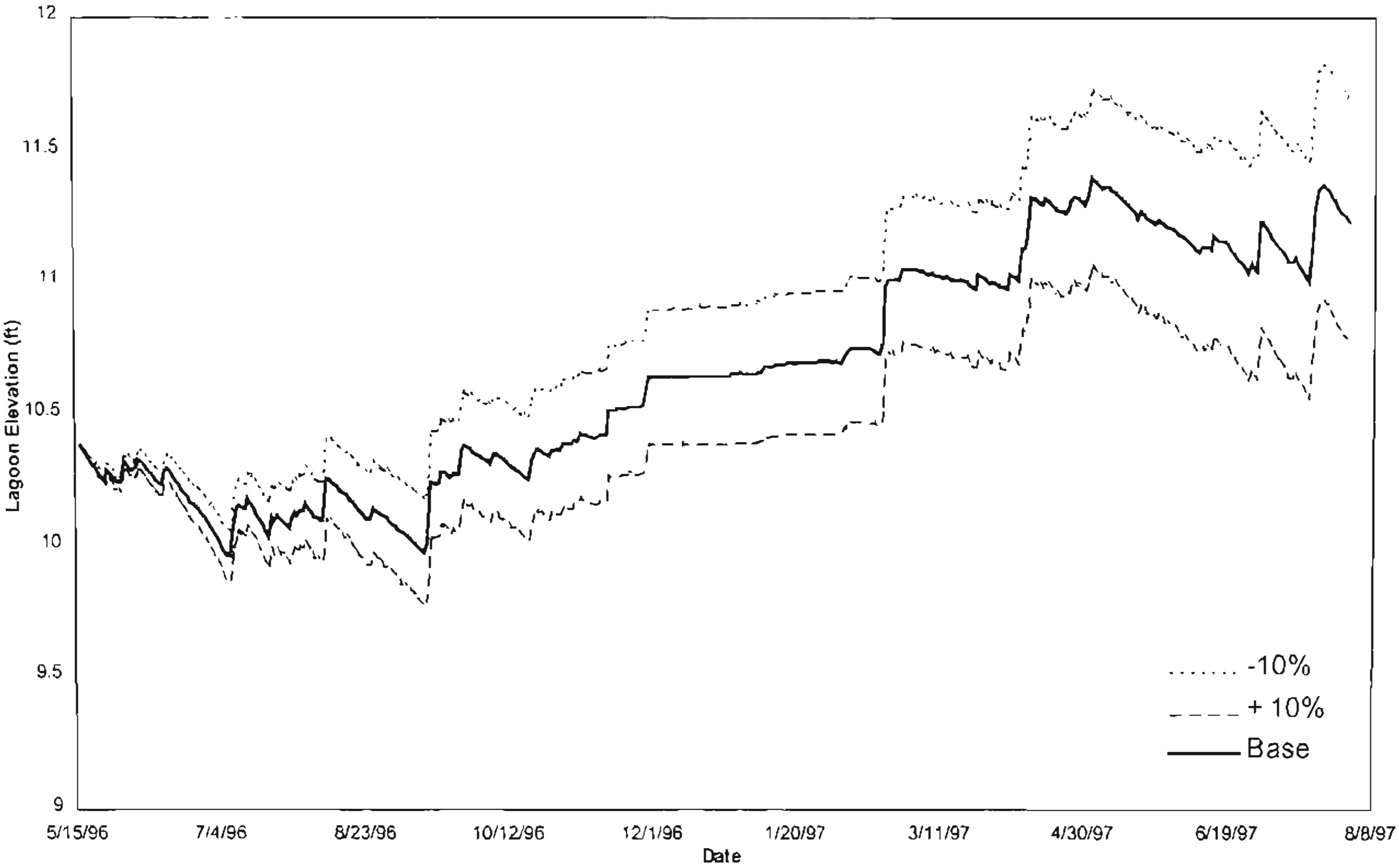


Figure 6. 1. Sensitivity of lagoon liquid level to the evaporation.

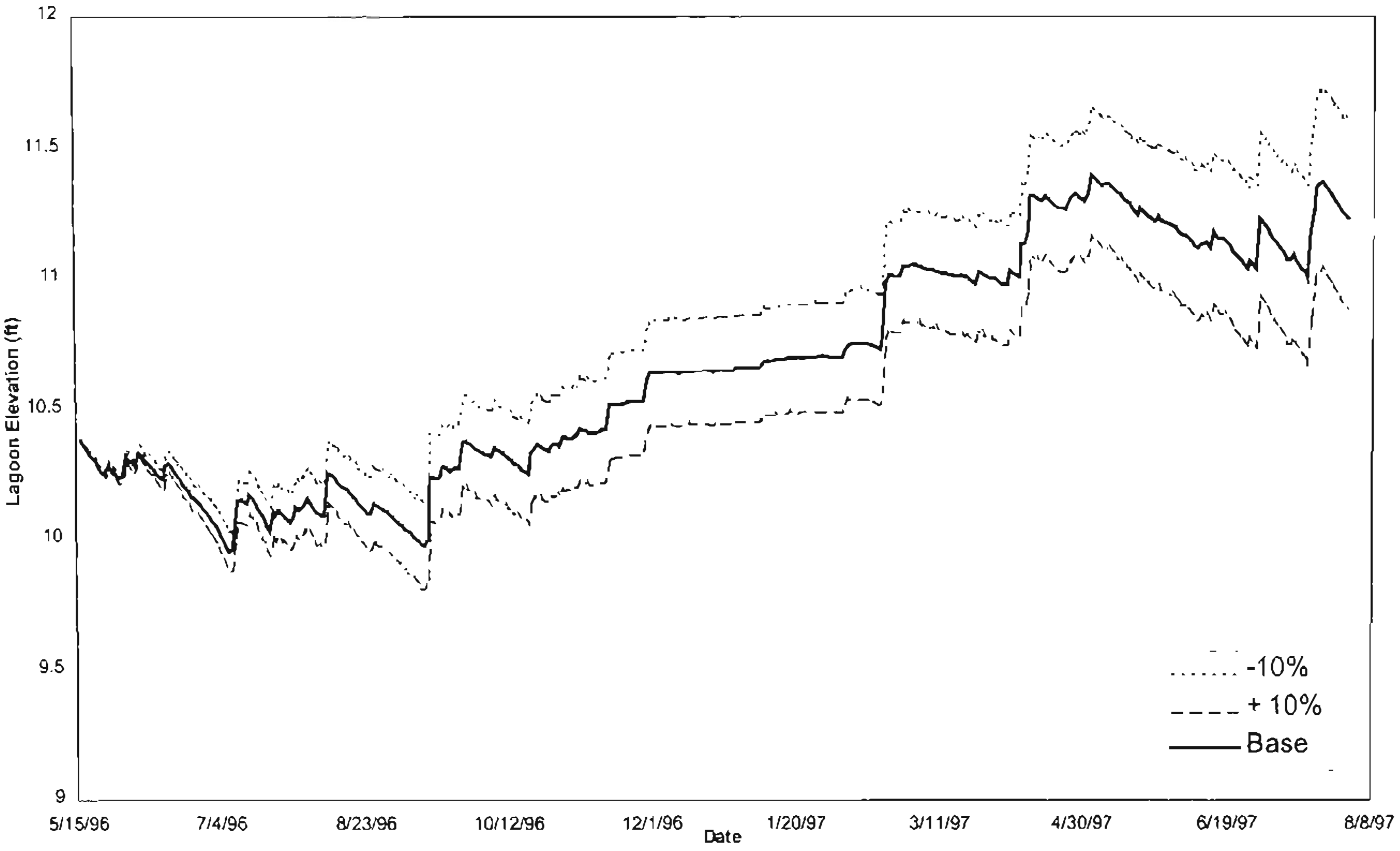


Figure 6. 2. Sensitivity of lagoon liquid level to the solar radiation (R_s).

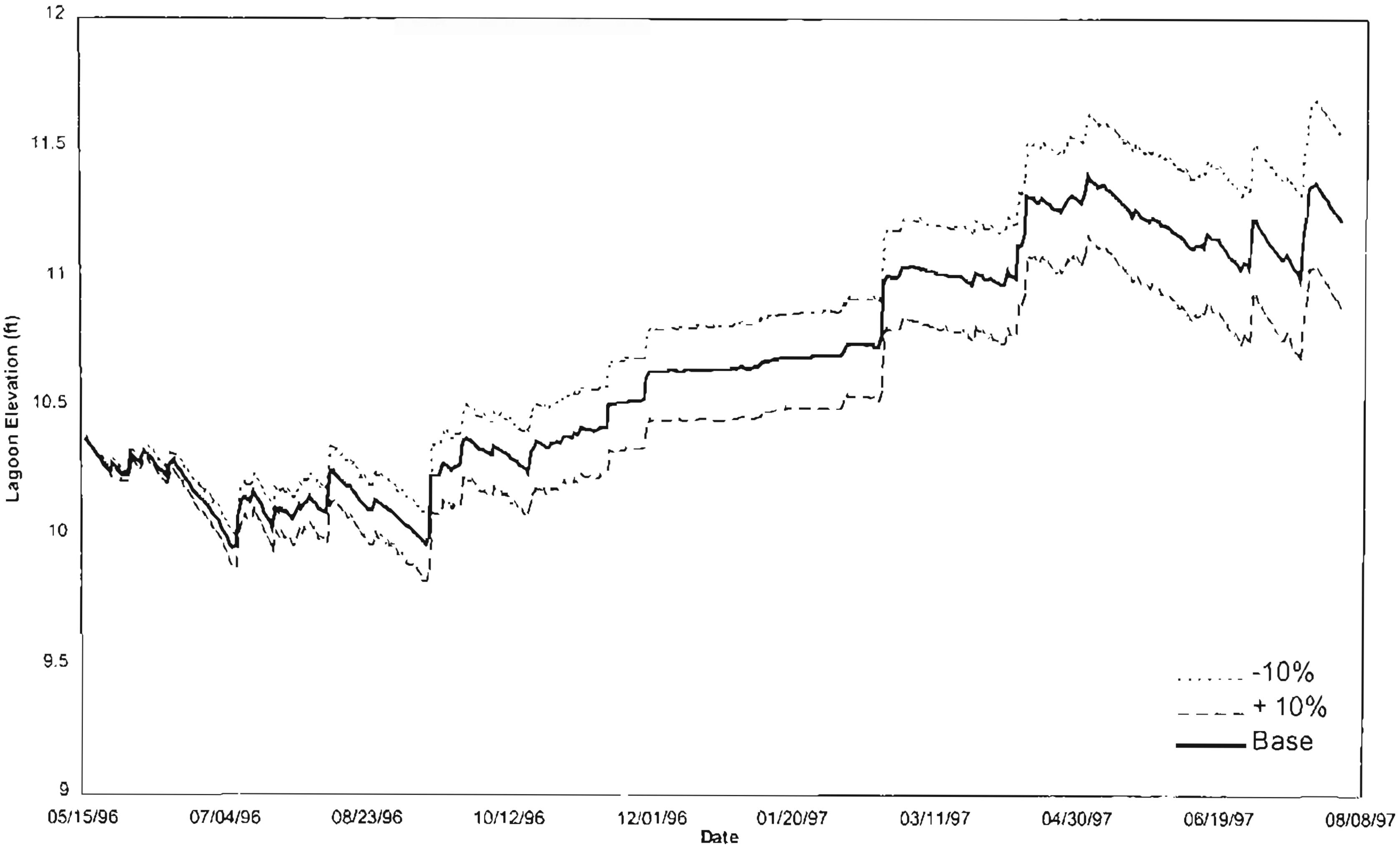


Figure 6. 3. Sensitivity of lagoon liquid level to the air temperature (T_c).

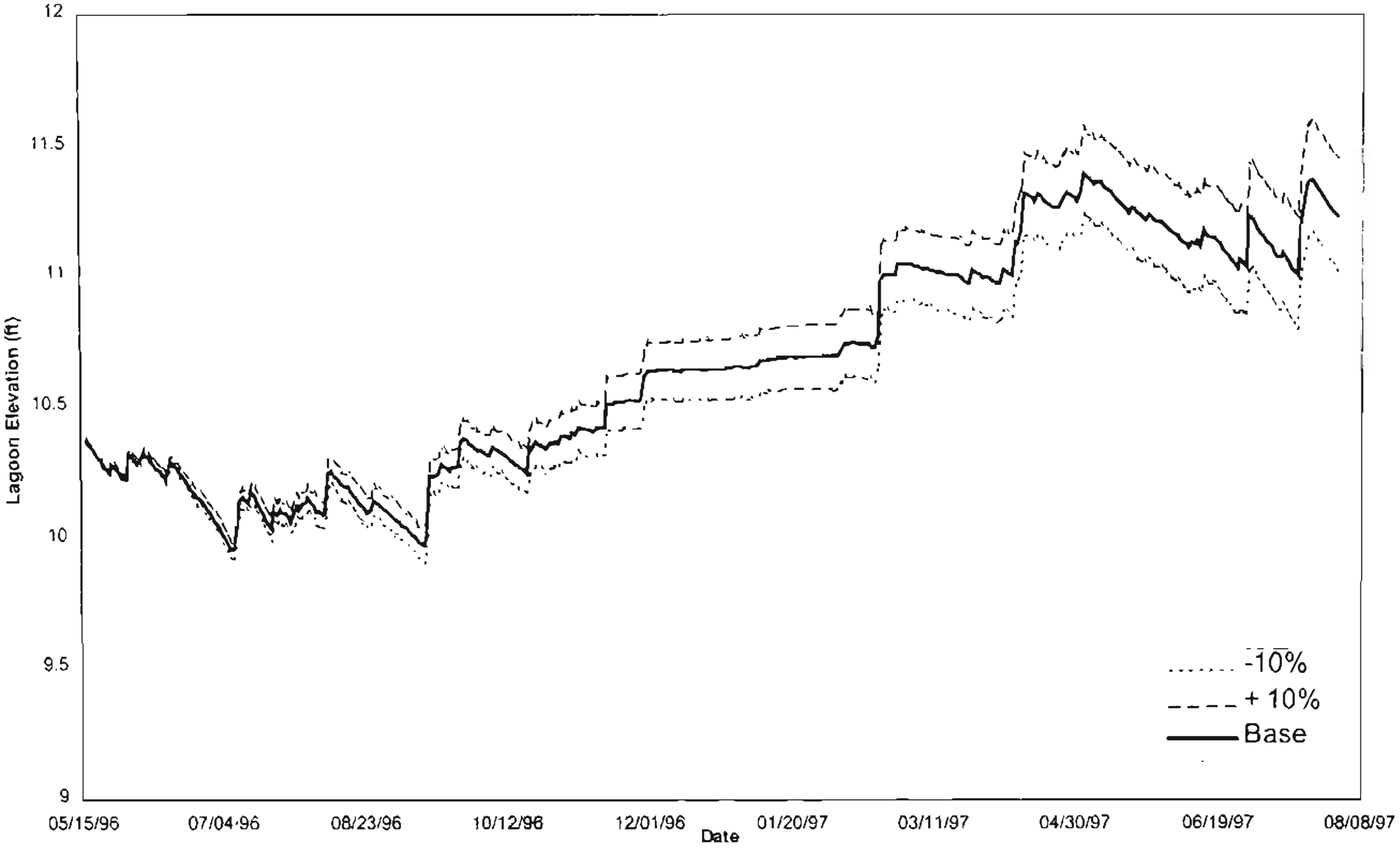


Figure 6. 4. Sensitivity of lagoon liquid level to the relative humidity (R_h).

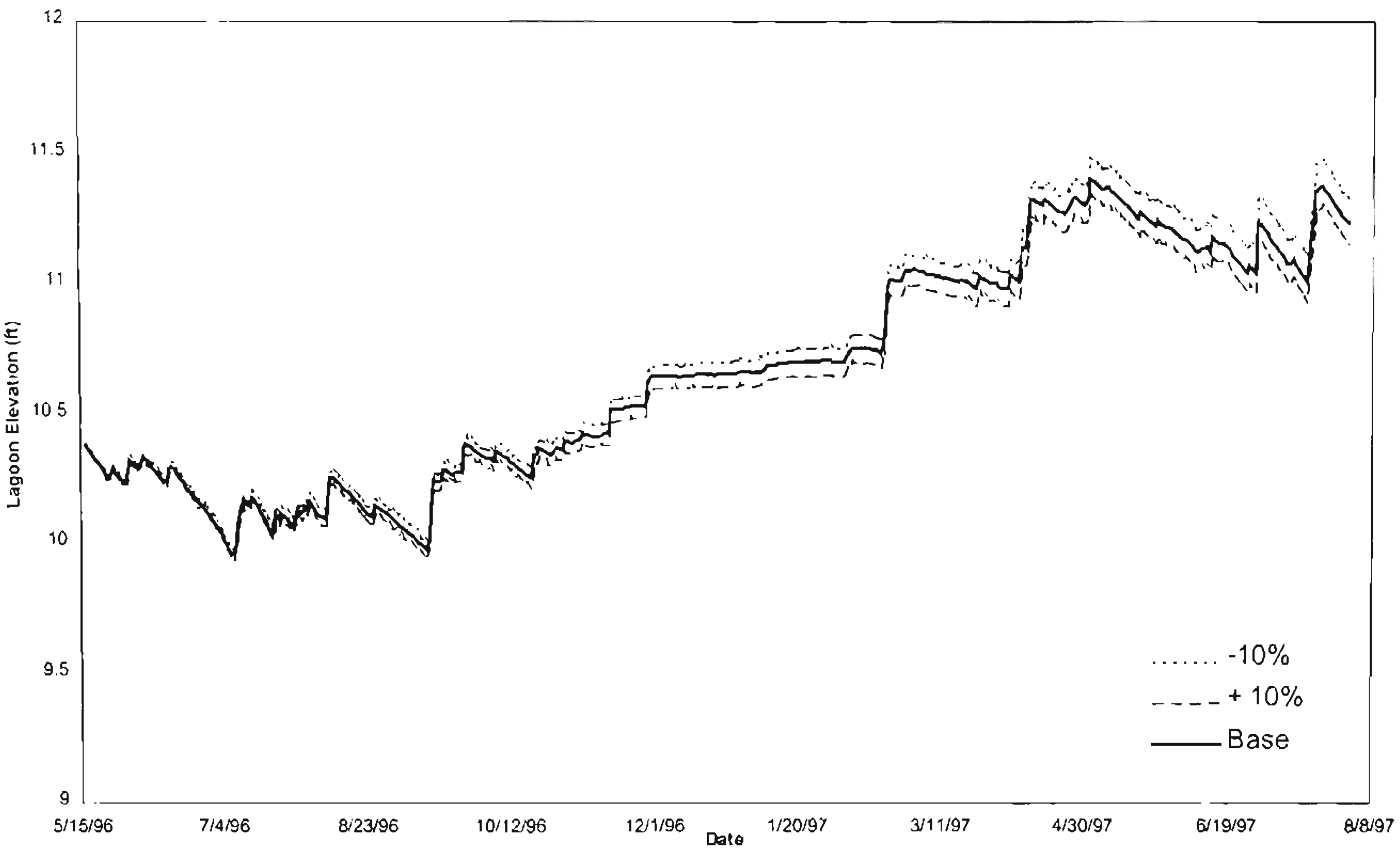


Figure 6. 5. Sensitivity of lagoon liquid level to the wind (u_2).

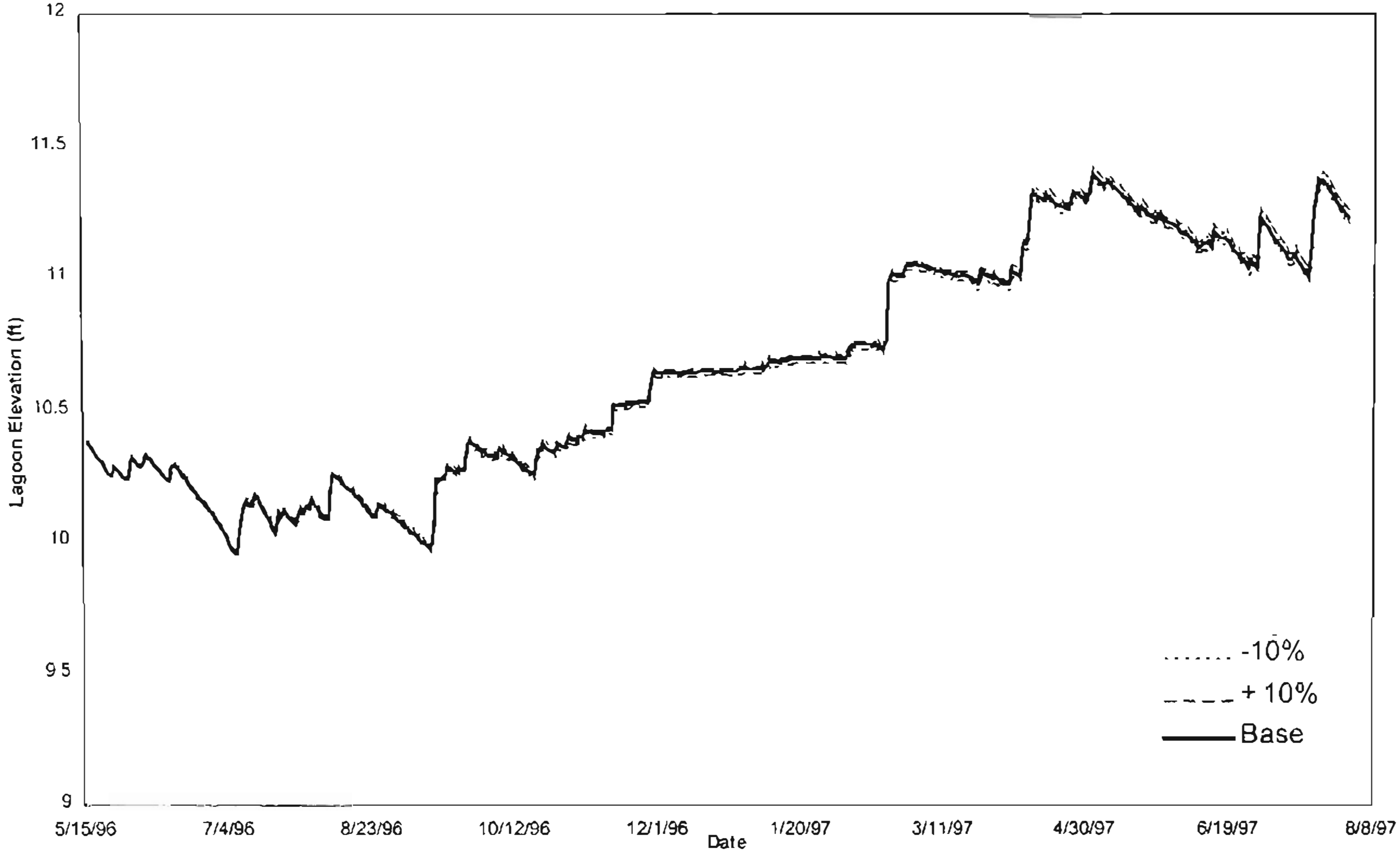


Figure 6. 6. Sensitivity of lagoon liquid level to the albedo number (α).

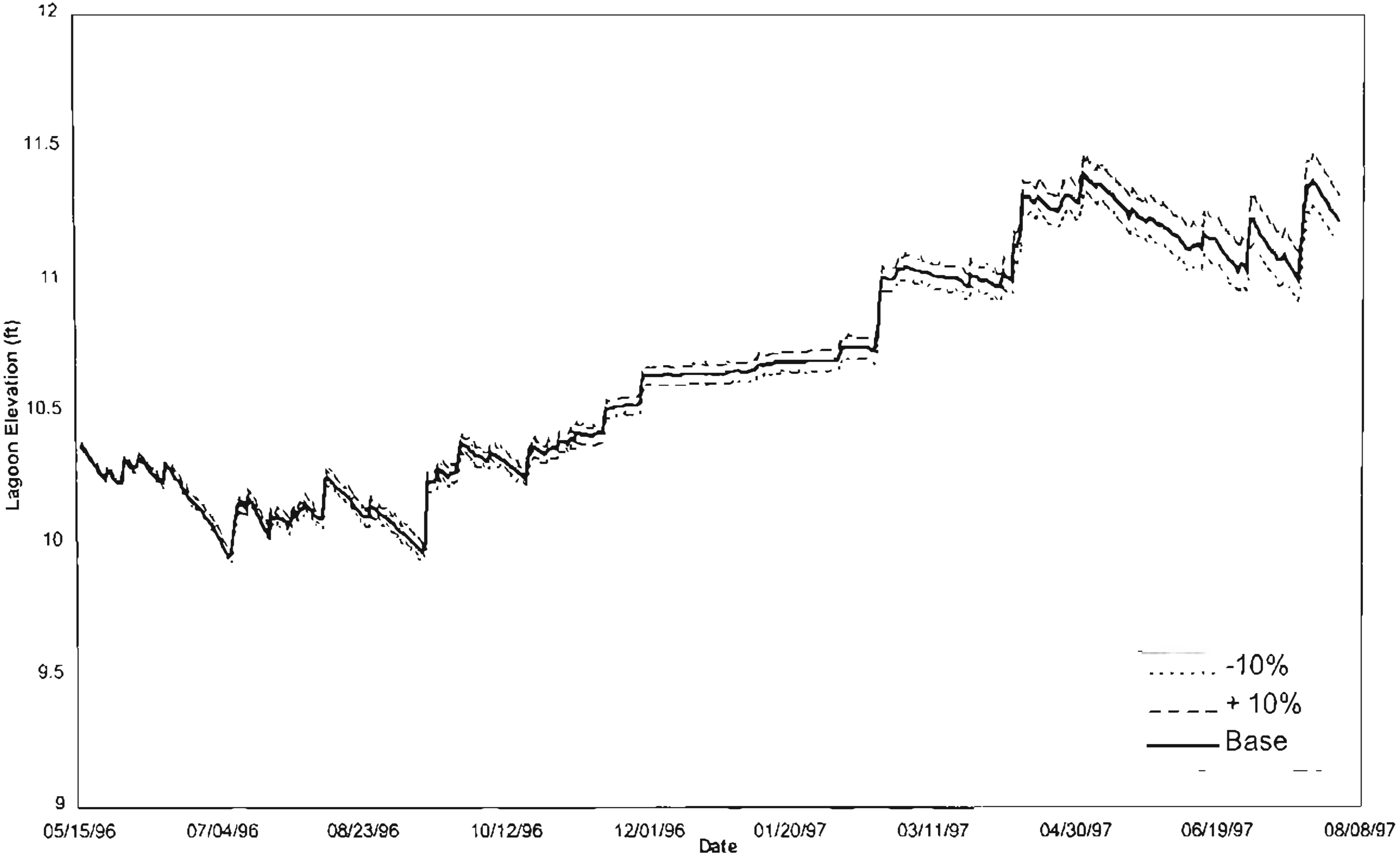


Figure 6. 7. Sensitivity of lagoon liquid level to the energy storage factor (f_{sc}).

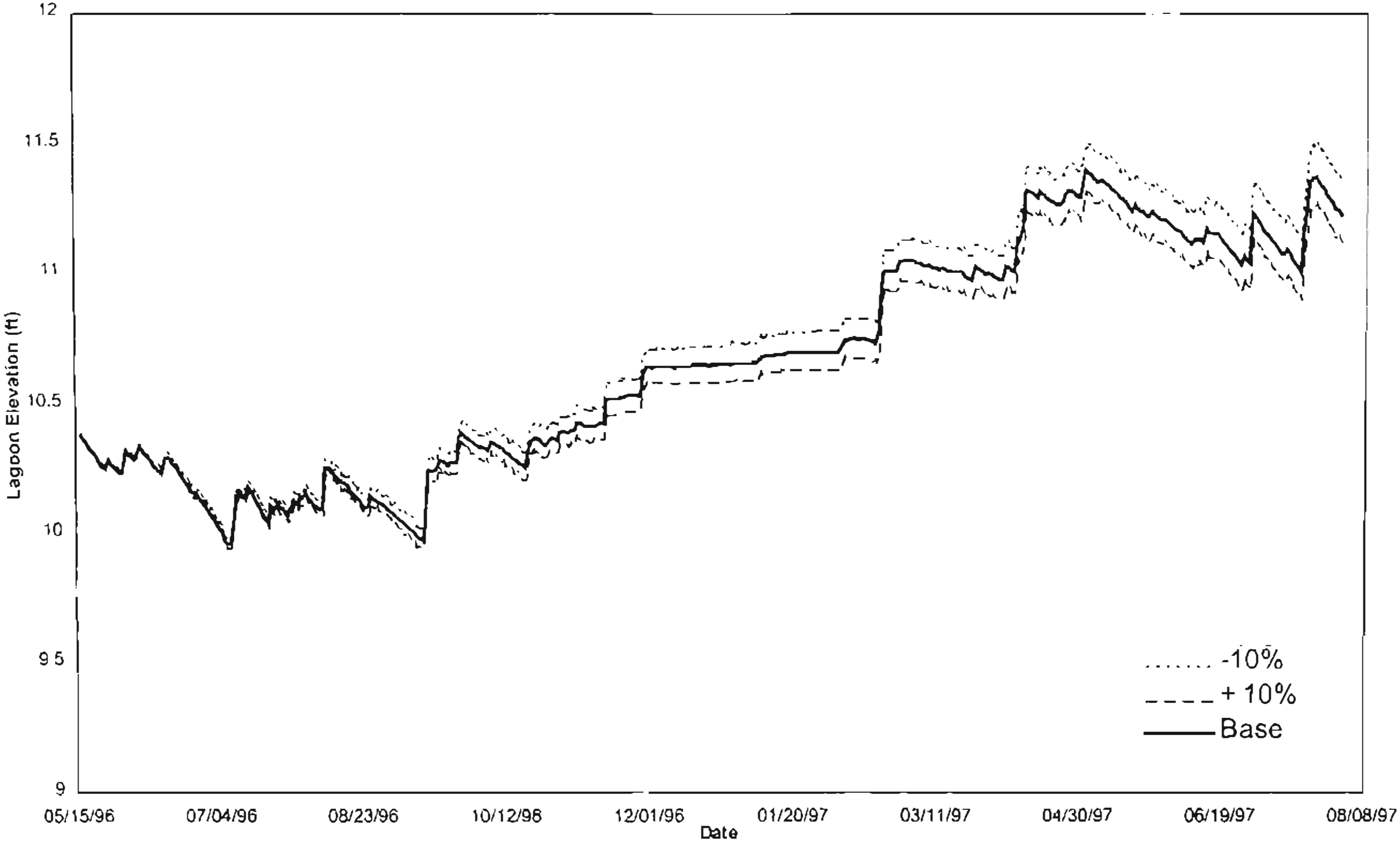


Figure 6. 8. Sensitivity of lagoon liquid level to the mean solar radiation for cloudless skies (R_{so}).

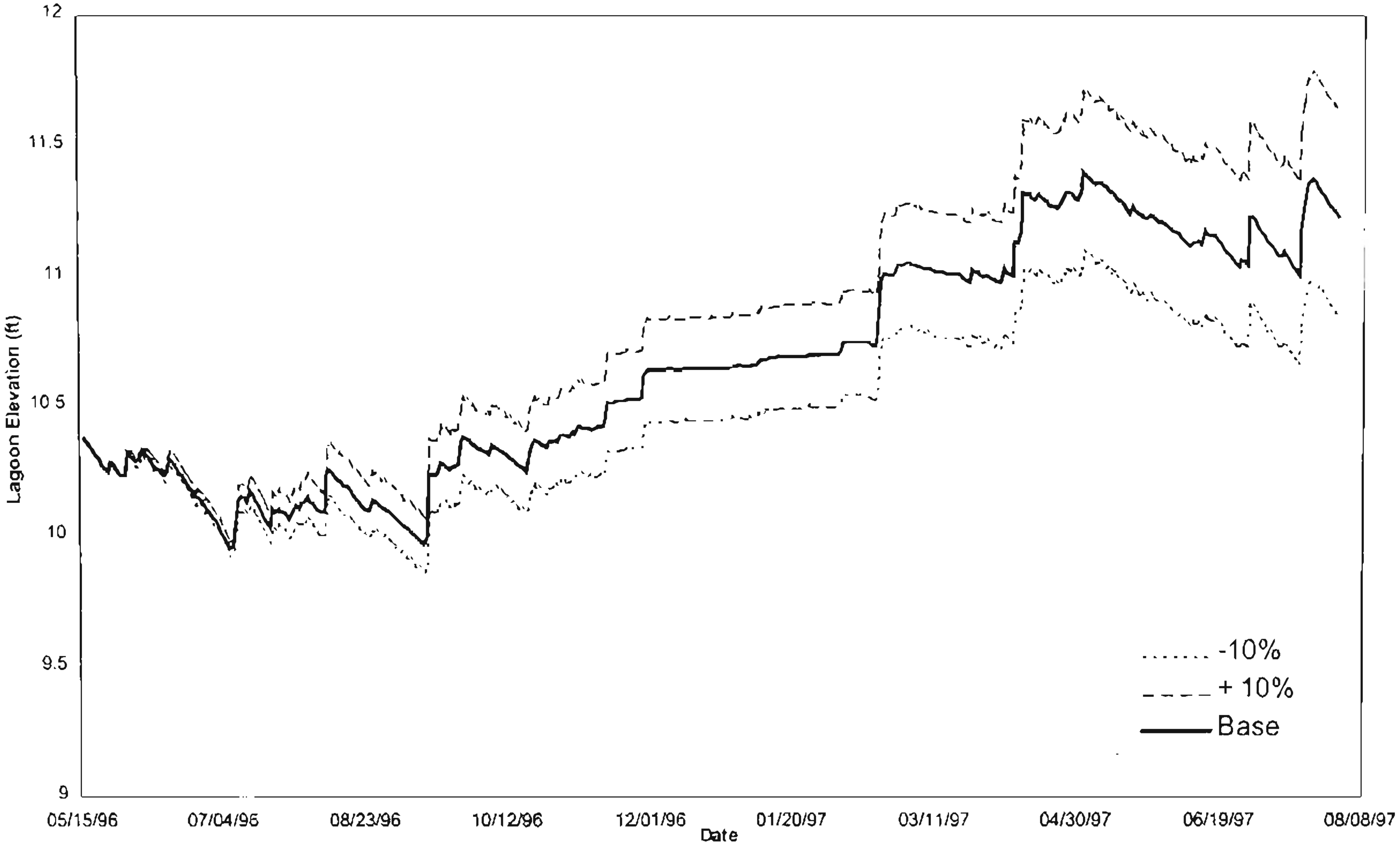


Figure 6. 9. Sensitivity of lagoon liquid level to the precipitation (P).

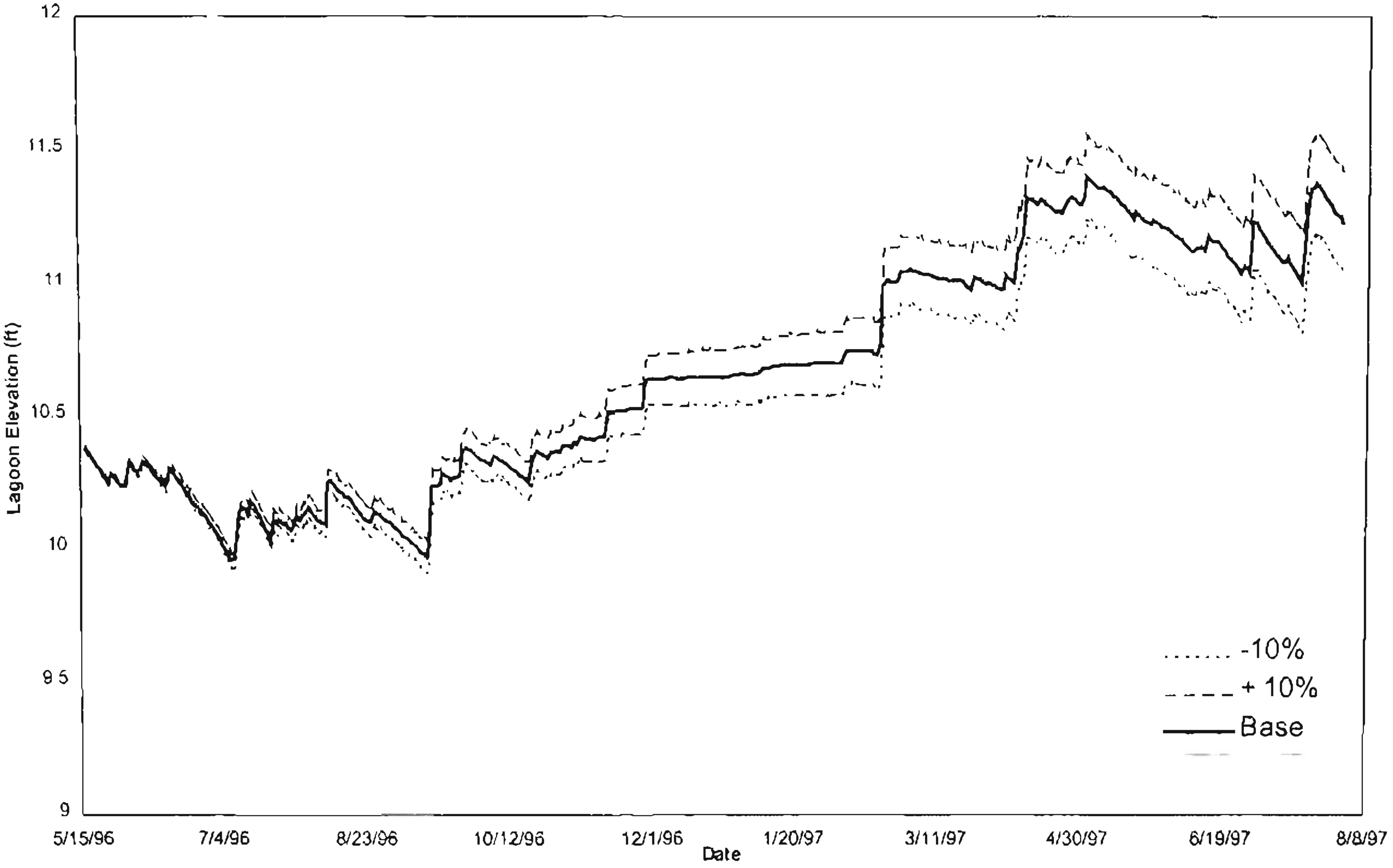


Figure 6. 10. Sensitivity of lagoon liquid level to the manure and washout water volume (MW).

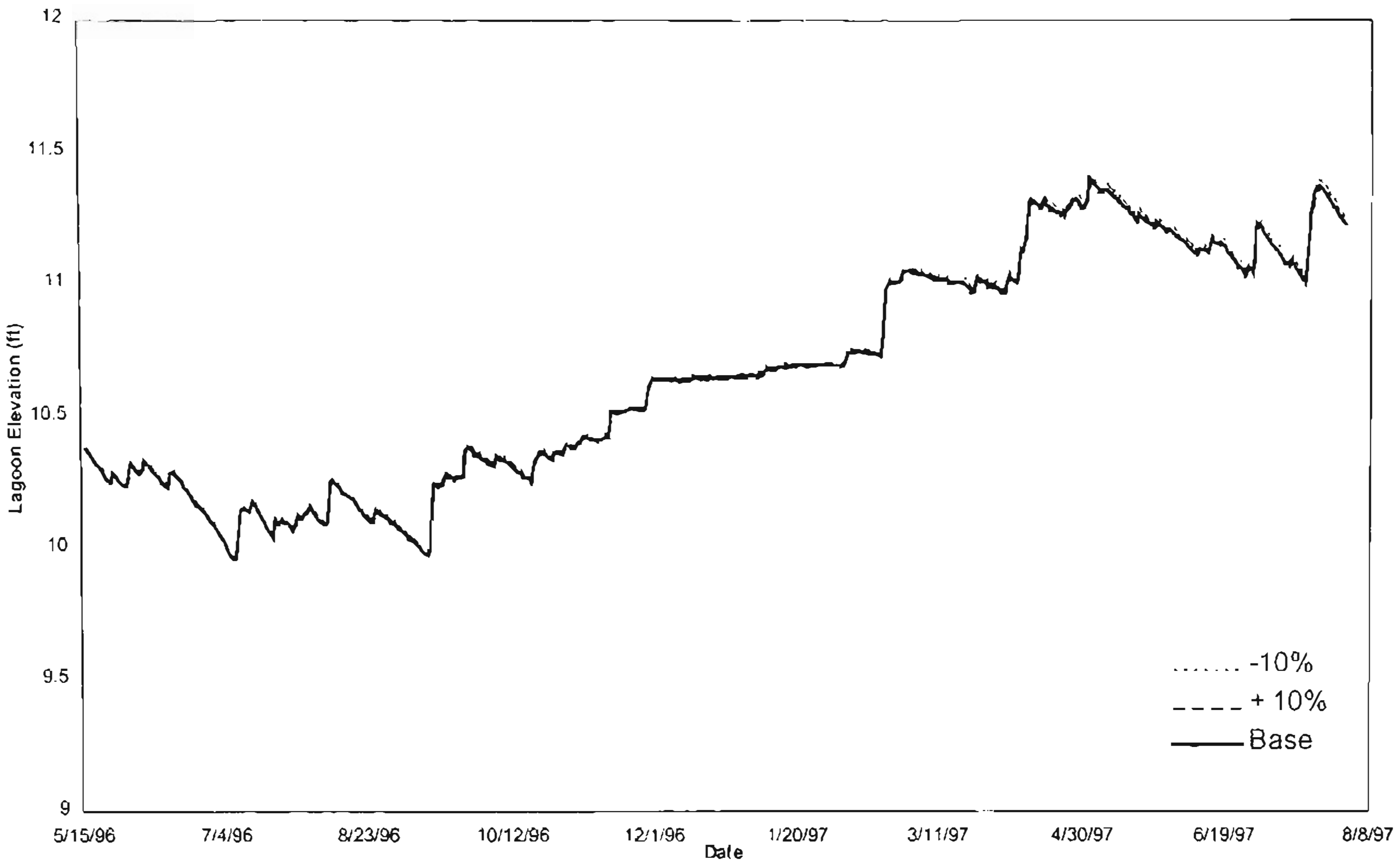


Figure 6. 11. Sensitivity of lagoon liquid level to the runoff (S).

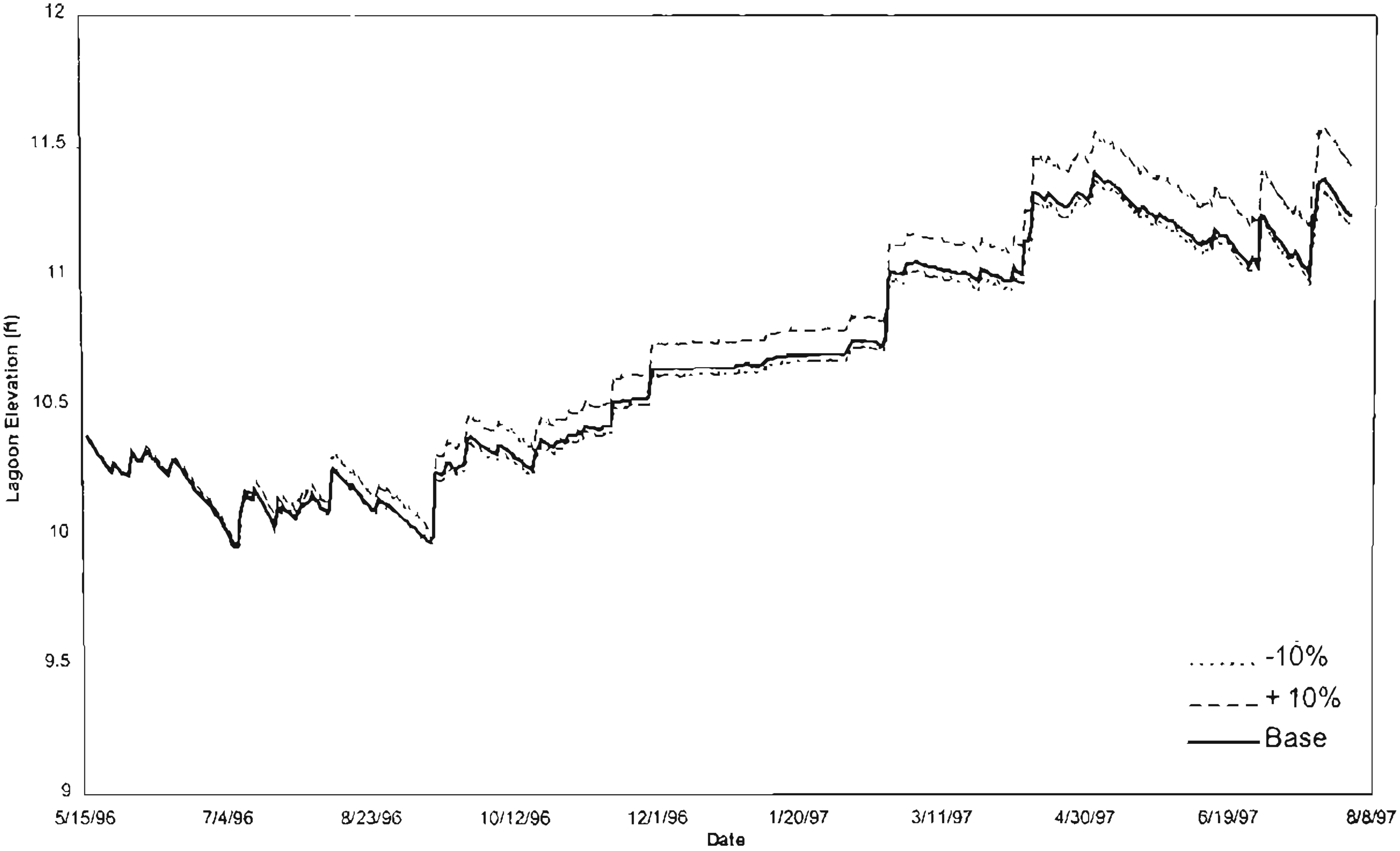


Figure 6. 12. Sensitivity of lagoon liquid level to the runoff (CN).

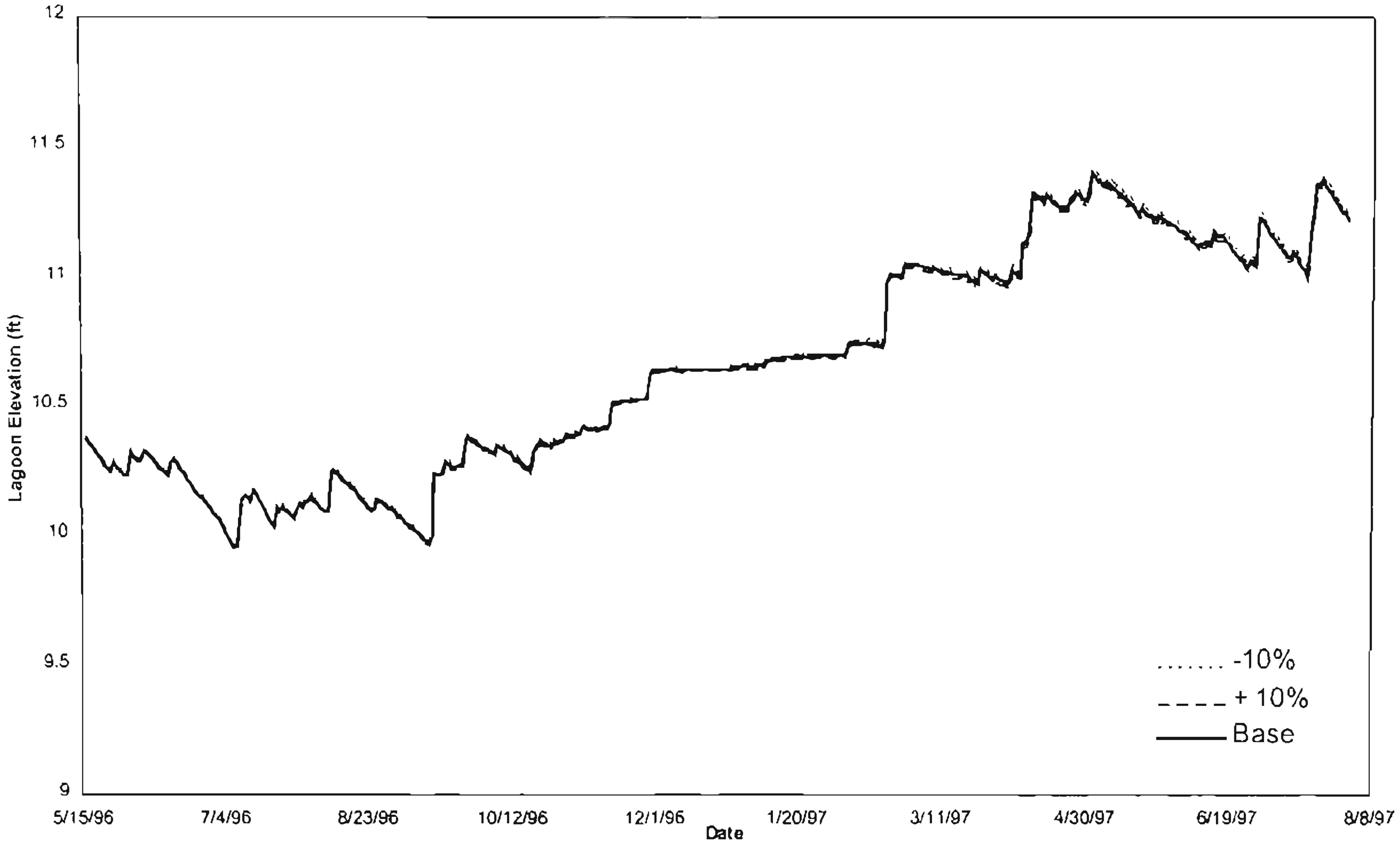


Figure 6. 13. Sensitivity of lagoon liquid level to the hydraulic conductivity (k).

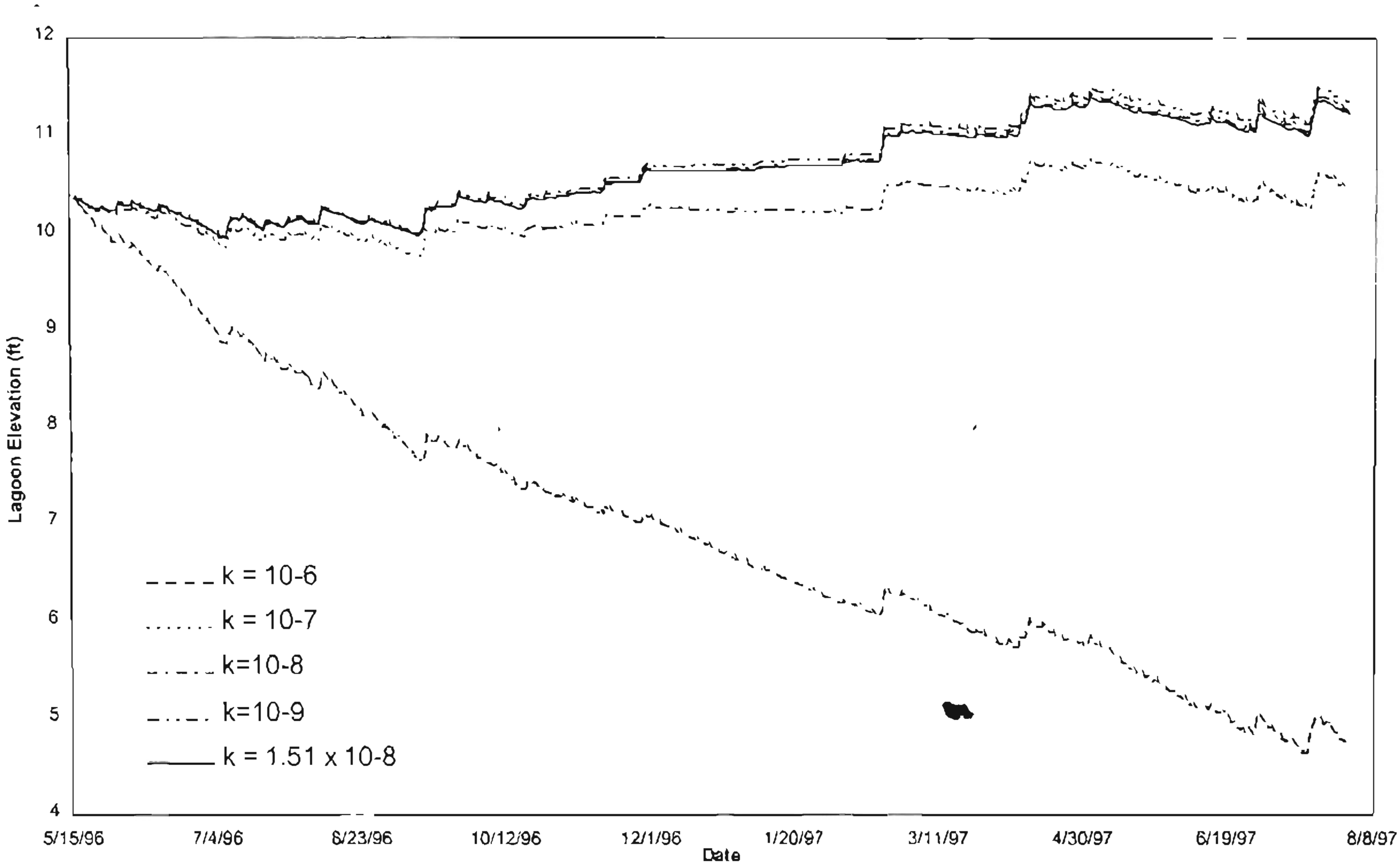


Figure 6. 14. Sensitivity of lagoon liquid level to various hydraulic conductivity values.

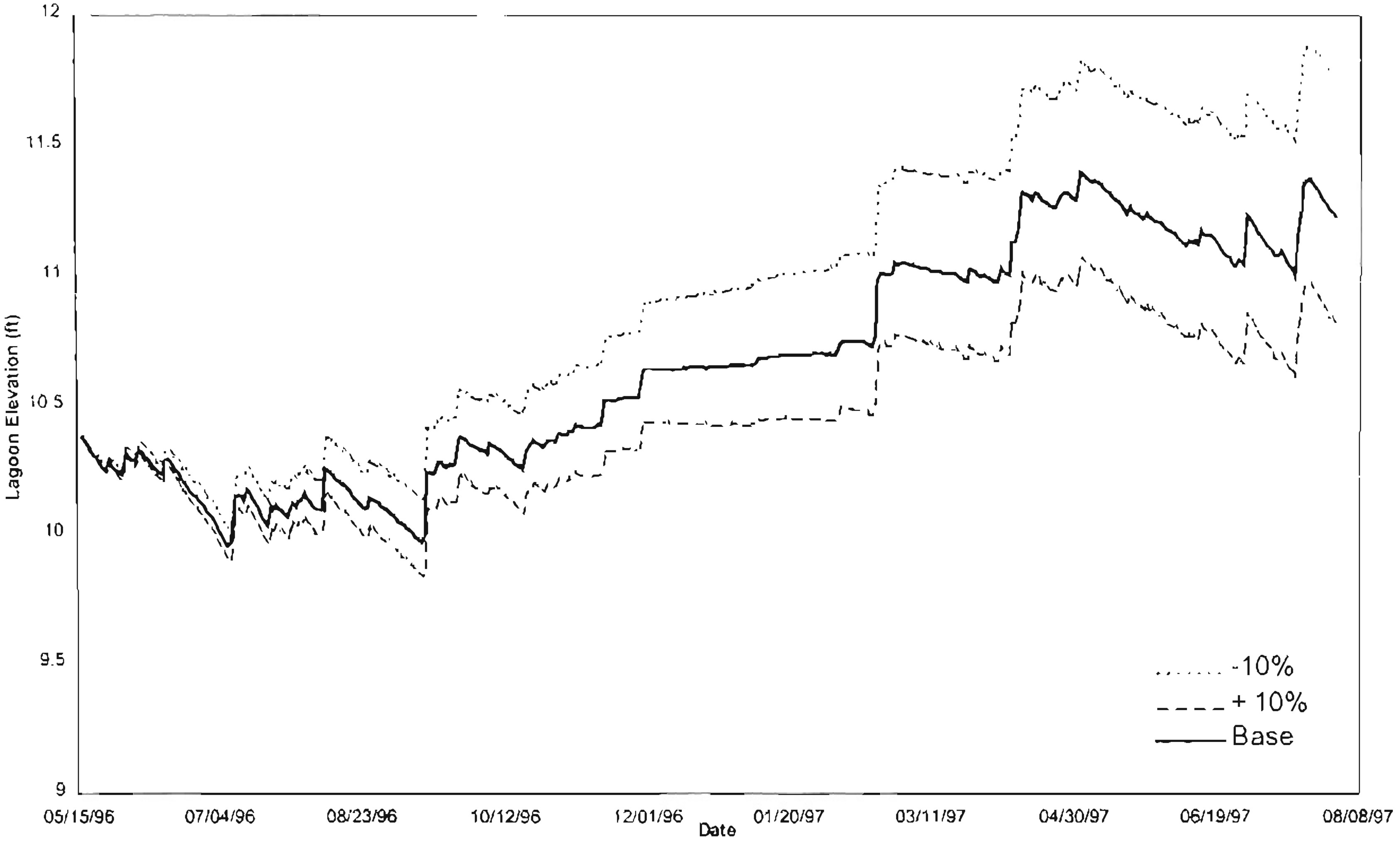


Figure 6. 15. Sensitivity of lagoon liquid level to the lagoon top dimensions.

6. 3 Electrical Conductivity Balance - Sensitivity Procedure and Results

Sensitivity Procedure

The sensitivity analysis of the EC balance included the period from September 4, 1996 through October 2, 1997. The adjusted parameters in the hydraulic balance were not altered. Required input data used during the calibration of the hydraulic balance was used here to estimate lagoon volume and supernatant EC. The resulting EC was considered as the base case. A constant percent change of ±10 % was applied to each parameters (Table 6.3) to determine the new concentration of EC from manure flowing to the lagoon (Equation 3.49). The resulting EC from the estimates (±10 %) of each parameter was inputted in the model, and the results from the simulation were compared with the baseline EC.

Sensitivity Results

Results from the sensitivity analysis are presented with time-series plots for visual comparison (Figures 6.15 to 6.18). The effect of the ±10 % change of each parameter were analyzed only with respect to the supernatant EC (dS/m). As expected, only slightly different value were obtained after 397 days of the simulation. This is attributed to the small soluble salts contribution from manure and washout water compared to volume of the lagoon.

Table 6. 5. Parameters used in the sensitivity analysis of the EC balance.

Parameter	EC (mg/L) -10 %	EC (mg/L) + 10 %
Total pounds fed daily (F_d)	2.43	4.40
Wastewater volume (Q_w)	4.48	2.53
Percent of feed cation in the excreted waste (γ_i)	1.7	5.13
Percent of soluble cation in supernatant (σ_i)	0.021	6.81

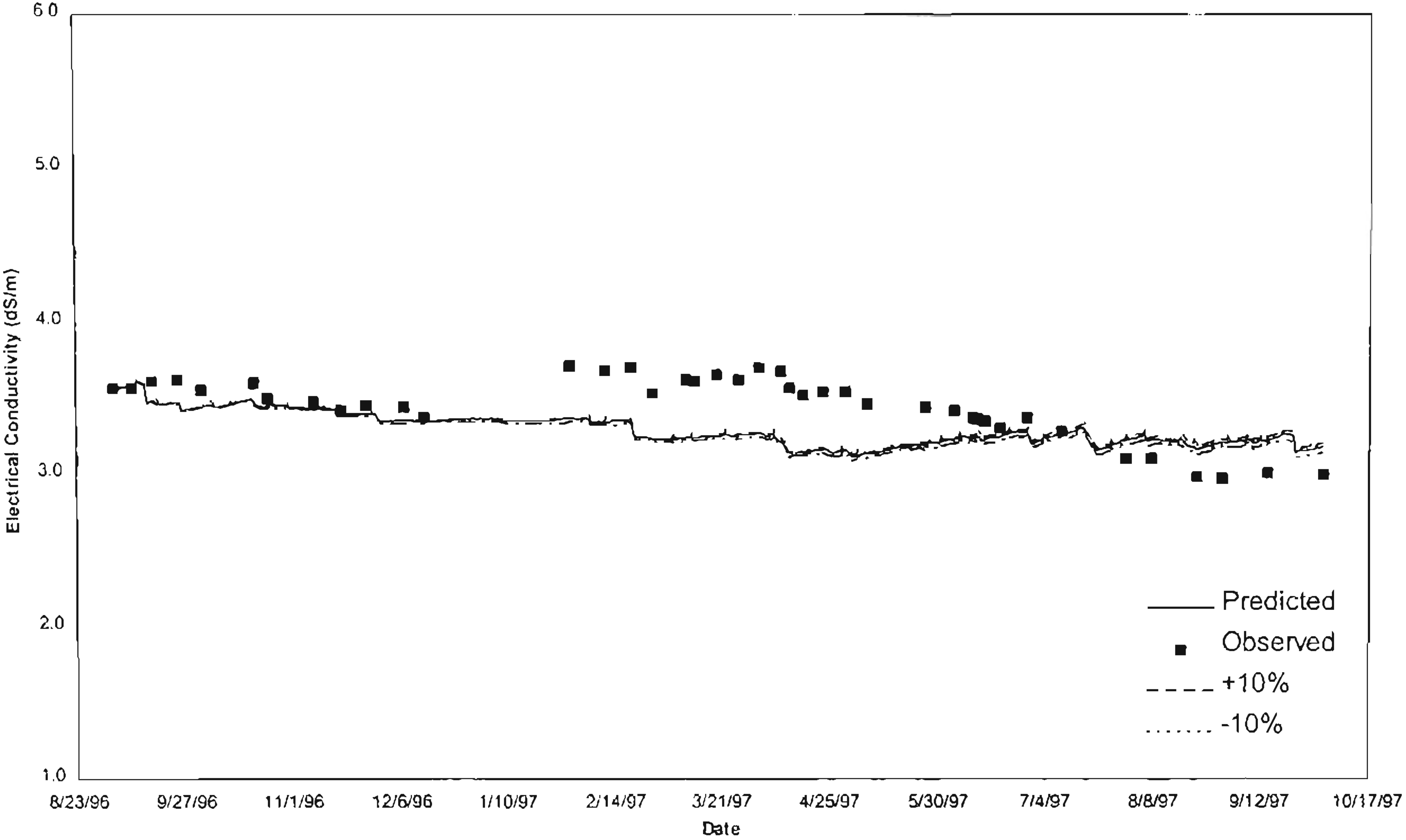


Figure 6. 16. Sensitivity of EC to total pound of feed consumed (F_d).

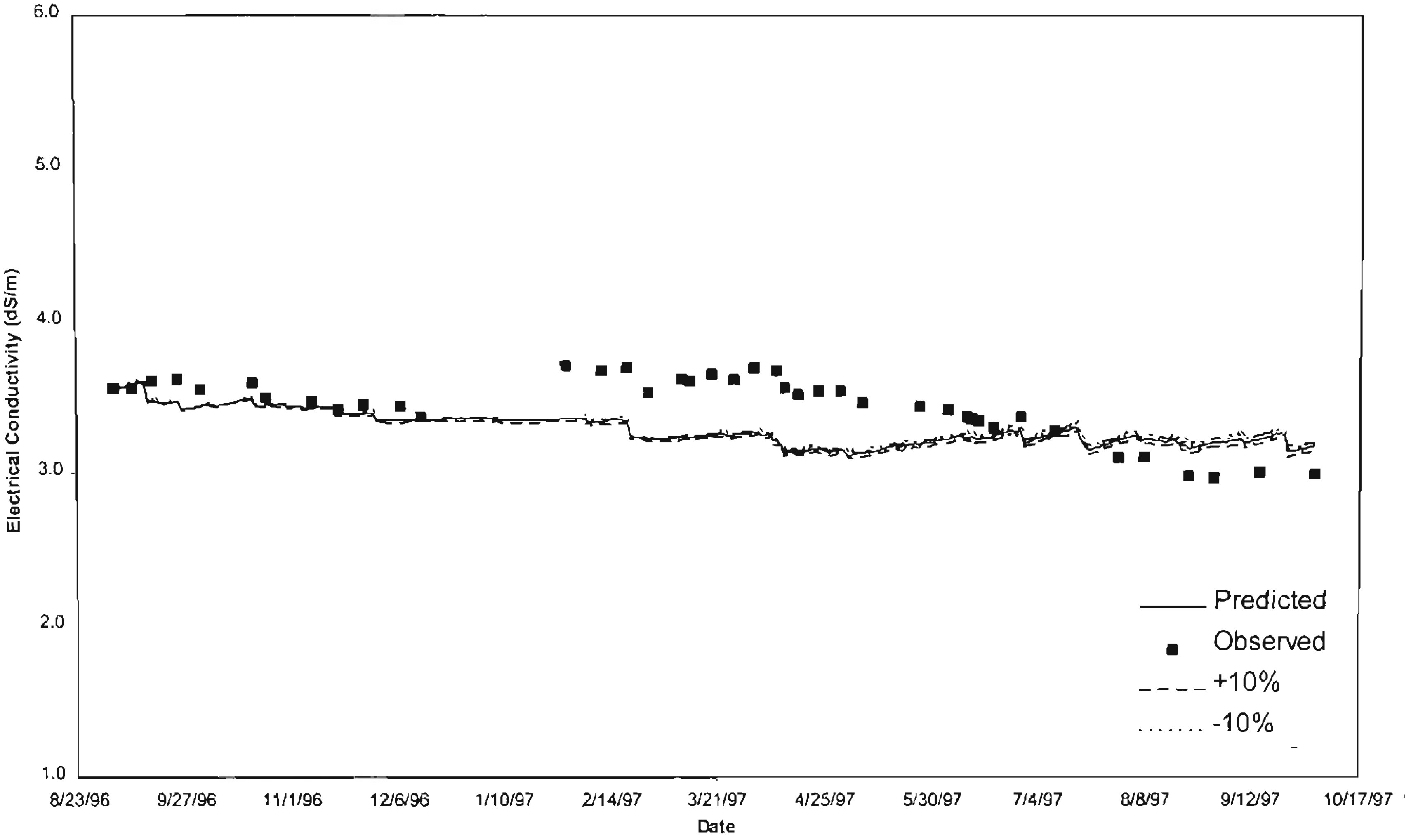


Figure 6. 17. Sensitivity of EC to volume of washout water loading (O_w)

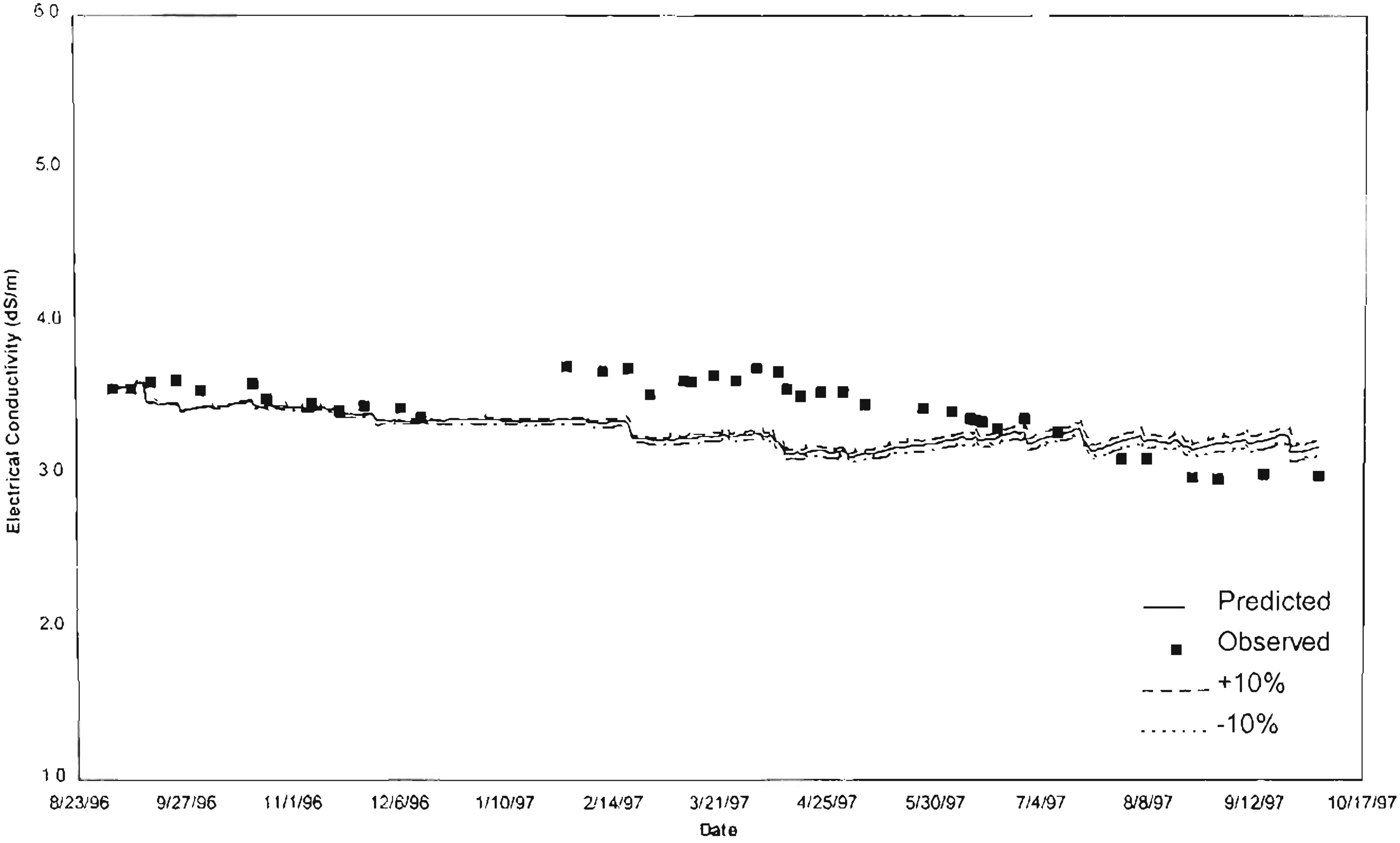


Figure 6. 18. Sensitivity of EC to percent of feed in the waste (γ).

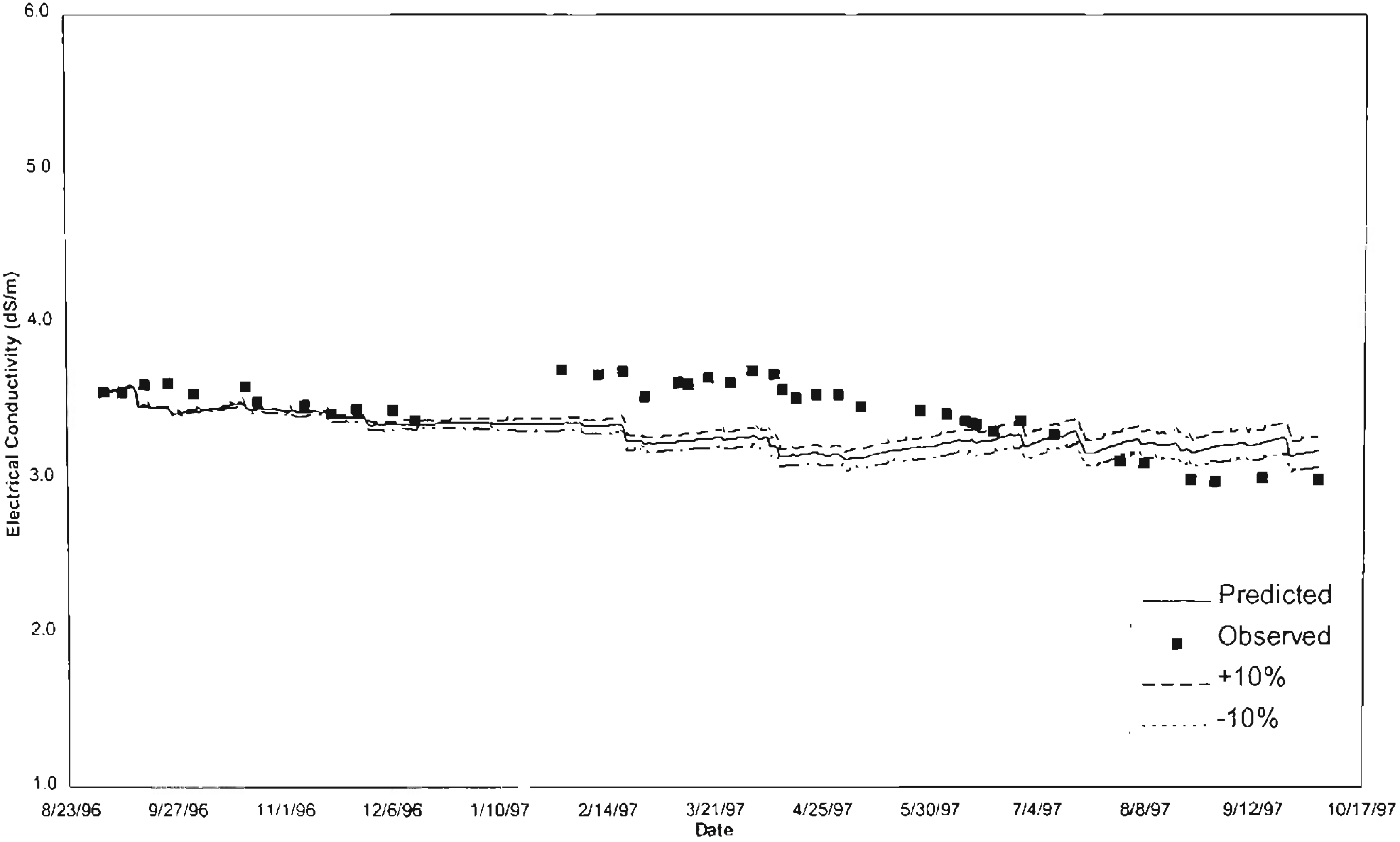


Figure 6. 19. Sensitivity of EC to percent of cations in the supernatant (σ).

CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary

Liquid handling plays several important roles in swine waste management. The primary advantages of liquid handling are: 1) Liquid handling provides an economical mechanism to transport waste from production units, 2) If properly operated, liquid handling reduces odors from the facility, and 3) Treated liquids are easily transported to cropping systems, providing numerous nutrients required for crop production which could minimize the application of man-made fertilizers and result in a higher return to farmers. Manure and wastewater are removed from the production units and transported to a lagoon for treatment and storage of liquids, sludge, and nutrients. Improper handling of liquids in the facility affects the performance of lagoons, causes emission of odors from buildings and lagoons, and reduces irrigation effluent quality.

The overall goal of this research was to develop a user-friendly mass-balance computer program that combines facility operation and weather data to predict daily liquid levels and supernatant EC for single stage lagoons. The computer program provides a step-by-step mode of data input that will allow farmers to develop the best strategy of liquid handling.

The computer program developed allows farmers to select the best liquid management practice for their type of hog production operation. This program predicts two important parameters that define the performance of the lagoon. These are the lagoon liquid level and the supernatant EC. These two parameters will guide the farmer toward a more cost effective waste treatment system for swine operations. For example, recycling lagoon effluent to recharge the flush tanks or pits reduces both the labor and the volume of wasted freshwater that must be discarded from the system.

The computer model uses historical Mesonet weather data to determine volume of rainfall and runoff entering and evaporation leaving the lagoon. Facility operational information is obtained from the facility managers. The facility managers supply data on the number and type of hogs, type of waste collection system, volume of pits or flush tanks, recharge frequency either with fresh water or recycled effluent, frequency of hose water cleaning, misters and drippers for cooling, and lagoon physical information (top dimensions and depth). All the operational information is carefully analyzed by the operator before the mass balance is performed to minimize errors in the output. The daily time-step model can be altered while running so farmers can try different combinations of flushing, storing and irrigating to determine the best liquid operations.

A file containing weather database tailored to each site has been prepared from Mesonet archives that can be read by the program. This database contains temperature, humidity, wind velocity, precipitation and solar radiation. The model combines a mass balance approach and empirically derived relationships to estimate lagoon liquid level and supernatant EC.

Some equations were developed to determine the lagoon volume, surface area, sidewalls area, total wetted area, and mass of EC carryover in the manure. Evaporation from the lagoon surface is estimated by the combined aerodynamic and energy balance methods developed by Penman (1948). Values of energy storage, G_w, were adjusted with pan evaporation observations and observe liquid levels. Lagoon seepage is estimated following the USDA-NRCS (1993) procedure to calculate the specific discharge rate. It was assumed that the hydraulic conductivity does not change during the simulation.

The model was developed and calibrated using OSU's Swine Research Center operational data and lagoon information. Several advantages of using this facility for the model calibration were: the easy access to operational information from the facility manager, routine inspection of the waste handling systems, periodic observation of lagoon liquid level, electrical conductivity measurements, and rain gage data; and the vicinity of the Mesonet Station located at the OSU Agronomy Farm less than one mile north of the swine facility.

Lagoon liquid levels and EC output were compared with observed liquid elevations and EC measurements. The model performed well in predicting the liquid level and supernatant EC. The predicted liquid level was within 0.10 foot of the observed elevation data. Fluctuations in the observed EC were attributed to temperature effects on biological activity. The predicted EC does not respond to these fluctuations because the EC model was developed to be dependent on only hydraulic conditions and base cations from feed. It is assumed that biological activity affects other cations and ions, most notably ammonium and ionized organic acids.

The model was validated east of the 97th meridian in Oklahoma using operational data from two facilities located at Shawnee and Poteau. Both facilities have similar operational characteristics but different climatic conditions, especially rainfall and evaporation. Weather data from Mesonet stations nearest to the facilities were used to compile the weather input files. On-site rain gauge readings were substituted for

Mesonet's precipitation data. This substitution minimized the errors in the predicted liquid level. Actual operational data were provided by the facility managers and carefully analyzed before input to the model.

The hydraulic balance successfully predicted the lagoon liquid level when compared with the observed elevation data of both facilities. During the simulations, the program was stopped after irrigation to adjust water level to the manager supplied data. In both simulations, the predicted elevation was within an average of 0.17 foot of the observed data. Runs between irrigation range from 30 to 60 days.

The predicted EC in both simulations followed the same trend as the observed data; however, at Poteau the predicted EC underestimated the observed EC measurements. At Poteau the EC loading from feed was higher and the operator recycled flushwater year-round. Based on input data it was expected that EC would increase over time, but the estimated EC remained within a small range of values. This condition happened due to the continuous irrigation of lagoon effluent and addition of freshwater from rainfall and wasted wastewater from the drinking channels.

At Shawnee, the predicted EC trends followed the liquid operation. When pits were recharged with recycled effluent, the predicted EC increased faster than in periods with no recycle. The highest EC value occurred at the ends of the recycle periods. The addition of freshwater after irrigation brought down the predicted EC.

According to the hydraulic and EC balance, a facility located in eastern Oklahoma (positive rainfall minus evaporation) requires at least 6 gallons/hog/day of fresh water to maintain supernatant EC levels below 6 dS/m. Freshwater required to maintain EC below 6 dS/m may double in the central region of the state where evaporation exceeds rainfall. For the Panhandle, where the net rainfall minus evaporation is -57 inches, it is expected that the manager will need to add approximately 20 gallons/hog/day of fresh water to keep supernatant EC between 4 to 6 dS/m. The above reasoning was based on a 600-sow breeding facility with pit recycle recharge system and rations containing 1.1 % Ca^{2+} and 0.75 Na^{+}.

Results from the sensitivity analysis show that among the model components, the evaporation had the greatest effect on the performance of the model followed by lagoon dimensions, rainfall, and volume of manure and washout water. The parameter that has the highest impact on the model output is the solar radiation.

7. 2 Conclusions

The following conclusions were drawn from this study:

1. The hydraulic balance successfully predicted the daily water levels within one tenth of a foot of the observed data. Mean absolute error was within ± 2 percent of the observed data.
2. The electrical conductivity balance has shown good performance with EC levels within ± 4 percent of the measured supernatant EC.
3. The adjusted factors in the evaporation and seepage equation gave reasonable results in the validated sites. A hydraulic conductivity of 1.51×10^{-8} cm/sec can be used to estimate lagoon seepage from the swine operations and for calibration and validation.

This value may be higher for lagoons that have been in operation for less than five years.

4. The introduction of the energy storage factor in the evaporation equation allows users to estimate daily evaporation for periods longer than one year without overestimating or underestimating lagoon evaporation cause by temperature fluctuations in the lagoon.
5. Relative sensitivity shown that evaporation had the greatest effect on the model output. The model estimate of evaporation is quite sensitive to solar radiation.
6. Curve number for the lagoon inner sidewalls with a predominant grass cover and with a soil (clay) layer ranged between 85 - 90 and 90 - 95, respectively, for lagoons with a 3:1 slope.
7. The model can be used to teach farmers to determine the best liquid operation practice in a hog production facility

7. 3 Recommendations for Future Research

1. Validate the model using more facilities across the state of Oklahoma and for longer periods, with especial interest for facilities located in the Panhandle.
2. Determine the distribution of cations throughout the lagoon system.
3. Compare model output using Mesonet data with statistical weather generation programs.
4. Expand model to calculate water balance on more complex systems, for example two-stage lagoons, settling basin followed by lagoons, partially covered lagoons.

5. Validate model in other regions, (southeastern of the United States and upper Midwest) using weather generation programs.
6. Use validated model as a tool to estimate seepage through lagoon liners.

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APPENDIX A

OSU's Swine Research Center Information

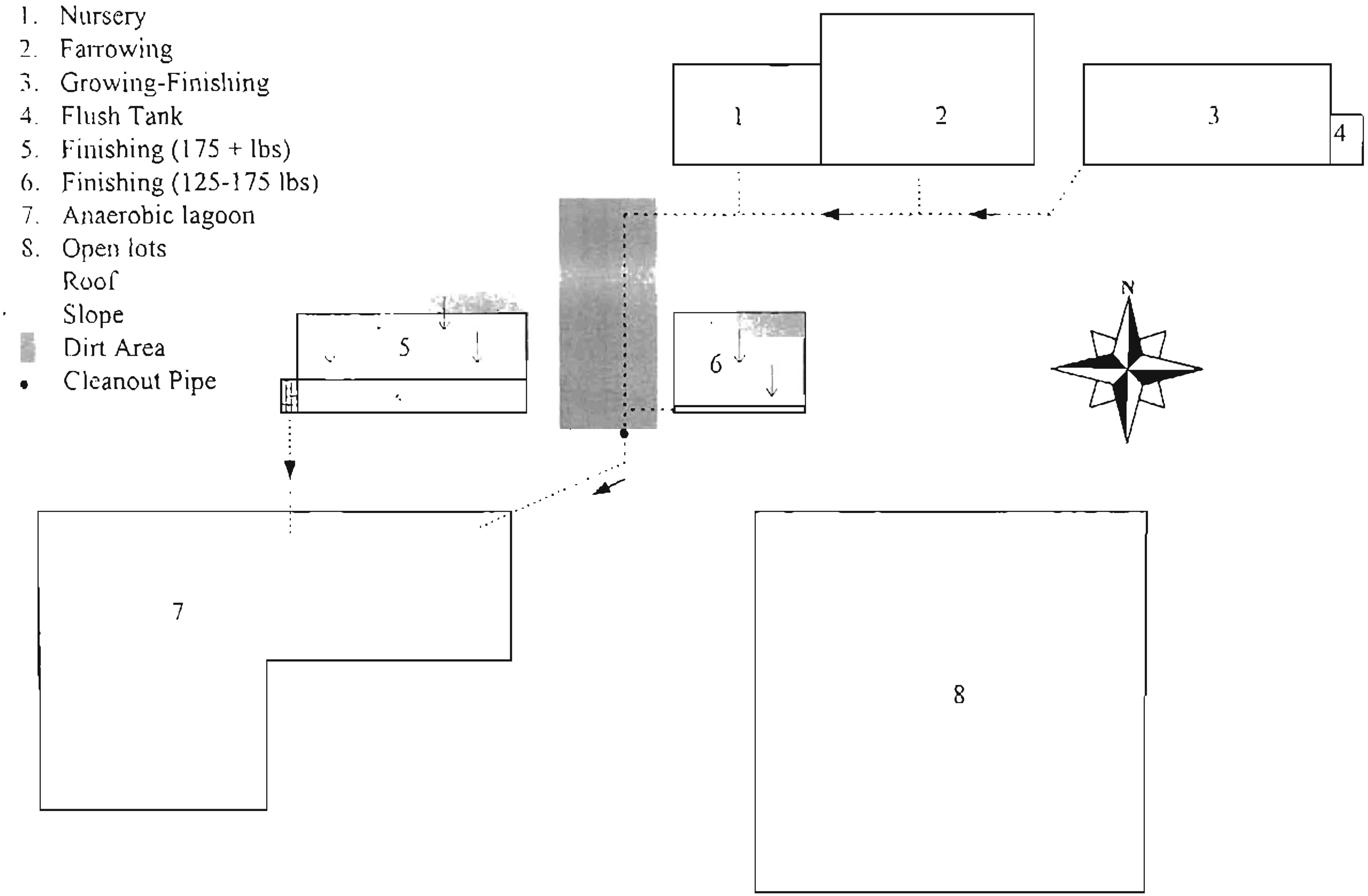


Figure A. 1. System schematic of swine production and lagoon treatment.

Table A. 1. Farm values for mass and volume[1].

Type	# of pigs	Pigs wt. lbs/each	Total wt. lbs	TS lbs/day	VS lbs/day	Manure Volume ft^3/day
Boar	5	400	2,000	4	3.4	0.65
Sow + Litter	22	375	8,250	57	50.6	9.02
Nursery	168	35	5,880	62	52.1	10.1
Grower 50 - 125 lbs.	181	90	16,290	109	97.7	18.1
Finisher 125-175 lbs.	172	150	25,800	138	123.8	7.45
Finisher 175 + lbs	238	200	47,600	224	202.3	12.00
Total	786		105,820	593.08	529.96	57.32

[1] Hamilton et al. (1997).

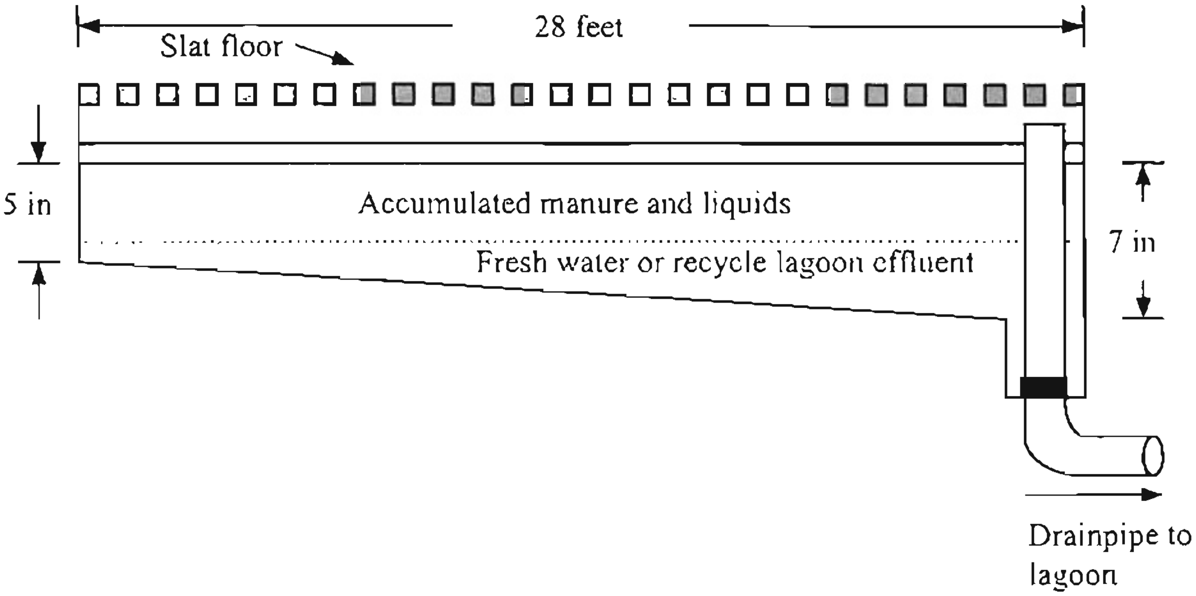


Figure A. 2. Nursery room - slatted floor storage pit layout.

Table A. 2. Water meter data

Reading Date	Beginning Meter Reading (gals.)	Ending Meter Reading (gals.)	Washout Volume (gals.)
1/14/97	112,380		
1/22/97		114,380	
1/30/97		116,419	
2/6/97		118,706	
2/11/97		119,928	
2/14/97		120,202	
2/19/97		120,890	
2/21/97		121,925	
2/26/97		132,575	
3/9/97		134,870	
3/12/97		135,713	
3/17/97		137,317	
3/19/97		137,730	
3/26/97		137,990	
4/2/97		138,510	
4/7/97		138,880	
4/9/97		139,790	
4/12/97		140,110	
4/16/97		140,797	
4/23/97		141,190	
4/30/97		142,610	
5/7/97		143,370	
6/4/97		151,430	
6/11/97		152,950	
6/17/97		153,380	
6/29/97		156,640	
7/7/97		158,110	
7/18/97		159,500	47,120
Daily Nursery Washout Volume (ft^3)			**34**[1]

[1] Based on 186 days.

Table A. 3. Washout volume production values.

Unit	Average Flow Rate (GPM)	Washout Volume (ft^3/day)
Nursery	4.2	25
Farrowing	4.2	9
Finishing 125 - 175 lbs	3	7
Finishing 175 lbs +	9	21

Table A. 4. Lagoon survey data.

Location	BS	HI	FS	Elevation
BM	3.175	103.18		100
A 1			6.87	96.31
2			6.54	96.64
3			7.41	95.77
B			6.12	97.06
C			4.87	98.31
D			4.30	98.88
E			5.01	98.17
F			2.83	100.35
G			4.41	98.77
H			5.48	97.70
I			2.83	100.35
water level			9.34	93.84

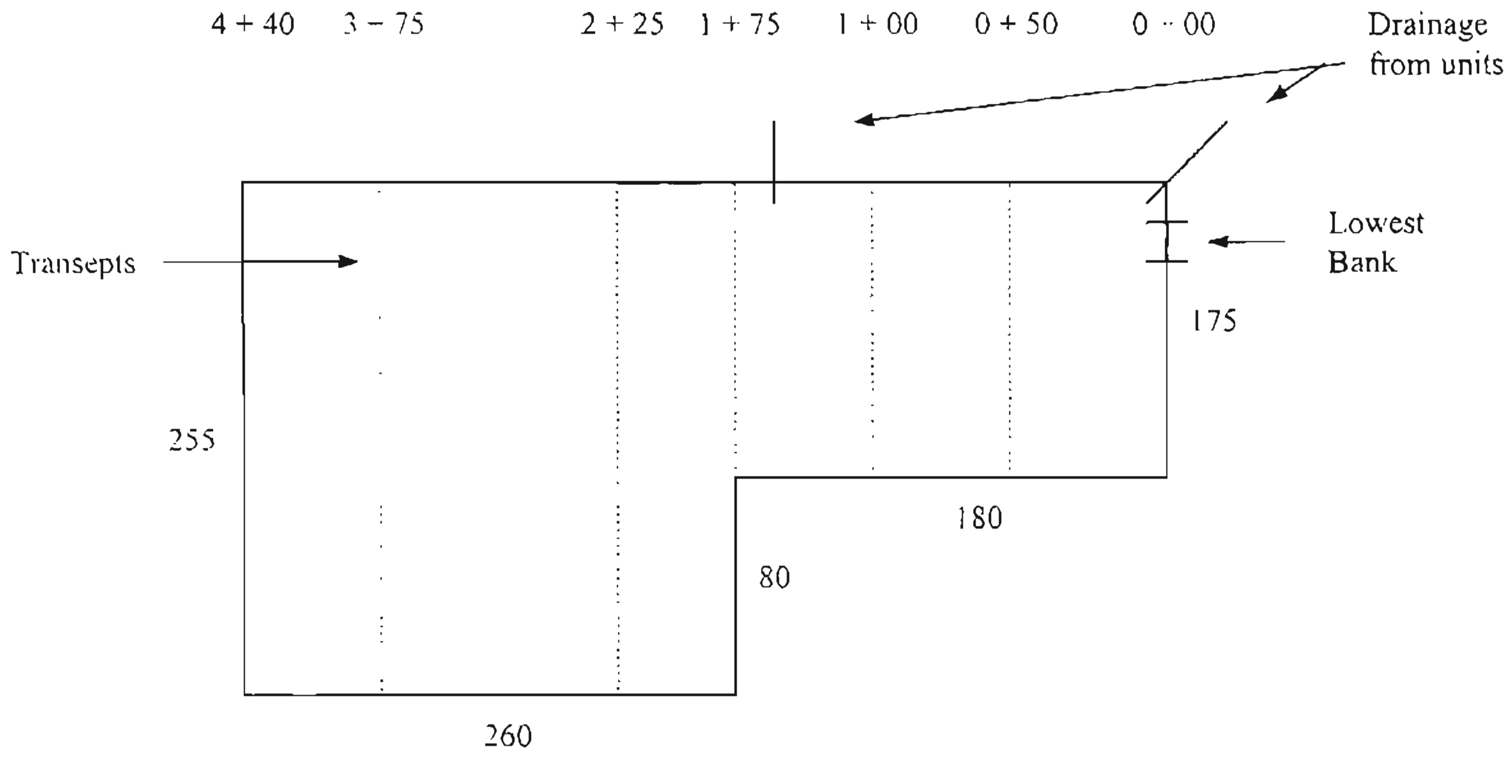


Figure A. 3. Lagoon top dimensions (ft).

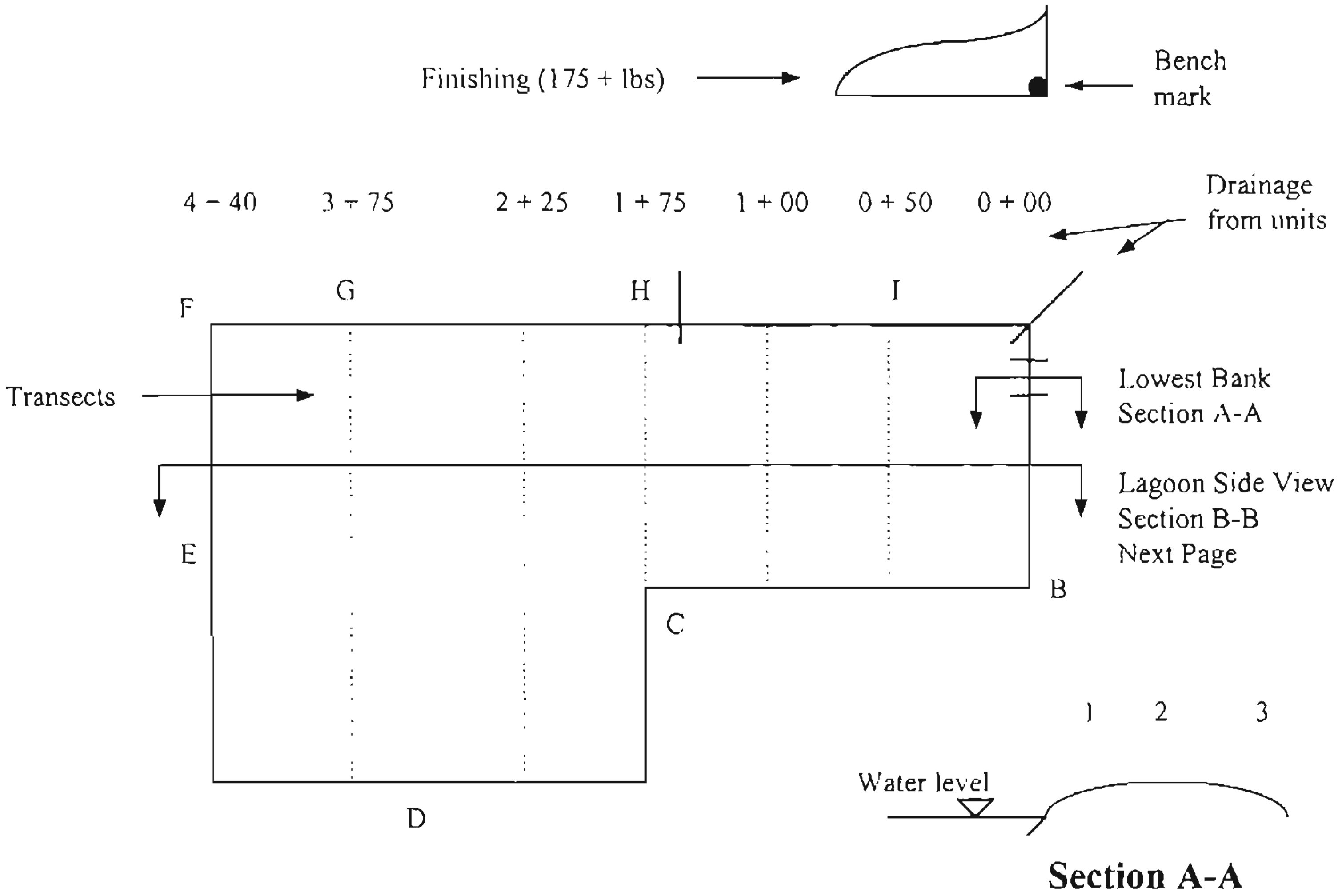


Figure A. 4. Lagoon survey layout.

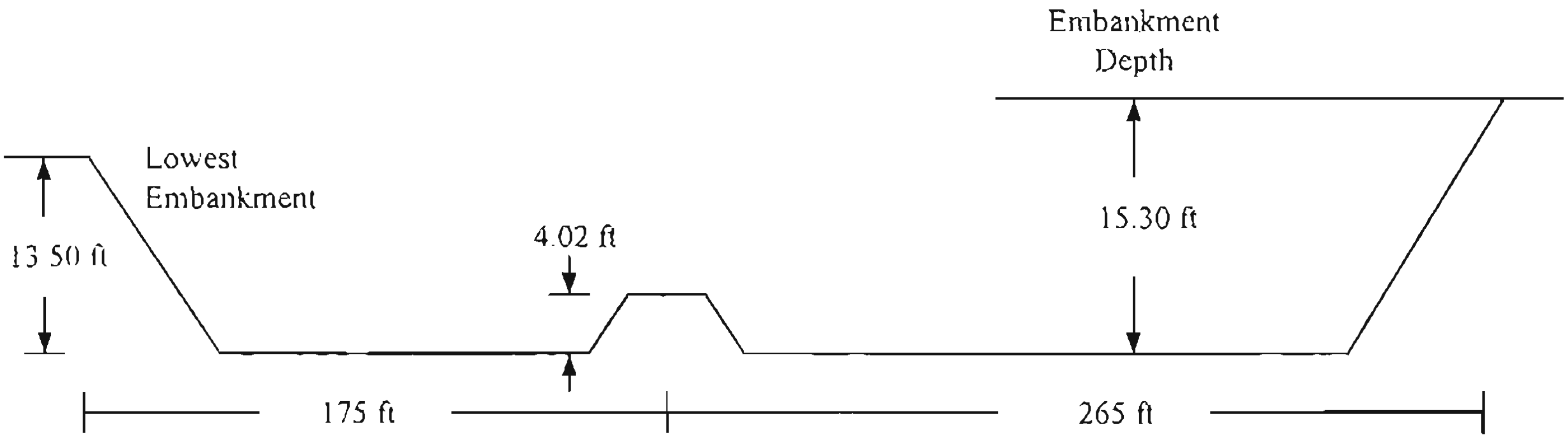


Figure A. 5. Section B-B, lagoon side view.

Table A. 5. Depth data at 0 + 50 ft during the survey in May 17, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.7	4.5	1.8
20	4.1	6.9	2.8
30	6	8.9	2.9
40	6.6	9	2.4
50	6.2	9.3	3.1
60	6.4	8.9	2.5
70	6.5	9.2	2.7
80	6.7	9.9	3.2
90	7.2	10.2	3.0
100	6.5	10.1	3.6
110	4.9	10	5.1
120	4.8	8.3	3.5
130	4.9	9.5	4.6
140	4.5	6	1.5
150	3.3	3.7	0.4
158	waterline		

Table A. 6. Depth data at 1 + 00 ft during the survey in May 17, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.9	3.5	0.6
20	5.4	7.8	2.4
30	7	9.2	2.2
40	7.2	9.3	2.1
50	7.4	9.4	2.0
60	6.5	10	3.5
70	6.4	9.9	3.5
80	7.1	10.1	3.0
90	6.5	9.8	3.3
100	5.8	9.8	4.0
110	6	9.5	3.5
120	6.2	9.4	3.2
130	5.7	9.1	3.4
140	5.1	7.2	2.1
150	2.6	2.7	0.1
160	waterline		

Table A. 7. Depth data at 1 + 75 ft during the survey in May 17, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.0	2.3	0.3
20	4.1	4.6	0.5
30	5.0	5.6	0.6
40	5.2	5.9	0.7
50	5.5	5.9	0.4
60	5.3	5.8	0.5
70	5.5	6.0	0.5
80	5.5	6.0	0.5
90	5.6	6.0	0.4
100	5.6	5.9	0.3
110	5.3	5.5	0.2
120	3.0	3.2	0.2
130	waterline		

Table A. 8. Depth data at 2 + 25 ft during the survey in May 17, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.5	2.5	0.0
20	4.5	5.2	0.7
30	6.6	6.9	0.3
40	7.3	7.6	0.3
50	8.1	8.1	0.0
60	8.1	8.3	0.2
70	8.2	8.4	0.2
80	8.2	8.5	0.3
90	8.2	8.6	0.4
100	8.6	9.0	0.4
110	8.6	9.1	0.5
120	8.5	9.2	0.7
130	8.6	9.0	0.4
140	8.3	9.0	0.7
150	8.8	9.5	0.7
160	9.2	9.4	0.2
170	9.5	9.8	0.3
180	9.4	9.7	0.3
190	9.2	9.3	0.1
200	8.3	8.5	0.2
210	5.5	5.5	0.0
220	2.4	2.6	0.2
228	waterline		

Table A. 9. Depth data at 3 + 25 ft during the survey in May 17, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.1	2.4	0.3
20	5.4	5.9	0.5
30	8.1	8.4	0.3
40	8.7	8.9	0.2
50	8.7	8.8	0.1
60	9.2	9.3	0.1
70	9.3	9.3	0
80	9.9	10	0.1
90	10.1	10.4	0.3
100	10.1	10.8	0.7
110	10.1	10.3	0.2
120	10.4	10.6	0.2
130	10.5	10.5	0
140	10.3	10.4	0.1
150	10.1	10.2	0.1
160	9.9	9.9	0
170	9.7	9.7	0
180	9	9	0
190	7.9	7.9	0
200	5.2	5.2	0
210	2.2	2.2	0
215	waterline		

Table A.10. Statistical analysis for the depth data taken in May 17, 1996.

	0 + 50			1 + 00			1 + 75			2 + 25			3 + 25		
	AVE[1]	SD[2]	CV[3]	AVE	SD	CV	AVE	SD	CV	AVE	SD	CV	AVE	SD	CV
Lagoon depth, ft	9.58	0.53	0.06	9.69	0.29	0.03	5.93	0.08	0.01	8.91	0.61	0.07	9.87	0.66	0.07
Sludge depth, ft	6.38	0.66	0.10	6.57	0.55	0.08	5.43	0.15	0.03	8.55	0.57	0.07	9.73	0.60	0.06
Sludge thickness, ft	3.20	0.86	0.27	3.12	0.67	0.21	0.50	0.11	0.21	0.36	0.21	0.59	0.14	0.18	1.28

[1] average

[2] standard deviation

[3] coefficient of variation

Table A. 11. Depth data at 0 + 66 ft during the survey in May 26, 1997.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	3.7	5.15	1.45
20	4.9	7.35	2.45
30	6.0	10.25	4.25
40	6.8	10.8	4.00
50	6.9	11.24	4.34
60	7.4	11.05	3.65
70	7.6	11.15	3.55
80	7.6	11.0	3.40
90	7.2	11.33	4.13
100	6.0	11.4	5.40
110	6.2	11.2	5.00
120	6.5	11.1	4.60
130	6.4	10.68	4.28
140	6.0	9.70	3.70
150	5.0	5.80	0.80
160	1.5	1.50	0.00
164	waterline		

Table A. 12. Depth data at 2 + 54 ft during the survey in May 26, 1997.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	3.0	3.15	0.15
20	5.8	6.25	0.45
30	8.3	8.7	0.40
40	9.45	9.8	0.35
50	9.78	10.08	0.30
60	9.9	10.08	0.18
70	10.3	10.6	0.30
80	11.1	11.45	0.35
90	11.1	11.39	0.29
100	11.0	11.6	0.60
110	10.8	11.39	0.59
120	10.8	11.45	0.65
130	10.8	11.48	0.68
140	10.8	11.6	0.8
150	11.3	11.65	0.35
160	11.4	11.6	0.20
170	10.8	11.15	0.35
180	10.4	10.7	0.30
190	9.9	10.18	0.28
200	7.9	8.15	0.25
210	5.21	5.21	0
220	2.38	2.38	0
229	waterline		

Table A. 13. Statistical analysis for the depth data taken in May 26, 1997.

	0 + 66			2 + 54		
	AVE	SD	CV	AVE	SD	CV
Sludge depth, ft	6.93	0.63	0.09	10.73	0.48	0.04
Sludge thickness, ft	4.26	0.71	0.17	0.42	0.19	0.47

Table A. 14. Average thickness values at the bottom of each lagoon.

	Sludge Side (ft)	Clear Side (ft)
1996	3.15	0.25
1997	4.26	0.42
Difference	1.11	0.17

Table A. 15. Side slope sludge production.

	1996			1997		
	Ave	SD	CV	Ave	SD	CV
Sludge	2.06	1.30	0.63	2.82	1.48	0.53
Clear	0.21	0.23	1.09	0.21	0.19	0.93

Table A. 16. Sludge volume production.

	Bottom Volume (ft^3)		Side Volume (ft^3)		Total (ft^3)
	OLD	NEW	OLD	NEW	
1996	35,434	7,853	21,820	0	
1997	51,079	13,269	36,063	0	
Increment	15,645	5,416	14,243	0	35,304

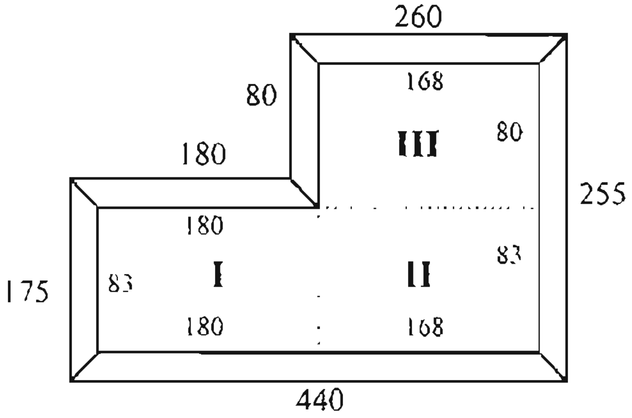


Figure A. 6. Three-section area (ft).

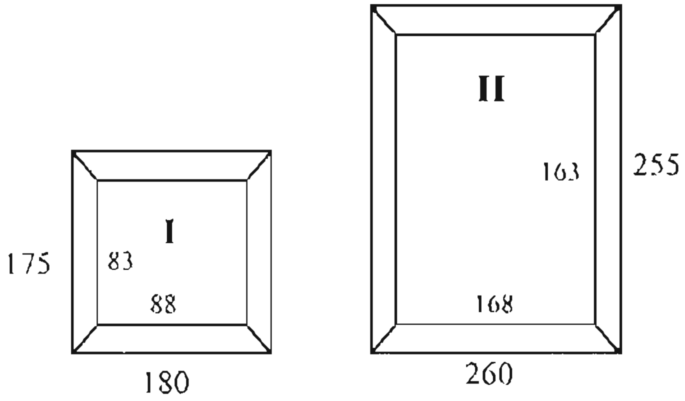


Figure A. 7. Two-Section area (ft).

Table A. 17. Surface area - three rectangular sections (ft^2).

Area	Rectangular Sections	Total
I	(180 + 3h)(83 + 6h)	14940 + 1329h + 18 h^2
II	(168 + 3h)(83 + 3h)	13944 + 753h + 9 h^2
III	(168 + 6h)(80 + 3h)	13440 + 984h + 18h^2

Table A. 18. Surface area - Two rectangular sections (ft^2) .

Area	Rectangular Sections	Total
I	(88 + 6h)(83 + 6h)	7304 + 1026h + 36h^2
II	(168 + 6h)(163 + 6h)	27384 + 1986h + 36h^2

Table A. 19. Runoff areas.

Zone	Area (ft^2)
Roof	2555
Concrete	4000
Dirt	1250

Table A. 20. Fixed lagoon runoff area

Height (ft)	W_B (ft)	W_S (ft)	L_S (ft)	SWA (ft^2)
15.30	180	260	255	53,926
13.5	169.2	249.2	244.2	46,199
Runoff Area				7,726

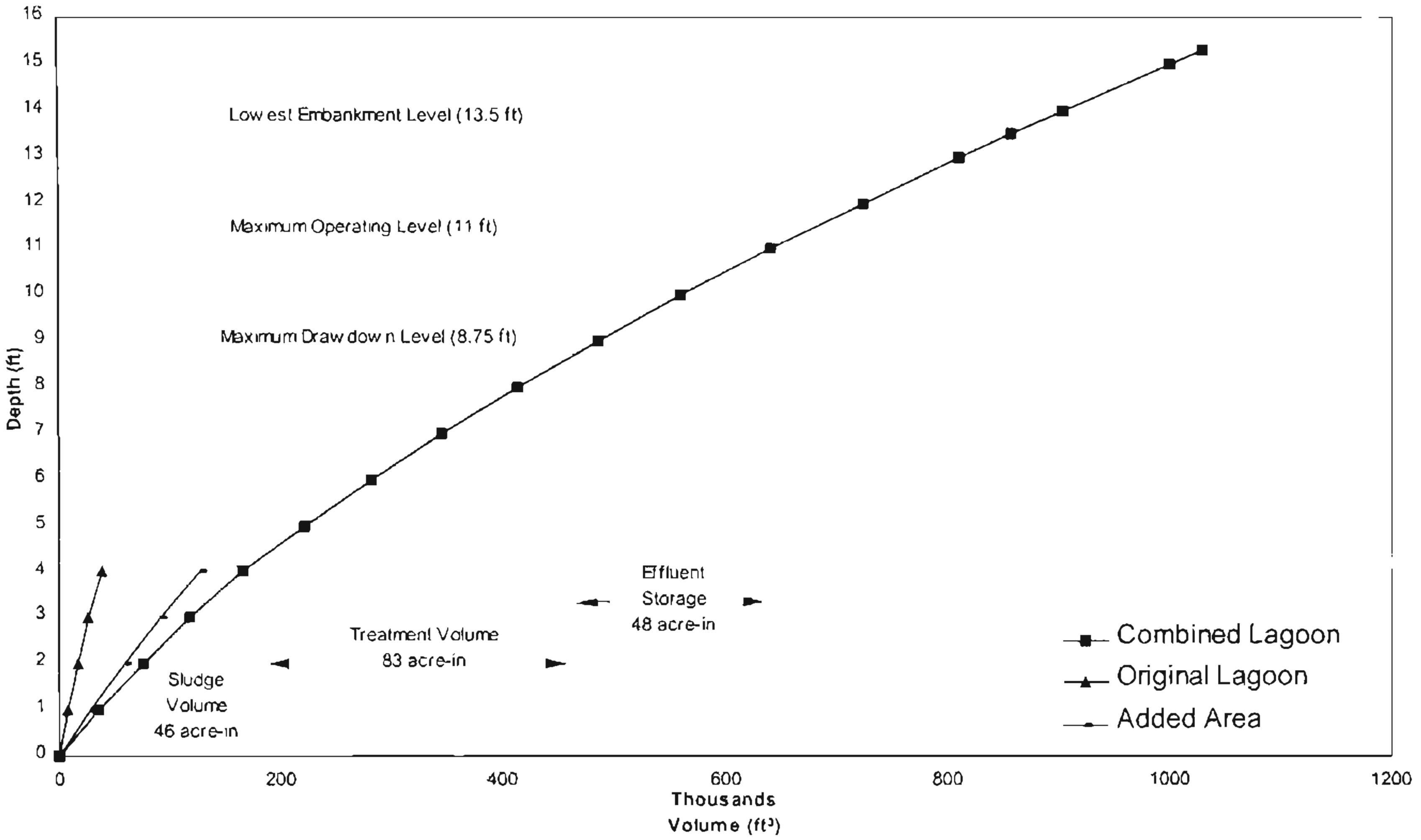


Figure A.8. Storage stage curve.

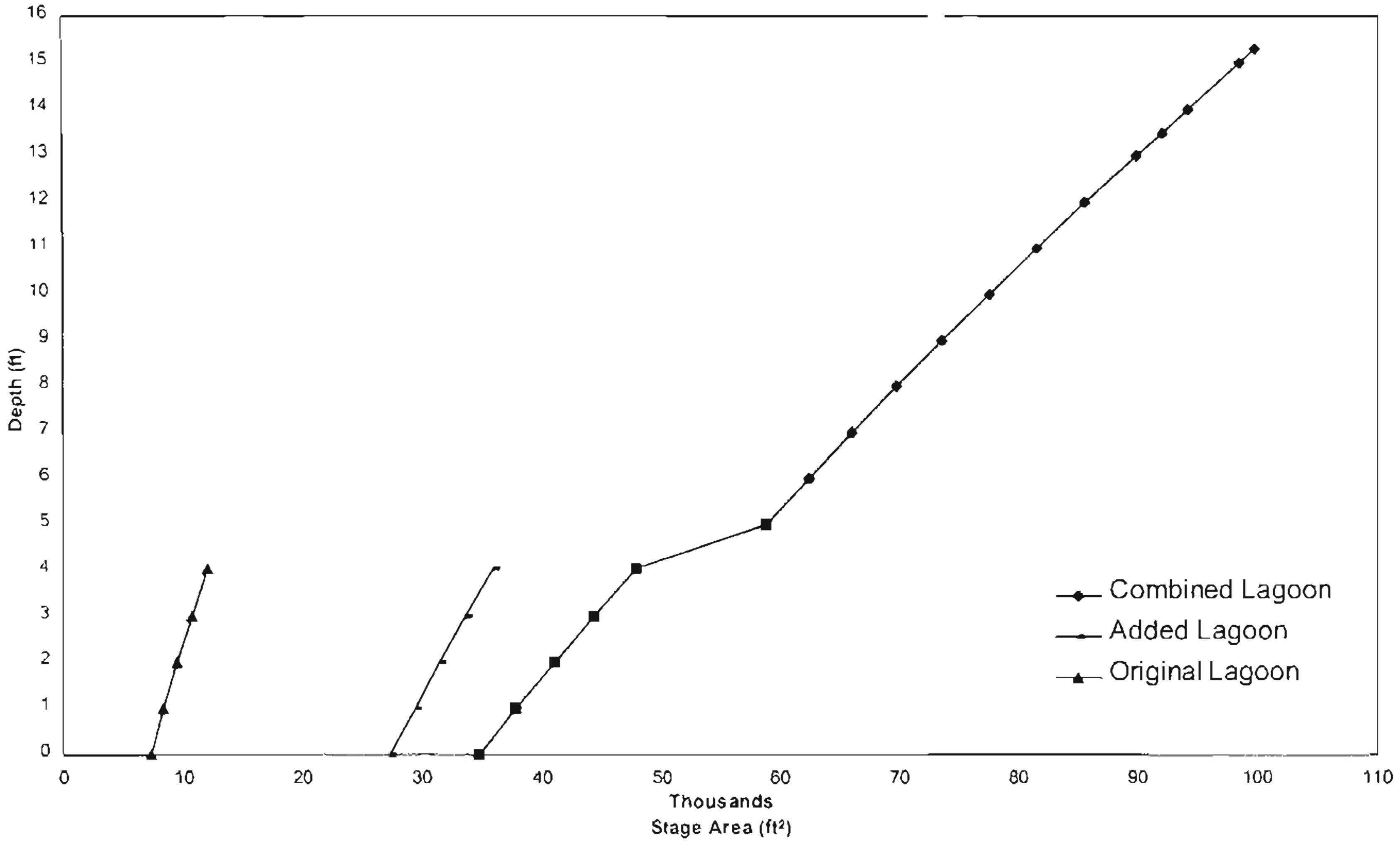


Figure A. 9. Stage surface curve.

Table A. 21. Lagoon liquid level.

Date	Elevation (ft)		Date	Elevation (ft)
05/17/96	10.40		3/23/97	10.97
8/15/96	10.23		3/26/97	11.02
8/21/96	10.11		3/31/97	10.98
8/27/96	10.13		4/3/97	10.96
9/4/96	10.07		4/7/97	11.01
9/10/96	9.995		4/9/97	11.13
9/17/96	10.24		4/12/97	11.34
9/25/96	10.27		4/16/97	11.33
10/3/96	10.34		4/23/97	11.28
10/10/96	10.33		4/30/97	11.31
10/20/96	10.22		5/7/97	11.37
10/24/96	10.35		5/26/97	11.22
11/8/96	10.40		6/4/97	11.16
11/17/96	10.52		6/12/97	11.13
11/25/96	10.515		6/13/97	11.20
12/7/96	10.63		6/19/97	11.155
12/14/96	10.64		6/23/97	11.10
1/14/97	10.68		6/28/97	11.05
1/22/97	10.69		7/1/97	11.24
1/30/97	10.68		7/7/97	11.11
2/5/97	10.68		7/11/97	11.06
2/11/97	10.74		7/16/97	11.02
2/19/97	10.73		7/18/97	11.36
2/21/97	11.02		7/30/97	11.31
2/26/97	11.04		8/7/97	11.31
3/9/97	11.01		8/20/97	11.45
3/12/97	11.01		8/30/97	11.41
3/17/97	10.98		9/14/97	11.40
3/19/97	10.98		10/2/97	11.53

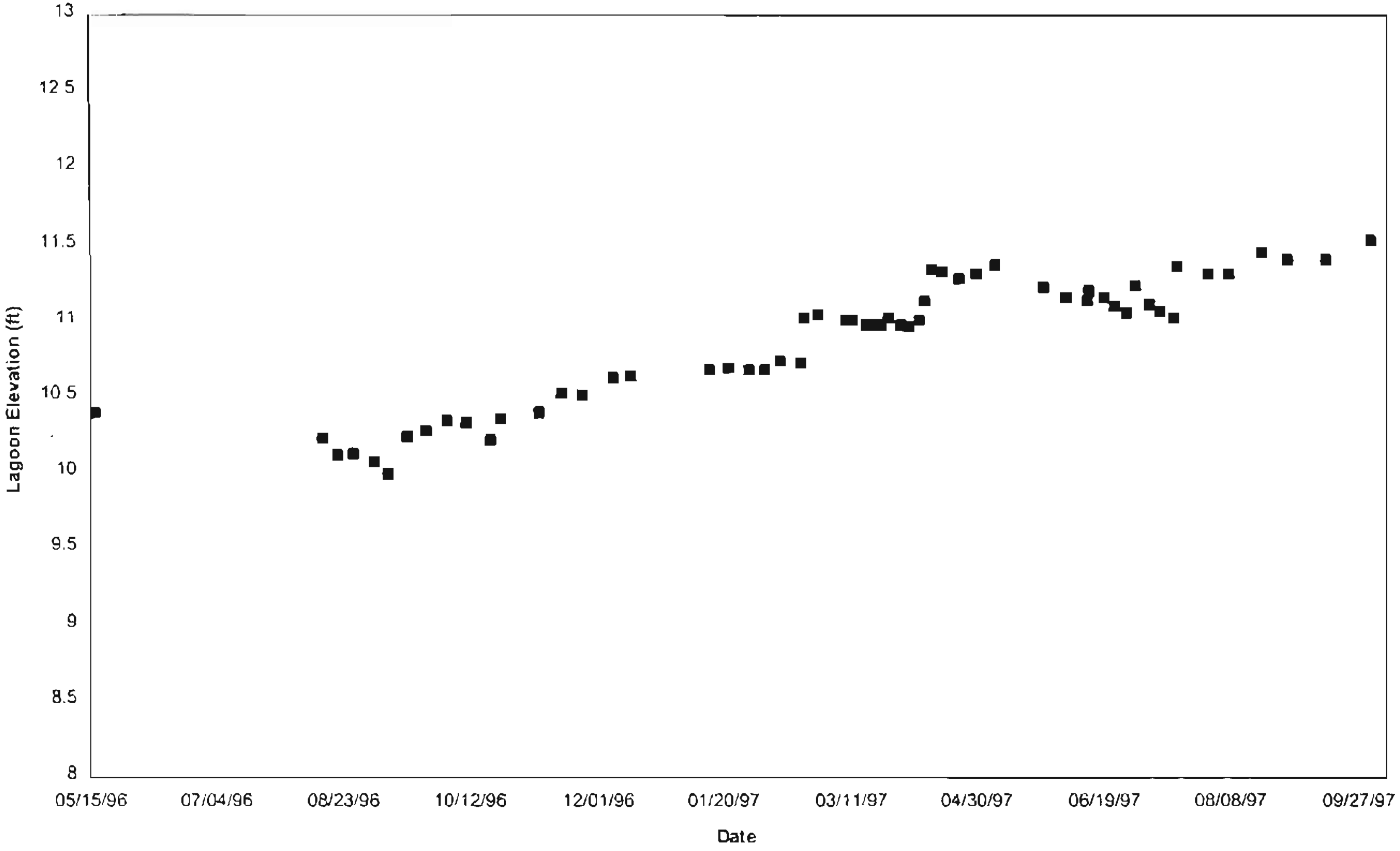


Figure A. 11. Lagoon liquid elevation.

Table A. 22. Electrical conductivity values taken in May 17, 1996.

Depth beneath the liquid surface (ft)	EC of the Sludge Side (dS/m)	EC of the Clear Side (dS/m)
0.5	3.80	3.79
1	3.81	3.79
2	3.81	3.79
3	3.82	3.79
4	3.87	3.81
5	3.98	3.82
6		3.82
7		3.87
8		3.96

Table A. 23. Lagoon supernatant analysis.

Sample ID[1]	Na^+ mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K^+ mg/L	SO_4^{2-} mg/L	EC dS/m	TSS mg/L	Na %	SAR	PAR
C05179602	176	66	23	380	97	3.69	2,435	59.6	4.8	6.0
C05179604	202	67	22	443	101	4.11	2,713	63.0	5.5	7.1
C05179606	171	66	36	375	82	3.63	2,396	54.3	4.2	5.4
C05179608	170	63	32	377	89	3.65	2,409	56.1	4.4	5.7
S0517960.5	195	53	24	444	89	2.98	1,967	64.7	5.6	7.5
S05179603	184	48	32	418	86	3.12	2,059	61.4	5.0	6.7
S05179605	194	49	16	445	90	3.01	1,987	69.2	6.2	8.3
S05179608	253	56	13	519	54	5.41	3,571	74.0	7.9	9.6
C1010960.5	186	45	12	425	86	3.03	2,000	71.4	6.4	8.5
C10109603	196	50	24	420	92	3.00	1,980	65.6	5.7	7.7
C10109605	191	57	40	440	88	2.90	1,914	57.5	4.7	6.4
C10109608	7	39	17	109	13	.581	383	8.30	0.2	2.2
S05259704	179	59	23	414	92	3.28	2,165	61.7	5.0	6.8
C05259701	180	60	27	414	85	3.32	2,191	60.0	4.8	6.6
C05259704	180	60	28	417	89	3.36	2,218	59.6	4.8	6.6
Average										
05/17/96	189	59	25	421	93	3.48	2294	62	5	7
10/10/96	191	48	18	423	89	3.01	1990	69	6	8
05/25/97	180	60	26	415	89	3.32	2191	60	5	7

[1] The letter C and S before the date stands for Clear and Sludge, respectively. The number after the date indicates the depth (ft) at which the samples were taken.

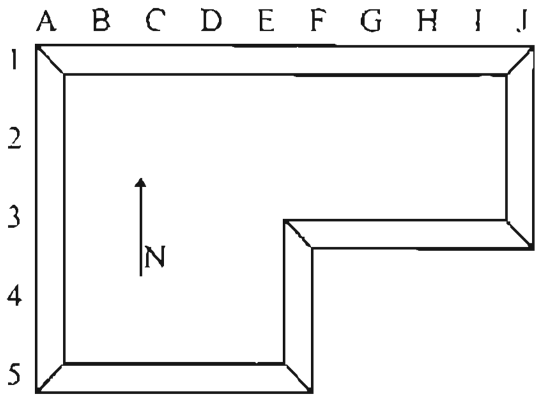


Figure A. 11. Location of EC measurements.

Table A. 24. Supernatant EC and temperature data.

Date	Location	Temp. °C	EC @ 25°C dS/m	Conductivity dS/m	Salinity
9/4/96	J1	28.6	3.58	3.83	1.90
	G3	28.1	3.57	3.78	1.90
	E4	27.6	3.55	3.74	1.90
9/10/96	G1	31.5	3.57	3.99	1.90
	I1	31.5	3.56	3.99	1.90
	G3	30.0	3.56	3.91	1.90
	C5	30.5	3.57	3.93	1.90
	D1	31.0	3.55	3.98	1.90
9/17/96	J1	21.9	3.62	3.41	1.90
	G3	21.7	3.62	3.41	1.80
	C5	21.1	3.60	3.33	1.90
	E1	21.7	3.60	3.35	1.90
9/25/96	J1	21.5	3.62	3.38	1.90
	G3	21.5	3.61	3.37	1.90
	C5	21.5	3.61	3.36	1.90
10/3/96	J1	19.8	3.59	3.23	1.90
	G4	20.4	3.56	3.24	1.90
	C5	23.9	3.51	3.43	1.80
10/20/96	J1	16.4	3.63	3.04	1.90
	G4	16.1	3.57	2.97	1.90
	C5	17.0	3.57	3.02	1.90

10/24/96	G1	17.5	3.51	3.03	1.90
	J1	17.8	3.46	2.98	1.80
	G3	18.6	3.54	2.92	1.80
	C5	15.1	3.46	2.80	1.80
11/8/96	G1	12.5	3.49	2.65	1.80
	J1	12.3	3.48	2.64	1.80
	G3	11.6	3.46	2.57	1.80
	C5	12.3	3.46	2.62	1.80
11/17/96	G1	10.8	3.42	2.52	1.80
	J1	11.1	3.44	2.51	1.80
	G3	11.0	3.42	2.54	1.80
	A3	11.8	3.41	2.55	1.80
11/25/96	G1	6.8	3.47	2.27	1.80
	J1	6.9	3.44	2.25	1.80
	G3	6.7	3.45	2.25	1.80
	C5	6.9	3.44	2.25	1.80
12/7/96	G1	7.2	3.46	2.28	1.80
	J1	7.2	3.43	2.27	1.80
	G3	7.3	3.43	2.27	1.80
	C5	7.9	3.45	2.32	1.80
	A2	6.6	3.45	2.24	1.80
12/14/96	G1	10.1	3.44	2.46	1.80
	J1	10.2	3.30	2.38	1.80
1/30/97	G1	2.2	3.77	2.13	2.00
	J1	3.0	3.68	2.13	1.90
	G3	3.2	3.67	2.14	1.90
	A3	2.7	3.69	2.12	1.90
2/11/97	G1	5.9	3.69	2.35	1.90
	J1	5.8	3.67	2.33	1.90
	G3	5.5	3.67	2.31	1.90
	A3	5.5	3.67	2.30	1.90
2/19/97	G1	10.2	3.74	2.69	2.00
	J1	10.1	3.70	2.65	2.00
	G3	10.4	3.69	2.66	2.00
	A2	11.3	3.66	2.70	1.90
2/26/97	G1	9.1	3.50	2.44	1.80
	J1	9.3	3.53	2.47	1.90
	G3	9.1	3.53	2.46	1.90
	A2	9.0	3.54	2.46	1.90
3/9/97	G1	13.3	3.64	2.82	1.90
	J2	13.1	3.63	2.81	1.90
	G3	13.1	3.60	2.79	1.90
	C5	12.8	3.60	2.76	1.90
	A2	12.8	3.60	2.76	1.90
3/12/97	G1	14.5	3.61	2.89	1.90
	J2	14.0	3.62	2.86	1.90
	G3	14.1	3.61	2.86	1.90
	C5	15.1	3.59	2.91	1.90
	A2	15.4	3.59	2.93	1.90
3/19/97	G1	16.0	3.69	3.06	2.00

	J2	16.8	3.66	3.08	1.90
	G3	18.0	3.64	3.15	1.90
	C5	18.4	3.61	3.15	1.90
	A2	15.8	3.67	3.02	1.90
	E1	14.5	3.66	2.92	1.90
3/26/97	G1	22.2	3.58	3.40	1.90
	J2	21.3	3.61	3.35	1.90
	G3	20.2	3.62	3.29	1.90
	C5	17.1	3.65	3.10	1.90
	A2	19.6	3.61	3.23	1.90
	E1	20.7	3.60	3.30	1.90
4/2/97	G1	18.1	3.69	3.21	2.00
	J2	17.3	3.70	3.16	2.00
	G3	17.5	3.70	3.17	2.00
	C5	18.0	3.69	3.20	2.00
	A2	19.2	3.67	3.27	1.90
	E1	18.2	3.69	3.21	2.00
4/9/97	G1	12.6	3.69	2.82	2.00
	J2	12.6	3.67	2.79	1.90
	G3	12.5	3.67	2.79	1.90
	C5	13.0	3.67	2.83	1.90
	A2	13.6	3.66	2.87	1.90
	E1	13.0	3.67	2.87	1.90
4/12/97	G1	10.7	3.56	2.59	1.90
	J2	10.6	3.59	2.60	1.90
	G3	10.6	3.57	2.58	1.90
	C5	10.7	3.57	2.59	1.90
	A2	10.9	3.55	2.59	1.90
	E1	10.5	3.56	2.57	1.90
4/16/97	G1	17.1	3.54	3.01	1.90
	J2	16.2	3.48	2.90	1.90
	G3	17.0	3.52	2.98	1.90
	C5	18.4	3.52	3.08	1.90
	A2	18.8	3.51	3.09	1.90
	E1	18.0	3.53	3.06	1.90
4/23/97	G1	18.8	3.58	3.16	1.90
	J2	19.4	3.53	3.16	1.90
	G3	20.9	3.52	3.24	1.90
	C5	20.9	3.52	3.24	1.90
	A2	19.5	3.55	3.17	1.90
	E1	19.1	3.54	3.14	1.90
4/30/97	G1	19.1	3.56	3.15	1.90
	J2	18.7	3.55	3.11	1.90
	G3	18.6	3.54	3.10	1.90
	C5	19.3	3.54	3.15	1.90
	A2	19.0	3.54	3.13	1.90
	E1	18.5	3.54	3.10	1.90
5/7/97	G1	22.2	3.48	3.30	1.80
	J2	23.3	3.47	3.35	1.80
	G3	22.9	3.45	3.31	1.80

	C5	22.8	3.45	3.30	1.80
	A2	23.4	3.45	3.34	1.80
	E1	23.4	3.45	3.34	1.80
6/4/97	G1	22.9	3.45	3.31	1.80
	J2	22.5	3.44	3.27	1.80
	G3	23.3	3.41	3.30	1.80
	C5	23.7	3.40	3.32	1.80
	A2	24.5	3.40	3.36	1.80
	E1	23.3	3.41	3.30	1.80
6/11/97	G1	24.4	3.43	3.39	1.80
	J2	24.5	3.39	3.36	1.80
	G3	23.7	3.39	3.31	1.80
	C5	23.9	3.37	3.30	1.80
	A2	27.6	3.29	3.45	1.70
	E1	26.5	3.34	3.43	1.70
6/12/97	G1	30.5	3.38	3.73	1.80
	J2	29.8	3.37	3.68	1.80
	G3	29.0	3.37	3.62	1.80
	C5	29.3	3.36	3.63	1.70
	A2	30.4	3.34	3.68	1.70
	E1	31.3	3.35	3.74	1.70
6/13/97	G1	23.7	3.38	3.29	1.80
	J2	23.8	3.34	3.26	1.70
	G3	24.0	3.35	3.28	1.80
	C5	24.1	3.34	3.29	1.80
	A2	23.9	3.33	3.26	1.70
	E1	23.9	3.36	3.29	1.80
6/19/97	G1	27.7	3.32	3.49	1.70
	J2	27.6	3.30	3.46	1.70
	G3	26.2	3.31	3.40	1.70
	C5	26.6	3.31	3.41	1.70
	A2	28.2	3.29	3.50	1.70
	E1	28.9	3.28	3.53	1.70
7/9/97	G1	31.5	3.31	3.72	1.70
	J2	30.8	3.29	3.66	1.70
	G3	29.9	3.31	3.62	1.70
	C5	31.5	3.27	3.68	1.70
	A2	33.4	3.22	3.75	1.70
	E1	32.4	3.27	3.73	1.70
7/30/97	G1	29.7	3.12	3.38	1.60
	J2	29.2	3.11	3.35	1.60
	G3	29.5	3.11	3.38	1.60
	C5	30.9	3.09	3.43	1.60
	A2	30.9	3.10	3.46	1.60
	E1	31.1	3.10	3.41	1.60
8/7/97	G1	26.7	3.15	3.25	1.60
	J2	24.9	3.14	3.14	1.60
	G3	24.5	3.12	3.09	1.60
	C5	26.9	3.07	3.20	1.60
	A2	27.2	3.08	3.21	1.60

	E1	30.1	3.03	3.33	1.60
8/20/97	G1	31.1	2.97	3.31	1.50
	J2	31.3	2.99	3.34	1.50
	G3	31.5	2.94	3.31	1.50
	C5	31.4	2.98	3.31	1.50
	A2	30.2	3.01	3.31	1.60
	E1	30.6	3.00	3.32	1.50
8/30/97	G1	31.1	2.97	3.32	1.50
	J2	30.5	3.00	3.32	1.50
	G3	30.6	3.01	3.33	1.50
	C5	30.2	3.00	3.29	1.50
	A2	32.0	2.92	3.31	1.50
	E1	31.7	2.93	3.32	1.50
9/14/97	G1	31.8	3.02	3.40	1.50
	G3	31.8	2.97	3.35	1.50
	A2	30.7	3.01	3.33	1.50
10/2/97	G1	27.0	3.03	3.14	1.60
	J2	25.9	3.00	3.06	1.60
	G3	24.7	3.00	2.98	1.60
	C5	23.5	3.01	2.95	1.60
	A2	24.9	2.99	2.98	1.60
	E1	29.0	2.90	3.12	1.50

Table A. 25. Supernatant EC and temperature - average results

Date	Temp.°C	EC @ 25°C dS/m	EC dS/m	Salinity
9/4/96	28.10	3.57	3.78	1.90
9/10/96	30.90	3.56	3.96	1.90
9/17/96	21.60	3.61	3.38	1.88
9/25/96	21.50	3.61	3.37	1.90
10/3/96	21.37	3.55	3.30	1.87
10/20/96	16.50	3.59	3.01	1.90
10/24/96	17.25	3.49	2.93	1.83
11/8/96	12.18	3.47	2.62	1.80
11/17/96	11.18	3.42	2.53	1.80
11/25/96	6.83	3.45	2.26	1.80
12/7/96	7.24	3.44	2.28	1.80
12/14/96	10.15	3.37	2.42	1.80
1/30/97	2.78	3.70	2.13	1.93
2/11/97	5.68	3.68	2.32	1.90
2/19/97	10.50	3.70	2.67	1.98
2/26/97	9.13	3.53	2.46	1.88
3/9/97	13.02	3.61	2.79	1.90
3/12/97	14.62	3.60	2.89	1.90
3/19/97	16.58	3.65	3.06	1.92
3/26/97	20.18	3.61	3.28	1.90
4/2/97	18.05	3.69	3.20	1.98
4/9/97	12.88	3.67	2.83	1.92
4/12/97	10.67	3.57	2.59	1.90
4/16/97	17.58	3.52	3.02	1.90
4/23/97	19.77	3.54	3.18	1.90
4/30/97	18.87	3.54	3.12	1.90
5/7/97	23.00	3.46	3.32	1.80
6/4/97	23.37	3.42	3.31	1.80
6/11/97	25.10	3.37	3.37	1.77
6/12/97	30.05	3.36	3.68	1.75
6/13/97	23.90	3.35	3.28	1.77
6/19/97	27.53	3.30	3.46	1.70
7/9/97	31.58	3.28	3.69	1.70
7/30/97	30.22	3.10	3.40	1.60
8/7/97	26.72	3.10	3.20	1.60
8/20/97	31.02	2.98	3.32	1.52
8/30/97	31.02	2.97	3.31	1.50
9/14/97	31.43	3.00	3.36	1.50

10/2/97	25.83	2.99	3.04	1.58

Table A. 26. Composition of Diets (lb/2000 lbs. Mix)

Ingredients	Boars	Sows & Litters	Nursery	Growers 50 - 125 lbs	Finisher 125-175 lbs	Finisher 125-175 lbs
Soybean Meal 48%	320	350	550	564	320	320
Corn	1631	1392	1379.7	1379.7	1631	1631
Tylan 40	1	0	2.5	2.5	1	1
Copper Sulphate	2	0	1.6	2	2	2
Calcium Carbonate	15	17	12	14.8	15	15
Vitamin Premix	5	6	5	5	5	5
Dicalcium phosphate	19	35	38	25	19	19
Salt	7	10	8.4	7	7	7
Lysine		0	3			
CTC - 50		4				
Psyllium		6				
Soy Oil		80				
Fish Meal		50				
Whey, Dehydrated		50				

APPENDIX B

600-Sow Breeding, Farm, LeFlore County

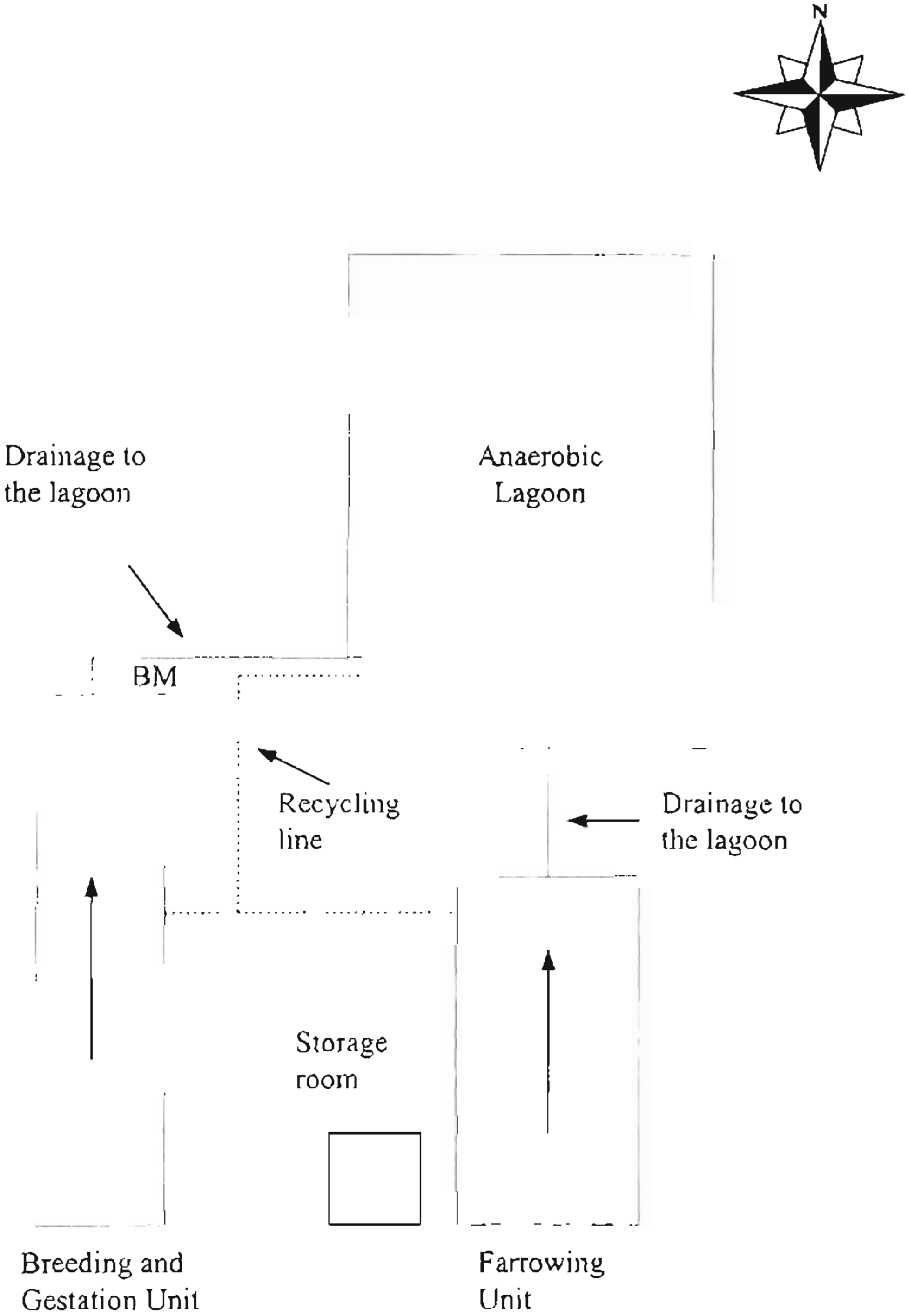


Figure B. 1. System schematic of the 600- sow breeding farm, LeFlore County

Table B. 1. Farm values for mass and volume[1].

Type	# of pigs	Pigs wt. lbs/each	Total wt. lbs	TS lbs/day	VS lbs/day	Manure Volume ft^3/day
Boars	12	400	4,800	9.12	8.16	1.56
Gilts	25	250	6,250	20.5	18.25	3.25
Gestation Sow	393	300	117,900	294.75	255.45	51.09
Sows & Litters	84	375	31,500	218.4	193.2	34.44
Total	514		160.450	542.77	475.06	90.34

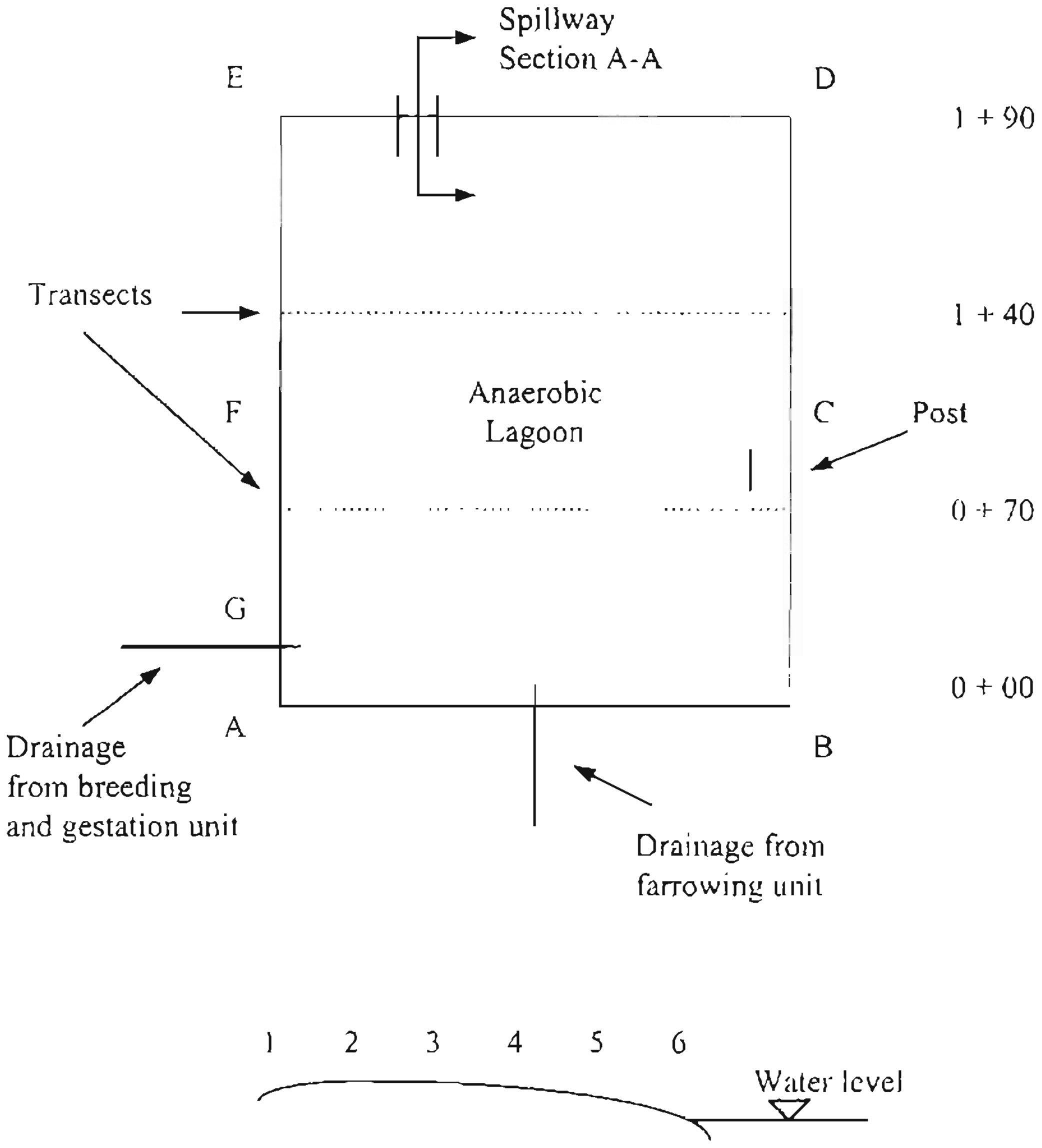
[1] Hamilton et al. (1997).

Table B. 2. Drinking channels operational time.

Operating Hour	Time (min.)
6:00 a.m.	15
8:00	30
10:00	15
12:00 p.m.	15
2:00	15
3:30	15
4:00	feed
5:00	30
7:00	15
9:00	15
11:00	15
6:00	15
Total	195

Table B. 3. Lagoon bank survey data (ft).

Location	BS	HI	FS	Elevation
BM	4.2	104.2		100
Top of post			6.37	97.83
A			4.68	99.52
B			3.92	100.28
C			3.91	100.29
D			3.91	100.29
spillway 1			6.08	98.12
spillway 2			5.89	98.31
spillway 3			5.97	98.23
spillway 4			5.95	98.25
spillway 5			6.18	98 02
spillway 6			6.55	97.65
water level			7.63	96.57
E			3.66	100.54
F			5.20	99.00
G			5.54	98.66



Section A-A

Figure B. 2. Layout of the lagoon survey.

Table B. 4. Depth data at 0 + 70 during the survey in May 23, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.70	3.10	0.40
20	6.00	6.40	0.40
30	6.90	7.35	0.45
40	9.00	9.20	0.20
50	8.80	9.30	0.50
60	8.20	9.30	1.10
70	8.30	9.15	0.85
80	8.40	9.10	0.70
90	8.20	9.00	0.80
100	8.00	8.30	0.30
110	6.70	6.90	0.20
120	3.00	3.90	0.90
125	2.20	2.70	0.50
135	waterline		

Table B. 5. Depth data at 1 + 40 during the survey in May 23, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	2.20	3.00	0.80
20	5.80	5.90	0.10
30	8.55	8.55	0.00
40	9.10	9.30	0.20
50	9.40	9.50	0.10
60	9.50	9.60	0.10
70	9.50	9.70	0.20
80	9.00	9.70	0.70
90	9.00	9.50	0.50
100	8.40	9.30	0.90
110	7.10	7.90	0.80
120	5.00	5.60	0.60
130	1.80	2.40	0.60
135	waterline		

Table B. 6. Lagoon depth and sludge accumulation values taken in May 23, 1996.

	0 + 70			1 + 40			Lagoon		
	AVE	SD	CV	AVE	SD	CV	AVE	SD	CV
Lagoon depth, ft	9.05	0.35	0.04	9.51	0.17	0.02	9.40	0.22	0.02
Sludge depth, ft	8.48	0.34	0.04	9.25	0.24	0.03	8.87	0.49	0.06
Sludge thickness, ft	0.69	0.34	0.45	0.30	0.24	0.80	0.49	0.34	0.68

Table B. 7. Depth data at 0 + 70 during the survey in May 13, 1997.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	1.90	3.30	1.40
20	4.40	5.65	1.25
30	6.70	8.30	1.60
40	8.40	9.40	1.00
50	8.30	9.35	1.05
60	8.90	9.68	0.78
70	8.10	9.67	1.57
80	8.30	9.64	1.34
90	8.50	9.70	1.20
100	8.30	9.10	0.80
110	6.30	7.34	1.04
120	4.00	4.90	0.90
130	1.10	1.97	0.87
139	waterline		

Table B. 8. Depth data at 1 + 40 during the survey in May 13, 1997.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	1.80	4.03	2.23
20	5.60	6.37	0.77
30	7.50	8.64	1.14
40	9.60	9.75	0.15
50	8.80	9.70	0.90
60	9.00	9.75	0.75
70	9.60	9.82	0.22
80	9.40	9.72	0.32
90	9.50	9.84	0.34
100	9.00	9.50	0.50
110	7.80	8.30	0.50
120	4.70	5.43	0.73
130	2.00	2.88	0.88
140	waterline		

Table B. 9. Sludge production values of May 13, 1997.

	0 + 70			1 + 40			Lagoon		
	AVE	SD	CV	AVE	SD	CV	AVE	SD	CV
Sludge depth, ft	8.40	0.25	0.03	9.27	0.33	0.04	8.84	0.53	0.06
Sludge thickness, ft	1.11	0.29	0.26	0.65	0.30	0.46	0.87	0.37	0.42

Table B. 10. Increase in sludge accumulation during 360 days of operation.

	Transect at 0 + 70 ft (ft)	Transect at 1 + 40 ft (ft)	Bottom flat region (ft)	Increment between transects (%)
1996	0.69	0.30	0.49	57
1997	1.11	0.65	0.87	41
Increment (%)	61	117	78	

Table B. 11. Side slope sludge production (ft).

	1996			1997		
	Ave	SD	CV	Ave	SD	CV
0 + 70	0.48	0.23	0.49	1.12	0.29	0.26
1 + 40	0.48	0.35	0.72	1.01	0.66	0.65
Ave. Side Slope	0.48	0.28	0.59	1.10	0.49	0.45

Table B. 12. Sludge volume production.

	Sludge thickness Bottom (ft)	Sludge thickness Side (ft)	Volume Bottom (ft^3)	Volume Side (ft^3)
1996	0.46	0.48	4,349	8,903
1997	0.87	1.10	7,918	22,165
Increment	0.41	0.62	3,569	13,262
Total sludge volume			16,831	

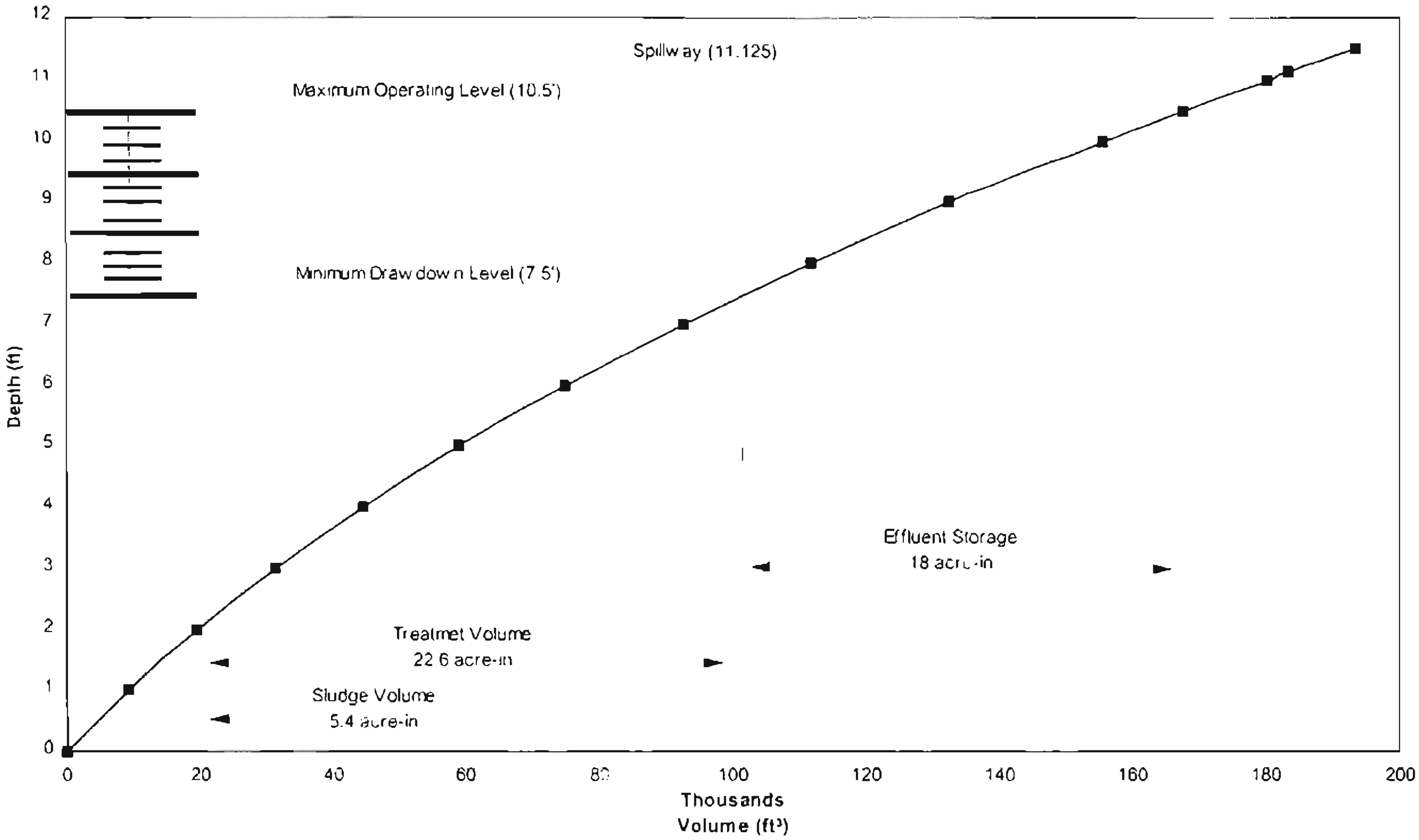


Figure B. 3. Stage storage curve.

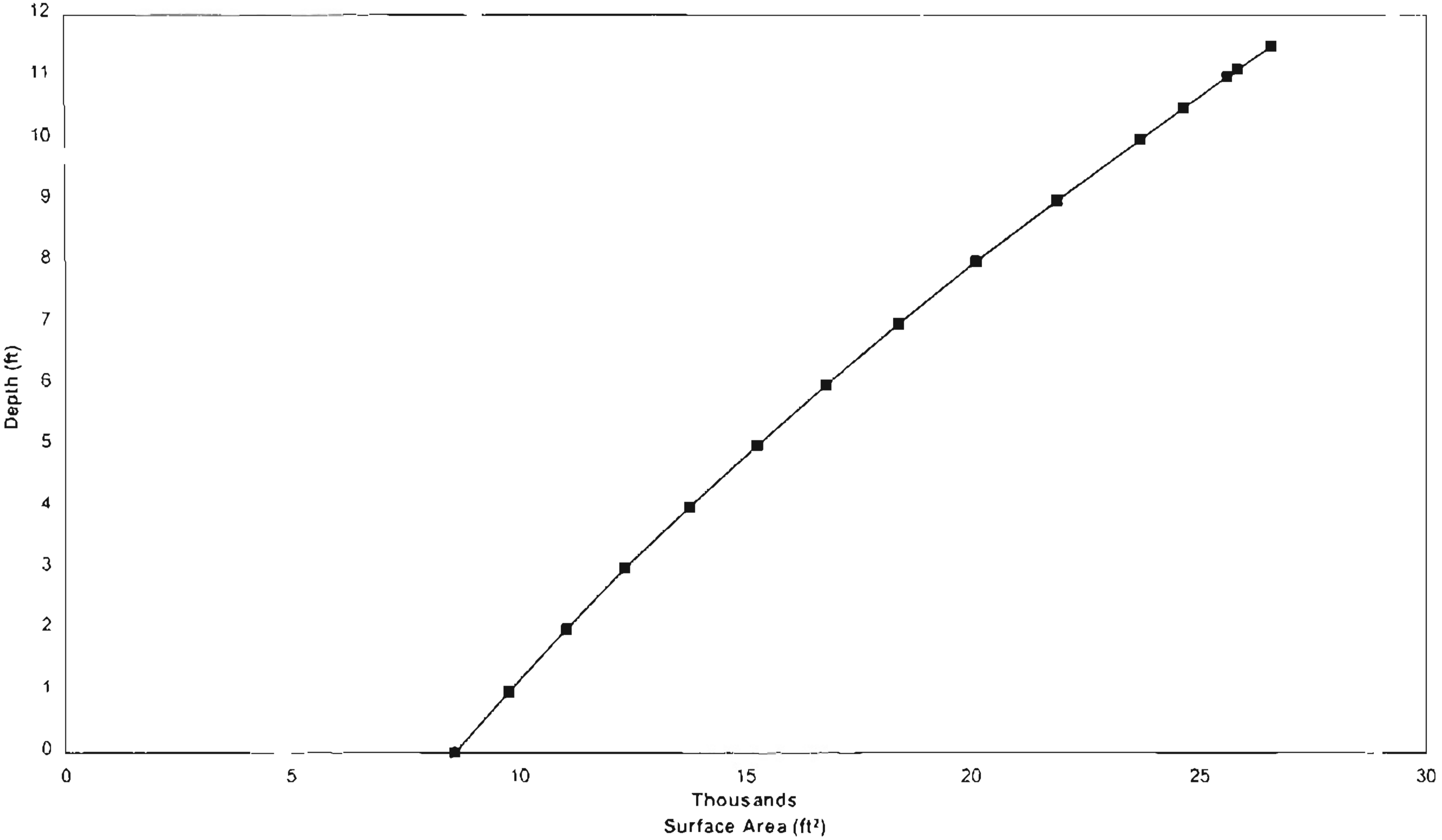


Figure B. 4. Stage surface curve.

Table B. 13. Observed lagoon liquid level (ft).

Date	Liquid level
11/21/96	9.50
12/02/96	10.17
12/04/96	9.25
01/01/97	9.83
01/03/97	9.17
02/08/97	10.0
02/11/97	9.17
02/19/97	9.50
02/27/97	9.92
03/07/97	8.83
03/14/97	9.17
03/21/97	9.33
03/28/97	9.60
04/04/97	9.80
04/12/97	9.83
04/17/97	9.17
04/25/97	9.25
05/02/97	9.42
05/09/97	9.58
05/13/97	9.75
05/16/97	9.58
05/23/97	9.67
05/30/97	9.75
06/06/97	9.83
06/13/97	10.0
06/15/97	9.83
06/17/97	10.17
06/20/97	9.50
07/09/97	9.83
07/10/97	9.33
07/30/97	9.67
08/02/97	8.50
09/22/97	9.50

Table B. 14. Precipitation data (in)

Date	Precipitation
11/24/96	2.70
11/25/96	0.80
11/29/96	0.80
11/30/96	0.20
12/4/96	0.40
12/14/96	0.60
1/1/97	0.30
2/3/97	0.90
2/7/97	1.00
2/13/97	0.20
2/20/97	1.00
2/21/97	1.30
2/26/97	0.70
3/1/97	1.40
3/2/97	0.60
3/13/97	1.00
3/25/97	0.70
4/5/97	1.50
4/11/97	0.60
4/22/97	0.40
4/23/97	0.30
4/27/97	0.90
5/8/97	0.30
5/9/97	0.40

Date	Precipitation
5/24/97	0.60
5/25/97	0.50
6/9/97	0.80
6/12/97	0.90
6/13/97	0.30
6/15/97	0.90
6/16/97	2.40
6/21/97	0.25
6/28/97	0.50
6/29/97	0.70
6/30/97	0.25
7/10/97	0.30
7/22/97	0.40
7/29/97	1.00
8/6/97	0.80
8/7/97	0.40
8/13/97	0.20
8/17/97	1.60
8/18/97	1.30
8/22/97	0.30
9/8/97	0.60
9/13/97	0.70
9/14/97	0.10
9/15/97	0.70

Table B. 15. Irrigation data.

Irrigation Date	Beginning Liquid Level (ft)	Ending Liquid Level (ft)	Beginning Volume (ft^3)	Ending Volume (ft^3)	Volume Pumped (ft^3)
12/2/96	10.17		159,568		
12/4/96		9.25		138,248	21,320
01/01/97	9.83		151,506		
01/03/97		9.17		136,468	15,038
02/08/97	10.0		155,510		
02/11/97		9.17		136,468	19,042
02/27/97	9.92		153,619		
03/07/97		8.83		129,030	24,589
04/12/97	9.83		151,506		
04/17/97		9.17		136,468	15,038
05/13/97	9.75		149,641		
05/16/97		9.58		145,716	3,925
06/13/97	10.0		155,510		
06/15/97		9.83		151,506	4,004
06/17/97	10.17		159,568		
06/20/97		9.50		143,887	15,681
07/09/97	9.83		151,506		
07/10/97		9.33		140,040	11,466
07/30/97	9.67		147,787		
08/02/97		8.50		122,009	25,778
Total effluent volume pumped					155,881

Table B. 16. Level of feed consumed daily.

Animal	No. of each	Dry Feed lbs./day	Total lbs/day
Breeding and Gestation Unit			
Boar	12	5	60
Gilt	25	5	125
Gest Sow	393	5	1,965
Farrowing Unit			
Sow Litter	84	10	840

Table B. 17. Values of calcium and sodium in diets.

Units	Ca^{2+}, %	Na^{+}, %
Breeding and Gestation	1.15	0.75
Farrowing	1.10	0.80

Table B. 18. Observed EC measurements from lagoon supernatant.

Date	EC, dS/m
11/21/96	4.73
03/26/97	5.63
05/13/97	6.13
09/23/97	5.61

APPENDIX C

600-Sow Breeding, Farm, Pottawatomie County

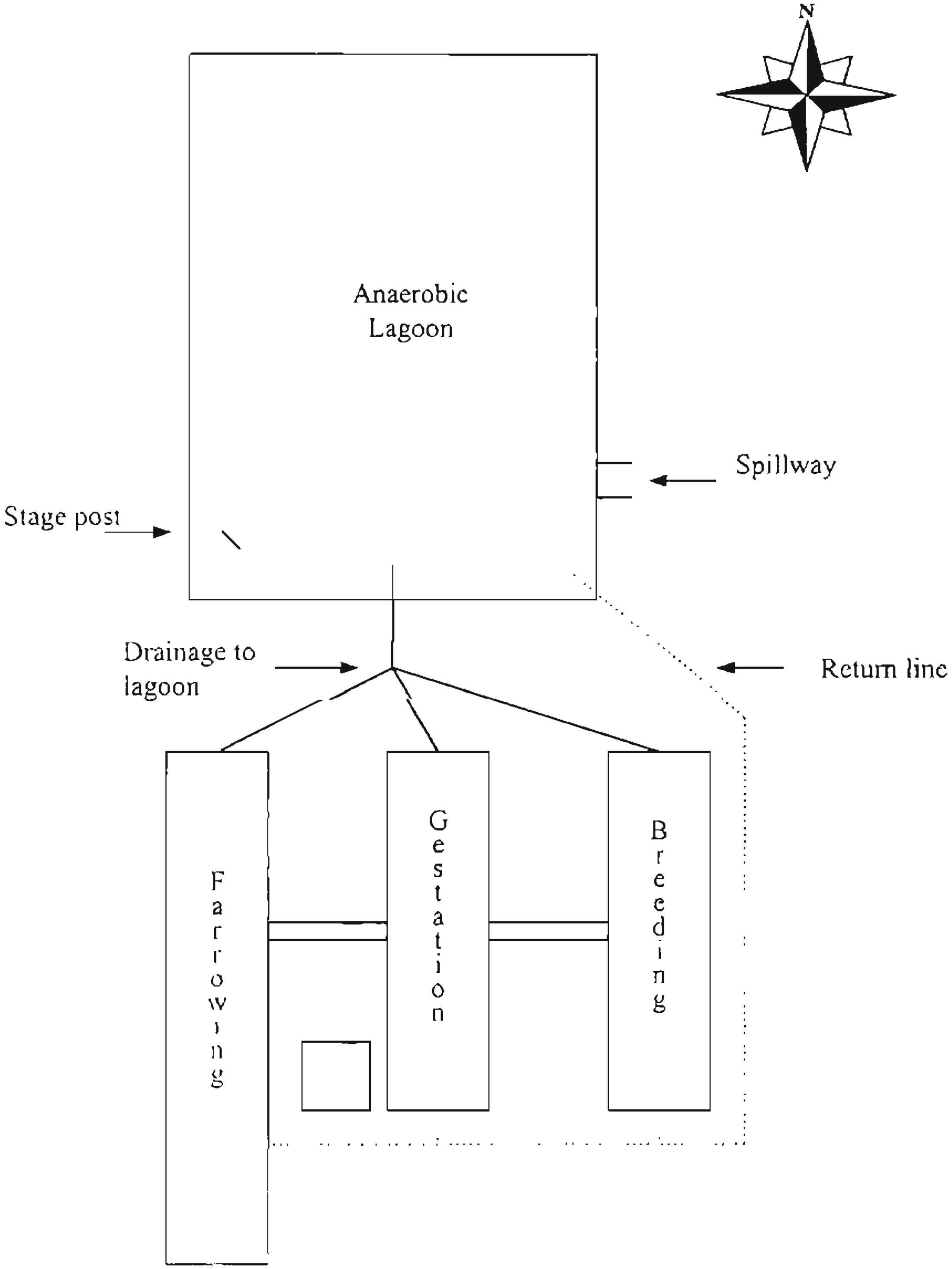
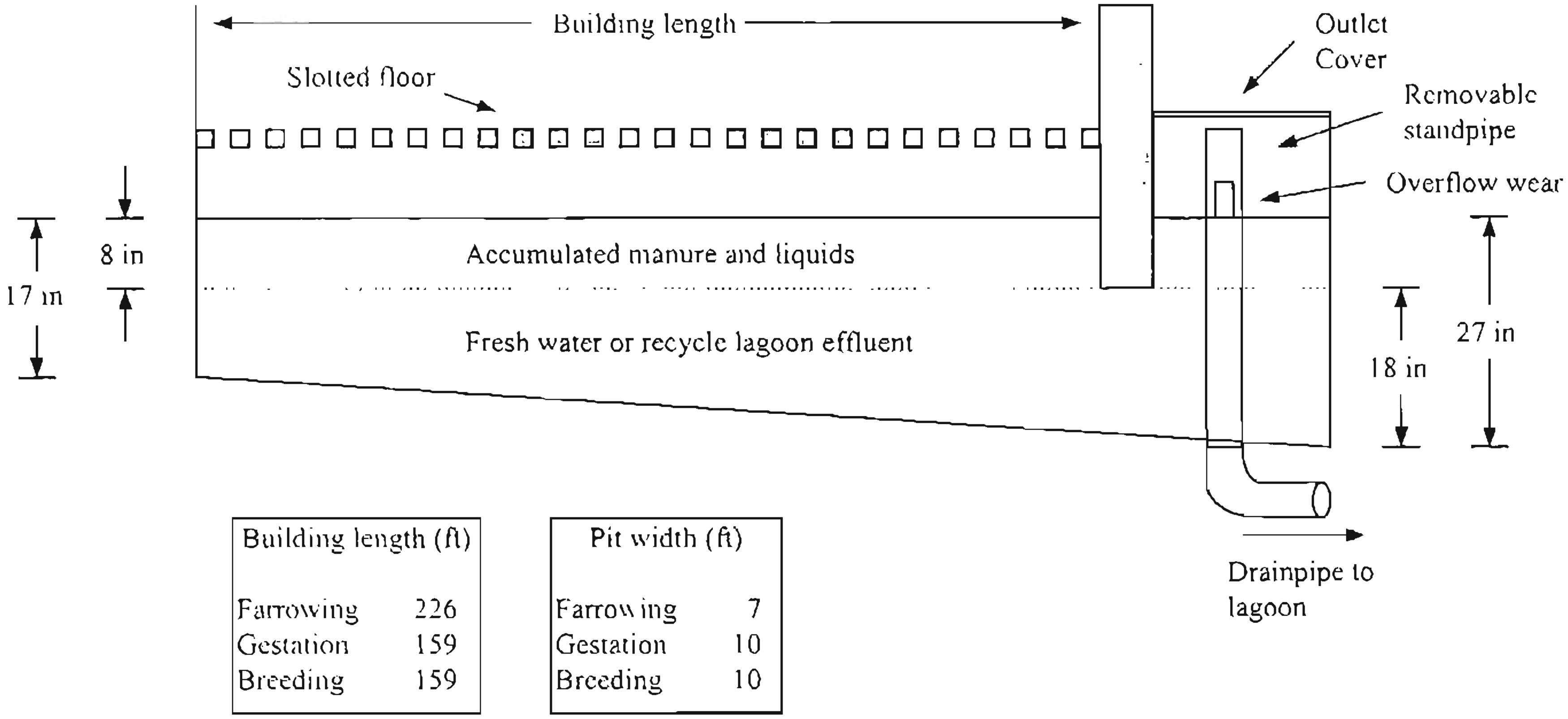


Figure C. 1. System schematic of the 600- sow breeding farm, Pottawatomie County.

Table C. 1. Farm values for mass and volume[1].

Type	# of pigs	Pigs wt. lbs/each	Total wt. lbs	TS lbs/day	VS lbs/day	Manure Volume ft^3/day
Boar	6	400	2,000	3.80	3.40	0.65
Gilt	15	250	3,750	12.30	10.95	1.95
Gest Sow	480	300	144,000	360.0	312.0	62.40
Sow + Litter	120	375	45,000	312.0	276.0	49.20
Total	620		194,750	688.1	602.35	114.20

[1] Hamilton et al. (1997).



Building length (ft)	
Farrowing	226
Gestation	159
Breeding	159

Pit width (ft)	
Farrowing	7
Gestation	10
Breeding	10

Figure C. 2. Underfloor storage pit dimensions.

Table C. 2. Underfloor storage pits capacity.

	Freshwater or recycled effluent (ft^3)	Manure and wastewater (ft^3)	Total capacity (ft^3)
Farrowing	5,537	3,164	8,701
Gestation	3,710	2,120	5,830
Breeding	3,710	2,120	5,830
Total	12,957	7,404	20,361
% of Total	64 %	36 %	

Table C. 3. Lagoon survey data (ft).

Location	BS	HI	FS	Elevation
BM	1.18	101.18		100
A			1.99	99.19
B			4.09	97.10
spillway 1			5.32	95.87
spillway 2			5.31	95.88
spillway 3			5.34	95.85
spillway 4			5.43	95.76
spillway 5			5.57	95.62
water level			6.31	94.88
C			3.48	97.71
E			3.24	97.99
F			3.00	98.19
G			3.88	97.31
top of post			6.01	95.18

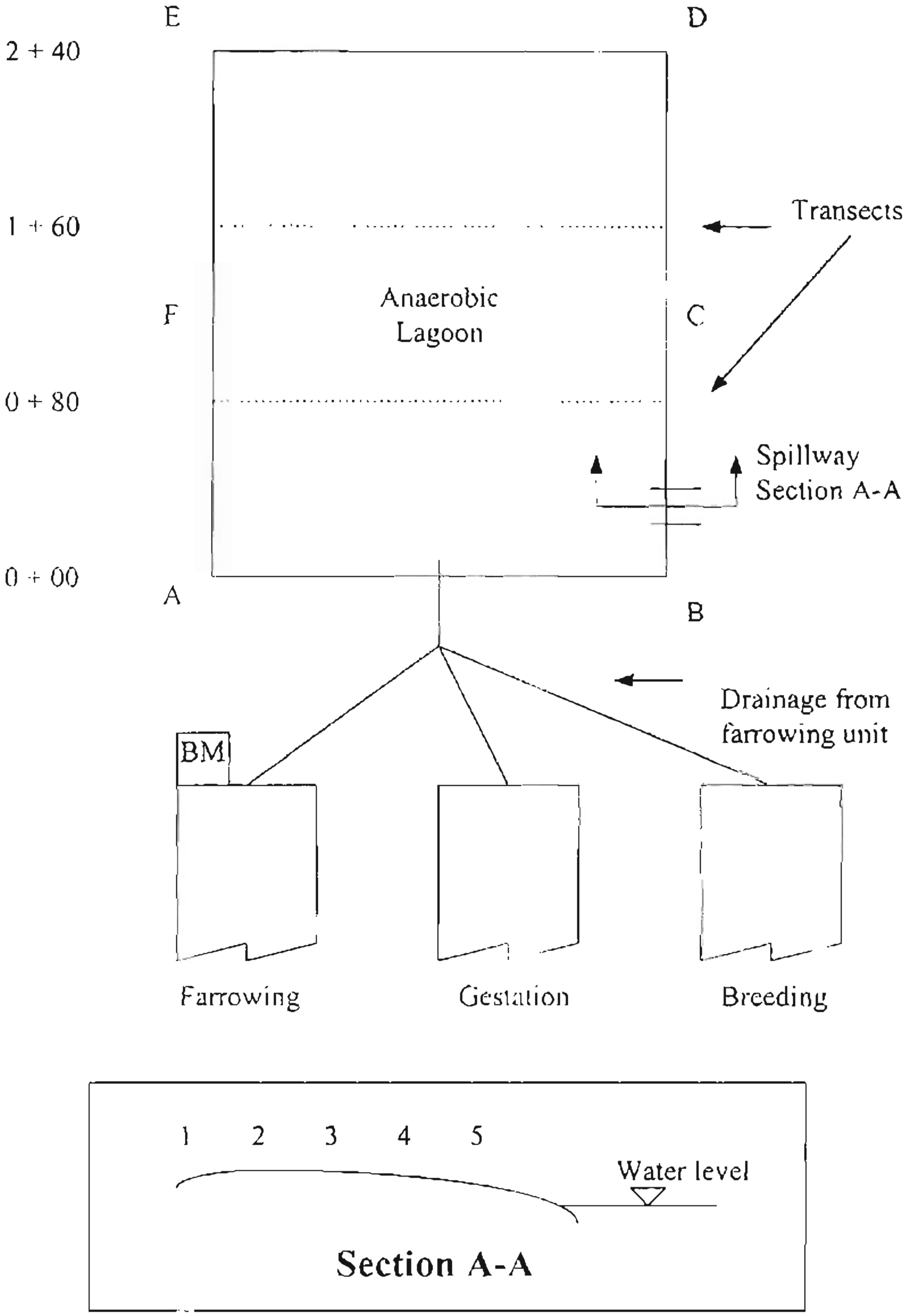


Figure C. 3. Layout of the lagoon survey.

Table C. 4. Depth data at 0 + 80 ft during the survey in May 21, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	3.80	4.20	0.40
20	7.20	7.50	0.30
30	8.20	8.30	0.10
40	8.20	8.45	0.25
50	7.80	8.40	0.60
60	7.90	8.40	0.50
70	8.50	8.90	0.40
80	8.30	9.00	0.70
90	8.20	8.90	0.70
100	8.00	8.50	0.50
110	7.00	7.30	0.30
120	3.35	3.35	0.00
126	waterline		

Table C. 5. Depth data at 1 + 60 ft during the survey in May 21, 1996.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	3.80	3.80	0.00
20	7.20	7.65	0.45
30	7.70	8.20	0.50
40	7.90	8.30	0.40
50	7.80	8.15	0.35
60	8.00	8.40	0.40
70	7.80	8.30	0.50
80	7.90	8.30	0.40
90	7.80	8.35	0.55
100	7.60	8.00	0.40
110	6.50	6.90	0.40
120	2.90	2.90	0.00
125	waterline		

Table C. 6. Statistical analysis for the depth data taken in May 21, 1996.

	0 + 80 ft			1 + 60 ft			Lagoon		
	AVE	SD	CV	AVE	SD	CV	AVE	SD	CV
Lagoon depth, ft	8.65	0.27	0.03	8.25	0.13	0.02	8.46	0.27	0.03
Sludge depth, ft	8.14	0.29	0.04	7.88	0.08	0.01	7.98	0.24	0.03
Sludge thickness, ft	0.49	0.17	0.35	0.30	0.24	0.80	0.45	0.15	0.34

Table C. 7. Depth data at 0 + 80 ft during the survey in May 15, 1997.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	3.70	4.53	0.83
20	6.16	7.22	1.06
30	6.80	7.80	1.00
40	6.70	7.83	1.13
50	6.70	7.97	1.27
60	6.75	8.05	1.30
70	7.00	8.40	1.40
80	6.70	8.30	1.60
90	6.70	8.45	1.75
100	6.60	7.96	1.36
110	5.60	6.24	0.64
120	1.90	2.44	0.54
125	waterline		

Table C. 8. Depth data at 1 + 60 ft during the survey in May 15, 1997.

Distance	Sludge depth ft	Lagoon depth ft	Sludge thickness ft
0	waterline		
10	3.20	3.78	0.58
20	6.00	7.00	1.00
30	6.70	7.72	1.02
40	6.60	7.64	1.04
50	6.50	7.49	0.99
60	6.50	7.73	1.23
70	6.60	7.70	1.10
80	6.65	7.68	1.03
90	6.60	7.80	1.20
100	6.30	7.30	1.00
110	5.00	6.30	1.30
120	1.20	1.80	0.60
124.7	waterline		

Table C. 9. Statistical analysis for the depth data taken in May 15, 1997.

	0 + 80 ft			1 + 60 ft			Lagoon		
	AVE	SD	CV	AVE	SD	CV	AVE	SD	CV
Sludge depth, ft	6.76	0.11	0.02	6.59	0.07	0.01	6.68	0.13	0.02
Sludge thickness, ft	1.35	0.26	0.19	1.09	0.09	0.09	1.22	0.23	0.19

Table C. 10. Variation in sludge accumulation during 360 days of operation.

	Transect at 0 + 80 ft (ft)	Transect at 1 + 60 ft (ft)	Increment (%)
1996	0.49	0.30	39 %
1997	1.35	1.09	19 %
Increment (%)	175 %	263 %	

Table C. 11. Side slope sludge production.

	1996			1997		
	Ave	SD	CV	Ave	SD	CV
0 + 80 ft	0.25	0.17	0.69	0.77	0.23	0.30
1 + 60 ft	0.20	0.23	1.15	0.87	0.35	0.40
Ave. Side Slope	0.23	0.19	0.88	0.82	0.28	0.34

Table C. 12. Sludge volume production.

	Sludge thickness Bottom (ft)	Sludge thickness Side (ft)	Bottom Volume (ft^3)	Side Slope Volume (ft^3)
1996	0.45	0.23	6,948	2,719
1997	1.22	0.82	19,592	12,397
Increment	0.77	0.59	12,644	9,678
Total			22,322	

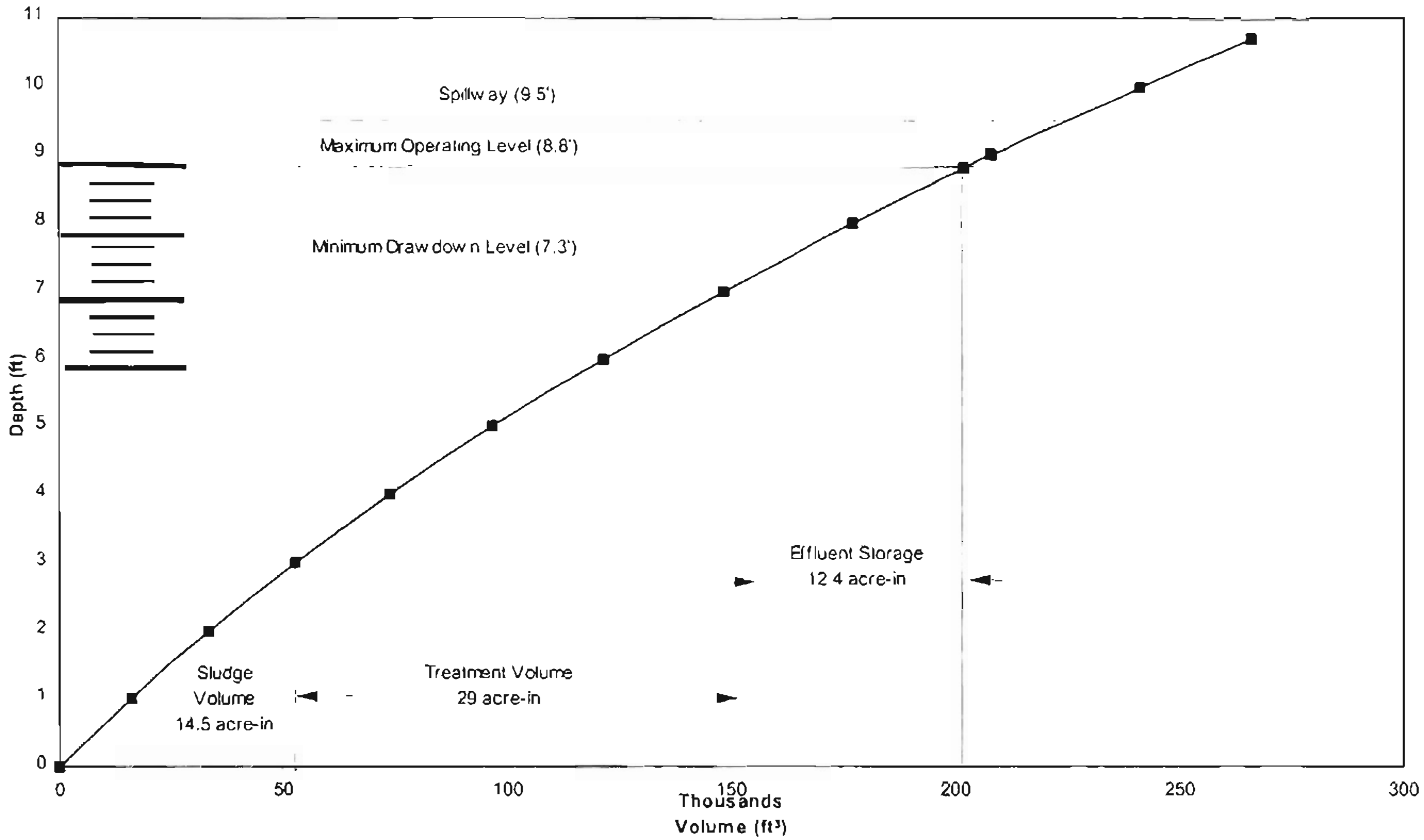


Figure C. 4. Stage storage curve.

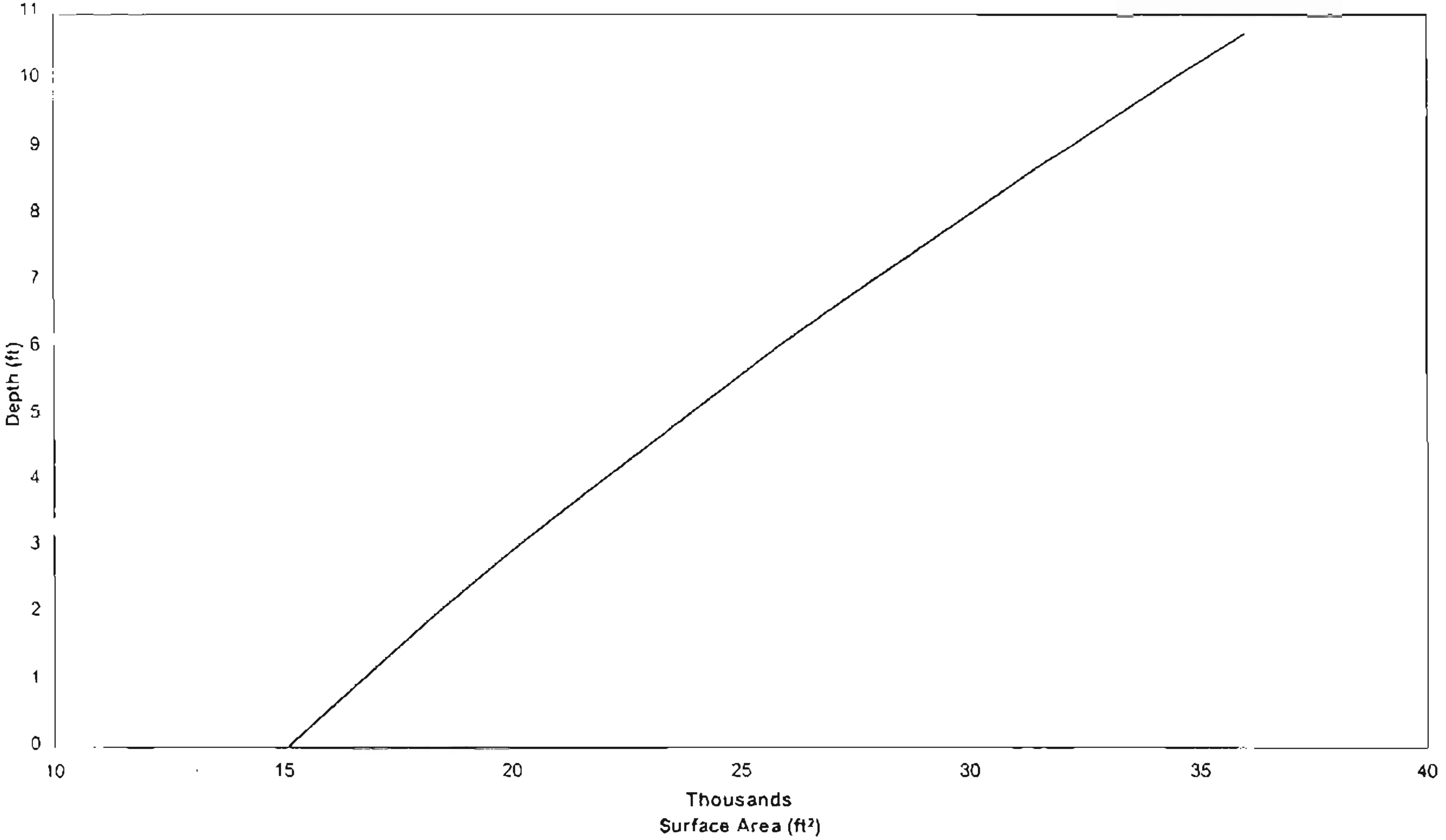


Figure C. 5. Stage surface curve.

Table C. 13. Lagoon liquid level data (ft)

Date	Elevation
5/21/96	8.46
5/25/96	8.66
6/1/96	9.00
6/8/96	9.00
6/15/96	8.00
6/22/96	8.00
6/29/96	8.00
7/6/96	8.00
7/13/96	8.00
7/20/96	8.42
7/27/96	8.45
8/3/96	9.00
8/10/96	9.00
8/17/96	9.00
8/24/96	9.00
8/31/96	9.00
9/7/96	9.00
9/14/96	9.00
9/21/96	8.00
9/28/96	8.00
10/5/96	8.00
10/12/96	8.00
10/19/96	7.42
10/28/96	7.42
11/2/96	7.42
11/9/96	7.42
11/16/96	7.42
11/23/96	7.42
11/28/96	8.00
11/30/96	8.42
12/7/96	9.00
12/14/96	9.00
12/21/96	9.00
12/28/96	9.00
1/4/97	9.00
1/11/97	9.00
1/18/97	8.17
1/25/97	8.25
2/1/97	8.33
2/8/97	8.50
2/15/97	8.75
2/22/97	9.00
3/1/97	9.00
3/8/97	8.75
3/11/97	8.75
3/18/97	9.00
4/19/97	9.00
4/22/97	8.58
4/28/97	8.50
5/5/97	8.33
5/6/97	8.25
5/13/97	8.00
5/15/97	8.00

Table C. 14. Operation of liquids throughout the lagoon.

Simulation Period	Recycle Effluent for Pits (%)	Pit Recharge Frequency (days)
05/21/96 - 08/02/96	0	21
08/03/96 - 11/23/96	100	21
11/23/96 - 12/05/96	0	7
12/06/96 - 01/17/97	100	7
01/18/97 - 03/17/97	0	21
03/18/97 - 05/15/97	100	21

Table C. 15. Irrigation data.

Irrigation Date	Beginning liquid level (ft)	Ending liquid level (ft)	Beginning Volume (ft^3)	Ending Volume (ft^3)	Volume Pumped (ft^3)
6/8/96	9.00		208,070		
6/15/96		8.00		177,040	31,030
9/14/96	9.00		208,070		
9/21/96		8.00		177,040	31,030
10/12/96	8.00		177,040		
10/19/96		7.50		162,335	14,705
1/11/97	9.00		208,070		
1/18/97		8.17		182,059	26,011
4/19/97	9.00		208,070		
4/22/97		8.58		194,771	13,299
4/28/97		8.50		192,282	2,489
5/5/97		8.33		187,039	5,243
5/6/97		8.25		184,594	2,445
5/13/97		8.00		177,040	7,554
Total lagoon effluent pumped					133,806

Table C. 16. On-site precipitation data (in)

Date	Precipitation
5/26/96	0.2
6/1/96	2.0
6/6/96	1.3
6/7/96	1.9
7/2/96	0.1
7/8/96	0.1
7/9/96	1.0
7/10/96	1.0
7/11/96	0.5
7/12/96	1.0
7/14/96	1.7
7/23/96	0.1
7/24/96	0.3
7/26/96	1.5
7/30/96	1.0
8/2/96	2.0
8/11/96	1.0
8/12/96	2.0
8/17/96	0.5
8/25/96	0.1
8/26/96	0.2
8/28/96	1.5
9/15/96	0.5
9/18/96	0.5
9/25/96	0.5
9/26/96	1.5
10/22/96	0.6
10/27/96	1.0
10/31/96	2.0
11/6/96	1.7
11/18/96	1.5
11/25/96	0.25
11/28/96	1.0
2/6/97	0.6
2/7/97	0.8
2/20/97	2.5
2/26/97	1.0
3/1/97	0.5
3/7/97	0.7
3/8/97	0.2
3/28/97	2.0
4/1/97	1.0
4/11/97	1.5
4/24/97	1.0
4/25/97	1.5
5/2/97	1.0
5/8/97	1.5
5/9/97	0.5
5/25/97	1.0
6/9/97	1.0
6/11/97	0.01
6/12/97	1.5
6/16/97	1.5
6/28/97	1.0
6/29/97	1.0
7/4/97	0.01
7/14/97	0.01

Table C. 17. Level of feed consumed daily.

Animal	No. of each	Dry Feed lbs./day	Total lbs/day
Breeding and Gestation Unit			
Boar	6	5.5	33
Gilt	15	5.5	82.5
Gest Sow	480	5.5	2,640
Farrowing Unit			
Sow Litter	120	13	1,560

Table C. 18. Observed EC measurements from lagoon supernatant.

Date	EC, dS/m
05/21/96	6.88
12/17/96	5.88
03/12/97	6.93
07/15/97	7.42

APPENDIX D

2000-Sow Breeding Farm, Texas County

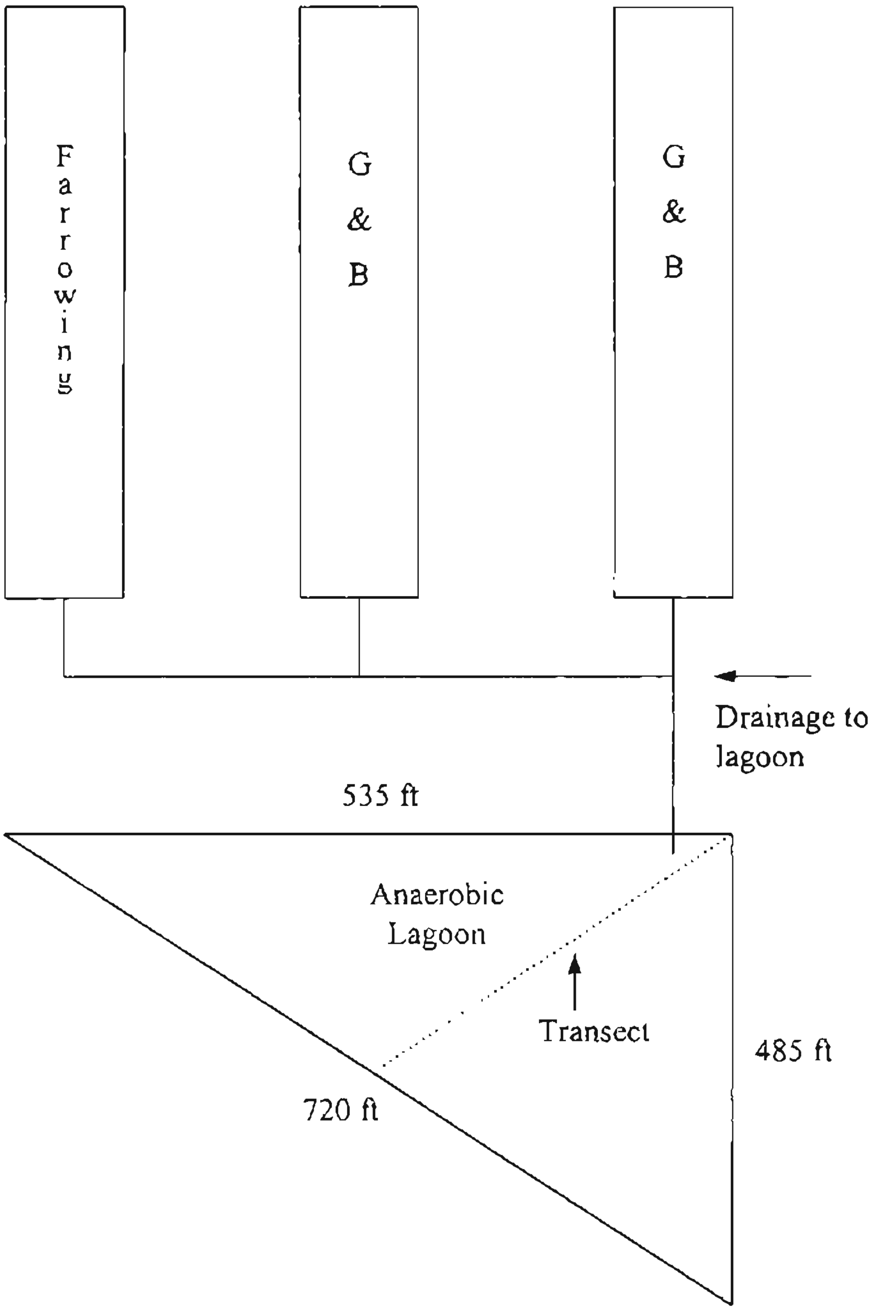


Figure D. 1. System schematic of the 2000-sow breeding farm, Texas County

Table D. 1. Farm values for mass and volume.

Type	# of pigs	Pigs wt. lbs/each	Total wt. lbs	TS lbs/day	VS lbs/day	Manure Volume ft^3/day
Boars	50	400	20,000	38	34.0	6.5
Gilts	100	250	25,000	82	73.0	13.0
Gestation Sow	2,012	300	603,600	1,509	1307.8	261.6
Sows & Litters	288	375	108,000	749	662.4	118.1
Total	2,450		756,600	2,377.8	2,077.2	399.14

Table D. 2. Depth data during the survey in May 22, 1997.

Distance	Sludge depth	Lagoon depth	Sludge thickness
0	waterline		
10	2.40	2.80	0.40
20	4.20	5.20	1.00
30	5.40	6.55	1.15
40	5.40	6.55	1.15
50	5.50	6.55	1.05
60	5.70	6.60	0.90
70	5.60	6.50	0.90
80	5.70	6.50	0.80
90	5.50	6.45	0.95
100	5.50	6.50	1.00
110	5.60	6.45	0.85
120	5.60	6.50	0.90
130	5.60	6.45	0.85
140	5.50	6.50	1.00
150	5.80	6.50	0.70
160	5.80	6.50	0.70
170	5.80	6.65	0.85
180	6.10	6.70	0.60
190	6.10	6.68	0.58
200	6.00	6.70	0.70
210	6.00	6.70	0.70
220	5.80	6.70	0.90
230	5.70	5.78	0.08
240	6.00	6.90	0.90
250	5.70	6.60	0.90
260	5.80	6.50	0.70
270	5.60	6.00	0.40
280	4.90	4.90	0.00
290	3.20	3.20	0.00
310	waterline		

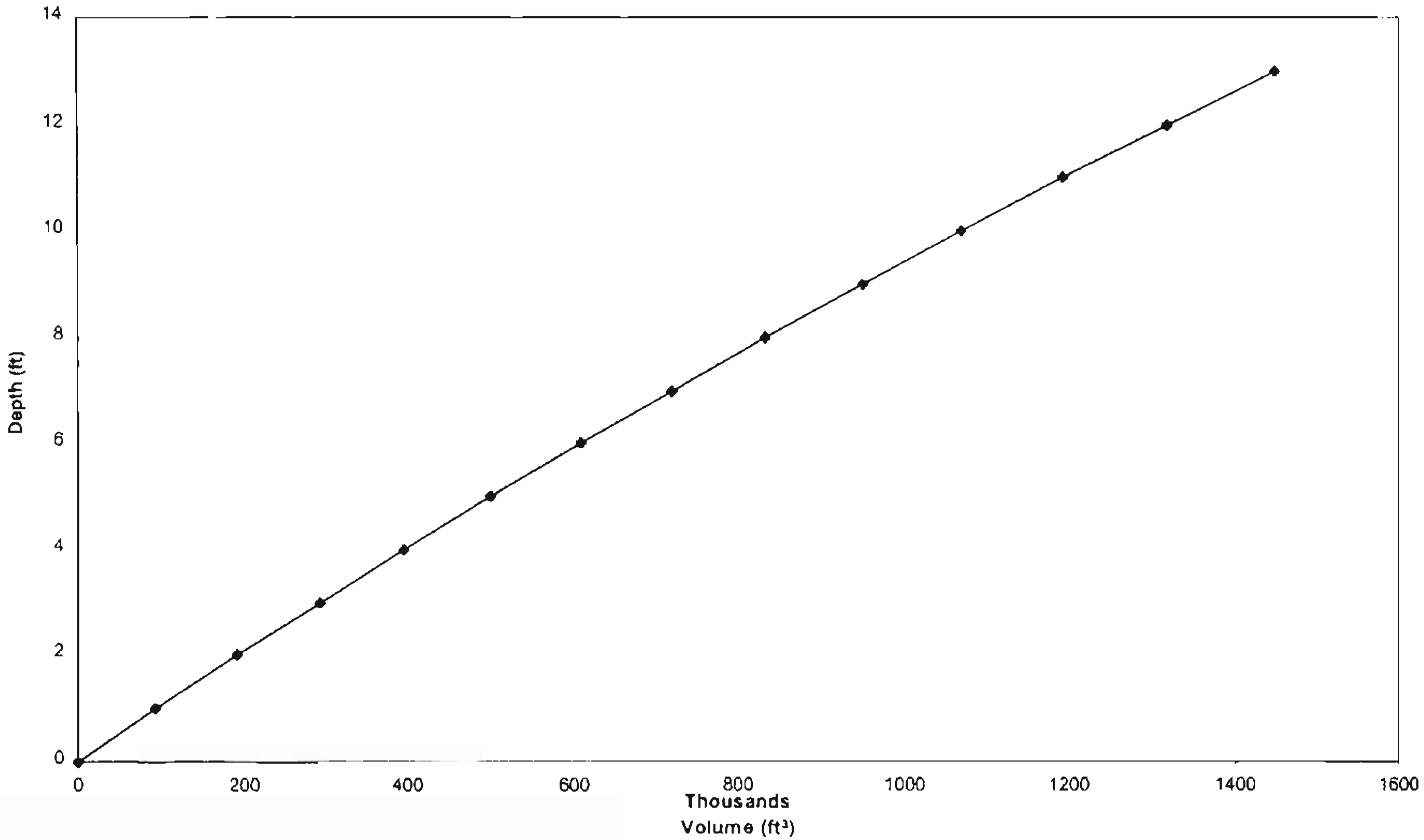


Figure D. 2. Stage storage curve.

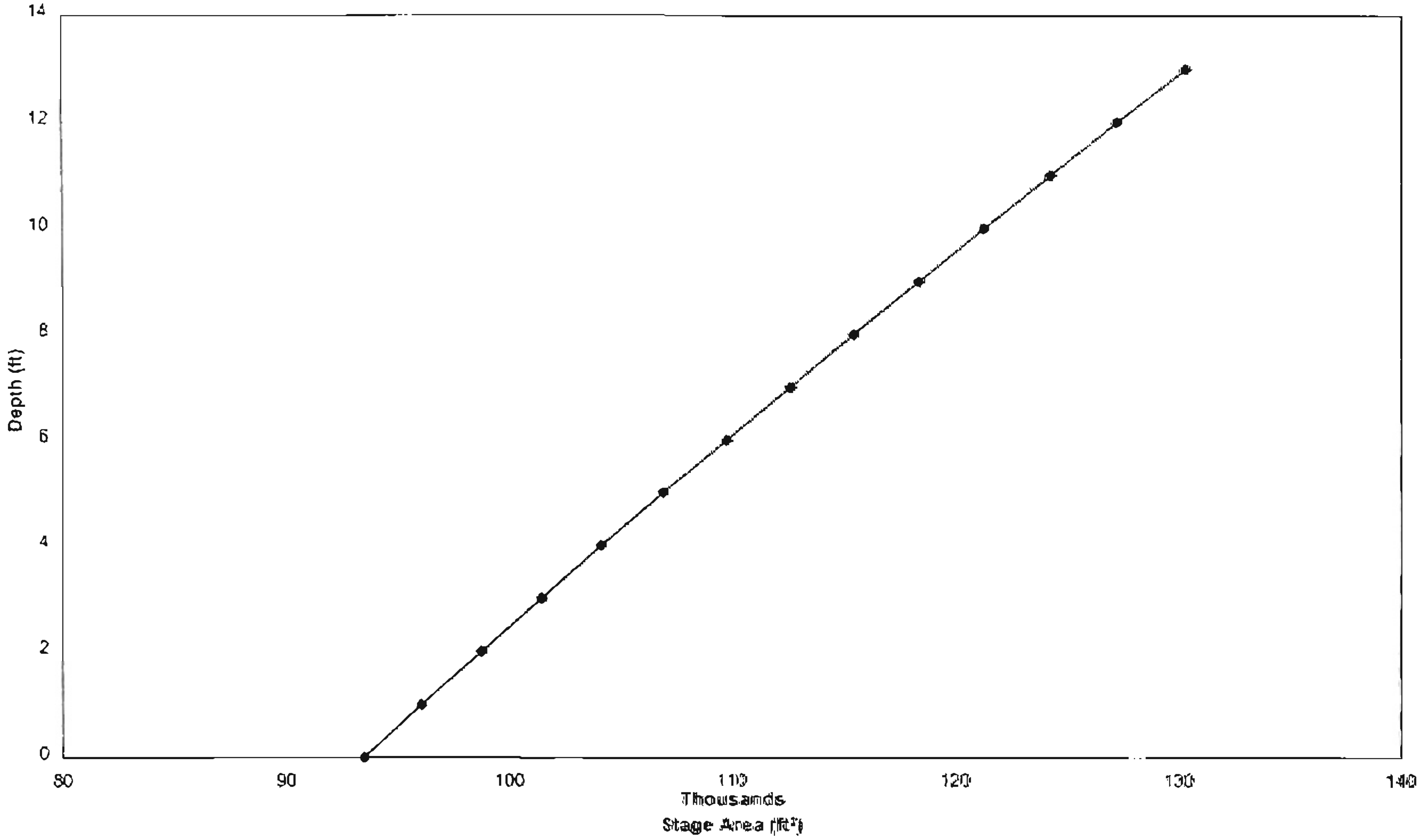


Figure D.3. Stage surface curve.

Table D. 3. Irrigation data.

Beginning Date	Ending Date	Volume Pumped (ft^3)
9/29/96	10/3/96	427,298
12/27/96	12/29/96	93,453
02/17/97	02/18/97	34,853
02/19/97	02/21/97	64,240
03/07/97	03/09/97	49,933
05/16/97	05/18/97	131,209
06/18/97	06/20/97	214,758

Table D. 4. Precipitation data (in).

Month/Year	Monthly precipitation
2/96	0
3/86	0
4/96	0
5/96	4.60
6/96	1.8
7/96	7.1
8/96	5.7
9/96	3.3
10/96	1.6
11/96	3.65
12/96	0.10
1/97	1.0
2/97	1.0
3/97	0
4/97	4.35
5/97	3.10
6/97	0.7

Table D. 5. Observed lagoon liquid level (ft).

Date	Liquid level ft
5/15/96	0.6
6/1/96	1.3
6/15/96	1.3
7/1/96	3.3
7/15/96	5.3
8/1/96	7.3
8/15/96	7.3
9/1/96	7.3
9/15/96	7.3
10/1/96	7.3
10/15/96	9.8
11/1/96	9.8
11/15/96	9.3
12/1/96	9.3
12/15/96	7.3
3/1/97	9.3
3/15/97	3.8
4/1/97	6.3
4/15/97	6.8
5/1/97	6.3
5/15/97	7.8
6/1/97	7.3
6/15/97	7.8
7/1/97	6.3

APPENDIX E

Calculations for the Sensitivity Analysis

Table E. 1. Mean solar radiation for cloudless skies (R_{so})

Month	0 %	-10%	+10%
1	14.95	13.45	16.44
2	19.55	17.59	21.50
3	24.58	22.12	27.03
4	29.31	26.37	32.24
5	32.11	28.89	35.32
6	33.49	30.14	36.83
7	32.95	29.65	36.24
8	30.14	27.12	33.15
9	25.25	22.72	27.77
10	20.52	18.46	22.57
11	15.91	14.31	17.50
12	13.52	12.16	14.87

Table E. 2. Energy storage factor (f_{es})

Month	0 %	-10%	+10%
1	0.4	0.36	0.44
2	0.38	0.342	0.418
3	0.36	0.324	0.396
4	0.32	0.288	0.352
5	0.3	0.27	0.33
6	0.24	0.216	0.264
7	0.12	0.108	0.132
8	0.1	0.09	0.11
9	0.05	0.045	0.055
10	0.01	0.009	0.011
11	0.05	0.045	0.055
12	0.3	0.27	0.33

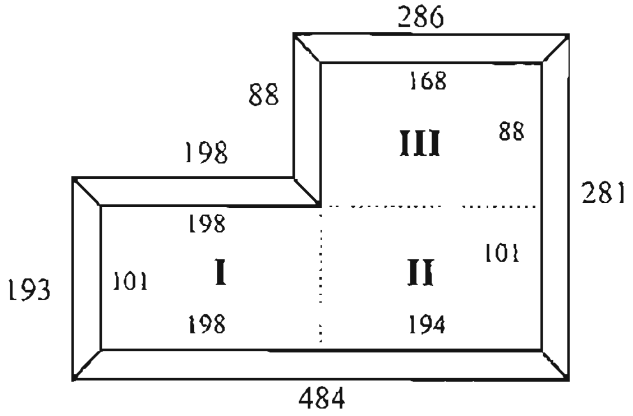


Figure E. 1. Lagoon top dimensions at + 10 % from baseline (ft).

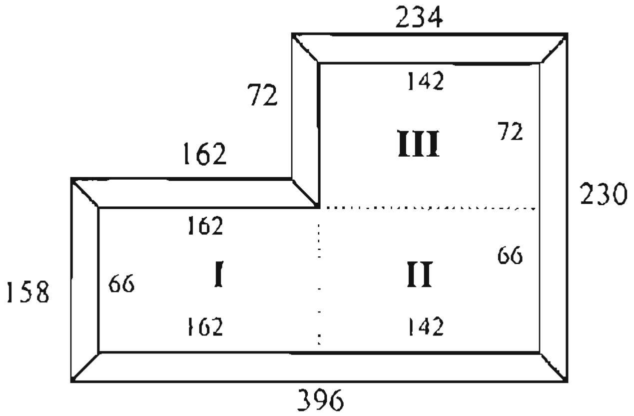


Figure E. 2. Lagoon top dimensions at - 10 % from baseline (ft).

APPENDIX F

Inorganic Salts Analysis

Table F. 1. Nutrient composition of four swine anaerobic lagoons.

Sample No.	Sample Identification	Ca^{2+} mg/L	Mg^{2+} mg/L	K^{+} mg/L	Na^{+} mg/L	EC dS/m
1	COSU05179602	66	23	380	176	3.69
2	COSU05179604	67	22	443	202	4.11
3	COSU05179606	66	36	375	171	3.63
4	COSU05179608	63	32	377	170	3.65
5	SOSU051796.5	53	24	444	195	2.98
6	SOSU05179603	48	32	418	184	3.12
7	SOSU05179605	49	16	445	194	3.01
8	SOSU05179608	56	13	519	253	5.41
9	COSU101096.5	45	12	425	186	3.03
10	COSU10109603	50	24	420	196	3.00
11	COSU10109605	57	40	440	191	2.90
12	SOSU05259704	59	23	414	179	3.28
13	COSU05259701	60	27	414	180	3.32
14	COSU05259704	60	28	417	180	3.36
15	SBJ05229701	74	15	544	203	6.42
16	SBJ05229704	73	15	547	204	6.45
17	SBF05229704	88	20	378	179	5.39
18	SS12179602	38	4	534	260	4.84
19	SS121796.5	51	38	418	182	3.26
20	SS05149701	61	8	674	290	7.37
21	SS05149704	63	8	677	291	7.40
22	JO05139701	62	31	559	236	5.90
23	JO05139704	61	29	559	234	5.91

Sample No. 1 to 14 were taken at OSU, sample 15 to 17 were taken at Goodwell, samples 18 to 21 were taken at Shawnee, and samples 22 and 23 were taken at Poteau. The number after the date indicates the depth (ft) at which the samples were collected.

Table F. 2. Coefficient of determination between EC and metal cations.

Combinations	r^2
Ca	0.21
Mg	0.29
Na	0.59
K	0.73
CaMg	0.53
CaNa	0.91
CaK	0.93
MgNa	0.59
MgK	0.74
NaK	0.74
CaMgNa	0.91
CaMgK	0.94
MgNaK	0.75
CaNaK	0.94
CaMgNaK	0.94

APPENDIX G

Calculation of the Level of Cations in Feed

Table G. 1. Selected element content in ration (lbs/day)

Animal	Ingredients	Ca^{2+}	Na^{2+}	K^{+}	Mg^{2+}
Boars	Dicalcium phosphate	0.01	0.00	0.00	0.00
	Calcium Carbonate	0.02	0.00	0.00	0.00
	Corn	0.00	0.00	0.02	0.01
	Soybean Meal 48%	0.00	0.00	0.02	0.00
	Salt		0.01		
	Total lbs/day-AH	0.03	0.01	0.03	0.01
	Total lbs/day	0.15	0.05	0.17	0.05
Sows & Litters	Dicalcium phosphate	0.02	0.00	0.00	0.00
	Calcium Carbonate	0.02	0.00	0.00	0.00
	Corn	0.00	0.00	0.01	0.01
	Soybean Meal 48%	0.00	0.00	0.02	0.00
	Salt		0.01		
	Fish Meal	0.01	0.00	0.00	0.00
	Whey, dried	0.00	0.00	0.00	0.00
	Total lbs/day-AH	0.05	0.02	0.04	0.01
	Total lbs/day	1.14	0.39	0.81	0.23
Nursery	Dicalcium phosphate	0.01	0.00	0.00	0.00
	Calcium Carbonate	0.00	0.00	0.00	0.00
	Corn	0.00	0.00	0.00	0.00
	Soybean Meal 48%	0.00	0.00	0.01	0.00
	Salt		0.00		
	Total lbs/day-AH	0.01	0.00	0.01	0.00
	Total lbs/day	1.69	0.50	1.89	0.48
Growers	Dicalcium phosphate	0.01	0.00	0.00	0.00
	Calcium Carbonate	0.01	0.00	0.00	0.00
	Corn	0.00	0.00	0.01	0.00
	Soybean Meal 48%	0.00	0.00	0.02	0.00
	Salt		0.01		
	Total lbs/day-AH	0.02	0.01	0.03	0.01
	Total lbs/day	4.30	1.23	5.54	1.38

Animal	Ingredients	Ca^{2+}	Na^{1+}	K^{+}	Mg^{2+}
Finishing 125 - 175 lbs.	Dicalcium phosphate	0.01	0.00	0.00	0.00
	Calcium Carbonate	0.01	0.00	0.00	0.00
	Corn	0.00	0.00	0.01	0.01
	Soybean Meal 48%	0.00	0.00	0.02	0.00
	Salt		0.01		
	Total lbs/day-AH	0.03	0.01	0.03	0.01
	Total lbs/day	4.43	1.45	4.94	1.50
Finishing 175+ lbs.	Dicalcium phosphate	0.01	0.00	0.00	0.00
	Calcium Carbonate	0.02	0.00	0.00	0.00
	Corn	0.00	0.00	0.02	0.01
	Soybean Meal 48%	0.00	0.00	0.02	0.00
	Salt		0.01		
	Total lbs/day-AH	0.03	0.01	0.03	0.01
	Total lbs/day	7.36	2.41	8.20	2.50
		Ca^{2+}	**Na^{+}**	**K^{+}**	**Mg^{2+}**
Amount in swine feed (lbs/day)		**19.07**	**6.03**	**21.55**	**6.15**

APPENDIX H

Computer Program to Estimate Lagoon Liquid Level and Electrical Conductivity

This program is used to estimate lagoon liquid level and electrical conductivity. The user of the program can save the output on a file in the ASCII format. The output file contain the following data: weather data, rainfall, runoff, evaporation, seepage, irrigation, recycle, manure and wastewater, lagoon volume, surface area, liquid level, spillway volume, and electrical conductivity.

```
DECLARE SUB LAGOONINF ()
DECLARE SUB ECCALC ()
DECLARE SUB SALTIN ()
DECLARE SUB FEEDIN ()
DECLARE SUB ECINPUT ()
DECLARE SUB SPILLCAL ()
DECLARE SUB OUTFILE ()
DECLARE SUB LAGOONLEVEL ()
DECLARE SUB LAGOONMENU2 ()
DECLARE SUB RERUN ()
DECLARE SUB DRINKING ()
DECLARE SUB ANTECEDENT ()
DECLARE SUB GROWING ()
DECLARE SUB DORMANT ()
DECLARE SUB SEEPAGECALC ()
DECLARE SUB EVAPORATION ()
DECLARE SUB NEWDEPTH ()
DECLARE SUB LAGOONDIM ()
DECLARE SUB LAGOONINCALC ()
DECLARE SUB LAGOONOUTCAL ()
DECLARE SUB RUNOFFCALC ()
DECLARE SUB PRINTOUT ()
DECLARE SUB FORMT ()
DECLARE SUB REVISE ()
DECLARE SUB ERRORR ()
DECLARE SUB STATUS ()
DECLARE SUB CALC ()
DECLARE SUB DRIPPERSMENU ()
DECLARE SUB RECHARGEMENU ()
DECLARE SUB BEDMENU ()
DECLARE SUB PRESETS ()
DECLARE SUB HOGSMENU ()
DECLARE SUB FLUSHMENU ()
DECLARE SUB MISTERSMENU ()
DECLARE SUB RUNOFFMENU ()
DECLARE SUB WASHMENU ()
DECLARE SUB WEATHERMENU ()
DECLARE SUB LAGOONMENU ()
DECLARE SUB OUTPUTMENU ()
DECLARE SUB IRRIGATION ()
DECLARE SUB RECYCLING ()
DECLARE SUB INPUTMENU ()
DECLARE SUB LAGOONITMECNF ()
COMMON SHARED TMEC, ECMGL, LEC, ECFW, ECL, SCA, SNA, PFB, PFG, PFGS, PFSL, PFN, PFGR, PF125, PF175,
MTEMP, NUM, DTEMP, DTVOL2, MTVOL2, DTVOL1, WL, WW1, CNC, CND, CNG, CNSW, MO, RAIN, RAINS, Z(), AC1C,
AC1D, AC1G, AC1SW, L, SEEPAGE, EVAP, wind1, _
solar1, AD, TVOLTEST, DRINKVOL, f$, QUIT1, LOCATION$, DATE1, DATE2, SURFAREA2, W, RECYCLE, EVAPLOSS,
EVAP1, LAGOONIN, LAGOONOUT, VOLWASTEIN, f, RAINFALL, STORAGE, RUNOFFIN, VOLUME, VOLTOTAL,
SURFAREA, IDS, STATS, temp1, rh1, wind, RAIN1, RRAIN, _
CRAIN, DRAIN, GRAIN, RSWA, FW, TL, S, TD, DL, OL, MOL, CS, NB, NG, NGS, NSL, NN, NGROW, NFIN125, NFIN175,
MVB, MVG, MVGS, MVSL, MVN, MVGROW, MVFIN125, MVFIN175, IMAN, RE, VOL, PVOL, PTVOL, tim, PTIM, WVOL,
WTIM, WTVOL, MNUM, MVOL, MHOURS, MTVOL,
MTVOL1, OVOL, DNUM, DHOURS, DTVOL, LSV, CSV, SV, SDV, SAV, RTA, CTA, DTA, GTA, TPER, PPER, BTVOL,
IRRIGATE, IRRIR, LST, CST, ST, SDT, SAT, TANKS, PIT, TRI, REC, RROL, SPILLVOL, CSI
CALL PRESETS
  ON ERROR GOTO HANDLER

10 CLS
```

```
LOCATE 4, 26: PRINT "OKLAHOMA STATE UNIVERSITY"
LOCATE 5, 14: PRINT "BIOSYSTEMS AND AGRICULTURAL ENGINEERING DEPARTMENT"
LOCATE 7, 25: PRINT "LAGOON PERFORMANCE PROGRAM"
LOCATE 9, 28: PRINT "A.  HYDRAULIC LOADING"
LOCATE 10, 28: PRINT "B.  SALTS LOADING"
LOCATE 11, 28: PRINT "C.  LAGOON INFORMATION"
LOCATE 12, 28: PRINT "D.  LAGOON OUTPUT"
LOCATE 13, 28: PRINT "E.  WEATHER DATA"
LOCATE 14, 28: PRINT "F.  MOISTURE BALANCE"
LOCATE 15, 28: PRINT "G.  PRINTOUT"
LOCATE 16, 28: PRINT "H.  PROGRAM RE-RUN"
LOCATE 17, 28: PRINT "I.  QUIT "
LOCATE 19, 22: INPUT "ENTER THE LETTER OF YOUR CHOICE: ", choice1$
PRINT
IF UCASE$(choice1$) = "A" THEN
      CALL INPUTMENU
      GOTO 10
ELSEIF UCASE$(choice1$) = "B" THEN
      CALL FCINPUT
      GOTO 10
ELSEIF UCASE$(choice1$) = "C" THEN
      CALL LAGOONINF
      GOTO 10
ELSEIF UCASE$(choice1$) = "D" THEN
      CALL OUTPUTMENU
      GOTO 10
ELSEIF UCASE$(choice1$) = "E" THEN
      CALL WEATERMENU
      GOTO 10
ELSEIF UCASE$(choice1$) = "F" THEN
      CALL CALC
      GOTO 10
ELSEIF UCASE$(choice1$) = "G" THEN
      CALL PRINTOUT
      GOTO 10
ELSEIF UCASE$(choice1$) = "H" THEN
      CALL RERUN
      GOTO 10
ELSEIF UCASE$(choice1$) = "I" THEN GOTO 11
ELSE GOTO 10
END IF

11 CLS
LOCATE 12, 15: PRINT " THANKS FOR USING THE LAGOON PERFORMACE PROGRAM "
END

HANDLER:
  CALL ERRORR
  WHILE INKEY$ = "": WEND
  RESUME NEXT

QUIT:
   CLS 2
   QUIT1 = 1
   KEY(1) OFF
RETURN

HOGS:
      CALL INPUTMENU
RETURN

OUTPUT2:
      CALL OUTPUTMENU
RETURN

PAUSE:
      WHILE INKEY$ = "": WEND
```

```
RETURN

INCREASE:
     AD = 50000
     KEY(5) OFF
RETURN

DECREASE
     AD = 200000
     KEY(6) OFF
RETURN


SUB ANTECEDENT
   RAIN5 = 0
   FOR J = 0 TO 4
   RAIN5 = RAIN5 + Z(J)          '5-DAY ANTECEDENT RAINFALL IN INCHES
   NEXT J
   FOR J = 4 TO 1 STEP -1
   Z(J) = Z(J - 1)
   NEXT J
   Z(0) = RAIN                  ' RAIN IN INCHES
END SUB


SUB BEDMENU

181 CLS 2
LST = 0
CST = 0
ST = 0
SDT = 0
SAT = 0
LOCATE 8, 30: PRINT "BEDDING MENU"
LOCATE 10, 45: PRINT "TONS PER MONTH"
LOCATE 11, 20: PRINT "A. LONG STRAW"
LOCATE 12, 20: PRINT "B. CHOPPED STRAW"
LOCATE 13, 20: PRINT "C. SHAVINGS"
LOCATE 14, 20: PRINT "D. SAWDUST"
LOCATE 15, 20: PRINT "E. SAND"

186
LOCATE 17, 20: PRINT "ENTER THE LETTER OF YOUR CHOICE OR";
LOCATE 18, 20: INPUT "PRESS (R) TO RETURN TO INPUT MENU:  ", CHOICE6$
IF UCASE$(CHOICE6$) = "A" THEN GOTO 206
IF UCASE$(CHOICE6$) = "B" THEN GOTO 207
IF UCASE$(CHOICE6$) = "C" THEN GOTO 208
IF UCASE$(CHOICE6$) = "D" THEN GOTO 209
IF UCASE$(CHOICE6$) = "E" THEN GOTO 301
IF UCASE$(CHOICE6$) = "R" THEN GOTO 302
IF CHOICE6$ = "" THEN GOTO 181 ELSE GOTO 181

206
LOCATE 11, 50: INPUT , LST
LSV = LST * 27
GOTO 186

207
LOCATE 12, 50: INPUT ; CST
CSV = CST * 11
GOTO 186

208
LOCATE 13, 50: INPUT ; ST
SV = ST * 7.5
GOTO 186
```

```
209
LOCATE 14, 50: INPUT ; SDT
SDV = SDT * 5 5
GOTO 186

301
LOCATE 15, 50: INPUT ; SAT
SAV = SAT * 7
GOTO 186

302
BTVOL = LSV + CSV + SV + SDV + SAV

END SUB


SUB CALC
RROL = OL
IF TD = 0 THEN ERROR 77
IF DATE1 = 0 THEN CALL WEATERMENU

CALL STATUS

DO UNTIL UCASE$(CHOICE7$) = "Y"
   LOCATE 24, 15: INPUT "DOES THIS INFORMATION LOOK CORRECT (Y/N): "; CHOICE7$
   IF UCASE$(CHOICE7$) = "N" THEN CALL REVISE
   IF UCASE$(CHOICE7$) = "N" THEN CALL STATUS
LOOP

CLS
TRE = 0
AD = 150000
432 LOCATE 12, 30: INPUT "PRINT DATA (Y/N) "; CHOICE15$
   IF UCASE$(CHOICE15$) = "Y" THEN
      TRE = 1
      LPRINT ; SPC(2); "DATE"; SPC(5); "RAIN"; SPC(3); "EVAP"; SPC(3); "MANURE"; SPC(2); "RUNOFF"; SPC(2);
"DEPTH"; SPC(4);
     "VOLUME"; SPC(3); "IRRIGATION"
      LPRINT ; SPC(12); "IN"; SPC(5); "IN"; SPC(7); "&"; SPC(5); "FT^3"; SPC(5); "FT"; SPC(6); "FT^3"; SPC(7); "FT^3"
      LPRINT ; SPC(26); "FLUSH"
      LPRINT ; SPC(27); "FT^3"
      LPRINT
   END IF
   IF UCASE$(CHOICE15$) = "N" THEN TRE = 0
   IF UCASE$(CHOICE15$) = "" THEN GOTO 432

KEY(1) ON
KEY(2) ON
KEY(3) ON
KEY(4) ON
KEY(5) ON
KEY(6) ON
WW = 0
QUIT1 = 0
OPEN H$ FOR INPUT AS #1

CALL FORMT
CALL LAGOONDIM

ON KEY(1) GOSUB QUIT
DIM Z(4)

DO WHILE (NOT EOF(1))
      KEY(5) ON
      KEY(6) ON
      ON KEY(2) GOSUB HOGS
      ON KEY(3) GOSUB OUTPUT2
```

```
    ON KEY(4) GOSUB PAUSE
    ON KEY(5) GOSUB INCREASE
    ON KEY(6) GOSUB DECREASE
    IF QUIT1 = 1 THEN EXIT DO
    INPUT #1, IDS, STATS, TEMP, RH, wind, RAIN, SOLAR, D
    COUNT2 = COUNT2 + 1
    IF COUNT2 >= DATE1 AND COUNT2 <= DATE2 THEN
       MOS = STATS
       MO = VAL(LEFTS(MOS, 2))

       rh1 = RH / 100
       temp1 = (5 / 9 * (TEMP - 32))        'F to C
       wind1 = (wind / 2.237)              'mile/hr to m/s
       solar1 = SOLAR * .0418424          'CAL/cm2 TO MJ/m2

       CALL ANTECEDENT
       CALL EVAPORATION

       A = 0
       STORAGE = 0

       RAIN1 = RAIN / 12    'convert variables to ft
       EVAP1 = EVAP / 12    'convert variable to ft

       CALL RUNOFFCALC
       CALL LAGOONINCALC
       CALL LAGOONOUTCAL
       CALL SEEPAGECALC

       LAGOONIN = VOLWASTEIN + RAINFALL + RUNOFFIN
       LAGOONOUT = EVAPLOSS + IRRIGATE + RECYCLE + SEEPAGE
       STORAGE = LAGOONIN - LAGOONOUT
       IRRIR = IRRIGATE

       IF IRRIGATE > 0 THEN IRRIGATE = 0

       CALL SPILLCAL
       VOLTOTAL = VOLUME + STORAGE - SPILLVOL

       IF OL < .25 THEN EXIT DO

       CALL NEWDEPTH
       CALL ECCALC

       IF CSL = 1 THEN ERROR 78
       IF OL < DL THEN ERROR 79
       IF OL > TD THEN ERROR 80
       IF OL > MOL AND OL < CS THEN ERROR 81
       FOR A = 1 TO AD: NEXT A
       PRINT STATS, SPC(5);   PRINT USING "#,###,###"; VOLUME; SPC(8);   PRINT USING "###,###"; SURFAREA2;
SPC(8);   PRINT
          USING "## ##"; OL; SPC(8);   PRINT USING "### ##"; LEC
       IF TRF = 1 THEN
           LPRINT STATS, SPC(2);   LPRINT USING "## ##"; RAIN, SPC(2); : LPRINT USING "#.####", EVAP; SPC(2); :
LPRINT USING
                    "####.#", VOLWASTEIN, SPC(2); : LPRINT USING "######", RUNOFFIN; SPC(2); : LPRINT USING
                    "##.##"; OL, SPC(2),    LPRINT USING "####### #"; VOLUME, SPC(2),   LPRINT USING "#######",
                    IRRIGATE
       END IF
       WRITE #2, IDS, STATS, temp1, rh1, wind, RAIN, SOLAR, EVAP, RAINFALL, EVAPLOSS, SEEPAGE, RAINS,
RUNOFFIN, IRRIR,
          RECYCLE, VOLWASTEIN, VOLUME, SURFAREA2, OL, LEC, ECMOL, TMEC, SPILLVOL, D
       SURFAREA = SURFAREA2

    END IF
LOOP
CLOSE #1
```

```
CLOSE #2
IF QUIT1 = 1 THEN GOTO 555
DIFF = (DATE2 - DATE1) + 1
PRINT
PRINT
PRINT "TOTAL OF DAYS = "; DIFF
PRINT
PRINT "PRESS ANY KEY TO RETURN TO MAIN MENU"
WHILE INKEY$ = "": WEND
555 CLS
SCREEN 0
END SUB


SUB DORMANT                    'FACTOR TO CONVERT CN FOR CONDITION II(CN) TO I AND II
IF RAIN5 < .5118 THEN                              'CONDITION I
   AC1C = (4.2 * CNC) / (10 - (.058 * CNC))
   AC1D = (4.2 * CND) / (10 - (.058 * CND))
   AC1G = (4.2 * CNG) / (10 - (.058 * CNG))
   AC1SW = (4.2 * CNSW) / (10 - (.058 * CNSW))
ELSEIF (RAIN5 >= .5118) AND (RAIN5 <= 1.1024) THEN       'CONDITION II
   AC1C = CNC
   AC1D = CND
   AC1G = CNG
   AC1SW = CNSW
ELSE                                          'CONDITION III
   AC1C = (23 * CNC) / (10 + (.13 * CNC))
   AC1D = (23 * CND) / (10 + (.13 * CND))
   AC1G = (23 * CNG) / (10 + (.13 * CNG))
   AC1SW = (23 * CNSW) / (10 + (.13 * CNSW))
END IF

END SUB

SUB DRINKING
CLS 2

DRINKVOL = 0
TK = 0
A = 0
LOCATE 7, 30: PRINT "DRINKING CHANNELS MENU"
LOCATE 9, 22: INPUT "ENTER THE NUMBER OF CHANNELS USED: "; CHAN
LOCATE 11, 9: PRINT "CHANNEL NUM."
LOCATE 11, 25: PRINT "WATER USE (GAL/MIN)"
LOCATE 11, 48: PRINT "DAILY DRINKING TIME (MIN)"
A = 12
QP = 1
TK = CHAN + 12
IF TK = 12 THEN GOTO 33
DO
   LOCATE A, 12: PRINT , QP; ")"
   LOCATE A, 32: INPUT "", VOL
   LOCATE A, 58: INPUT "", tim
   DRINKVOL = DRINKVOL + (VOL * tim)
   A = A + 1
   QP = QP + 1
LOOP UNTIL A = TK
DRINKVOL = DRINKVOL / 7.5
A = A + 2
LOCATE A, 10: PRINT "CHANNEL VOL = ", DRINKVOL
A = A + 2
LOCATE A, 10: PRINT "PRESS ANY KEY TO CONTINUE"
WHILE INKEY$ = "": WEND

33 END SUB

SUB DRIPPERSMENU
```

```
CLS 2
LOCATE 7, 30: PRINT "DRIPPER MENU"
LOCATE 9, 20: INPUT "ENTER THE NUMBER OF DRIPPERS. ", DNUM
IF DNUM = 0 THEN GOTO 150
LOCATE 10, 20: INPUT "ENTER THE WATER USE (GAL/HR). ", DVOL
LOCATE 11, 20: INPUT "ENTER THE AMOUNT OF HOURS USED PER DAY (HR/DAY). ", DHOURS
LOCATE 12, 20: INPUT "AT WHAT TEMPERATURE THE DRIPPERS START WORKING (F). ", DDTEMP1
DDTEMP1 = DDTEMP1 - 10
DTEMP = (DDTEMP1 - 32) * (5 / 9)
DTVOL = (DNUM * DVOL * DHOURS) / 7.5
DTVOL1 = DTVOL
DTVOL2 = DTVOL
150 END SUB


SUB ECCALC
WASHV = MTVOL + DTVOL + WTVOL + TVOLTEST + DRINKVOL + PTVOL
MECIRRI = (MEC2 * IRRIR) / 15992.95
MECI = (ECL / 15992.95) * VOLUME
IF MECI = 0 THEN MECI = TMEC
CAMGL = (SCA / WASHV) * 15992.95
NAMGL = (SNA / WASHV) * 15992.95
ECMGL = -7.62 + (CAMGL * .08) + (NAMGL * .035)
MECW = (ECMGL * TMANURE) / 15992.95
MECFW = (ECFW * WASHV) / 15992.95
TMEC = MECI + MECW + MECFW - MECIRRI
ECL = 0
MECI = TMEC
LEC = (TMEC * 15992.95) / VOLUME
END SUB


SUB ECINPUT
1023
CLS 2
LOCATE 7, 24: PRINT "SALTS LOADING INFORMATION MENU"
LOCATE 9, 30: PRINT "A. FEED CONSUMPTION"
LOCATE 10, 30: PRINT "B. FEED COMPOSITION"
LOCATE 11, 30: PRINT "C. ELECTRICAL CONDUCTIVITY"
LOCATE 12, 33: PRINT "OF THE LAGOON"
LOCATE 13, 30: PRINT "R. RETURN"
LOCATE 15, 22: INPUT "CHOOSE A LETTER AND PRESS ENTER "; CHOICE21$

IF UCASE$(CHOICE21$) = "A" THEN
   CALL FEEDIN
   GOTO 1023
END IF
IF UCASE$(CHOICE21$) = "B" THEN
   CALL SALTIN
   GOTO 1023
END IF
IF UCASE$(CHOICE21$) = "C" THEN
   LOCATE 17, 22: INPUT "ELECTRICAL CONDUCTIVITY OF THE LAGOON - dS/m: ", ECL
   LOCATE 18, 22: INPUT "ELECTRICAL CONDUCTIVITY OF FRESHWATER - dS/m: ", ECFW
   GOTO 1023
END IF
IF UCASE$(CHOICE21$) = "R" THEN GOTO 1024
IF CHOICE21$ <> "A" OR CHOICE21$ <> "B" OR CHOICE21$ <> "C" OR CHOICE21$ <> "R" THEN GOTO 1023
1024 END SUB


SUB ERRORR
SELECT CASE ERR
    CASE 1
        PRINT "NEXT without FOR"
    CASE 37
        PRINT "Argument-count mismatch"
```

```
CASE 2
      PRINT "Syntax error "
CASE 38
      PRINT "Array not defined"
CASE 3
      PRINT " RETURN without GOSUB"
CASE 40
      PRINT "Variable required"
CASE 4
      PRINT "Out of DATA "
CASE 50
      PRINT "FIELD overflow"
CASE 5
      PRINT "Illegal function call"
CASE 51
      PRINT "Internal error"
CASE 6
      PRINT "Overflow"
CASE 52
      PRINT "Bad file name or number"
     CALL FILS
CASE 7
      PRINT "Out of memory"
CASE 53
      PRINT "File NOT found"
     CALL FILS
CASE 8
      PRINT "Label not defined "
CASE 54
      PRINT "Bad file mode"
CASE 9
      PRINT "Subscript out of range"
CASE 55
      PRINT "File already open"
CASE 10
      PRINT "Duplicate definition"
CASE 56
      PRINT "FIELD statement active"
CASE 11
      PRINT "Division by zero"
CASE 57
      PRINT "Device I/O error"
CASE 12
      PRINT "Illegal in direct mode"
CASE 58
      PRINT "File already exists"
CASE 13
      PRINT "Type mismatch"
CASE 59
      PRINT "Bad record length"
CASE 14
      PRINT "Out of string space"
CASE 61
      PRINT "Disk full"
CASE 16
      PRINT "String formula too complex"
CASE 62
      PRINT
CASE 17
      PRINT "Cannot continue"
CASE 63
      PRINT "Bad record number"
CASE 18
      PRINT "Function not defined"
CASE 64
      PRINT "Bad file name"
CASE 19
```

```
        PRINT "No RESUME"
    CASE 67
        PRINT "Too many files"
    CASE 20
        PRINT "RESUME without error"
    CASE 68
        PRINT "Device unavailable"
    CASE 24
        PRINT "Device timeout"
    CASE 69
        PRINT "Communication-buffer overflow"
    CASE 25
        PRINT "Device fault"
    CASE 70
        PRINT "Permission denied"
    CASE 26
        PRINT "FOR without NEXT"
    CASE 71
        PRINT "Disk NOT ready"
        'CALL FILS
    CASE 27
        PRINT "Out of paper "
    CASE 72
        PRINT "Disk-media error"
    CASE 29
        PRINT "WHILE without WEND "
    CASE 73
        PRINT "Feature unavailable"
    CASE 30
        PRINT "WEND without WHILE "
    CASE 74
        PRINT "Rename across disks"
    CASE 33
        PRINT "Duplicate label"
    CASE 75
        PRINT "Path/File access error"
    CASE 35
        PRINT "Subprogram not defined"
    CASE 76
        PRINT "Path NOT found"
    CASE 77
        PRINT "PLEASE FILL OUT THE LAGOON INFO "
        CALL LAGOONINF
    CASE 78
        PRINT "LAGOON IS OVER SPILLWAY "
    CASE 79
        PRINT "LAGOON IS OPERATING BELOW MINIMUM OPERATING LEVEL"
    CASE 80
        PRINT "LAGOON HAS FAILED"
    CASE 81
        PRINT "LAGOON IS OVER MAXIMUM OPERATING LEVEL"
END SELECT
END SUB


SUB EVAPORATION
    KELVIN = tempi + 273
    IF MO = 1 THEN RSO = 14.95
    IF MO = 2 THEN RSO = 19.55
    IF MO = 3 THEN RSO = 24.58
    IF MO = 4 THEN RSO = 29.31
    IF MO = 5 THEN RSO = 32.11
    IF MO = 6 THEN RSO = 33.49
    IF MO = 7 THEN RSO = 32.95
    IF MO = 8 THEN RSO = 30.14
    IF MO = 9 THEN RSO = 25.25
    IF MO = 10 THEN RSO = 20.52
```

```
    IF MO = 11 THEN RSO = 15.91
    IF MO = 12 THEN RSO = 13.52

                    'GRN

    IF MO = 1 THEN GRN = .4
    IF MO = 2 THEN GRN = .38
    IF MO = 3 THEN GRN = .36
    IF MO = 4 THEN GRN = .32
    IF MO = 5 THEN GRN = .3
    IF MO = 6 THEN GRN = .24
    IF MO = 7 THEN GRN = .12
    IF MO = 8 THEN GRN = .1
    IF MO = 9 THEN GRN = .05
    IF MO = 10 THEN GRN = .01
    IF MO = 11 THEN GRN = .05
    IF MO = 12 THEN GRN = .3


    EMI = -.02 + .261 * EXP(-.000777 * (273 - KELVIN) ^ 2)
    RBO = EMI * 4.903E-09 * (KELVIN) ^ 4

    IF NUM = 1 THEN
     SHA = 1
     SHB = 0
    ELSE
     SHA = 1.1
     SHB = -.1
    END IF

    RB = ((SHA * solar1) / RSO + SHB) * RBO
    RN = (1 - .05) * solar1 - RB
    GC = RN * GRN          'STORAGE ENERGY
    TE = RN - GC
    TE2 = TE * 11.5812       'MJ/m2 to W/m2

    LV = 2501000! - (2370 * temp1)
    ER = (TE2 / (LV * 997)) * 86400 * 39.37
    DEN = (.00002 * temp1 ^ 2) - (.0048 * temp1) + 1.2928

    B = (.622 * (.4 ^ 2) * DEN * wind1) / (((LOG(2 / .0003)) ^ 2) * 101300! * 997)

    EAS = 611 * EXP((17.27 * temp1) / (237.3 + temp1))
    EA = B * (EAS - (EAS * rh1)) * 86400 * 39.37
    SIGMA = (12793.59 / 2) / LV
    DELTA = (4098 * EAS) / ((237.3 + temp1) ^ 2)
    EVAP = ((DELTA * ER) / (DELTA + SIGMA)) + ((SIGMA * EA) / (DELTA + SIGMA))
END SUB


SUB FEEDIN
CLS 2

QUIT1 = 0
KEY(1) ON
ON KEY(1) GOSUB QUIT

LOCATE 7, 25: PRINT "POUNDS OF FEED CONSUMED DAILY"
LOCATE 8, 48: PRINT "QUANTITY"
LOCATE 9, 20: PRINT "A. BOAR"
LOCATE 10, 20: PRINT "B. GILT"
LOCATE 11, 20: PRINT "C. GEST SOW"
LOCATE 12, 20: PRINT "D. SOW + LITTER"
LOCATE 13, 20: PRINT "E. NURSERY"
LOCATE 14, 20: PRINT "F. GROWER 50-125"
LOCATE 15, 20: PRINT "G. FINISHER 125-175"
LOCATE 16, 20: PRINT "H. FINISHER  175"
```

```
LOCATE 18, 15: PRINT "TO QUIT OR RETURN TO THE LAGOON INPUT MENU"
LOCATE 19, 15: PRINT "PRESS F1 & ENTER"

LOCATE 9, 50: INPUT ; PB
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 10, 50: INPUT ; PG
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 11, 50: INPUT ; PGS
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 12, 50: INPUT ; PSL
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 13, 50: INPUT ; PN
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 14, 50: INPUT ; PGR
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 15, 50: INPUT ; P125
IF QUIT1 = 1 THEN GOTO 1020
LOCATE 16, 50: INPUT ; P175

1020
PFB = NB * PB
PFG = NG * PG
PFGS = NGS * PGS
PFSL = NSL * PSL
PFN = NN * PN
PFGR = NGROW * PGR
PF125 = NFIN125 * P125
PF175 = NFIN175 * P175
KEY(1) OFF
END SUB


SUB FLUSHMENU
CLS 2
TVOLTEST = 0
TK = 0
A = 0
LOCATE 7, 35: PRINT "FLUSH MENU"
LOCATE 9, 22: INPUT "ENTER THE NUMBER OF TANKS USED "; TANKS
LOCATE 11, 10: PRINT "TANK NUM."
LOCATE 11, 27: PRINT "VOL. OF TANK (GAL)"
LOCATE 11, 48: PRINT "FLUSHES PER DAY"
A = 12
QP = 1
TK = TANKS + 12
IF TK = 12 THEN GOTO 34
DO
   LOCATE A, 12: PRINT ; QP; "?"
   LOCATE A, 32: INPUT ; VOL
   LOCATE A, 54: INPUT ; tim
   TVOLTEST = TVOLTEST + (VOL * tim)
   A = A + 1
   QP = QP + 1
LOOP UNTIL A = TK
TVOLTEST = TVOLTEST / 7.5
A = A + 2
LOCATE A, 10: PRINT "TVOL = "; TVOLTEST
A = A + 2
LOCATE A, 10: PRINT "PRESS ANY KEY TO CONTINUE"
WHILE INKEY$ = "": WEND
34 END SUB


SUB FORMT
   CLS
   SCREEN 12
   LOCATE 1, 30: PRINT "LAGOON MASS BALANCE";
```

```
    LOCATE 3, 2: PRINT "MESONET STATION = "; LOCATION5
    LOCATE 5, 3: PRINT "DATE"
    LOCATE 5, 17: PRINT "VOLUME"
    LOCATE 5, 28: PRINT "SURFACE AREA"
    LOCATE 5, 45: PRINT "HEIGHT"
    LOCATE 5, 57: PRINT "LAGOON EC"
    LOCATE 6, 1: FOR JJ = 1 TO 80
              PRINT CHR$(196);
           NEXT JJ
    LOCATE 25, 1: FOR JJJ = 1 TO 80
              PRINT CHR$(196);
           NEXT JJJ

    LOCATE 26, 5: PRINT "F1 = QUIT"
    LOCATE 27, 5: PRINT "F2 = HOGS MENU"
    LOCATE 26, 30: PRINT "F3 = LAGOON OUTPUT"
    LOCATE 27, 30: PRINT "F4 = PAUSE"
    LOCATE 26, 55: PRINT "F5 = INCREASE SPEED"
    LOCATE 27, 55: PRINT "F6 = DECREASE SPEED"
    VIEW PRINT 7 TO 24
END SUB


SUB GROWING
     IF RAIN5 < 1.4173 THEN                    'CONDITION I
    AC1C = (4.2 * CNC) / (10 - (.058 * CNC))
    AC1D = (4.2 * CND) / (10 - (.058 * CND))
    AC1G = (4.2 * CNG) / (10 - (.058 * CNG))
    AC1SW = (4.2 * CNSW) / (10 - (.058 * CNSW))
ELSEIF (RAIN5 >= 1.4173) AND (RAIN5 <   2.0866) THEN   'CONDITION II
    AC1C = CNC
    AC1D = CND
    AC1G = CNG
    AC1SW = CNSW
ELSE
    AC1C = (23 * CNC) / (10 + (.13 * CNC))          'CONDITION III
    AC1D = (23 * CND) / (10 + (.13 * CND))
    AC1G = (23 * CNG) / (10 + (.13 * CNG))
    AC1SW = (23 * CNSW) / (10 + (.13 * CNSW))
END IF
END SUB


SUB HOGSMENU
443
CLS 2

QUIT1 = 0
KEY(1) ON
ON KEY(1) GOSUB QUIT

LOCATE 7, 35: PRINT "HOG MENU"
LOCATE 8, 48: PRINT "QUANTITY"
LOCATE 9, 20: PRINT "A. BOAR"
LOCATE 10, 20: PRINT "B. GILT"
LOCATE 11, 20: PRINT "C. GEST SOW"
LOCATE 12, 20: PRINT "D. SOW + LITER"
LOCATE 13, 20: PRINT "E. NURSERY"
LOCATE 14, 20: PRINT "F. GROWER 50-125"
LOCATE 15, 20: PRINT "G. FINISHER 125-175"
LOCATE 16, 20: PRINT "H. FINISHER >175"
LOCATE 18, 15: PRINT "TO QUIT OR RETURN TO THE LAGOON INPUT MENU"
LOCATE 19, 15: PRINT "PRESS F1 & ENTER"

LOCATE 9, 50: INPUT ; NB
IF QUIT1 = 1 THEN GOTO 444
LOCATE 10, 50: INPUT ; NG
```

```
IF QUIT1 = 1 THEN GOTO 444
LOCATE 11, 50: INPUT ; NGS
IF QUIT1 = 1 THEN GOTO 444
LOCATE 12, 50: INPUT , NSL
IF QUIT1 = 1 THEN GOTO 444
LOCATE 13, 50: INPUT ; NN
IF QUIT1 = 1 THEN GOTO 444
LOCATE 14, 50: INPUT , NGROW
IF QUIT1 = 1 THEN GOTO 444
LOCATE 15, 50: INPUT , NFIN125
IF QUIT1 = 1 THEN GOTO 444
LOCATE 16, 50: INPUT , NFIN175

PRINT
444                    'VOL WASTE (FT^3 / DAY )
  MVB = NB * .13          'BOAR
  MVG = NG * .13          'GILT
  MVGS = NGS * .13         'GEST & SOW
  MVSL = NSL * .41         'SOW & LITTER
  MVN = NN * .06          'NURSERY
  MVGROW = NGROW * .1       'GROWERS
  MVFIN125 = NFIN125 * .13   'FINISHER 125-175
  MVFIN175 = NFIN175 * .15   'FINISHER 175-250

  TMANURE = MVFIN175 + MVFIN125 + MVGROW + MVN + MVB + MVG + MVGS + MVSL
KEY(1) OFF
END SUB


SUB INPUTMENU
20 CLS 2
LOCATE 7, 32: PRINT "INPUT MENU"
LOCATE 9, 30: PRINT "A.  HOGS"
LOCATE 10, 30: PRINT "B.  FLUSH TANKS"
LOCATE 11, 30: PRINT "C.  RECHARGE PITS"
LOCATE 12, 30: PRINT "D.  MISTERS"
LOCATE 13, 30: PRINT "E.  DRIPPERS "
LOCATE 14, 30: PRINT "F.  RUNOFF"
LOCATE 15, 30: PRINT "G.  WASH WATER"
LOCATE 16, 30: PRINT "H.  BEDDING"
LOCATE 17, 30: PRINT "I.  DRINKING CHANNELS"
LOCATE 18, 30: PRINT "R.  RETURN"
LOCATE 20, 20: INPUT "CHOOSE A LETTER AND PRESS ENTER  ", CHOICE2$
PRINT
IF UCASE$(CHOICE2$) = "A" THEN
CALL HOGSMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "B" THEN
CALL FLUSHMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "C" THEN
CALL RECHARGEMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "D" THEN
CALL MISTERSMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "E" THEN
CALL DRIPPERSMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "F" THEN
CALL RUNOFFMENU
GOTO 20
```

```
END IF
IF UCASE$(CHOICE2$) = "G" THEN
CALL WASHMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "H" THEN
CALL BEDMENU
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "I" THEN
CALL DRINKING
GOTO 20
END IF
IF UCASE$(CHOICE2$) = "R" THEN GOTO 14
IF CHOICE2$ = "" THEN GOTO 20 ELSE GOTO 20
14
CLS 2
END SUB


SUB IRRIGATION
776
CLS 2

LOCATE 8, 30: PRINT "IRRIAGATION MENU"
LOCATE 10, 15: PRINT "LAGOON EFFLUENT IS PUMPDOWN BASE ON WHICH OF "
LOCATE 11, 15: PRINT "THE FOLLOWING PROCEDURES "
LOCATE 13, 25: PRINT "A. VOLUME (ACRE - IN)"
LOCATE 14, 25: PRINT "B. DEPTH (FT)"
LOCATE 16, 15: INPUT "ENTER THE LETTER OF YOUR CHOICE. ", CHOICE11$

IF UCASE$(CHOICE11$) = "A" THEN
   ACREIN = 1
ELSEIF UCASE$(CHOICE11$) = "B" THEN
   ELLEF1 = 1
ELSE
   GOTO 776
END IF

778
CLS 2
LOCATE 8, 25: PRINT "IRRIAGATION MENU -"
LOCATE 8, 45: PRINT , STAT$
LOCATE 11, 5: PRINT "VOLUME (FT^3)"
LOCATE 12, 5: PRINT "VOLUME (ACRE-IN)"
LOCATE 10, 26: PRINT "LAGOON"
LOCATE 10, 37: PRINT "DRAWDOWN"
LOCATE 10, 50: PRINT "MAX. IRRIGATION"
LOCATE 13, 5: PRINT "ELEVATION (FT)"

VOLDRAW = (W * L * DL) + (S * (W + L) * DL ^ 2) + ((4 / 3) * (S ^ 2) * (DL ^ 3))
IF TRI = 2 THEN
   VOLDRAW = VOLDRAW * .5
END IF

MAXIRRI = VOLUME - VOLDRAW
BDL = OL - DL
ACL = VOLUME / 3630          'ACRE-IN = 3630 FT^3
ACD = VOLDRAW / 3630
ACM = MAXIRRI / 3630

LOCATE 11, 23: PRINT USING "#,###,###"; VOLUME
LOCATE 11, 38: PRINT USING "###,###"; VOLDRAW
LOCATE 11, 58: PRINT USING "###,###"; MAXIRRI
LOCATE 12, 25: PRINT USING "####.##"; ACL
LOCATE 12, 38: PRINT USING "####.##"; ACD
LOCATE 12, 58: PRINT USING "####.##"; ACM
```

```
LOCATE 13, 27: PRINT USING "##.##"; OL
LOCATE 13, 40: PRINT USING "##.##"; DL
LOCATE 13, 60: PRINT USING "##.##"; BDL

IF ELEFT = 1 THEN
   LOCATE 15, 5: INPUT "ENTER THE DEPTH THAT YOU WHICH TO IRRIGATE (FT) = "; DW
   DWW = OL - DW
   IRRI = (W * L * DWW) + (S * (W + L) * DWW ^ 2) + ((4 / 3) * (S ^ 2) * (DWW ^ 3))

   IF TRI = 2 THEN
      IRRI = IRRI * .5
   END IF

   IRRIGATE = VOLUME - IRRI
   IF DW = 0 THEN IRRIGATE = 0
   LOCATE 17, 20: PRINT "NEW DEPTH"
   LOCATE 17, 34: PRINT "VOLUME IRRIGATED (FT^3)"
   LOCATE 18, 22: PRINT USING "##.##"; DWW
   LOCATE 18, 40: PRINT USING "###,###"; IRRIGATE
END IF

IF ACREIN = 1 THEN
   LOCATE 15, 5: INPUT "ENTER THE VOLUME THAT YOU WHICH TO IRRIGATE (ACRE-IN) = "; AI
   IRRIGATE = AI * 3630
   VOLIRRI = VOLUME - IRRIGATE
   OL4 = OL
779
   VOLAF = (W * L * OL4) + (S * (W + L) * OL4 ^ 2) + ((4 / 3) * (S ^ 2) * (OL4 ^ 3))
   IF TRI = 2 THEN
      VOLAF = VOLAF * .5
   END IF
   IF = VOLIRRI - VOLAF
   OL3 = OL4 + OL4 * (IF / VOLIRRI)      'NEW HEIGHT
   G = ABS(OL3 - OL4)
   IF G > .001 THEN          'ORIGINAL = .00001
     OL4 = OL3
     GOTO 779
   END IF

   LOCATE 17, 20: PRINT "NEW DEPTH"
   LOCATE 17, 34: PRINT "VOLUME IRRIGATED (FT^3)"
   LOCATE 18, 22: PRINT USING "##.##"; OL4
   LOCATE 18, 40: PRINT USING "###,###"; IRRIGATE
END IF
781
LOCATE 20, 5: INPUT "THE VOLUME IRRIGATED IS CORRECT (Y/N)"; YY$
IF UCASES(YY$) = "Y" THEN
   GOTO 777
ELSEIF UCASES(YY$) = "N" THEN
   GOTO 778
ELSE GOTO 781
END IF
777
CLS 2
END SUB


SUB LAGOONDIM

SD = TD - OL
WL = TL - (2 * S * SD)
WW1 = TW - (2 * S * SD)

W = TW - (2 * S * TD)   'botton width
L = TL - (2 * S * TD)   'botton lenght

SURFAREA = (W * L) + ((W + L) * 2 * S * OL) + (4 * (S ^ 2) * (OL ^ 2))
```

```
VOLUME = (W * L * OL) + (S * (W + L) * OL ^ 2) + ((4 / 3) * (S ^ 2) * (OL ^ 3))

IF TRI = 2 THEN
    SURFAREA = SURFAREA * .5
    VOLUME = VOLUME * .5
END IF
END SUB


SUB LAGOONINCALC

IF temp1 < MTEMP THEN
    MTVOL = 0              'IF TEMP < 75 NO MIST AND NO DRIPPERS
ELSE
    MTVOL = MTVOL1
END IF

IF temp1 < DTEMP THEN
    DTVOL = 0
ELSE
    DTVOL = DTVOL1
END IF

VOLWASTEIN = TMANURE + MTVOL + DTVOL + WTVOL + TVOLTEST + DRINKVOL + PTVOL + BTVOL
RAINFALL = SURFAREA * RAIN1
END SUB


SUB LAGOONINF
1005
CLS 2

LOCATE 7, 28: PRINT "LAGOON INFORMATION MENU"
LOCATE 9, 28: PRINT "A. SHAPE, DIMENSIONS, AND"
LOCATE 10, 28: PRINT "   OPERATING LEVELS"
LOCATE 11, 28: PRINT "B. STARTING LIQUID LEVEL"
LOCATE 12, 28: PRINT "R. RETURN"
LOCATE 14, 24: INPUT "CHOOSE A LETTER AND PRESS ENTER ", CHOICE20$

IF UCASE$(CHOICE20$) = "A" THEN
    CALL LAGOONMENU
    GOTO 1005
END IF
IF UCASE$(CHOICE20$) = "B" THEN
7   LOCATE 17, 15: INPUT "ENTER THE DEPTH THAT YOU WOULD LIKE TO START AT ", OL
    IF OL = 0 THEN GOTO 7
    GOTO 1005
END IF
IF OL = 0 THEN
    LOCATE 17, 21: PRINT "ENTER THE STARTING LIQUID LEVEL, OPTION-B"
    LOCATE 18, 30: PRINT "PRESS ANY KEY TO CONTINUE"
    WHILE INKEY$ = "": WEND
END IF
IF UCASE$(CHOICE20$) = "R" THEN GOTO 1006
IF CHOICE20$ <> "A" OR CHOICE20S <> "B" OR CHOICE20$ <> "R" THEN GOTO 1005
1006 END SUB


SUB LAGOONLEVEL
SCREEN 12
VIEW
LINE (150, 400)-(300, 400), 6
LINE (300, 400)-(400, 300), 6
LINE (400, 300)-(500, 300), 6
LINE (500, 300)-(525, 325), 6
LINE (385, 315)-(515, 315), 3
LINE (150, 355)-(345, 355), 2
```

```
LINE (150, 325)-(375, 325), 13
LINE (361, 340)-(361, 366), 9
LINE (334, 366)-(360, 366), 9

LOCATE 16, 20: PRINT "LAGOON OPERATING LEVELS - FT"
LOCATE 20, 10: PRINT "MAX. OPER. LEVEL"
LOCATE 22, 10: PRINT "MAX. DRAWDOWN"
LOCATE 25, 20: PRINT "BOTTOM"
LOCATE 18, 50: PRINT "TOP OF EMBANKMENT"
LOCATE 21, 53: PRINT "EMERGECY SPILLWAY"
LOCATE 23, 47: PRINT "1"
LOCATE 24, 44: PRINT "S"

LOCATE 18, 68: INPUT "", TD          'TOTAL DEPTH, FT
LOCATE 21, 71: INPUT "", CS          'CONSTRUCTED CREST OF THE SPILLWAY
LOCATE 20, 28: INPUT "", MOL           'MAX. OPERATION LEVEL
LOCATE 22, 25: INPUT "", DL          'DRAWDOWN LEVEL
LOCATE 24, 47: INPUT "", S          'SLOPE
SCREEN 0
END SUB


SUB LAGOONMENU

1007
CLS 2
TRI = 0

LOCATE 7, 28: PRINT "LAGOON INFORMATION MENU"
LOCATE 9, 30: PRINT "SHAPE OF THE LAGOON"
LOCATE 10, 32: PRINT "A. RECTANGULAR"
LOCATE 11, 32: PRINT "B. TRIANGULAR"
LOCATE 12, 32: PRINT "R. RETURN"
LOCATE 14, 24: INPUT "CHOOSE A LETTER AND PRESS ENTER:", CHOICE21$

IF UCASE$(CHOICE21$) = "A" THEN
   REC = 1
   GOTO 1008
END IF
IF UCASE$(CHOICE21$) = "B" THEN
   TRI = 2
   GOTO 1008
END IF
IF UCASE$(CHOICE21$) = "R" THEN GOTO 1009
IF CHOICE21$ <> "A" OR CHOICE21$ <> "B" OR CHOICE21$ <> "R" THEN GOTO 1007

1008
SCREEN 12
LOCATE 3, 27: PRINT "LAGOON DIMENSIONS"

IF REC = 1 THEN
   VIEW (150, 50)-(400, 175), , 6
END IF

IF TRI = 2 THEN
   VIEW
   LINE (400, 50)-(400, 150), 6
   LINE (150, 150)-(400, 150), 6
   LINE (150, 150)-(400, 50), 6
END IF

LOCATE 7, 52: PRINT "TOP WIDTH"
LOCATE 11, 28: PRINT "TOP LENGTH"
VIEW
LINE (150, 400)-(300, 400), 6
LINE (300, 400)-(400, 300), 6
LINE (400, 300)-(500, 300), 6
```

```
LINE (500, 300)-(525, 325), 6
LINE (385, 315)-(515, 315), 3
LINE (150, 355)-(345, 355), 2
LINE (150, 325)-(375, 325), 13
LINE (361, 340)-(361, 366), 9
LINE (334, 366)-(360, 366), 9

LOCATE 16, 20: PRINT "LAGOON OPERATING LEVELS - FT"
LOCATE 20, 10: PRINT "MAX  OPER  LEVEL"
LOCATE 22, 10: PRINT "MAX. DRAWDOWN"
LOCATE 25, 20: PRINT "BOTTOM"
LOCATE 18, 50: PRINT "TOP OF EMBANKMENT"
LOCATE 21, 53: PRINT "EMERGECY SPILLWAY"
LOCATE 23, 47: PRINT "E"
LOCATE 24, 44: PRINT "S"

LOCATE 7, 62: INPUT "", TW             'TOTAL WIDTH
LOCATE 11, 40: INPUT "", TL            'TOTAL LENGTH
LOCATE 18, 68: INPUT "", TD            'TOTAL DEPTH, FT
LOCATE 21, 71: INPUT "", CS            'CONSTRUCTED CREST OF THE SPILLWAY
LOCATE 20, 28: INPUT "", MOL             'MAX  OPERATION LEVEL
LOCATE 22, 25: INPUT "", DL            'DRAWDOWN LEVEL
LOCATE 24, 47: INPUT "", S            'SLOPE

SCREEN 0
1009 END SUB


SUB LAGOONMENU2

1017
CLS 2
REC = 0
TRI = 0

LOCATE 7, 30: PRINT "SHAPE OF THE LAGOON"
LOCATE 9, 32: PRINT "A. RECTANGULAR"
LOCATE 10, 32: PRINT "B. TRIANGULAR"
LOCATE 12, 24: INPUT "CHOOSE A LETTER AND PRESS ENTER "; CHOICE27$

IF UCASE$(CHOICE27$) = "A" THEN
   REC = 1
   GOTO 1018
END IF
IF UCASE$(CHOICE27$) = "B" THEN
   TRI = 2
   GOTO 1018
END IF
IF CHOICE27$ <> "A" OR CHOICE27$ <> "B" THEN GOTO 1017

1018
SCREEN 12
LOCATE 9, 27: PRINT "LAGOON DIMENSIONS"

IF REC = 1 THEN
   VIEW (150, 155)-(400, 280), , 6
END IF

IF TRI = 2 THEN
   VIEW
   LINE (150, 280)-(400, 180), 6
   LINE (400, 280)-(400, 180), 6
   LINE (150, 280)-(400, 280), 6
END IF

LOCATE 14, 52: PRINT "TOP WIDTH"
LOCATE 19, 30: PRINT "TOP LENGTH"
```

```
LOCATE 14, 62: INPUT "", TW            'TOTAL WIDTH
LOCATE 19, 42: INPUT "", TL           'TOTAT LENGTH
SCREEN 0
END SUB


SUB LAGOONOUTCAL
EVAPLOSS = SURFAREA * EVAP1
RECYCLE = (TVOLTEST * TPER) + (PTVOL * PPER)
END SUB


SUB MISTERSMENU
CLS 2
LOCATE 7, 30: PRINT "MISTER MENU"
LOCATE 9, 20: INPUT "ENTER THE NUMBER OF MISTERS. ", MNUM
IF MNUM = 0 THEN GOTO 140
LOCATE 10, 20: INPUT "ENTER THE WATER USE (GAL/HR). ", MVOL
LOCATE 11, 20: INPUT "ENTER THE TOTAL HOURS PER DAY (HR/DAY). ", MHOURS
LOCATE 12, 20: INPUT "AT WHAT TEMPERATURE THE MISTERS START WORKING (F). ", MTEMP1
MTEMP1 = MTEMP1 - 10
MTEMP = (MTEMP1 - 32) * (5 / 9)
MTVOL = (MNUM * MVOL * MHOURS) / 7.5
MTVOL1 = MTVOL
MTVOL2 = MTVOL
140 END SUB


SUB NEWDEPTH

100
   VOLTOTAL1 = (W * L * OL) + (S * (W + L) * OL ^ 2) + ((4 / 3) * (S ^ 2) * (OL ^ 3))
   IF TRI = 2 THEN
      VOLTOTAL1 = VOLTOTAL1 * .5
   END IF
   F = VOLTOTAL - VOLTOTAL1
   OL2 = OL + OL * (F / VOLTOTAL1)      'NEW HEIGHT
   G = ABS(OL2 - OL)
   IF G > .0001 THEN          'ORIGINAL = .00001
     OL = OL2
     GOTO 100
   END IF
   VOLUME = VOLTOTAL1
   OL = OL2
   SURFAREA2 = (W * L) + ((W + L) * 2 * S * OL) + (4 * (S ^ 2) * (OL ^ 2))
   IF TRI = 2 THEN
      SURFAREA2 = SURFAREA2 * .5
   END IF
END SUB


SUB OUTFILE

LOCATE 21, 18: PRINT "ENTER THE FILE NAME TO SAVE THE NEW OUTPUT DATA "
LOCATE 22, 18: INPUT "C:\OUTPUT\########.DAT> ", MM$

IF NUM = 1 THEN MMMM$ = "C:\OUTPUT\WIST\"
IF NUM = 2 THEN MMMM$ = "C:\OUTPUT\STIG\"
IF NUM = 3 THEN MMMM$ = "C:\OUTPUT\WIST\"
IF NUM = 4 THEN MMMM$ = "C:\OUTPUT\SALL\"
IF NUM = 5 THEN MMMM$ = "C:\OUTPUT\SHAW\"
IF NUM = 6 THEN MMMM$ = "C:\OUTPUT\BOWL\"
IF NUM = 7 THEN MMMM$ = "C:\OUTPUT\CALV\"
IF NUM = 8 THEN MMMM$ = "C:\OUTPUT\SHAW\"
IF NUM = 9 THEN MMMM$ = "C:\OUTPUT\GOOD\"
IF NUM = 10 THEN MMMM$ = "C:\OUTPUT\BOOK\"
```

```
IF NUM = 11 THEN MMMM$ = "C:\OUTPUT\STIL\"

MMM$ = MMMM$ + MM$ + ".DAT"
OPEN MMM$ FOR OUTPUT AS #2
END SUB


SUB OUTPUTMENU
30 CLS 2

IF OL = 0 THEN
   LOCATE 10, 13: PRINT "PLEASE ENTER THE LAGOON LOADING AND SIZE INFORMATION"
   LOCATE 11, 13: PRINT "BEFORE SELECTING THE OUTPUT MENU"
   LOCATE 13, 25: PRINT "PRESS ANY KEY TO CONTINUE"
   WHILE INKEY$ = "": WEND
   GOTO 17
END IF

LOCATE 7, 31: PRINT "OUTPUT MENU"
LOCATE 9, 30: PRINT "A.  IRRIGATION"
LOCATE 10, 30: PRINT "B.  RECYCLING"
LOCATE 11, 30: PRINT "R.  RETURN"
LOCATE 13, 20: INPUT "ENTER THE LETTER OF YOUR CHOICE. ", CHOICE4$
PRINT
IF UCASE$(CHOICE4$) = "A" THEN
     CALL IRRIGATION
     GOTO 30
ELSEIF UCASE$(CHOICE4$) = "B" THEN
     CALL RECYCLING
     GOTO 30
ELSEIF UCASE$(CHOICE4$) = "R" THEN GOTO 17

ELSE GOTO 30
END IF
17
CLS 2
END SUB


SUB PRESETS
'CHOICE1$              'MAIN MENU CHOICES
'CHOICE2$              'INPUT MENU CHOICES
'CHOICE3$              'WEATHER CHOICES
'CHOICE4$              'OUTPUT MENU CHOICES
'CHOICE5$              'HOG TYPE MENU CHOICES
'CHOICE6$              'BEDDING MENU
'CHOICE15$             'PRINT DATA
CHOICE7$ = "Y"         'INFORMATION CORRECT
NB = 0                 '# BOARS'
NG = 0                 '# GILTS'
NGS = 0                '# GEST SOWS'
NSL = 0                '# SOW + LITER'
NN = 0                 '# NURSERY'
NGROW = 0              '# GROWERS'
NFIN125 = 0            '# FINISHERS 125-175'
NFIN175 = 0            '# FINISHERS 175+'
MVB = 0                'MANURE VOLUME BOARS'
MVG = 0                'MANURE VOLUME GILTS'
MVGS = 0               'MANURE VOLUME GEST SOWS'
MVSL = 0               'MANURE VOLUME SOW + LITER'
MVN = 0                'MANURE VOLUME NURSERY'
MVGROW = 0             'MANURE VOLUME GROWERS'
MVFIN125 = 0           'MANURE VOLUME FINISHERS 125-175'
MVFIN175 = 0           'MANURE VOLUME FINISHERS 175+'
TW = 0                 'TOP WIDTH'
TL = 0                 'TOP LENGTH'
S = 0                  'EMBANKMENT SLOPE'
```

```
TD = 0              'TOTAL DEPTH'
DL = 0              'DRAWDOWN LEVEL'
OL = 0              'OPERATING LEVEL - FT
CS = 0              'CREST OF SPILLWAY'
VOL = 0             'VOL OF TANK '
TVOLTEST = 0        'TOTAL VOLUME OF TANKS'
PVOL = 0            'VOL OF PIT'
PTVOL = 0           'TOTAL VOLUME OF PITS'
tim = 0             'FREQUENCY OF USE ON TANKS'
PTIM = 0            'FREQUENCY OF USE ON PITS'
WVOL = 0            'WASH VOLUME'
WTIM = 0            'WASH FREQUENCY'
WTVOL = 0           'WASH TOTAL VOLUME'
MVOL = 0            'MISTER VOLUME'
MNUM = 0            '# OF MISTERS'
MHOURS = 0          '# OF HOURS ON (MISTERS)'
MTVOL = 0           'MISTER TOTAL VOLUME'
DVOL = 0            'DRIPPER VOLUME'
DNUM = 0            '# OF DRIPPERS'
DHOURS = 0          '# OF HOURS ON (DRIPPERS)'
DTVOL = 0           'DRIPPER TOTAL VOLUME'
'ID$                'STATION ID
'STAT$              'MONTH AND TIMEOF DATA
'TIM$               'MONTH AND TIMEOF DATA
'TEMP               'TEMPERATURE
'RH                 'RELATIVE HUMIDITY
'WIND               'WIND SPEED
'RAIN               'RAIN IN INCHES
TMANURE = 0         'TOTAL MANURE
EVAPLOSS = 0        'LAGOON EVAPORATION SURFACE AREA * EVAP
RTA = 0             'ROOF TOTAL AREA
CTA = 0             'CONCRETE TOTAL AREA
DTA = 0             'DIRT TOTAL AREA
GTA = 0             'GRASS TOTAL AREA
IRRIGATE = 0        'IRRIGATION VOLUME
SEEPAGE = 0
QUIT = 0
'QUIT               EXIT
'LOCATION$          MESONET STATION
'DATES$2            BEGINING DATE
'SDV                SAWDUST
'LST                LONG STRAW
'CST                CHOPPED STRAW
'ST & SV            SHAVINGS
'SDT                SAWDUST
'SAT                 SAND
'OL2                NEW OPERATION LEVEL - FT (TODAY)
'SURFAREA           LAGOON SURFACE AREA
'SURFAREA2          LAGOON SURFACE AREA WITH NEW DEPTH (OL2) (TODAY)
'VOLTOTAL           TOTAL VOLUME OF THE LAGOON (TODAY)
'VOLTOTAL1          LAGOON VOLUME @ OL (YESTERDAY)
'VOLUME             LAGOON VOLUME (TODAY)
'VOLTOTAL2          VOLUME WITHOUT SPILLAGE
'f                  DIFFRENCE BETWEEN YESTERDAY VOL (VOLTOTAL1) AND TODAY VOL (VOLTOTAL)
'g                  DIFERENCE BETWENT YESTERDAY DEPTH AND TODAY DEPTH
'SLV                SLUDGE ACCUMULATION YES=1 NO=2
'TRI                TRIANGLE LAGOON
END SUB


SUB PRINTOUT
LPRINT CHR$(12).
LPRINT ; SPC(27). "EXPECTED WASTE VOLUME"
LPRINT , SPC(31); "FT^3 PER DAY"
LPRINT
LPRINT "MANURE VOLUME"
LPRINT "ANIMAL", SPC(20), "NO. OF EACH", SPC(20), "MANURE VOLUME"
```

```
LPRINT "BOAR"; SPC(18); : LPRINT USING "###########"; NB; SPC(20); : LPRINT USING "#############"; MVB
LPRINT "GILT"; SPC(18); : LPRINT USING "###########"; NG; SPC(20); : LPRINT USING "#############"; MVG
LPRINT "GEST SOW"; SPC(14); : LPRINT USING "###########"; NGS; SPC(20); : LPRINT USING "#############"; MVGS
LPRINT "SOW + LITER"; SPC(11); : LPRINT USING "###########"; NSL; SPC(20); : LPRINT USING "#############";
MVSL
LPRINT "NURSERY"; SPC(15); : LPRINT USING "###########"; NN; SPC(20); : LPRINT USING "#############"; MVN
LPRINT "GROWER 50-125"; SPC(9); : LPRINT USING "###########"; NGROW; SPC(20); : LPRINT USING
"#############"; MVGROW
LPRINT "FINISHER 125-175"; SPC(6); : LPRINT USING "###########"; NFIN125; SPC(20); : LPRINT USING
"#############"; MVFIN125
LPRINT "FINISHER 175+"; SPC(9); : LPRINT USING "###########"; NFIN175; SPC(20); : LPRINT USING "#############";
MVFIN175
LPRINT ; SPC(34); "TOTAL MANURE VOLUME"; SPC(7); : LPRINT USING "######"; TMANURE
LPRINT
LPRINT
LPRINT "FLUSH TANK"
LPRINT "TOTAL NO. OF TANKS"; SPC(20); "TOTAL FLUSHWATER VOLUME"
LPRINT ; SPC(7); : LPRINT USING "###"; TANKS; SPC(35); : LPRINT USING "#######"; TVOLFLST
LPRINT
LPRINT
LPRINT "PIT RECHARGE WATER"
LPRINT "TOTAL NO. OF PITS"; SPC(21); "TOTAL PIT RECHARGE VOLUME"
LPRINT ; SPC(7); : LPRINT USING "###"; PIT; SPC(35); : LPRINT USING "#######"; PTVOL
LPRINT
LPRINT
LPRINT "WASHOUT WATER"
LPRINT "TOTAL VOL. OF WASH WATER"; SPC(10); "FREQUENCY"; SPC(16); "VOL. OF WATER"
LPRINT ; SPC(7); : LPRINT USING "######"; WVOL; : LPRINT " GALLONS"; SPC(16); : LPRINT USING "##"; WTIM;
SPC(21); : LPRINT USING "######"; WTVOL
LPRINT
LPRINT
LPRINT "MISTERS AND DRIPPERS"
LPRINT ; SPC(13); "NO OF:"; SPC(5); "WATER USE(GAL/DAY)"; SPC(5); "HRS/DAY"; SPC(5); "VOL. OF WATER"
LPRINT "MISTERS"; SPC(7); : LPRINT USING "###"; MNUM; SPC(11); : LPRINT USING "#######"; MVOL; SPC(14);
LPRINT USING "##"; MHOURS; SPC(11); : LPRINT USING "####"; MTVOL1
LPRINT "DRIPPERS"; SPC(6); : LPRINT USING "###"; DNUM; SPC(11); : LPRINT USING "#######"; DVOL; SPC(14);
LPRINT USING "##"; DHOURS; SPC(11); : LPRINT USING "####"; DTVOL1
LPRINT
LPRINT
LPRINT "BEDDING"
LPRINT "TYPE"; SPC(20); "TONS PER MONTH"; SPC(9); "TOTAL BEDDING VOLUME"
LPRINT "LONG STRAW"; SPC(18); : LPRINT USING "####"; LST; SPC(24); : LPRINT USING "#####.##"; LSV
LPRINT "CHOPPED STRAW"; SPC(15); : LPRINT USING "####"; CST; SPC(24); : LPRINT USING "#####.##"; CSV
LPRINT "SHAVINGS"; SPC(20); : LPRINT USING "####"; ST; SPC(24); : LPRINT USING "#####.##"; SV
LPRINT "SAWDUST"; SPC(21); : LPRINT USING "####"; SDT; SPC(24); : LPRINT USING "#####.##"; SDV
LPRINT "SAND"; SPC(24); : LPRINT USING "####"; SAT; SPC(24); : LPRINT USING "#####.##"; SAV
LPRINT ; SPC(34); "TOTAL BEDDING VOLUME"; SPC(2); : LPRINT USING "#####.##"; BTVOL
LPRINT
LPRINT
LPRINT "TOTAL MANURE AND WASTEWATER = "; VOLWASTEIN; "FT^3/DAY"

LPRINT CHR$(12);

LPRINT
LPRINT ; SPC(30); "FACILITY RUNOFF VOLUME"
LPRINT
LPRINT
TOPAREA = TW * TL
TOPAREA2 = TOPAREA / 12
RTA2 = RTA / 12
CTA2 = CTA / 48
DTA2 = DTA / 48
GTA2 = GTA / 60
TONEINRAIN = RTA2 + CTA2 + DTA2 + GTA2 + TOPAREA2

TOPAREA3 = TOPAREA / 2
RTA3 = RTA / 2
```

```
CTA3 = CTA / 2.5
DTA3 = DTA / 2.5
GTA3 = GTA / 2.8
TSIXINRAIN = RTA3 + CTA3 + DTA3 + GTA3 + TOPAREA3

LPRINT "RAINFALL VOLUME TO POND AFTER 1 in. RAIN"
LPRINT
LPRINT "OPEN AREAS CONNECTED TO STORAGE"; SPC(8); "AREA (FT^2)"; SPC(8); "TOTAL VOLUME (FT^3)"
LPRINT "LAGOON/POND SURFACE"; SPC(19); : LPRINT USING "#########"; TOPAREA; SPC(14); : LPRINT USING
"#######"; TOPAREA2
LPRINT "ROOFS"; SPC(33); : LPRINT USING "#########"; RTA; SPC(14); : LPRINT USING "#######"; RTA2
LPRINT "CONCRETE"; SPC(30); : LPRINT USING "#########"; CTA; SPC(14); : LPRINT USING "#######"; CTA2
LPRINT "DIRT"; SPC(34); : LPRINT USING "#########"; DTA; SPC(14); : LPRINT USING "#######"; DTA2
LPRINT "GRASS"; SPC(33); : LPRINT USING "#########"; GTA; SPC(14); : LPRINT USING "#######"; GTA2
LPRINT ; SPC(50); "TOTAL"; SPC(6); : LPRINT USING "#######"; TONEINRAIN
LPRINT
LPRINT
LPRINT
LPRINT "RAINFALL VOLUME TO POND AFTER 6 in. RAIN"
LPRINT
LPRINT "OPEN AREAS CONNECTED TO STORAGE"; SPC(8); "AREA (FT^2)"; SPC(8); "TOTAL VOLUME (FT^3)"
LPRINT "LAGOON/POND SURFACE"; SPC(19); : LPRINT USING "#########"; TOPAREA; SPC(14); : LPRINT USING
"#######"; TOPAREA3
LPRINT "ROOFS"; SPC(33); : LPRINT USING "#########"; RTA; SPC(14); : LPRINT USING "#######"; RTA3
LPRINT "CONCRETE"; SPC(30); : LPRINT USING "#########"; CTA; SPC(14); : LPRINT USING "#######"; CTA3
LPRINT "DIRT"; SPC(34); : LPRINT USING "#########"; DTA; SPC(14); : LPRINT USING "#######"; DTA3
LPRINT "GRASS"; SPC(33); : LPRINT USING "#########"; GTA; SPC(14); : LPRINT USING "#######"; GTA3
LPRINT ; SPC(50); "TOTAL"; SPC(6); : LPRINT USING "#######"; TSIXINRAIN
END SUB


SUB RECHARGEMENU
CLS 2
PTVOL = 0
TK = 0
A = 0
QP = 0
LOCATE 7, 30: PRINT "RECHARGE PIT MENU"
LOCATE 9, 22: INPUT "ENTER THE NUMBER OF PITS USED: "; PIT
LOCATE 11, 10: PRINT "PIT NUM "
IF PIT = 0 THEN GOTO 15
IF PIT > 15 THEN GOTO 15
LOCATE 11, 25: PRINT "VOL. OF PIT - FT^3 "
LOCATE 11, 47: PRINT "FREQUENCY OF USE (DAYS)"
A = 12
QP = 1
PT = PIT + 12
DO
   LOCATE A, 12: PRINT ; QP; ")"
   LOCATE A, 32: INPUT ; PVOL
   LOCATE A, 56: INPUT ; PTIM
   PTVOL = PTVOL + (PVOL / PTIM)
   A = A + 1
   QP = QP + 1
LOOP UNTIL A = PT

A = A + 1
LOCATE A, 10: PRINT "PTVOL = "; PTVOL
A = A + 1
LOCATE A, 10: PRINT "PRESS ANY KEY TO CONTINUE"
WHILE INKEY$ = "": WEND
15 END SUB

SUB RECYCLING

CLS 2
LOCATE 8, 32: PRINT "RECYCLING MENU"
```

```
PRINT
LOCATE 10, 10: PRINT "ENTER THE PERCENTAGE OF RECYCLED EFFLUENT BEING USED FOR:"
LOCATE 12, 30: PRINT "PERCENTAGE (0 TO 100)"
LOCATE 13, 15: PRINT "FLUSH TANKS"
LOCATE 14, 15: PRINT "PITS"
LOCATE 13, 40: INPUT ; TPER
LOCATE 14, 40: INPUT ; PPER

TPER = (TPER) / 100
PPER = (PPER) / 100
CLS 2
END SUB


SUB RERUN

FILEO = 0
NOL = 0

1015
CLS 2
LOCATE 7, 32: PRINT "PROGRAM RE-RUN"
LOCATE 9, 21: PRINT "A. NEW OPERATING LIQUID LEVEL"
LOCATE 10, 21: PRINT "B. NEW LAGOON SHAPE AND DIMENSIONS"
LOCATE 11, 21: PRINT "C. NEW OPERATING LEVEL"
LOCATE 12, 21: PRINT "D. NEW LAGOON OUTPUT"
LOCATE 13, 21: PRINT "E. NEW OUTPUT DATA FILE"
LOCATE 14, 21: PRINT "F. RETURN TO MAIN MENU FOR OTHER CHANGES"
LOCATE 15, 21: PRINT "G. MOISTURE BALANCE"
LOCATE 16, 21: PRINT "R. RETURN"
LOCATE 18, 21: INPUT "CHOOSE A LETTER AND PRESS ENTER ", CHOICE25$

IF UCASE$(CHOICE25$) = "A" THEN
   LOCATE 21, 18: INPUT "ENTER THE DEPTH THAT YOU WOULD LIKE TO START AT (FT).", OL
   NOL = 1
   GOTO 1015
END IF
IF UCASE$(CHOICE25$) = "B" THEN
   CALL LAGOONMENU2
   GOTO 1015
END IF
IF UCASE$(CHOICE25$) = "C" THEN
   CALL LAGOONLEVEL
   GOTO 1015
END IF
IF UCASE$(CHOICE25$) = "D" THEN
   TPER = 0
   PPER = 0
   CALL OUTPUTMENU
   GOTO 1015
END IF
IF UCASE$(CHOICE25$) = "E" THEN
   FILEO = 1
   CALL OUTFILE
   GOTO 1015
END IF
IF UCASE$(CHOICE25$) = "F" THEN
   GOTO 1016
END IF
IF UCASE$(CHOICE25$) = "G" THEN
   IF FILEO = 0 THEN
      LOCATE 21, 18: PRINT "ENTER THE FILE NAME TO SAVE OUTPUT   SELECT E"
      LOCATE 22, 27: PRINT "PRESS ANY KEY TO CONTINUE"
      WHILE INKEY$ = "": WEND
      GOTO 1015
   END IF
   IF NOL = 0 THEN OL = RROL
```

```
   CALL CALC
   GOTO 1016
END IF

IF UCASE$(CHOICE25$) = "R" THEN GOTO 1016
IF CHOICE25$ <> "A" OR CHOICE25$ <> "B" OR CHOICE25$ <> "C" OR CHOICE25$ <> "D" OR CHOICE25$ <> "E" OR
CHOICE25$ <> "F" OR CHOICE25$ <> "G" OR CHOICE25$ <> "R" THEN GOTO 1015

1016 END SUB


SUB REVISE
1000 CLS
LOCATE 8, 24: PRINT "LAGOON MASS BALANCE PROGRAM"
LOCATE 10, 25: PRINT "A  LAGOON LOADING"
LOCATE 11, 25: PRINT "B. LAGOON SIZE"
LOCATE 12, 25: PRINT "C  LAGOON OUTPUT"
LOCATE 13, 25: PRINT "D  RETURN TO MOISTURE BALANCE"
LOCATE 15, 24: INPUT "ENTER THE NUMBER OF YOUR CHOICE  ", choice1$
IF UCASE$(choice1$) = "A" THEN
     CALL INPUTMENU
     GOTO 1000
END IF
IF UCASE$(choice1$) = "B" THEN
     CALL LAGOONINF
     GOTO 1000
END IF
IF UCASE$(choice1$) = "C" THEN
     CALL OUTPUTMENU
     GOTO 1000
END IF
IF UCASE$(choice1$) = "D" THEN
     GOTO 1001
END IF
IF UCASE$(choice1$) = "" THEN GOTO 1000 ELSE GOTO 1000

1001 END SUB


SUB RUNOFFCALC

CRAIN = 0     'CONCRETE
DRAIN = 0     'DIRT
GRAIN = 0     'GRASS
RSWA = 0      'LAGOON SIDE WALLS

CNC = 98
CND = 90
CNG = 90
CNSW = 95                    ' CNSW = CURVE NUMBER FOR THE SIDE WALLS
                      ' SW = SIDE WALLS
RRAIN = RAIN1 * RTA          ' RAIN1 IS IN FT

IF RAIN > 0 THEN

   IF MO = 11 OR MO = 12 OR MO = 1 OR MO = 2 THEN   'DORMANT MONTH
      CALL DORMANT
   ELSE
      CALL GROWING
   END IF

   SC = (1000 / AC1C) - 10          ' in inches
   SDD = (1000 / AC1D) - 10         ' in inches
   SG = (1000 / AC1G) - 10          ' in inches
   SCSW = (1000 / AC1SW) - 10       ' in inches

   SCTST = SC * .2                  ' SOIL WATER RETENTION PARAMETER
```

```
    SDTST = SDD * .2
    SGTST = SG * .2
    SWTST = SCSW * .2

    IF RAIN > SCTST THEN            'FACTOR# = Q = ACCUMULATED RUNOFF VOL
    FACTOR1 = ((RAIN - SCTST) ^ 2) / (RAIN + (.8 * SC))
    ELSE
    FACTOR1 = 0
    END IF

    IF RAIN > SDTST THEN
    FACTOR2 = ((RAIN - SDTST) ^ 2) / (RAIN + (.8 * SDD))
    ELSE
    FACTOR2 = 0
    END IF

    IF RAIN > SGTST THEN
    FACTOR3 = ((RAIN - SGTST) ^ 2) / (RAIN + (.8 * SG))
    ELSE
    FACTOR3 = 0
    END IF

    IF RAIN > SWTST THEN
    FACTOR4 = ((RAIN - SWTST) ^ 2) / (RAIN + (.8 * SCSW))

    TWSA = (((S ^ 2 + 1) ^ .5) * TD * 2 * (TL + TW)) + ((S * TD * (((TD ^ 2) + ((S * TD) ^ 2)) ^ .5)) * 4)  '@ TOP OF
EMBANKMENT
    WSA = (((S ^ 2 + 1) ^ .5) * OL * 2 * (WL + WW)) + ((S * OL * (((OL ^ 2) + ((S * OL) ^ 2)) ^ .5)) * 4)  '@ OPERATION
LEVEL

    IF TRI = 2 THEN
        TWSA = TWSA * .5
        WSA = WSA * .5
    END IF

    SWA = TWSA - WSA
    ELSE
    FACTOR4 = 0
    END IF

    CRAIN = (FACTOR1 / 12) * CTA
    DRAIN = (FACTOR2 / 12) * DTA
    GRAIN = (FACTOR3 / 12) * GTA
    RSWA = (FACTOR4 / 12) * SWA       'RUNOFF OF THE SIDE WALLS
END IF

RUNOFFIN = RRAIN + CRAIN + DRAIN + GRAIN + RSWA
END SUB


SUB RUNOFFMENU
600 CLS 2

LOCATE 7, 32: PRINT "RUNOFF MENU"
LOCATE 9, 15: PRINT "SELECT THE AREAS WHICH RUNOFF FLOWS INTO THE LAGOON "
LOCATE 11, 32: PRINT "A. ROOFS"
LOCATE 12, 32: PRINT "B. CONCRETE"
LOCATE 13, 32: PRINT "C. DIRT"
LOCATE 14, 32: PRINT "D. GRASS"
LOCATE 15, 32: PRINT "R. RETURN"

605
LOCATE 17, 21: INPUT "ENTER THE LETTER OF YOUR CHOICE  ", CHOICE8$
IF UCASE$(CHOICE8$) = "A" THEN GOTO 610
IF UCASE$(CHOICE8$) = "B" THEN GOTO 620
IF UCASE$(CHOICE8$) = "C" THEN GOTO 630
IF UCASE$(CHOICE8$) = "D" THEN GOTO 640
```

```
IF UCASE$(CHOICE8$) = "R" THEN GOTO 650
IF UCASE$(CHOICE8$) = "" THEN GOTO 600 ELSE GOTO 600

610
LOCATE 19, 15: INPUT "ENTER THE AREA COVERED BY ROOFS (FT^2) ", RTA
GOTO 600

620
LOCATE 19, 15: PRINT "ENTER THE AREA COVERED BY CONCRETE (FT^2) "
LOCATE 19, 60: INPUT ; CTA
GOTO 600

630
LOCATE 19, 15: PRINT "ENTER THE AREA COVERD BY DIRT (FT^2) "
LOCATE 19, 60: INPUT ; DTA
GOTO 600

640
LOCATE 19, 15: PRINT "ENTER THE AREA COVERED BY GRASS (FT^2) "
LOCATE 19, 60: INPUT ; GTA
GOTO 600
650 END SUB


SUB SALTIN

CLS 2
QUIT1 = 0
KEY(1) ON
ON KEY(1) GOSUB QUIT

LOCATE 7, 25: PRINT "PERCENT OF Ca AND SALT IN FEED"
LOCATE 8, 46: PRINT "Ca     SALT"
LOCATE 9, 20: PRINT "A. BOAR"
LOCATE 10, 20: PRINT "B. GILT"
LOCATE 11, 20: PRINT "C. GEST SOW"
LOCATE 12, 20: PRINT "D. SOW + LITER"
LOCATE 13, 20: PRINT "E. NURSERY"
LOCATE 14, 20: PRINT "F. GROWER 50-125"
LOCATE 15, 20: PRINT "G. FINISHER 125-175"
LOCATE 16, 20: PRINT "H. FINISHER >175"
LOCATE 18, 15: PRINT "TO QUIT OR RETURN TO THE LAGOON INPUT MENU"
LOCATE 19, 15: PRINT "PRESS F1 & ENTER"

LOCATE 9, 45: INPUT ; CAB
LOCATE 9, 54: INPUT ; NAB
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 10, 45: INPUT ; CAG
LOCATE 10, 54: INPUT ; NAG
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 11, 45: INPUT ; CAGS
LOCATE 11, 54: INPUT ; NAGS
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 12, 45: INPUT ; CASL
LOCATE 12, 54: INPUT ; NASL
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 13, 45: INPUT ; CAN
LOCATE 13, 54: INPUT ; NAN
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 14, 45: INPUT ; CAGR
LOCATE 14, 54: INPUT ; NAGR
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 15, 45: INPUT ; CA125
LOCATE 15, 54: INPUT ; NA125
IF QUIT1 = 1 THEN GOTO 1022
LOCATE 16, 45: INPUT ; CA175
LOCATE 16, 54: INPUT ; NA175
```

```
1022
PCSCA = .2
PCSNA = .76

PFWCA = ((48.571 * CAGS) + 15.714) / 100
PFWNA = ((40 * NAGS) + 52) / 100

CAB = (PFB * CAB) / 100
CAG = (PFG * CAG) / 100
CAGS = (PFGS * CAGS) / 100
CASL = (PFSL * CASL) / 100
CAN = (PFN * CAN) / 100
CAGR = (PFGR * CAGR) / 100
CA125 = (PF125 * CA125) / 100
CA175 = (PF175 * CA125) / 100

NAB = (PFB * NAB) / 100
NAG = (PFG * NAG) / 100
NAGS = (PFGS * NAGS) / 100
NASL = (PFSL * NASL) / 100
NAN = (PFN * NAN) / 100
NAGR = (PFGR * NAGR) / 100
NA125 = (PF125 * NA125) / 100
NA175 = (PF175 * NA125) / 100

TCA = CAB + CAG + CAGS + CASL + CAN + CAGR + CA125 + CA175
TNA = NAB + NAG + NAGS + NASL + NAN + NAGR + NA125 + NA175

SCA = TCA * PFWCA * PCSCA
SNA = TNA * PFWNA * PCSNA
KEY(1) OFF
END SUB


SUB SEEPAGECALC

   SA = (((S ^ 2 + 1) ^ .5) * OL * 2 * (WL + WW1)) + ((S * OL * (((OL ^ 2) + ((S * OL) ^ 2)) ^ .5)) * 4) + (W * L)   'SEEPAGE
AREA

   IF TRI = 2 THEN
      SA = SA * .5
   END IF
   KINFILT = 1.51E-08              'CM/SEC
   KP = KINFILT * 2834.645            'FT/DAY
   HG = (OL + 1.5) / 1.5            'HYDRAULIC GRADIENT
   SEEPAGE = SA * KP * HG              'FT/DAY
END SUB


SUB SPILLCAL
CSL = 0
VOLTOTAL2 = VOLUME + STORAGE
VOLCS = (W * L * CS) + (S * (W + L) * CS ^ 2) + ((4 / 3) * (S ^ 2) * (CS ^ 3)) 'VOL AT SPILLWAY
SPILLVOL = VOLTOTAL2 - VOLCS
IF SPILLVOL < 0 THEN SPILLVOL = 0
IF SPILLVOL > 0 THEN CSL = 1
END SUB


SUB STATUS
CLS 2
GTV = 0
TOTMA = 0
LOCATE 3, 25: PRINT "MANURE AND FLUSHWATER VOLUME"
LOCATE 5, 5: PRINT "ANIMAL          NO. OF HEAD                MANURE VOLUME"
LOCATE 6, 60: PRINT "FT^3/DAY"
PRINT
```

```
PRINT "BOAR", TAB(30); NB; TAB(60); : PRINT USING "#### ##", MVB
PRINT "GILT"; TAB(30); NG; TAB(60); : PRINT USING "#### ##"; MVG
PRINT "GEST SOW"; TAB(30); NGS; TAB(60); . PRINT USING "#### ##", MVGS
PRINT "SOW-LITER"; TAB(30), NSL , TAB(60), : PRINT USING "#### ##", MVSL
PRINT "NURSERY", TAB(30), NN, TAB(60),  PRINT USING "#### ##", MVN
PRINT "GROWER 50-125", TAB(30), NGROW, TAB(60),  PRINT USING "####.##", MVGROW
PRINT "FINISHER 125-175", TAB(30), NFIN125, TAB(60),  PRINT USING "#### ##", MVFIN125
PRINT "FINISHER 175+", TAB(30), NFIN175, TAB(60),  PRINT USING "#### ##"; MVFIN175

TOTMA = MVB + MVG + MVGS + MVSL + MVN + MVGROW + MVFIN125 + MVFIN175
BED = LSV + CSV + SV + SDV + SAV

LOCATE 16, 50: PRINT "TOTAL =",
LOCATE 16, 59: PRINT USING "#####.##": TOTMA
LOCATE 18, 1: PRINT ; "FLUSHWATER                         FLUSHWATER VOLUME"
LOCATE 19, 61  PRINT USING "######"; TVOLTEST
LOCATE 21, 1  PRINT , "PIT RECHARGE WATER                   RECHARGE WATER VOLUME"
LOCATE 22, 61  PRINT USING "######"; PTVOL

LOCATE 24, 25: PRINT "PRESS ANY KEY TO CONTINUE"
WHILE INKEY$ = "": WEND

CLS 2
LOCATE 3, 30  PRINT "OTHER WASTE VOLUME"
LOCATE 5, 1: PRINT ; "WASHWATER                         WASHWATER VOLUME"
LOCATE 6, 61: PRINT USING "######"; WTVOL
LOCATE 8, 1: PRINT , "MISTERS                      MISTER WATER VOLUME"
LOCATE 9, 61: PRINT USING "######"; MTVOL2
LOCATE 11, 1: PRINT ; "DRIPPERS                     DRIPPER WATER VOLUME"
LOCATE 12, 61: PRINT USING "######"; DTVOL2
LOCATE 14, 1: PRINT , "DRINKING CHANNELS                 DRINKING WATER VOLUME"
LOCATE 15, 61: PRINT USING "######"; DRINKVOL
LOCATE 17, 1  PRINT "BEDDING                          BEDDING VOLUME"
LOCATE 18, 61  PRINT USING "######", BED

GTV = BED + DTVOL2 + MTVOL2 + WTVOL + PTVOL + TVOLTEST + DRINKVOL + TOTMA

LOCATE 20, 40  PRINT "GRAND TOTAL = "
LOCATE 20, 60  PRINT USING "####.##", GTV
END SUB


SUB WASHMENU
CLS 2
LOCATE 7, 32: PRINT "WASH MENU"
LOCATE 9, 15: INPUT "ENTER THE AMOUNT OF WASH WATER USED (GAL). ", WVOL
IF WVOL = 0 THEN GOTO 170
LOCATE 10, 15  INPUT "ENTER THE FREQUENCY (DAYS BETWEEN) ", WTIM
170 WTVOL = (WVOL / WTIM) * 7.5
END SUB


SUB WEATERMENU
200 CLS
NUM = 0

LOCATE 5, 29: PRINT "WEATHER LOCATION DATA"
LOCATE 7, 22: PRINT "1. JACK O  DATA"
LOCATE 8, 22  PRINT "2  STIGLER"
LOCATE 9, 22: PRINT "3. WISTER"
LOCATE 10, 22: PRINT "4. SALLISAW"
LOCATE 11, 22: PRINT "5. SHAWNEE"
LOCATE 12, 22  PRINT "6. BOWLEGS"
LOCATE 7, 42  PRINT "7  CALVIN"
LOCATE 8, 42  PRINT "8  STEWART-DATA"
LOCATE 9, 42  PRINT "9  GOODWELL"
LOCATE 10, 42  PRINT "10  HOOKER"
```

```
LOCATE 11, 42: PRINT "11. STILLWATER"
LOCATE 12, 42: PRINT "12. RETURN"
LOCATE 14, 8: INPUT "SELECT THE NUMBER FOR THE LOCATION OF THE WEATHER DATA INPUT > ", NUM

PRINT

IF NUM > 12 OR NUM < 1 THEN GOTO 200
IF NUM = 1 THEN f$ = "C:\WEATHER\JOWEAT.DAT"
IF NUM = 2 THEN f$ = "C:\WEATHER\STIGWEAT.DAT"
IF NUM = 3 THEN f$ = "C:\WEATHER\WISTWEAT.DAT"
IF NUM = 4 THEN f$ = "C:\WEATHER\SALLWEAT.DAT"
IF NUM = 5 THEN f$ = "C:\WEATHER\SHAWWEAT.DAT"
IF NUM = 6 THEN f$ = "C:\WEATHER\BOWLWEAT.DAT"
IF NUM = 7 THEN f$ = "C:\WEATHER\CALVWEAT.DAT"
IF NUM = 8 THEN f$ = "C:\WEATHER\SSWEAT.DAT"
IF NUM = 9 THEN f$ = "C:\WEATHER\GOODWEAT.DAT"
IF NUM = 10 THEN f$ = "C:\WEATHER\HOODWEAT.DAT"
IF NUM = 11 THEN f$ = "C:\WEATHER\STILWEAT.DAT"

IF NUM = 12 THEN GOTO 500

300 OPEN f$ FOR INPUT AS #1
   BE$ = ""
   EN$ = ""
   DATE1 = 0
   DATE2 = 0
   DIF = 0
   COUNT = 0
   COUNT2 = 0

   LOCATE 16, 8: INPUT "ENTER THE BEGINNING DATE (MM/DD/YY) > ", BE$
   LOCATE 17, 8: INPUT "ENTER THE ENDING DATE (MM/DD/YY) > ", EN$

DO WHILE (NOT EOF(1))
   INPUT #1, ID$, STAT$, TEMP, RH, wind, RAIN, SOLAR, D
   COUNT = COUNT + 1
   IF BE$ = STAT$ THEN DATE1 = COUNT
   IF EN$ = STAT$ THEN DATE2 = COUNT
   IF COUNT = 1 THEN START$ = STAT$
   IF COUNT = COUNT THEN END$ = STAT$
   LOCATION$ = ID$
LOOP

IF DATE1 = 0 OR DATE2 = 0 OR DATE1 > DATE2 THEN
  CLS 2
  LOCATE 5, 10: PRINT "SELECTED DATES ARE NOT IN FILE OR ARE IN INCORRECT ORDER"
  LOCATE 7, 10: PRINT "THE FILE CONTAIN WEATHER DATA FROM "; START$, " TO "; END$
  LOCATE 9, 15: PRINT "BEGINNING DATE = ", BE$
  LOCATE 10, 15: PRINT "ENDING DATE = ", EN$
  LOCATE 12, 10: PRINT "PRESS ANY KEY TO RETURN TO THE SELECTION OF DATES"
  PRINT
  WHILE INKEY$ = "": WEND
  CLOSE #1
  GOTO 300

END IF
CLOSE #1
LOCATE 19, 8: PRINT "ENTER THE FILE NAME TO SAVE THE NEW OUTPUT DATA "
LOCATE 20, 8: INPUT "C:\OUTPUT\######.DAT -> ", MM$
IF NUM = 1 THEN MMMM$ = "C:\OUTPUT\WIST\"
IF NUM = 2 THEN MMMM$ = "C:\OUTPUT\STIG\"
IF NUM = 3 THEN MMMM$ = "C:\OUTPUT\WIST\"
IF NUM = 4 THEN MMMM$ = "C:\OUTPUT\SALL\"
IF NUM = 5 THEN MMMM$ = "C:\OUTPUT\SHAW\"
IF NUM = 6 THEN MMMM$ = "C:\OUTPUT\BOWL\"
IF NUM = 7 THEN MMMM$ = "C:\OUTPUT\CALV\"
IF NUM = 8 THEN MMMM$ = "C:\OUTPUT\SHAW\"
```

```
IF NUM = 9 THEN MMMMS = "C:\OUTPUT\GOOD\"
IF NUM = 10 THEN MMMM$ = "C:\OUTPUT\HOOK\"
IF NUM = 11 THEN MMMMS = "C:\OUTPUT\STILL\"

MMM$ = MMMMS + MM$ + ".DAT"
OPEN MMMS FOR OUTPUT AS #2
PRINT
500 END SUB
```

VITA

Héctor J. Cumba

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF A DAILY-BALANCE COMPUTER MODEL FOR ESTIMATING HYDRAULIC AND ELECTRICAL CONDUCTIVITY FOR SINGLE-STAGE ANAEROBIC SWINE LAGOONS

Major Field: Biosystems Engineering

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