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Evaporation Estimation Using a Floating Pan

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EVAPORATION ESTIMATION USING A FLOATING PAN

A Thesis
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the Graduate School of
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In Partial Fulfillment
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Master of Science
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by
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Accepted by:
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ABSTRACT

Almost all regions in the United States must accurately estimate evaporation to have effective water management programs. The purpose of this study is to develop a better method for measuring evaporation. Lake evaporation along with meteorological data are measured directly from a floating pan. The floating pan is specifically designed to account for one of the most sensitive parameters of evaporation, the water surface temperature. However, other factors such as air movement, solar radiation, stability, heat transfer, wave action, water level range, and site location were also taken into consideration while designing the floating pan system. The evaporation measured from the floating pan is compared to the two aerodynamic methods. Overall, the evaporation estimate using the Sill (1983) method is in close agreement to the evaporation data from the floating pan. The evaporation estimate for the months of September and October, 2006 from the two aerodynamic methods are compared to the data obtained from a land based pan. Both methods provide a lower estimate of evaporation compared to the SCDNR land based pan data. It is recommended that a water level sensor that is not influenced by temperature changes be used. The design of the floating pan allowed for the lake's water surface temperature to be similar to that of the floating pan's water surface temperature, which is one of the major components in evaporation prediction.

DEDICATION

Throughout my life I have received a significant amount of support and love from my family. I would like to dedicate this thesis to my parents, Nancy and Robert, and my three sisters, Erika, Sarah, and Carmen.

ACKNOWLEDGEMENTS

Most importantly, the author would like to express immense gratitude towards his major advisor, Dr. Abdul A. Khan, for his constant guidance, patience, and friendship. Special thanks to South Carolina Department of Natural Resources for their financial support of this research. The author extends a sincere appreciation to Dr. Nadim M. Aziz and Dr. Ben L. Sill for their assistance and review of this thesis. Also, immense gratitude is given towards Ph. D. candidate John Raiford for his continual aid throughout the study. In addition, two former Clemson University master students William T. Robinson and Jeffery L. Reck are greatly appreciated for their guidance and past research. For the technical support, auto cad drawings, and digital pictures of the floatation device much thanks is extended to Danny Metz. And finally, the author would like to give great thanks for the understanding and support from his girlfriend Jessica Heitmann during the research process.

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CHAPTER I
INTRODUCTION

The time period from June 1998 to August 2002 marked the worst multiyear drought in South Carolina history (Badr et al., 2004). Many lakes were being drained to hazardously low levels due to downstream demands. It made the state realize that the water in South Carolina can run out and should not be taken for granted. Therefore, the South Carolina Department of Natural Resources has established a *South Carolina Water Plan*, which sets guidelines for the state to follow for effective water management.

Understanding the water budget is essential for a successful water management plan. The water budget can be represented by the following equation, which accounts for the total amount of water in the watershed:

Inflow – Outflow = Change in Storage

According to the South Carolina Department of Natural Resources (Badr et al., 2004) an estimated average of 56 inches of water enters South Carolina annually from all sources. The largest of these sources is precipitation. It makes up 48 inches of the 56 inches of water entering the state of South Carolina, 85 percent of the total amount. The other 8 inches is streamflow from North Carolina. Loss of water results mainly from evapotranspiration and streams discharging into the ocean (Badr et al., 2004). Evapotranspiration is the loss of water to the atmosphere from water bodies or soil by evaporation and transpiration from plants. Out of the 48 inches of precipitation, an estimated 34 inches is lost to evaporation, which is 71 percent of the annual precipitation (Badr et al., 2004). Even in other humid regions in the United States, there have been predictions that up to 60 percent of the annual precipitation is lost to evaporation (Zurawski, 1978). Thus evaporation from lakes and reservoirs has a major impact on water management and environmental studies, since it accounts for such a large portion of the water balance.

Low water levels due to evaporation can have a considerable effect on instream and offstream uses. Instream uses, which do not withdraw water from a water body, include maintenance of fish and wildlife habitats, recreation, navigation, wastewater assimilation, and hydroelectric power generation. Offstream uses, which divert water from a lake or reservoir, include power generating facilities, industrial discharges, public supply, golf course irrigation, and crop irrigation (Badr, et al., 2004). Therefore, accurate measurement of evaporation is of critical importance to the state and its occupants.

Problem Statement

Lake evaporation is estimated from land based pans, floating pans, or by applying the water budget method with empirical equations. The most common method used to measure evaporation is the land based pan method. It consists of measuring evaporation from a pan that is either in or above the ground by a water depth sensor. However, due to differences between the pan and the lake’s water temperature, wind speed, and other parameters, a pan coefficient is required to correct for a higher evaporation rate from the land based pan. In general, the pan coefficient is a function of pan design and location and is determined by using the energy budget or aerodynamic method. Water surface temperature is one of the most important parameters in evaporation estimates. Reducing the difference in temperature between the water in the pan and in the lake will bring the pan coefficient closer to one, increasing the accuracy of evaporation measurements.

Considering that evaporation has such a significant role in the water balance, it is necessary to have a more accurate estimation of evaporation to allow government agencies to improve their assessment of regional water resources.

Objective

The primary objective is to develop a more accurate estimation of lake evaporation in the southeast region of the United States. The lake evaporation will be measured directly by suspending a pan in Lake Hartwell located in South Carolina. Analysis of the data obtained from the submerged pan will allow for a comparison of other evaporation methods. More specifically, the research will entail:

1. Designing a floatation device that will allow a pan to be submerged in a lake that can handle the lake's environmental challenges and having the device mimic the lake's water surface characteristics.
2. Compare and analyze the measured evaporation rate from the submerged pan to the aerodynamic methods that use meteorological data.
3. Compare and analyze the measured evaporation rate from the submerged pan to the Standard NWS Class-A Pan located near Lake Hartwell.
4. Improve empirical equations and pan coefficients for the southeast region of the United States.

Water is a limited natural resource that is an essential part of human life and economic development. A better assessment of water management can be obtained by an accurate estimation of evaporation from lakes and reservoirs, which will in turn benefit all residents in the state. Due to the water level sensor's data being faulty, only objectives one and two were accomplished in this study.

CHAPTER II
LITERATURE REVIEW

General

Evaporation plays a major role in the hydrological cycle. Water evaporates from a body of water such as the ocean or land surface or from vegetation through the process of transpiration. Water vapors are transported into the atmosphere until conditions are appropriate for it to precipitate back in the form of rain or snow, which provides moisture for the growth of vegetation, runoff to streams and reservoirs, and groundwater replenishment as a result of infiltration. Water from the precipitation eventually makes its way back into water bodies and reservoirs and the hydrological cycle continues (Maidment, 1993).

The hydrological cycle requires an energy source to initiate evaporation. The intermolecular attractive forces of liquid water and water vapor are different. Molecules in the liquid phase are ten times closer than those in water vapor. Since water vapor molecules are farther apart, the intermolecular forces are not quite as strong. When evaporation begins to take place, work is done against the intermolecular forces and energy is absorbed. The energy required to move a water molecule from the liquid to the gas phase is called latent heat of vaporization, λ. The latent heat required for evaporation to occur will slightly decrease when there is an increase in water temperature due to the increase in separation of molecules. The primary source of energy needed for evaporation comes from the radiation of the sun. It takes about 2.5 million joules to evaporate one kilogram of water, which can be calculated from the following latent heat of vaporization equation (Maidment, 1993):

$$\lambda = 2.501 - 0.002361 T_s \tag{2.1}$$

where

T_s = water surface temperature, °C.

Natural evaporation results in the exchange of water molecules between the air and the water surface. Vapor molecules are constantly moving freely and colliding with the water surface, which either bounce back to the atmosphere or attach to the water surface. A molecule requires a certain amount of energy to leave the water surface, determined by the water surface temperature. Evaporation occurs when there is a positive difference between the vaporization rate (dependent on temperature) and the condensation rate (dependent on vapor pressure). When the vapor pressure increases to the point where the vaporization and condensation rates become equal, the water molecules can no longer diffuse from the water surface and the air is said to be saturated. When no evaporation occurs, this is called saturated vapor pressure (Maidment, 1993). Therefore when the actual vapor pressure is lower then the saturated vapor pressure the result is evaporation. If the actual vapor pressure is equal to the saturated vapor pressure then no evaporation occurs.

As stated above, evaporation depends on the difference in saturated vapor pressure and actual vapor pressure. Evaporation can continue only if the water vapor is removed from the air close to the water surface at a rate at least equal to the rate at which it enters. Usually the air close to the water surface will become saturated before the atmosphere above it, which will cause molecular or turbulent diffusion of the vapor to the atmosphere above. Further aid in the process of evaporation comes from air that is overland with lower moisture content and is blown across a water body to replace the existing air near the water surface (Pailey, 1974). Hence, evaporation occurs when the air is calm or when the wind is blowing, which is known as free convection or forced convection, respectively.

Robinson (1992) presented the development of the bulk aerodynamic method. In 1802, Dalton was the first to propose the evaporation theory for a free water surface. Dalton wrote an essay summarizing the consensus among scientists at the end of the eighteenth century as follows (Brutsaert, 1982):

> "The following positions have been established by others, and need therefore only to be mentioned here.
>
> 1.) Some fluids evaporate much more quickly than others.
>
> 2.) The quantity evaporated is in direct proportion to the surface exposed, all other circumstances alike.
>
> 3.) An increase of temperature in the liquid is attended with an increase of evaporation, not directly proportionable.
>
> 4.) Evaporation is greater where there is a stream of air than where the air is stagnant.
>
> 5.) Evaporation from water is greater the less the humidity previously existing in the atmosphere, all other circumstances the same."

The quantifications of positions 3 and 5 were Dalton's contribution. Dalton's findings allow the present day notation of the bulk aerodynamic equation to be written in the following form:

$$E = f(\bar{u})(e_s - e_a) \tag{2.2}$$

E = evaporation rate in length unit per unit time

$f(\bar{u})$ = wind speed function

e_s = saturation vapor pressure at the water surface temperature

e_a = vapor pressure of the air

It is common to use an equation based on the bulk aerodynamic equation (2.2) to calculate evaporation. Due to uncertainty in other factors and difficulty in measuring evaporation accurately, close to a hundred different modifications of the original equation have been proposed (Pailey, 1974). In this study two different types of the bulk aerodynamic equation will be examined; the Sill (1983) method and the bulk aerodynamic transfer method.

The Sill (1983) Method

A respected British modeler, Henderson-Sellers (1986), conducted an extensive study of the surface energy balance for lakes and reservoirs by modeling eight different equations, six empirical and two theoretical. The study used two climatologically different regions, the United Kingdom and the Republic of South Africa. After evaluation of all the formulas he concluded that the equation with the most consistent predictions for both areas was the Sill (1983) theoretical method, Henderson-Sellers states (1986):

> "…the two mechanical-convective formulae are in relatively good agreement throughout the year and exceed the USGS formula, as might be anticipated, emphasizing the need to include convective removal of water vapor in the evaporation calculation. By use of the peak observed values quoted above, it is possible to conclude that the USGS formula, and by inference the other empirical forms in Table 5, are inadequate. Although objective differentiation between the mechanical-convective formulae is more difficult, the quoted observed values are best represented by the Sill (1983) formula."

The Sill (1983) method incorporates the correlation between heat, momentum, and mass transfer from a flat plate to develop an expression for forced and free convection of mass transport. The following expression used existing data from seven different water bodies to develop an equation for estimating evaporation (Sill, 1983):

$$E = C_D u(1 + 0.73C_R^2)(C_s - C_a) \qquad \text{valid for } C_R \leq 1.37 \qquad (2.3a)$$

$$E = C_D u(1 + C_R)(C_s - C_a) \qquad \text{valid for } C_R \geq 1.37 \qquad (2.3b)$$

$$C_R = \frac{0.0017(T_s - T_a)^{1/3}}{C_D u}$$

E = evaporation rate, g/m^2/s

C_D = drag coefficient of the surface, dimensionless (typically 0.0015)

u = wind speed, m/s (measured at a height of 2 m)

C_R = convection ratio, dimensionless

C_s = water vapor density of the air adjacent to the water surface, g/m^3

C_a = water vapor density of the air, g/m^3

T_s = temperature at the water surface, °C

T_a = temperature of the air, °C

The present study measures the wind velocity at a height of about 1.23 m above the water surface of the lake. However, the Sill (1983) expression has the wind speed measured at a height of 2 m from the water surface of the lake. Therefore, it is necessary to adjust the wind velocity of the current study using Gupta's (2001) equation:

$$u_2 = u_1\left(\frac{Z_2}{Z_1}\right)^{0.2} \qquad (2.4)$$

where

u_1 = wind velocity at height 1

u_2 = wind velocity at height 2

Z_1 = measurement height for u_1

Z_2 = measurement height for u_2

Equation (2.3) is similar to other forms of Dalton's formula; however, it does reveal the importance of including a surface roughness factor and air temperature within the wind speed function, which had not been included previously in evaporation analyses using the aerodynamic method. The Sill (1983) method uses the variables of relative humidity, air temperature, water surface temperature, and wind speed, which can all be accurately measured with little difficulty. The (C_s-C_a) term in equation (2.3) is the difference between the water vapor density of the air adjacent to the water surface and the water vapor density of the air. These two parameters are empirically calculated as follows (Ryan and Harleman, 1973):

$$C_s = 25.4 \exp\left(17.62 - \frac{5278}{T_S + 273}\right) \tag{2.5}$$

$$C_a = \left(\frac{RH}{100}\right) 25.4 \exp\left(17.62 - \frac{5278}{T_a + 273}\right) \tag{2.6}$$

RH = relative humidity, in percent

The C_R in equation (2.3) is the dimensionless convection ratio, which combines the effects of free and forced convection on evaporation. The convection ratio is represented by the ratio of the Dalton numbers for free and forced convection. This is written as:

$$E = (Da_{forced} + Da_{free}) u_h (C_s - C_h) \tag{2.7}$$

$$E = \left(1 + \frac{Da_{free}}{Da_{forced}}\right) Da_{forced} u_h (C_s - C_h) \tag{2.8}$$

$$C_R = \left(\frac{Da_{free}}{Da_{forced}}\right) \tag{2.9}$$

$$Da_{free} = 0.0017\frac{(\Delta T)^{1/3}}{u} \tag{2.10}$$

$$Da_{forced} = \frac{E}{u(C_s - C_a)} = \frac{Sh}{(Sc)(\mathrm{Re})} \tag{2.11}$$

Sh = Sherwood number

Sc = Schmidt number

Re = Reynolds number

ΔT = virtual temperature difference, °C

Substituting Da_{free} and Da_{forced} into equation (2.9) results in the convection ratio of:

$$C_R = \frac{0.0017(T_s - T_a)^{1/3}}{C_D u}$$

which is from equation (2.3). Substituting the convection ratio, C_R, into equation (2.8) and simplifying the expression yields equation (2.3) (Sill, 1983).

Evaporation increases as the wind speed increases. The lake's shape, area, and surrounding terrain affect the fetch, which is the unaffected horizontal distance along which wind is blowing over water (Robinson, 1992). According to Robinson (1992), the expressions of Harbeck (1962) and Goodling et al. (1976) which the Sill (1983) method is based on, suggest the need for an area correction factor. Therefore Robinson (1992) and Reck (1992) modified equation (2.3) by multiplying a lake area correction factor and also a terrain correction factor.

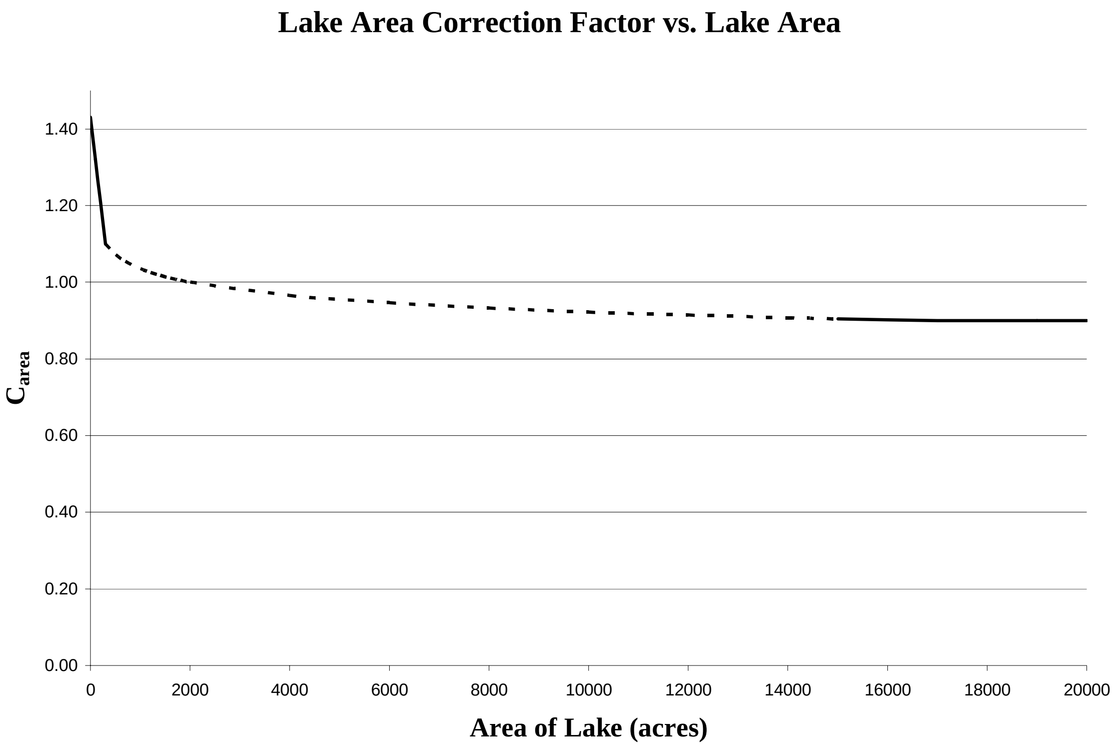
$$E = C_D u(1 + 0.73C_R^2)(C_s - C_a)(C_t)(C_{area}) \qquad \text{valid for } C_R \leq 1.37 \tag{2.12a}$$

$$E = C_D u(1 + C_R)(C_s - C_a)(C_t)(C_{area}) \qquad \text{valid for } C_R \geq 1.37 \tag{2.12b}$$

The terrain correction factor (C_t) for the floating pan study is assumed to be one since its typical value is extremely close to one thus, the terrain coefficient has a negligible effect on the estimated evaporation. However, the area correction factor (C_{area}) does have an impact on the evaporation and is given by (Harbeck, 1962 & Goodling, 1976)

$$C_{area} = \left(\frac{A_{ref}}{A_{lake}} \right)^{n} \tag{2.13}$$

where A_{ref} is the area of the reference lake in acres, A_{lake} is the area of the lake being studied, and n is a numerical exponent. In this study, A_{ref} and n are assumed to be constants and the values presented by Harbeck (1962) are used with A_{ref} equaling 2000 acres and n equaling 0.05. However, this correction factor is only valid for areas between 300 and 15,000 acres (Harbeck, 1962). The area correction factor increases linearly from 1.1 to 1.43 as the area of a lake reduces from 300 acres to 0. However, the linear increase to 1.43 is based on the assumption that the pan evaporation uses a 70 percent correction factor where 1.43 is the inverse of 0.70. Above 15,000 acres, like Lake Hartwell in South Carolina, the correction factor is constant at 0.91 (Reck, 1993). The lake area correction factor decreases as the area of the water body increases due to longer period of air contact with water body resulting in higher relative humidity. Figure 2.1 represents the lake area correction factor versus the lake area in acres.



0 - 300 acres:

$$C_{Area} = 1.43 - \left(\frac{1.43 - 1.10}{300}\right) A_{Lake}$$

300 – 15,000 acres:

$$C_{Area} = \left(\frac{2000}{A_{lake}}\right)^{0.05}$$

15,000 acres and greater:

$$C_{Area} = 0.91$$

Figure 2.1: Lake Area Correction Factor vs. Lake Area

Bulk Aerodynamic Transfer Method

Another method that uses meteorological data to calculate evaporation is the bulk aerodynamic transfer model. Ham (1999), Lakshman (1972), Quinn (1979), Bill et al. (1980), and White and Denmead (1989) all found that the following two equivalent equations (2.14) and (2.15) have been extensively used to estimate evaporation.

$$E = C_e U_r \rho (q_s^* - q_a) \tag{2.14}$$

E = rate of evaporation, kg/(m^{2}s)

ρ = air density, kg/m^3

q_s* = saturated specific humidity at the water surface temperature, kg/kg

q_a = specific humidity of the air, kg/kg

U_r = average wind, m/s

C_e = bulk aerodynamic transfer coefficient for vapor transport, dimensionless

An approximation of equation (2.14) in vapor pressure is represented by (Ham, 1999):

$$E = \frac{0.622}{R_d T_s}(e_s^* - e_a) U_r C_e \tag{2.15}$$

R_d = gas constant, 287.04 J/(kgK)

T_s = temperature of the surface, K

e_s* = saturation vapor pressure at the temperature of the water surface, Pa

e_a = vapor pressure of the air, Pa

U_r = average wind speed, m/s (measured typically at a height of 2 to 3m)

C_e = bulk aerodynamic transfer coefficient for vapor transport, dimensionless

The above equation represents only the forced convection part of the evaporation as evaporation is zero when wind velocity is zero. The bulk aerodynamic transfer coefficient for vapor transport, C_e, is determined empirically by field studies and is dependent on the two variables, wind speed (U_r) and vapor pressure (e_a). Knowing the evaporation value and solving for C_e from equation (2.15) will result in a bulk aerodynamic transfer coefficient for a particular study. Typical values of the coefficient range from 1.0 x 10^{-3} to 2.0 x 10^{-3} for instruments measuring wind speed and vapor pressure at 2 to 3 m above the water surface (Ham, 1999). In 1999, Ham calculated a bulk aerodynamic transfer coefficient of 2.81 x 10^{-3} for a lagoon situated at 40 km from Ulysses, Kansas which is higher than normal values. However, the U_r and e_a were measured at 1 m above the water surface which will result in a higher C_e (Ham, 1999). The bulk aerodynamic transfer coefficient for the floating pan study is expected to have a similar C_e value as Ham (1999), due to the instruments' height.

There are several parameters that affect the rate of evaporation. Factors such as air temperature, water surface temperature, relative humidity, wind speed and empirical dimensionless coefficients are all a significant part of computing evaporation. The common goal of all of the different forms of Dalton's equation is to incorporate these variables to best calculate evaporation.

Evaporation is a very slow process. Because of this, the measurement errors increase and the accuracy of the estimated evaporation reduces. That is why it is important to find a particular empirical equation that will best fit the specific area of interest, which analyzing the two aerodynamic equations will accomplish for the southeast region of the United States.

Evaporation Pans

The evaporation pan is the most commonly used instrument to measure evaporation. However, there are over twenty-five different designs and the list will continue to increase (Maidment, 1993). Some of the more familiar evaporation pans are the Sunken Pan of Bureau of Plant Industry, the GGI-3000 Pan, the $20m^2$ Basin, the Colorado Sunken Pan, the Class-A Pan of the U.S. Weather Bureau, and the floating pan.

The Sunken Pan of Bureau of Plant Industry (Brutsaert, 1982) was developed and used at dry locations in the western part of the U.S. for the U.S. Department of Agriculture. The Sunken Pan is made out of galvanized iron or some other non-rusting metal with a 6 foot (182.9 cm) diameter and a depth of 2 feet (61 cm). The evaporation pan is buried 20 inches (51cm) in the ground with 4 inches (10 cm) exposed above land. The pan is filled with water equal to that of the ground level. This pan was used more often before the acceptance of the Class A Pan of the U.S. Weather Bureau.

The GGI-3000 Pan (Brutsaert, 1982) is an evaporation pan that was developed in the U.S.S.R., and is used most extensively in Eastern Europe. The pan consists of a cylindrical shape with a conical base. The pan is made out of galvanized sheet iron with a surface area of 3000 cm^2, hence the name, with a diameter of 61.8 cm. Since the pan is cone like in shape the wall depth is 60 cm and the center depth is 68.5 cm in length. The GGI-3000 Pan is buried in the ground with 7.5 cm of the pan above the ground.

The 20 m^2 Basin (Brutsaert, 1982) also originated in the U.S.S.R. The evaporation basin is cylindrical in shape with a flat base made of 4-5 mm boiler plate sheets or concrete. The basin has a diameter of 5 m, which is a surface area of 20 m^2, and its depth is 2 m. Similar to the GGI-3000 Pan the 20 m^2 Basin is buried in the ground with a 7.5 cm rim above the terrain and the water in the basin is approximately level with the ground.

The Colorado Sunken Pan (Brutsaert, 1982) is one of the oldest standardized evaporation pans, dating back to the late 1800's. The pan is square in shape with 3-foot (91.5 cm) sides and a depth of 1.5 feet (45.7 cm). This pan is also buried in the ground with 4 inches of the sides out of the soil and the water surface is approximately equal to that of the ground.

The Class-A Pan of the U.S. Weather Bureau (Gupta, 2001) is the most commonly used pan in the United States. The pan is made of unpainted galvanized iron with a diameter of 4 feet (121.9 cm) and a depth of 10 inches (25.4 cm). The Class-A Pan is mounted 12 inches (30.5 cm) above the ground on a wooden frame to allow air underneath the pan for heat transfer. The pan is filled and kept at a depth of 8 inches (20.3 cm). A hook gauge is installed in the pan to measure the water level. In addition, an anemometer is installed about 6 inches (15 cm) above the pan to measure the wind speed. A temperature sensor is used to measure the water temperature. The evaporation is measured by the change in water level, with an adjustment for precipitation.

According to pan evaporation research it has been observed that the pan's measurement of evaporation is greater than that of larger water bodies. The variance of the evaporation is due to the difference in water surface temperature of the pan, wind velocity and its relative humidity, and obstruction of the wind by the pan walls. Thus, it is necessary to apply a coefficient to provide a better estimate of lake or reservoir evaporation. This can be represented by (Gupta, 2001)

$$K_P = \frac{E_L}{E_P} \tag{2.16}$$

where

K_P = pan coefficient

E_L = evaporation of a water body

E_P = evaporation from the pan

Annual pan coefficients typically range between 0.60 and 0.80, with a mean value of 0.70 (Maidment, 1982). However, the pan coefficient is less reliable for smaller time periods. The studies done in Lake Hefner, Oklahoma had a monthly coefficient variance from 0.13 to 1.31 (*Water-Loss Investigations: Lake Hefner Studies, Technical Report*, 1954). The Class-A Pan studied by Doorenbos and Pruitt (1977) yielded the pan coefficients as shown in Table 2.1. This wide range of values shows the large range of error that can occur due to the pan location, relative humidity, surrounding terrain, and wind condition. Other minute types of error that can result in pan evaporation is the layer of dust on the water surface of the pans, oily secretions of insects landing on the pans, birds bathing in the pans, animals drinking form the pans, and protective screens over the pans (Meyer, 1942). Despite these drawbacks, evaporation pans are convenient and economical. Thus, pans are still widely used to estimate evaporation.

Table 2.1: Suggested Values for the Class-A Pan of the U.S. Weather Bureau Pan Coefficient (K_P) (Doorenbos and Pruitt, 1977)

		Case A: Pan surrounded by short green crop Mean relative humidity, %				Case B: Pan surrounded by dry, bare area Mean relative humidity, %		
Wind	Upwind fetch of green crop, m	Low < 40	Med 40 - 70	High > 70	Upwind fetch of dry fallow, m	Low < 40	Med 40 - 70	High > 70
Light (< 1 m/s)	0	0.55	0.65	0.75	0	0.70	0.80	0.85
	10	0.65	0.75	0.85	10	0.60	0.70	0.80
	100	0.70	0.80	0.85	100	0.55	0.65	0.75
	1000	0.75	0.85	0.85	1000	0.50	0.60	0.70
Moderate (2-5 m/s)	0	0.50	0.60	0.65	0	0.65	0.75	0.80
	10	0.60	0.70	0.75	10	0.55	0.65	0.70
	100	0.65	0.75	0.80	100	0.50	0.60	0.65
	1000	0.70	0.80	0.80	1000	0.45	0.55	0.60
Strong (5-8 m/s)	0	0.45	0.50	0.60	0	0.60	0.65	0.70
	10	0.55	0.60	0.65	10	0.50	0.55	0.65
	100	0.60	0.65	0.70	100	0.45	0.50	0.60
	1000	0.65	0.70	0.75	1000	0.40	0.45	0.55
Very Strong (>8 m/s)	0	0.40	0.45	0.50	0	0.50	0.60	0.65
	10	0.45	0.55	0.60	10	0.45	0.50	0.55
	100	0.50	0.60	0.65	100	0.40	0.45	0.50
	1000	0.55	0.60	0.65	1000	0.35	0.40	0.45

Note: Mean relative humidity is the average maximum and minimum daily relative humidity.

Floating pans provide the possibility of eliminating the broad range of pan coefficients as it is submerged in the lake. Floating pans are not as common as the above mentioned pans and much research is yet to be conducted. The floating pan is basically trying to mimic its surrounding environment, including the evaporation. Although the water surface temperatures of the lake and the floating pan are extremely close, there will be some difference and some type of correction factor is still necessary but a more consistent value can be obtained. Floating pans suffer from problems such as wave action, stability, and water level measurements. Chapter III provides details of the pan design and Chapter IV will discuss alteration needed to the original design.

CHAPTER III
EXPERIMENTAL SETUP

The experimental setup of the floating pan was the most challenging part of this study. There were six issues that were looked at carefully to ensure that the floating evaporation pan would be successful.

The first concern was to make sure that the lake temperature and the pan temperature were equal or extremely close. Robinson (1992) performed a sensitivity analysis of the different parameters of evaporation and the error in the evaporation rate. The parameters investigated were water surface temperature, air temperature, wind speed, and relative humidity. Of the four parameters, water surface temperature had the largest effect on evaporation estimation. When a 3-degree Celsius error was introduced in the water surface temperature, an error of 40% to 90% was found in evaporation rate (Robinson, 1992). This analysis showed how important it was for the water temperature in the lake and pan to be as close as possible, if not equal. Therefore, the pan was submerged low enough in Lake Hartwell to allow the pan's water surface level to be equal to or lower than the lake's water surface, which would ensure heat transfer from the lake only. A 4-foot diameter stainless steel pan was used. It was 18 inches deep and 1/16th of an inch thick, see Figures 3.1, 3.2, and 3.3. The thin metal walls allowed for an easy exchange of heat between the ambient water and the water in the pan through conduction.

Figure 3.1: Stainless Steel Pan (4-ft diameter and 18-inch depth)

Figure 3.2: Stainless Steel Pan (top view)

Figure 3.3: Stainless Steel Pan Thickness

The second issue was the buoyancy of the floatation device. The pan itself was buoyant up to a depth of 16.2 inches of water. However, there was additional equipment that had to be supported and kept out of the water. The pan was also unstable in a wave environment. Therefore, a treated wood frame was constructed with wood strips that were 1.5-inch wide and 0.75-inch thick. The wooden frame was 8 feet by 8 feet with a clear spacing of 1.5 inches between wood strips. The wooden frame had 50% of open area, which allowed the radiation from the sun to hit the water surface of the lake around the pan. The pan was placed in the center of the wooden frame. Since wind speed affects convection and surface mixing, which is a significant part of the evaporation process, the open space of the wooden frame allowed more air movement, similar to the water surface of the lake (Ham, 1999). Figures 3.4, 3.5, and 3.6 shows the wooden frame, the pan opening of the frame, and wood strip spacing.

Figure 3.4: 8-ft x 8-ft Wooden Frame

Figure 3.5: 8-ft x 8-ft Wooden Frame (pan opening)

Figure 3.6: 8-ft x 8-ft Wooden Frame (spacing of wooden boards)

The wooden frame also provided protection against waves and made the pan stable. The buoyancy had to be calculated in order to have the pan water level equal or less then the lake water surface level. The weights considered in the calculation were that of the pan, water in the pan, the meteorological equipment, the wooden frame itself, and the ability for a 200-pound man to walk safely on the wooden frame. Taking into account the buoyancy of the floatation device, it was necessary to attach three metal rods through which the pan could be lowered to a desired level at maximum water level in the pan (see Figures 3.7 and 3.8).

Figure 3.7: Metal Rod Connection to Pan

Figure 3.8: Metal Rods Connected to Pan and Wooden Frame

Considering that the pan will be submerged in a wave environment, a technique had to be developed to measure the average water depth in the pan. Wave action around the pressure transducer could alter the actual depth readings. Therefore, the probe was installed in a circular cylinder (2 inches in diameter and 14 inches in height) at the center of the pan. The cylinder was mounted on a Plexiglas plate and attached to the bottom of the pan. At about an inch from the bottom of the cylinder six equally spaced holes were drilled around the cylinder, as shown in Figures 3.9 and 3.10. These holes allowed the water to enter and fill the cylinder up to the same level as the pan depth; however, the water in the cylinder stayed level and was not affected by the wave action within the pan. At the top of the Plexiglas cylinder was a cap with four 1/16th-inch holes to limit water from splashing into the cylinder and filling with water and affect the depth reading. The pressure transducer was placed at the top of the cylinder and provided accurate changes in water depth in the pan.

Figure 3.9: Plexiglas Cylindrical Measuring Tube

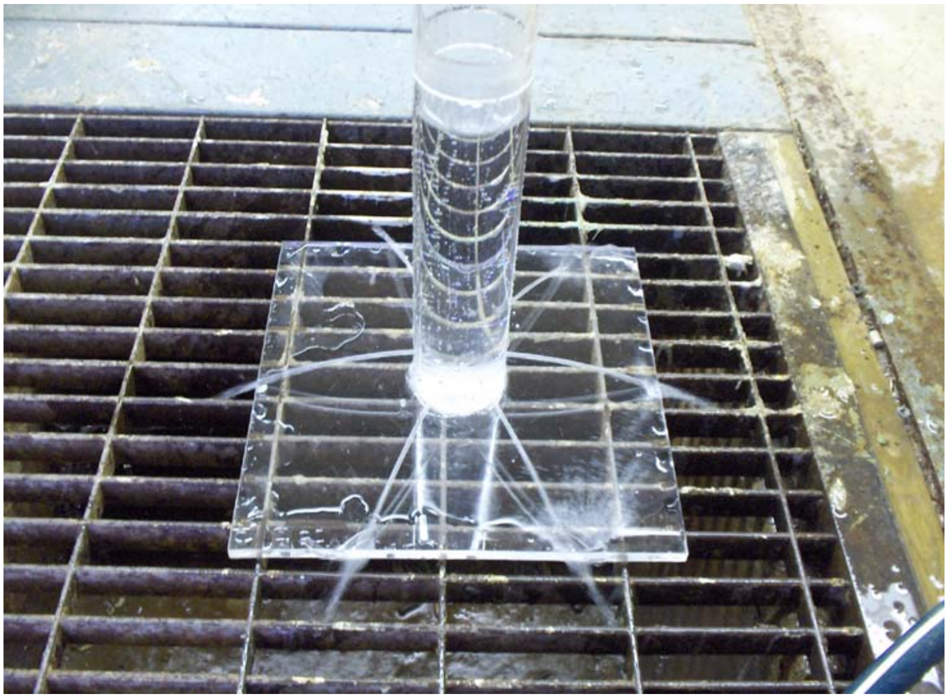


Figure 3.10: Plexiglas Cylindrical Measuring Tube (6 holes at cylinder's bottom)

Figure 3.11: Plexiglas Cylinder Four 1/16th-inch Holes (top view)

For the lake temperature to have a direct effect on the pan's water temperature, a heat conductive material was needed for the pan. Thus, the pan was built using stainless steel. However the portion of the pan above the water level would be exposed to direct radiation from the sun and would heat the water in the pan. Ham (1999) found that the difference in water temperature between the pan and the water body was due to the extended sidewall of the pan not in contact with the water. Therefore, the fourth issue was related to controlling the heat transfer between the wall of the pan exposed to the air and the portion of the pan in the lake. To solve this problem, a light grey linex water proof insulation was used on the upper 4 inches of the pan. The linex coating used would not be in contact with the lake water but only the atmosphere, see Figure 3.11. Also, the maximum water level in the pan was lower than the linex insulation.

Figure 3.12: Light Grey Linex Water Proof Insulation

A device that could be left in the environment without constant monitoring would be the ideal measuring apparatus. Therefore, a system had to be designed to add or remove water automatically from the floating pan in order to control the minimum and maximum depth of water. A two-pump system was devised to overcome the problem. One pump automatically took water out of the pan when the water in the pan became higher than the maximum allowable depth of 12.75 inches. The water was pumped down to 11 inches. The second pump added water to the pan when the depth fell to a level less than the minimum allowable depth of 9.25 inches. Water was pumped into the pan until the depth became 11 inches. The designed depth is at a 1.75 inch range from 11 inches (12.75 inches to 11 inches or a depth of 9.25 inches to 11 inches) to eliminate the possibility of the two pumps running concurrently. The pumps were operated by programming the data logger in conjunction with the water level recorder reading. The pressure transducer was located at the top of the plexiglass cylinder and had a measurement range from 0.75 inches to 4.25 inches, see Figure 3.12, 3.13, and Table 3.1. The initial design had to be changed as discussed in Chapter IV due to error in water level readings.

Figure 3.13: Pump System (top view)

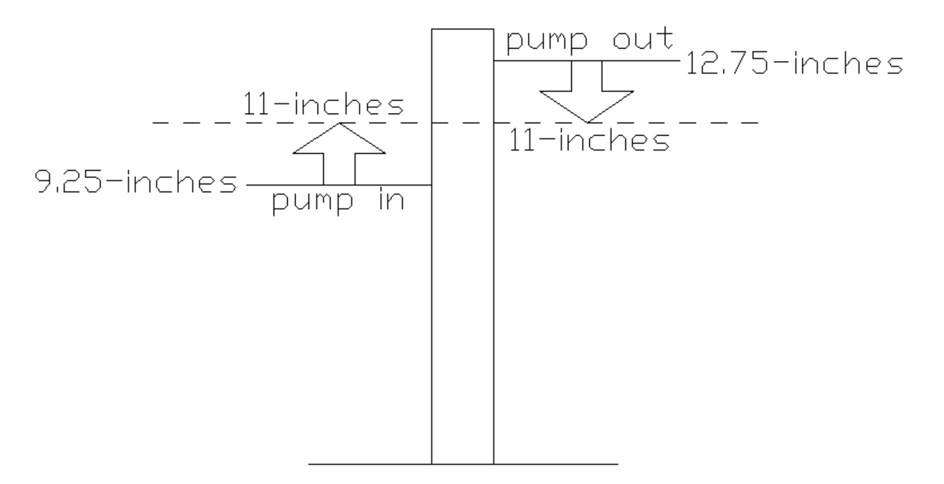


Figure 3.14: Diagram Schematic of Pump in/out Heights of Cylinder

Table 3.1: Pump in/out Heights

Datum	Pump Starts (inches)	Pump Stops (inches)
Bottom of Pan*	> 12.75	< 11
Top of Cylinder**	> 4.25	< 2.5
Bottom of Pan*	< 9.25	> 11
Top of Cylinder**	< 0.75	> 2.5

*Actual height from the bottom of the pan to the top of the pan
**Actual readings and data collected from the pressure transducer

The last problem was the selection of location at which the evaporation station could be installed. The selected site had to be away from the shore in relatively deeper water, away from the trees, and out of the way of boat traffic on the lake. In addition, the accessibility of the site by a boat was also a major concern. After scouting several sites on Lake Hartwell, a site at Clemson University was selected (see Figure 3.14).

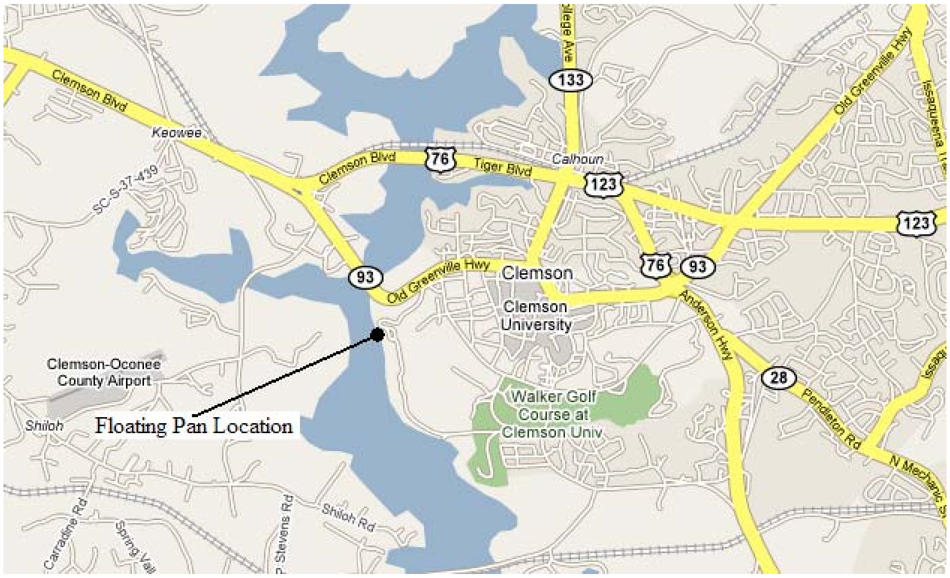


Figure 3.15: Floating Pan Location on Lake Hartwell (©2006 Google- Map data)

As stated earlier the pan was made of stainless steel and was 4 feet in diameter and 18 inches deep. The pan used was deeper than the typical Standard NWS Class-A pans used for overland installation. The increase in the depth of the pan allowed for an increase in the water level range for the two-pump system.

Also mentioned earlier was the 8 feet by 8 feet wooden frame floatation device. This frame has several purposes. The wooden frame allowed for stability of the pan and the entire setup including the electronic equipment. The design of the frame (1.5 inches wide and 0.75 of an inch thick wood strips with the inch and a half spacing between the boards) helped dissipate waves. In addition, it allowed the sunlight hit the lake water surface surrounding the floating pan to accurately mimic the environment around the floating pan. The wood spacing also has the advantage of allowing a similar air movement to that of the lake's water surface. The wooden frame floatation device (including the four black floats, see Figure 3.15) serves as a floating dock for mounting and maintenance of the meteorological and data logging equipment.

Figure 3.16: Black Floating Device

The following meteorological equipment are used are: one pressure transducer to measure the depth of the water in the pan, one anemometer to measure the wind speed at a height of 1 m, one humidity sensor and air temperature sensor also measured at a height of 1 m, and four water temperature sensors. The reason for four water temperature sensors is to find the water temperature gradient of the lake and pan. Two water temperature sensors are for the water surface of the pan and the lake. The other two water temperature sensors are placed about 14-inches from the lake's water surface, one in the pan and one in the lake. The meteorological data will be used in empirical equations to predict evaporation and compare it to the measurements from the pan.

All the meteorological instruments are connected to the data logger. The data logger supplies power to the instruments to take data and records the measurements. The storage space in the data logger allows for continuous operation for several weeks before downloading is necessary. A 12-volt battery is connected to the data logger to supply power to the meteorological equipment. It is recharged by a solar panel. The data logger also controls the two-pump system that maintains a desired water level range in the pan. All of this equipment is above the water surface on the wooden frame, see Figure 3.16.

The final product can be seen in Figure 3.17. The floating pan method will provide a better estimate of lake evaporation than a land based pan as it closely mimics the lake environment. The meteorological equipment attached to the wooden frame allows for comparison between the actual evaporation and those estimated using aerodynamic methods.

Figure 3.17: Data Logger and Electronic Setup

Figure 3.18: Floating Evaporation Pan Complete Setup on Lake Hartwell

CHAPTER IV
DISCUSION OF RESULTS

The purpose of the present study was to develop a more accurate method for measuring evaporation. The main focus of the study was to develop a viable and more accurate alternative to the land based evaporation pan. The ultimate goal is to develop a device that would be able to mimic its surrounding environment and collect accurate data in order to estimate and calculate evaporation.

The first week, middle of August, of data received from the floating evaporation pan agreed with expectations. The time variation of depth in Figure 4.1 illustrates several events occurring in the environment,

1.) Evaporation, with a decrease in water depth

2.) Rain event, with increase in water depth

3.) Pump event, with a sharp increase or decrease of water depth

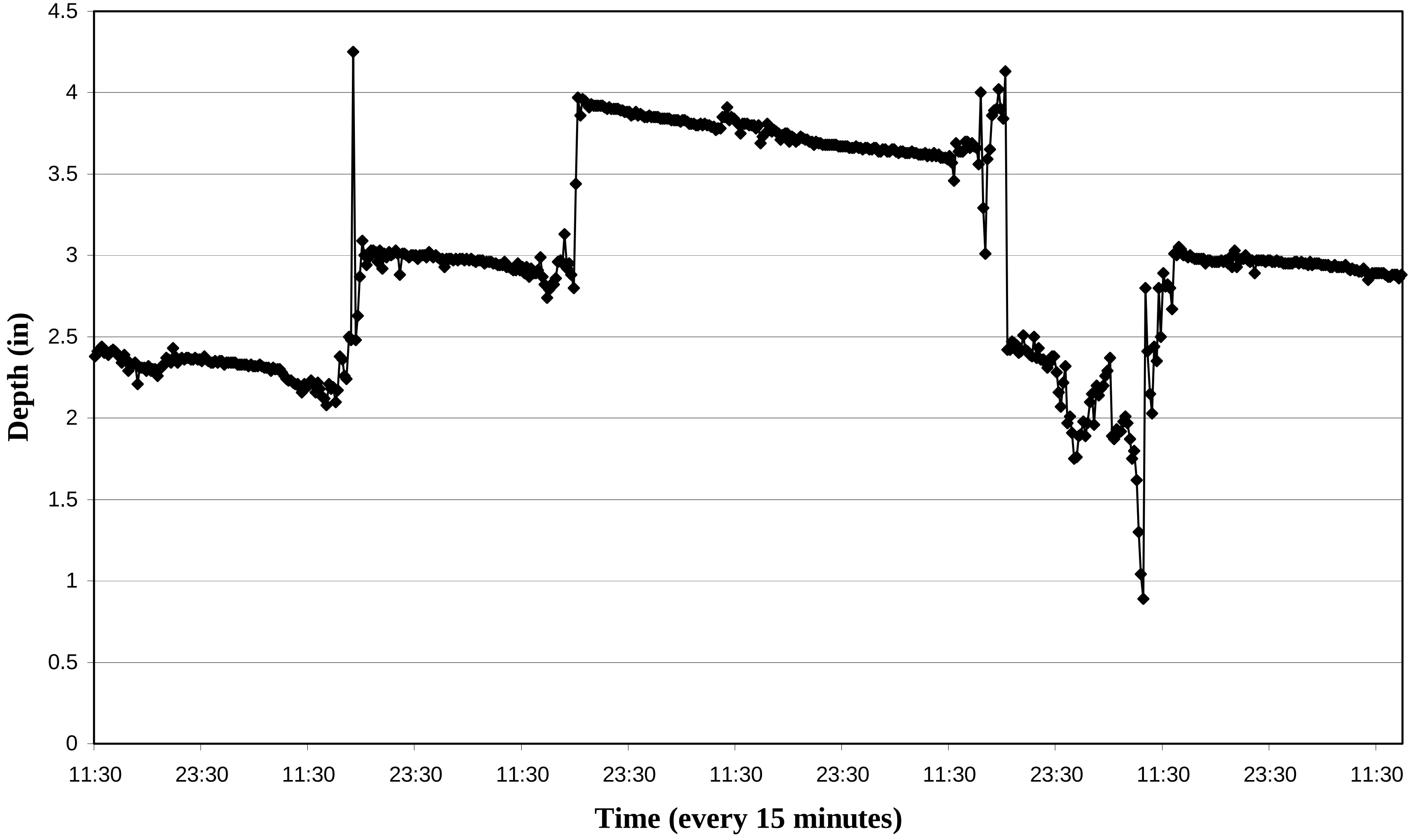
Figure 4.1 Notes:

1.) The measured depth is relative to the bottom of the pressure transducer, it is not the actual depth in the floating pan.

2.) The abscissa is in military time.

3.) The data towards the end of the graph shows oscillation due to a test done on the two-way pump system, in order to make sure the programming worked correctly.

Figure 4.1: Depth of the Flotaing Pan vs. Time (8/18/06 - 8/24/06)



After the first week, the water depth data unknowingly became oscillatory. The following improvements were made to rectify the problem.

1.) Cables were attached to the black floats and tightened to counteract the buoyant force of the floats, which was causing the wooden frame to bow. A leveled floatation device allowed the pan and the depth sensor to be in parallel horizontal planes, see Figure 4.2.

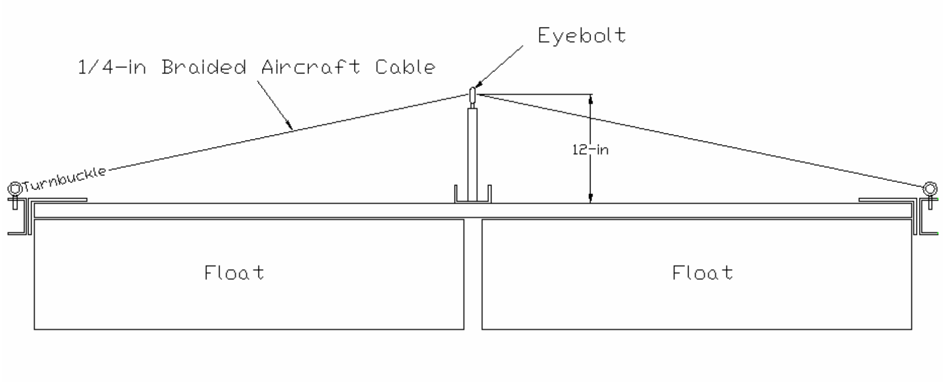


Figure 4.2: Cables to Counteract the Buoyant Force (side view)

2.) A piece of rubber was placed on the pressure transducer and attached to the Plexiglas cylinder to stop the possible threat of the probe moving up and down relative to the Plexiglas cylinder under wave action, thus creating oscillations in data points. This was not found to be the problem and was removed.

3.) The depth sensor has a tube that must be open to the atmosphere to take into account the barometric pressure changes. The barometric tube on the pressure transducer was mounted completely open to the atmosphere and not covered by any material.

4.) The four holes on the top of the Plexiglas were increased from 1/16th of an inch to 1/4th of an inch. The enlargement of the smaller holes was to eliminate surface tension effects within the Plexiglas holes. It was thought that the surface tension was not allowing the water surface in the cylinder to be open to the atmosphere which was creating higher pressure and the possibility of condensation within the Plexiglas cylinder after a rain event or splash from a large wave.

5.) Several elements of the programming of the data logger were changed. The warm up time of the pressure transducer was increased. The instruments were read at different starting times. Unused programs were deleted and over all clean up was conducted to remove any possible errors. Lastly, the pressure transducer was recalibrated.

6.) To eliminate the possibility that the closed portion at the top of the cylinder was causing oscillation, it was removed. The reason for opening the Plexiglas cylinder to the atmosphere is to eliminate the possibility of pressure increase and condensation.

7.) In addition, the pressure transducer was being exposed to two different temperatures, the water and the part of the probe that is exposed to the air. To get a more constant temperature across the probe and to lessen the direct heat of the sun, the pressure transducer was completely submerged. The instrument was recalibrated for the increase in depth and the pumps were reprogrammed to handle the new depth range.

The location of the floating pan was in a higher traffic area of Lake Hartwell than expected which could have resulted in water depth oscillations. It was discovered that when large waves came by the device for a long period of time, it rocked the wooden platform back and forth and caused oscillation with a long wavelength within the cylinder. However, after analyzing the data with respect to temperature it was observed that the pressure transducer was highly sensitive to the temperature change more than the technical manual stated. The water level follows the trends of the daytime and nighttime water temperature, increasing during the day and decreasing through the night. Figure 4.3 represents the first week in September, Figure 4.4 is the data measured in the middle of September, and Figure 4.5 shows data from the beginning of October after all the above changes were completed. Each graph is later in the year than the previous one with a greater water temperature change from the daytime to nighttime hours.

After making the changes discussed above, the final product of the floating pan has been improved. In conclusion, a pressure transducer that corrects for temperature change is needed to accurately measure minute changes in depth. Therefore, the depth data for this study are not available considering the error due to the water level instrument used.

Figure 4.3: Depth of the Floating Pan vs. Time (9/01/06 - 9/06/06)

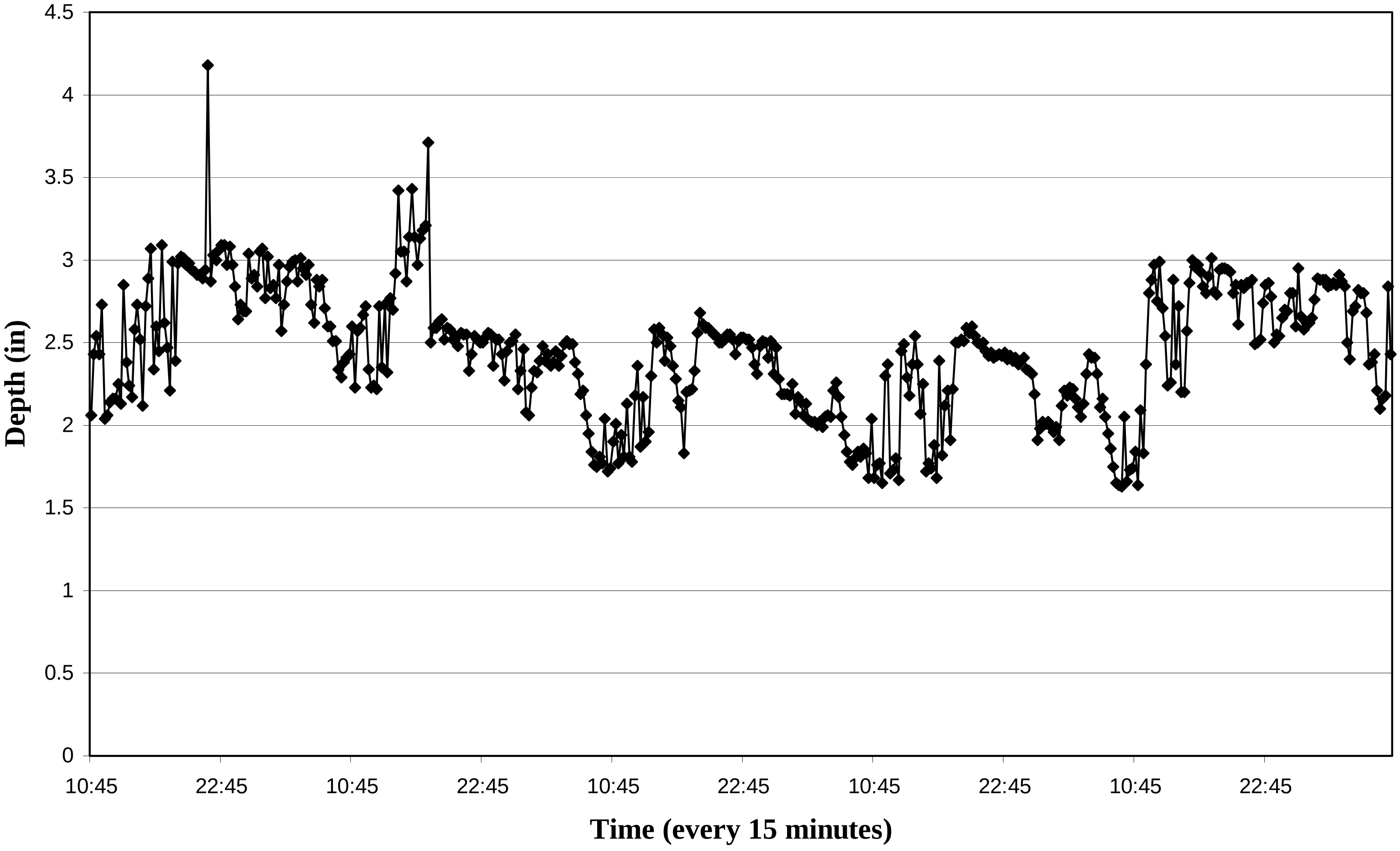


Figure 4.4: Depth of the Floating Pan vs. Time (9/14/06 - 9/18/06)

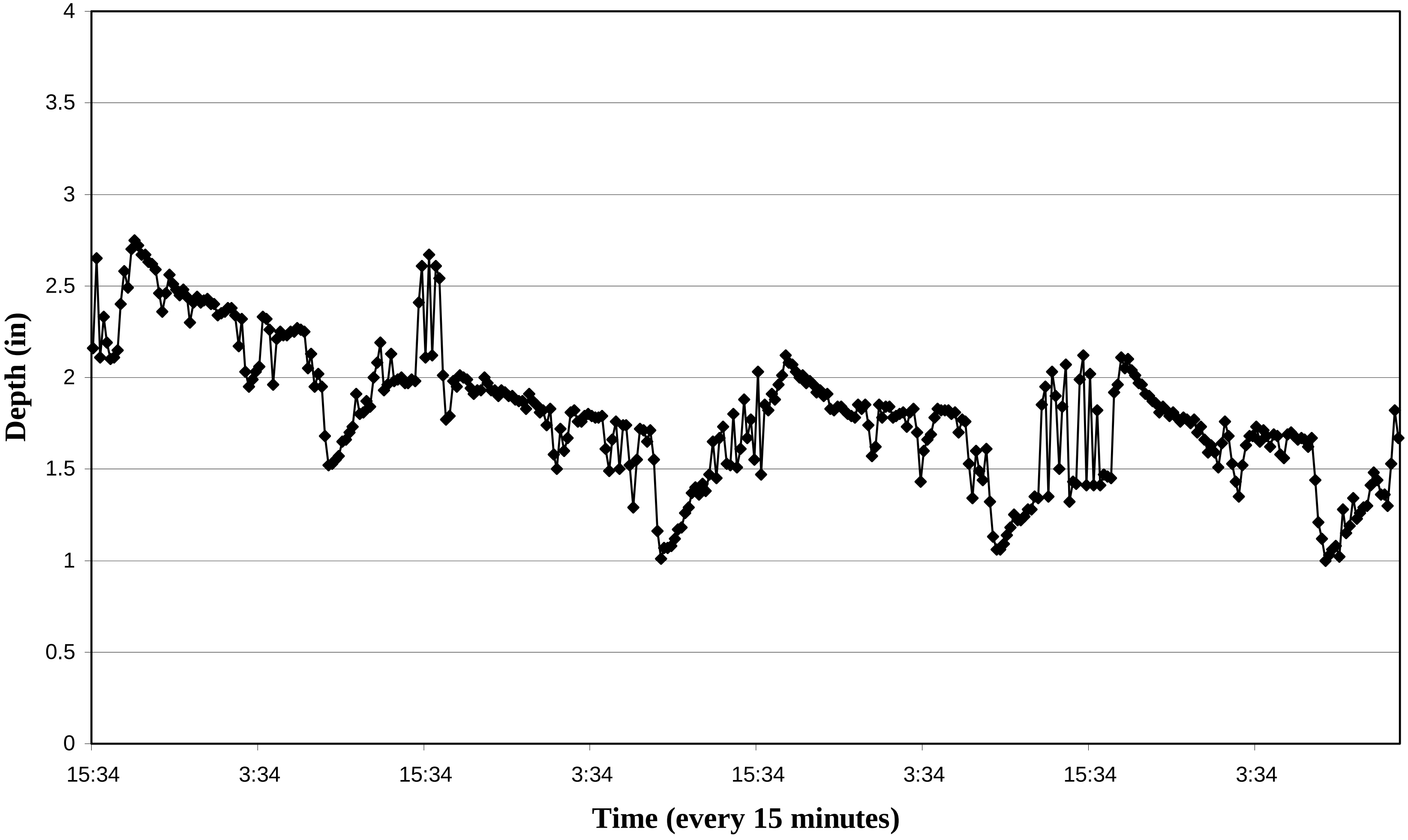
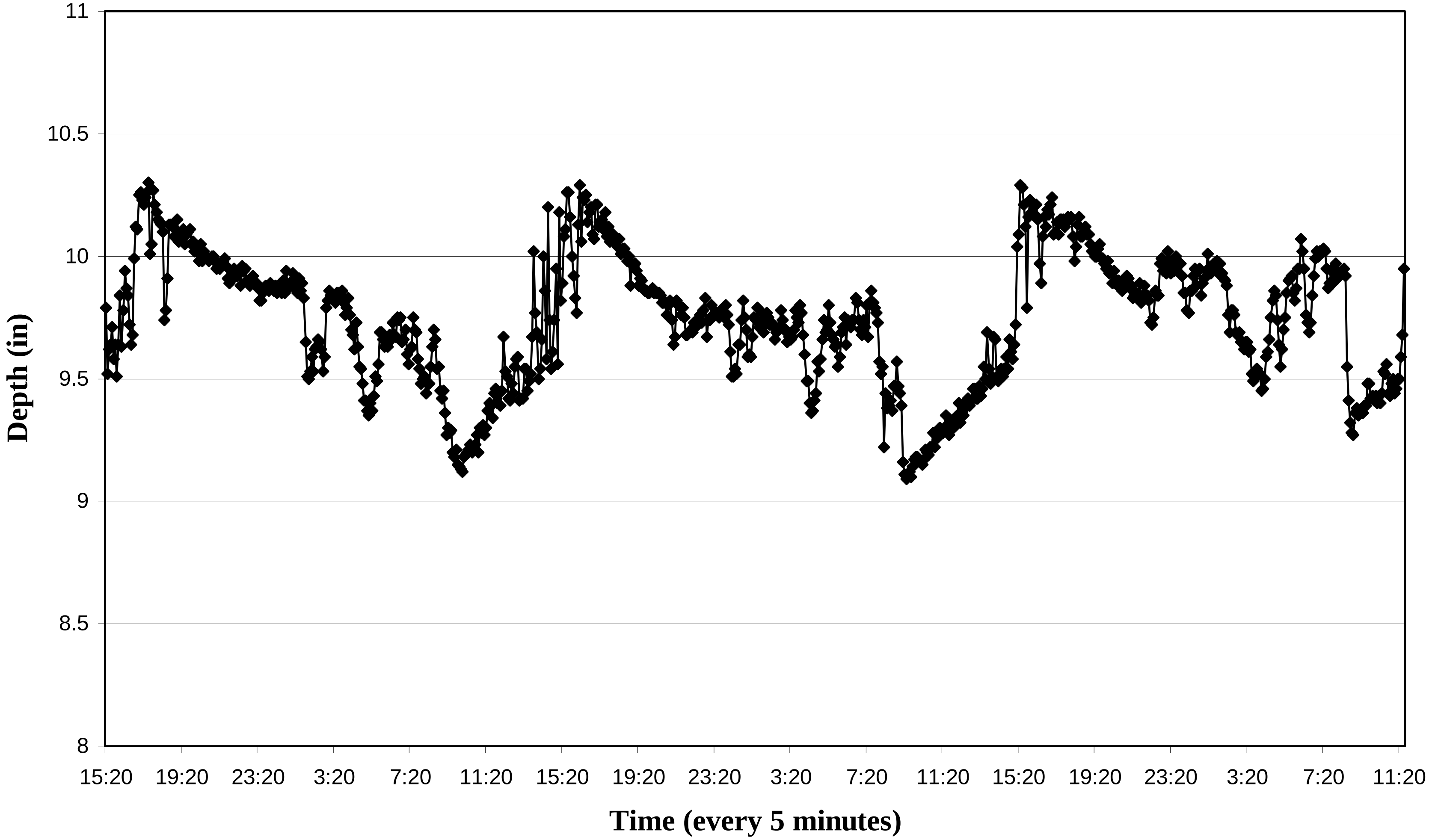


Figure 4.5: Depth of the Floating Pan vs. Time (10/03/06 - 10/06/06)



Another way of assessing the effectiveness of the design of the floating evaporation pan is to look at the temperature of the lake versus the pan. It was stated by Robinson (1992) that the most sensitive parameter of evaporation was the water surface temperature. Therefore, if the water surface temperature of the pan is the same or extremely close to that of the lake's water surface temperature then one of the design objectives will be achieved. Also, since the water in the pan is drawn directly from the lake, the chemical composition of water is same (apart from the times when there is rainfall) and hence the evaporation characteristics of the two water bodies will be similar.

The first set of data, observing Figure 4.6, shows the water surface temperature of the pan and the lake following each other within one or two degrees, except for two locations where the water surface temperature of the pan is closer to the air temperature. Looking at Figure 4.1 and 4.6 it can be noticed that at these two locations the depth was at its lowest point, and the probe measuring the water surface temperature in the pan was outside of the water. To eliminate the problem, the temperature probe was put 0.75 inches below the lowest possible water level of the pan taking into account the water level fluctuation due to wave action.

Figure 4.6: Temperature vs. Time (8/18/06 - 8/24/06)

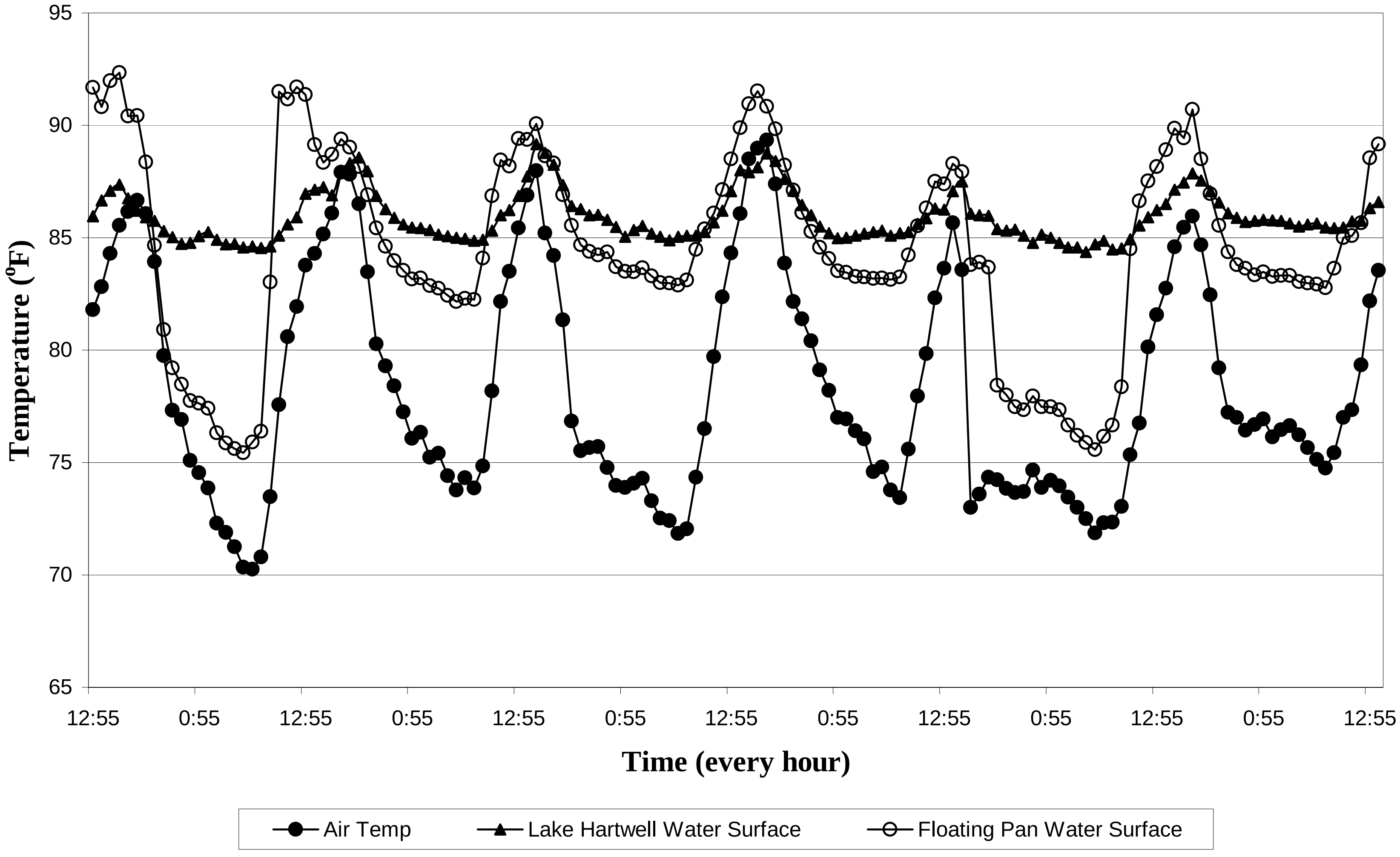


Figure 4.7 and Figure 4.8 are plots of the water surface temperature difference between the lake and the pan for the months of September and October, which can be represented by the expression:

$$\Delta T_{\text{water surface}} = T_{\text{lake}} - T_{\text{pan}} \tag{4.1}$$

Ham (1999) measured a water surface temperature difference as high as 7.2 °F (4 °C) for his floating evaporation pan. For the present floating evaporation pan study, the highest temperature difference for the month of September is 2.75 °F (1.53 °C), which is 62% less than the observation made by Ham (1999). In addition, the largest temperature difference for the month of October is 2.46 °F (1.37 °C), which is 66% less than measured by Ham (1999). The temperature difference of the lake and pan varies depending on the time of the day. Figure 4.9 shows temperature difference variation over a 24 hour period. Ham (1999) calculated an average K_P value of 0.81 for his floating pan. Due to the decrease in temperature difference between the lake and pan water for the present study, there should be an increase in the K_P value.

Figure 4.7: Monthly Water Surface Temperature Difference between Lake Hartwell and the Floating Pan (9/01/06 - 9/30/06)

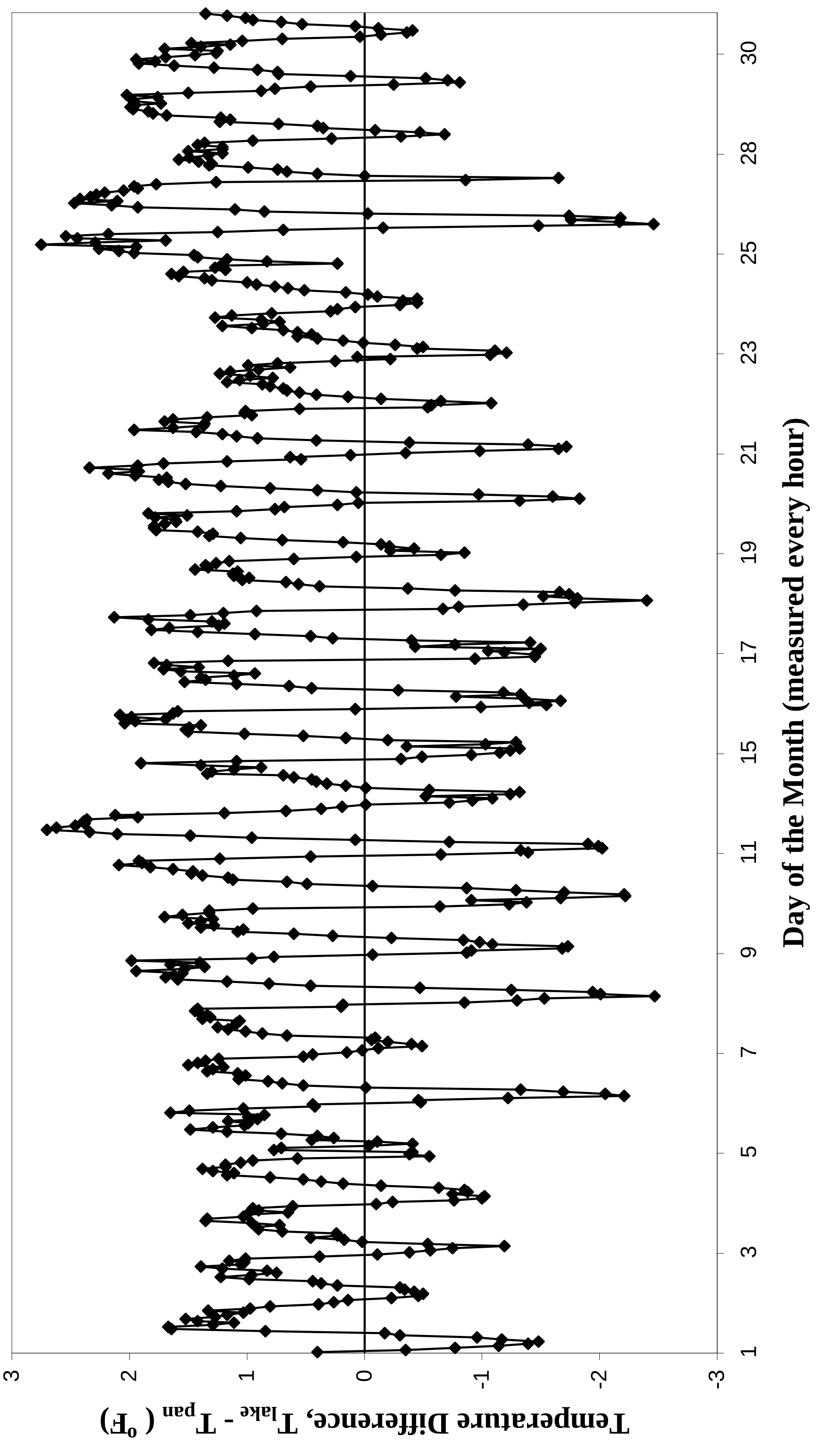


Figure 4.8: Monthly Water Surface Temperature Difference between Lake Hartwell and the Floating Pan (10/01/06 - 10/30/06)

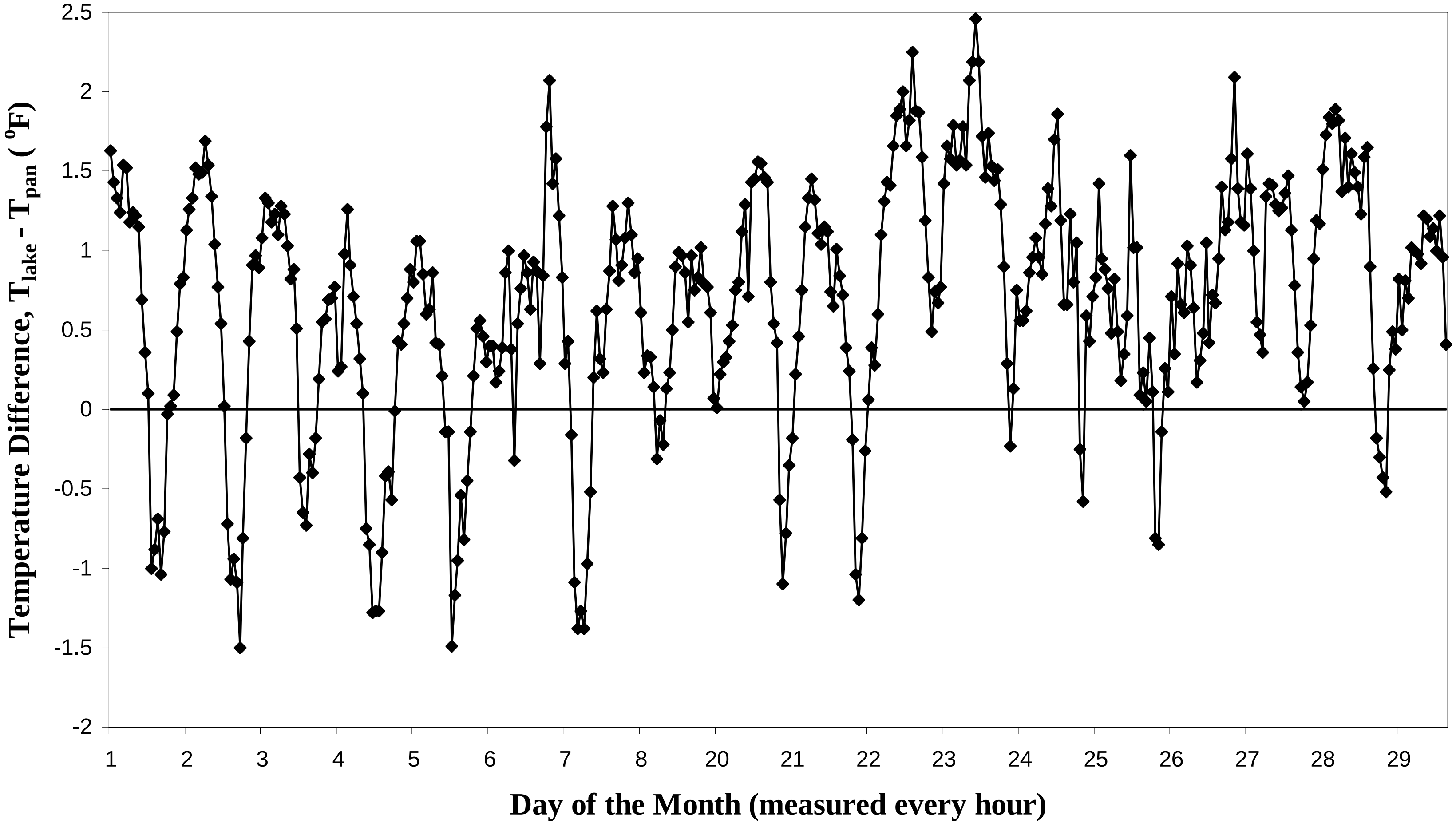
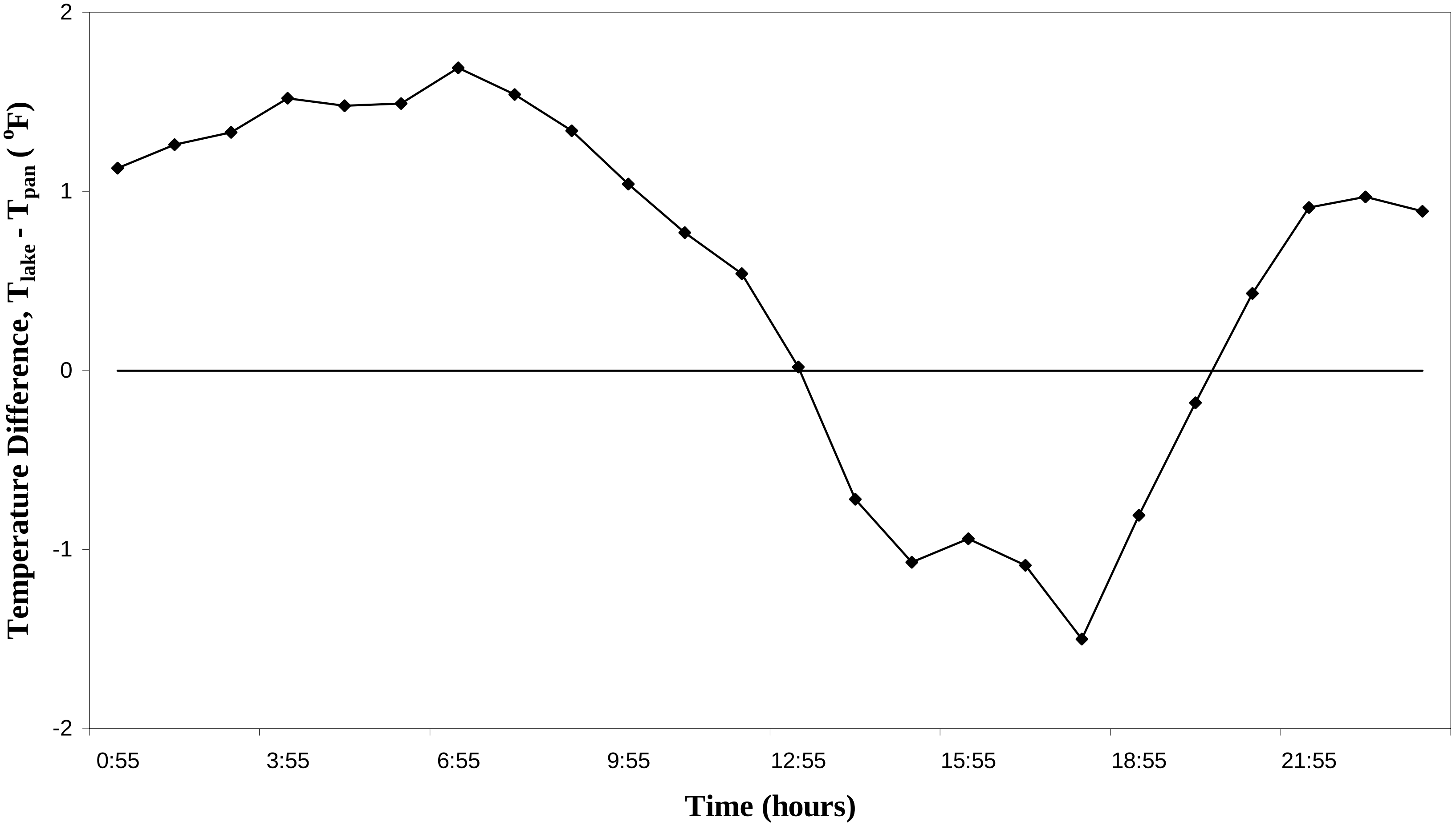


Figure 4.9: Typical 24 Hour Water Surface Temperature Difference between Lake Hartwell and the Floating Pan (10/02/06)



In addition, the daily average temperature differences between Lake Harwell and the floating pan are even closer, with the largest temperature difference in two months equaling only 1.50 °F (0.83 °C) (see Figure 4.10). Also observed is the fact that the daily average temperature of Lake Hartwell is slightly higher than that of the floating pan, which is the opposite of a land based pan. To assess the effect of temperature difference observed in the lake and the floating pan on the evaporation rate, the aerodynamic methods calculations based on the pan and the lake temperatures are carried out with all other factors being the same and are shown in Figure 4.11 and Figure 4.12 (for calculations see Tables A.1 to D.2 in the appendix). The two figures show that Sill (1983) method of estimating evaporation rate is slightly more sensitive to temperature difference than the bulk aerodynamic transfer method.

Figure 4.10: Daily Average Temperature Difference between Lake Hartwell and the Floating Pan

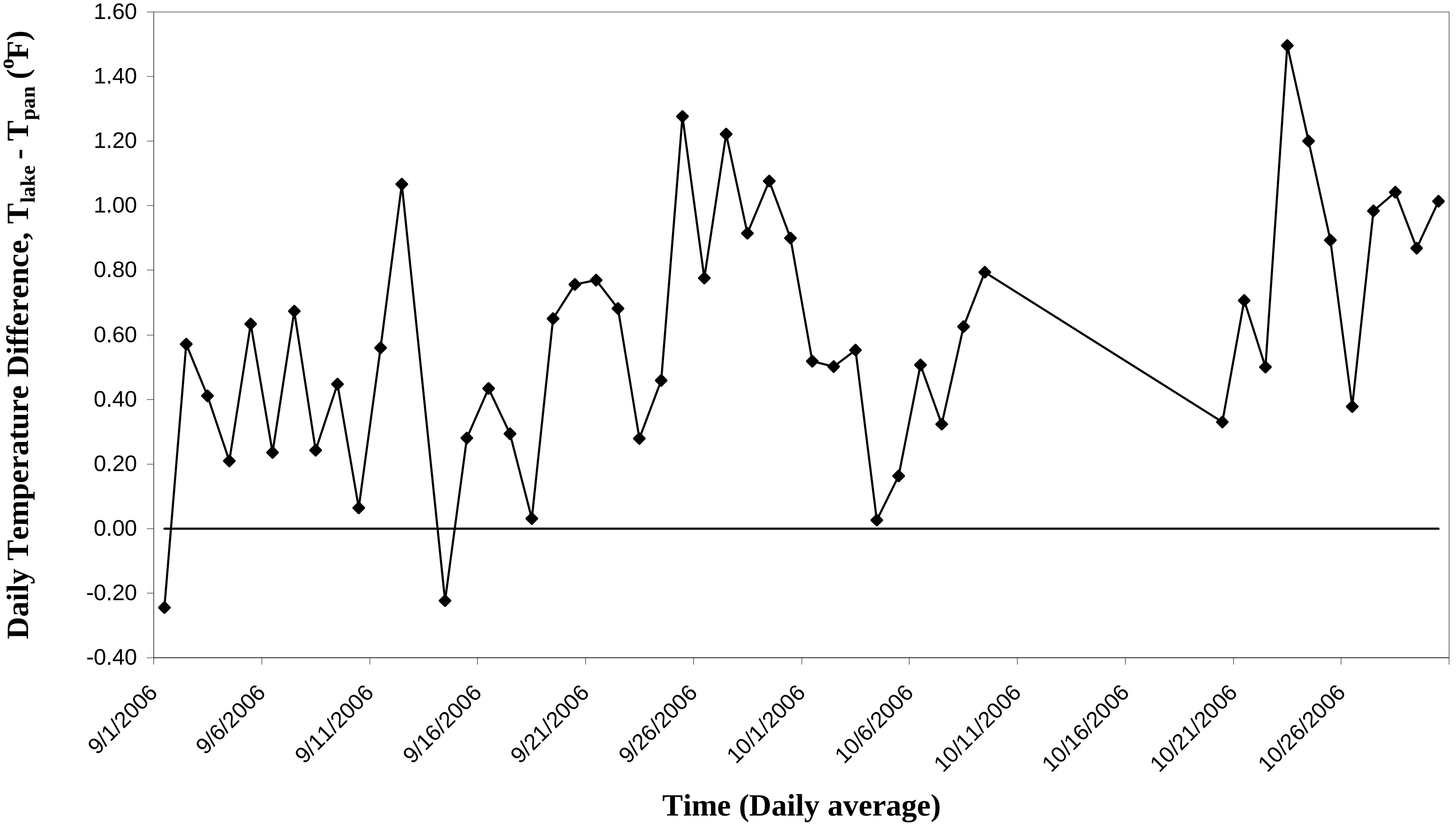


Figure 4.11: Bulk Aerodynamic Transfer Method, Daily Evaporation Difference between Lake Hartwell and the Floating Pan for September and October

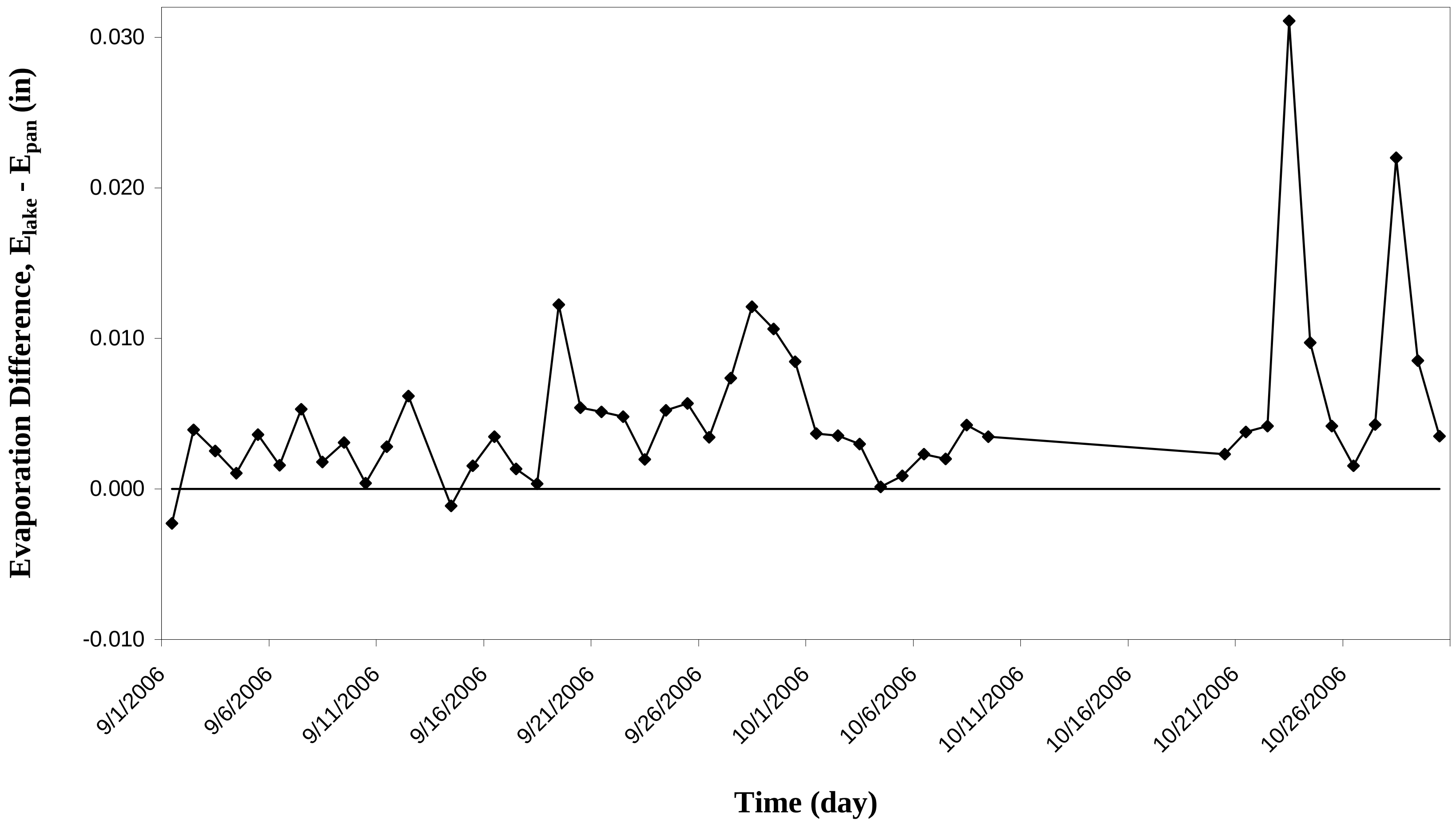
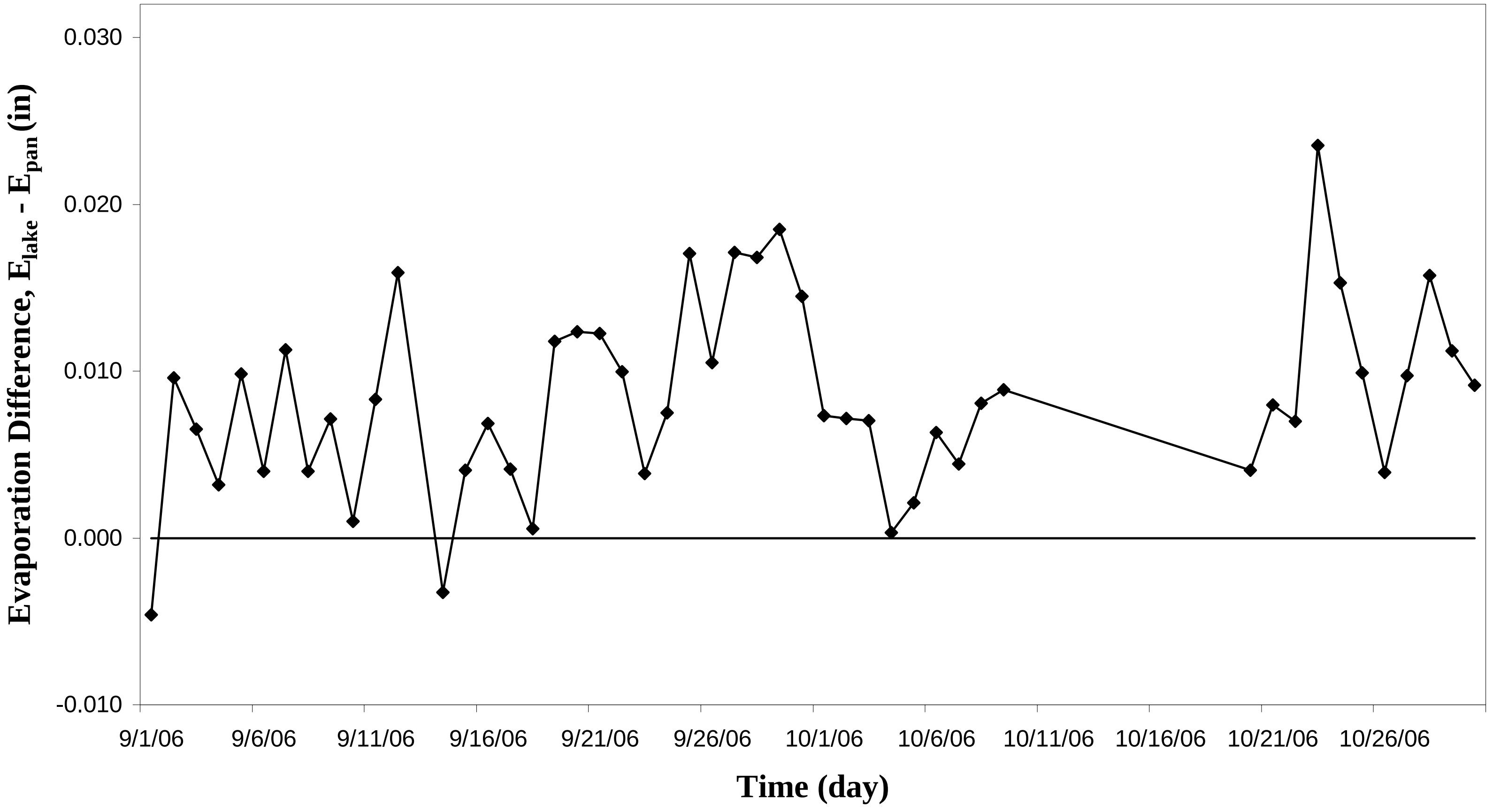


Figure 4.12: Sill (1983) Method, Daily Evaporation Difference between Lake Hartwell and the Floating Pan for September and October



Purvis (1992) stated in a report prepared for the South Carolina Department of Natural Resources (SCDNR) that the National Climatic Data Center (NCDC) had been measuring evaporation with the National Weather Service's Class-A evaporation pan since 1950. Evaporation data for the Clemson, SC area is available and has been analyzed for a 42-year period from 1950 to 1992. The present study had several missing days in the months of September and October due to modifications of the floating pan design. Therefore, the SCDNR mean daily evaporation values for the month of September and October averaged over the period of 42 years are compared with the mean daily evaporation values estimated by the two aerodynamic methods. From Table 4.1, it is clear that Sill (1983) method compares well with 42-year average pan data. The averaged daily evaporation data for the months of September and October for the year 2006, as reported by Linville (2006), was also compared with the two aerodynamic methods. As shown in Table 4.1, Sill (1983) method performs better in this case also.

Table 4.1: Daily Lake Evaporation Calculation Summary

	(in/day)		
Month	**Sill (1983) Method**	**Clemson SCDNR Class-A Pan (42 year average)**	**Difference**
September	0.164	0.156	0.008
October	0.147	0.121	0.026
Month	**Bulk Aerodynamic Transfer Method**	**Clemson SCDNR Class-A Pan (42 year average)**	**Difference**
September	0.103	0.156	-0.053
October	0.119	0.121	-0.002
Month	**Sill (1983) Method**	**Clemson Class-A Pan (2006)**	**Difference**
September	0.164	0.146	0.018
October	0.147	0.117	0.03
Total	0.311	0.263	0.048
Month	**Bulk Aerodynamic Transfer Method**	**Clemson Class-A Pan (2006)**	**Difference**
September	0.103	0.146	-0.043
October	0.119	0.117	0.002
Month	**Clemson SCDNR Class-A Pan (42 year average)**	**Clemson Class-A Pan (2006)**	**Difference**
September	0.156	0.146	0.01
October	0.121	0.117	0.004
Month	**Sill (1983) Method**	**Bulk Aerodynamic Transfer Method**	**Difference**
September	0.164	0.103	0.061
October	0.147	0.119	0.028

Figure 4.13 shows the water level measurements in the floating pan from 8/18/06 to 8/26/06, where the recorded data was reliable. This set of water level data was compared to the two aerodynamic methods. The data were categorized into six different time periods, see Figure 4.13. For each time period the difference in water level was calculated to find the evaporation, see Table 4.2. In addition, average meteorological data was computed for each period and the evaporation from the two aerodynamic methods was calculated (Table E.1 and F.1 in the appendix). The results of the evaporation calculations show that the Sill (1983) method provides a better estimate. The average ratio of the estimated evaporation of the Sill (1983) method to the floating pan evaporation is close to one (see Table 4.3). Although the evaporation estimates concur fairly well with the floating pan evaporation, there needs to be more data recorded over a longer time frame. Due to problems with the water level recorder, a sufficient amount of data was not available for a concrete analysis. However, in summary the Sill (1983) method seems to estimate evaporation relatively close to the SCDNR Class-A Pan and the evaporation recorded from the floating evaporation pan.

Figure 4.13: Depth of the Flotaing Pan vs. Time (8/18/06 - 8/26/06)

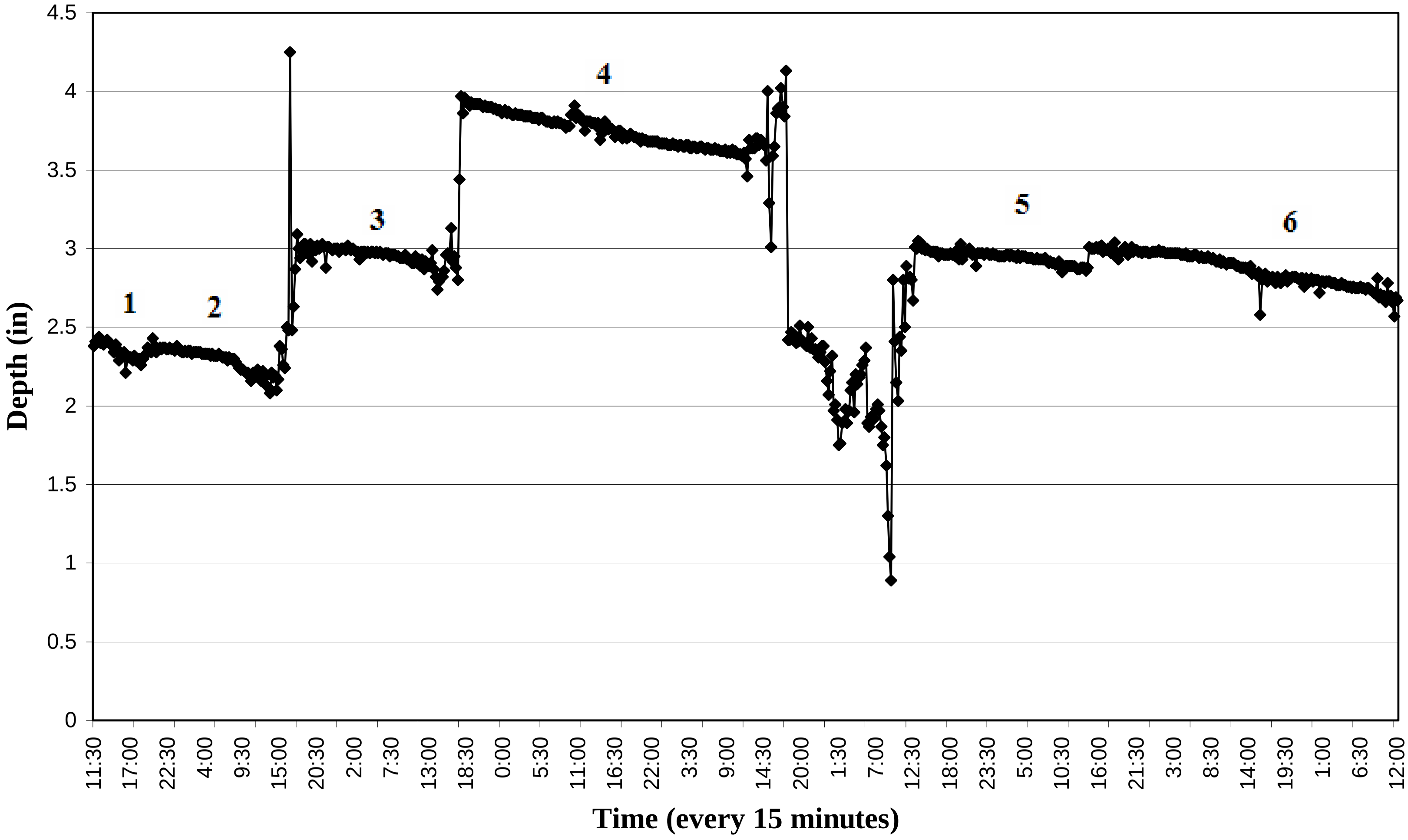


Table 4.2: Calculated Evaporation from Floating Pan (8/18/06 – 8/26/06)

	Point 1		**Point 2**			
Evap. Interval	**Starting Time**	**Depth (in)**	**Ending Time**	**Depth (in)**	**E_{actual} (in)**	**Total hrs**
1	11:45	2.41	18:30	2.26	0.15	6.75
2	20:15	2.43	13:30	2.08	0.35	17.25
3	17:30	3.09	13:45	2.87	0.22	20.25
4	17:45	3.97	11:45	3.57	0.4	32
5	13:15	3.05	14:15	2.88	0.17	25
6	16:00	3.01	12:00	2.67	0.34	44

Note: Refer to Graph 4.13 to find the total time period of each section.

Table 4.3: Calculated Aerodynamic Method vs. Floating Pan Evaporation (8/18/06 – 8/26/06)

		(in/section time)		
Evap. Interval	**Time Interval (hrs)**	**Sill (1983) Method**	**$E_{flaoting\ pan}$**	**E_{Sill}/ $E_{floating\ pan}$**
1	6.75	0.127	0.15	1.18
2	17.25	0.111	0.35	3.16
3	20.25	0.157	0.22	1.40
4	32	0.283	0.4	1.41
5	25	0.201	0.17	0.85
6	44	0.397	0.34	0.86
			Average =	**1.48**
		(in/section time)		
Evap. Interval	**Time Interval (hrs)**	**Bulk Aerodynamic Transfer Method**	**$E_{flaoting\ pan}$**	**$E_{B.A.T.}$/ $E_{floating\ pan}$**
1	6.75	0.079	0.15	1.89
2	17.25	0.041	0.35	8.48
3	20.25	0.063	0.22	3.50
4	32	0.116	0.4	3.46
5	25	0.076	0.17	2.22
6	44	0.148	0.34	2.29
			Average =	**3.64**

CHAPTER V
CONCLUSION

The floating evaporation pan design for the present study captures several features of Lake Hartwell's environment. The water surface temperature is one of the major parameters of evaporation that affects the amount of error in estimating evaporation.

The water surface temperature difference between the lake and the pan in the present study is reduced over 60% compared to Ham's (1999) study. Considering that the floating pan and Lake Hartwell's water surface temperatures are similar allows the assumption that the design is successful in obtaining one of the major objectives of the study. In addition, the chemical composition of the water in the pan and the lake is the same because the pan water is drawn from the lake.

Although the pressure transducer eventually failed in measuring the depth because of temperature sensitivity, the first week of data shows a good representation of the device working as expected. Overall the design of the device was successful in mimicking the characteristics of the lake, mainly the water surface temperature.

Of the two methods studied the evaporation measured by Sill (1983) method correlates better with the data obtained from the SCDNR Class-A evaporation pan and the floating pan. However, until the evaporation has been measured accurately with the floating pan for an extended period of time, the best method for measuring evaporation cannot be determined from this study.

Suggestions for Future Study

The floating evaporation pan was able to reproduce water surface temperature similar to that of Lake Hartwell. The following recommendations are provided for future modifications of the floating evaporation pan.

The floating pan was able to obtain one of the major parameters of evaporation, the water surface temperature of the lake. However, it is suggested to investigate the impact of wind speed modifications due to the floating pan and the wooden platform. The wooden platform is approximately eight inches above the water surface in the lake and the water surface in the pan is 4 to 6 inches lower than the top of the pan. Therefore, the wind speed over the water surface in the pan is different than that over a lake surface and a correction factor for the wind speed relative to the water surface of the lake should be determined.

To eliminate large wave action within the floating evaporation pan it is suggested that the floating device be put at a low traffic site. There will always be a possibility of waves disrupting the data; however, limiting that issue from the beginning can help reduce other problems from occurring.

The wooden frame did start to warp. Since this study is conducted in a harsh environment, a frame consisting of more metal may hold the original shape of the floating device better. Ham (1999) used an entire metal frame for his floating evaporation pan and the water surface temperature of the floating pan was higher than the water surface temperature of the water body. A mixture of wood and metal would be recommended to allow normal heat transfer and a solid frame.

In addition to the frame, it may be useful to create some type of apparatus that may aid in the dissipation of waves outside of the floating pan. Lessening the wave action will lower the chance of water splashing into the floating pan and altering the depth measurement.

Evaporation relies on accurate measurements of water level. The current instrument is sensitive to the temperature and the water level measurements cannot be relied upon. Other types of instruments with lower temperature sensitivity should be considered for water level measurements. For example, another option for measuring depth is by a floating device in a stilling well outside the pan.

Evaporation is an important process in the hydrological cycle and is an integral part of the water budget calculations. Accurate estimates of evaporation will help develop an effective water management plan.

APPENDICES

Appendix A

Bulk Aerodynamic Method Calculations for Lake Hartwell in the Month of September and October

Table A.1: Bulk Aerodynamic Method Calculations for Lake Hartwell in the Month of September

Date	T_a (°C)	$T_{W Lake}$ (°C)	RH (%)	U_r (m/s)	$e^*_{T W Lake}$ (kPa)	e^*_{Ta} (kPa)	e_a (kPa)	$(e^*_s - e_a)$ (kPa)	E_{lake} (mm/day)	E_{lake} (in/day)
9/1/2006	25.22	30.18	76.89	1.02	4.29	3.21	2.47	1.82	3.23	0.127
9/2/2006	23.31	29.79	86.17	0.77	4.19	2.86	2.47	1.73	2.32	0.091
9/3/2006	24.77	29.70	83.92	0.70	4.17	3.12	2.62	1.55	1.88	0.074
9/4/2006	25.36	29.78	82.83	0.57	4.19	3.24	2.68	1.51	1.49	0.059
9/5/2006	22.65	29.18	91.01	0.66	4.05	2.75	2.50	1.54	1.77	0.070
9/6/2006	23.40	29.43	78.26	0.77	4.11	2.88	2.25	1.85	2.48	0.098
9/7/2006	22.31	28.72	84.19	0.94	3.94	2.69	2.27	1.67	2.73	0.108
9/8/2006	23.55	28.78	79.93	0.87	3.96	2.90	2.32	1.63	2.48	0.098
9/9/2006	23.29	28.70	82.20	0.82	3.94	2.86	2.35	1.59	2.27	0.089
9/10/2006	24.16	28.91	79.13	0.70	3.99	3.01	2.38	1.60	1.96	0.077
9/11/2006	23.16	28.03	74.02	0.62	3.79	2.84	2.10	1.69	1.82	0.072
9/12/2006	20.84	27.44	80.39	0.74	3.66	2.46	1.98	1.68	2.16	0.085
9/14/2006	23.38	27.57	72.97	0.62	3.69	2.87	2.10	1.59	1.71	0.067
9/15/2006	21.91	26.98	74.00	0.70	3.56	2.63	1.95	1.62	2.00	0.079
9/16/2006	22.04	27.42	81.07	1.00	3.65	2.65	2.15	1.50	2.64	0.104
9/17/2006	22.89	27.79	78.84	0.56	3.73	2.79	2.20	1.53	1.51	0.059
9/18/2006	22.95	27.55	87.39	1.44	3.68	2.80	2.45	1.23	3.11	0.122
9/19/2006	23.45	27.65	79.28	2.34	3.70	2.89	2.29	1.42	5.80	0.228
9/20/2006	19.38	26.98	67.40	0.93	3.56	2.25	1.52	2.04	3.33	0.131
9/21/2006	17.19	26.25	67.30	0.90	3.41	1.96	1.32	2.09	3.32	0.131
9/22/2006	20.57	26.28	81.58	0.94	3.42	2.42	1.98	1.44	2.38	0.094
9/23/2006	23.51	26.89	86.40	0.91	3.54	2.90	2.50	1.04	1.65	0.065
9/24/2006	22.99	26.90	91.02	1.46	3.54	2.81	2.55	0.99	2.53	0.099
9/25/2006	19.23	26.36	86.16	0.60	3.43	2.23	1.92	1.51	1.59	0.062
9/26/2006	18.94	26.01	79.11	0.60	3.36	2.19	1.73	1.63	1.72	0.068
9/27/2006	18.35	25.83	86.83	0.83	3.33	2.11	1.83	1.49	2.18	0.086
9/28/2006	18.69	25.94	82.12	1.81	3.35	2.16	1.77	1.58	5.01	0.197
9/29/2006	15.98	25.49	68.55	1.39	3.26	1.82	1.24	2.02	4.95	0.195
9/30/2006	16.31	24.98	79.76	1.34	3.16	1.85	1.48	1.69	4.00	0.157

Table A.2: Bulk Aerodynamic Method Calculations for Lake Hartwell in the Month of October

Date	T_a (°C)	$T_{W\ Lake}$ (°C)	RH (%)	U_r (m/s)	$e^*_{T\ W\ Lake}$ (kPa)	e^*_{Ta} (kPa)	e_a (kPa)	$e^*_s - e_a$ (kPa)	E_{lake} (mm/day)	E_{lake} (in/day)
10/1/2006	20.38	25.45	78.82	0.99	3.25	2.39	1.89	1.37	2.37	0.093
10/2/2006	20.00	25.44	77.91	0.98	3.25	2.34	1.82	1.43	2.46	0.097
10/3/2006	20.01	25.28	87.24	0.75	3.22	2.34	2.04	1.18	1.57	0.062
10/4/2006	21.45	25.53	84.19	0.79	3.27	2.56	2.15	1.12	1.55	0.061
10/5/2006	21.91	25.91	81.76	0.72	3.34	2.63	2.15	1.19	1.51	0.059
10/6/2006	19.77	24.74	76.40	0.65	3.12	2.31	1.76	1.36	1.56	0.062
10/7/2006	15.76	23.64	71.75	0.94	2.92	1.79	1.28	1.64	2.73	0.107
10/8/2006	17.14	23.18	80.81	1.05	2.84	1.95	1.58	1.26	2.35	0.093
10/9/2006	16.96	22.85	85.04	0.69	2.78	1.93	1.64	1.14	1.40	0.055
10/20/2006	16.55	21.16	68.98	1.21	2.51	1.88	1.30	1.21	2.62	0.103
10/21/2006	12.96	20.54	78.19	0.96	2.42	1.49	1.17	1.25	2.14	0.084
10/22/2006	14.80	20.63	80.13	1.47	2.43	1.68	1.35	1.08	2.85	0.112
10/23/2006	9.48	19.45	57.75	3.99	2.26	1.19	0.68	1.58	11.30	0.445
10/24/2006	7.62	18.61	60.69	1.62	2.14	1.05	0.63	1.51	4.41	0.174
10/25/2006	7.27	19.13	73.02	0.91	2.22	1.02	0.75	1.47	2.40	0.094
10/26/2006	11.57	19.43	70.57	0.77	2.26	1.36	0.96	1.29	1.79	0.071
10/27/2006	11.93	19.61	93.96	0.81	2.28	1.40	1.31	0.97	1.42	0.056
10/28/2006	14.96	20.12	65.58	3.86	2.36	1.70	1.12	1.24	8.59	0.338
10/29/2006	14.37	19.15	54.58	1.89	2.22	1.64	0.89	1.32	4.51	0.177
10/30/2006	10.79	18.62	92.54	0.68	2.15	1.29	1.20	0.95	1.16	0.046

Appendix B

Bulk Aerodynamic Method Calculations for the Floating Pan in the Month of September and October

Table B.1: Bulk Aerodynamic Method Calculations for the Floating Pan in the Month of September

Date	T_a (^oC)	$T_{W\ Pan}$ (^oC)	RH (%)	U_r (m/s)	$e^*_{T\ W\ pan}$ (kPa)	e^*_{Ta} (kPa)	e_a (kPa)	(e^*_s - e_a) (kPa)	E_{pan} (mm/day)	E_{pan} (in/day)
9/1/2006	25.22	30.31	76.89	1.02	4.32	3.21	2.47	1.85	3.28	0.129
9/2/2006	23.31	29.48	86.17	0.77	4.12	2.86	2.47	1.65	2.22	0.087
9/3/2006	24.77	29.47	83.92	0.70	4.12	3.12	2.62	1.49	1.81	0.071
9/4/2006	25.36	29.66	82.83	0.57	4.16	3.24	2.68	1.48	1.47	0.058
9/5/2006	22.65	28.83	91.01	0.66	3.97	2.75	2.50	1.46	1.68	0.066
9/6/2006	23.40	29.30	78.26	0.77	4.08	2.88	2.25	1.82	2.44	0.096
9/7/2006	22.31	28.34	84.19	0.94	3.86	2.69	2.27	1.59	2.60	0.102
9/8/2006	23.55	28.65	79.93	0.87	3.92	2.90	2.32	1.60	2.43	0.096
9/9/2006	23.29	28.45	82.20	0.82	3.88	2.86	2.35	1.53	2.19	0.086
9/10/2006	24.16	28.88	79.13	0.70	3.98	3.01	2.38	1.59	1.95	0.077
9/11/2006	23.16	27.72	74.02	0.62	3.72	2.84	2.10	1.62	1.75	0.069
9/12/2006	20.84	26.85	80.39	0.74	3.53	2.46	1.98	1.55	2.01	0.079
9/14/2006	23.38	27.69	72.97	0.62	3.71	2.87	2.10	1.61	1.74	0.069
9/15/2006	21.91	26.83	74.00	0.70	3.53	2.63	1.95	1.58	1.96	0.077
9/16/2006	22.04	27.18	81.07	1.00	3.60	2.65	2.15	1.45	2.55	0.101
9/17/2006	22.89	27.62	78.84	0.56	3.70	2.79	2.20	1.50	1.47	0.058
9/18/2006	22.95	27.53	87.39	1.44	3.68	2.80	2.45	1.23	3.10	0.122
9/19/2006	23.45	27.29	79.28	2.34	3.63	2.89	2.29	1.34	5.49	0.216
9/20/2006	19.38	26.56	67.40	0.93	3.47	2.25	1.52	1.96	3.20	0.126
9/21/2006	17.19	25.82	67.30	0.90	3.33	1.96	1.32	2.01	3.19	0.126
9/22/2006	20.57	25.90	81.58	0.94	3.34	2.42	1.98	1.37	2.26	0.089
9/23/2006	23.51	26.73	86.40	0.91	3.51	2.90	2.50	1.01	1.60	0.063
9/24/2006	22.99	26.65	91.02	1.46	3.49	2.81	2.55	0.94	2.39	0.094
9/25/2006	19.23	25.65	86.16	0.60	3.29	2.23	1.92	1.37	1.44	0.057
9/26/2006	18.94	25.57	79.11	0.60	3.28	2.19	1.73	1.55	1.63	0.064
9/27/2006	18.35	25.15	86.83	0.83	3.20	2.11	1.83	1.36	1.99	0.078
9/28/2006	18.69	25.43	82.12	1.81	3.25	2.16	1.77	1.48	4.71	0.185
9/29/2006	15.98	24.89	68.55	1.39	3.15	1.82	1.24	1.90	4.68	0.184
9/30/2006	16.31	24.48	79.76	1.34	3.07	1.85	1.48	1.59	3.78	0.149

Table B.2: Bulk Aerodynamic Method Calculations for the Floating Pan in the Month of October

Date	**T_a (^oC)**	**$T_{W\ Pan}$ (^oC)**	**RH (%)**	**U_r (m/s)**	**$e^*_{T\ W\ pan}$ (kPa)**	**e^*_{Ta} (kPa)**	**e_a (kPa)**	**(e^*_s - e_a) (kPa)**	**E_{pan} (mm/day)**	**E_{pan} (in/day)**
10/1/2006	20.38	25.16	78.82	0.99	3.20	2.39	1.89	1.31	2.28	0.090
10/2/2006	20.00	25.16	77.91	0.98	3.20	2.34	1.82	1.38	2.37	0.093
10/3/2006	20.01	24.97	87.24	0.75	3.16	2.34	2.04	1.12	1.49	0.059
10/4/2006	21.45	25.52	84.19	0.79	3.27	2.56	2.15	1.11	1.54	0.061
10/5/2006	21.91	25.82	81.76	0.72	3.33	2.63	2.15	1.18	1.49	0.059
10/6/2006	19.77	24.45	76.40	0.65	3.07	2.31	1.76	1.30	1.50	0.059
10/7/2006	15.76	23.46	71.75	0.94	2.89	1.79	1.28	1.60	2.67	0.105
10/8/2006	17.14	22.83	80.81	1.05	2.78	1.95	1.58	1.20	2.24	0.088
10/9/2006	16.96	22.41	85.04	0.69	2.71	1.93	1.64	1.07	1.31	0.052
10/20/2006	16.55	20.97	68.98	1.21	2.48	1.88	1.30	1.18	2.56	0.101
10/21/2006	12.96	20.15	78.19	0.96	2.36	1.49	1.17	1.19	2.04	0.080
10/22/2006	14.80	20.35	80.13	1.47	2.39	1.68	1.35	1.04	2.74	0.108
10/23/2006	9.48	18.62	57.75	3.99	2.15	1.19	0.68	1.46	10.51	0.414
10/24/2006	7.62	17.94	60.69	1.62	2.06	1.05	0.63	1.42	4.16	0.164
10/25/2006	7.27	18.64	73.02	0.91	2.15	1.02	0.75	1.40	2.29	0.090
10/26/2006	11.57	19.22	70.57	0.77	2.23	1.36	0.96	1.27	1.75	0.069
10/27/2006	11.93	19.07	93.96	0.81	2.21	1.40	1.31	0.89	1.31	0.052
10/28/2006	14.96	19.54	65.58	3.86	2.27	1.70	1.12	1.16	8.03	0.316
10/29/2006	14.37	18.67	54.58	1.89	2.15	1.64	0.89	1.26	4.29	0.169
10/30/2006	10.79	18.06	92.54	0.68	2.07	1.29	1.20	0.87	1.07	0.042

Appendix C

Sill (1983) Method Calculations for Lake Hartwell in the Month of September and October

Table C.1: Sill (1983) Method Calculations for Lake Hartwell in the Month of September

Date	T_a (^oC)	$T_{W\,Lake}$ (^oC)	RH (%)	U_r (m/s)	Corrected U_r (m/s)	C_s	C_a	C_R	C_t	C_{area}	E (g/(m^{2}s)	E_{lake} (mm/day)	E_{lake} (in/day)
9/1/06	25.22	30.18	76.89	1.02	1.13	31.37	18.06	1.71	1.0	0.91	0.06	4.801	0.189
9/2/06	23.31	29.79	86.17	0.77	0.85	30.68	18.06	2.47	1.0	0.91	0.05	4.416	0.174
9/3/06	24.77	29.70	83.92	0.70	0.77	30.52	19.19	2.51	1.0	0.91	0.04	3.607	0.142
9/4/06	25.36	29.78	82.83	0.57	0.63	30.65	19.61	2.96	1.0	0.91	0.04	3.240	0.128
9/5/06	22.65	29.18	91.01	0.66	0.73	29.62	18.32	2.92	1.0	0.91	0.04	3.789	0.149
9/6/06	23.40	29.43	78.26	0.77	0.85	30.05	16.48	2.43	1.0	0.91	0.05	4.659	0.183
9/7/06	22.31	28.72	84.19	0.94	1.03	28.83	16.61	2.03	1.0	0.91	0.05	4.525	0.178
9/8/06	23.55	28.78	79.93	0.87	0.96	28.95	16.99	2.05	1.0	0.91	0.05	4.127	0.162
9/9/06	23.29	28.70	82.20	0.82	0.90	28.80	17.21	2.20	1.0	0.91	0.05	3.956	0.156
9/10/06	24.16	28.91	79.13	0.70	0.77	29.16	17.45	2.46	1.0	0.91	0.04	3.704	0.146
9/11/06	23.16	28.03	74.02	0.62	0.68	27.71	15.37	2.82	1.0	0.91	0.04	3.788	0.149
9/12/06	20.84	27.44	80.39	0.74	0.81	26.77	14.50	2.62	1.0	0.91	0.05	4.249	0.167
9/14/06	23.38	27.57	72.97	0.62	0.68	26.97	15.35	2.69	1.0	0.91	0.04	3.434	0.135
9/15/06	21.91	26.98	74.00	0.70	0.78	26.06	14.25	2.51	1.0	0.91	0.04	3.794	0.149
9/16/06	22.04	27.42	81.07	1.00	1.11	26.73	15.74	1.79	1.0	0.91	0.05	4.008	0.158
9/17/06	22.89	27.79	78.84	0.56	0.62	27.32	16.11	3.11	1.0	0.91	0.04	3.362	0.132
9/18/06	22.95	27.55	87.39	1.44	1.59	26.94	17.92	1.19	1.0	0.91	0.04	3.424	0.135
9/19/06	23.45	27.65	79.28	2.34	2.58	27.10	16.75	0.71	1.0	0.91	0.05	4.306	0.170
9/20/06	19.38	26.98	67.40	0.93	1.02	26.06	11.12	2.17	1.0	0.91	0.07	5.733	0.226
9/21/06	17.19	26.25	67.30	0.90	1.00	24.95	9.68	2.37	1.0	0.91	0.07	6.047	0.238
9/22/06	20.57	26.28	81.58	0.94	1.04	25.00	14.47	1.95	1.0	0.91	0.04	3.800	0.150
9/23/06	23.51	26.89	86.40	0.91	1.00	25.91	18.33	1.70	1.0	0.91	0.03	2.414	0.095
9/24/06	22.99	26.90	91.02	1.46	1.60	25.94	18.70	1.11	1.0	0.91	0.03	2.609	0.103
9/25/06	19.23	26.36	86.16	0.60	0.66	25.13	14.08	3.32	1.0	0.91	0.04	3.699	0.146
9/26/06	18.94	26.01	79.11	0.60	0.66	24.60	12.70	3.30	1.0	0.91	0.05	3.982	0.157
9/27/06	18.35	25.83	86.83	0.83	0.91	24.35	13.44	2.43	1.0	0.91	0.05	4.025	0.158
9/28/06	18.69	25.94	82.12	1.81	1.99	24.50	12.98	1.10	1.0	0.91	0.06	5.103	0.201
9/29/06	15.98	25.49	68.55	1.39	1.53	23.86	9.14	1.56	1.0	0.91	0.08	6.832	0.269
9/30/06	16.31	24.98	79.76	1.34	1.48	23.16	10.86	1.57	1.0	0.91	0.06	5.526	0.218

Table C.2: Sill (1983) Method Calculations for Lake Hartwell in the Month of October

Date	**T_a (°C)**	**$T_{W\,Lake}$ (°C)**	**RH (%)**	**U_r (m/s)**	**Corrected U_r (m/s)**	**C_s**	**C_a**	**C_R**	**C_t**	**C_{area}**	**E (g/(m^{2}s)**	**E_{lake} (mm/day)**	**E_{lake} (in/day)**
10/1/06	20.38	25.45	78.82	0.99	1.09	23.80	13.82	1.79	1.0	0.91	0.04	3.570	0.141
10/2/06	20.00	25.44	77.91	0.98	1.08	23.80	13.35	1.85	1.0	0.91	0.04	3.782	0.149
10/3/06	20.01	25.28	87.24	0.75	0.83	23.57	14.95	2.37	1.0	0.91	0.03	2.850	0.112
10/4/06	21.45	25.53	84.19	0.79	0.87	23.92	15.76	2.09	1.0	0.91	0.03	2.577	0.101
10/5/06	21.91	25.91	81.76	0.72	0.79	24.47	15.74	2.27	1.0	0.91	0.03	2.668	0.105
10/6/06	19.77	24.74	76.40	0.65	0.72	22.82	12.91	2.69	1.0	0.91	0.04	3.100	0.122
10/7/06	15.76	23.64	71.75	0.94	1.04	21.37	9.44	2.18	1.0	0.91	0.05	4.634	0.182
10/8/06	17.14	23.18	80.81	1.05	1.16	20.79	11.59	1.78	1.0	0.91	0.04	3.495	0.138
10/9/06	16.96	22.85	85.04	0.69	0.76	20.38	12.06	2.69	1.0	0.91	0.03	2.753	0.108
10/20/06	16.55	21.16	68.98	1.21	1.33	18.39	9.54	1.42	1.0	0.91	0.04	3.360	0.132
10/21/06	12.96	20.54	78.19	0.96	1.05	17.72	8.60	2.11	1.0	0.91	0.04	3.526	0.139
10/22/06	14.80	20.63	80.13	1.47	1.62	17.81	9.91	1.26	1.0	0.91	0.04	3.253	0.128
10/23/06	9.48	19.45	57.75	3.99	4.40	16.57	5.06	0.55	1.0	0.91	0.08	7.309	0.288
10/24/06	7.62	18.61	60.69	1.62	1.78	15.73	4.70	1.41	1.0	0.91	0.06	5.600	0.220
10/25/06	7.27	19.13	73.02	0.91	1.00	16.24	5.52	2.59	1.0	0.91	0.05	4.531	0.178
10/26/06	11.57	19.43	70.57	0.77	0.85	16.54	7.09	2.66	1.0	0.91	0.04	3.456	0.136
10/27/06	11.93	19.61	93.96	0.81	0.90	16.73	9.67	2.49	1.0	0.91	0.03	2.610	0.103
10/28/06	14.96	20.12	65.58	3.86	4.26	17.26	8.20	0.46	1.0	0.91	0.06	5.250	0.207
10/29/06	14.37	19.15	54.58	1.89	2.08	16.26	6.57	0.92	1.0	0.91	0.04	3.840	0.151
10/30/06	10.79	18.62	92.54	0.68	0.75	15.73	8.84	3.01	1.0	0.91	0.03	2.439	0.096

Appendix D

Sill (1983) Method Calculations for the Floating Pan in the Month of September and October

Table D.1: Sill (1983) Method Calculations for the Floating Pan in the Month of September

Date	T_a (^oC)	$T_{W\,Pan}$ (^oC)	RH (%)	U_r (m/s)	Corrected U_r (m/s)	C_s	C_a	C_R	C_t	C_{area}	E ($g/(m^2s)$)	E_{pan} (mm/day)	E_{pan} (in/day)
9/1/06	25.22	30.31	76.89	1.02	1.13	31.61	18.06	1.73	1.0	0.91	0.06	4.918	0.194
9/2/06	23.31	29.48	86.17	0.77	0.85	30.13	18.06	2.43	1.0	0.91	0.05	4.171	0.164
9/3/06	24.77	29.47	83.92	0.70	0.77	30.13	19.19	2.47	1.0	0.91	0.04	3.441	0.135
9/4/06	25.36	29.66	82.83	0.57	0.63	30.45	19.61	2.93	1.0	0.91	0.04	3.159	0.124
9/5/06	22.65	28.83	91.01	0.66	0.73	29.02	18.32	2.87	1.0	0.91	0.04	3.539	0.139
9/6/06	23.40	29.30	78.26	0.77	0.85	29.82	16.48	2.41	1.0	0.91	0.05	4.557	0.179
9/7/06	22.31	28.34	84.19	0.94	1.03	28.21	16.61	1.99	1.0	0.91	0.05	4.238	0.167
9/8/06	23.55	28.65	79.93	0.87	0.96	28.72	16.99	2.03	1.0	0.91	0.05	4.025	0.158
9/9/06	23.29	28.45	82.20	0.82	0.90	28.39	17.21	2.17	1.0	0.91	0.04	3.774	0.149
9/10/06	24.16	28.88	79.13	0.70	0.77	29.10	17.45	2.45	1.0	0.91	0.04	3.678	0.145
9/11/06	23.16	27.72	74.02	0.62	0.68	27.21	15.37	2.76	1.0	0.91	0.04	3.577	0.141
9/12/06	20.84	26.85	80.39	0.74	0.81	25.85	14.50	2.54	1.0	0.91	0.04	3.845	0.151
9/14/06	23.38	27.69	72.97	0.62	0.68	27.16	15.35	2.71	1.0	0.91	0.04	3.517	0.138
9/15/06	21.91	26.83	74.00	0.70	0.78	25.82	14.25	2.48	1.0	0.91	0.04	3.690	0.145
9/16/06	22.04	27.18	81.07	1.00	1.11	26.36	15.74	1.77	1.0	0.91	0.04	3.833	0.151
9/17/06	22.89	27.62	78.84	0.56	0.62	27.06	16.11	3.07	1.0	0.91	0.04	3.257	0.128
9/18/06	22.95	27.53	87.39	1.44	1.59	26.91	17.92	1.18	1.0	0.91	0.04	3.410	0.134
9/19/06	23.45	27.29	79.28	2.34	2.58	26.54	16.75	0.69	1.0	0.91	0.05	4.007	0.158
9/20/06	19.38	26.56	67.40	0.93	1.02	25.43	11.12	2.13	1.0	0.91	0.06	5.419	0.213
9/21/06	17.19	25.82	67.30	0.90	1.00	24.33	9.68	2.34	1.0	0.91	0.07	5.736	0.226
9/22/06	20.57	25.90	81.58	0.94	1.04	24.45	14.47	1.91	1.0	0.91	0.04	3.547	0.140
9/23/06	23.51	26.73	86.40	0.91	1.00	25.68	18.33	1.68	1.0	0.91	0.03	2.316	0.091
9/24/06	22.99	26.65	91.02	1.46	1.60	25.55	18.70	1.09	1.0	0.91	0.03	2.418	0.095
9/25/06	19.23	25.65	86.16	0.60	0.66	24.09	14.08	3.20	1.0	0.91	0.04	3.265	0.129
9/26/06	18.94	25.57	79.11	0.60	0.66	23.98	12.70	3.23	1.0	0.91	0.04	3.714	0.146
9/27/06	18.35	25.15	86.83	0.83	0.91	23.39	13.44	2.35	1.0	0.91	0.04	3.590	0.141
9/28/06	18.69	25.43	82.12	1.81	1.99	23.78	12.98	1.08	1.0	0.91	0.05	4.675	0.184
9/29/06	15.98	24.89	68.55	1.39	1.53	23.03	9.14	1.53	1.0	0.91	0.07	6.362	0.250
9/30/06	16.31	24.48	79.76	1.34	1.48	22.48	10.86	1.54	1.0	0.91	0.06	5.159	0.203

Table D.2: Sill (1983) Method Calculations for the Floating Pan in the Month of October

Date	T_a (°C)	$T_{W\,Pan}$ (°C)	RH (%)	U_r (m/s)	Corrected U_r (m/s)	C_s	C_a	C_R	C_t	C_{area}	E (g/(m^{2}s))	E_{pan} (mm/day)	E_{pan} (in/day)
10/1/06	20.38	25.16	78.82	0.99	1.09	23.40	13.82	1.76	1.0	0.91	0.04	3.383	0.133
10/2/06	20.00	25.16	77.91	0.98	1.08	23.41	13.35	1.82	1.0	0.91	0.04	3.599	0.142
10/3/06	20.01	24.97	87.24	0.75	0.83	23.15	14.95	2.33	1.0	0.91	0.03	2.671	0.105
10/4/06	21.45	25.52	84.19	0.79	0.87	23.90	15.76	2.09	1.0	0.91	0.03	2.569	0.101
10/5/06	21.91	25.82	81.76	0.72	0.79	24.34	15.74	2.26	1.0	0.91	0.03	2.614	0.103
10/6/06	19.77	24.45	76.40	0.65	0.72	22.44	12.91	2.64	1.0	0.91	0.03	2.940	0.116
10/7/06	15.76	23.46	71.75	0.94	1.04	21.14	9.44	2.16	1.0	0.91	0.05	4.521	0.178
10/8/06	17.14	22.83	80.81	1.05	1.16	20.36	11.59	1.75	1.0	0.91	0.04	3.289	0.130
10/9/06	16.96	22.41	85.04	0.69	0.76	19.84	12.06	2.62	1.0	0.91	0.03	2.527	0.100
10/20/06	16.55	20.97	68.98	1.21	1.33	18.19	9.54	1.40	1.0	0.91	0.04	3.257	0.128
10/21/06	12.96	20.15	78.19	0.96	1.05	17.29	8.60	2.08	1.0	0.91	0.04	3.323	0.131
10/22/06	14.80	20.35	80.13	1.47	1.62	17.51	9.91	1.24	1.0	0.91	0.04	3.075	0.121
10/23/06	9.48	18.62	57.75	3.99	4.40	15.74	5.06	0.54	1.0	0.91	0.08	6.712	0.264
10/24/06	7.62	17.94	60.69	1.62	1.78	15.09	4.70	1.38	1.0	0.91	0.06	5.211	0.205
10/25/06	7.27	18.64	73.02	0.91	1.00	15.75	5.52	2.55	1.0	0.91	0.05	4.279	0.168
10/26/06	11.57	19.22	70.57	0.77	0.85	16.33	7.09	2.63	1.0	0.91	0.04	3.356	0.132
10/27/06	11.93	19.07	93.96	0.81	0.90	16.17	9.67	2.43	1.0	0.91	0.03	2.363	0.093
10/28/06	14.96	19.54	65.58	3.86	4.26	16.66	8.20	0.44	1.0	0.91	0.06	4.850	0.191
10/29/06	14.37	18.67	54.58	1.89	2.08	15.78	6.57	0.88	1.0	0.91	0.04	3.555	0.140
10/30/06	10.79	18.06	92.54	0.68	0.75	15.19	8.84	2.93	1.0	0.91	0.03	2.206	0.087

Appendix E

Calculated Bulk Aerodynamic Transfer Method vs. the Floating Pan Evaporation (8/18/06 – 8/26/06)

Table E.1: Bulk Aerodynamic Transfer Method vs. the Floating Pan Evaporation (8/18/06 – 8/26/06)

Evap. Section	**Time hrs**	**T_a (^oC)**	**$T_{W Pan}$ (^oC)**	**RH (%)**	**U_r (m/s)**	**$e^*_{T W pan}$ (kPa)**	**e^*_{Ta} (kPa)**	**e_a (kPa)**	**$(e^*_s - e_a)$ (kPa)**	**$E_{B.A.T.}$ (mm/section)**	**$E_{B.A.T.}$ (in/section)**	**$E_{flaoting\ pan}$ (in)**	**$E_{B.A.T.}$ / $E_{floating\ pan}$**
1	6.75	29.3	32.7	50.87	1.45	4.95	4.08	2.07	2.87	2.01	0.08	0.15	0.53
2	17.25	24.6	27.53	79.73	0.69	3.68	3.10	2.47	1.21	1.05	0.04	0.35	0.12
3	20.25	26.5	29.66	81.08	0.8	4.16	3.45	2.80	1.36	1.60	0.06	0.22	0.29
4	32	25.6	29.63	82.94	0.89	4.15	3.29	2.73	1.43	2.94	0.12	0.4	0.29
5	25	26.3	29.84	82.33	0.77	4.20	3.41	2.81	1.39	1.94	0.08	0.17	0.45
6	44	24.9	29.09	80.46	0.79	4.03	3.14	2.53	1.50	3.77	0.15	0.34	0.44

Appendix F

Calculated Sill (1983) Method vs. the Floating Pan Evaporation (8/18/06 – 8/26/06)

Table F.1: Calculated Sill (1983) Method vs. the Floating Pan Evaporation (8/18/06 – 8/26/06)

Evap. Section	Time (hrs)	T_a (^oC)	$T_{W\ pan}$ (^oC)	RH (%)	U_r (m/s)	Corrected U_r (m/s)	C_s	C_a	C_R	C_t	C_{area}	E_{Sill} (g/(m^{2}s)	E_{Sill} (in/section)	$E_{floating\ pan}$	E_{Sill} / $E_{floating\ pan}$
1	6.75	29.3	32.7	50.87	1.45	1.60	36.21	15.18	1.07	1.0	1.43	0.13	0.127	0.15	1.18
2	17.25	24.6	27.53	79.73	0.69	0.76	26.91	18.07	2.13	1.0	1.43	0.05	0.111	0.35	3.16
3	20.25	26.5	29.66	81.08	0.8	0.88	30.45	20.48	1.90	1.0	1.43	0.05	0.157	0.22	1.40
4	32	25.6	29.63	82.94	0.89	0.98	30.40	19.96	1.83	1.0	1.43	0.06	0.283	0.4	1.41
5	25	26.3	29.84	82.33	0.77	0.85	30.77	20.56	2.04	1.0	1.43	0.06	0.201	0.17	0.85
6	44	24.9	29.09	80.46	0.79	0.87	29.46	18.52	2.10	1.0	1.43	0.06	0.397	0.34	0.86

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