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Evaluating Surface Area-Basin Volume Relationships for Prairie Potholes

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EVALUATING SURFACE AREA-BASIN VOLUME RELATIONSHIPS FOR PRAIRIE POTHOLES

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This thesis, submitted by Mike A. Davis in partial fulfillment of the requirements for the Degree of Master of Arts from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is herby approved.

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ABSTRACT

Establishing a relationship between surface area and volume of prairie potholes provides a simple method to estimate changes in water storage across the landscape. Applications include better prediction of floods and improved design for wetland restoration. Length, width, depth, surface area, and volumes were surveyed for eighty-two potholes within the upper Turtle River watershed which lies sixty kilometers west of Grand Forks, ND. These data were used to determine the relationship and uncertainty between pothole surface and volume. Chi squared tests defined distributions of each variable. F and T statistical tests resolved similarities in variance and mean. The eighty-two potholes were separated according to their National Wetlands Inventory (NWI) classification and tested using chi squared. T and F tests on the separate classes verified if the populations have a different mean and variance. Difference in depth, in particular, suggests that the two most common NWI classes PEMC and PEMA in the watershed are separate and distinct, based on the results from discriminant analysis. Despite this conclusion and the fact that PEMC wetlands are physically larger than PEMA wetlands, there is a stronger correlation between surface area and volume when the two classes remain combined. Regression of surface area and volume leads to an equation that can be applied to similar watershed throughout the prairie pothole region.

CHAPTER I

INTRODUCTION

Problem Statement

The Prairie Pothole Region (PPR) of the North American Continent (Fig. 1) hosts hundreds of thousands of small depressions that function as important habitats for wildlife and storage for surface water. Human impacts and the variable climatic conditions of the prairie in the north central U.S. and south central Canada provide significant variations in the distribution and size of these potholes. These differences affect avian breeding (Delphey and Dinsmore, 1993), agriculture (Wienhold and van der Valk, 1989), and local climate and hydrology (Johnson et al., 2005). Remote sensing provides a record of the short-term changes in pothole surface area (Sethre, et al. 2005), but their depth and volume are more difficult to estimate. The accurate prediction of pothole and wetland expansion and contraction resulting primarily from climate variability requires accurate assessment of these parameters.

Hypothesis

Individual potholes have similar geometric properties that make it possible to use area and shoreline shape to estimate depth and volume. To test this hypothesis, bathymetric profiles and the general shape of 82 potholes in the upper Turtle River watershed of North Dakota were measured using level line surveying during the ice-free months of 2003 and 2004. These data are applied to: (1) establish differences between and/or similarities with the various National Wetland Inventory classes, (2) develop a relationship between pothole area and volume, (3) compare the result to estimates of pothole area-depth-volume relationships determined elsewhere based on little data, and (3) establish a connection, if any, between the geometry of the profiles, the ecology of the region, and water persistence.

Prairie Potholes and Their Significance

The prairie pothole region (PPR) comprises portions of the states of North and South Dakota and Minnesota as well as the Canadian provinces of Manitoba, Saskatchewan, and Alberta (Figure 1). The PPR covers approximately 700,000 square kilometers and, because of its rich soils and numerous depressions, is considered to be one of the most important agricultural and ecological regions of North America (Kantrud et al., 1989).

The United States Environmental Protection Agency (2001) estimates that the prairie pothole region's wetlands are responsible for up to one-half of North American bird species' nesting or feeding. Although they only compose five percent of the land surface in the conterminous United States, they are home to 31% of the plant species. Agriculturally-related drainage practices altered approximately 65% percent of the original wetlands within the PPR, directly threatening their sustainability as an ecosystem (Tiner, 1982 and Dahl, 1990).

Figure 1: The Prairie Pothole Region. Locations of the Upper Turtle River Watershed (this study), St. Denis Wildlife Area (Hayashi and Van der Kamp, 2000), Upper Assiniboine River Basin (Weins, 2001), Emmet County, Iowa (Hahn and Johnson, 1967), Churdin, Iowa (Hahn and Johnson, 1967), and Not Pictured Martin County, Florida (Wise, 2000). (Modified from Woo et al. 1993).

The ratio of open water to vegetation-covered areas, as well as species zonation, is directly linked to water depth in the potholes (Aro and Branson, 1962). While there are distinct differences in flora and fauna between potholes, they are primarily due to differences in basin morphometry, specifically depth, size, hydrology, and basin water chemistry (Galatowitsch and van der Valk, 1994). Murkin et al. (2000) cite water level as the direct cause for a pothole's water storage capacity, primary production, and mineral cycling, which can vary according to wet-dry cycles and affect biodiversity.

The prairie potholes seen throughout the PPR are the result of glacial ablation during the Wisconsinan glacial retreat (Bluemle, 2000). During glacial recession, ice calves off smaller, scattered pieces that result in the formation of depressions (Figure 2). The southern extent of the Wisconsinan glaciation during its retreat directly coincides with the southern reaches of the PPR.

Figure 2: A Typical Pothole Seen in the Upper Turtle River Watershed.

The term “wetland” or “pothole” is subject to varying definitions and classification schemes depending on the professional discipline in which it is used (Woo and Young, 1997). The United States Fish and Wildlife Service (USFWS) established a definition that places an emphasis on the relationship between soil, water, and wildlife (Shaw and Fredine, 1956). The definition given by the Farm Service Agency (FSA) for “wetlands” is predominantly associated with soil types (Tiner, 2006) The National Wetlands Inventory (NWI), which uses the classification scheme developed by Cowardin et al. (1979), define “wetland” on the presence of one or more of the following three attributes:

(1) Hydrophytes occur seasonally or throughout the year,
(2) Substrate is predominantly undrained hydric soil, or
(3) Sediments comprise the substrate, which is saturated or covered with shallow water periodically during each growing season of every year.

The Cowardin (1979) system was applied to describe ecological units that have certain homogenous natural attributes, to arrange these units in a system that will aid decisions about resource management, to furnish units for inventory and mapping; and to provide uniformity in concepts and terminology throughout the United States (Appendix 1). The US Fish and Wildlife Service is close to completing the mapping and digitization of wetland regions throughout the United States. Access to this readily available online data and a method of quantifying the width, length, and surface area is all that is required to calculate an individual watershed storage capacity as well as individual potholes internal geometry and volume.

Previous Studies

Researchers have had with limited and localized success in determining relationships between a potholes width, length, depth, surface area, and volume. Quantifying the relationship between surface area and volume would provide researchers and land managers with the ability to access quickly and accurately the storage capacity of watersheds and their constituent potholes.

Hahn and Johnson (1967) established relationships that quantitatively describe the three-dimensional shapes of the depressions. Their emphasis was on the geometry and distribution of the wetlands and the initial phase was the construction of half-meter contour interval topographic maps from pre-existing maps of the East Fork Hardin Creek watershed, Greene County, Iowa. Analysis of the maps allowed for estimates of volume, depth, and area values. Means and standard deviations were calculated for the volume, depth, and areas. Through the application of standard regression; this relationship is illustrated through the equation:

$$V = 2.7*10^{-3} A^{1.44} \qquad (1)$$

V = volume (m^3)
A = area (m^2)

The relationship of volume to surface area was found to have a correlation coefficient of 0.86.

The second part of the Hahn and Johnson (1967) study was completed in Emmet County, Iowa. Measurements of volume, depth, and area were made in a similar manner to East Fork Hardin Creek. The equation generated from this study was:

$$V = 4.1*10^{-3} A^{1.36} \quad (2)$$

The resulting correlation coefficient was 0.87. The values for both of these study areas were then combined and a final correlation coefficient of 0.87 was calculated, resulting in a combined equation relating volume to area:

$$V = 3.6*10^{-3} A^{1.38} \quad (3)$$

Hayashi and van der Kamp (2000) conducted their research on 27 depressions in the St. Denis National Wildlife Area (NWA), approximately 40 kilometers east of Saskatoon, Saskatchewan, Canada. Emphasis was placed on the relationship between the area, volume and depth. The purpose of the study is to interpolate area-depth and volume-depth from a detailed survey, approximate these relationships, and establish a geometrical model of depressions for applications in simulations.

The first step in the calculation of the area-volume relationship is to establish the slope profile of the depression. This is obtained through the application of the following equation:

$$\frac{y}{yo} = \left(\frac{r}{ro}\right)^p \qquad (4)$$

y = relative elevation of surface at distance r from center (m)
y_0 = unit elevation (1 m)
r = radius (m)
r_0= radius corresponding to y_0 (m)
p = dimensionless constant

The slope profile "p" is derived from equation 4 by establishing a ratio between a unit representation of the pothole at unit radius and elevation. From equation 4, Hayashi and Van der Kamp (2000) estimate the area from the following equation:

$$A = \pi\, r_0^2 (h/h_0)^{2/p} = s(h/h_0)^{2/p} \qquad (5)$$

h = maximum height (m)
h_0 = unit height (m)
s = scaling constant (unitless)

The scaling constant "s" is equal to the area of the surface water when $h = h_0$. The constant p is the link between the area-depth relationship, with a p that equals two representing a parabolic shaped basin and, in an extreme case, $p \rightarrow \infty$, which corresponds to a cylinder. Volume can also be estimated in a similar manner with the following equation:

$$V= (s/(1+2/p))*(h^{1+(2/p)}/\ h_0^{2/p}) \qquad (6)$$

Hayashi and van der Kamp (2000) surveyed the catchments of the wetlands and depressions using a total station. Survey points were located at a 9 to 15 m horizontal spacing in the uplands and 5 to 9 m interval within the wetlands. For smaller wetlands the survey points were spaced at a 2-5 m interval. SURFER (Golden Software, 2004) was used to estimate all other grid points and in the construction of digital elevation models (DEMs).

The profile variable "p" is greater for larger wetlands and less for smaller wetlands. This translates to a gentler slope in smaller wetlands and a cylindrical shape for larger wetlands. The result is that the area-depth and volume-depth relationships can be estimated through the calculation of only two constants, s and p, which can be obtained through two independent measurements of area and depth (Hayashi and van der Kamp, 2000).

Wise et al. (2000) completed a study focusing on the hydraulic connectivity between a wetland and an underlying aquifer. The study site was an isolated marsh located in Martin County, Florida. The wetland depth was measured at 3 m intervals along west-east, south-north, southeast-northwest, and southwest-northeast transects. Solver, the linear programming code in Excel, was used to fit the measurements taken to produce the following equation for stage-volume relationship,

$$V = 3{,}454((3.818+h_w)-3.77)^2-148.5(h_w-3.77) \qquad (7)$$

h_w = height of water (m)

Wise et al. (2000) concluded that there was a connection between the aquifer and the surveyed wetland, judged by repeated volume measurements in response to meteorological events. For the current study, $h_w + 3.818$ is set as the maximum depth of the given pothole, allowing for its maximum volume to be estimated. The value 3.818 is used by Wise et al. (2000) as the datum for the bottom of the pothole.

Weins (2001) obtained datasets from the Prairie Farm Rehabilitation Administration (PFRA) and Ducks Unlimited Canada (DU). These datasets contained 96 surveyed depressions from the PFRA and 81 from DU, all from the Upper Assiniboine River Basin (UARB), Saskatchewan, Canada. Each of the datasets consisted of the mean, median, standard deviation, minimum and maximum for the area and volume. The two datasets were combined and separated into potholes under $7.0*10^6$ m^2 and those that had a larger area. A series of regression analyses were performed on the two datasets to establish an area-volume relationship that could be integrated into a hydrological model. The resulting equation follows:

$$V = 3.8*10^{-2} A^{1.22} \qquad (A < 7.0*10^6 \text{ m}^2) \qquad (8)$$

Weins (2001) concluded that the relationships established in this study were applicable for watershed volumetric estimations (correlation coefficient of 0.89), however, on smaller sample sizes the accuracy decreases and the equation is only applicable to the watershed for which it was created. Hansen (2002) made corrections to Weins' (2001) work by first determining how Weins (2001) computed the standard error.

Once the standard error was calculated, a correction factor (C_F) was found using the method described by Finney (1941).

$$C_F = \exp(2.65\ SE^2) \qquad (9)$$

C_F = correction factor
SE = standard error

$$SE = \sum_{i=1}^{n} (Yi - Y^i) \qquad (10)$$

n = number of data points
k = number of independent variables (=1 in this case)
Yi = value of observed data point i
Y^i = value of computed point i

The calculated C_F was found to be 1.17, meaning that the results obtained from the original Weins (2001) equation were too small. With the corrections applied to the original Weins (2001) equation, the following equation is derived for wetlands with areas less than $7.0*10^6\ m^2$:

$$V = 4.39*10^{-2}\ A^{1.22} \qquad (A < 7.0*10^6\ m^2) \qquad (11)$$

Despite the previous researcher's examination of the same problem, there is a large variability in their conclusions with only moderate success (largest correlation coefficient of 0.89). These studies are all isolated to their subject watersheds with the exception of Hahn and Johnson (1967). The motivation behind completing these studies is that conclusions drawn can be applied to watersheds that have not undergone such extensive field surveying or map analysis. It is also noted that although there is a common undercurrent of emphasis on the surface area- volume correlation, work completed by Hayashi and Van der Kamp (2000) demonstrate another connection between the pothole slope curvature, surface area, and volumes (Appendix 2).

There is a need to standardize the approach behind the analysis of the potholes within the PPR. A single equation,or set of equations, relating surface area to volume needs to be established. By combining the existing equations, area-volume relationships for other pothole regions not yet surveyed can be determined. This prevents the need for continuously developing new equations and allows for a convenient method for estimating total surface water in storage for any watershed within the PPR. By analyzing existing equations and incorporating new field data collected in the upper Turtle River watershed, I attempt to demonstrate the effectiveness of this approach.

Description of Study Site

The upper Turtle River watershed (UTR) is located approximately 60 km. west of Grand Forks, North Dakota (Figure 3). The UTR watershed covers an area of roughly 93 square kilometers and is composed primarily of gently rolling hills. The depressions contained within the UTR watershed are underlain by glacial sediments deposited during the Wisconsinan glaciation. Winter and Rosenberry (1995) recognized that these wetlands are typically filled with runoff from the spring snowmelt and, to a lesser extent, summer precipitation. This trend results in complete loss of water during the periodic dry cycles. The climate within the UTR tends to be extreme, with variations up to 85°C seasonally with sporadic and localized precipitation.

The Pleistocene and Holocene deposits that underlie the region are known collectively as the Coleharbor Formation. Bluemle (2000) describes the Coleharbor Formation as the lithostratigraphic unit that includes all bouldery, cobbly, pebbly, sandy, silty clay; sand and gravel and silt and clay, covering 99% of Nelson County and unconformably overlying the Pierre Shale.

The Wisconsinan ice sheet advanced across Nelson County from the northwest, and was separated into two lobes by the Turtle Mountains. The western lobe is known as the Souris River and the eastern lobe, which overrode Nelson County, is known as the Leeds lobe (Lemke and Colton, 1958). Prest and Grant (1969) estimated this advance to have occurred approximately 13,200 radiocarbon years ago. The southernmost extent of the most recent glacial advance coincides with the southern margin of the PPR.

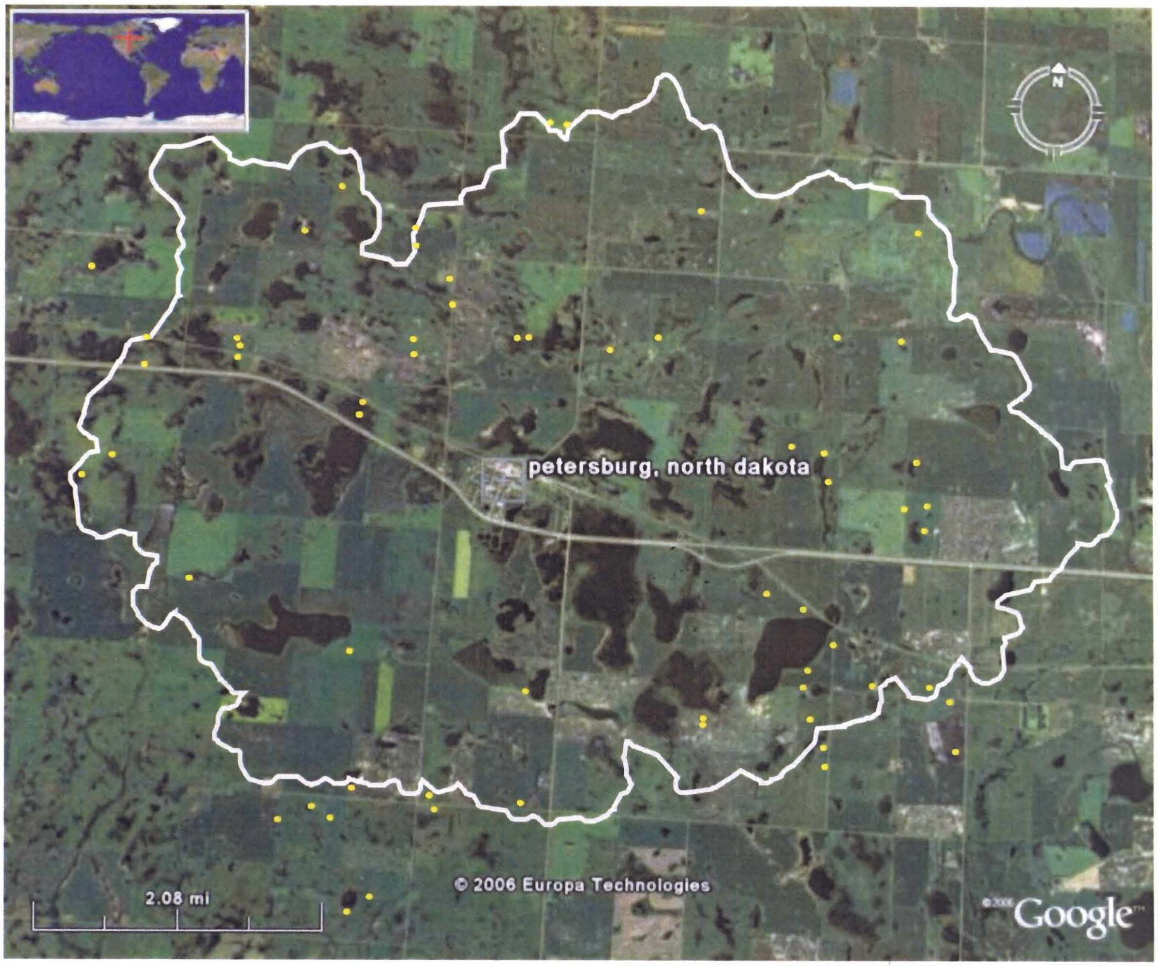

Figure 3: Upper Turtle River Watershed. Located Approximately 60 km West of Grand Forks, North Dakota. Yellow Dots Designate the Surveyed Potholes.

CHAPTER II

METHODS

Sampling and Statistics

The potholes measured during the course of this study were selected based on two criteria: (1) the pothole is singular, with no obvious sign of coalescence with surrounding potholes and (2) the pothole is isolated from section roads and tilled fields, which suggests a more natural boundary. U.S. Highway 2 provided a boundary that allowed the UTR to be divided into a northern and southern half. The two criteria were applied within this delineated area. The northern half was sampled from east to west; , the southern half was also sampled from east to west

Eighty-two singular potholes were surveyed across two transects using an auto-level and stadia rod. Depth measurements were taken at three meter intervals. These two transects are orientated roughly north-south and east-west. The latitude and longitude of each transect end point were recorded using a Garmin handheld GPS and entered into a separate spreadsheet that was then downloaded into Arcview GIS (ESRI, 1999), where it was overlain with the wetlands inventory dataset. This dataset permitted each of the potholes to be cataloged according to the National Wetlands Inventory system. Four wetland classes were sampled within the UTR watershed: 21 PEMA, 45 PEMC, 3 PEMF, and 11 unknown. The unknown potholes were those near clusters that exemplified varying characteristics that precluded the determination of an exact classification.

Because of the small number of PEMF class potholes and the uncertainty associated with the unknowns, only the PEMA and PEMC(d) were suitable for further analysis.

Once plotted, the geographic distribution pattern can be tested using the nearest neighbor index test. The nearest neighbor index test measures the similarity of the observed mean distance between surveyed potholes and the expected mean distance for a hypothetical random distribution (Mitchell, 2005). This nearest neighbor index can be tested for significance using a Z-test with the null hypothesis indicating that the potholes are randomly distributed. This result will expose any biases present within the sampling strategy across the UTR watershed.

The collective length, width, and depth values were tabulated using SURFER (Golden Software, 2004). A digital elevation model was generated from the data which allowed SURFER to calculate the estimated volume and produce a graphical representation of each recorded pothole (Figure 4).

The kriging contouring algorithm was used to create the bathymetric grid. Kriging is referred to as an “exact interpolator,” meaning that the depths estimated at the survey points will be the same as those measured. The error variances of the kriging method are also the lowest of any of the linear estimation methods (Davis, 2002). Simpson’s rule was used for the volume estimation. It applies third order polynomial integration on the arc segments between the kriging points (Keckler, 1994).

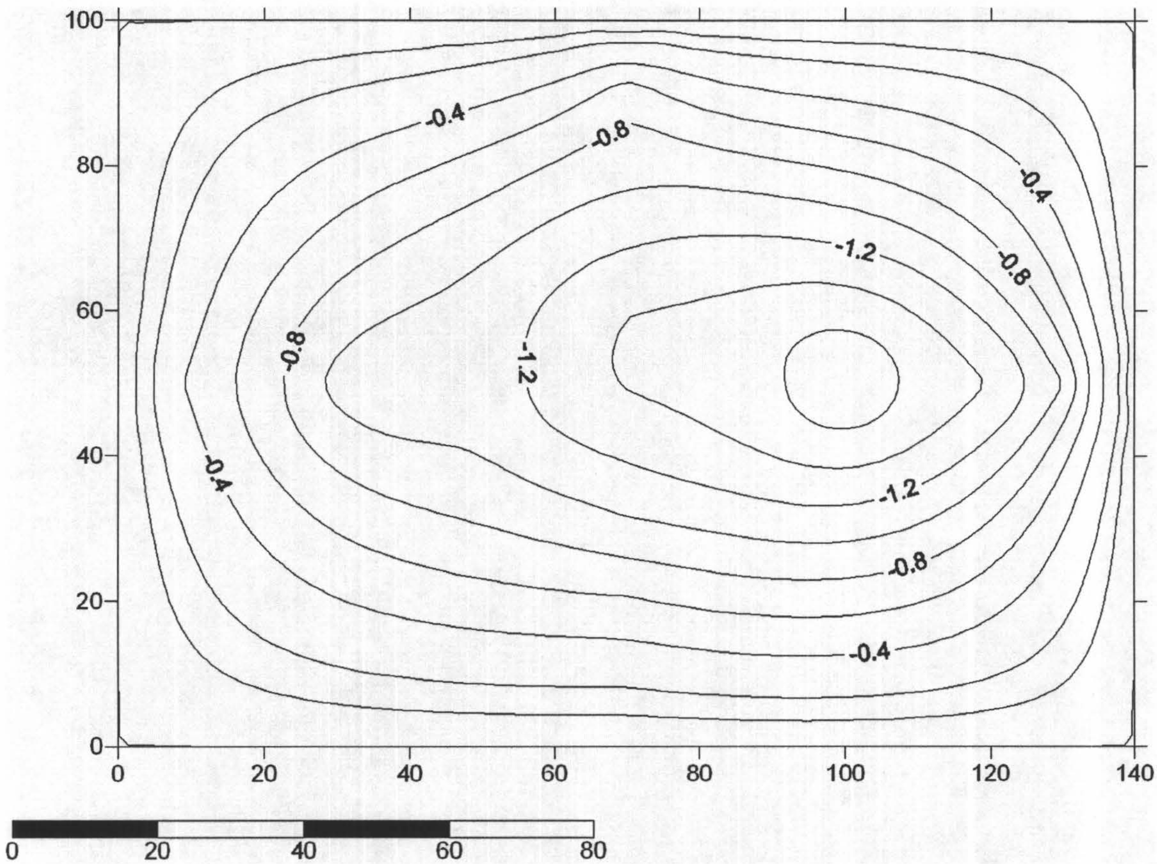

Figure 4: SURFER Generated Digital Elevation Model. Measured in Meters. Note the Greater Slope on the Eastern (right) Side of the Map. Contour Interval = 0.2 meters.

Volume estimates were generated for each of the 82 potholes and these values were entered into the Excel spreadsheet along with the length, width, and the maximum depth. Surface areas were estimated using the length and width values then added to the spreadsheet. The mean, median, and, standard deviation were calculated for each of these values (Appendix 3).

Linear regression analysis was used to calculate the correlation between the different measured variables as well as highlighting the differences of the PEMA and PEMC classes. Linear regression is a regression method of modeling the conditional expected value of one variable, *y*, given the values of some other variable, *x*. The correlation coefficient (R^2) is a measure of the proportion of variability in a sample of paired data. It is a number between zero and one. A value close to zero suggests a weak model (Davis,2000).

Chi-squared tests were completed to establish the distribution of both classes independent of one another and also on the combined data. The chi-squared distribution requires that the data are standardized to the standard normal form. This normal form is then applied to a goodness of fit test, which determines whether or not the sample populations are normally distributed. This is completed by comparing the observed frequency of measured traits (length, width, depth, surface area, and volume) to their expected frequency. The more that the observed frequencies deviate from the expected frequency, the greater the chances that it is not normally distributed (Davis, 2002). In cases where the data are not found to be normally distributed, it was log-transformed and then tested for a log-normal distribution.

An F-test is performed to statistically determine if the two sample sets, PEMC and PEMA, have the same variance. The hypothesis is that the standard deviations of two normally distributed populations are equal and thus are of comparable origin. This test analyzed the length, width, depth, surface area, and volume measurements. Once the variance is found to be the same between the two datasets, the T-test can be performed.

The T-test null hypothesis states that the means of two normally distributed populations are equal and thus that they are of comparable origin. Both of these tests use the observed data to calculate a value which is then compared to a tabular value that either supports or rejects the proposed hypothesis.

Each of the 75 potholes had their cross-sections divided into four sections that represented the shoreline slopes surveyed: north-middle, south-middle, east-middle, and west-middle transects. These were designated as T1-T4 respectively. Second order polynomial best-fit lines were calculated for each of these slopes and the resulting value for the second-order coefficient (x^2) was entered into the spreadsheet (Appendix 4). The second root of the polynomial was emphasized because it is sensitive to the degree of curvature- the larger the value the greater the curve. A second-order polynomial implies a single inflection point in the curve, which provides a general sense of the curvature represented in a pothole bank slope. The second derivative of the second-order coefficient was determined to further illustrate the concavity or convexity of a given graph, or in this case, the slope of the shoreline. A pothole that has a smooth V- shape slope profile will have a second derivative that approaches zero, with a linear fit. Both the T and F tests were completed on each transect with the others, divided into their respective classes as well as the combined group.

Discriminant analysis was performed to statistically support their separation into two groups, PEMC and PEMA. Discriminant analysis is a multivariate statistical method that involves testing the separation of two groups through the linear combination of a series of variables (discriminant function) that would produce the greatest difference between the two groups (Davis, 2002). In terms of pothole discrimination, this tests the separation of the PEMA and PEMC classes based on the measured variables. The analysis transforms the individual PEMA and PEMC measurements into a single value called the discriminant score, which illustrates the degree of certainty with which the pothole can be assigned to a specific group. The separation of the two groups is measured by the Mahalanobis distance (D^2)- the multivariate distance between the means of the two groups and D_o. D_o represents the halfway point on the Mahalanobis distance line (Davis, 2002); therefore D_o is the position at which the best separation of the two groups and the discriminant scores occurs. Once the D_o and D^2 are calculated, it is necessary to test the significance of the separation of the two classes, PEMC and PEMA. This is done using an F test, as described previously. This statistical test was performed using the DISCRIM software (LeFever, unknown date). The DISCRIM program provides an F-ratio value that can be compared with the tabular values in Davis (2000).

Uncertainty in the Measurements

The lengths, depths, and widths surveyed in the field were measured with a stadia rod to an accuracy of 0.06 meters. Prior to any pond survey, a clear line of sight between the auto-level and the stadia rod was established. The relative error of each of the volume estimates generated by SURFER was calculated using the following formula (Keckler, 1994):

$$RE = (LR-SR)*100/Aver. \qquad (12)$$

RE = Relative Error
LR = Largest Result
SR = Smallest Result
Aver = Average of Three Methods

The largest result (LR) is the volume calculated by the trapezoidal rule and the smallest result(SR), by Simpson's 3/8 rule. Both of these volume estimates are generated by SURFER in its grid volume report. The relative error for the SURFER calculated volumes ranged between ±0.01% and ±0.04% (Equation 12). This range of relative error is less than ±1% and can be considered insignificant in the analysis of this dataset. For example, a pothole with a volume of 1,000 m^3 would vary between 1,000.1 m^3 to 1,000.4 m^3, having a minimal effect on the analysis.

CHAPTER III

RESULTS AND DISCUSSION

Descriptive Statistics

The Z-test for random distribution of the surveyed potholes was rejected, meaning that the distribution of the potholes was more dispersed, i.e. distances between surveyed potholes is greater than the mean or expected distance. There is less than a 1% likelihood that this dispersed pattern could be the result of random chance. It more likely due to the nature of land management of UTR than sampling error, as the watershed has been greatly impacted for agricultural and municipal use.

The mean, median, mode, standard deviation, maximum and minimum were calculated for the width, length, depth, and volume of the 82 potholes (Table 1).

Table 1: Basic Statistics for Combined Potholes.

	Mean	Median	Standard Deviation	Maximum	Minimum
Length (m)	71.81	60.96	34.99	170.69	21.34
Width (m)	53.73	48.77	25.52	152.40	18.29
Depth (m)	0.77	0.70	0.43	1.68	0.13
Surface Area (m^2)	4,518	3,014.93	4,435.17	26,006.55	355.73
Volume (m^3)	1,504.08	644.51	1,887.88	7,323.19	15.68

The combined lengths have a mean that is approximately 30% greater than the combined widths, meaning that the average pothole has an overall elliptical shape. The large standard deviations seen for each of the five measured values illustrate the large variability within the population. A correlation matrix was generated for the five physical measurements (Table 2).

Table 2: Correlation Matrix for Combined Physical Measurements.

	Length	Width	Max. depth	Surface area	Volume
Length (m)					
Width (m)	0.86				
Depth (m)	0.56	0.58			
Surface Area (m^2)	0.91	0.95	0.50		
Volume (m^3)	0.85	0.89	0.72	0.90	

Correlations above 70% exist between the surface area and length, width, and volume. The length for the combined dataset was found to be log-normally distributed; the width and depth were found to be normally distributed. The surface area for the combined dataset was found to be lognormally distributed while the volume had neither a normal or lognormal distribution.

Derivation of Empirical Formula Relating Area-Volume

Standard linear regression techniques were used to derive a relationship between pothole area and volume seen in the UTR watershed. Linear regression was applied to this relationship and the resulting correlation coefficient was 0.87 (Figure 5). This relationship (Figure 5) yielded the following equation:

$$V = 1.4*10^{-3}\ A^{1.61} \quad (13)$$

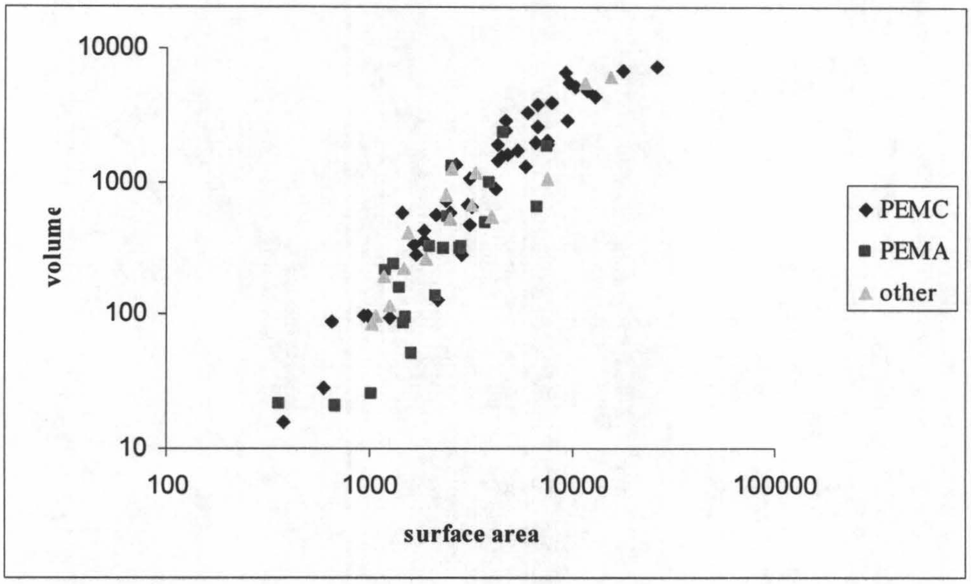

Figure 5: Correlation Between Surface Area and Volume for PEMC, PEMA and Other (Composed of PEMF, U, and Unknown). Volume is in Cubic Meters and Surface Area, Square Meters.

While this appears similar to the equations derived in previous research, it is specific to the UTR. If the data were available from all of the previous works, a combined equation could be constructed as outlined by Hahn and Johnson (1967). The lack of additional datasets makes it impossible to construct a combined equation.

Comparison with Prior Approaches

The values collected for length, width, depth, and surface area were entered into the previous equations (equations 1-11) to determine their applicability in the UTR watershed. The Hayashi and van der Kamp (2000) and Wise (2000) relationships were transformed into power functions. Wiens' (2001) equation was applied according to corrections outlined by Hansen (2002). After the corrections were applied, the values were plotted versus the SURFER volumes (Appendix 5). The results showed significant variability between the SURFER and calculated volumes (Table 3).

Table 3: Correlation Coefficients for Other Methods. Applied to the Data Collected from the UTR Watershed.

Researcher	Correlation Coefficient
Hahn and Johnson (1967)	0.87 (Emmit County) 0.86 (East Fork Creek), 0.87 combined
Wiens (2001)	0.89
Hayashi and van der Kamp (2000)	0.04
Wise et al. (2000)	0.49
Hansen (2002)	0.89

Wiens' (2001), Hahn and Johnson's (1967), and Hansen's (2002) equations all produced strong correlations between their derived volumes and the observed volumes obtained by this study. The methods outlined by Hayashi and van der Kamp (2000) provided the weakest correlation between the calculated volume and actual modeled volumes. Hayashi (personal communitcation, 2006) recommends two additional equations that could be used to increase this correlation. The problem with using the Hayashi and van der Kamp (2000) and newly developed Hayashi equations is that they require high-precision surveying that would effectively eliminate the need to apply these equations. The equations are also unable to be applied to any pothole having a unit depth less than one. This means that if a pothole has a depth less than, or equal to, one unit depth, it is unable to calculate the "p" variable.

The negative correlations seen with Wise et al. (2000) indicate that as one variable increases, the other decreases. In the context of most statistical applications, the absolute value is taken, indicating the strength of the correlation. In this case, the Wise et al. (2000) equation produced a strong correlation coefficient of 0.71.

The strong correlations produced by Weins (2001), Hahn and Johnson (1967), and Hansen (2000) indicates a similarity in the physical characteristics of the potholes throughout the entire PPR. With access to the previous researcher's data or the collection of new data it will be possible to combine all of these equations into a single equation that could be applied to most cases.

Comparison of Profiles

Quantifying the relationship between the length, width, depth, surface area, and volume were done with a combination of statistical tests on the collected data. Attempting to qualitatively measure and compare/contrast the pothole bank slope requires a different approach. These tests were completed to determine any symmetry that these pothole bank slopes may exhibit and how they relate to each-other and between the two classes, PEMC and PEMA.

Each of the potholes were divided into quarter transects. These quarter transects were then plotted in Excel and fitted with a second order polynomial. To better approximate slope, the second order derivative of the second order polynomial was calculated. The slope values were then examined using the chi-squared test for distribution. This test was completed at the 95^{th} percentile.

The PEMA class of wetland is log-normally distributed for the T1 and T2 (north-center and south center) and neither normal nor log-normal for the T3 and T4 (east-center, west-center). When all the slopes were combined there was a log-normal distribution. There is little to no correlation between the four transects, with the strongest correlation having only a coefficient of 0.75 between the south-center (T2) and the west-center (T4) (Table 4).

Table 4: Correlation Matrix for Slope Values of PEMA Class Wetlands.

	T1: North-Mid	T2: South-Mid	T3: East-Mid	T4: West-Mid
T1: North-Mid				
T2: South-Mid	0.06			
T3: East-Mid	0.46	0.31		
T4: West-Mid	0.09	0.75	0.38	

The PEMC class has a lognormal distribution for T2 (south-center), normal distribution for T1 and T3 (north-center, east-center), and neither normal nor log-normal distribution for T4 (west-center). No strong correlation can be drawn between any of the slopes, with the highest correlation coefficient of 0.55 between the south-center (T2) and north-center (T1) slopes (Table 5).

Table 5: Correlation Matrix for Slope Values of PEMC Class Wetlands.

	T1: North-Mid	T2: South-Mid	T3: East-Mid	T4: West-Mid
T1: North-Mid				
T2: South-Mid	0.55			
T3: East-Mid	0.11	0.38		
T4: West-Mid	0.01	0.04	0.11	

When all of the slope values were combined and tested for distributions, there is a log-normal distribution in the T3 direction (east-center) and neither normal or log-normal for the T1,T2, and T4. There is also no distribution evident with the total combined slopes. The combined slopes demonstrate no correlations, with the strongest having a correlation coefficient of 0.42 between the south-center (T2) and north-center (T1).

Table 6: Correlation Matrix for the Combined Slopes of PEMA/PEMC Class Wetlands.

	T1: North-Mid	T2: South-Mid	T3: East-Mid	T4: West-Mid
T1: North-Mid				
T2: South-Mid	0.42			
T3: East-Mid	0.18	0.35		
T4: West-Mid	0.03	0.23	0.18	

There is no significant correlation between the measured transects and no symmetry observed in the potholes surveyed in the UTR. This means that attempting to apply a symmetrical approach to depression analysis is not feasible because the slope of each bank is essentially different.

Correlation Between NWI Class and Physical Shape

The Cowardin et al. (1979) classification system is based on a combination of hydrology, soil type and vegetation. This excludes any differentiation based on the lengths, widths, depths, surface areas, and volumes. A closer examination of the two classes PEMC and PEMA as individual entities based on physical constraints yield interesting results (Appendix 6).

Chi-squared tests have concluded that the length, width, and depth of the PEMA class wetlands are all normally distributed at the 95th percentile. The surface area and volume were found to have a log-normal distribution. The PEMC class wetlands were found to have normal distributions for the length, width, depth, and surface area, with only the volume measurements being log-normal.

The standard deviation of both the length and width of PEMC are greater than PEMA, meaning that their dispersion about the means are greater, The means of PEMA are approximately 50% greater in length, 30% less in width, meaning a larger and more elongate form than seen in the PEMC (Figure 6)

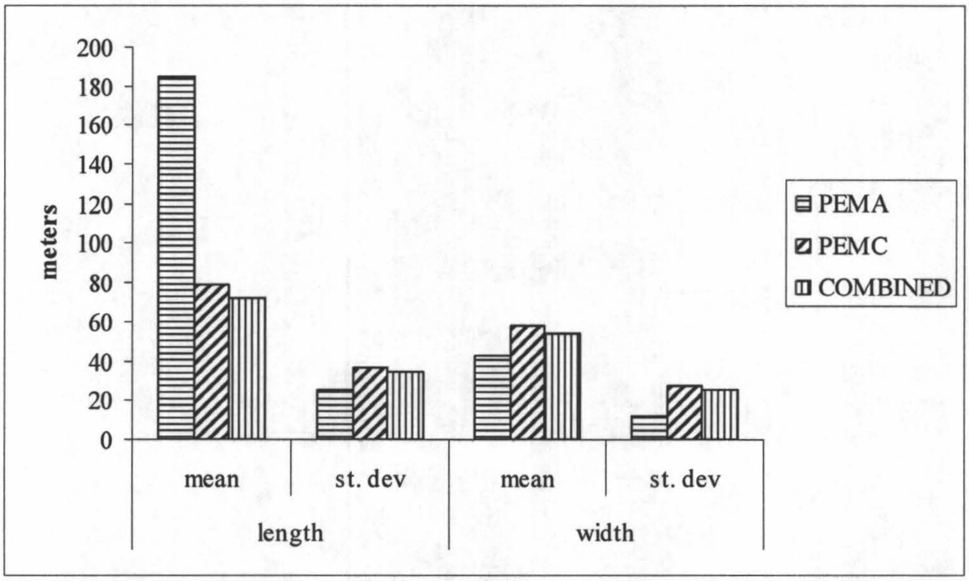

Figure 6: Comparison of Length/Width Mean and Standard Deviation of PEMA, PEMC, and Combined Classes.

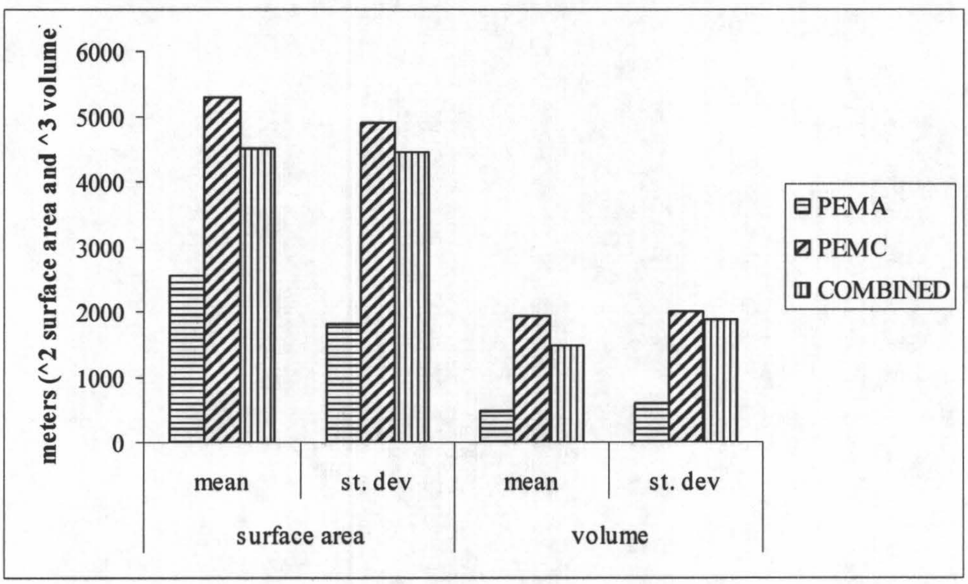

Figure 7: Comparison of Surface Area/Volume Mean and Standard Deviation of PEMA, PEMC, and Combined Classes.

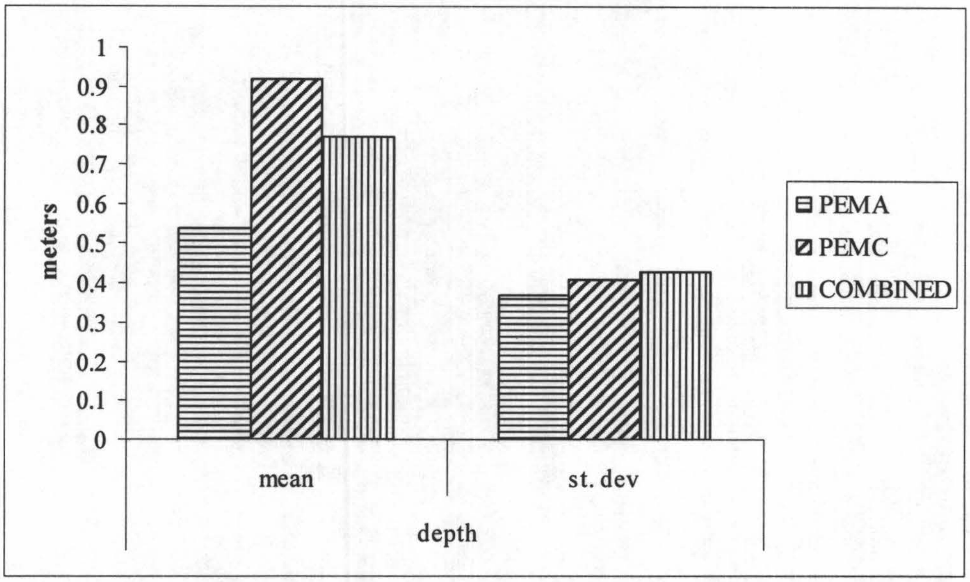

Figure 8: Comparison of Depth Mean and Standard Deviation of PEMA, PEMC, and Combined Classes.

The volume of PEMC is approximately 25% greater than PEMA and the standard deviation is approximately 30% greater. (Figure 7). The surface area of PEMC class wetlands are twice as large as the PEMA class. Lastly, the standard deviation of the PEMC class area are found to be twice that of the PEMA class.

Surface area and volume further illustrate the larger geometries of the PEMC class of wetland. (Combined with a larger standard deviation) This illustrates a higher degree of dispersion in PEMC, which are flooded each year, whereas PEMC are subject to ephemeral and short-term flooding and therefore have less time when there is no water present.

To verify whether the PEMC and PEMA values for length, width, depth, surface area, and volume come from the same population, both a T-test and an F-test were completed at the 95th percentile. The T-test calculates the probability that both classes come from a population with the same mean, while the F-test is used to establish whether both the PEMC and PEMA come from populations with the same variance.

The T and F tests found that variance and means for the lengths of the PEMC and PEMA are from the same populations. Although the PEMC displays overall larger lengths, this essentially means that the means and the variance were the same. The widths were from populations with different means but the same variance. This illustrates the fact that the PEMC has an overall larger mean when compared to the PEMA, while the variance or dispersion about that mean are statistically the same. The depths were found to have the same mean but different variance. This indicates the PEMC has greater dispersion about that same mean. The surface area of PEMC and PEMA were found to have the same means and variances. Lastly, the volumes of PEMC and PEMA were found to have the same mean with different variance.

The correlation between PEMC values of length, width, depth, volume, and surface area (Table 7) shows that surface area has a significant relationship between all of the measured traits except for depth, which has its strongest correlation with volume (0.68).

Table 7: Correlation Matrix for Physical Measurement Values for PEMC Wetlands.

	Length	Width	Max. Depth	Surface Area	Volume
Length					
Width	0.86				
Max. depth	0.50	0.55			
Surface area	0.91	0.95	0.44		
Volume	0.87	0.89	0.68	0.90	

The PEMA correlation matrix (Table 8) suggests a close connection between all of the measured traits except depth, which, as seen in the PEMC class, has its strongest correlation with volume (0.90).

Table 8: Correlation Matrix for Physical Measurement Values for PEMA Wetlands.

	Length	Width	Max. depth	Surface area	Volume
Length					
Width	0.79				
Max. depth	0.48	0.47			
Surface area	0.96	0.89	0.47		
Volume	0.71	0.67	0.90	0.74	

There are higher correlations when the PEMC and PEMA classes are combined. There is an increased correlation (90%) between the maximum depth and volume seen in the PEMA classes. In PEMC, the maximum depth- area correlation is greater, and the PEMA maximum depth- volume correlation is greater. This is due to geometrical differences involving their shapes.

Discriminant analysis on PEMC and PEMA was conducted using the DISCRIM program at the 95th percentile. The DISCRIM program provides an end F-ratio value that can be compared with the tabular values in Davis (2000). The discriminant analysis F-ratio calculated was 4.54. In order for the data to be considered as one group, the F-ratio must be below 2.83 (Davis, 2000). This indicates that the two groups are distinct and separate, with depth contributing the largest to the difference. The depth value also had the highest correlation, as illustrated by Table 8. Galatowitsch and van der Valk (1994) stated that while there are differences in the presence of flora and fauna between potholes, this is primarily due to differences in basin morphology (specifically depth), size, hydrology, and water chemistry.

Separate power functions were generated for both PEMA and PEMC classesin order to illustrate any differences between the two. Figure 9 shows the power regression for the PEMC class. A correlation coefficient of 0.90 was calculated which, when compared to the other approaches, can be considered significant.

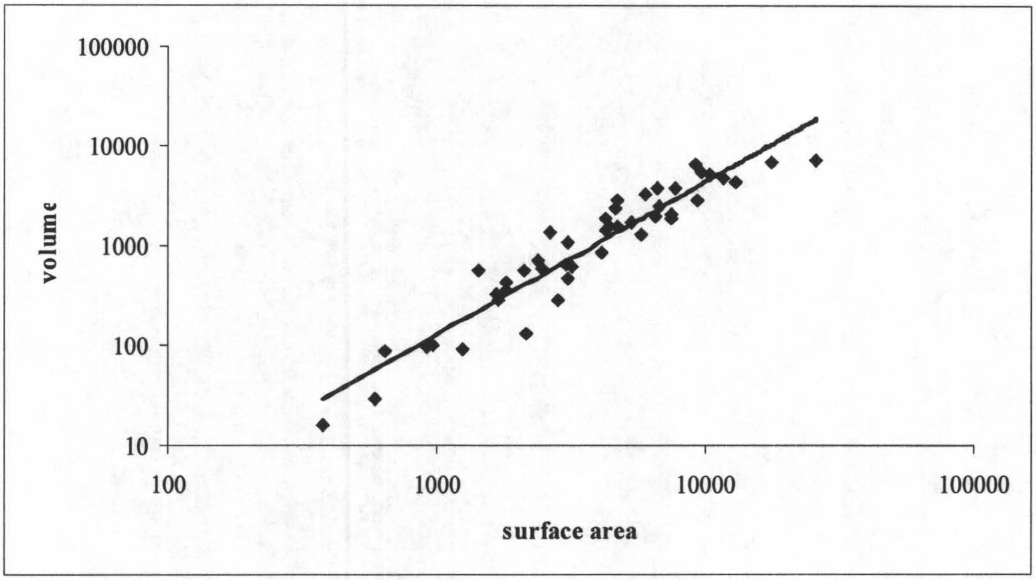

Figure 9: Best Fit Power Regression Line for PEMC Class Wetlands (Surface Area in Square Meters and Volume, Cubic Meters).

The PEMA class has a somewhat lower correlation coefficient (0.76). (Figure 10). This value is within the acceptable range demonstrated by the other statistical methods.

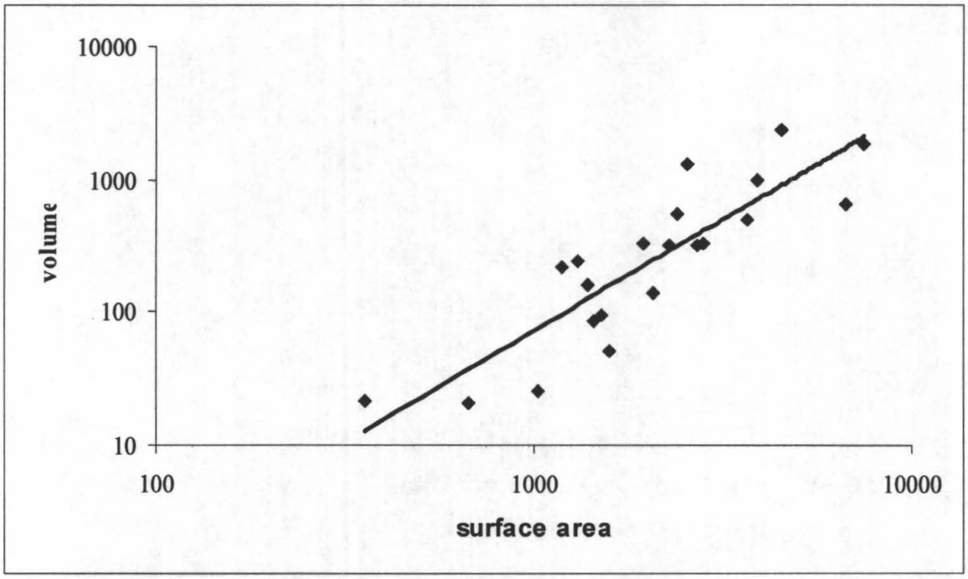

Figure 10: Best Fit Power Regression Line for PEMA Class Wetlands (Surface Area in Square Meters and Volume, Cubic Meters).

CHAPTER IV

CONCLUSIONS

There is a high degree of variability between the potholes in different sub-regions of the PPR and within an individual watershed. Attempts to quantify the differences in volume in relation to surface area have met with moderate success on a local basis. Difficulties in deriving an equation that can be successfully applied to all watersheds within the PPR are partially due to the lack of a classification scheme based on geometrical properties.

The system of classification of wetlands developed by Cowardin (1979) proved successful in differentiating two classes of pothole found in the UTR watershed, the PEMA and PEMC. These two classes, separated by differences in water permanence, will have distinct physical differences in depth, surface area and volume. Aro and Branson (1962) state that the ratio of open water to vegetation-covered areas, as well as species zonation, is linked directly to the depth of water in the potholes. This fact, in light of the discriminant analyses results presented herein, indicate that depth is the major factor for distinguishing the two groups.

Curve values generated for the different transects for each pothole failed to produce any viable correlations or distributions. This means that subsurface symmetry is lacking log-normal or normal distributions, with each of the different transects displaying no correlation to each other. This helps to explain the inability of other regression equations to adequately model potholes in other watersheds.

Additional surveying needs to be completed within the different sub-regions of the PPR to increase bathymetric data. Analysis of these additional data could be used to support or refute the applicability of the Cowardin et al. (1979) system of classification and NWI data for simple predictions of pothole volume. These measurements need to include classes not outlined in this study and on a scale that makes our assumptions more meaningful. The divisions may exist at the subsystem or system levels of the NWI classification system.

Careful consideration to include all data collected will provide subsequent researchers with the ability to produce single, combined equations relating surface area to volume, as seen in Hahn and Johnson (1967). It is only through this inclusion that a single set of equations can be produced for separate NWI classes as well as the possibility of a single, master equation for the PPR.

APPENDIX 1: NATIONAL WETLANDS INVENTORY (NWI) CLASSIFICATIONS

The national wetlands inventory (NWI) classification system was developed by Cowardin et al. (1979) to provide a framework for classifying wetlands. The first delineation is the system, which divides the wetlands into five distinct categories: marine, estuarine, riverine, lacustrine, and palustrine. The first letter P in the PEMC and PEMA designations, represents palustrine. The palustrine category includes marshes, wet meadows, fens, playas, pocosins, bogs, swamps, and small shallow ponds. The palustrine system displays the following characteristics:

(1) Area less than 81 square decameters

(2) Lack of wave-formed or bedrock shoreline

(3) Water depth less than 2 meters at low water

(4) Salinity due to ocean derived salts less than 0.5‰

The next delineation is subsystem. Since this level of classification does not apply to palustrine systems, it will not be discussed further. Each system/subsystem is further divided into classes, which describe the substrate or dominant vegetative form. There are five vegetative classes for areas across which vegetation covers 30% or more of the surface. These include aquatic bed, moss-lichen, emergent, scrub-shrub, and forested wetlands. There are an additional six classes that designate a general lack of vegetative cover. The EM in PEMC and PEMA classify these potholes within the emergent wetlands class. The emergent wetland class is characterized by erect, herbaceous, rooted, hydrophytes, excluding mosses and lichens.

Each class is further subdivided into subclass, which define the dominant vegetation and the substrate in non-vegetated areas. Within this subclass, a variety of modifiers can be added to illustrate characteristics such as soil types, chemistry, and human effects.

In the context of this study, the A, C, or F modifier designates the water regime present in the pothole. A refers to temporarily flooded, F semi-permanently flooded, and C seasonally flooded. The lower case d seen in PEMCd is a special modifier that signifies the poorly drained nature of this class of wetland.

APPENDIX 2: DERIVING THE HAYASHI AND VAN DER KAMP EQUATIONS

When deriving the Hayashi and Van der Kamp (2000) equations the first step is to complete two transects for each pothole, one in the north-south direction and another in the east-west direction by measuring depth at three meter intervals. Once collected they are entered into a mapping program such as SURFER and gridded/mapped.

The first step is to determine what the "p" (profile) constant for the particular depression. This is completed by using the equation:

$$\frac{y}{y_o} = \left(\frac{r}{r_o}\right)^p \tag{14}$$

The r variable represents the overall radius of the surveyed depression and the y variable is referencing the total depth, y_o is the unit depth. Since the interval and unit applied is one meter, this means that y_o is always one meter. The r_o represents what the radius of the depression would be at the unit depth (h_o). Once these three values are known we can then enter them into a modified version of the above equation:

$$p = \frac{\ln \frac{y}{y_o}}{\ln \frac{r}{r_o}} \tag{15}$$

The p constant is essentially a ratio of the unit radius and depth to the total depression radius and depth. The p value is the degree of curvature of the pothole bank slope.

The third step is to derive s using the following equation:

$$s = \Pi r_o^2 \tag{16}$$

Solving for s gives us what Hayashi and Van der Kamp (2000) refer to as a scaling constant; essentially it is the area of the water surface when the depth is one meter.

The volume is then calculated using the following equation:

$$V = \left(\frac{s}{(1+2/p)}\right)\left(\frac{h^{1+(2/p)}}{h_o^{2/p}}\right) \qquad (17)$$

APPENDIX 3: SURVEY DATA

Pond #	Lat	Long	NWI Class	Length meters	Width meters	Depth meters	Volume meters ^3	Area meters^2
1	48.01	-97.90	PEMCd	67.06	45.72	1.07	1074.33	3064.15
2	48.01	-97.91	PEMCd	131.06	79.25	1.22	5223.01	10342.05
3	48.01	-97.91	PEMC	155.45	76.20	1.21	4847.04	11786.86
4	48.02	-97.90	PEMCd	85.34	54.86	1.26	2394.10	4680.68
5	n/a	n/a	unknown	115.82	100.58	1.11	5478.57	11635.70
6	n/a	n/a	unknown	60.96	54.86	0.85	683.58	3150.89
9	48.04	-97.91	U	88.39	45.72	0.42	550.88	3987.39
10	48.04	-97.92	PEMA	36.58	33.53	0.54	212.61	1187.39
11	n/a	n/a	unknown	45.72	33.53	0.43	224.67	1477.03
12	48.00	-97.93	PEMC	70.10	67.06	1.53	2841.84	4695.16
14	47.99	-97.92	PEMA	45.72	36.58	0.16	50.28	1598.21
15	47.99	-97.92	PEMA	21.34	21.34	0.22	21.16	355.73
16	47.99	-97.92	PEMA	42.67	30.48	0.55	243.96	1299.64
17	47.99	-97.92	PEMA	54.86	51.82	0.57	331.24	2826.42
18	47.99	-97.92	PEMA	121.92	54.86	0.39	652.33	6657.27
19	47.99	-97.92	PEMA	39.62	39.62	0.37	160.29	1397.63
20	47.99	-97.92	PEMA	33.53	30.48	0.26	25.69	1020.70
21	47.99	-97.93	PEMF	134.11	115.82	1.13	6202.67	15530.13
22	47.99	-97.93	PEMC	57.91	42.67	0.92	595.05	2465.71
23	47.98	-98.00	PEMC	146.30	91.44	0.90	4340.14	13042.61
24	47.98	-98.00	PEMC	94.49	70.10	1.41	3769.06	6621.77
25	47.98	-98.00	PEMC	85.34	54.86	1.12	1564.28	4421.42
26	47.96	-97.99	PEMC	82.30	57.91	0.93	1584.01	4763.38
27	47.96	-97.99	PEMC	67.06	45.72	0.47	480.05	3064.42
28	47.95	-97.99	PEMC	100.58	57.91	0.69	1298.85	5822.99
29	48.00	-98.01	PEMA	57.91	48.77	0.35	319.12	2730.77
30	47.98	-98.01	PEMA	57.91	39.62	0.60	313.85	2292.70
31	47.96	-98.01	PEMC	170.69	152.40	1.08	7323.19	26006.55
32	47.97	-98.01	PEMA	39.62	36.58	0.23	86.11	1448.25
33	47.97	-98.01	PEMA	48.77	42.67	0.33	140.35	2078.58
34	47.98	-98.02	PEMC	103.63	67.06	0.79	2567.02	6751.23
35	47.98	-97.92	PEMC	134.11	73.15	1.58	5577.16	9736.44
36	47.98	-97.92	PEMC	106.68	73.15	1.60	3875.04	7786.15
37	47.98	-98.03	PEMC	82.30	39.62	0.77	644.51	3196.17
40	48.03	-98.01	PEMC	146.30	146.30	1.36	6914.35	17855.49
41	48.03	-98.01	PEMC	33.53	27.43	0.29	97.18	918.34
42	48.03	-98.01	PEMC	85.34	76.20	0.91	1950.79	6501.06
43	48.03	-98.00	PEMC	118.87	79.25	0.92	2882.21	9415.74
44	48.04	-98.00	PEMF	33.53	30.48	0.38	85.15	1019.90
45	48.04	-97.99	PEMC	97.54	54.86	0.86	1722.82	5347.58
46	48.04	-97.99	PEMC	45.72	27.43	0.42	93.07	1248.41
47	48.05	-98.02	PEMC	27.43	21.34	0.15	28.29	584.46
48	48.05	-98.00	U	45.72	27.43	0.26	114.28	1252.11
49	48.05	-98.00	PEMC	48.77	48.77	0.90	714.22	2372.85
50	48.04	-97.98	PEMC	103.63	73.15	0.78	2060.35	7577.99
51	48.01	-97.90	PEMC	57.91	36.58	1.04	575.46	2103.91

Pond #	Lat	Long	NWI Class	Length meters	Width meters	Depth meters	Volume meters ^3	Area meters^2
52	48.01	-97.90	PEMC	42.67	42.67	0.83	433.77	1818.66
53	48.02	-97.92	PEMA	60.96	39.62	0.65	549.42	2414.25
54	48.02	-98.06	PEMC	42.67	42.67	0.60	362.27	1818.42
55	48.03	-98.05	PEMA	91.44	42.67	0.70	999.33	3896.73
56	48.04	-98.05	PEMA	45.72	42.67	0.54	324.40	1948.41
57	n/a	n/a	unknown	91.44	85.34	0.42	1071.84	7581.79
58	48.01	-98.04	PEMC	33.53	33.53	0.40	99.32	960.67
59	47.98	-98.02	PEMA	39.62	39.62	0.34	94.49	1504.62
60	47.98	-97.98	PEMC	94.49	64.01	1.55	3294.73	6032.32
61	48.05	-98.06	PEMC	67.06	64.01	1.05	1429.57	4274.63
62	48.06	-98.01	PEMC	39.62	36.58	1.19	584.45	1417.39
63	48.06	-97.97	PEMC	54.86	51.82	0.31	287.57	2822.78
64	48.06	-97.97	PEMC	76.20	30.48	0.34	128.85	2135.98
65	48.03	-97.96	PEMF	33.53	33.53	0.33	99.05	1069.72
66	48.04	-97.95	PEMA	60.96	42.67	1.29	1282.65	2545.42
67	48.02	-97.91	PEMC	73.15	57.91	0.70	891.18	4111.20
68	48.05	-97.90	PEMC	45.72	36.58	0.65	337.55	1652.38
69	48.04	-98.03	PEMA	82.30	54.86	1.68	2306.64	4504.54
70	48.04	-98.03	PEMC	27.43	24.38	0.55	87.71	640.23
71	48.03	-98.03	PEMC	42.67	39.62	0.66	288.57	1680.71
72	47.99	-97.91	PEMA	106.68	73.15	0.88	1863.39	7483.22
73	47.99	-97.90	PEMC	100.58	91.44	1.67	6714.24	9182.93
74	47.99	-97.90	PEMC	67.06	64.01	1.58	1889.17	4285.74
75	47.99	-97.94	PEMCd	103.63	73.15	0.60	1890.69	7565.92
76	48.02	-98.06	PEMA	64.01	60.96	0.47	502.67	3675.63
77	48.00	-97.93	PEMA	27.43	24.38	0.13	20.68	666.87
78	47.99	-97.98	PEMC	60.96	51.82	1.04	671.92	3014.93
79	48.04	-97.98	PEMC	27.43	18.29	0.17	15.68	372.15
80	48.05	-98.00	PEMC	51.82	51.82	1.30	1350.12	2651.63
81	n/a	n/a	unknown	45.72	33.53	0.87	412.67	1529.50
82	n/a	n/a	unknown	45.72	42.67	0.44	269.78	1876.67
83	n/a	n/a	unknown	51.82	45.72	1.08	791.97	2367.37
84	n/a	n/a	unknown	51.82	48.77	1.44	1274.65	2511.81
85	n/a	n/a	unknown	73.15	45.72	1.11	1176.33	3305.74
86	n/a	n/a	unknown	48.77	24.38	0.43	191.93	1168.01
87	n/a	n/a	unknown	54.86	45.72	0.75	522.03	2484.45

APPENDIX 4: SLOPE DATA

Pond #	NWI Class		SLOPES	x2	
		North-Mid	Mid-South	West-Mid	Mid-East
		T1	T2	T3	T4
1	PEMCd	1.00E-04	5.00E-04	5.00E-04	2.00E-05
2	PEMCd	1.00E-04	1.00E-04	2.00E-04	4.00E-03
3	PEMC	2.00E-04	2.00E-04	1.00E-04	8.00E-05
4	PEMCd	2.00E-04	4.00E-04	4.00E-04	6.00E-04
10	PEMA	8.00E-04	6.00E-07	8.00E-04	6.00E-04
12	PEMC	5.00E-04	2.00E-04	4.00E-04	4.00E-04
14	PEMA	5.00E-07	1.00E-04	3.00E-04	2.00E-04
15	PEMA	3.00E-04	1.30E-03	6.00E-04	2.80E-03
16	PEMA	3.00E-04	2.00E-04	3.00E-04	8.00E-04
17	PEMA	4.00E-04	2.00E-04	5.00E-04	1.00E-04
18	PEMA	5.00E-06	5.00E-07	1.00E-04	5.00E-10
19	PEMA	5.00E-04	-1.00E-05	6.00E-04	-8.00E-05
20	PEMA	1.00E-04	3.00E-04	1.00E-04	5.00E-04
21	PEMF	2.00E-04	2.00E-05	2.00E-04	2.00E-04
22	PEMC	2.00E-04	4.00E-04	6.00E-04	9.00E-05
23	PEMC	1.00E-05	8.00E-05	5.00E-05	1.00E-04
24	PEMC	5.00E-04	4.00E-04	2.00E-04	3.00E-04
25	PEMC	3.00E-04	2.00E-04	4.00E-04	3.00E-04
26	PEMC	5.00E-04	3.00E-04	2.00E-04	2.00E-04
27	PEMC	1.00E-04	2.00E-06	1.00E-04	3.00E-05
28	PEMC	9.00E-05	6.00E-05	7.00E-04	2.00E-04
29	PEMA	1.00E-04	3.00E-04	1.00E-04	2.00E-04
30	PEMA	2.00E-04	2.00E-05	6.00E-04	9.00E-04
31	PEMC	2.00E-05	2.00E-05	9.00E-05	1.00E-04
32	PEMA	7.00E-04	8.00E-05	2.00E-04	1.00E-04
33	PEMA	3.00E-04	1.00E-04	2.00E-05	1.00E-05
34	PEMC	2.00E-05	6.00E-04	2.00E-04	7.00E-05
35	PEMC	6.00E-05	6.00E-05	2.00E-04	1.00E-04
36	PEMC	4.00E-04	3.00E-04	9.00E-05	2.00E-04
37	PEMC	1.90E-03	7.00E-04	4.00E-06	2.00E-04
40	PEMC	2.00E-04	5.00E-04	1.00E-04	9.00E-05
41	PEMC	4.00E-04	7.00E-04	2.00E-04	2.00E-04
42	PEMC	9.00E-05	2.00E-04	8.00E-05	2.00E-04
43	PEMC	3.00E-05	3.00E-04	2.00E-04	1.00E-04
45	PEMC	2.00E-04	2.00E-04	4.00E-04	2.00E-04
46	PEMC	9.00E-04	1.20E-03	2.00E-04	4.00E-04
47	PEMC	3.00E-04	1.10E-03	4.00E-04	4.00E-04
49	PEMC	7.00E-04	2.00E-04	2.00E-04	5.00E-04
50	PEMC	7.00E-06	6.00E-05	2.00E-04	4.00E-04
51	PEMC	8.00E-05	1.00E-03	6.00E-04	6.00E-04
52	PEMC	8.00E-05	1.00E-04	1.60E-03	1.00E-04
53	PEMA	1.10E-03	2.00E-04	3.00E-04	4.00E-04
54	PEMC	5.00E-04	2.00E-04	5.00E-04	6.00E-04
55	PEMA	1.00E-04	1.00E-04	2.00E-04	3.00E-04
56	PEMA	3.00E-04	7.00E-04	3.00E-04	6.00E-05
58	PEMC	4.00E-04	7.00E-04	1.10E-03	9.00E-04
59	PEMA	3.00E-04	1.00E-04	4.00E-04	7.00E-05
60	PEMC	3.00E-04	3.00E-04	3.00E-04	3.00E-04

			SLOPES	x2	
Pond #	NWI Class	North-Mid	Mid-South	West-Mid	Mid-East
		T1	T2	T3	T4
61	PEMC	3.00E-04	3.00E-04	2.00E-05	8.00E-05
62	PEMC	9.00E-04	1.50E-03	3.00E-03	8.00E-04
63	PEMC	1.00E-04	2.00E-04	6.00E-05	2.00E-06
66	PEMA	7.00E-04	6.00E-04	2.00E-03	1.20E-03
67	PEMC	3.00E-04	1.00E-04	1.00E-04	5.00E-04
68	PEMC	8.00E-04	8.00E-04	3.00E-04	1.00E-04
69	PEMA	4.00E-04	5.00E-04	4.00E-04	4.00E-04
70	PEMC	9.00E-04	1.40E-03	1.00E-04	7.00E-04
71	PEMC	5.00E-04	3.00E-04	2.00E-04	6.00E-04
73	PEMC	2.00E-04	3.00E-04	3.00E-04	5.00E-04
74	PEMC	3.00E-04	6.00E-04	6.00E-04	5.00E-05
75	PEMCd	3.00E-04	2.00E-04	1.00E-04	1.00E-04
76	PEMA	3.00E-04	1.00E-04	1.00E-04	2.00E-04
77	PEMA	5.00E-04	3.00E-04	1.00E-03	1.00E-04
78	PEMC	6.00E-04	6.00E-04	5.00E-04	2.00E-04
79	PEMC	3.00E-04	5.00E-04	2.10E-03	n/a
80	PEMC	1.00E-03	8.00E-04	8.00E-04	6.00E-04

APPENDIX 5: COMPARISON FIGURES FOR PREVIOUS STUDIES

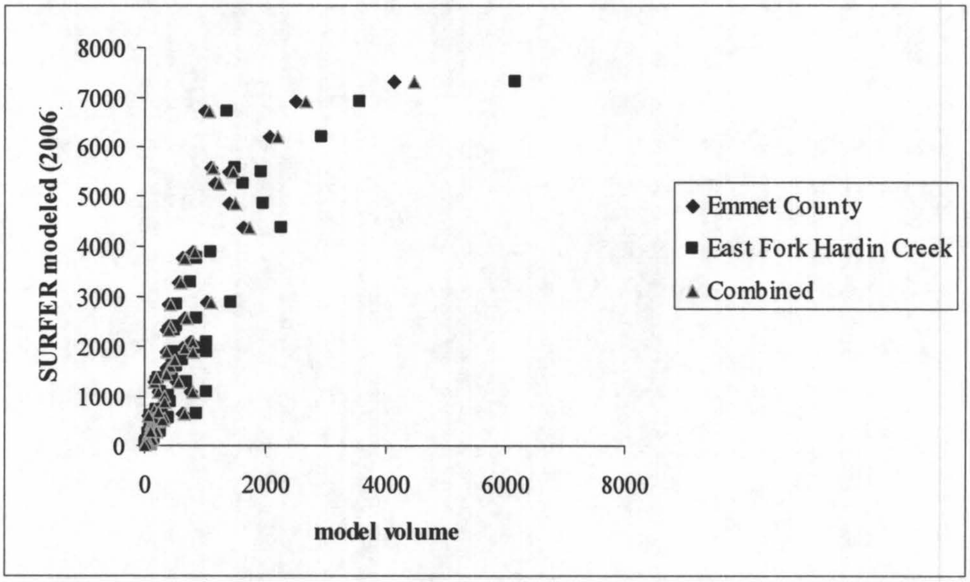

Figure 11: Hahn and Johnson (1967) Generated Volumes Versus the SURFER Modeled Volumes (Both in Meters Cubed).

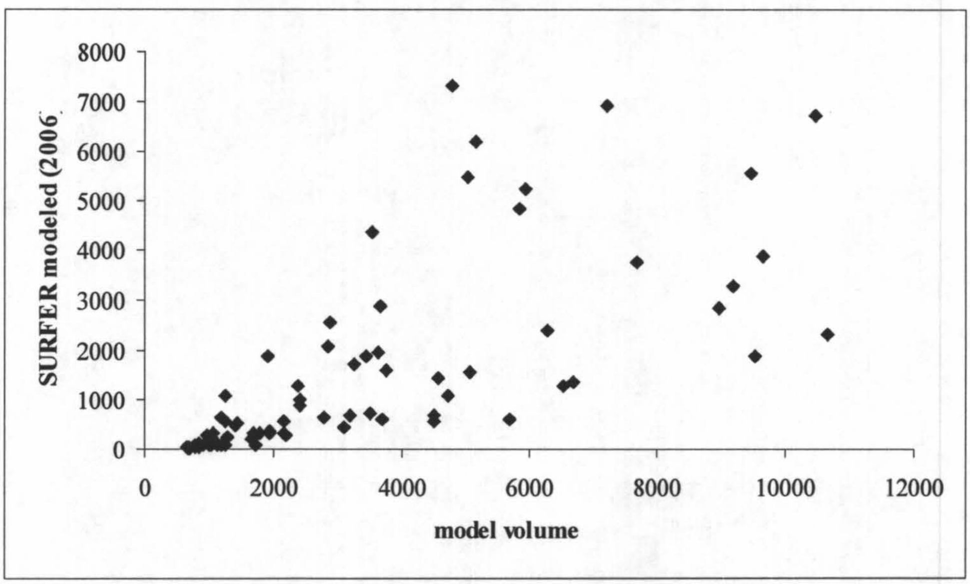

Figure 12: Wise et al. (2000) Generated Volumes Versus the SURFER Modeled Volumes (Both in Meters Cubed).

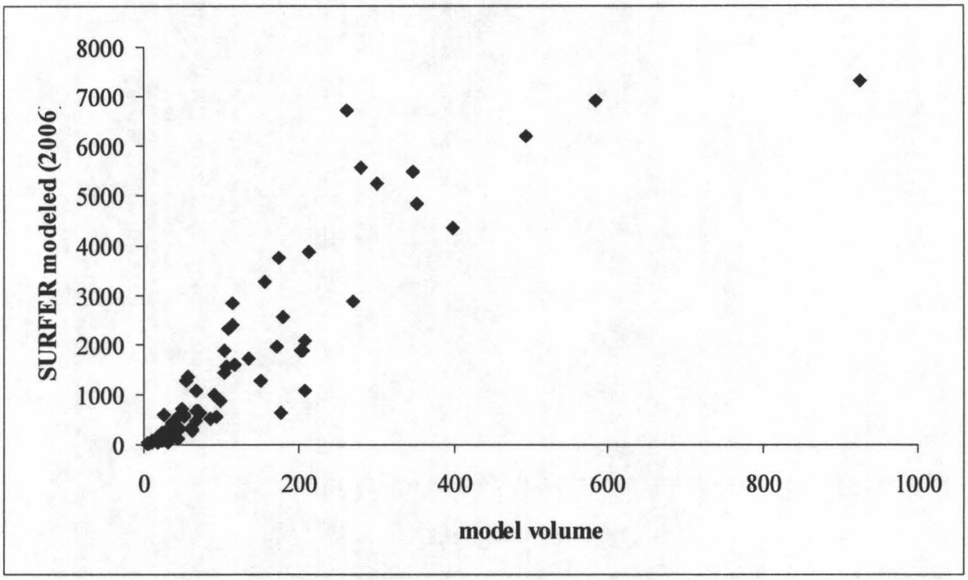

Figure 13: Weins (2001) Generated Volumes Versus the SURFER Modeled Volumes (Both in Cubic Meters).

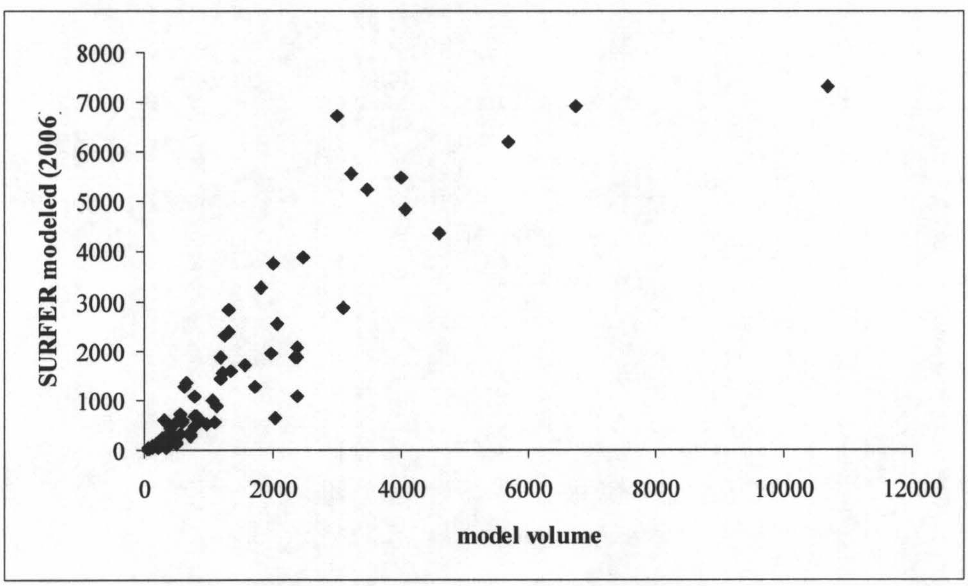

Figure 14: Hansen (2002) Generated Volume Versus the SURFER Modeled Volume (Both in Meters Cubed).

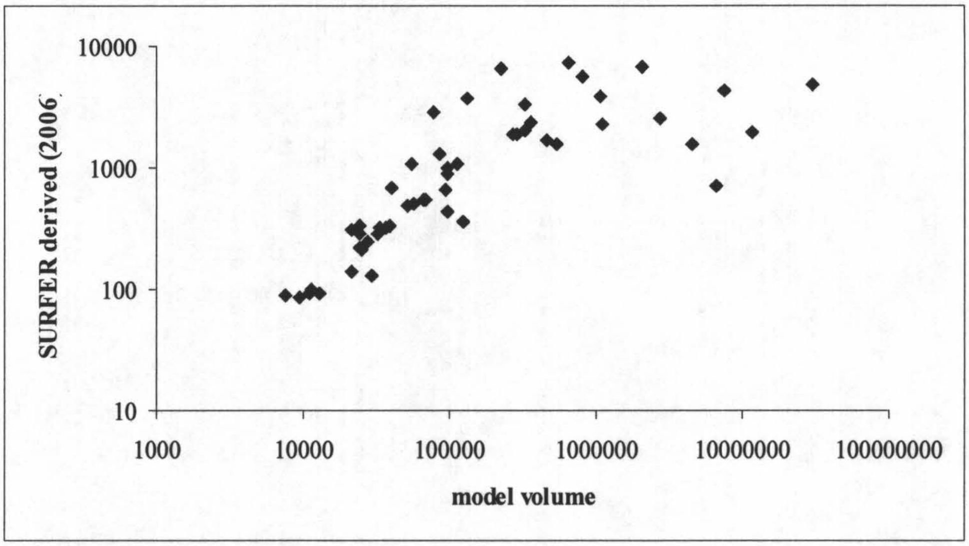

Figure 14: Hayashi and van der Kamp (2001) Generated Volume Versus the SURFER Generated Volume (Both in Meters Cubed).

APPENDIX 6: PEMA / PEMC DESCRIPTIVE STATISTICS

Descriptive Statistics for PEMA Class Wetlands

	length	meters	width	meters	depth	meters	volume	cub. Meters	area	sq. meters	vol/area
Mean	1.84E+02	5.62E+01	1.39E+02	4.22E+01	1.76E+00	5.36E-01	1.77E+04	5.00E+02	2.74E+04	2.55E+03	5.22E-01
Median	1.60E+02	4.88E+01	1.30E+02	3.96E+01	1.55E+00	4.72E-01	1.11E+04	3.14E+02	2.24E+04	2.08E+03	3.84E-01
Mode	1.30E+02	3.96E+01	130, 140	;24, 42.672	-	-	-	-	-	-	-
Std Error	1.83E+01	5.59E+00	8.71E+00	2.65E+00	2.67E-01	8.14E-02	4.80E+03	1.36E+02	4.32E+03	4.01E+02	9.68E-02
Std Dev.	8.41E+01	2.56E+01	3.99E+01	1.22E+01	1.22E+00	3.73E-01	2.20E+04	6.23E+02	1.98E+04	1.84E+03	4.43E-01
Variance	7.07E+03	6.56E+02	1.59E+03	1.48E+02	1.50E+00	1.39E-01	4.83E+08	3.88E+05	3.91E+08	3.38E+06	1.97E-01
Coeff. Var.	4.56E+01	4.56E+01	2.88E+01	2.88E+01	6.96E+01	6.96E+01	1.25E+02	1.25E+02	7.21E+01	7.21E+01	8.50E+01
Minimum	7.00E+01	2.13E+01	7.00E+01	2.13E+01	4.20E-01	1.28E-01	7.30E+02	2.07E+01	3.83E+03	3.56E+02	8.26E-02
Maximum	4.00E+02	1.22E+02	2.40E+02	7.32E+01	5.52E+00	1.68E+00	8.15E+04	2.31E+03	8.06E+04	7.48E+03	1.68E+00
Range	3.30E+02	1.01E+02	1.70E+02	5.18E+01	5.10E+00	1.55E+00	8.07E+04	2.29E+03	7.67E+04	7.13E+03	1.60E+00
Count	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01	2.10E+01
Skewness	1.22E+00	1.22E+00	6.79E-01	6.79E-01	1.86E+00	1.86E+00	1.91E+00	1.91E+00	1.52E+00	1.52E+00	1.71E+00
P(Skewnes	1.99E-02	1.99E-02	1.65E-01	1.65E-01	1.27E-03	1.27E-03	1.01E-03	1.01E-03	5.58E-03	5.58E-03	2.42E-03
Kurtosis	1.20E+00	1.20E+00	9.21E-01	9.21E-01	3.93E+00	3.93E+00	3.17E+00	3.17E+00	2.11E+00	2.11E+00	2.78E+00
P(Kurtosis)	2.03E-01	2.03E-01	2.83E-01	2.83E-01	1.11E-02	1.11E-02	2.33E-02	2.33E-02	7.12E-02	7.12E-02	3.45E-02

Descriptive Statistics for PEMC Class Wetlands

	length	meters	width	meters	depth	meters	volume	cub. Meters	area	sq. meters	vol/area
Mean	2.59E+02	7.90E+01	1.91E+02	5.81E+01	3.02E+00	9.20E-01	6.89E+04	1.95E+03	5.71E+04	5.30E+03	1.01E+00
Median	2.40E+02	7.32E+01	1.80E+02	5.49E+01	3.00E+00	9.14E-01	4.77E+04	1.35E+03	4.60E+04	4.27E+03	9.84E-01
Mode	2.20E+02	6.71E+01	2.40E+02	7.32E+01	-	-	-	-	-	-	-
Std Error	1.79E+01	5.46E+00	1.33E+01	4.05E+00	2.00E-01	6.10E-02	1.06E+04	3.00E+02	7.84E+03	7.29E+02	8.07E-02
Std Dev.	1.20E+02	3.67E+01	8.90E+01	2.71E+01	1.34E+00	4.09E-01	7.12E+04	2.01E+03	5.26E+04	4.89E+03	5.41E-01
Variance	1.45E+04	1.34E+03	7.93E+03	7.37E+02	1.80E+00	1.68E-01	5.06E+09	4.06E+06	2.77E+09	2.39E+07	2.93E-01
Coeff. Var.	4.64E+01	4.64E+01	4.67E+01	4.67E+01	4.45E+01	4.45E+01	1.03E+02	1.03E+02	9.22E+01	9.22E+01	5.37E+01
Minimum	9.00E+01	2.74E+01	6.00E+01	1.83E+01	5.00E-01	1.52E-01	5.54E+02	1.57E+01	4.01E+03	3.72E+02	1.38E-01
Maximum	5.60E+02	1.71E+02	5.00E+02	1.52E+02	5.47E+00	1.67E+00	2.59E+05	7.32E+03	2.80E+05	2.60E+04	2.40E+00
Range	4.70E+02	1.43E+02	4.40E+02	1.34E+02	4.97E+00	1.51E+00	2.58E+05	7.31E+03	2.76E+05	2.56E+04	2.26E+00
Count	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01	4.50E+01
Skewness	6.38E-01	6.38E-01	1.60E+00	1.60E+00	3.44E-02	3.44E-02	1.27E+00	1.27E+00	2.24E+00	2.24E+00	4.39E-01
P(Skewnes	7.22E-02	7.22E-02	1.62E-04	1.62E-04	9.18E-01	9.18E-01	1.39E-03	1.39E-03	2.69E-06	2.69E-06	2.03E-01
Kurtosis	-1.96E-01	-1.96E-01	4.10E+00	4.10E+00	-7.45E-01	-7.45E-01	7.66E-01	7.66E-01	6.80E+00	6.80E+00	-2.86E-01
P(Kurtosis)	6.11E-01	6.11E-01	2.02E-03	2.02E-03	2.49E-01	2.49E-01	2.40E-01	2.40E-01	1.37E-04	1.37E-04	5.30E-01

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