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A Roof Runoff Strategy and Model for Augmenting Public Water Supply

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A Roof Runoff Strategy and Model for Augmenting Public Water Supply

by

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To my father and mother, to whom I owe everything.

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AAS	Atomic Absorption Spectrophotometry
Ancedent	abbreviated form of Antecedent
(aq.)	Aqueous Solutions
As	Arsenic
Avg	Average
Cd	Cadmium
Co	Cobalt
coef	coefficient
Con	Control
Cr	Chromium
Cu	Copper
cf	cubic feet
c.f.s	cubic-feet-per-second (also cfs)
DRRH	Domestic Roof Rainwater Harvesting
eff	efficiency
EPA	(United States) Environmental Protection Agency
°F	degrees Fahrenheit
Fe	Iron
F.A.C	Florida Administrative Code
FDEP	Florida Department of Environmental Protection

FDOT	Florida Department of Transportation
F.S.	Florida Statute
g	gram
(g)	gaseous
GIS	Geographic Information Systems
gpm	gallons per minute
g/cap -day	gallons capacity per day
HDPE	high-density polyethylene
HNO_3	nitric acid
ICP	Inductively Coupled Plasma
ICP-MS	Inductive Coupled Plasma-Mass Spectrometry
Max	maximum
MCLs	maximum contaminant levels
MGD	million gallons per day
Min	minimum
ml	millimeter
Mg	Magnesium
mg/L	miligram per liter
Mn	Manganese
nm	nanometer
Ni	Nickel
%RSD	relative standard deviation express as a percentage
Pcpn	precipitation

Pb	Lead
QA	Quality Assurance
Ref	Reference
S1	Clay Barrel tile
S2	Glazed tile
S3	Shaker tile
S4	Painted galvanized tin
S5	Galvanized tin
16 Θ ”	sixteen inch diameter pipe
SDWA	Safe Drinking Water Act
SFWMD	South Florida Water Management District
SWFWMD	Southwest Florida Water Management District
sf/home	square feet per home
TDS	Total Dissolved Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
Vol	Volume
WMD	Water Management District
yr	year
Zn	Zinc

Statistically significant at .01 **

Statistically significant at .05*

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ABSTRACT

Water is the essential resource that is becoming extremely scarce worldwide. The 21st century will further stress all available water resources through the growth and expansion of developing nations. It is not only the quantity of cheap water that is being depleted, but the quality of these waters is being endangered. Florida is an example where rapid development and an exploding population are competing for shrinking groundwater resources. Current water use does not address the use of alternative supplies and reuses in the United States.

The objective of this research was to determine a strategy for augmenting existing water supplies with alternative sources that could be developed economically. Having reviewed numerous alternative sources, it was determined that runoff from roofs potentially provides a source that might meet the augmentation requirement for a small community of a population of 30,000 or less.

This research has shown that the quality of water collected from five different roof surfaces meets the drinking water standards and will not degrade the current quality of the main source of water supply. This work not only required the collection of hydrological data from the roof systems, but chemically and biological analyzes samples for contaminants. Since rainfall events vary periodically and in duration, 100,000 meteorological events were analyzed for wind speed, relative humidity, rainfall intensity,

and the rainwater runoff across five roofing surfaces to analyze variables that contribute to the effects on the water quality of the source. The model establishes the economics and the public health value of this water. The research assesses the local regulatory aspects of using the water with the outcome of a working objective and rational decision matrix that will permit agencies to select an optimal and safe utilization of the water sources.

CHAPTER I: INTRODUCTION

Background

Water is the essence of life—the most precious resource of the 21st century. Florida is an example of a region where rapid development and an exploding population are competing for shrinking groundwater resources. The Floridian peninsula is unique in that it is on the same latitude as some of the world's major deserts, yet its average yearly rainfall is 53 inches. The most common climate classification is the Köppen, which divides the state of Florida into two climate types. Most of Florida has a humid subtropical climate, as at the study site, with the southern portion of the state as a tropical savanna from approximately Ft. Pierce to Miami to the Keys (Fernald & Purdem, 1998). The study site was located in a suburban neighborhood in West-Central Florida area in the City of Temple Terrace. This area is considered a humid mesothermal climate using the Thornthwaite classification system which uses evapotranspiration and rainfall to determine boundaries which divides the state into three climate types and is most often used by water resource professionals (Fernald & Purdem, 1998). Florida exhibits a bimodal annual rainfall pattern: the dry season from December through May, which has an average seasonal total precipitation of 14.73 inches and average temperature of 67.3 °F; and the rainy season from June through November, which has an average seasonal total precipitation of 30.04 inches and average temperature of 78.9 °F (NOAA, 2005).

Table 1-1: Seasonal Temperature and Precipitation for Tampa Florida.

	Temperature °F			Degree Days		Pcpn inches
Season	**Max**	**Min**	**Avg**	**Heating**	**Cooling**	**Total**
Winter (Dec/Jan/Feb)	71.2	53.6	62.4	467	192	7.24
Spring (Mar/Apr/ May)	81.1	63.3	72.2	76	721	7.49
Summer (Jun/Jul/Aug)	89.5	74.9	82.2	0	1600	19.59
Autumn (Sep/Oct/Nov)	83.7	67.5	75.6	48	969	10.45

Ref: National Weather Service Ruskin, Florida

Table 1-1 illustrates the seasonal temperatures for Tampa, especially the maximum temperature during the seasons and the importance of the inland heating and evaporation effect that drive the weather patterns of Florida. The degree-days provides the ability to compare different years' seasons to each other; for example, degree-days cooling is the average daily temperature degrees F minus 65 F degrees equal the cooling days. The degree-days are accumulated each day over the course of a heating/cooling season and can be compared to a long-term (multi-year) average, or normal, to see if that season was warmer or cooler than usual. The precipitation in total inches is 44.77, which is deficit from the norm of 53 inches.

The highest evaporation period is during the rainy season, when it ranges from 46 to 50 inches in central Florida (Fernald & Purdem, 1998). In the dry winter months, there is a dramatic increase in demand for water by agriculture and industry. This seasonality of rainfall and water demand affects the water budget of local communities. In Florida, a bimodal annual rainfall pattern provided extremes during this investigation. Other locations throughout the country, such as Asheville, North Carolina, with an annual rainfall of 47.7 inches, are consistent each month in the average rainfall. Likewise, Lexington, Kentucky has an average rainfall of 45.68 inches. Both locations usually have consistent precipitation with three (3) to four (4) inches per month based upon a standard 30 year period recorded between 1951 to 1980 (Leeden, et al., 1990).

Florida's significant drainage systems move the water in the rainy season. Florida's gulf coastal lowlands are flat, with productive agricultural land interspersed with wetlands. The same drainage system carries urban runoff in a highly populated area. When the soil becomes saturated, the precipitation exceeds the infiltration capacity of the soil and the soil can no longer absorb water, reducing the amount of infiltrated water that reaches the aquifer. Instead, the overland water flows commence as surface runoff, thus bypassing aquifer recharge to the system that local communities rely on for their water supply.

According to the United States Geological Survey (USGS) in 2000, approximately 85 percent of the population of the United States receives their water from a public supplier; 63 percent is from surface water sources. California and Florida public suppliers have the largest groundwater withdrawals (Hutson, et al., 2004). Approximately 80 percent of the water used in the Tampa Bay region is groundwater, with coastal areas experiencing saltwater intrusion due to over-pumping of the Floridian aquifer system (Hydrologic Evaluation Section, 2002). Florida's population grew by more than 3 million between 1990 and 2000, more than any other state except California and Texas. This represented a 23.5 percent increase, the seventh largest growth rate of any state, and Florida is expected to surpass New York by around 2010 to become the nation's third largest state. If the projections are correct, Florida's population is expected to reach almost 26 million by 2030 (Smith, 2005). Florida is a microcosm of the scarcity of freshwater and the demands of an increasing population growth around the globe.

To meet the ever-growing population's water demands, local municipalities and counties in the Tampa Bay area have created a regional water supplier, which supplies approximately 172 million-gallons-per-day to the region. Florida's population is approximately 13 million persons. Previous estimates had Florida growing at a rate of 487 persons-per-day. This does not include the influx of approximately 100,000 temporary residents to the Tampa Bay area during the winter months, in the same period as decreased rainfall. According to the 2003 United States Geological Survey's "Water Use Report," the average Florida resident uses 174 gallons-per-day for household use (USGS, 2004). The growth in population and high demand for water requires that new alternative water sources be utilized.

Statement of the Problem

Fresh water worldwide is a limited resource. Florida is an example where rapid development and an exploding population are competing for finite or shrinking groundwater resources. Current water use does not address the use of alternative supplies such as roof runoff and reuse in the United States. There is a need for planning and development of alternative fresh water sources that are economically available and viable to develop, while assessing public health aspects and government policies towards this proposed alternative.

Problem Identification

The current rate of housing development in Florida has increased by 23.5 percent, which exceeds the capacity and the ability of governmental agencies to supply adequate water to consumers (Smith, 2005). One example of increased demand in Florida for potable water was the formation of a regional water supplier: Tampa Bay Water. The focus changed from local counties and cities to regional planning to create projects to supply regional needs for water to approximately two million persons in three counties and three metropolitan cities. The current strategy is to continue groundwater and surface water withdrawals and examine the feasibility of creating large reservoirs for impounding the water. There are other potential alternative sources for potable water, such as capture of rainfall from roofs, brackish water sources, and seawater desalination.

The use of Domestic Roof Rainwater Harvesting (DRRH) represents a feasible supplemental water supply. It appears to be the most economical alternative, because of the low capital investment of implementation, but there are seasonal limitations. Both brackish and seawater sources present high capital, operation and maintenance costs for the amount of water production, but the source is sustainable. There is a need for a rational model that provides a method for selecting the appropriate use of roof runoff water.

Purpose of the Study

The objective of this investigation was to determine if roof runoff from five common roof surfaces could be a viable potable source considering regional treatment. The scope of this research was to assess the quantity, quality and economics of recovered water from roofs delivered to a regional treatment facility. The concentrations of the metal elements were used as water quality indices because these would be the most costly public health risks to assess and treat. The economics of using the roof runoff for a smaller community with a population of approximately 30,000 was examined. The research briefly investigated the local and state regulatory issues of using the recovered water, but social acceptance issues were not examined. The results and outcomes of the investigations is an objective and rational decision matrix that will permit agencies to determine if this is an operational alternative for safe, economical, and optimal use of water sources for their community and their consumers.

The factors that contribute to the quantity and quality of the roof runoff were identified, such as the physiographic elements of the roofing material composition and climatic and atmospheric deposition factors that are essential to the development of the model.

The types of climatic factors and variables are precipitation type, convective, orographic, and cyclonic type precipitation, the direction and trajectory of the storm, temperature, and humidity, which can all affect the constituents and particle deposition within the water. In addition, the time and duration, intensity, and the antecedent period between rain events can affect the concentration of the constituents in the sample. These variables provided insight to the variation and the larger weather system factors that need to be included in the development of a model. Physiographic variables of significant concern consist of the composition of the roof surface materials, slope, and roughness of the material. These characteristics are important variables in high-intensity and short duration storms when determining the capacity of the roof for runoff production.

Roofing material has a potential for leaching metals along with potential of collecting atmospheric deposition of suspended metals, which are major factors in evaluating the quality of the water. The physical and chemical processes of the interaction of roofing material with the atmospheric constituents has a potential to pose an increase in concentration of a complex in the water runoff and, hence, an increase in exposure.

Precipitation is geographically and spatially temporal and random. Because of these properties, this experiment requires that samples be taken and tested to assess the variability in concentration. The chemical analysis of the water from each event provided guidance as to the required treatment level needed to remediate water quality to a safe level for potable use that meet the requirements of the EPA and/or local regulatory agencies.

The combination of on-site climatic data, field sampling, and laboratory analysis of the control and five different roofing surfaces' water samples for each event provided a mechanism to compare the water quality. Using statistical methods and analyses, a comparison of the water quality and quantity between the control sample and roofing samples allowed for the selection of the roofing material that is preferred from a water quality perspective. The development of the model incorporated these nuances of the experimental research findings for selecting appropriate use of the water resource.

Methodology of the Dissertation

The significance and uniqueness of this research is the integration of engineering and public health risks in assessing the use of DRRH. The experimental research phase of this study with the utilization of hydrological and chemical data adds to the knowledge of the effects of metal leaching from different roofing materials and provides basic understanding of the water quality discharged from the roofs located in the Southeastern United States.

One research outcome was to develop a management model for use of roof runoff as a potable water source. The purpose of this work was to accurately calculate the quality and quantity of the water that is recovered from roofs. Meteorological data and roof surfaces were used to analyze the effects of the variables on the water quality of the roof runoff. Next, the economics and the public health value, the potential risk of concentration levels found in this water, was established. The research briefly examined the regulatory issue of using the water. The analyses of the data collected allowed the creation and the development that resulted in a formulated decision matrix model that permits agencies to select an optimal and safe utilization of this alternative water source.

This dissertation was structured as compilations of independent research chapters with specific study objectives.

Chapter II: Background consists of a review of current literature to identify gaps in the body of knowledge of the use of potable DRRH for regional treatment. Despite the years of using rooftop harvesting, there are not many references in literature as to the constituents and elements found in the water runoff. The review did not find specific roof runoff information on the materials used in this study in Florida, and a study in Texas on roof runoff had only one similar material of the five that were tested in this study. The majority of the literature investigates the labor savings and quality of life improvement in water access and the role it plays in poverty-stricken regions and countries. Other research investigators concentrated on the storage of water in cisterns and based their investigations upon the types of construction materials and how the structures and materials affected the overall water quality. The area of concern in investigating alternative water sources is the public health safety issues and their long-term exposure effects.

Chapter III: Methodology presents the means in which the selection and description of the experimental apparatus was determined. In order to provide more accurate estimates of the temporal quantity and quality variation of the water from the various types of roofing material, an experimental design was initiated. Five different roofing materials were selected based upon the frequency and popularity of the customers in the region according to a local roofing and construction company. This chapter presents the instrumentation and standard methods necessary to conduct the experiments and the standards in addition to the data collection procedures. The chapter includes the data analysis of the variables and limitations with a final summary.

Chapter IV: Results, the outcomes of the water quality data analyses are presented, with specific item analysis and implications of the results.

In Chapter V: Water Quality Results and Discussion, the outcomes of data analysis are discussed in the context of the implication of drinking water standards and public health issues for the potable use of the roof runoff water.

Chapter VI: Model Development and Discussion presents the parameters that are needed for inclusion in the regional collection system design. This chapter discusses the modules, elements, and conditions in the development of a model. The model constraints and piping for optimal use of roof runoff are discussed.

Chapter VII: Conclusions, describes the outcomes of the investigation, field research and the augmentation model.

Finally, Chapter VIII: Recommendations presents suggestions for further study and future investigations.

CHAPTER II: BACKGROUND

Overview

This chapter background and literature review was divided into smaller sections, such as meteorological effects on rainwater, biogeochemical processes, and stormwater compared to roof runoff. This interdisciplinary approach to roof runoff identifies gaps within the literature in some of the sections, whereas other section topics had significant information available for review.

The scientific literature discusses several approaches to the collection and use of rainwater. Sur, Bhardwaj, & Jindal (2001) reported that in Australia, India, and parts of Southeast Asia, DRRH is a traditional practice and part of the national water policy. Taiwan has successfully incorporated a DRRH system to supplement its potable water supply (Liaw & Tsai, 2004). Studies of rainwater collection in the U.S. have focused mainly on cisterns and cistern microbiology (Lye, 2002), while the Australian government recommends above-ground storage to prevent seepage and overflow into the tanks (Cunliffe, 1998).

The thrust of most of this literature is the use of DRRH as a water source in remote or arid regions. It is understandable that in arid locations, the need for water takes precedence over the concern for its quality. However, there is new research emerging on the microbacterial interaction on roof surface and cisterns, interaction of rainwater with roofing materials, and the subsequent health risks to the population. There are numerous studies throughout the world examining the different concentrations of the various elements, metals, and other items of interest. The object was to review the literature, in the context of asking what are the processes and variables that affect the concentration of elements that might pose a risk.

Meteorological Effects on Rainwater

Water vapor can be considered the start of the hydrological cycle. The quantity of atmosphere water varies with location and time. On occasions, there may not be any relationship between the amount of water vapor over a region and resulting precipitation. For example, at times there is more water vapor over the dry southwest than in the humid northern regions of the U.S. that receive the precipitation (Viessman & Lewis, 2003). The anthropogenic use of fossil fuel, slash and burn clearing of forest, forest fires, and smelting emissions all contribute to the already existing fine particulate in the atmospheric addition to the natural occurring geochemical processes.

Thunderstorms

It is the unique chemical properties of rainwater in equilibrium with the atmospheric gases and the particulates combined with the geography of the state of Florida that creates the largest number of thunderstorms in North America (Cooper, et al., 1998; Fernald & Purdem, 1998; Parker & Corbitt, 1993; Viessman & Lewis, 1996, 2003). Cooper et al., (1998) examined the effects of a convective storm's wind trajectory velocity both horizontally and vertically, inland temperatures, and the atmospheric pressures that develop as cooler sea breezes converge over the latent heated peninsula land in summertime. The undisturbed large-scale flow over the peninsula is strongly influenced by the relative position of the Azores Bermuda high. This position of the high during the summer creates the higher temperatures over a peninsula and a strong breeze that induces rising air while enhancing rainfall. These summer months are the most active times on both coasts; the variation in rainfall is lowest during the summer because of the consistency of the summertime pattern of the daily rainfall from thunderstorm cells which form from the sea breeze. Studies have shown summer thunderstorms have a higher frequency on the east coast, and the convective storms occur earlier in the day on the west coast than they do on the east coast (Cooper, et al., 1998; Fernald & Purdem, 1998). Under these conditions, evaporation of the rainfall after a storm's passage is greater for the west coast, attenuating post-storm evaporation and diminishing the amount of rainfall available for roof runoff. Numerous studies have shown that there is a general trend under a westerly flow; convection storms develop earlier in the day on the west coast and then propagate eastward across the peninsula (Cooper, et al., 1998; Fernald & Purdem, 1998). The opposite occurs for easterly flow: convective storms have a general tendency of convection starting on the east coast early in the day and then propagating towards the west coast later in the day (Cooper, et al., 1998; Fernald & Purdem, 1998). In the winter months, however, storms in Florida are generally cyclonic and characterized as broad north-to-south trajectory cross-peninsula fronts. The remaining seasons, spring and autumn, are characterized by an uneven rainfall intermittent frontal sea breeze and random tropical storms (Cooper, et al., 1998; Fernald & Purdem, 1998).

Large quantities of African dust are carried long distances by trade wind transport processes that affect Florida during the summer months (Garcia, et al., 2006; Guentzel, et al., 2001; Petersen, et al., 1998). Several European researchers have investigated the effects of the African dust. All have found that calcium (Ca) ions dominate as the precipitation-neutralizing agent of the strong acidity of marine aerosols. Thus, alkaline precipitation prevails, and when there is the lack of the calcium dust, more acidic rain is observed (Glavas & Moschonas, 2002; Loye-Pilot & Morelli, 1988).

Scavenging Effects of Rain

The origins of the trajectories are important because of the scavenging activities of convective storms and frontal storms for the spatial and temporal trends in concentration and deposition. The transport of metals to the atmosphere is integral to biogeochemical cycling, and the dynamic nature of these transports accounts for deposits in remote areas far from the original sources. Long-range atmospheric transport occurs worldwide, and there are known natural sources of metals in the atmosphere from soil, sea salt, water, volcanic dust, and gas as well as anthropogenic emissions from fossil fuel combustion, industrial gas and particulates, and tillage. There is no national program in the United States or worldwide for assessing trace metals in atmospheric deposition. A review and assessment of trace metals and atmospheric deposition data from numerous studies were compiled to give a reference point for researchers (Galloway, et al., 1982). Galloway et al., (1982) reviewed the literature and compared the concentrations of metals in rainwater emission rates from “human sources and natural sources with a mobilization factor.” A modified version of the findings is illustrated in Table 2-1.

Table 2-1: Global Mobilization Factors Based on Annual Emission Rates.

Emissions(10µ gy⁻¹)			
Elements	**Natural**	**Anthropogenic**	**Mobilization Factor**
Cadmium(Cd)	2.90	55.00	19.00
Chromium (Cr)	580.00	940.00	1.60
Copper (Cu)	190.00	2,600.00	14.00
Lead (Pb)	59.00	20,000.00	340.00
Manganese (Mn)	6,100.00	3,200.00	0.52
Nickel (Ni)	280.00	980.00	3.50
Zinc (Zn)	360.00	8,400.00	23.00

Source: Galloway et al., (1980)

Table 2-1 illustrates the mobilization factor results which is one of the three different techniques examined by Galloway, et al., (1982). The mobilization factor is the measurement of the flux between the actual metal emission between natural, and anthropogenic sources. Upon examining the mobilization factor and enrichment factor, a comparison of atmospheric concentrations to the earth's crust concentration, which are predictive measures and the third technique, is the actual measurement of metal concentrations over time, historical trends. All three techniques, both the predictive conditions were in agreement with the historical trends, for the concentrations of Cd, Cu, Pb, and Zn had an increased rate of deposition. Galloway et al. (1982) argues that the processes that control the rate of atmospheric deposition of Cd, Cu, Pb, and Zn in the eastern United States is at a minimum strongly influenced by the anthropogenic process. At the time, because of a lack of data from a systematic collection of metals in wet deposition, the investigations were divided into three categories: remote, rural and urban.

The working definition of "…remote [is] any area of the lowest concentration [excluding] Antarctica and Arctic. Rural is defined as representing the regional backgrounds and not directly influenced by local anthropogenic emissions, [and] Urban any site in a city or elsewhere directly influenced by local anthropogenic emissions" (Galloway, et al., 1982).

Table 2-2: Concentrations of Metals Ranges Found in Wet Deposition.

Urban Elements	Range ($\mu g \ell^{-1}$)	Median ($\mu g \ell^{-1}$)
Cadmium (Cd)	0.48 - 2.30	0.7
Chromium (Cr)	0.51 - 15.00	3.2
Copper (Cu)	6.80 -120.00	41
Lead (Pb)	5.40 -147.00	44
Manganese (Mn)	1.90 - 80.00	23
Nickel (Ni)	2.40 -114.00	12
Zinc (Zn)	18.00 -280.00	34
Rural Elements	Range ($\mu g \ell^{-1}$)	Median ($\mu g \ell^{-1}$)
Cadmium (Cd)	0.08 - 46.00	0.5
Chromium (Cr)	<0.10 - 30.00	0.88
Copper (Cu)	0.40 - 150.00	5.4
Lead (Pb)	0.59 - 64.00	12
Manganese (Mn)	0.20 - 84.00	5.7
Nickel (Ni)	0.60 - 48.00	2.4
Zinc (Zn)	<1.00 - 311.00	36
Remote Elements	Range ($\mu g \ell^{-1}$)	Median ($\mu g \ell^{-1}$)
Cadmium (Cd)	0.004 - 0.639	0.008
Chromium (Cr)	---------	-----
Copper (Cu)	0.035 - 0.850	0.06
Lead (Pb)	0.020 - 0.410	0.09
Manganese (Mn)	0.018 - 0.320	0.194
Nickel (Ni)	---------	----
Zinc (Zn)	0.007 - 1.100	0.22

Source: Galloway et al., (1982)

Table 2-2 illustrates the wide ranges of rainwater concentrations of metals from wet depositions for the three different categories, with the median within these categories. It is noted there are orders of magnitude differences in observed concentrations for any constituent, which reflects different locations and sampling techniques. The urban median concentrations are higher, possibly because of the influence of point sources, whereas the remote sites were consistently lower. It is the physical characteristics of the metal and its compounds, in particle size, vapor pressure, heats of solution, and solubility, where the process affects the raindrop formation. Rain deposition is dependent on particle size and is determined by the rainout and the washout or scavenging. Fine particles and gases from convective thunderstorms which are considered tall and in the range of 12 to 16 km in altitude are generated in Florida in the wet season and have been recorded to scavenge particles from the middle and upper troposphere and are transformed in rain drops (Guentzel, et al., 2001). Several researchers in Florida have, "…reported these tall convective thunderstorms entrain 60 percent of the air from the boundary level and 40 percent from the troposphere." (Garcia, et al., 2006; Guentzel, et al., 2001; Petersen, et al., 1998; Viessman & Lewis, 2003).

As the primary input for the hydrological cycle, precipitation type is defined by the vertical transport conditions generated, with the two most common found in Florida: convective precipitation in the summer and cyclonic precipitation in the winter (Fernald & Purdem, 1998; Viessman & Lewis, 2003). Convective type precipitation is typical of the tropics where the precipitation is created by the process of heated water vapor at the land surface that rises, creating an upwelling of vertical wind and downdrafts. The dynamic cooling of the water vapor results in condensation and precipitation; this typically takes the form of light showers or extremely high intensity thunderstorms. Cyclonic type precipitation is associated with the uneven heating of the earth that creates high and low pressure large-scale air movement of non-frontal or frontal origin. Hence, precipitation varies geographically, temporally, and seasonally. Spatially, precipitation varies within the same storm precipitation and can considerably vary within a distance 20 feet apart from two recording devices as much as 20 percent (Fernald & Purdem, 1998; Viessman & Lewis, 2003).

Biogeochemical Processes

These complex processes and interactions in a heterotrophic atmospheric environment is where the biogeochemical cycling of metal species occurs, and some are toxic (James N. Galloway, et al., 1982; Tanner & Wong, 2000). Atmospheric gases such as NOx(*g*) are adsorbed, causing acidification by nitric acid (HNO_3^-) into the raindrop under the coexistence of gaseous sulfur dioxide ($SO_2(g)$), gaseous nitrous oxide ($HNO_2(g)$), and gaseous hydrogen peroxide ($H_2O_2(g)$) in washout and rainout scavenging. The atmospheric fluxes are important because increased pollution emissions alter the pH levels, metal deposition, and concentration of toxic metals. The chemical reactions caused by the disassociation and oxidation reactions of gases with the raindrops generates sulfate ions (SO_4^{2-}) and hydrogen ions (H^+) from the oxidation reaction of hydrogen sulfite ions (HSO_3^-) with hydrogen peroxide ($H_2O_2(aq)$) in the raindrops. The oxidation reaction of hydrogen peroxide ($H_2O_2(aq)$) is an irreversible reaction, as shown in Equation 2.0. According to Henry's Law of Constants (solubilities) characterize the equilibrium distribution between gas and liquid phases, where the equilibrium ratio in liquid phase concentration to gas concentration is much larger than in gaseous sulfur dioxide ($SO_2(g)$). The gaseous hydrogen peroxide ($H_2O_2(g)$) and gaseous nitric acid ($HNO_3^-(g)$) are more soluble in water than gaseous sulfur dioxide ($SO_2(g)$) (Alfonso & Raga, 2002; Bachmann, et al., 1993; Mudgal, et al., 2007; Seinfeld, 1975). Equations 2.1, and 2.2 illustrate these processes.

$$HSO_3^- + H_2O_2\,(aq) \rightarrow SO_4^{2-} + H_3\,O^+ \qquad \text{(Equation 2.0)}$$

$$HNO_3^-(g) \leftrightarrows HNO_3\,(aq) \qquad \text{(Equation 2.1)}$$

$$HNO_3^-\,(aq) \rightleftarrows NO_3^- + H^+ \qquad \text{(Equation 2.2)}$$

Microbial Effects on Water Quality

There are two modes of microbial contamination of harvested water from roof runoff: roof contamination and cistern contamination.

Roof Surface

Numerous studies have analyzed the chemical composition of water. The prevalence of microbiological contaminants on rooftops has been less studied. The bacterial composition of roof runoff has not been widely explored in the published literature nor has the prevalence of microbiological contaminants. The literature review for the microbial presence on the rooftop and in the catchment entrainment to the storage tank is still of controversy, with Lye's (2002) data in Kentucky where he states the high bacteria was from the process of the catchment. Others disagree and regard the roof runoff as a source of clean water (Gould, 1999). Other researchers attribute the increased coliform and fecal coliform counts to the antecedent period on the roof surface area (Yaziz, et al., 1989). Yaziz et al. (1989) reports a positive correlation between the Heterotrophic Plate Counts (HPC) and the duration of the antecedent dry period.

Meteorological Influences on Microbial Concentrations on Roofs

Aerobiological studies have found diurnal rhythms and a positive correlation with daily maximum temperatures, with monthly rainfall average, and temperature day-to-day spore levels for the fungal spores *Alternaria* (Corden & Millington, 2001). This research confirms the importance of rainfall and temperature on spore concentration where the occasional rainfall resulted in higher monthly concentration of *Alternaria* spores. This further demonstrates the seasonal meteorological influences on concentrations, which has been positively correlated, with the incidence of allergic and infectious outbreaks in United States, Australia, and the United Kingdom (Corden & Millington, 2001; Evans, et al., 2006) . The physical mass, size, shape of a virus, bacteria, and/or spore plays a role in efficient atmospheric dispersion. The wind velocity and other meteorological conditions such as relative humidity, direction of the air trajectory, and the frontal system have been shown under suitable conditions to spread airborne viruses more than 100 km (Jones & Harrison, 2004). Evans et al. (2007) reports wind direction influences the contribution of the total bacteria load on the roof area. There is a strong correlation of the HPC and the wind velocity, which is a function of the prevailing wind and location of the source contamination (Evans, et al., 2006; Evans, et al., 2007). The natural processes of UV exposures, temperature of the roof, physiochemical reactions of contact, surface complexation reactions, the surface charges on the suspended particles, the rate of intensities and quantities of rainfall, and the microtransport and macrotransport mechanical movements across the roof surfaces are all processes that improve water quality. This improvement is supported by the observed microbial improvement in bacteria water quality in a collection system (Benjamin, 2002; Coombes, et al., 2000; Evans, et al., 2006; Tchobanoglous & Schroeder, 1985; Viesssman & Lewis, 2003; Zhu, et al., 2004). The roof surface collection system is the sum of the process of the catchment water entrainment as the first phase towards an integrated system.

Cisterns

There are risks associated with rainwater storage; yet in arid regions such as southern Australia, approximately 800,000 systems are in use by the rural population along with the urban population of Aliadiae (Heyworth et al., 1998). In a study of the five different types of cisterns in Micronesia, the examination and report found that of the acceptable drinking quality, the ferro-cement cistern had the best water quality, and the metal cisterns had the poorest water quality (Dillaha & Zolan, 1985). In a comparative study of the water quality of cisterns in the area, receiving acidic deposition–Kentucky and Tennessee–compared to regions that had not received acidic deposition–St. Maarten, Netherlands Antilles–the rainwater was neutralized upon contact with masonry cisterns (Olem & Berthouex, 1989).

Samples from stored rainwater in tanks (in place) reported by Thomas and Greene (1993) were high in bacteria counts due to the tanks' environments. In contrast, other researchers state that it is the stored rainwater tank environment that reduces the bacteria counts, and different water depths in the tanks foster different bacteria counts within that particular zone within the cistern tank (Spinks, et al., 2006). In some circumstances, geography dictates that the only viable water source is to harvest roof runoff, particularly on the islands of the South Pacific (Connell & Lea, 1992; Ebi, et al., 2006; White, et al., 2007), on the United States Virgin Islands (Crabtree, et al., 1996; Heymann, 2004; Robertson, et al., 1992; Wyngaarden & Smith, 1985) and on some of the Greek islands (Sazakli, et al., 2007).

Cisterns Founded in the South Pacific

In these small island countries in the Pacific, the water resources are limited due to the scarcity of potable fresh water. These land masses are relatively small, preventing adequate groundwater storage on islands that have an elevation of a few meters above sea level, whereas others are several meters above sea level (Connell & Lea, 1992). The population of these islands range from inhabited and rural to urban concentrations of large, unorganized population migrations into urban areas that have no water or sanitation infrastructure, a situation typically found in most Third World cities. Many small island countries have relatively high rainfalls that are constrained by small land areas and atoll geology, and water is usually treated as a common resource (White, et al., 2007). The socio-economical pressures, combined with cultural value (or lack of value) of water resources, and an increasing population growth competing for limited resources such as water, housing, and employment creates an unsustainable situation for these islands. In higher density population areas, pit latrines replace defecation on the beach, while the water supply source moves to shallow groundwater wells because of demand, where the pits lead to groundwater contamination (Ebi, et al., 2006; White, et al., 2007).

Usually in small tropical islands and rural areas of larger islands, drinking water is from roof catchments because the shallow wells have a high risk of contamination due to the lack of sanitation and the presence of industrial pollution (Taylor, 2001). The South Pacific island region is climatically sensitive. This region also has experienced extreme droughts as well as several severe storms and any changes in precipitation or rising sea levels will present challenges to the water supply and public health (Ebi, et al., 2006). The United Nations' recommendations for the atolls and many of the other small islands of the South Pacific include a strategy of conjunctive use of different sources of water such as combining the use of rainwater with groundwater (Taylor, 2001). The South Pacific's haphazard approach to waters resources is a contrast to the methodical development and reliance of the U.S. Virgin Islands on harvested roof runoff.

Cisterns Founded in the U.S. and British Virgins Islands

The U.S. and British Virgin Islands have a compulsory requirement in design and construction that a cistern must be used in every building (Crabtree, et al., 1996; Lye, 2002). Title 29, chapter 3, of the Virgin Islands Building Code, requires ten gallons-per-square foot of roof for a single story dwelling and requires fifteen gallons-per-square-foot of roof for a multi-story dwelling. Crabtree et al. (1996) "…found no significant correlations…between cysts and oocysts and the bacteria or turbidity." However, they reported a statistically significant association between the heterotrophic plate counts and total coliform counts ($r = 0.42638$, $P = 0.0061$), and they also reported the association of the heterotrophic plate and the turbidity readings ($r = 0.3249$, $P = 0.0305$) (Crabtree, et al., 1996). The robustness of *Giardia* cysts' and *Cryptosporidium* oocysts' viability and hardiness to resist disinfection are a public health concern in drinking water. There are many species of *Cryptosporidium*; it can be found in 45 vertebrate species, including birds, rodents, reptiles, lizards, frogs, small mammals (squirrels, cats and dogs), and large mammals (cattle and sheep). *Giardia* is similarly found in a large variety of invertebrate species like *Cryptosporidium* (Crabtree, et al., 1996; Heymann, 2004; Robertson, et al., 1992). The species *Cryptosporidium parvum* from mammals is the only species associated with disease for humans, whereas *Guardia lamblia* is the species associated with human infections (Heymann, 2004; Wyngaarden & Smith, 1985). An investigation of cisterns in the U.S. and British Virgin Islands over a one-year period concluded that 81 percent of the samples from public cisterns were positive for *Cryptosporidium* or *Giardia,* and only 47 percent of the private cisterns were positive for both (Crabtree, et al., 1996). However, the study did not examine the cysts and oocysts for viability. The researchers alluded to the fact that more research needs to be done in reference to viability and suggested that the warm temperatures of 30°C may facilitate inactivation. Investigators in a non-laboratory setting monitoring the oocysts' viability found desiccation was 100 percent lethal, freezing was also lethal (but a small portion can survive for extended periods of time), whereas a significant portion of oocysts were killed in all the environments investigated over a six-month period (Robertson, et al., 1992). The vast majority of the investigations in the literature, counted the presence of cysts or oocysts in excretions as infections, and the measures used are not determined by illness (Heymann, 2004; Stites, et al., 1987; *Waterborne Pathogens: manual of water supply practices*, 1999). There are conflicting reports in the literature regarding the high percentage of asymptomatic children and adults in the population, which will be presented in more detail in the discussion section (Eisenberg, et al., 2007; Eisenberg, et al., 1998; Haas, et al., 1996; Haas, et al., 1991). These findings in the cisterns and water supply of the U.S. and British Virgin Islands are very different from the findings in Kefalonia Island, Greece.

Cisterns Founded in the Greece Islands

The island of Kefalonia has the similar limited water resources as all islands which have tourism as the major industry. Kefalonia's population of 2,000 doubles in the winter and triples in the summer according to the investigator (Sazakli, et al., 2007). The investigation of the water quality of rainwater, catchment runoff, and cisterns over a period of three years resulted in favorable physiochemical water quality for rainwater collection. The microbiological water quality of the rainwater is in concordance with previous studies (Crabtree, et al., 1996; Evans, et al., 2006; Evans, et al., 2007), with the microbial indicators and pathogens counts found to vary greatly. Sazakli et al. (2007) investigation, found the microbial indicators counts were in low numbers but in high percentages of the samples. The microbiological quality using common microbial indices were contaminated in 80.3 percent of the samples (n= 156) (Sazakli, et al., 2007). These results are similar to the U.S. Virgin Islands' contamination of 81 percent (n=16) for public cisterns and 47 percent for private cisterns (n=30) (Crabtree, et al., 1996). In this particular investigation, the microbial contamination was a result of the contact with the catchment area rather than the water itself (Crabtree, et al., 1996). Upon examination of a number of the samples taken during rainfall events, the investigators found there was no microbiological contamination present in a rainfall sample (Sazakli, et al., 2007). The investigators also detected a statistical difference ($p < 0.05$) in the microbiological counts at 22°C and 37°C, indicating that there were higher count values with a higher temperature. This contrasts to Crabtree et al. (1996), who suggested the possible inactivation of bacteria cysts and oocysts at higher temperatures. Sazakli, et al. (2007) found the microbiological indicators showed the seasonal variations with a high count in autumn and a decreased count in winter. In addition, they found that microbiological indicators have a high negative correlation with chlorides, which illustrates the importance of location of the cistern, environment, and meteorological effects on the water quality.

Process That Changes Rainwater pH

According to several researchers, usually 80 percent of the wet deposition of the heavy metals are dissolved in rainwater (Garcia, et al., 2006; Kaya & Tuncel, 1997). The solubility of elements depends on a variety of factors including rainwater pH and the type of particles that are associated in the atmosphere. If the element is already soluble in the rainwater, the higher the solubility and less significant effect the pH has on the element. Variation may be related to differences in particle size and the efficiency of scavenging (J.N. Galloway, et al., 1993). The reactions within the raindrop become a function of the drop size, where oxidation by H_2O_2 at a pH of less than 5 occurs in small raindrops where oxidation by O_3 at pH values greater than five occurs in large raindrops (Bachmann, et al., 1993). Bachmann et al. (1993) states the radius variations of the raindrops appear to be dependent on the efficiency of scavenged raindrops. Industrial aerosol particles such as Fe^{3+} and Mn^{2+} may influence the oxidation of SO_2. Likewise, the aerosol particles of Ca^{2+} and Mg^{2+} may have a significant effect on the droplet pH (Williams, et al., 1988).

The presence of H_2S_4, HN_3, and organic acids, small ligands, organic macromolecules, and natural particles, depend on the availability of the acidic and basic species, but the reaction, and reaction between the reactions can be neutralized predominantly by NH_3 and $CaCO_3$ (Kaya & Tuncel, 1997; Manahan, 1990, 1994). An example of neutralizing the acidic raindrop conditions is the effect of long distance transport of soil particulates from Ca found in desert areas and African dust on the precipitation and atmospheric deposition.

The main effect on rainwater pH is not from a local anthropogenic source; rather, this regional long transport of aerosol particles neutralizes an acidic rain event (Glavas & Moschonas, 2002; Herut, et al., 2000). Likewise, the examination of storm origin suggests Cu is present in higher concentrations in continental storms when compared to marine dominated storms. These continental storms had elevated concentrations hydrogen ion in rainwater relative to marine dominated events, where a concentration of hydrogen ion has differed by an order of magnitude (Tanner & Fai, 2000; Tanner & Wong, 2000). This would imply that Cu is an anthropogenic source similar to Fe.

In contrast to the impact and effect of storm origin, the Cr total concentrations were statistically equivalent, for both continental and marine origins have no effect on the concentration of Cr. (Kieber, et al., 2004; Kieber, et al., 2002). A negative correlation of the total copper concentrations in rain amounts indicates that Cu is a storm washout, which implies the origin is of anthropogenic local sources, and the copper concentration decreases as rain increases (Kieber, et al., 2005; Kieber, et al., 2004; Kieber, et al., 2002).

However, Fe and Cr had no correlation with rain volume, suggesting that concentrations are the result of the long distance transport at the site (Kieber, et al., 2003; Kieber, et al., 2002).

In addition to the complexities of thunderstorms, there is a variety of processes occurring simultaneously, such as activity within the storm itself, besides the oxidations of various metals (Bachmann, et al., 1993). Recent literature suggests that lightning affects the dynamics of pH in the atmosphere of rainwater, subsequently affecting the solubility of metals within a storm event (Railsback, 1997). Railsback (1997) suggests the lightning generates in-cloud oxidization of SO_2 and NO_2, which contribute to rainwater having a lower pH associated with lightning. A comparison of solubilities of metals in rainwater from the literature in two different research locations is illustrated in Table 2-3.

Table 2-3: pH Effects on Solubilities of Metals in Rainwater Between Locations in Turkey and Mexico.

	Ankara Turkey	Ankara Turkey	Rancho Viejo Edo. Mexico	Ankara Turkey	Rancho Viejo Edo. Mexico
Element	solubility of element in whole data set %	solubility of element in sample with pH < 5 %	solubility of element in sample with pH < 5 %	solubility of element in sample with pH > 5 %	solubility of element in sample with pH > 5 %
Mg2 +	61 ± 26	64 ± 23	ma	50 ± 25	na
Cd	88 ± 17	93 ± 10	82.6	79 ± t9	73.9
Cu	49 ± 27	53 ± 22	na	30 ± 27	na
Cr	35 ± 29	31 ± 28	66.7	II ± 15	39.3
Zn	43 ± 29	46 ± 27	na	38 ± 30	na
Pb	40 ± 35	40 ± 33	62.4	II ± 15	43.3
Fe	17 ± 16	21 ± 19	na	12 ± 11	na
Ni	72 ± 31	84 ± 19	56.2	18 ± 21	63.4
Mn	na	na	74.6	na	75.6

Source: (Baez, et al., 2006; Kaya & Tuncel, 1997)

In Table 2-3, illustrates the solubilities are different and the range in variance between different locations. One example of this was for Ni at the pH values > 5 in the individual samples; yet in the bulk samples for Ankara, Turkey, the corresponding values are all in the same range as the Rancho Viejo Endo, Mexico samples.

Public Policy for Drinking Water

Federal Regulations for Drinking Water in the United States

There was not a federal program to protect drinking water quality in the United States until Congress passed the Safe Drinking Water Act (SDWA) in 1974, which was subsequently amended in 1996 and again in 1999. This Act created a federal-state partnership, which ensures compliance with federal regulation to protect the public from a variety of contaminants in drinking water. The Environmental Protection Agency (EPA) establishes maximum contaminant levels (MCLs) for more than 90 biological, chemical, and radioactive pollutants (E.P.A., 2002a, 2002b). These are federal legally enforceable mandatory compliances as the primary and secondary drinking standards whereas the primary standards require compliance and secondary are recommendations of unregulated drinking water contaminants that may pose a health risk (E.P.A., 2002a, 2002b, 2005). The MCLs must be met by every community water system, which the EPA defines as any water conveyance having at least 15 connections year-round or serving 25 or more people. Currently the EPA is investigating and researching an additional contaminant candidate list of 51 unregulated contaminants. If the investigation and data show specific contaminants present a public health risk, a regulatory determination is made to add these contaminants to the primary drinking standards (E.P.A., 2005).

State of Texas Regulations for Rainwater Harvesting

The Texas government does not regulate private water systems. According to a 2004 report by the Texas Natural Resource Conservation Commission (TNRCC), “It is up to the individual to regulate their own water system” (Texas Natural Resource

Conservation Commission, 2004). The Texas population shows a growing awareness regarding the limit of water resources and the need for DRRH. For example, the cities of Austin and San Antonio are providing rebates of up to $450 to homeowners who install DRRH, and other counties waive application fees and exempt the DRRH system from property taxes as an incentive (TNRCC, 2004). No federal or Texas water quality standards exist currently; however, the Texas legislature established a rainwater harvesting evaluation committee in May 2005 to recommend minimum standards (Texas Water Development Board, 2005).

State of Florida Regulations for Rainwater Harvesting

Florida's Administrative Code Chapter 64 E-8 sets the standards for private and limited use of water systems, and it establishes requirements and MCLs for community public works systems in the state of Florida. The Department of Health administers Chapter 64E-8 through program coordination with all of Florida's 67 county health departments. A review of chapter 64E-8 and other Florida administrative codes did not produce a regulatory code for roof runoff. A further investigation of chapter 373 of the Florida Statutes and the State of Florida water policy set forth in Chapter 62-40 did not find regulations for use of roof runoff at this time.

Regulations for Drinking Water in the Western United States

In the states located to the west of the Mississippi River, water rights are classified much like real property and whoever diverts the water first retains priority. In contrast, in the states located east of the Mississippi River, water rights are based upon the British Riparian Rights system, which allows a property owner the water rights to all water on their properties provided that usage will not impact downstream property owners. For example, in the Four Corners Region, which consists of the intersection of the states of Arizona, Colorado, New Mexico, and Utah, recently Colorado passed a law allowing limited rooftop rainfall collection. Prior to this 2009 ruling, it was illegal to gather the rainwater from a property's rooftop unless the property owner also owned the water rights to said property. In Santa Fe, New Mexico, it is now mandatory that new construction have rainfall catchments and in Tucson, Arizona, rainfall catchment is actively promoted for all new construction as well (Johnson, 2009). However in Utah, it is still illegal to harvest rainwater from a property owner's roof unless the property owner has water rights to said property. If the property owner does not have the water rights to a property, they must be appropriated via permit through the State Engineer and the original water rights' owner must agree to this arrangement. For most of the history of the United States, the water rights to states west of the Mississippi River were determined by diversion of a water body and have been sold off much like real estate properties (Utah Division of Water Rights, 2009).

Regulations for Drinking Water in Other Countries

In Australia, 13 percent of all households use rainwater tanks as a source of drinking water. In southern Australia, the figure is 37 percent (Cunliffe, 1998). In the capital cities, 6.5 percent of households use the tanks, but the usage rate is 28 percent in the southern city of Adelaide (Australian Bureau of Statistics, 1994). Of rural dwellers, 82 percent rely on DRRH as their primary water source (Heyworth, et al., 1998). Australian rainwater tanks are constructed in accordance with the Australian/New Zealand standards for material selection, installation, and associated fixtures and fittings. The Australian/New Zealand literature emphasizes the proper selection, construction, and maintenance of the tanks. The brief discussion of the types of roofing materials available (tiles, terracotta tiles, galvanized steel, polycarbonate sheeting, slate, and wooden shingles) recommends that consumers consult the manufacturer as to the materials' suitability for DRRH. The Australian literature does not discuss the safety of different roofing materials.

Regarding public attitudes toward DRRH, a survey of the Australian population found that most citizens thought DRRH was both necessary and safe (Australian Bureau of Statistics, 1994). This population preference is for rainwater; therefore, they utilize rainwater tanks in both urban and rural settings and even when the municipal water supply is available. Researchers also reported considerable support for water conservation and recognition that water is a limited resource (Australian Bureau of Statistics, 1994). In summary, specific research on rooftop materials' effects on the quality of DRRH water is lacking. Research on public perception of DRRH is limited to the Australian case.

Stormwater Compared to Roof Runoff

Numerous effects of urban stormwater runoff shows that the best management practices are to manage the stormwater using low-impact development and community design (Gaffield, et al., 2003). The authors raise concern that the stormwater, while more readily accessible than rooftop runoff, contains more potential risk factors such as high nitrogen, vehicle exhaust, and various other sediments. In general, there is more literature on impervious area, and highway runoff conveyance such as solids, hydrocarbons, heavy metals, and chemicals. Researchers found high concentrations of zinc and other metals in the dissolved form in 35 to 65 percent of the stormwater runoff whole-water samples. The high proportions of the metals were bioavailable in the water and soil sediment samples (Marsalek, et al., 1997; Stumm & Morgan, 1996). Tire-wear is a source of Zn where it is used in the manufacturing process to facilitate the vulcanization of the rubber (Councell, et al., 2004). The research on stormwater runoff quality in Texas found that the maximum contaminant levels MCLs for the EPA's drinking water regulations were exceeded 42 times for mercury (Hg) and 23 times for lead (Pb) in the total 272 samples (Zartman, et al., 2001). There is research that is beginning to fill the gap in the literature, quantifying water quality difference between the rooftop runoff and stormwater runoff per se in the context of urban roads and highways (Gobel, et al., 2007). Table 2-4 illustrates the difference in the concentration of the various locations and the differences found in the literature review.

Table 2-4: Comparisons of Concentrations from Rainfall and Roof Runoff.

Parameter	Unit	Comments on review of literature	Rainwater		Roofs		Trafficked areas with high density	
			Min.	Max	Min.	Max	Min.	Max
pH	----	Good data basis for all types of surfaces	3.9	7.5	4.7	6.8	6.4	7.9
Heavy metals								
Cd	ug/l	Above average data basis for all surface types	0.1	3.9	0.2	1.0	0.3	13.0
Zn	ug/l	Above average data basis for all surface types	5	235	24	4880	120	2000
Cu	ug/l	Above average data basis for all surface types	1	355	6	3.416	97	104
Pb	ug/l	Above average data basis for all surface types	2	76	2	493	11	525
Ni	ug/l	Poor data basis, average data basis for trafficked areas	1	14	2	7	4	70
Cr	ug/l	Poor data basis, average data basis for trafficked areas	2	8	2	6	6	50

Source: Gobel et al. (2007).

CHAPTER III: METHODOLOGY

This chapter addresses the methodology of water quality sampling and collection roof runoff, and includes the following subsections: material selection and description, instrumentation, data collection procedures, and data analysis.

Material Selection and Description

Roof Panels

Two 4' X 8' roofing panels were constructed in accordance with the local and Florida state building codes. The panels were constructed from CDX roofing plywood, with 1"X 2" pine boards for the frame and 1"X 6" fascia boards for the gutter framing. The panel's surface was covered with roofing paper, and the edges were encased with a galvanized drip edge. The wooden panels were then fitted with the five experimental surfaces. The first panel was topped with S4, galvanized steel, half painted with the manufacturer's acrylic paint, and the other half with S5, galvanized steel unpainted. The second panel was fitted one-third with S1, a natural clay barrel, one-third with S2, a glazed clay barrel, and the remaining third with S3, a flat shaker impregnated tile. Each section of the panels had its own gutter and downspout made of painted galvanized steel, since conventional plastic materials tend to accumulate trace metals. The water samples drained directly into individual high-density polyethylene HDPE five-gallon containers. Each roofing panel was supported with concrete blocks; one side was 44½ inches above the ground and the other was 30½ inches above the ground. This slope was set to accommodate most building codes in the southeastern United States, and similar to those of the majority of Florida roofs, with an approximate fifteen-degree pitch.

Control or Reference Sample

A sixth container was used for collection of the control samples. The HDPE five-gallon control container was elevated to the same height as the experimental panels, 30½ inches above the ground, and placed three feet from the corner of the nearest experimental panel to prevent collection of deflected rainwater bouncing from the panels. This container was left open to the air and subject to natural rain events. The collected water was tested after each rain event. The differences between the control sample and the rooftop-collected samples clearly showed the influence of surface materials on water quality.

Instrumentation

This section briefly describes the instrumentation sensitivity, accuracy and detection limits of water quality testing.

Field Sample Instrumentation

The pH was measured using the Oakton Instruments Acorn series pH 5, with resolution at 0.01 pH, and with accuracy +/-0.01 pH at the field site. The meter was calibrated using three point USA pre-pack standardized solutions for pH 4.01, 7.00, and 10.01. In order to avoid contamination, prior to inserting the probe into the next sample, the probe was rinsed with pre-pack standardized rinse solution. Once the digital meter stabilized, the reading was recorded in the laboratory research notebook.

The total dissolved solids (TDS) reading at the field site was accomplished using a Myron L deluxe DS meter model 532. The calibration of the meter was built into the instrument, with accuracy of +/-2 percent of the full scale. The measuring cup was filled three times with the sample to receive an accurate reading. On the third measure, the scale was selected, and the reading recorded. The instrument's measuring cup was then rinsed with distilled water before proceeding to the next sample.

The alkalinity at the field site was measured using a Hach test kit model Al-Ap colorimetric test in accordance with the kit's instructions and recommendations. After the titration was completed, the quantities of drops were recorded in the laboratory notebook and the titrated sample was disposed of, and the small vial was rinsed with distilled water prior to proceeding to the next sample.

Biological Instrumentation

If there was any sample volume left in the field, a sterile 1320 ml sample (volume permitting) was taken for biological testing. It was sealed and refrigerated, or transported to the laboratory in an ice chest. The sample was kept cold in the University of South Florida's College of Public Health's walk-in laboratory research cooler until it was analyzed, and was plated within eight hours. Biological testing was according to the Millipore method. If sample volume permitted, the Standard Pour Plating Method was also performed. According to the Millipore method, each 500 ml of the sample was individually filtered through a sterile glass funnel, which has a sterile 45μg filter to collect microorganisms. Using a standard laboratory vacuum pump, the water sample was filtered through a sterile paper filter with the water passing into a fritted flask. Once the sample had passed through the assemblage, the filter was removed with sterile tweezers and placed on a certified sterile media-specific agar plate for heterotrophic colonies. All of the above occurred in the University of South Florida's College of Public Health's Cell Media Laboratory in a sterile, negative hood environment. This procedure was performed twice for each sample, hence two individual plates per sample. The closed agar plate was sealed with parafilm from the outside environment, retaining its moisture content. The plates were placed in the College's walk–in incubator assigned to this project at the temperature of 35°C for 48 hours to develop the culture colonies (Clesceri, et al., 1998). The plates were then examined in the media laboratory under the microscope for heterotrophic colonies. The specific heterotrophic agar's colorimetric system aided in identification and colony counts, but quantifying the organisms precisely was out of the scope of this investigation. Afterwards, the assemblage used was sent for cleaning. After all the U.S. E.P.A. certified biological sterile samples jars had been used for the sample collection, a method was applied and used for the reuse of the bottles and caps in accordance with Standard Methods (Clesceri, et al., 1998; E.P.A., 1992). All the apparatus components and sample bottles along with sealing caps were washed and cleaned in the automatic laboratory instrument washing and drying machine. Then they were placed in the autoclave for sterilization of the apparatus and the dark certified glass sampling jars for future collection in accordance to operating procedures and Standard Methods (Clesceri, et al., 1998; E.P.A., 1992). There were numerous occasions that there was insufficient volume for the Standard Methods' Millipore plate method.

Meteorological Instrumentation

Due to the specificity of the rain events in this subtropical region (weather can vary significantly within 20 m), the primary data was obtained at the research site-specific weather station during the period of 28 August 2005 through 25 February 2006, using the Davis Instruments “Vantage Pro2 Plus.”

At the station the following variables were monitored:

- Date and time in minute intervals
- Ambient temperature, temperature under each of the five surfaces, and temperature near collection containers
- Humidity, dew point, and evapotranspiration rate
- Wind speed, wind direction, wind run, wind chill, and wind sample
- High wind speed and high direction of wind (shows trajectory of the rainstorm)
- Barometric pressure
- Rain and rain rate
- Solar energy, solar radiation, and UV dose
- Hot and cool days between rain events
- Temp-humidity-wind (THW) index and temp-humidity-sun–wind (THSW) index
- Wind chill factor and heat index.

The meteorological data recorded 296,113 individual records and resulted in 11,844,520 data points. The data was collected on one-minute intervals continuously until the end of the research program. Measurements of ISS reception and Arc Interval monitored the function of the weather station itself. This indicator provided a mechanism as to the quality and integrity of the data at that particular time. The ISS and Arc Interval provided the strength of the wireless reception between the outside monitoring device and the data logger to the computer inside the house. It was scientifically prudent to data log all the variables possible so that bias and selection type errors could be diminished. Any of these variables may affect the quality of the samples. Temperatures of the panels were monitored because of possible effect on organism growth and of water evaporation on the panel. After the data was analyzed, only those variables that show statistically significant correlations were retained in the model. Figure 3-1 is a picture of the residential location of the meteorological apparatus and the experimental material in-situ used in the research.

Figure 3-1: Photo of the Apparatus and Monitoring Station

Analytical Instrumentation

Atomic Absorption Spectrophotometry (AAS) was used to measure the analyte concentration of a few trace metals found in several of the collected water samples from the six different panels (more details on this are in the Data Collection Procedures section, under Preliminary Testing). Some samples were split, with one part analyzed with instrumentation at the University, and all the others were analyzed at a certified reference laboratory: Benchmark Enviroanalytical Laboratories. An aliquot was retained for quality assurance. Using Varian Graphite Furnace AAS permits determination of the trace metals with sensitivities and detection limits 20 to 1000 times better than those of conventional flame techniques, without the need for extraction or sample concentration (Clesceri et al., 1998). Many elements can be detected at concentrations as low as 1.0 μg per liter. Some preliminary elements of interest for the investigation were Cd, Co, Cr, Cu, Fe, Ni, Mn, Pb, and Zn because of their known health effects; however, Pb was the chosen for the preliminary go or no go analyses. Ascorbic acid and palladium solution (500-2000 μg/ml) were used as matrix modifiers to reduce background noise of the detector. These analyses confirmed the presence of the constituents' concentration levels and different concentrations on different surfaces, and this exploratory investigation provided a valid reason to proceed with this completed study and final analyses. The data for the preliminary investigation is presented in a table format in Chapter IV.

All of the final analyses were performed using Inductive Coupled Plasma-Mass Spectrometry (ICP-MS) which conforms to EPA standards at the certified EPA, Florida, and nationally certified reference laboratory, Benchmark Enviroanalytical Laboratories. The samples required that 5,364 individual chemical analyses were performed in triplicate to establish the mean for the final concentration of 1,788 individual chemical observations of the following elements: Cd, Cr, Cu, Fe, Ni, Mg, Mn, Pb, and Zn. These concentration levels included all the automated quality assurances and standard laboratory referenced calibrations after every twenty samples. The calibration required calibration for each element, several blanks of known reference solutions for the specific element, and quality assurance references for the sensitivity and accuracy of the specific.

As discussed in the literature review, the concern for roof runoff water was to meet the EPA primary drinking water standards for Cd, Cu, Pb, whereas Fe, Mg, and Zn were secondary standards. The objective was to determine the concentrations of some elements that could pose a health risk in water roof runoff and to determine if the concentration exceeds the national drinking standards; if the concentration exceeded the standards, the objective was then to assess that risk (Aldrich & Griffith, 2002). The data for the elements' concentration analyses is presented in a table format in Chapter IV.

Data Collection Procedures

Preliminary Testing

In order to provide a baseline for future analysis, preliminary testing was performed before the actual research project commenced. The rainwater collected in the control container and rainwater runoff from the five panels' collection containers were tested for pH, alkalinity, and total dissolved solids, and Pb concentration was analyzed using the AA. There was a significant difference in pH and in levels of metals between the control rainwater and the panel runoff. The metals' concentration results from the five different panels varied significantly, enough to warrant proceeding with the multiple variable investigation. The preliminary data is discussed and illustrated in Chapter IV.

Primary Meteorological Data Collection

Prior to starting the research, a preliminary study, was conducted to ensure the meteorological station would properly function and integrate with the collection database. This site-specific station monitored 40 separate weather variables at one-minute intervals during this period. The meteorological system recorded 296,113 individual records and 11,844,520 individual data points. The type of rainfall events in the region required a station on-site because of variation in rain and convective nature of storms, which can change within 20 meters of a location. Bias and selection type errors were diminished by logging all the variables possible. Any of these variables may affect the quality of the samples. Temperatures of the panels were monitored because this may affect organism growth on the panel and evaporation. After the data was analyzed, only those variables that showed statistically significant correlations were retained in the model.

Primary Water Data Collection

Rainwater washed down each sloped surface, which was collected in each surface's individual gutter, and then drained into individual collection containers. The composite samples were tested according to the EPA (E.P.A., 2002a, 2002b) and Standard Methods (Clesceri, et al., 1998). The water runoff samples contained dissolved, suspended material, and the particulate matter that had accumulated. Each vial or bottle met specifications established in the EPA's "Specification and Guidance for Contaminant–Free Sample Containers" (E.P.A., 1992). From each collection container, a one 40 ml sample was preserved with 1 ml trace metal-grade HNO_3 that was added in the field at time of sampling to prevent speciation of the metals. The vial was sealed and taken to the laboratory for metals testing. The remainder of the sample was tested for pH, total dissolved solids, and alkalinity at the field site. If the volume remaining permitted, a sterile 1320 ml sample was taken for biological testing; the sterile bottle was sealed with the cap and refrigerated or transported to the laboratory in an ice chest. The sample was kept cold until it was analyzed and was plated within eight hours. The remaining water was discarded, and the container was placed back under its respective waterspout for the next rain event.

The chemical and atmospheric processes at the surface of the panel are a major concern in periods of wet and dry deposition in the harvesting roof rainwater. The control sample provided the reference for establishing possible interaction between the roofing material and the rainwater. Water samples from each panel and the control were analyzed for dissolved heavy metals after each rain event.

The literature indicates that low dosage chronic exposure to metals in drinking water may lead to serious health conditions (Aldrich & Griffith, 2002; Hee, 1993; Louvar & Louvar, 1998; Manahan, 1991; Ness, 1994). The analysis of the water quality is critical in the development and design of the water model for water use. For drinking water, the EPA has established maximum contaminant level (MCL) for primary trace contaminants, which are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and mercury (Hg); and secondary trace contaminants, which are iron (Fe), magnesium (Mn), total dissolved solids, and zinc (Zn). Based upon these criteria, it was decided that each panel sample would be analyzed for Cd, Cr, Cu, Fe, Ni, Mg, Mn, Pb, and Zn. The sampling and analyses for these trace metals occurred over a period of nine months, which permitted capturing conditions during the wet and dry season. These analyses contributed to the economics and public health portion of the model for determining if a particular roofing material increased or reduced water quality through the leaching or absorption processes.

Data Analysis

Several programs were used to process and manage the dataset, in particular: Microsoft Access, for managing the 11,844,560 weather data-points; Microsoft Excel, for managing the parse data in a more efficient structure; and Origin Labs Origin 7.5, for analysis and charts. The statistical program used for the analysis was SAS 9.1.3 (SAS Institute, Carey, NC.); a number of statistical analyses were used in this study such as groups paired student t-test analyses, correlation testing, and parametric and nonparametric testing.

Meteorological Data Analysis

The weather data from the site location recorded 296,114 records of 40 different variables. The size of the database required the use of Microsoft Access to create queries to parse the data to only those events that produced sufficient rainfall to allow collection of water samples, since there were rain events that occurred which did not produce a sufficient volume of rainwater for a chemical analysis. Microsoft Access queries were used to determine the time the rain event occurred and to extract all data related to that event. The query rule for an event would require a positive indication of both rain and beginning intensity, while the query rule for the end of a storm was indicated by zero (0) for both rain rate and accumulation. In addition, the various Access queries were used to calculate the number of antecedent days prior to the rain event, and this information was added to the dataset. The parse data then was transferred to Microsoft Excel for additional graphing and analyses, creating a more manageable dataset. The categorical variables, such as wind direction, were analyzed using the program SAS (SAS Institute, Carey, NC.), for the prevailing wind direction over the storm periods or periods during that sample date. The weather data was then compiled with concentration analyses from the water samples using Inductive Plasma–Mass Spectrometry (ICP-MS).

Antecedent Historical Analysis

The historical data obtained from the Southwest Water District Management was analyzed using SAS for the frequency analysis of the antecedents from 01 January 2000 through 25 December 2006 for site-55, site-56, and site-396 (the closest government weather stations to the research site-specific station). These numbers were also used as parameters and as means for the development of the economical portion of the rational model.

Rainfall Data Records for the Model

The site locations provided accurate meteorological data over nine (9) months for both the dry and wet periods. However, rainfall data for a longer period was required to develop the model accurately. A digital data file was obtained from the National Climatic Data Center (NCDC) for a station site COOPID 84797 Lakeland, Florida (National Climatic Data Center, 2009). This weather station was the nearest to the research location site that was representative of general area conditions. This weather station had continuous 15-minute interval rainfall records over the most recent period of time from1997 through 1998. If any of the individual records were flagged or the entry was questioned, it was removed from the dataset. The use of this data file in the development of the model is discussed in Chapter VI.

Experimental Design

Precipitation and runoff are often considered random variables because of the complexity of understanding the atmospheric processes that are known to drive precipitation (Viessman & Lewis, 2003). An experimental design is based on collection of a control sample and the difference between the control concentration and the collected samples' concentrations from the various roof surfaces. The paired t-test analysis of data was used because the samples are not independent samples (Box, et al., 2005; Frigon & Mathews, 1997; Kachigan, 1991; Sirkin, 1994). This statistical methodology provides a mechanism of comparison between the control and the other surface concentrations. Due to the Central Limit Theorem, a sample size of thirty will often result in sample distributions that appear normally distributed even if the original population deviates from a normal distribution, hence the need for thirty or more rain events for the experiment (Box, et al., 2005; Kachigan, 1991).

Sample Size

All measurements were performed in triplicate, and the number of event samples were sufficient (30+) to be statistically significant. The data collection enabled the parsing and combining of the various datasets into a dataset for water sample analyses and weather data that resulted in 31 unique events over the two distinct seasonal weather patterns. The data set was considered of sufficient and significant sample size to permit statistical analysis of the interaction of the variables. This comprehensive dataset permitted the development of a management decision-making model for water resources for roof runoff.

Data Exclusion Criteria

The plots also revealed the need to analyze the outliers: thus the use of exclusion criteria. The data was examined first without any exclusion criterion. Graphical examination of the data illustrated that some exclusion criterion must be applied to the dataset. Outliers have an important impact on the conclusion of this study; by using the extreme studentized deviate (or ESD statistic) which allows the creation of decision rules for the outliers, the data is more readily manageable. After applying the decision rules for outliers, the analysis was run again without the outliers.

The analysis of the ESD statistic was based on the following conditions: we hypothesize that H_o= no outliers are present versus H_1 and H_1= a single outlier is present with a type I error of ∞ .

$$ESD = max_{t=1...,n} \frac{|x_i - \bar{x}|}{s} \quad \text{(Equation 4-0)}$$

The sample value x_i such that $ESD = max_{t=1...,n} \frac{|x_i - \bar{x}|}{s}$ is refer to as $x^{(n)}$. Therefore, if $ESD > ESD_{n,1-\infty}$ then we reject H_o and declare $x^{(n)}$is an outlier; if $ESD > ESD_{n,1-\infty}$ then we declare that no outliers are present.

Figures 4-1 and 4-2 are examples of the outlier's effect on the study (Appendix I should be referred to for the complete analysis of all the elements examined in the study).

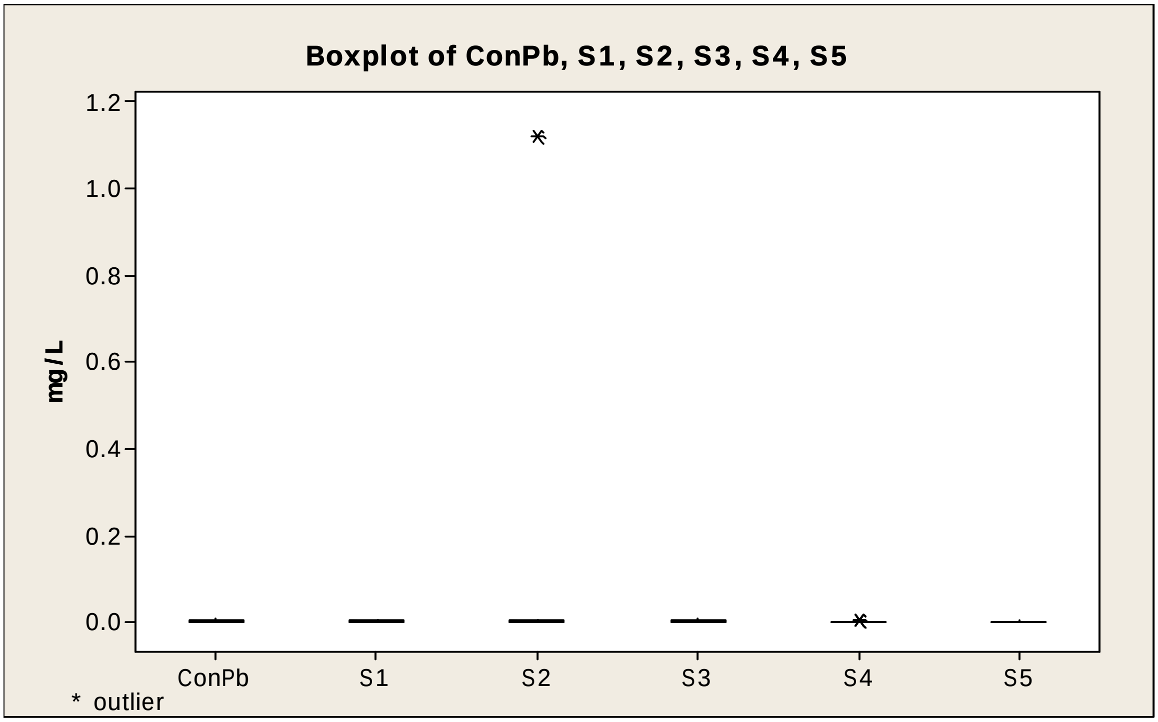

Figure 4-1: Outliers' Effect on the Lead Concentration Data

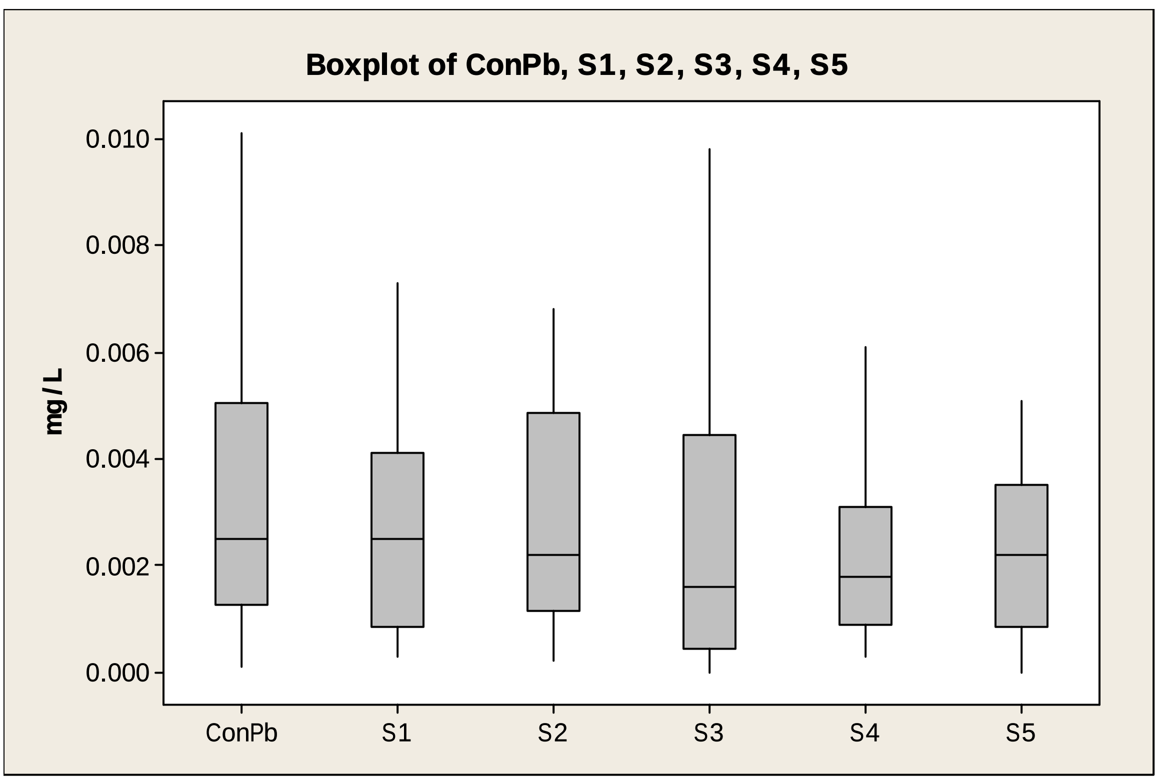

Figure 4-2: The Results of Removal of Outlier from the Lead Concentrations

CHAPTER IV: RESULTS

This chapter reports the results of the experimental research and methods used to analyze the data collected. As previously noted, this research encompassed both field and analytical laboratory measures of key variables within meteorological, chemical, and biological areas. To ensure that all the measures were reliable and valid, replicate measures were taken prior to logging the data in the laboratory notebook. The objective of this investigation was to determine the chemical and biological water quality of roof runoff across the five selected roof surfaces commonly found in the southeastern United States. The purpose of the investigation was to quantify the potential health risk of small concentration of metals in potable water, due to the high cost to remediate those small concentrations of metals in potable water supply.

Table 4-1 is the preliminary data from AA spectrometry that showed a difference in concentration of Pb over the different surfaces. The highlighted cells in the table are indication that Relative Standard Deviation in percent %RSD was at 100 percent. This is a measure of the reproducibility of the results of multiple measurement of the same sample. The measurements are more reproducible the larger the %RSD. For example, in row 2 the water off the clay tile had a lead concentration of 0.0014. mgℓ^{-1},whereas the water from the shaker tile had 0.0017 mgℓ^{-1}. The interesting observation was that the actual rain contained only 0.0013 mgl^{-1} (control sample). The data showed that both clay tile and shaker tile were releasing lead. However, the data from the four rain events showed that the water from the clay tile was 0.0013 mgl^{-1} and the glazed tile was 0.0134

mgl^{-1} of lead. Table 4-1 is the summary of the data for this study. The values for the individual elements are detailed in Tables 4-2 through 4-14. The concentrations in all these tables are expressed in $mg\ell^{-1}$.

Table 4-1: Preliminary Data Results for Samples at the Site Using the AA.

Event	Date	Elements	Rain Control	Tile 1	DIFF.	Glazed Tile 2	DIFF.	Shaker Tile 3	DIFF.	Coated Tin 4	DIFF.	Tin 5	DIFF.	Mean Temp °F	High Temp °F	DIFF.	Wind Dir
		pH	5.82	6.86	**-1.04**	6.89	**-1.07**	6.89	**-1.07**	6.03	**-0.21**	5.94	**-0.12**				
		Alk	6.80	13.60	**-6.80**	13.60	**-6.80**	13.60	**-6.80**	13.60	**-6.80**	13.60	**-6.80**				
1	**08-31-05**	**TDS**	9.00	9.50	**-0.50**	14.50	**-5.50**	20.00	**-11.00**	7.50	**1.50**	8.00	**1.00**	81.40	94.70	**-13.30**	SW
		Pb	0.0012	0.0007	**0.0005**	0.0025	**-0.0013**	0.0023	**-0.0011**	0.0031	**-0.0019**	0.0004	**0.0008**				
		%RSD	>100	>100	**0.00**	43.40	**56.60**	9.70	**90.30**	>100	**0.00**	>100	**0**				
		pH	4.15	4.33	**-0.18**	6.25	**-2.10**	6.63	**-2.48**	4.20	**0.05**	4.33	**-0.18**				
		Alk	13.6	6.8	**6.8**	6.8	**6.8**	13.6	**0**	13.6	**0**	13.6	**0**				
2	**09-02-05**	**TDS**	19	15	**4**	12	**7**	18	**1**	16	**3**	13	**6**	79.00	94.90	**-15.90**	SSE
		Pb	0.0013	0.0014	**-0.0001**	0.0009	**0.0004**	0.0017	**-0.0004**	0.0007	**0.0006**	0.0027	**-0.0014**				
		%RSD	89.90	>100	**-10.10**	25.80	**64.10**	>100	**-10.10**	4.30	**85.60**	15.50	**74.4**				
		pH	3.7	4.27	**-0.57**	6.75	**-3.05**	7.2	**-3.5**	4.13	**-0.43**	4.57	**-0.87**				
		Alk	13.6	13.6	**0.00**	13.6	**0**	13.6	**0**	13.6	**0**	13.6	**0**				
3	**09-03-05**	**TDS**	31.1	28	**3.10**	37	**-5.9**	45	**-13.9**	39	**-7.9**	30	**1.1**	80.90	94.30	**-13.40**	NE
		Pb	0.0027	0.0045	**-0.0018**	0.0024	**0.0003**	0.0005	**0.0022**	0.0031	**-0.0004**	0.0039	**-0.0012**				
		%RSD	31.1	5	**26.10**	38.8	**-7.7**	41.3	**-10.2**	20.5	**10.6**	0.3	**30.8**				
		pH	7.5	7.28	**0.22**	7.26	**0.24**	7.37	**0.13**	4.85	**2.65**	5.83	**1.67**				
		Alk	13.6	13.6	**0.00**	13.6	**0**	13.6	**0**	13.6	**0**	13.6	**0**				
4	**09-06-05**	**TDS**	50	25	**25.00**	30	**20**	36	**14**	25	**25**	25	**25**	80.30	94.00	**-13.70**	NE
		Pb	0.0030	0.0003	**0.0027**	0.0158	**-0.0128**	0.0016	**0.0014**	0.0036	**0.0006**	0.0014	**0.0016**				

Table 4-2: Roof Runoff Concentrations Summary Results from the Site.

element	Surface	median	mean	std dev	max	min	n=
Zn	control	0.0533	0.1686	0.2171	0.7509	0.0086	31
	S1	0.0341	0.0722	0.0859	0.3444	0.0040	31
	S2	0.0328	0.0585	0.0627	0.2230	0.0004	31
	S3	0.0450	0.1164	0.2063	1.0440	0.0002	31
	S4	0.0816	0.1345	0.1186	0.5769	0.0022	31
	S5	1.0230	1.2633	0.9787	3.7420	0.0371	31
Pb	control	0.0022	0.0030	0.0024	0.0090	0.0001	31
	S1	0.0025	0.0028	0.0021	0.0073	0.0003	31
	S2	0.0020	0.0026	0.0020	0.0068	0.0002	31
	S3	0.0021	0.0027	0.0025	0.0098	0.0000	31
	S4	0.0018	0.0024	0.0019	0.0070	0.0003	31
	S5	0.0022	0.0022	0.0015	0.0051	0.0000	31
Cd	control	0.0001	0.0001	0.0001	0.0003	0.0000	31
	S1	0.0001	0.0001	0.0001	0.0004	0.0000	31
	S2	0.0001	0.0002	0.0004	0.0020	0.0000	31
	S3	0.0001	0.0001	0.0001	0.0003	0.0000	31
	S4	0.0001	0.0001	0.0001	0.0005	0.0000	31
	S5	0.0001	0.0001	0.0001	0.0008	0.0000	31
Ni	control	0.0017	0.0020	0.0014	0.0050	0.0000	24
	S1	0.0014	0.0017	0.0011	0.0042	0.0004	24
	S2	0.0013	0.0016	0.0010	0.0040	0.0000	24
	S3	0.0017	0.0032	0.0069	0.0352	0.0001	24
	S4	0.0015	0.0016	0.0011	0.0045	0.0001	24
	S5	0.0016	0.0018	0.0012	0.0049	0.0002	24
Fe	control	0.0627	0.0705	0.0420	0.1963	0.0176	31
	S1	0.0501	0.0532	0.0276	0.1184	0.0084	31
	S2	0.0600	0.0611	0.0287	0.1253	0.0176	31
	S3	0.0602	0.0735	0.0522	0.2142	0.0135	31
	S4	0.0599	0.0635	0.0247	0.1312	0.0226	31
	S5	0.0597	0.0571	0.0246	0.1009	0.0095	31
Mn	control	0.0025	0.0065	0.0113	0.0550	0.0008	24
	S1	0.0024	0.0036	0.0027	0.0094	0.0007	24
	S2	0.0018	0.0030	0.0025	0.0099	0.0007	24
	S3	0.0023	0.0036	0.0051	0.0257	0.0009	24
	S4	0.0025	0.0044	0.0057	0.0271	0.0003	24
	S5	0.0029	0.0057	0.0089	0.0433	0.0006	24
Cr	control	0.0008	0.0008	0.0003	0.0013	0.0001	31
	S1	0.0007	0.0006	0.0002	0.0009	0.0000	31
	S2	0.0010	0.0012	0.0013	0.0080	0.0001	31
	S3	0.0014	0.0014	0.0005	0.0030	0.0001	31
	S4	0.0008	0.0008	0.0004	0.0021	0.0000	31
	S5	0.0007	0.0007	0.0004	0.0016	0.0001	31
Cu	control	0.0033	0.0066	0.0072	0.0242	0.0008	31
	S1	0.0021	0.0059	0.0071	0.0240	0.0009	31
	S2	0.0027	0.0059	0.0070	0.0233	0.0004	31
	S3	0.0030	0.0069	0.0067	0.0209	0.0010	31
	S4	0.0028	0.0055	0.0064	0.0197	0.0003	31
	S5	0.0022	0.0054	0.0066	0.0203	0.0004	31
Mg	control	0.3790	0.6230	0.5509	1.6170	0.1050	7
	S1	0.2240	0.2240	0.1633	0.4750	0.0540	7
	S2	0.2630	0.3336	0.2135	0.7040	0.0860	7
	S3	0.3530	0.4293	0.3075	1.0540	0.1080	7
	S4	0.3660	0.4440	0.3748	1.0880	0.0650	7
	S5	0.3890	0.4586	0.4082	1.2110	0.0710	7

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Table 4-3: Roof Runoff Analyzed for pH Analyses from the Site.

Date	ConpH	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	.	.	.	.	.	.	SW	1	85	0.96	0.96
31-Aug-05	5.82	6.86	6.89	6.89	6.03	5.94	SW	2	77	0.30	0.31
2-Sep-05	4.15	4.33	6.25	6.63	4.20	4.33	N	1	103	1.03	0.97
3-Sep-05	3.67	4.27	6.75	7.20	4.13	4.57	NE	1	32	0.07	0.24
6-Sep-05	7.45	7.28	7.26	7.37	4.85	5.83	N	3	24	0.13	0.44
20-Sep-05	6.23	6.28	6.88	6.91	6.54	6.40	NNE	14	25	0.22	0.95
21-Sep-05	7.15	6.73	7.37	7.51	6.36	6.12	NE	1	120	0.21	0.14
22-Sep-05	6.01	6.53	7.20	7.56	4.91	6.13	NNE	1	34	0.07	0.17
27-Sep-05	4.36	5.31	6.73	6.95	4.54	4.87	ESE	5	55	0.38	0.54
28-Sep-05	4.41	5.12	6.71	7.05	4.50	4.90	SW	1	52	0.41	0.61
1-Oct-05	4.90	6.20	6.99	7.22	5.70	6.03	NNE	2	34	0.21	0.51
2-Oct-05	5.20	5.99	7.00	7.26	5.05	5.50	SE	1	52	0.26	0.41
5-Oct-05	4.63	5.47	6.78	7.11	5.05	5.36	SW	3	51	0.70	1.02
6-Oct-05	5.85	5.78	6.94	7.16	5.52	5.67	SW	1	135	0.90	0.47
8-Oct-05	5.42	6.09	7.09	7.37	5.37	6.01	S	2	23	0.07	0.31
23-Oct-05	7.71	8.15	8.09	8.17	8.52	8.36	NE	15	100	0.17	0.12
1-Nov-05	7.28	7.46	7.70	7.69	7.46	7.30	ESE	8	200	0.57	0.19
21-Nov-05	7.24	7.36	7.64	7.44	7.21	6.92	SW	20	60	0.05	0.13
28-Nov-05	7.33	6.85	7.06	7.23	6.56	6.24	SW	7	127	0.88	0.56
5-Dec-05	5.45	5.86	6.80	7.04	5.12	5.27	SSW	7	110	0.31	0.22
7-Dec-05	6.37	5.05	6.89	7.26	4.95	5.07	NE	2	218	0.37	0.11
17-Dec-05	7.43	6.79	7.30	7.63	6.15	6.33	NE	10	17	0.01	0.08
18-Dec-05	6.74	6.25	7.02	7.31	4.91	5.45	NW	1	61	0.04	0.06
25-Dec-05	6.66	6.77	7.17	7.50	6.40	6.24	WSW	7	17	0.01	0.06
3-Jan-06	7.35	6.75	7.10	7.32	6.54	6.16	SW	9	26	0.20	0.70
17-Jan-06	6.81	6.80	7.03	7.19	6.53	6.34					
24-Jan-06	6.30	6.36	6.88	7.00	6.30	6.07	SSW	14	43	0.21	0.41
29-Jan-06	6.77	6.74	7.12	7.37	6.55	6.31	SE	6	64	0.08	0.09
30-Jan-06	6.63	6.28	7.09	7.24	6.05	5.85	SW	0	114	0.13	0.09
3-Feb-06	6.75	5.71	6.61	6.90	5.16	5.22	SSE	3	666	4.53	0.54
11-Feb-06	8.14	6.53	7.06	7.03	6.65	6.41	SW	8	64	0.05	0.08
23-Feb-06	8.21	7.39	7.21	7.22	6.68	6.43	ESE	13	25	0.03	0.09
25-Feb-06	6.36	6.21	6.76	6.97	6.18	5.91	SW	2	84	0.24	0.24
median	**6.50**	**6.32**	**7.03**	**7.23**	**6.04**	**6.02**		**3**	**61**	**0.21**	**0.28**
mean	**6.27**	**6.30**	**7.04**	**7.24**	**5.83**	**5.92**		**5**	**91**	**0.43**	**0.37**
std dev	**1.20**	**0.87**	**0.34**	**0.29**	**1.01**	**0.79**		**5**	**116**	**0.80**	**0.30**
max	**8.21**	**8.15**	**8.09**	**8.17**	**8.52**	**8.36**		**20**	**666**	**4.53**	**1.02**
min	**3.67**	**4.27**	**6.25**	**6.63**	**4.13**	**4.33**		**0**	**17**	**0.01**	**0.06**
n=	**32**	**32**	**32**	**32**	**32**	**32**		**32**	**32**	**32**	**32**

Table 4-4: Roof Runoff Analyzed for Alkalinity from the Site.

Date	ConALK	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	.	.	.	.	.	.	SW	1	85	0.96	0.96
31-Aug-05	1	2	2	2	2	2	SW	2	77	0.30	0.31
2-Sep-05	2	1	1	2	2	2	N	1	103	1.03	0.97
3-Sep-05	2	2	2	2	2	2	NE	1	32	0.07	0.24
6-Sep-05	2	2	2	2	2	2	N	3	24	0.13	0.44
20-Sep-05	2	2	2	2	2	2	NNE	14	25	0.22	0.95
21-Sep-05	2	2	2	2	2	2	NE	1	120	0.21	0.14
22-Sep-05	2	2	2	3	2	2	NNE	1	34	0.07	0.17
27-Sep-05	2	2	2	3	2	2	ESE	5	55	0.38	0.54
28-Sep-05	2	2	2	2	2	2	SW	1	52	0.41	0.61
1-Oct-05	2	2	2	2	2	2	NNE	2	34	0.21	0.51
2-Oct-05	2	2	2	2	2	2	SE	1	52	0.26	0.41
5-Oct-05	2	2	2	2	2	2	SW	3	51	0.70	1.02
6-Oct-05	2	2	2	2	2	2	SW	1	135	0.90	0.47
8-Oct-05	2	2	2	2	2	2	S	2	23	0.07	0.31
23-Oct-05	2	2	2	2	2	2	NE	15	100	0.17	0.12
1-Nov-05	2	2	2	3	2	2	ESE	8	200	0.57	0.19
21-Nov-05	2	2	2	2	2	2	SW	20	60	0.05	0.13
28-Nov-05	2	2	2	2	2	2	SW	7	127	0.88	0.56
5-Dec-05	2	2	2	2	2	2	SSW	7	110	0.31	0.22
7-Dec-05	2	2	2	2	2	2	NE	2	218	0.37	0.11
17-Dec-05	2	2	2	2	2	2	NE	10	17	0.01	0.08
18-Dec-05	2	2	2	2	2	2	NW	1	61	0.04	0.06
25-Dec-05	2	2	3	3	2	2	WSW	7	17	0.01	0.06
3-Jan-06	2	2	2	2	2	2	SW	9	26	0.20	0.70
17-Jan-06	2	2	2	2	2	2					
24-Jan-06	2	2	2	2	2	2	SSW	14	43	0.21	0.41
29-Jan-06	2	2	2	2	2	2	SE	6	64	0.08	0.09
30-Jan-06	2	2	2	2	2	2	SW	0	114	0.13	0.09
3-Feb-06	2	2	2	2	2	2	SSE	3	666	4.53	0.54
11-Feb-06	2	2	2	2	2	2	SW	8	64	0.05	0.08
23-Feb-06	2	2	3	2	2	2	ESE	13	25	0.03	0.09
25-Feb-06	2						SW	2	84	0.24	0.24
median	2.0	2.0	2.0	2.0	2.0	2.0		3	61	0.21	0.28
mean	2.0	2.0	2.0	2.1	2.0	2.0		5	91	0.43	0.37
std dev	0.2	0.2	0.3	0.3	0.0	0.0		5	116	0.80	0.30
max	2.0	2.0	3.0	3.0	2.0	2.0		20	666	4.53	1.02
min	1.0	1.0	1.0	2.0	2.0	2.0		0	17	0.01	0.06
n=	32	31	31	31	31	31		32	32	32	32

Table 4-5: Roof Runoff Analyzed for Total Dissolved Solids at the Site.

Date	ConTDS	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	.	.	.	.	.	.	SW	1	85	0.96	0.96
31-Aug-05	9	10	15	20	8	8	SW	2	77	0.30	0.31
2-Sep-05	19	15	12	18	16	13	N	1	103	1.03	0.97
3-Sep-05	0	28	37	45	39	30	NE	1	32	0.07	0.24
6-Sep-05	50	25	30	36	25	25	N	3	24	0.13	0.44
20-Sep-05	19	15	18	28	13	18	NNE	14	25	0.22	0.95
21-Sep-05	10	6	25	35	7	7	NE	1	120	0.21	0.14
22-Sep-05	32	15	40	50	19	20	NNE	1	34	0.07	0.17
27-Sep-05	20	15	20	25	17	16	ESE	5	55	0.38	0.54
28-Sep-05	16	13	16	21	15	12	SW	1	52	0.41	0.61
1-Oct-05	15	9	17	22	8	8	NNE	2	34	0.21	0.51
2-Oct-05	12	7	16	22	8	9	SE	1	52	0.26	0.41
5-Oct-05	9	5	10	15	5	5	SW	3	51	0.70	1.02
6-Oct-05	8	3	9	14	3	3	SW	1	135	0.90	0.47
8-Oct-05	20	13	23	32	12	10	S	2	23	0.07	0.31
23-Oct-05	6	5	15	22	3	3	NE	15	100	0.17	0.12
1-Nov-05	9	5	13	21	3	3	ESE	8	200	0.57	0.19
21-Nov-05	40	18	26	50	42	44	SW	20	60	0.05	0.13
28-Nov-05	7	6	14	22	6	7	SW	7	127	0.88	0.56
5-Dec-05	13	9	19	25	12	11	SSW	7	110	0.31	0.22
7-Dec-05	23	18	30	41	20	18	NE	2	218	0.37	0.11
17-Dec-05	60	20	50	80	24	28	NE	10	17	0.01	0.08
18-Dec-05	27	15	35	60	25	17	NW	1	61	0.04	0.06
25-Dec-05	70	26	60	80	28	37	WSW	7	17	0.01	0.06
3-Jan-06	22	10	16	20	11	16	SW	9	26	0.20	0.70
17-Jan-06	28	22	28	35	23	25					
24-Jan-06	20	16	23	31	18	19	SSW	14	43	0.21	0.41
29-Jan-06	28	13	30	40	16	18	SE	6	64	0.08	0.09
30-Jan-06	13	8	26	40	7	8	SW	0	114	0.13	0.09
3-Feb-06	5	4	10	14	4	4	SSE	3	666	4.53	0.54
11-Feb-06	50	29	45	60	35	35	SW	8	64	0.05	0.08
23-Feb-06	60	25	45	60	41	50	ESE	13	25	0.03	0.09
25-Feb-06	16	10	18	26	8	8	SW	2	84	0.24	0.24
median	**19.0**	**13.0**	**21.5**	**29.5**	**14.0**	**14.5**		**3**	**61**	**0.21**	**0.28**
mean	**23.0**	**13.7**	**24.7**	**34.7**	**16.3**	**16.7**		**5**	**91**	**0.43**	**0.37**
std dev	**17.7**	**7.5**	**12.7**	**18.0**	**11.4**	**12.2**		**5**	**116**	**0.80**	**0.30**
max	**70.0**	**29.0**	**60.0**	**80.0**	**42.0**	**50.0**		**20**		**4.53**	**1.02**
min	**0.0**	**3.0**	**9.0**	**14.0**	**3.0**	**2.5**		**0**		**0.01**	**0.06**
n=	**32**	**32**	**32**	**32**	**32**	**32**		**32**	**32**	**32**	**32**

Table 4-6: Roof Runoff Analyzed for Zinc from the Site.

Date	ConZn	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.1066	0.0327	0.0228	0.0852	0.0816	0.3093	SW	1	85	0.9600	0.9600
31-Aug-05	0.2503	0.2445	0.1451	0.2924	0.2593	0.8464	SW	2	77	0.3000	0.3141
2-Sep-05	0.2459	0.0798	0.0593	0.1011	0.1149	0.8025	N	1	103	1.0300	0.9716
3-Sep-05											
6-Sep-05	0.7509	0.2428	0.2230	0.3427	0.5769	1.7950	N	3	24	0.1300	0.4421
20-Sep-05	0.6905	0.3444	0.1687	1.0440	0.2783	1.3370	NNE	14	25	0.2200	0.9504
21-Sep-05	0.4826	0.1797	0.1586	0.4803	0.2289	1.1750	NE	1	120	0.2100	0.1377
22-Sep-05											
27-Sep-05	0.1623	0.1489	0.1404	0.1839	0.1727	1.1240	ESE	5	55	0.3800	0.5442
28-Sep-05	0.3776	0.0990	0.1261	0.1829	0.1384	0.7103	SW	1	52	0.4100	0.6069
1-Oct-05	0.6718	0.1975	0.1015	0.2406	0.2610	1.0230	NNE	2	34	0.2100	0.5050
2-Oct-05	0.0535	0.0304	0.0193	0.0467	0.0595	0.6457	SE	1	52	0.2600	0.4077
5-Oct-05	0.0553	0.0250	0.0237	0.0301	0.0468	0.4060	SW	3	51	0.7000	1.0225
6-Oct-05	0.0387	0.0170	0.0153	0.0233	0.0304	0.0371	SW	1	135	0.9000	0.4660
8-Oct-05	0.0354	0.0503	0.0529	0.0947	0.1277	1.1160	S	2	23	0.0700	0.3141
23-Oct-05	0.0184	0.0210	0.0072	0.0154	0.0348	0.4896	NE	15	100	0.1700	0.1238
1-Nov-05	0.0134	0.0093	0.0074	0.0085	0.0239	0.5935	ESE	8	200	0.5700	0.1894
21-Nov-05	0.0511	0.0259	0.0233	0.0486	0.2365	3.4180	SW	20	60	0.0500	0.1262
28-Nov-05	0.0107	0.0097	0.0091	0.0080	0.0421	0.6802	SW	7	127	0.8800	0.5627
5-Dec-05	0.0244	0.0149	0.0133	0.0094	0.0658	0.9900	SSW	7	110	0.3100	0.2151
7-Dec-05	0.0317	0.0208	0.0168	0.0119	0.0550	1.0240	NE	2	218	0.3700	0.1089
17-Dec-05	0.0486	0.0379	0.0410	0.0521	0.2127	3.2400	NE	10	17	0.0100	0.0776
18-Dec-05	0.0269	0.0343	0.0386	0.0450	0.2244	2.8320	NW	1	61	0.0400	0.0621
25-Dec-05	0.1815	0.0765	0.0472	0.0218	0.1077	2.1600	WSW	7	17	0.0100	0.0594
3-Jan-06	0.0244	0.0040	0.0004	0.0002	0.0022	0.3342	SW	9	26	0.2000	0.7046
17-Jan-06	0.0563	0.0262	0.0184	0.0260	0.0582	0.7534					
24-Jan-06	0.0843	0.0341	0.0328	0.0418	0.0780	1.0930	SSW	14	43	0.2100	0.4105
29-Jan-06	0.0273	0.0104	0.0131	0.0121	0.0706	1.5790	SE	6	64	0.0800	0.0855
30-Jan-06	0.0146	0.0070	0.0020	0.0048	0.0590	1.0610	SW	0	114	0.1300	0.0900
3-Feb-06	0.0086	0.0060	0.0042	0.0172	0.0215	0.2770	SSE	3	666	4.5300	0.5355
11-Feb-06	0.1375	0.0555	0.0632	0.0645	0.1649	2.7410	SW	8	64	0.0500	0.0752
23-Feb-06	0.4107	0.1153	0.1793	0.0265	0.2606	3.7420	ESE	13	25	0.0300	0.0900
25-Feb-06	0.1345	0.0360	0.0409	0.0475	0.0755	0.8268	SW	2	84	0.2400	0.2359
median	**0.0553**	**0.0341**	**0.0328**	**0.0450**	**0.0816**	**1.0230**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.1686**	**0.0722**	**0.0585**	**0.1164**	**0.1345**	**1.2633**		**6**	**94**	**0.4553**	**0.3798**
std dev	**0.2171**	**0.0859**	**0.0627**	**0.2063**	**0.1186**	**0.9787**		**5**	**119**	**0.8252**	**0.3047**
max	**0.7509**	**0.3444**	**0.2230**	**1.0440**	**0.5769**	**3.7420**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0086**	**0.0040**	**0.0004**	**0.0002**	**0.0022**	**0.0371**		**0**	**17**	**0.0100**	**0.0594**
n=	**31**	**31**	**31**	**31**	**31**	**31**		**30**	**30**	**30**	**30**

Table 4-7: Roof Runoff Analyzed for Lead from the Site.

Date	ConPb	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.0032	0.0004	0.0016	0.0005	0.0022	0.0008	SW	1	85	0.9600	0.9600
31-Aug-05	0.0015	0.0003	0.0019	0.0015	0.0006	0.0009	SW	2	77	0.3000	0.3141
2-Sep-05	0.0011	0.0009	0.0007	0.0029	0.0028	0.0031	N	1	103	1.0300	0.9716
3-Sep-05											
6-Sep-05	0.0050	0.0011	0.0057	0.0037	0.0015	0.0014	N	3	24	0.1300	0.4421
20-Sep-05	0.0040	0.0041	0.0002	0.0098	0.0025	0.0023	NNE	14	25	0.2200	0.9504
21-Sep-05	0.0017	0.0006	0.0004	0.0008	0.0007	0.0022	NE	1	120	0.2100	0.1377
22-Sep-05											
27-Sep-05	0.0003	0.0017	0.0013	0.0000	0.0025	0.0009	ESE	5	55	0.3800	0.5442
28-Sep-05	0.0001	0.0008	0.0006	0.0006	0.0010	0.0014	SW	1	52	0.4100	0.6069
1-Oct-05	0.0018	0.0025	0.0003	0.0001	0.0016	0.0004	NNE	2	34	0.2100	0.5050
2-Oct-05	0.0011	0.0024	0.0009	0.0007	0.0008	0.0001	SE	1	52	0.2600	0.4077
5-Oct-05	0.0002	0.0014	0.0011	0.0004	0.0003	0.0016	SW	3	51	0.7000	1.0225
6-Oct-05	0.0058	0.0020	0.0049	0.0046	0.0038	0.0040	SW	1	135	0.9000	0.4660
8-Oct-05	0.0001	0.0041	0.0004	0.0002	0.0021	0.0027	S	2	23	0.0700	0.3141
23-Oct-05	0.0017	0.0004	0.0020	0.0004	0.0009	0.0005	NE	15	100	0.1700	0.1238
1-Nov-05	0.0025	0.0035	0.0024	0.0031	0.0030	0.0000	ESE	8	200	0.5700	0.1894
21-Nov-05	0.0022	0.0004	0.0012	0.0001	0.0004	0.0020	SW	20	60	0.0500	0.1262
28-Nov-05	0.0022	0.0007	0.0028	0.0026	0.0028	0.0022	SW	7	127	0.8800	0.5627
5-Dec-05	0.0065	0.0051	0.0022	0.0051	0.0009	0.0051	SSW	7	110	0.3100	0.2151
7-Dec-05	0.0022	0.0025	0.0026	0.0044	0.0032	0.0029	NE	2	218	0.3700	0.1089
17-Dec-05	0.0038	0.0045	0.0049	0.0014	0.0048	0.0030	NE	10	17	0.0100	0.0776
18-Dec-05	0.0005	0.0034	0.0019	0.0040	0.0013	0.0033	NW	1	61	0.0400	0.0621
25-Dec-05	0.0056	0.0029	0.0018	0.0064	0.0018	0.0002	WSW	7	17	0.0100	0.0594
3-Jan-06	0.0041	0.0072	0.0068	0.0045	0.0042	0.0046	SW	9	26	0.2000	0.7046
17-Jan-06	0.0010	0.0028	0.0022	0.0003	0.0018	0.0004					
24-Jan-06	0.0054	0.0073	0.0048	0.0081	0.0003	0.0037	SSW	14	43	0.2100	0.4105
29-Jan-06	0.0085	0.0031	0.0060	0.0035	0.0061	0.0015	SE	6	64	0.0800	0.0855
30-Jan-06	0.0027	0.0030	0.0025	0.0007	0.0013	0.0049	SW	0	114	0.1300	0.0900
3-Feb-06	0.0014	0.0045	0.0018	0.0021	0.0009	0.0014	SSE	3	666	4.5300	0.5355
11-Feb-06	0.0051	0.0071	0.0054	0.0016	0.0066	0.0041	SW	8	64	0.0500	0.0752
23-Feb-06	0.0090	0.0051	0.0062	0.0047	0.0070	0.0042	ESE	13	25	0.0300	0.0900
25-Feb-06	0.0041	0.0022	0.0035	0.0052	0.0053	0.0039	SW	2	84	0.2400	0.2359
median	**0.0022**	**0.0025**	**0.0020**	**0.0021**	**0.0018**	**0.0022**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.0030**	**0.0028**	**0.0026**	**0.0027**	**0.0024**	**0.0022**		**6**	**94**	**0.4553**	**0.3798**
std dev	**0.0024**	**0.0021**	**0.0020**	**0.0025**	**0.0019**	**0.0015**		**5**	**119**	**0.8252**	**0.3047**
max	**0.0090**	**0.0073**	**0.0068**	**0.0098**	**0.0070**	**0.0051**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0001**	**0.0003**	**0.0002**	**0.0000**	**0.0003**	**0.0000**		**0**	**17**	**0.0100**	**0.0594**
n=	**31**	**31**	**31**	**31**	**31**	**31**		**30**	**30**	**30**	**30**

Table 4-8: Roof Runoff Analyzed for Cadmium from the Site.

Date	ConCd	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	SW	1	85	0.9600	0.9600
31-Aug-05	0.0002	0.0002	0.0000	0.0001	0.0000	0.0001	SW	2	77	0.3000	0.3141
2-Sep-05	0.0001	0.0001	0.0003	0.0002	0.0001	0.0001	N	1	103	1.0300	0.9716
3-Sep-05											
6-Sep-05	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	N	3	24	0.1300	0.4421
20-Sep-05	0.0002	0.0003	0.0001	0.0003	0.0000	0.0000	NNE	14	25	0.2200	0.9504
21-Sep-05	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	NE	1	120	0.2100	0.1377
22-Sep-05											
27-Sep-05	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	ESE	5	55	0.3800	0.5442
28-Sep-05	0.0002	0.0000	0.0001	0.0001	0.0001	0.0001	SW	1	52	0.4100	0.6069
1-Oct-05	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	NNE	2	34	0.2100	0.5050
2-Oct-05	0.0001	0.0001	0.0001	0.0000	0.0001	0.0002	SE	1	52	0.2600	0.4077
5-Oct-05	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	SW	3	51	0.7000	1.0225
6-Oct-05	0.0002	0.0002	0.0001	0.0002	0.0001	0.0001	SW	1	135	0.9000	0.4660
8-Oct-05	0.0002	0.0000	0.0000	0.0001	0.0002	0.0001	S	2	23	0.0700	0.3141
23-Oct-05	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	NE	15	100	0.1700	0.1238
1-Nov-05	0.0001	0.0001	0.0000	0.0001	0.0001	0.0008	ESE	8	200	0.5700	0.1894
21-Nov-05	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002	SW	20	60	0.0500	0.1262
28-Nov-05	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	SW	7	127	0.8800	0.5627
5-Dec-05	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	SSW	7	110	0.3100	0.2151
7-Dec-05	0.0002	0.0001	0.0000	0.0001	0.0005	0.0002	NE	2	218	0.3700	0.1089
17-Dec-05	0.0001	0.0001	0.0003	0.0000	0.0001	0.0000	NE	10	17	0.0100	0.0776
18-Dec-05	0.0001	0.0002	0.0000	0.0000	0.0003	0.0001	NW	1	61	0.0400	0.0621
25-Dec-05	0.0002	0.0001	0.0002	0.0001	0.0000	0.0001	WSW	7	17	0.0100	0.0594
3-Jan-06	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	SW	9	26	0.2000	0.7046
17-Jan-06	0.0001	0.0000	0.0002	0.0002	0.0001	0.0001					
24-Jan-06	0.0002	0.0001	0.0020	0.0001	0.0000	0.0000	SSW	14	43	0.2100	0.4105
29-Jan-06	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	SE	6	64	0.0800	0.0855
30-Jan-06	0.0000	0.0004	0.0002	0.0001	0.0003	0.0003	SW	0	114	0.1300	0.0900
3-Feb-06	0.0003	0.0000	0.0000	0.0003	0.0000	0.0003	SSE	3	666	4.5300	0.5355
11-Feb-06	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	SW	8	64	0.0500	0.0752
23-Feb-06	0.0001	0.0003	0.0000	0.0003	0.0002	0.0001	ESE	13	25	0.0300	0.0900
25-Feb-06	0.0000	0.0003	0.0001	0.0003	0.0001	0.0002	SW	2	84	0.2400	0.2359
median	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.0001**	**0.0001**	**0.0002**	**0.0001**	**0.0001**	**0.0001**		**6**	**94**	**0.4553**	**0.3798**
std dev	**0.0001**	**0.0001**	**0.0004**	**0.0001**	**0.0001**	**0.0001**		**5**	**119**	**0.8252**	**0.3047**
max	**0.0003**	**0.0004**	**0.0020**	**0.0003**	**0.0005**	**0.0008**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**		**0**	**17**	**0.0100**	**0.0594**
n=	**31**	**31**	**31**	**31**	**31**	**31**		**30**	**30**	**30**	**30**

Table 4-9: Roof Runoff Analyzed for Nickel from the Site.

Date	ConNi	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.0040	0.0014	0.0020	0.0352	0.0015	0.0016	SW	1	85	0.9600	0.9600
31-Aug-05	0.0009	0.0017	0.0010	0.0007	0.0016	0.0016	SW	2	77	0.3000	0.3141
2-Sep-05	0.0017	0.0025	0.0014	0.0024	0.0014	0.0017	N	1	103	1.0300	0.9716
3-Sep-05											
6-Sep-05	0.0021	0.0019	0.0007	0.0021	0.0016	0.0012	N	3	24	0.1300	0.4421
20-Sep-05	0.0018	0.0017	0.0022	0.0040	0.0023	0.0026	NNE	14	25	0.2200	0.9504
21-Sep-05	0.0000	0.0004	0.0011	0.0006	0.0008	0.0002	NE	1	120	0.2100	0.1377
22-Sep-05											
27-Sep-05	0.0017	0.0014	0.0008	0.0009	0.0015	0.0023	ESE	5	55	0.3800	0.5442
28-Sep-05	0.0010	0.0012	0.0010	0.0010	0.0009	0.0008	SW	1	52	0.4100	0.6069
1-Oct-05	0.0010	0.0014	0.0008	0.0002	0.0002	0.0005	NNE	2	34	0.2100	0.5050
2-Oct-05	0.0011	0.0005	0.0014	0.0013	0.0007	0.0008	SE	1	52	0.2600	0.4077
5-Oct-05	0.0005	0.0005	0.0008	0.0008	0.0010	0.0005	SW	3	51	0.7000	1.0225
6-Oct-05	0.0030	0.0030	0.0024	0.0026	0.0028	0.0030	SW	1	135	0.9000	0.4660
8-Oct-05	0.0016	0.0006	0.0009	0.0026	0.0015	0.0015	S	2	23	0.0700	0.3141
23-Oct-05	0.0013	0.0006	0.0006	0.0012	0.0012	0.0011	NE	15	100	0.1700	0.1238
1-Nov-05	0.0011	0.0007	0.0000	0.0001	0.0007	0.0021	ESE	8	200	0.5700	0.1894
21-Nov-05	0.0018	0.0008	0.0015	0.0020	0.0025	0.0018	SW	20	60	0.0500	0.1262
28-Nov-05	0.0001	0.0009	0.0011	0.0012	0.0001	0.0004	SW	7	127	0.8800	0.5627
5-Dec-05	0.0037	0.0030	0.0026	0.0034	0.0026	0.0037	SSW	7	110	0.3100	0.2151
7-Dec-05	0.0028	0.0033	0.0040	0.0031	0.0032	0.0031	NE	2	218	0.3700	0.1089
17-Dec-05	0.0050	0.0042	0.0033	0.0026	0.0035	0.0036	NE	10	17	0.0100	0.0776
18-Dec-05	0.0042	0.0027	0.0033	0.0036	0.0045	0.0049	NW	1	61	0.0400	0.0621
25-Dec-05	0.0044	0.0039	0.0029	0.0012	0.0003	0.0011	WSW	7	17	0.0100	0.0594
3-Jan-06	0.0006	0.0017	0.0010	0.0010	0.0008	0.0006	SW	9	26	0.2000	0.7046
17-Jan-06	0.0016	0.0008	0.0016	0.0022	0.0013	0.0016					
24-Jan-06							SSW	14	43	0.2100	0.4105
29-Jan-06							SE	6	64	0.0800	0.0855
30-Jan-06							SW	0	114	0.1300	0.0900
3-Feb-06							SSE	3	666	4.5300	0.5355
11-Feb-06							SW	8	64	0.0500	0.0752
23-Feb-06							ESE	13	25	0.0300	0.0900
25-Feb-06							SW	2	84	0.2400	0.2359
median	**0.0017**	**0.0014**	**0.0013**	**0.0017**	**0.0015**	**0.0016**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.0020**	**0.0017**	**0.0016**	**0.0032**	**0.0016**	**0.0018**		**5**	**77**	**0.3648**	**0.4292**
std dev	**0.0014**	**0.0011**	**0.0010**	**0.0069**	**0.0011**	**0.0012**		**5**	**56**	**0.3202**	**0.3193**
max	**0.0050**	**0.0042**	**0.0040**	**0.0352**	**0.0045**	**0.0049**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0000**	**0.0004**	**0.0000**	**0.0001**	**0.0001**	**0.0002**		**0**	**17**	**0.0100**	**0.0594**
n=	**24**	**24**	**24**	**24**	**24**	**24**		**30**	**30**	**30**	**30**

Table 4-10: Roof Runoff Analyzed for Iron from the Site.

Date	ConFe	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.1963	0.0690	0.0702	0.0963	0.0700	0.0803	SW	1	85	0.9600	0.9600
31-Aug-05	0.0863	0.0639	0.1127	0.0718	0.0934	0.0434	SW	2	77	0.3000	0.3141
2-Sep-05	0.0595	0.0814	0.0790	0.1165	0.0901	0.0806	N	1	103	1.0300	0.9716
3-Sep-05											
6-Sep-05	0.0800	0.0556	0.0824	0.0851	0.0599	0.0597	N	3	24	0.1300	0.4421
20-Sep-05	0.0894	0.0353	0.0963	0.0641	0.0540	0.0943	NNE	14	25	0.2200	0.9504
21-Sep-05	0.0627	0.0270	0.0396	0.0290	0.0408	0.0555	NE	1	120	0.2100	0.1377
22-Sep-05											
27-Sep-05	0.0668	0.0375	0.0616	0.0512	0.0644	0.0595	ESE	5	55	0.3800	0.5442
28-Sep-05	0.0417	0.0399	0.0877	0.1031	0.0379	0.0679	SW	1	52	0.4100	0.6069
1-Oct-05	0.0227	0.0390	0.0509	0.0519	0.0701	0.0374	NNE	2	34	0.2100	0.5050
2-Oct-05	0.0176	0.0218	0.0255	0.0232	0.0277	0.0397	SE	1	52	0.2600	0.4077
5-Oct-05	0.0333	0.0177	0.0304	0.0230	0.0578	0.0124	SW	3	51	0.7000	1.0225
6-Oct-05	0.0748	0.0732	0.0608	0.0746	0.0568	0.0633	SW	1	135	0.9000	0.4660
8-Oct-05	0.0431	0.0205	0.0406	0.0602	0.0339	0.0320	S	2	23	0.0700	0.3141
23-Oct-05	0.0515	0.0316	0.0187	0.0219	0.0439	0.0127	NE	15	100	0.1700	0.1238
1-Nov-05	0.0699	0.0244	0.0600	0.0311	0.0735	0.0466	ESE	8	200	0.5700	0.1894
21-Nov-05	0.0893	0.0501	0.0369	0.0382	0.0419	0.0790	SW	20	60	0.0500	0.1262
28-Nov-05	0.0505	0.0322	0.0232	0.0480	0.0346	0.0223	SW	7	127	0.8800	0.5627
5-Dec-05	0.0462	0.0521	0.0471	0.0712	0.0687	0.0633	SSW	7	110	0.3100	0.2151
7-Dec-05	0.0362	0.0492	0.0434	0.0353	0.0514	0.0489	NE	2	218	0.3700	0.1089
17-Dec-05	0.1135	0.0697	0.0392	0.0413	0.0596	0.0835	NE	10	17	0.0100	0.0776
18-Dec-05	0.0890	0.0592	0.0495	0.0541	0.0416	0.0534	NW	1	61	0.0400	0.0621
25-Dec-05	0.1520	0.1169	0.0780	0.0915	0.0226	0.1009	WSW	7	17	0.0100	0.0594
3-Jan-06	0.0666	0.0084	0.0176	0.0135	0.0547	0.0095	SW	9	26	0.2000	0.7046
17-Jan-06	0.0841	0.0733	0.0810	0.1290	0.0802	0.0311					
24-Jan-06	0.0727	0.0944	0.1253	0.2142	0.1020	0.0878	SSW	14	43	0.2100	0.4105
29-Jan-06	0.0360	0.0373	0.0636	0.0436	0.0823	0.0771	SE	6	64	0.0800	0.0855
30-Jan-06	0.0572	0.0749	0.0841	0.1007	0.0745	0.0843	SW	0	114	0.1300	0.0900
3-Feb-06	0.0535	0.0652	0.0912	0.2034	0.0759	0.0712	SSE	3	666	4.5300	0.5355
11-Feb-06	0.1782	0.1184	0.1084	0.1799	0.1312	0.0688	SW	8	64	0.0500	0.0752
23-Feb-06	0.0394	0.0781	0.0339	0.0139	0.1079	0.0606	ESE	13	25	0.0300	0.0900
25-Feb-06	0.0268	0.0332	0.0543	0.0973	0.0639	0.0439	SW	2	84	0.2400	0.2359
median	**0.0627**	**0.0501**	**0.0600**	**0.0602**	**0.0599**	**0.0597**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.0705**	**0.0532**	**0.0611**	**0.0735**	**0.0635**	**0.0571**		**6**	**94**	**0.4553**	**0.3798**
std dev	**0.0420**	**0.0276**	**0.0287**	**0.0522**	**0.0247**	**0.0246**		**5**	**119**	**0.8252**	**0.3047**
max	**0.1963**	**0.1184**	**0.1253**	**0.2142**	**0.1312**	**0.1009**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0176**	**0.0084**	**0.0176**	**0.0135**	**0.0226**	**0.0095**		**0**	**17**	**0.0100**	**0.0594**
n=	**31**	**31**	**31**	**31**	**31**	**31**		**30**	**30**	**30**	**30**

Table 4-11: Roof Runoff Analyzed for Manganese from the Site.

Date	ConMn	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.0025	0.0007	0.0007	0.0010	0.0005	0.0006	SW	1	85	0.9600	0.9600
31-Aug-05	0.0013	0.0024	0.0018	0.0026	0.0025	0.0041	SW	2	77	0.3000	0.3141
2-Sep-05	0.0008	0.0014	0.0012	0.0016	0.0010	0.0010	N	1	103	1.0300	0.9716
3-Sep-05											
6-Sep-05	0.0127	0.0038	0.0026	0.0029	0.0030	0.0029	N	3	24	0.1300	0.4421
20-Sep-05	0.0105	0.0069	0.0046	0.0069	0.0083	0.0118	NNE	14	25	0.2200	0.9504
21-Sep-05	0.0024	0.0015	0.0016	0.0015	0.0021	0.0017	NE	1	120	0.2100	0.1377
22-Sep-05											
27-Sep-05	0.0026	0.0041	0.0034	0.0022	0.0029	0.0032	ESE	5	55	0.3800	0.5442
28-Sep-05	0.0033	0.0036	0.0027	0.0027	0.0031	0.0034	SW	1	52	0.4100	0.6069
1-Oct-05	0.0022	0.0024	0.0017	0.0019	0.0019	0.0017	NNE	2	34	0.2100	0.5050
2-Oct-05	0.0009	0.0015	0.0016	0.0012	0.0010	0.0011	SE	1	52	0.2600	0.4077
5-Oct-05	0.0018	0.0024	0.0028	0.0024	0.0025	0.0028	SW	3	51	0.7000	1.0225
6-Oct-05	0.0008	0.0013	0.0009	0.0011	0.0008	0.0012	SW	1	135	0.9000	0.4660
8-Oct-05	0.0011	0.0017	0.0016	0.0017	0.0017	0.0014	S	2	23	0.0700	0.3141
23-Oct-05	0.0009	0.0018	0.0011	0.0012	0.0015	0.0024	NE	15	100	0.1700	0.1238
1-Nov-05	0.0039	0.0031	0.0017	0.0028	0.0039	0.0045	ESE	8	200	0.5700	0.1894
21-Nov-05	0.0108	0.0088	0.0076	0.0257	0.0271	0.0433	SW	20	60	0.0500	0.1262
28-Nov-05	0.0017	0.0020	0.0018	0.0017	0.0021	0.0021	SW	7	127	0.8800	0.5627
5-Dec-05	0.0028	0.0039	0.0027	0.0024	0.0032	0.0036	SSW	7	110	0.3100	0.2151
7-Dec-05	0.0013	0.0023	0.0016	0.0019	0.0024	0.0018	NE	2	218	0.3700	0.1089
17-Dec-05	0.0152	0.0094	0.0099	0.0091	0.0132	0.0143	NE	10	17	0.0100	0.0776
18-Dec-05	0.0550	0.0049	0.0032	0.0023	0.0059	0.0047	NW	1	61	0.0400	0.0621
25-Dec-05	0.0138	0.0084	0.0089	0.0023	0.0062	0.0126	WSW	7	17	0.0100	0.0594
3-Jan-06	0.0013	0.0008	0.0011	0.0009	0.0003	0.0015	SW	9	26	0.2000	0.7046
17-Jan-06	0.0067	0.0074	0.0052	0.0061	0.0077	0.0084					
24-Jan-06							SSW	14	43	0.2100	0.4105
29-Jan-06							SE	6	64	0.0800	0.0855
30-Jan-06							SW	0	114	0.1300	0.0900
3-Feb-06							SSE	3	666	4.5300	0.5355
11-Feb-06							SW	8	64	0.0500	0.0752
23-Feb-06							ESE	13	25	0.0300	0.0900
25-Feb-06							SW	2	84	0.2400	0.2359
median	**0.0025**	**0.0024**	**0.0018**	**0.0023**	**0.0025**	**0.0029**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.0065**	**0.0036**	**0.0030**	**0.0036**	**0.0044**	**0.0057**		**5**	**77**	**0.3648**	**0.4292**
std dev	**0.0113**	**0.0027**	**0.0025**	**0.0051**	**0.0057**	**0.0089**		**5**	**56**	**0.3202**	**0.3193**
max	**0.0550**	**0.0094**	**0.0099**	**0.0257**	**0.0271**	**0.0433**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0008**	**0.0007**	**0.0007**	**0.0009**	**0.0003**	**0.0006**		**0**	**17**	**0.0100**	**0.0594**
n=	**24**	**24**	**24**	**24**	**24**	**24**		**30**	**30**	**30**	**30**

Table 4-12: Roof Runoff Analyzed for Chromium from the Site.

Date	ConCr	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.0008	0.0006	0.0006	0.0009	0.0004	0.0005	SW	1	85	0.96	0.96
31-Aug-05	0.0007	0.0005	0.0007	0.0012	0.0006	0.0009	SW	2	77	0.30	0.31
2-Sep-05	0.0004	0.0006	0.0008	0.0010	0.0009	0.0006	N	1	103	1.03	0.97
3-Sep-05											
6-Sep-05	0.0009	0.0005	0.0010	0.0026	0.0009	0.0006	N	3	24	0.13	0.44
20-Sep-05	0.0008	0.0006	0.0009	0.0017	0.0012	0.0008	NNE	14	25	0.22	0.95
21-Sep-05	0.0010	0.0007	0.0014	0.0017	0.0010	0.0010	NE	1	120	0.21	0.14
22-Sep-05											
27-Sep-05	0.0007	0.0008	0.0013	0.0017	0.0010	0.0008	ESE	5	55	0.38	0.54
28-Sep-05	0.0010	0.0008	0.0012	0.0013	0.0010	0.0009	SW	1	52	0.41	0.61
1-Oct-05	0.0011	0.0006	0.0011	0.0014	0.0008	0.0006	NNE	2	34	0.21	0.51
2-Oct-05	0.0008	0.0008	0.0011	0.0014	0.0007	0.0008	SE	1	52	0.26	0.41
5-Oct-05	0.0009	0.0009	0.0010	0.0010	0.0007	0.0007	SW	3	51	0.70	1.02
6-Oct-05	0.0009	0.0008	0.0011	0.0009	0.0011	0.0008	SW	1	135	0.90	0.47
8-Oct-05	0.0010	0.0008	0.0011	0.0020	0.0011	0.0008	S	2	23	0.07	0.31
23-Oct-05	0.0010	0.0009	0.0009	0.0010	0.0009	0.0010	NE	15	100	0.17	0.12
1-Nov-05	0.0007	0.0009	0.0007	0.0010	0.0009	0.0016	ESE	8	200	0.57	0.19
21-Nov-05	0.0010	0.0007	0.0011	0.0016	0.0020	0.0010	SW	20	60	0.05	0.13
28-Nov-05	0.0005	0.0007	0.0008	0.0013	0.0008	0.0010	SW	7	127	0.88	0.56
5-Dec-05	0.0008	0.0008	0.0010	0.0012	0.0007	0.0009	SSW	7	110	0.31	0.22
7-Dec-05	0.0008	0.0008	0.0080	0.0012	0.0012	0.0007	NE	2	218	0.37	0.11
17-Dec-05	0.0009	0.0007	0.0023	0.0021	0.0012	0.0007	NE	10	17	0.01	0.08
18-Dec-05	0.0010	0.0006	0.0013	0.0015	0.0012	0.0013	NW	1	61	0.04	0.06
25-Dec-05	0.0012	0.0007	0.0013	0.0008	0.0005	0.0001	WSW	7	17	0.01	0.06
3-Jan-06	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	SW	9	26	0.20	0.70
17-Jan-06	0.0002	0.0001	0.0006	0.0011	0.0005	0.0003					
24-Jan-06	0.0003	0.0004	0.0005	0.0014	0.0003	0.0001	SSW	14	43	0.21	0.41
29-Jan-06	0.0002	0.0002	0.0009	0.0016	0.0007	0.0004	SE	6	64	0.08	0.09
30-Jan-06	0.0004	0.0003	0.0007	0.0017	0.0006	0.0004	SW	0	114	0.13	0.09
3-Feb-06	0.0011	0.0002	0.0004	0.0010	0.0002	0.0001	SSE	3	666	4.53	0.54
11-Feb-06	0.0008	0.0008	0.0012	0.0030	0.0005	0.0002	SW	8	64	0.05	0.08
23-Feb-06	0.0013	0.0006	0.0013	0.0016	0.0021	0.0012	ESE	13	25	0.03	0.09
25-Feb-06	0.0001	0.0006	0.0011	0.0015	0.0005	0.0007	SW	2	84	0.24	0.24
median	**0.0008**	**0.0007**	**0.0010**	**0.0014**	**0.0008**	**0.0007**		**3**	**63**	**0.2150**	**0.3141**
mean	**0.0008**	**0.0006**	**0.0012**	**0.0014**	**0.0008**	**0.0007**		**6**	**94**	**0.46**	**0.38**
std dev	**0.0003**	**0.0002**	**0.0013**	**0.0005**	**0.0004**	**0.0004**		**5**	**119**	**0.8252**	**0.3047**
max	**0.0013**	**0.0009**	**0.0080**	**0.0030**	**0.0021**	**0.0016**		**20**	**666**	**4.5300**	**1.0225**
min	**0.0001**	**0.0000**	**0.0001**	**0.0001**	**0.0000**	**0.0001**		**0**	**17**	**0.0100**	**0.0594**
n=	**31**	**31**	**31**	**31**	**31**	**31**		**30**	**30**	**30**	**30**

Table 4-13: Roof Runoff Analyzed for Copper from the Site.

Date	ConCu	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05	0.0025	0.0011	0.0012	0.0017	0.0005	0.0004	SW	1	85	0.96	0.96
31-Aug-05	0.0016	0.0023	0.0018	0.0021	0.0027	0.0029	SW	2	77	0.30	0.31
2-Sep-05	0.0020	0.0021	0.0020	0.0030	0.0023	0.0022	N	1	103	1.03	0.97
3-Sep-05											
6-Sep-05	0.0034	0.0033	0.0027	0.0046	0.0040	0.0020	N	3	24	0.13	0.44
20-Sep-05	0.0036	0.0016	0.0046	0.0123	0.0037	0.0038	NNE	14	25	0.22	0.95
21-Sep-05	0.0020	0.0011	0.0008	0.0016	0.0003	0.0011	NE	1	120	0.21	0.14
22-Sep-05											
27-Sep-05	0.0047	0.0032	0.0038	0.0024	0.0032	0.0030	ESE	5	55	0.38	0.54
28-Sep-05	0.0089	0.0020	0.0027	0.0022	0.0021	0.0017	SW	1	52	0.41	0.61
1-Oct-05	0.0022	0.0015	0.0008	0.0016	0.0010	0.0010	NNE	2	34	0.21	0.51
2-Oct-05	0.0017	0.0009	0.0016	0.0022	0.0003	0.0012	SE	1	52	0.26	0.41
5-Oct-05	0.0010	0.0014	0.0009	0.0017	0.0020	0.0007	SW	3	51	0.70	1.02
6-Oct-05	0.0179	0.0176	0.0173	0.0171	0.0194	0.0180	SW	1	135	0.90	0.47
8-Oct-05	0.0024	0.0009	0.0012	0.0197	0.0018	0.0018	S	2	23	0.07	0.31
23-Oct-05	0.0016	0.0015	0.0004	0.0017	0.0005	0.0020	NE	15	100	0.17	0.12
1-Nov-05	0.0010	0.0010	0.0006	0.0010	0.0010	0.0016	ESE	8	200	0.57	0.19
21-Nov-05	0.0052	0.0033	0.0033	0.0057	0.0060	0.0035	SW	20	60	0.05	0.13
28-Nov-05	0.0022	0.0016	0.0027	0.0020	0.0011	0.0007	SW	7	127	0.88	0.56
5-Dec-05	0.0196	0.0195	0.0180	0.0175	0.0180	0.0198	SSW	7	110	0.31	0.22
7-Dec-05	0.0178	0.0176	0.0177	0.0176	0.0184	0.0185	NE	2	218	0.37	0.11
17-Dec-05	0.0242	0.0240	0.0233	0.0209	0.0197	0.0203	NE	10	17	0.01	0.08
18-Dec-05	0.0200	0.0178	0.0195	0.0200	0.0189	0.0198	NW	1	61	0.04	0.06
25-Dec-05	0.0214	0.0196	0.0189	0.0066	0.0095	0.0083	WSW	7	17	0.01	0.06
3-Jan-06	0.0057	0.0019	0.0028	0.0027	0.0028	0.0045	SW	9	26	0.20	0.70
17-Jan-06	0.0111	0.0128	0.0110	0.0117	0.0088	0.0110					
24-Jan-06	0.0008	0.0057	0.0022	0.0037	0.0019	0.0008	SSW	14	43	0.21	0.41
29-Jan-06	0.0019	0.0013	0.0020	0.0024	0.0020	0.0019	SE	6	64	0.08	0.09
30-Jan-06	0.0010	0.0020	0.0012	0.0017	0.0008	0.0011	SW	0	114	0.13	0.09
3-Feb-06	0.0014	0.0011	0.0015	0.0025	0.0038	0.0011	SSE	3	666	4.53	0.54
11-Feb-06	0.0054	0.0035	0.0038	0.0053	0.0034	0.0041	SW	8	64	0.05	0.08
23-Feb-06	0.0067	0.0054	0.0073	0.0114	0.0068	0.0058	ESE	13	25	0.03	0.09
25-Feb-06	0.0033	0.0040	0.0043	0.0064	0.0028	0.0034	SW	2	84	0.24	0.24
median	**0.0033**	**0.0021**	**0.0027**	**0.0030**	**0.0028**	**0.0022**		**3.0000**	**62.50**	**0.2150**	**0.3141**
mean	**0.0066**	**0.0059**	**0.0059**	**0.0069**	**0.0055**	**0.0054**		**5.6333**	**94.4000**	**0.4553**	**0.3798**
std dev	**0.0072**	**0.0071**	**0.0070**	**0.0067**	**0.0064**	**0.0066**		**5.2685**	**119.1304**	**0.8252**	**0.3047**
max	**0.0242**	**0.0240**	**0.0233**	**0.0209**	**0.0197**	**0.0203**		**20.0000**	**666.0000**	**4.5300**	**1.0225**
min	**0.0008**	**0.0009**	**0.0004**	**0.0010**	**0.0003**	**0.0004**		**0.0000**	**17.0000**	**0.0100**	**0.0594**
n=	**31**	**31**	**31**	**31**	**31**	**31**		**30**	**30**	**30**	**30**

Table 4-14: Roof Runoff Analyzed for Magnesium from the Site.

Date	ConMg	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
28-Aug-05							SW	1	85	0.96	0.96
31-Aug-05							SW	2	77	0.30	0.31
2-Sep-05							N	1	103	1.03	0.97
3-Sep-05											
6-Sep-05							N	3	24	0.13	0.44
20-Sep-05							NNE	14	25	0.22	0.95
21-Sep-05							NE	1	120	0.21	0.14
22-Sep-05											
27-Sep-05							ESE	5	55	0.38	0.54
28-Sep-05							SW	1	52	0.41	0.61
1-Oct-05							NNE	2	34	0.21	0.51
2-Oct-05							SE	1	52	0.26	0.41
5-Oct-05							SW	3	51	0.70	1.02
6-Oct-05							SW	1	135	0.90	0.47
8-Oct-05							S	2	23	0.07	0.31
23-Oct-05							NE	15	100	0.17	0.12
1-Nov-05							ESE	8	200	0.57	0.19
21-Nov-05							SW	20	60	0.05	0.13
28-Nov-05							SW	7	127	0.88	0.56
5-Dec-05							SSW	7	110	0.31	0.22
7-Dec-05							NE	2	218	0.37	0.11
17-Dec-05							NE	10	17	0.01	0.08
18-Dec-05							NW	1	61	0.04	0.06
25-Dec-05							WSW	7	17	0.01	0.06
3-Jan-06							SW	9	26	0.20	0.70
17-Jan-06											
24-Jan-06	0.3080	0.2240	0.2600	0.3220	0.3660	0.4140	SSW	14	43	0.21	0.41
29-Jan-06	0.3790	0.1860	0.3000	0.3590	0.4330	0.3890	SE	6	64	0.08	0.09
30-Jan-06	0.1050	0.0870	0.1850	0.3530	0.1480	0.1350	SW	0	114	0.13	0.09
3-Feb-06	0.5300	0.0540	0.0860	0.1080	0.0650	0.0710	SSE	3	666	4.53	0.54
11-Feb-06	1.1480	0.4490	0.5370	0.5630	0.8070	0.7860	SW	8	64	0.05	0.08
23-Feb-06	1.6170	0.4750	0.7040	1.0540	1.0880	1.2110	ESE	13	25	0.03	0.09
25-Feb-06	0.2740	0.2330	0.2630	0.2460	0.2010	0.2040	SW	2	84	0.24	0.24
median	**0.3790**	**0.2240**	**0.2630**	**0.3530**	**0.3660**	**0.3890**		**6.0000**	**64.0000**	**0.1300**	**0.0900**
mean	**0.6230**	**0.2440**	**0.3336**	**0.4293**	**0.4440**	**0.4586**		**6.5714**	**151.4286**	**0.7529**	**0.2175**
std dev	**0.5509**	**0.1633**	**0.2135**	**0.3075**	**0.3748**	**0.4082**		**5.4116**	**228.6773**	**1.6674**	**0.1866**
max	**1.6170**	**0.4750**	**0.7040**	**1.0540**	**1.0880**	**1.2110**		**14.0000**	**666.0000**	**4.5300**	**0.5355**
min	**0.1050**	**0.0540**	**0.0860**	**0.1080**	**0.0650**	**0.0710**		**0.0000**	**25.0000**	**0.0300**	**0.0752**
n=	**7**	**7**	**7**	**7**	**7**	**7**		**30**	**30**	**30**	**30**

Regression Model and Transformation of the Data

Based upon preliminary analysis, there was no apparent benefit in using more complex statistical methods, such as regression analysis. Chandler (1994) indicates that more complex statistics are justified only when considering similar results and methods derived from the same dataset. Therefore, the data was not transformed to create a better fit to the model, because the numeric transformation of the numeric concentration of chemical analysis would have no meaning and simply because there were only small differences exhibited overall.

Correlation Matrix

The next step required creating a correlation matrix, comparing data from the control with that from the various variables of interest. The significance of a correlation matrix is that the descriptive has the power potential for predicting information about the values on another variable. The correlation in the descriptive form serves as a mechanism in data reduction. Nevertheless, most of all the existence of a correlation between two variables does not imply causality; it is possible that there were confounding variables that were responsible for the observed correlation in whole or in part.

The chemicals' analyses data were analyzed using descriptive statistical methods and presented in graphical plots and matrix, as shown below in Figure 4-2. Analyses of all of the variables of interest are also shown in Appendix I.

Table 4-15: Roof Surfaces and Variables' Effect on the Copper Correlation.

Correlation Matrix

	ConCu	S1	S2	S3	S4	S5	ancedent	rain
ConCu	1.000							
S1	.953	1.000						
S2	.009	-.081	1.000					
S3	.736	.759	-.065	1.000				
S4	.912	.940	-.017	.839	1.000			
S5	.904	.934	-.042	.843	.985	1.000		
ancedent	-.010	.045	-.151	.068	.025	.016	1.000	
rain	-.185	-.150	-.087	-.172	-.063	-.130	-.182	1.000

32 sample size

It should be noted that the correlation matrix in Table 4-15 is a square, with as many rows as there are columns. The multivariate data matrix's first characteristic to be noticed is that the diagonal coefficients are equal to one by the perfect correlations with each other. Each cell of the matrix contains a correlation coefficient between the variables represented by the particular column that the cell occupies. A visual inspection of the matrix provides information as to the relationship that exists among the variables. The darker yellow highlights represent a critical value of the two-tailed significance level at 0.01, and the lighter yellow highlights represent a critical value of the two-tailed significance level at 0.05. For example, the matrix in Table 4-15 illustrates that there is a positive correlation at the significance level 0.01 between the copper in the control sample and the samples for S1, S3, S4, and S5. The matrix also illustrates that S1, S4, and S5 are highly correlated to each other, whereas S3 is correlated to a lesser value to the other samples. In contrast, S2 is not correlated to the control for copper or the other samples and is not statistically significant. An inspection of the correlation matrix cannot assess the extent or joined effects of two variables with one another or to the extent of the effects of a third or fourth variable, etc. (Frigon & Mathews, 1997; Kachigan, 1991). The variables analysis requires the use of other analytical techniques to determine the relationship.

Descriptive Statistical Analysis

Paired T-Test

After completing the various plots of the data, the next step was to analyze the data using the paired t-test and the Wilcoxon signed rank test to determine the relationship between the control and the following surfaces: S1-natural clay barrel, S2-glazed tile, S3-flat, shaker impregnated tile, S4-painted, galvanized steel, and S5-unpainted, galvanized steel. The data was collected simultaneously as samples for the rain event; the data does not represent independent random sampling, and therefore, the paired t-test is appropriate. The assumptions for a valid t-test are that the samples are random from the population of differences and the set of differences come from a normal population.

The assumption of normality for a t-test is only necessary for small samples (since for larger samples, the distribution of the sample mean has a normal distribution, regardless of the shape of the population from which the samples were selected). A sample size of 30 has been traditionally used to distinguish between "large" and "small" samples. However, it has been shown that as the sample size approaches 30 samples, the sample mean rapidly approaches normality. Since the samples sizes in the datasets were close to 30, there is no reason to doubt the validity of the procedure.

The paired t-test analyses tested the null hypothesis that the population means of the control group for each of the contaminants is equal to the population mean of the "treatment" grouping (in this case the panel roof surface samples). The data for the analysis was a set of differences between the set of the treatment group and the control group. The null hypothesis is, therefore, the same as saying that the mean of the population of such differences equals zero. Symbolically the null hypothesis is:

$$H_0 : \mu_{treatment} - \mu_{Control} = 0 \qquad \text{(Equation 4-1)}$$

Since $\mu_d = \mu_{treatment} - \mu_{Control}$, we can write the null hypothesis as:

$$H_0 : \mu_d = 0 \qquad \text{(Equation 4-2)}$$

The alternative hypothesis is:

$$H_A : \mu_d \neq 0 \quad \text{(Equation 4-3)}$$

The sample mean $\bar{x}_d$ was calculated from the set of differences in the sample and sample standard deviation, s_d .

The test statistic in the analysis is:

$$t = \frac{\bar{x}_d - \mu_0}{s_d / \sqrt{n-1}} \quad \text{(Equation 4-4)}$$

Since the assumed value of μ_0 in the null hypothesis is zero, the test statistic is:

$$t = \frac{\bar{x}_d}{s_d / \sqrt{n-1}}, \quad \text{(Equation 4-5)}$$

where n is the number of matched pairs in the sample,

D is the difference for each pair of scores in the sample,

$\bar{x}_d$ is the mean of all the sample's differences scores,

s_d is the sample deviation of the difference scores, and

u_0 is the mean of the difference scores for all possible pairs in the population.

$$S_d = \sqrt{\frac{\sum\left(D - \bar{D}\right)^2}{n}} \quad \text{(Equation 4-6)}$$

If the null hypothesis is true, each value calculated by this equation can be considered a randomly selected observation from a t distribution with $n-1$ degrees of freedom (sometimes called the null distribution).

The decision as to the validity of the null hypothesis or the alternative is based on the p-value. The p-value is the probability that a randomly selected observation from the stated t distribution is extreme or more extreme than the observed test statistic. If this probability is very small, then there is strong evidence that the observation did not come from the null distribution, and it can be concluded that the alternative is true. If the p-value is not small, there is no reason to suspect the test statistic came from a distribution other than the null distribution, and there is no reason to disbelieve the null hypothesis. The significance level is usually determined by convention as p-values are normally considered either 0.05 or 0.01. For example, Table 4-16 illustrates the paired t-test of the control sample and S1-natural clay barrel; the significance level is 0.05, and there are statistically significant differences between the control and S1 sample.

Table 4-16: Copper Paired T-Test S1 and Control.

0.0000000	hypothesized value
0.0058903	mean S1
0.0065871	mean ConCu
-0.0006968	mean difference (S1 - ConCu)
0.0018837	std. dev.
0.0003383	std. error
31	n
30	df
-2.06	t
.0482	p-value (two-tailed)
-0.0013877	confidence interval 95.% lower
-0.0000058	confidence interval 95.% upper
0.0006909	half-width

Wilcoxon Signed Rank Test

The chemical data was analyzed using the non-parametric equivalent of the paired t-test, the Wilcoxon signed rank test. The Wilcoxon signed rank test, also known as the Wilcoxon matched pairs test, is a non-parametric test used to test the median difference in paired data. As in the t-test, the null hypothesis is that the median of the population of differences (treatment–control) is zero, and the alternative is that the population of differences has a value other than zero. The Wilcoxon signed rank test is based on the concept of asymptotic relative efficiency. This test is appropriate for small sample sizes with an unknown distribution, as this test is more sensitive than the t-test. The p-values for this test are interpreted the same as the p-values for the t-test. Small p-values are evidence that we should reject the null hypothesis and conclude the alternative is true. Large p-values do not provide evidence against the assumption that the median is equal to zero. This provides a basis upon which to develop further analysis of the data. For example, in Table 4-17 the control and the glazed tile, S2, at the .01 significances level the control, and S2 is statistically significant.

Table 4-17: Copper Wilcoxon S2-Control.

variables:	S2 - ConCu
104	sum of positive ranks
361	sum of negative ranks
30	n
232.50	expected value
48.34	standard deviation
-2.66	z, corrected for ties
.0079	p-value (two-tailed)

CHAPTER V: WATER QUALITY RESULTS AND DISCUSSION

The objective of this investigation was to determine the water quality of roof runoff across the five selected surfaces. The investigation analyzed and characterized the chemical composition for the various heavy metals in the roof runoff. The study samples were obtained using approved standard methods and approved EPA containers to avoid possible contamination of the sample.

Ten (10) rain events that did not produce sufficient quantity of roof runoff for the analyses were: 1-Sep-05, 5-Sep-05, 9-Sep-05, 4-Oct-05, 7-Oct-05, 8-Dec-05, 9-Dec-05, 11-Dec-05, 16-Dec-05, and 20-Jan-06. The paired t-test and the nonparametric test, the Wilcoxon test, were used in the statistical analyses of the data, which allows the examination of roofing material effects on the water quality.

Using the National Primary Drinking Water Regulations as a standard, all results of the chemical analyses were examined for compliance with the maximum contaminant level (MCL) and their action level for all the roofing materials of S1, S2, S3, S4, and S5. If a specific substance exceeds the MCL, then the EPA requires that action be taken to lower the concentration of said substance. There was no exceedance of the regulatory standard in any of the thirty-one (31) samples obtained from the roofing materials S1, S2, S3, S4, and S5 over the nine (9) month investigation period. The examination of the data for all surfaces showed that there was no exceedance of the standard for chromium (Cr) 0.1 mgℓ^{-1}, and copper (Cu) 1.3 mgℓ^{-1} with an action level of 1.3 mgℓ^{-1}. The national secondary drinking water regulations, which are manganese (Mn) 0.05 mgℓ^{-1}, iron (Fe)

0.3 mgℓ$^{-1}$, pH 6.5 – 8.5, zinc (Zn) 5.O mgℓ$^{-1}$, and total dissolved solids (TDS) 500 mgℓ$^{-1}$ were not exceeded.

The specific cause of a response to the environmental variable was difficult to determine due to the concentration levels and the spatial occurrence. For example, the examination of the data for Pb indicated that there were some underlying processes occurring with the S5-unpainted, galvanized steel surfaces, because the samples for S5 were consistently lower than the control sample and lower than the S4-painted, galvanized steel. The data showed that S1-natural clay barrel, exhibited apparent adsorptive properties for lead (Pb) and zinc (Zn).

The Zn concentrations' analyses are shown in Table 5-1. The samples for S5 were higher than all other roof samples, with concentrations as high as 3.7 mgℓ$^{-1}$, which is approaching the MCL level of 5.0 mgℓ$^{-1}$. The surface S2-glazed tile, had the lowest mean concentration for Zn at 0.0585 mgℓ$^{-1}$, followed by S1-natural clay barrel, at 0.0722 mgℓ$^{-1}$, S3-flat, shaker impregnated tile, at 0.1164 mgℓ$^{-1}$, and S4-painted, galvanized steel at 0.1345 mgℓ$^{-1}$. Only the runoff from surface S4 had Zn concentrations statistically equal to that of the control samples. This means that zinc was being absorbed or exchanged.

Table 5-1: The Zinc Concentrations Analyses of the Roof Runoff mgℓ$^{-1}$ at the Site.

element	Surface	median	mean	std dev	max	min	n=
Zn	control	0.0533	0.1686	0.2171	0.7509	0.0086	31
	S1	0.0341	0.0722	0.0859	0.3444	0.0040	31
	S2	0.0328	0.0585	0.0627	0.2230	0.0004	31
	S3	0.0450	0.1164	0.2063	1.0440	0.0002	31
	S4	0.0816	0.1345	0.1186	0.5769	0.0022	31
	S5	1.0230	1.2633	0.9787	3.7420	0.0371	31

Table 5-2: A Comparison of pH Levels at the Site.

Date	ConpH	S1	S2	S3	S4	S5
median	6.50	6.32	7.03	7.23	6.04	6.02
mean	6.27	6.30	7.04	7.24	5.83	5.92
std dev	1.20	0.87	0.34	0.29	1.01	0.79
max	8.21	8.15	8.09	8.17	8.52	8.36
min	3.67	4.27	6.25	6.63	4.13	4.33
n=	32	32	32	32	32	32

Table 5-2 shows that the pH of the samples taken from surfaces S2-glazed tile, and S3-flat, shaker impregnated tile, were consistently more basic than the control sample. Overall, the mean pH of the samples from S2 and S3 were 7.04 and 7.24, and were 0.77 and 0.97 larger than that of the control, respectively. The hydroxide concentration in the samples of S2 and S3 are approximately 9.3 times greater than the controls. Conversely, the pH of samples from surfaces S4 and S5 are consistently more acidic than the control. The S4 and S5 samples, with mean pHs of 5.83 and 5.92 hydroxide concentration, is only 0.41 of that of the control, respectively. Only surface S1-natural clay barrel, had a sample pH close to the control. The control pH mean was 6.30, with a minimum of 3.67 and a maximum of 8.21. The difference in pH (acidic versus basic) did affect the metals' removal or concentrations.

The total dissolved solids' (TDS) mean concentration was 26.72 $mg\ell^{-1}$ for the surface S2-glazed tile, and this was the only surface found to be statistically representative of the control. For surface S3-flat, shaker impregnated tile, TDS concentrations were consistently higher than the control sample, with mean concentrations of 37.73 $mg\ell^{-1}$, which is approximately 1.43 times the control. This would imply that the material was dissolved from the roofing material, or atmospheric deposits are being retained and re-dissolved during the rain event. The opposite is true for surfaces S1, S4, and S5, where the TDS concentration levels are consistently lower than the mean control concentrations, 26.41 mgℓ$^{-1}$. In the latter case, the material would appear to be absorbed into the surface, as discussed previously. Samples from S1 had the lowest mean concentration levels 14.35 mgℓ$^{-1}$ with S4 at 17.67 mgℓ$^{-1}$ and S5 at 18.89 mgℓ$^{-1}$. A change in the TDS did not affect the activity of the solution and any release would be a function of the pH rather than the TDS. Table 5-3 illustrates the comparison of the different roof runoff and the control for TDS.

Table 5-3: Comparisons of Total Dissolved Solids mgℓ$^{-1}$, Levels at the Site.

	ConTDS	S1	S2	S3	S4	S5	prevailing	ancedent	event	rain	mean
median	20.0000	13.0000	23.0000	32.0000	14.0000	16.0000		7	64	0.21	0.23
mean	26.4134	14.3514	26.7283	37.7366	17.6780	18.8996		8	104	1.83	1.52
std dev	20.14812	8.670926	14.75959	20.67259	12.69072	14.57694		8	131	6.27	6.22
max	70.0000	32.0000	60.0000	80.0000	42.0000	50.0000		32		32.00	32.00
min	0.0000	3.0000	9.0000	14.0000	3.0000	2.5000		0		0.01	0.06
n=	32	32	32	32	32	32		32	32	32	32

The adsorption processes of S1-natural clay barrel consistently created lower mean concentrations of Fe, 0.0532 mgℓ$^{-1}$, while all the other surfaces were statistically representative of the control. The unglazed surface of the clay barrel tile provides pores and adsorption sites for the deposition of iron (Fe). Many researchers suggest that the low surface energy charge between the tile surface and the adsorbed ions arises from adsorbate quadrupole interaction, with varying electrostatic field gradients lattice of the solid (Benjamin, 2002; Jensen, 2003; Schwarzenbach, et al., 1993). Hydrogen is the simplest chemical substance that accounts for adsorption and surface diffusion, as well as distribution and character of the adsorption of the sites (McMillan, 1960). The lower concentration of Fe on S1, while all other surfaces were statistically equivalent to the control, could be explained via this adsorbate quadrupole interaction mechanism on the clay barrel tile.

From Table 5-4, it is evident that the Cr concentrations in the S1-natural clay barrel runoff samples were consistently lower than the control due to the adsorptive quadrupole interaction mechanism. The Cr mean concentrations in the sample runoff from the S2-glazed tile and S3-flat, shaker impregnated tile, were consistently higher than the control sample, with mean concentrations of 0.0012 $mg\ell^{-1}$ and 0.0014 $mg\ell^{-1}$, respectively. This is 1.50 and 1.75 times the mean concentration of the control. The samples from surfaces S4-painted, galvanized steel and S5-unpainted, galvanized steel were found to be statistically representative of the control sample. Based on my viewing of various tile-manufacturing machines, the rollers used to apply the ceramic glaze are manufactured in part from chromium (Cr). It is possible that there is a transfer effect that would add trace chromium (Cr) during the manufacturing process (Lyubenova, et al., 2009).

Table 5-4: Comparisons of Chromium mgℓ$^{-1}$, Levels at the Site.

	ConCr	S1	S2	S3	S4	S5
median	0.0008	0.0007	0.0010	0.0014	0.0008	0.0007
mean	0.0008	0.0006	0.0012	0.0014	0.0008	0.0007
std dev	0.0003	0.0002	0.0013	0.0005	0.0004	0.0004
max	0.0013	0.0009	0.0080	0.0030	0.0021	0.0016
min	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001
n=	31	31	31	31	31	31

The analysis of Cu in the samples, is illustrated in Table 5-5, revealed that only surface S3 contained concentrations representative of the control mean concentration of 0.0066 mgℓ$^{-1}$, whereas all other surface samples had reduced concentrations of copper (Cu) except S3-flat, shaker impregnated tile. These concentrations are well below any action level of 1.3 mgℓ$^{-1}$, required by the EPA primary drinking standards. An action level (AL) is the concentration of a contaminant over which a treatment is required.

Table 5-5: Comparisons of Copper mgℓ$^{-1}$ Levels at the Site.

	ConCu	S1	S2	S3	S4	S5
median	0.0033	0.0021	0.0027	0.0030	0.0028	0.0022
mean	0.0066	0.0059	0.0059	0.0069	0.0055	0.0054
std dev	0.0072	0.0071	0.0070	0.0067	0.0064	0.0066
max	0.0242	0.0240	0.0233	0.0209	0.0197	0.0203
min	0.0008	0.0009	0.0004	0.0010	0.0003	0.0004
n=	31	31	31	31	31	31

The concentration dataset illustrated in Table 5-6 for the Mg is limited due to the sample size. The data suggests that the S1 adsorptive quadrupole interaction processes also operate with Mg as seen with other elements, but due to the small sample size, it is difficult to fully infer this interaction. The standard deviation of the control was larger than that of the all the tiles.

Table 5-6: Comparisons of Magnesium $mg\ell^{-1}$ Levels at the Site.

Date	ConMg	S1	S2	S3	S4	S5
median	0.3790	0.2240	0.2630	0.3530	0.3660	0.3890
mean	0.6230	0.2440	0.3336	0.4293	0.4440	0.4586
std dev	0.5509	0.1633	0.2135	0.3075	0.3748	0.4082
max	1.6170	0.4750	0.7040	1.0540	1.0880	1.2110
min	0.1050	0.0540	0.0860	0.1080	0.0650	0.0710
n=	7	7	7	7	7	7

Table 5-7: Roof Surfaces and Variables' Effect on the pH Correlation.

	ConpH	S1	S2	S3	S4	S5	ancedent	rain
ConpH	1.000							
S1	.810	1.000						
S2	.703	.871	1.000					
S3	.562	.701	.916	1.000				
S4	.729	.836	.790	.615	1.000			
S5	.718	.902	.895	.747	.952	1.000		
ancedent	.510	.575	.518	.315	.688	.654	1.000	
rain	-.463	-.494	-.423	-.369	-.315	-.385	-.315	1.000

28 sample size

± .374 critical value .05 (two-tail)

± .479 critical value .01 (two-tail)

Table 5-8: Roof Surfaces and Variables' Effect on the Total Dissolved Solids Correlation.

	ConTDS	*S1*	*S2*	*S3*	*S4*	*S5*	*ancedent*	*rain*
ConTDS	1.000							
S1	.901	1.000						
S2	.907	.808	1.000					
S3	.872	.747	.971	1.000				
S4	.848	.888	.740	.750	1.000			
S5	.896	.875	.775	.766	.965	1.000		
ancedent	.332	.286	.217	.273	.444	.536	1.000	
rain	-.551	-.505	-.658	-.647	-.503	-.530	-.315	1.000

28 sample size

± .374 critical value .05 (two-tail)
± .479 critical value .01 (two-tail)

Table 5-9: Roof Surfaces and Variables' Effect on the Zinc Correlation.

	ConZn	*S1*	*S2*	*S3*	*S4*	*S5*	*ancedent*	*rain*
ConZn	1.000							
S1	.887	1.000						
S2	.870	.885	1.000					
S3	.755	.882	.684	1.000				
S4	.779	.755	.832	.547	1.000			
S5	.129	.092	.267	-.016	.510	1.000		
ancedent	-.050	-.013	-.041	.068	.054	.452	1.000	
rain	-.145	-.163	-.220	-.092	-.375	-.632	-.353	1.000

29 sample size

± .367 critical value .05 (two-tail)
± .471 critical value .01 (two-tail)

Table 5-10: Roof Surfaces and Variables' Effect on the Lead Correlation.

	ConPb	S1	S2	S3	S4	S5	ancedent	rain
ConPb	1.000							
S1	.487	1.000						
S2	.738	.537	1.000					
S3	.578	.486	.334	1.000				
S4	.590	.426	.661	.217	1.000			
S5	.381	.566	.460	.352	.359	1.000		
ancedent	.353	.324	.248	.296	.109	.057	1.000	
rain	-.244	-.425	-.221	-.095	-.104	-.107	-.353	1.000

29 sample size

± .367 critical value .05 (two-tail)
± .471 critical value .01 (two-tail)

Table 5-11: Roof Surfaces and Variables' Effect on the Cadmium Correlation.

	ConCd	S1	S2	S3	S4	S5	ancedent	rain
ConCd	1.000							
S1	-.043	1.000						
S2	.162	.022	1.000					
S3	.212	.373	-.068	1.000				
S4	-.014	.259	-.209	-.116	1.000			
S5	-.028	.076	-.209	.033	.165	1.000		
ancedent	-.089	-.093	.254	.185	-.173	-.118	1.000	
rain	.432	-.200	-.083	.422	-.171	.261	-.215	1.000

30 sample size

± .361 critical value .05 (two-tail)
± .463 critical value .01 (two-tail)

Table 5-12: Roof Surfaces and Variables' Effect on the Nickel Correlation.

	ConNi	S1	S2	S3	S4	S5	ancedent	rain
ConNi	1.000							
S1	.806	1.000						
S2	.786	.808	1.000					
S3	.396	.018	.194	1.000				
S4	.647	.547	.711	.102	1.000			
S5	.730	.632	.695	.088	.909	1.000		
ancedent	.020	-.058	-.035	-.159	.083	.061	1.000	
rain	-.170	-.113	-.150	.383	-.207	-.133	-.355	1.000

23 sample size

± .413 critical value .05 (two-tail)
± .526 critical value .01 (two-tail)

Table 5-13: Roof Surfaces and Variables' Effect on the Manganese Correlation.

	ConMn	S1	S2	S3	S4	S5	ancedent	rain
ConMn	1.000							
S1	.468	1.000						
S2	.372	.958	1.000					
S3	.171	.681	.622	1.000				
S4	.321	.809	.755	.975	1.000			
S5	.230	.768	.723	.973	.980	1.000		
ancedent	.025	.577	.509	.694	.697	.727	1.000	
rain	-.404	-.545	-.510	-.320	-.414	-.384	-.355	1.000

23 sample size

± .413 critical value .05 (two-tail)
± .526 critical value .01 (two-tail)

Table 5-14: Roof Surfaces and Variables' Effect on the Chromium Correlation.

	ConCr	*S1*	*S2*	*S3*	*S4*	*S5*	*ancedent*	*rain*
ConCr	1.000							
S1	.483	1.000						
S2	.148	.290	1.000					
S3	.161	.181	.078	1.000				
S4	.502	.428	.296	.298	1.000			
S5	.304	.575	.085	.037	.657	1.000		
ancedent	.056	.010	-.120	.054	.344	.061	1.000	
rain	.113	-.262	-.130	-.293	-.319	-.250	-.215	1.000

30 sample size

± .361 critical value .05 (two-tail)
± .463 critical value .01 (two-tail)

Table 5-15: Roof Surfaces and Variables' Effect on the Copper Correlation.

	ConCu	*S1*	*S2*	*S3*	*S4*	*S5*	*ancedent*	*rain*
ConCu	1.000							
S1	.967	1.000						
S2	.980	.987	1.000					
S3	.752	.755	.792	1.000				
S4	.927	.942	.954	.838	1.000			
S5	.926	.936	.950	.840	.985	1.000		
ancedent	-.002	.017	.012	.038	.001	-.016	1.000	
rain	-.183	-.167	-.162	-.192	-.077	-.150	-.215	1.000

30 sample size

± .361 critical value .05 (two-tail)
± .463 critical value .01 (two-tail)

Table 5-16: Roof Surfaces and Variables' Effect on the Magnesium Correlation.

	ConMg	S1	S2	S3	S4	S5	ancedent	rain
ConMg	1.000							
S1	.853	1.000						
S2	.894	.965	1.000					
S3	.861	.840	.946	1.000				
S4	.913	.943	.986	.938	1.000			
S5	.921	.933	.981	.955	.994	1.000		
ancedent	.574	.646	.624	.595	.698	.731	1.000	
rain	-.109	-.536	-.541	-.492	-.478	-.449	-.302	1.000

7 sample size

± .754 critical value .05 (two-tail)
± .875 critical value .01 (two-tail)

Table 5-17: Roof Surfaces and Variables' Effect on the Iron Correlation.

	ConFe	S1	S2	S3	S4	S5	ancedent	rain
ConFe	1.000							
S1	.617	1.000						
S2	.391	.613	1.000					
S3	.327	.636	.799	1.000				
S4	.201	.494	.534	.479	1.000			
S5	.479	.684	.628	.501	.238	1.000		
ancedent	.150	.084	-.089	-.083	.117	.133	1.000	
rain	-.063	.046	.180	.462	.092	.047	-.215	1.000

30 sample size

± .361 critical value .05 (two-tail)
± .463 critical value .01 (two-tail)

The correlations in Table 5-7 through Table 5-17 show a negative correlation with the rain and this suggests that the deposition process is local; this finding is consistent with the literature (Kieber, et al., 2003; Kieber, et al., 2005; Kieber, et al., 2004; Kieber, et al., 2002; Luidold & Antrekowitsch., 2007). Similarly, the positive correlation of Fe with rainwater is consistent with the long transport cycle of Fe that is not of local sources (Kieber, et al., 2003; Kieber, et al., 2002; Tanner & Fai, 2000; Tanner & Wong, 2000).

Summary of Chemical Analysis of Roof Runoff

The metal concentration levels of (Cd, Cr, Fe, Mg, Mn, Ni, Pb, and Zn) in over thirty-one (31) samples collected in this study from each of the five (5) roof surfaces were within EPA drinking water quality criteria standards, as shown in Table 4-2. There was no exceedance of the primary and secondary drinking water standards.

Item Analysis

Paired t-test and Wilcoxon statistical analysis are shown in Table 5-18. It can be seen from the data analysis that the roof surfaces are changing the quality of the water running off over these surfaces. The summary analysis suggests there is a preferred roofing material for collection of roof runoff. Table 5-18 suggests that the S1-natural clay barrel roof material and S4-painted, galvanized steel roof material, were the preferred roofing materials for collection of roof runoff. The S1 data illustrates that the adsorption properties are beneficial in that they lower the metals concentration below that of the control sample. S1-natural clay barrel, then later releases the adsorbed contaminant in a lower concentration, reducing the overall average concentration found in the runoff, but S1 did not reach an equilibrium. The data exhibits a strong decrease in the zinc concentration found in the S1-natural clay barrel, whereas S5-unpainted, galvanized steel, had concentrations that were 7.45 times that of the control samples of zinc (Zn). This research has shown that the analyte concentrations meet the primary and secondary drinking water standards set by the EPA. Thus, the study suggests the roofing material examined has only minimal impact on water quality.

Table 5-18: Summary of Statistical Analyses of the Surface Runoff Data for S1-S5.

Roofing Surfaces						
Analyte		S1	S2	S3	S4	S5
pH	T-Test	.8531	.0004 **	.0001 **	.0099 **	.0189 *
	Wilcoxon	.7211	.0003 **	.0002 **	.0175 *	.0378 *
TDS	T-Test	4.48E-05 **	.9199	1.20E-06 **	.0002 **	.0001 **
	Wilcoxon	6.48E-07 **	.6328	2.81E-05 **	2.73E-06 **	6.10E-06 **
Zn	T-Test	.0009 **	.0008 **	.0563	.1920	6.57E-07 **
	Wilcoxon	1.02E-05 **	8.47E-06 **	.0060 **	.6884	1.92E-06 **
Pb	T-Test	.4580	.1396	.3777	.0966	.0586
	Wilcoxon	.5855	.3280	.2560	.1893	.0901
Cd	T-Test	.6979	.5087	.6201	.9006	.4671
	Wilcoxon	.3942	.7454	.8484	.9199	.7677
Ni	T-Test	.1466	.0578	.3705	.1257	.3382
	Wilcoxon	.1727	.0853	.7578	.3229	.8129
Fe	T-Test	.0066 **	.2018	.7678	.3782	.0570
	Wilcoxon	.0073 **	.3886	.8446	.6735	.1264
Mn	T-Test	.1832	.1193	.2282	.3453	.7477
	Wilcoxon	.4823	.0484 *	.1225	.7076	.3452
Cr	T-Test	.0084 **	.0615	7.89E-07 **	.2102	.4232
	Wilcoxon	.0048 **	.0003 **	1.13E-05 **	.1212	.3409
Cu	T-Test	.0482 *	.0089 **	.7482	.0283 *	.0229 *
	Wilcoxon	.0086 **	.0079 **	.5958	.0229 *	.0047 **
Mg	T-Test	.0544	.0856	.1669	.1169	.1150
	Wilcoxon	.0180 *	.0910	.1282	.1763	.2367
P=0.05 * P=0.01**						

Wind Direction Analysis

The preliminary analysis suggested that the wind direction could have an effect on the outcome of the results, with eleven (11) events from the Southwest and five (5) events from the Northeast. The data analysis then sorted the data according to wind direction and examined if there were correlations, using SAS between the wind direction and outcome. The preliminary data suggests that wind direction could have an effect on the water quality; however, due to the small sample size, further investigations would be required to determine this with certainty.

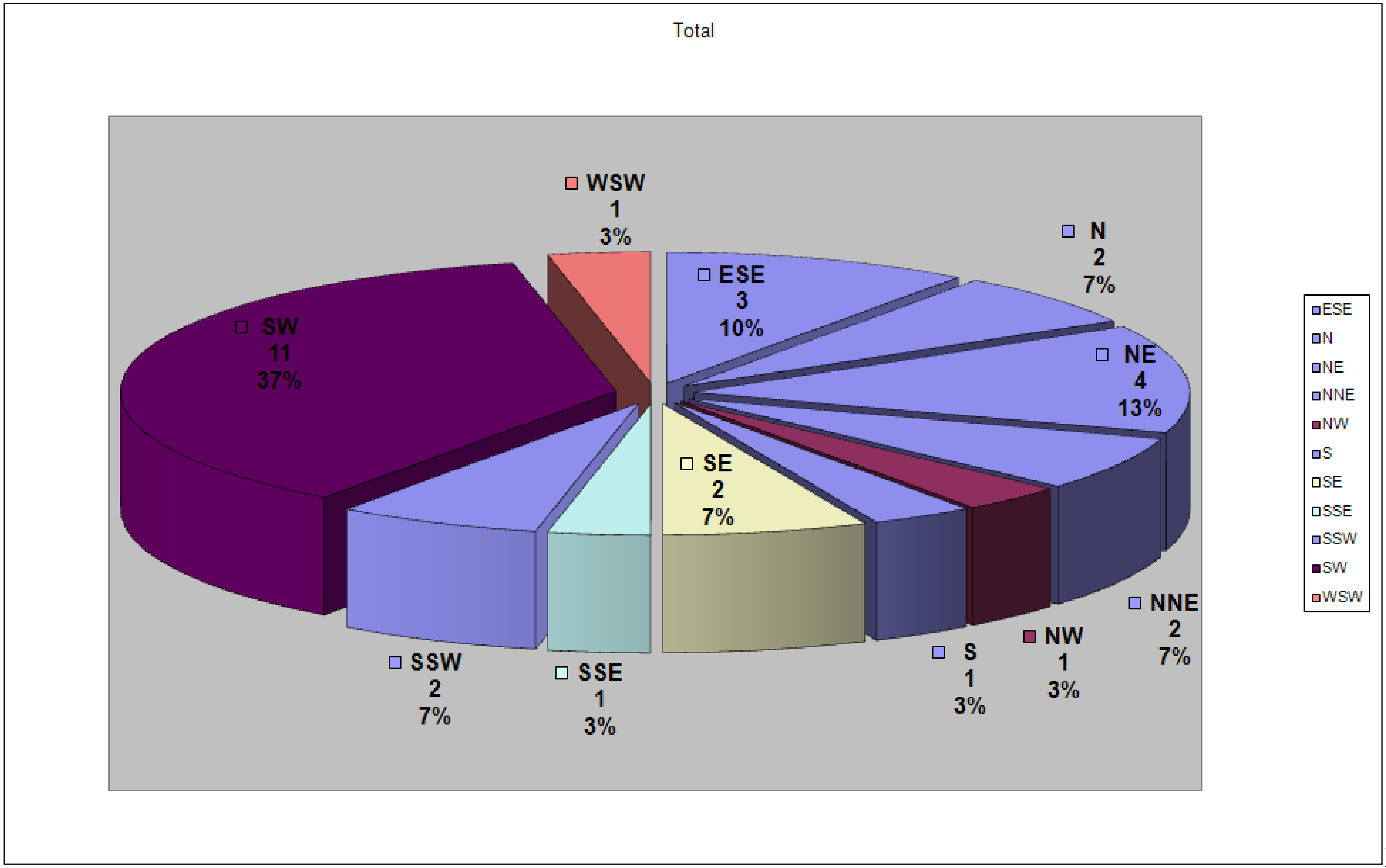

Figure 5-1: The Prevailing Wind Direction at the Research Site Over the Study Period.

There was an attempt to correlate the wind direction with the biological plate count where the thought was the dispersion process would affect the plate counts, as shown in the following Table 5-15. The effects of the wind direction and the velocity of the wind was a major contributor to biological media and dispersion of biological media found on rooftops. Figure 5-1 represents the prevailing wind direction of the study period of nine months, with 37 percent of the prevailing wind during this period coming from the southwest. Then there was a consolidation of the wind directions to the North and South to examine if there was an effect on the concentrations and biological counts. An effect of the Northern winds on concentration was observed, which is plausible with continental land mass fronts. In Tables 5-19 and 5-20, the mean Zn was 0.0844 mgℓ^{-1}, from a Southern wind, whereas the Northern wind mean Zn concentration was 0.3297 mgℓ^{-1}, approximately 3.9 times greater. The mean concentration of copper exhibited a large difference in the mean concentration of 0.0049 mgℓ^{-1} from the South and the mean copper concentration from the North was 0.0085 mgℓ^{-1}, approximately 1.73 times greater.

Table 5-19: The Southern Wind Effects on Concentration of the Control.

	pH	Alk	TDSTot	Zn	PB	Cd	Ni	Fe	Mn	Cr	Cu	Mg
Mean	6.2281	1.9375	18.0000	0.0844	0.0032	0.0001	0.0017	0.0688	0.0026	0.0007	0.0049	0.4573
Median	6.3300	2.0000	14.5000	0.0511	0.0027	0.0001	0.0011	0.0535	0.0017	0.0008	0.0024	0.3435
St Dev	1.0452	0.2500	12.3234	0.0979	0.0025	0.0001	0.0013	0.0490	0.0028	0.0003	0.0057	0.3656
Max	8.1400	2.0000	50.0000	0.3776	0.0085	0.0003	0.0040	0.1963	0.0108	0.0011	0.0196	1.1480
min	4.4100	1.0000	5.0000	0.0086	0.0001	0.0000	0.0001	0.0176	0.0008	0.0001	0.0008	0.1050
wind	s	s	s	s	s	s	s	s	s	s	s	s
n=	17	17	17	17	17	17	17	17	17	17	17	17

Table 5-20: The Northern Wind Effects on Concentration of the Control.

	pH	Alk	TDSTot	Zn	PB	Cd	Ni	Fe	Mn	Cr	Cu	Mg
Mean	6.4589	2.0000	25.4444	0.3297	0.0024	0.0001	0.0022	0.0672	0.0112	0.0009	0.0085	0.0000
Median	6.7400	2.0000	19.0000	0.2459	0.0018	0.0001	0.0018	0.0627	0.0024	0.0009	0.0034	0.0000
St Dev	1.2180	0.0000	18.0770	0.3185	0.0015	0.0001	0.0016	0.0286	0.0173	0.0002	0.0093	0.0000
Max	7.7100	2.0000	60.0000	0.7509	0.0050	0.0002	0.0050	0.1135	0.0550	0.0011	0.0242	0.0000
min	4.1500	2.0000	6.0000	0.0184	0.0005	0.0000	0.0000	0.0227	0.0008	0.0004	0.0016	0.0000
wind	n	n	n	n	n	n	n	n	n	n	n	n
n=	9	9	9	9	9	9	9	9	9	9	9	9

Unfortunately, the study was unable to obtain sufficient biological plates count events. However, it was noted that Yaziz et al. (1989) reported in the literature that bacteria is always present in the air and on the roof surfaces of the 24 samples collected. Yaziz et al.'s (1989) plate count ranged from six (6) minimum to a maximum of 39 times 10^3/100 ml, contrasting with some of the findings at our site location. In this study, there were several samples that did not produce heterotrophic colonies. For example, 08 Oct 05 sample did not produce any colonies from any surfaces, whereas 02 Oct 05 sample did not produce any colonies on S1, S4, and S5, but colonies were present on S2 and S3, which is in contrast to Yaziz et al. (1989). In both cases, this study and that of Yaziz et al. (1989) need more data points for a conclusion.

Table 5-21: Effects of Changes in West by Southwestern Wind Direction on Plate Counts.

Sample date	Total Values						
	Suface	Wind Dir.	Plate 1	Plate 2	Median	Avg	Std dev
			22.2	0.0	22.2	0.0	0.0
25-Dec-05	control						
25-Dec-05	1	WSW	28		28		
25-Dec-05	2	WSW	20		20		
25-Dec-05	3	WSW	19		19		
25-Dec-05	4	WSW	28		28		
25-Dec-05	5	WSW	16		16		

Table 5-22: Effects of Changes in East by Southeastern Wind Direction on Plate Counts.

Sample date	Total Values						
	Surface	Wind Dir.	Plate 1	Plate 2	Median	Avg	Std dev
			19.1	19.4	19.0	19.7	6.1
23-Feb-06	control						
23-Feb-06	1	ESE	28.0		28.0		
23-Feb-06	2	ESE	11.0		11.0		
23-Feb-06	3	ESE	21.0		21.0		
23-Feb-06	4	ESE	0.0		0.0		
23-Feb-06	5	ESE	31.0		31.0		
1-Nov-05	control						
1-Nov-05	1	ESE	14.0	22.0	18.0	18.0	5.7
1-Nov-05	2	ESE	42.0	27.0	34.5	34.5	10.6
1-Nov-05	3	ESE	36.0	45.0	40.5	40.5	6.4
1-Nov-05	4	ESE	0.0	3.0	1.5	1.5	2.1
1-Nov-05	5	ESE	8.0	0.0	4.0	4.0	5.7

Table 5-23: Effects of Changes in Southern Wind Direction on Plate Counts.

Sample date	Total Values						
	Season	Wind Dir.	Plate 1	Plate 2	Median	Avg	Std dev
			15.2	14.5	14.8	14.8	2.5
8-Oct-05	control						
8-Oct-05	1	S	0.0	0.0	0.0	0.0	0.0
8-Oct-05	2	S	0.0	0.0	0.0	0.0	0.0
8-Oct-05	3	S	0.0	0.0	0.0	0.0	0.0
8-Oct-05	4	S	0.0	0.0	0.0	0.0	0.0
8-Oct-05	5	S	0.0	0.0	0.0	0.0	0.0
2-Oct-05	control						
2-Oct-05	1	SE	0.0	0.0	0.0	0.0	0.0
2-Oct-05	2	SE	9.0	2.0	5.5	5.5	4.9
2-Oct-05	3	SE	3.0	6.0	4.5	4.5	2.1
2-Oct-05	4	SE	0.0	0.0	0.0	0.0	0.0
2-Oct-05	5	SE	0.0	0.0	0.0	0.0	0.0
29-Jan-06	1	SE	34.0	38.0	36.0	36.0	2.8
29-Jan-06	2	SE	31.0	33.0	32.0	32.0	1.4
29-Jan-06	3	SE	31.0	31.0	31.0	31.0	0.0
29-Jan-06	4	SE	27.0	36.0	31.5	31.5	6.4
29-Jan-06	5	SE	31.0	16.0	23.5	23.5	10.6
3-Feb-06	control						
3-Feb-06	1	SSE	28.0	18.0	23.0	23.0	7.1
3-Feb-06	2	SSE	31.0	30.0	30.5	30.5	0.7
3-Feb-06	3	SSE	29.0	33.0	31.0	31.0	2.8
3-Feb-06	4	SSE	20.0	26.0	23.0	23.0	4.2
3-Feb-06	5	SSE	29.0	20.0	24.5	24.5	6.4

Table 5-24: Effects of Changes in North Wind Direction on Plate Counts.

Sample date	Total Values						
	Season	Wind Dir.	Plate 1	Plate 2	Median	Avg	Std dev
			15.8	13.0	14.1	14.1	4.2
7-Dec-05	control						
7-Dec-05	1	NE	20.0	18.0	19.0	19.0	1.4
7-Dec-05	2	NE	37.0	23.0	30.0	30.0	9.9
7-Dec-05	3	NE	29.0	22.0	25.5	25.5	4.9
7-Dec-05	4	NE	26.0	22.0	24.0	24.0	2.8
7-Dec-05	5	NE	25.0	31.0	28.0	28.0	4.2
23-Oct-05	control						
23-Oct-05	1	NE	0.0	0.0	0.0	0.0	0.0
23-Oct-05	2	NE	0.0	16.0	8.0	8.0	11.3
23-Oct-05	3	NE	42.0	6.0	24.0	24.0	25.5
23-Oct-05	4	NE	0.0	0.0	0.0	0.0	0.0
23-Oct-05	5	NE	0.0	0.0	0.0	0.0	0.0
17-Dec-05	control						
17-Dec-05	1	NE	10.0	7.0	8.5	8.5	2.1
17-Dec-05	2	NE	0.0	0.0	0.0	0.0	0.0
17-Dec-05	3	NE	0.0	.	0.0	0.0	
17-Dec-05	4	NE	16.0	3.0	9.5	9.5	9.2
17-Dec-05	5	NE	0.0	0.0	0.0	0.0	0.0
1-Oct-05	control						
1-Oct-05	1	NNE	0.0	0.0	0.0	0.0	0.0
1-Oct-05	2	NNE	10.0	17.0	13.5	13.5	4.9
1-Oct-05	3	NNE	35.0	30.0	32.5	32.5	3.5
1-Oct-05	4	NNE	0.0	0.0	0.0	0.0	0.0
1-Oct-05	5	NNE	0.0	0.0	0.0	0.0	0.0
18-Dec-05	control						
18-Dec-05	1	NW	12.0	9.0	10.5	10.5	2.1
18-Dec-05	2	NW	33.0	32.0	32.5	32.5	0.7
18-Dec-05	3	NW	36.0	28.0	32.0	32.0	5.7
18-Dec-05	4	NW	34.0	20.0	27.0	27.0	9.9
18-Dec-05	5	NW	30.0	27.0	28.5	28.5	2.1

Table 5-25: Effects of Changes in Southwestern Wind Direction on Plate Counts.

Sample date	Total Values						
	Season	Wind Dir	Plate 1	Plate 2	Median	Avg	Std dev
			15.4	12.1	13.2	14.6	5.0
28-Sep-05	control						
28-Sep-05	1	SW	0.0	0.0	0.0	0.0	0.0
28-Sep-05	2	SW	0.0	0.0	0.0	0.0	0.0
28-Sep-05	3	SW	44.0	14.0	29.0	29.0	21.2
28-Sep-05	4	SW	0.0	0.0	0.0	0.0	0.0
28-Sep-05	5	SW	2.0	0.0	1.0	1.0	1.4
6-Oct-05	control						
6-Oct-05	1	SW	0.0	0.0	0.0	0.0	0.0
6-Oct-05	2	SW	0.0	0.0	0.0	0.0	0.0
6-Oct-05	3	SW	0.0	0.0	0.0	0.0	0.0
6-Oct-05	4	SW	0.0	0.0	0.0	0.0	0.0
6-Oct-05	5	SW	0.0	0.0	0.0	0.0	0.0
20-Nov-05	control						
20-Nov-05	1	SW	0.0		0.0		
20-Nov-05	2	SW	17.0		17.0		
20-Nov-05	3	SW	0.0		0.0		
20-Nov-05	4	SW	0.0		0.0		
20-Nov-05	5	SW	0.0		0.0		
28-Nov-05	control						
28-Nov-05	1	SW	8.0	16.0	12.0	12.0	5.7
28-Nov-05	2	SW	35.0	16.0	25.5	25.5	13.4
28-Nov-05	3	SW	12.0	15.0	13.5	13.5	2.1
28-Nov-05	4	SW	7.0	2.0	4.5	4.5	3.5
28-Nov-05	5	SW	4.0	5.0	4.5	4.5	0.7
2-Jan-06	control						
2-Jan-06	1	SW	47.0	27.0	37.0	37.0	14.1
2-Jan-06	2	SW	32.0	29.0	30.5	30.5	2.1
2-Jan-06	3	SW	15.0	4.0	9.5	9.5	7.8
2-Jan-06	4	SW	16.0	0.0	8.0	8.0	11.3
2-Jan-06	5	SW	26.0	3.0	14.5	14.5	16.3
30-Jan-06	control						
30-Jan-06	1	SW	20.0	24.0	22.0	22.0	2.8
30-Jan-06	2	SW	30.0	32.0	31.0	31.0	1.4
30-Jan-06	3	SW	35.0	42.0	38.5	38.5	4.9
30-Jan-06	4	SW	41.0	31.0	36.0	36.0	7.1
30-Jan-06	5	SW	48.0	41.0	44.5	44.5	4.9
11-Feb-06	control						
11-Feb-06	1	SW	29.0	32.0	30.5	30.5	2.1
11-Feb-06	2	SW	9.0	0.0	4.5	4.5	6.4
11-Feb-06	3	SW	36.0	26.0	31.0	31.0	7.1
11-Feb-06	4	SW	14.0	0.0	7.0	7.0	9.9
11-Feb-06	5	SW	0.0	0.0	0.0	0.0	0.0
5-Dec-05	control						
5-Dec-05	1	SSW	12.0	8.0	10.0	10.0	2.8
5-Dec-05	2	SSW	16.0	7.0	11.5	11.5	6.4
5-Dec-05	3	SSW	37.0	30.0	33.5	33.5	4.9
5-Dec-05	4	SSW	5.0	13.0	9.0	9.0	5.7
5-Dec-05	5	SSW	19.0	7.0	13.0	13.0	8.5

Limitations of the Study and the Data

One of the limitations of this study was the sample size of a few elements, such as Mg. However, the sample size was sufficient to examine the majority of the selected metals found in roof runoff, such as meeting the water quality standards for the metal in question because of the costly remediation to be in compliance.

With respect to the chemical analysis because of cost and time constraints, it would have been advantageous to have a confirmation by another certified laboratory to ensure no variance within the analysis. While the analysis was performed by the same individual in the same readings in triplicate, there is a possibility of a variance between laboratories.

Another limitation of the study was that the roof material was new. Further investigation and future study should include new material that has been followed through time to ascertain if corrosion or oxidation increases or decreases concentration release.

Another reason for long-term research is that weather phenomena are spatial, temporal, and random. During the period of this study, these weather events were not indicative of nor representative of a normal cycle of weather phenomenon. A study of longer duration would be beneficial to analyze trends over time.

This research has provided information on roof runoff water quality for five different roofing materials. In conducting this part of the research, the following conclusions were reached:

None of the water quality samples collected from the five roofing materials exceeds the primary or secondary drinking water standards. The metals were selected because they were among the most expensive contaminants to remove, in order to meet these standards. Biological and TSS of the contaminants would be removed from regional treatment systems as part of the normal processes and therefore were not considered critical.

There are preferred roofing materials such as the clay barrel tile, which was found to have adsorptive quadrupole interaction properties. The other preferred roofing material is the painted galvanized roofing material, because it decreases the concentrations of zinc (Zn) when compared to the unpainted galvanized material. The glazed tile, the flat shaker impregnated tile, and the unpainted galvanized steel were found to be less desirable roofing material for roof runoff collection, because of higher metal concentration levels.

The research findings and analyses were congruent with the Cu, Fe, and Cr correlations associated with the long transport systems and anthropogenic sources (J. N. Galloway, et al., 1993; James N. Galloway, et al., 1982; Kieber, et al., 2003; Kieber, et al., 2002; Mudgal, et al., 2007). Another similar outcome of these analyses was the association of the wind direction on the HPC (Yaziz, et al., 1989).

It is important to note that the experimental data were not compromised by using PVC or plastic products, which have been known to leach trace metals. Galloway et al., (1982) has stated that the older data in wet deposition are unreliable because at the time unknown leaching from the sample containers and plastics could raise the estimates higher by a factor of 10 for Cd, Cu, Pb and Zn (Barrie, et al., 1987).

Because none of the water quality samples collected from the five roofing materials exceeds a concentration action level or a concentration for the primary or secondary drinking water standards, this water met potable water standards. This enables us to examine the roof runoff as an alternative source for augmentation of potable water supplies. The results of this research potentially support the use of this roof runoff water to augment potable water supplies as a high quality source.

CHAPTER VI: MODEL DEVELOPMENT AND DISCUSSION

This chapter presents relevant design and cost consideration to address the economic feasibility of using roof runoff and regional treatment. The crucial aspect in the development of this model was to align and reflect the conditions of the community, followed by needs and inputs of the user. The applicability of this model design is that it incorporates the flexibility for the user to change a variety of variables and conditions found in the natural systems. This versatility allows the evaluation of the feasibility of the roof runoff augmentation system for large and diverse conditions found in a small-defined community. This permits the user to balance between the economics and the integration system, which includes roof runoff augmentation to municipal supplies.

This chapter discusses a strategy and assessment model that has been developed for determining the collection and cost of augmenting available water sources using roof runoff as a potential water source. The Rational Concept shown in Figure 6-1 is the cause-and-effect inputs on the outcome of the model. The water quality and quantity, the geographic and demographic, and roof materials all affect the feasibility and sustainability of model. These conceptual inputs, depicted in Figure 6-1, were parameters used to develop the modules of the Augmentation Model for the roof runoff as a potable water resource.

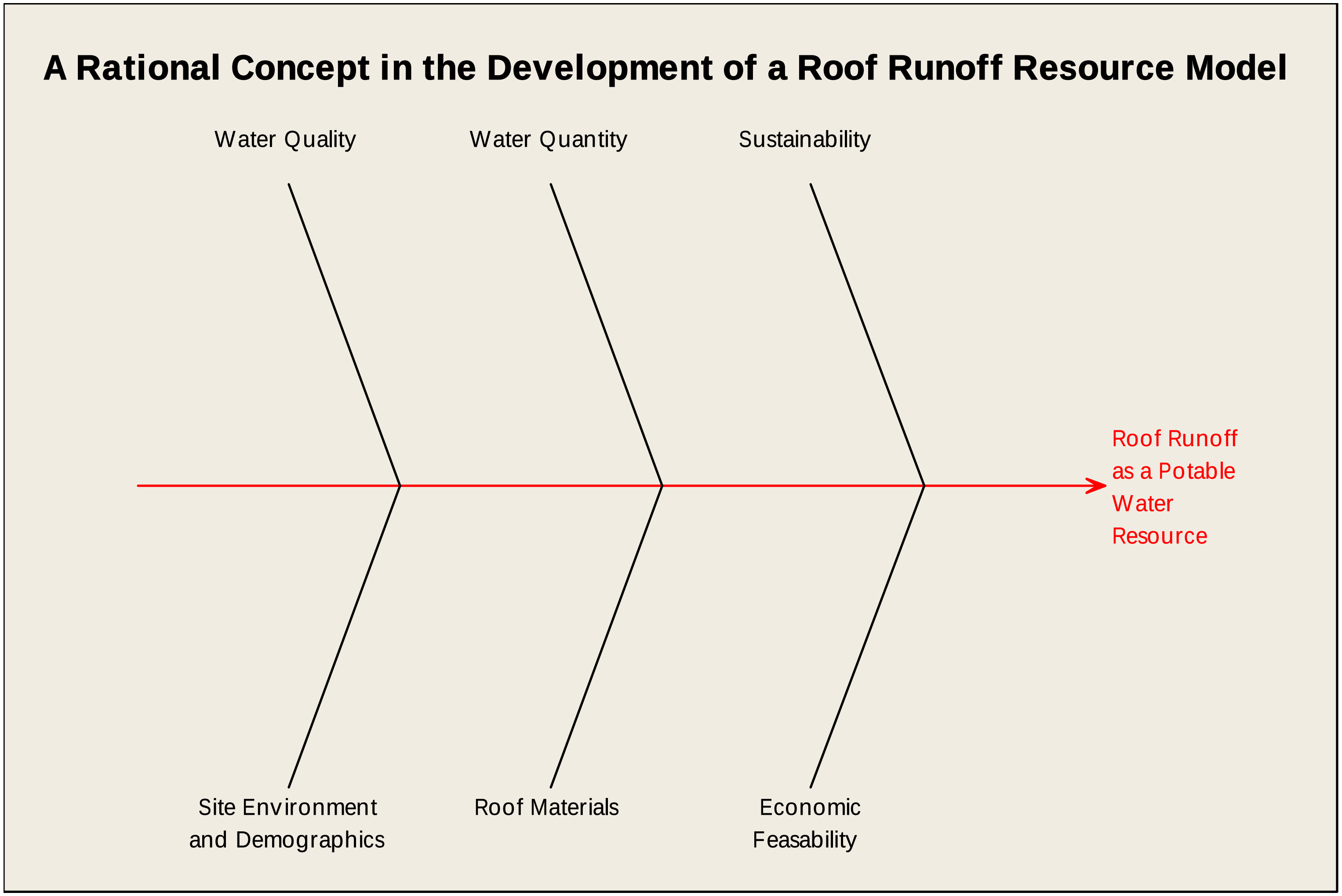

Figure 6-1: Conceptual Inputs for Creating the Augmentation Model Matrix

The Design and Processes Used in the Model Development

The framework used for the development of the Augmentation Model utilized a location in the city of Temple Terrace, Florida, as a test case. The model takes into consideration that each city has unique characteristics and therefore, some of the input variables must be changed in order to accurately represent the application. The model's methodology uses three (3) categories for the water quality data, the meteorological data, and the geographical data analyses. These data were analyzed to ensure compliance with standards, as shown in Figure 6-2.

Water Quality Parameter in the Model Development

Water quality was found to be a function of the environment, such as relevant location of potential polluters, like industrial complexes that produce atmospheric emissions. Thus, the water quality and environment were the first parameters assessed in the model. Water quality parameters dictate economics outcome, because water quality standards will determine the collection and treatment methods that are used. As previously discussed in Chapter V, this research has shown that there was no exceedance of the EPA's primary and secondary drinking water standards for the metals in question over a nine-month period. Hence, the metals do not present a remediation issue or additional treatment costs. Roof runoff water is a viable potable water resource.

Meteorological Parameters in the Model Development

In a preliminary analysis, the rainfall record from years 2000 through 2006 from the nearest gauging site from Southwest Florida Water Management District (SWFWMD) were analyzed and showed the average rainfall for this period was 47.38 inches-per-year, which is similar to the finding of several researchers (Fernald & Purdem, 1998; Wanielista, et al., 1997). Typical storms during the summer months in Florida are convective storms with high quantity of rainfall in short time periods. This water represents a substantial supplemental water supply to the city, based upon the research data collected. The meteorological characteristics will be unique for each site, thus effecting quantity of rainwater capture based upon demographics.

Flow Chart of the Model

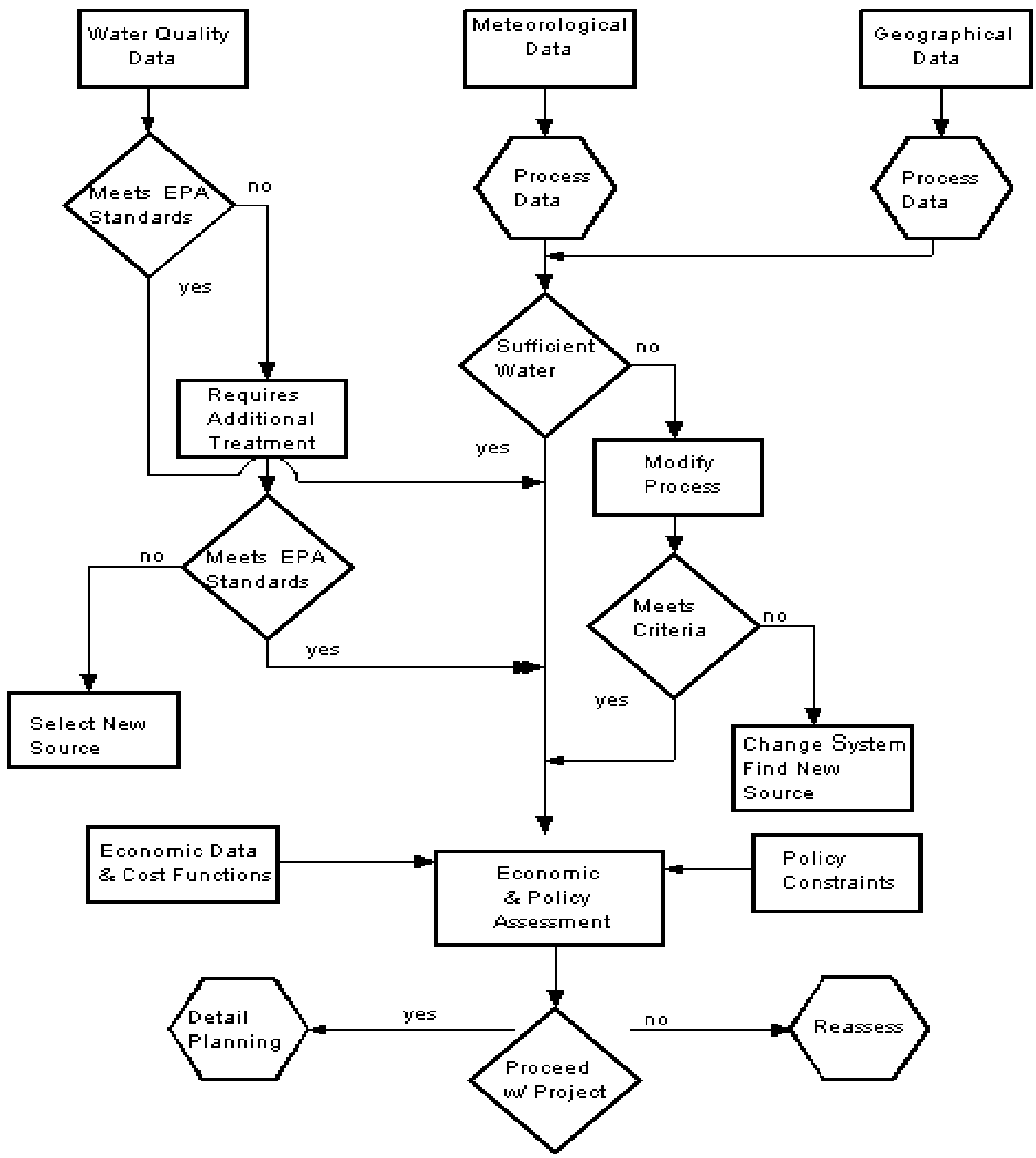

Figure 6-2: The Flow Chart of Processes for the Development of the Model

Demographic Parameters of the Model Development

Use of a stormwater runoff from rooftops represents an overlooked water resource for small communities such as Temple Terrace, and other communities that have a population of approximately 30,000 to 40,000. The uniqueness of this design allows water from the roof to be transported directly to the water treatment facility through a collection system. This represents a substantial change in water source strategy for water treatment and delivery to the customer. For example, Temple Terrace has a population of approximately 30,000, and 11,600 residential residences with an occupancy of 2.5 persons per home, as an average, within the community. This represents approximately 12,000 homes in the corporate limits of the city of Temple Terrace. The average rooftop of these homes is approximately 3000 square feet (City of Temple Terrace Planning Department, 2006; City of Temple Terrace Public Works Department, 2006).

Geographic and Demographics Conditions on the Model

The structure of the collection and distribution systems of the current water distribution systems can be used in developing this new strategy. However, the collection process requires piping and routing of water to relatively small transfer storage tanks. The augmentation strategy is to have the water treatment plant reduce the dependence on well water systems during and following a rain event, thus maintaining a sustainable water strategy for the city. This research has shown that roof runoff can serve as an alternative potable source, without additional treatment processes for metals, hence minimal treatment. This proposed Augmentation strategy allows throughput directly to the demand, thus reducing the need for other more expensive alternatives.

Sector Concept for the Feasibility and Viability of the Model

Demographics Conditions

The model area was defined from data provided by the city of Temple Terrace. For example, the area noted in yellow in Figure 6-3 is one section of the city showing the density and the typical grid configuration of the neighborhoods.

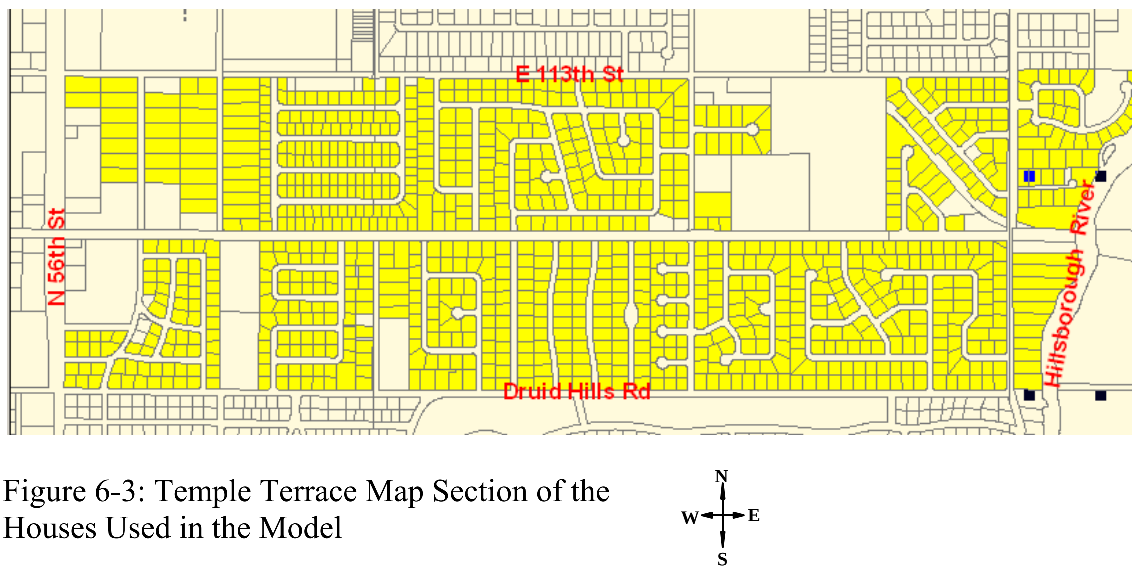

Figure 6-3: Temple Terrace Map Section of the Houses Used in the Model

This sector area depicted in Table 6-3 is the single-family residential area between East 113th Avenue and Druid Hills Drive, and North 56th Street North to the Hillsborough River. This sector was utilized in the development of a model configuration. This neighborhood section is primarily a typical grid North-South, East-West configuration, which is representative of most neighborhoods in Temple Terrace and of most of the Southeastern United States. The area is defined by 1,031 lots with approximately 24 lots per street with the gross roof area of 3,041,108 square feet (City of Temple Terrace

Planning Department, 2006). Temple Terrace has a population of approximately 29,000,with total residential water connections of 11,600 with a daily demand of 4.1674 million-gallons-per-day (City of Temple Terrace Public Works Department, 2006). The state of Florida's average daily demand is 174 gallons-per-capita-day, whereas Temple Terrace has an estimated water usage per capita of 143 gallons-per-capita-day, which is below the state average (City of Temple Terrace Public Works Department, 2006). The total numbers of homes in Temple Terrace are estimated to be 11,600 with a total roof surface area of $35.275 * 10^6$ square feet (City of Temple Terrace Planning Department, 2006).

Geographic Conditions

The total volume of roof runoff available from the average rainfall annually of 47.38 inches-per-year is 139,268,068.8 cubic-feet-per-years, which equates to $1{,}041 \times 10^9$ gallons-per-year. Temple Terrace's annual demand is 1.523×10^9 gallons-per-year (City of Temple Terrace Public Works Department, 2006). The Augmentation strategy using the runoff has the potential of reducing groundwater withdrawals by 56.93 percent. This strategy is a significant leap toward sustainability and conservation of our precious resource: the Floridian aquifer.

According to the State of Florida Department of Environmental Protection (FDEP) and the Florida Department of Transportation (FDOT), a "statistical analysis from Florida rainfall data and field investigations found that nearly 90 percent of all storm events that occur in any region of Florida in a given year will provide 1-inch of rainfall or less" (Florida Department of Environmental Protection, 2002). Based on this, we assume that a rain event of 60 minutes duration would have a volume of rainwater 1-inch or less over 1,000 roof units in the model area, producing 215.4 or less, cubic-feet-per-hour-per-roof or 26.85 or less, gallons-per-minute-per-roof of potable water. This was a preliminary analysis, and it was useful in determining if the strategy was feasible prior to modeling.

The Configurations and Hydraulic Conditions Incorporated into the Model

The hydraulic element of this model was based upon a gravity flow collection system and a forced main system returning collected water to the water treatment plant. The design of the system is a rational model that addresses the average approximate costs associated with components and appurtenances generally associated with the construction. All listed costs are presented as “general estimates” for the site: purchasing, designing, permitting, and construction; while also recognizing that each project is unique. A wide variety of site specifications and factors will come into play with individual projects in different areas, but the model purpose is to provide feasibility calculations for the Augmentation system.

Conceptual Description of the Configuration Design

In this analysis it was assumed that the homes’ roof gutters are connected to a leader pipe, which is subsequently connected to a lateral pipe. A typical lateral within Temple Terrace would have 12 to 24 connections, which equates to a flow of 322 to 644.4 gallons-per-minute. These laterals are then connected to the mains, which transfer the water to a central collection point. In one scenario, there are mains located under

Druid Hills Road, Whiteway Drive, and East 113th Avenue, which are parallel and have diminishing elevation from North 56th Street towards the Hillsborough River. The ground storage tanks are to be located on a property currently owned by the city, which represents a savings for the city of Temple Terrace that is not realized in this analysis. The model includes the capacity input for the land costs variable in the calculations to be applicable to other municipalities.

Hydraulic Conditions

In the creation and analysis of the model components, the capacity of the collection system during a specific rain event was constrained by the configuration of the piping routing system. Another constraint of the system was the plant's ability to process the volume of water received from the roof runoff piping configuration. The storage tank size is also constrained by land availability and economic cost factors. This fluid mechanics problem is constrained by economics and operational strategy implementation (Chase, 2004). The strategy of augmenting use of the ground water source to the storage catchments requires that the inflow is greater than the pumping rate of the force main out of the storage tanks. Manning’s equation was used to calculate the piping system for the gravity flow systems, while Darcy's equation was used for the pressure-piping network (Sincero & Sincero, 1996; Viessman & Lewis, 2003 ; Wanielista, et al., 1997).

The Model Data Modules for the Input and Output Screens

Water Data Module

The model is a culmination of several models and numerous refinements that were developed over several months. Using a three-pronged approach shown in the flow chart in Figure 6-2, the water quality module used the data collected during this research that demonstrated that the water quality parameters met the EPA standards.

Meteorological Data Module

The meteorological module used 19-years of rain records from the National Climatic Data Center (NCDC) for the nearby town of Lakeland, Florida. These rain records were used because of the proximity to the site location and the long record will not skew the results due to the random, spatial, and episodic nature of rainfall. The NCDC had to be transformed because the data file only contained rainfall events. In order to proceed with the time series analysis of data, it had to be transformed to include all 15-minute intervals throughout the record with or without indication of rain (Carnahan, et al., 1969).

Geographical and Demographic Module

The model used the previously discussed variables and constraints for the feasibility of the Augmentation Model. The configuration was based upon the sector previously described in Temple Terrace, which is representative of small towns in the southeastern United States. The model was developed in Microsoft Excel. The hydraulic elements of the model, sizing the pipes, and the various calculations, are contained in Appendix II.

The Model Elements for the Variables Sheet Input and Output Screens

Figure 6-4 is the user input variables page where the user inputs the values into cells to produce the calculations and graphs.

This rain model was developed by Robert Carnahan, and Jen Perone, with the guidance of Dr Mark Ross.

The data models and calculations are site specific. The models uses are for educational and research purposes only.

Model Catchment Variables	
The number of Roofs	1200
Roof size(sq ft)	3000
2.5	(p/home)
(gallons used/person/day)	143
Maximum Reservoir Tank	10,000,000
Derived Participant Demand/Day	429,000

Rain Model Effective Rain Variables	
interevent (hrs)	intercept (in)
6:00	0.05

Community or Participant Demand Per Day	Pump gal per min
429,000	2,000.0

Demand per 15 Minutes
4,468.75

Model Analyses from 19 Years of Data	
Supply	Percentage
Ground Water	0.536927
Rain	0.461961
Partial	0.001112
Reservoir	0

Maximum Plant (Gal)
4,000,000

Figure 6-4.: Variable Input Screen

User Inputs Variables

The variables can be changed by the user and are denoted by the white cells whereas the light blue tinted cells are calculated, or references that are not changeable. Under the model heading the "Catchment Variables" the user can adjust the number of groups, the number of roof sizes in square-feet, per capita information 2.5 persons-per-home. For convenience under the same column, the light blue cell labeled the "Derived Participant the Demand/Day" calculates the demand for the model catchment. Under the heading "Community or Participant Demand per Day" the user must input the demand. The demand can be a sector, or a catchment demand found in the "Derived Participant Demand per Day." The user can also input another demand, such as a larger community demand. The model is designed to allow the calculation of combining multiple sectors or catchments. The "Demand per 15 Minutes" is a calculated value based upon the "Community or Participant Demand per Day," the result is found in the light blue tinted cell. This results in the value used in the subroutine of the model for the time series analyses and calculations of the data output.

User Input Constraints

This variable page, Figure 6-4, also allows the constraints to be entered into the model. Under the same heading "Model a Catchment Variables," the user will find a "Maximum Reservoir Tank" size as a constraint of the model. This tank constraint value is zero, 4 million, 6 million, 8 million, or 10 million because this is linked to the financial reference module of the model. Using a value other than specified above will result in an output error.

Another constraint of consideration is the "Effective Rain Variables." These variables are dependent on the location of the site and the surface interception value in inches, which accounts for the volume of water required to wet the surface. This volume is then lost subsequent to the rain to evaporation. For this research site 0.05 inches was used as the "Interception capture volume" value to be subtracted from the volume of the first rain period in any event. The "Interevent" in hours is the time that has elapsed since the last rainfall event, for example is not uncommon during the Florida summers that there is a morning rain followed by afternoon rainfall. The increased temperature increases the evaporation of the morning rain, hence the roof surface is no longer saturated for afternoon rainfall flow over the roof. The interevent variable constraint takes the intercept value and subtracts that value from the first rainfall. If there was no rainfall between the last recorded rainfall in the time interval specified by the user in the interevent input cell, then the intercept value is substracted from the rain event until the intercept value has been reached. For example, in Figure 6-4, the user has specified the interevent at six (6) hours.

Since the design of the model is an optimization based upon the pumping rate to the water plant, the plant becomes a constraint. The system was designed for a forced main pump of 58 hp with variable speed capacity and user defined. Therefore, the pumping capacity will affect the utilization and optimization of the model outputs. The uniqueness of this approach is the immediate pumping from the collection and storage systems, a direct transfer of the roof runoff water to the treatment plant. This approach also creates a constraint based upon the capacity of the plant to process the transferred water. The capacity of the treatment plant at the site location was a maximum of

4,000,000 gallons-per-day. Located under the heading “Maximum Plant (Gal)” the user can define the constraint of the treatment plant at their specific location.

Variable Input Screen Output

The model outcomes of the variables are shown below the title heading “Model Analyses from 19 years of Data” in table format listing the supply percentage utilization of the captured roof runoff. Under the table heading “Supply” there are entries for use, such as groundwater, rain , partial and reservoir, with the adjacent column indicating the percentage of utilization based on the input demand. The partial is a combination of rain and groundwater.

The Model Inputs Elements for the Sector Collection and Piping System

The sector collection in piping system module consists of a user input page to facilitate the pipe sizing selection and to identify the piping constraints. Shown in Figure 6-5 is the screen input page for the piping module. Under the heading, "Characteristics," the user can find the slope of the pipes by changing the top row labeled "Depth in feet" and "Distance in feet" for the corresponding pipe diameters listed below in inches. The "Max Flow in gallons/15 Min" will change based upon the input of the slope. The "Max Flow in gallons/15 Min" value is calculated from the light blue tinted data for specific pipe diameters in the columns. The calculation consists of the Manning equation, the slope, cross-sectional area, roughness coefficient, and the hydraulic radius, with output of the velocity full in ft/sec. Using the continuity equation flow at full is calculated in cfs, gpm, and MGD, which are listed in the appropriate columns. The "Max Flow in gallons/15 Min" is the maximum carrying capacity for that "Pipe Size."

The second lower half of the input page allows the user to select the "Pipe Size" from the drop window in the input cell. The user then must input the "Run," the distance in feet for each of the connections or runs for the length of pipe. The user then uses a matrix to complete the pipe configuration for that specific sector. For example, in Figure 6-5 under the heading "Step 1" the "Pipe Size" is (8) inches, the "Run" is 100 feet, "Quantity units to connector" is 1, the "QA variable page" in tinted light blue indicates there are 1,200 homes from the user's previous entry, " Home to lateral" is 1, and "Home Connection flow to Lateral" duration is 24 homes. The previous inputs listed above calculate the "System Connection Flow" and the value is 14,645,190.52 gallons found in the tinted light blue cell.

The same procedure is followed for the adjacent column labeled "Lateral." The user selected "Pipe Size" at 14 inches, followed by the "Run" of 1,200 feet, and the "Quantity units to connectors" at 50. Proceeding down to the next tinted light blue cell, the calculated value is 606,947.69 gallons, which represents the maximum flow that the piping can receive. Looking at this stair step matrix below the piping and/or trunks, we find in Figure 6-5 "System Connection Flow" the value is 14,645,190.52, under "Step 1" under the "Lateral," the maximum value is 606,945.69 gallons.

Characteristic												
Depth in Feet:	3	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Distance in Feet:	100	100	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Pipe Diameters in inches											
	6	8	10	12	14	16	24	36	42	48	56	62
Slope in ft/ft	0.03	0.03	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Cross Section area in sf	0.1964	0.3491	0.5454	0.7854	1.0690	1.3963	3.1416	7.0686	9.6212	12.5664	17.1043	20.9658
roughness coef	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
hydraulic radius ft	0.125	0.167	0.208	0.250	0.292	0.333	0.500	0.750	0.875	1.000	1.167	1.292
velocity full ft/sec	4.29	5.19	1.35	1.52	1.69	1.84	2.42	3.17	3.51	3.84	4.25	4.55
flow full in cfs	0.84	1.81	0.74	1.20	1.80	2.57	7.59	22.39	33.77	48.22	72.73	95.42
flow full in gpm	377.76	813.62	329.89	536.47	809.26	1155.46	3407.14	10046.74	15155.57	21630.99	32642.54	42822.81
flow full in MGD	0.54	1.17	0.48	0.77	1.17	1.66	4.91	14.47	21.82	31.16	47.01	61.66
Max Flow in gallons /15 Min	5,666.33	12,204.33	4,948.32	8,047.00	12,138.95	17,331.88	51,107.09	150,701.15	227,333.61	324,584.79	489,638.16	642,342.15

Rain Model Collector System Configuration and Flow Analyses												
Characteristic	Step 1	Lateral	Trunk 1	Trunk 2	Trunk 3	Trunk 4	Trunk 5	Trunk 6	Trunk 7	Trunk 8	Trunk 9	Trunk 10
Pipe Size (select from Drop Window)	8	14	48	48	36	48	48	48	62	62	62	62
Run (distance in ft, length)to connector	100	1200	6500	6500								
Quantity units to connector	1	50	1	2								
QA Variable Page	1200											
Home to Lateral	1											
Home Connection flow to Lateral	24											
System Connection flow	14,645,190.52											
Step 1 to Lateral		606,947.69										
Lateral connection flow to Trunk 1			324,584.79									
Trunk 1 connection flow to Trunk 2				649,169.58								
Trunk 2 connection flow to Trunk 3												
Trunk 3 connection flow to Trunk 4												
Trunk 4 connection flow to Trunk 5												
Trunk 5 connection flow to Trunk 6												
Trunk 6 connection flow to Trunk 7												
Trunk 7 connection flow to Trunk 8										0.00		
Trunk 8 connection flow to Trunk 9											0.00	
Trunk 9 connection flow to Trunk 10												0.00

Figure 6-5: Piping Routing Input Page Screen

The trunk selection choice under labeled "Trunk 1" has the input value as one (1) trunk of 48 inch-diameter with a trunk line maximum of 347.584.79 gallons; whereas, the selection "Trunk 2" has a value of 649,169.58 gallons for two (2) trunks of 48 inch-diameter. The preferred choice is “Trunk 2” because the maximum value is greater than the lateral capacity. The stair step matrix in this example has identified the constraints of the piping configuration, which is the "Lateral" in this case, the lowest maximum flow compared to "Trunk 2" flows. The ability of the user to change the various inputs that comprise the stair step matrix allows a multitude of combinations for the outcome of this sector and the ability to combine multiple sectors.

Model Generated Results as Tables and Graphs

After the user inputs have been assigned to the respective cells within the model, the model then begins to process the input variables and to perform various calculations. The model takes the routing portion in piping constraints in a subroutine and then incorporates the information into the main model. Because of the size of the files and data, the model may not have the capacity to run on a personal computer and may require a server to obtain the results.

This rain model was developed by Robert Carnahan, and Jen Perone, with the guidance of Dr Mark Ross.

The data models and calculations are site specific. The models uses are for educational and research purposes only.

Model Catchment Variables	
The number of Roofs	1200
Roof size(sq ft)	3000
2.5	(p/home)
(gallons used/person/day)	143
Maximum Reservoir Tank	10,000,000
Derived Participant Demand/Day	429,000

Rain Model Effective Rain Variables	
interevent (hrs)	intercept (in)
6:00	0.05

Community or Participant Demand Per Day	Pump gal per min
429,000	2,000.0

Demand per 15 Minutes
4,468.75

Model Analyses from 20 Years of Data	
Supply	Percentage
Ground Water	0.430671
Rain	0.568525
Partial	0.000804
Reservoir	0

Maximum Plant (Gal)	Max Rain Event
4,000,000	360

Figure 6-6: The Variable Input Sheet Output Table for the Model

Variable Outcome Output

The model outcomes of the variables are shown above in Figure 6-6 under the heading "Model Analyses from 19 years of Data" in table format listing the ”Supply” and the “Percentage” of utilization of the capture roof runoff. Under the heading “Supply” there is groundwater, rain, partial, and reservoir, with the adjacent column indicating the percentage utilization based on the input demand. The partial indication is a combination of rain and groundwater. This table was placed in the variable input for the ease of the user to see the effect of the changes on the input without referring to another section in the model output.

Row Labels	Count of Reservoir	Percent
0-500000	674856	0.9166
500000-1000000	21105	0.0287
1000000-1500000	17909	0.0243
1500000-2000000	22407	0.0304
Grand Total	**736277**	**100%**

Supply	Percentage	QA
Ground Water	0.4307	736277
Rain	0.5685	
Partial	0.0008	
Reservoir	0.0000	
	100%	**736277**

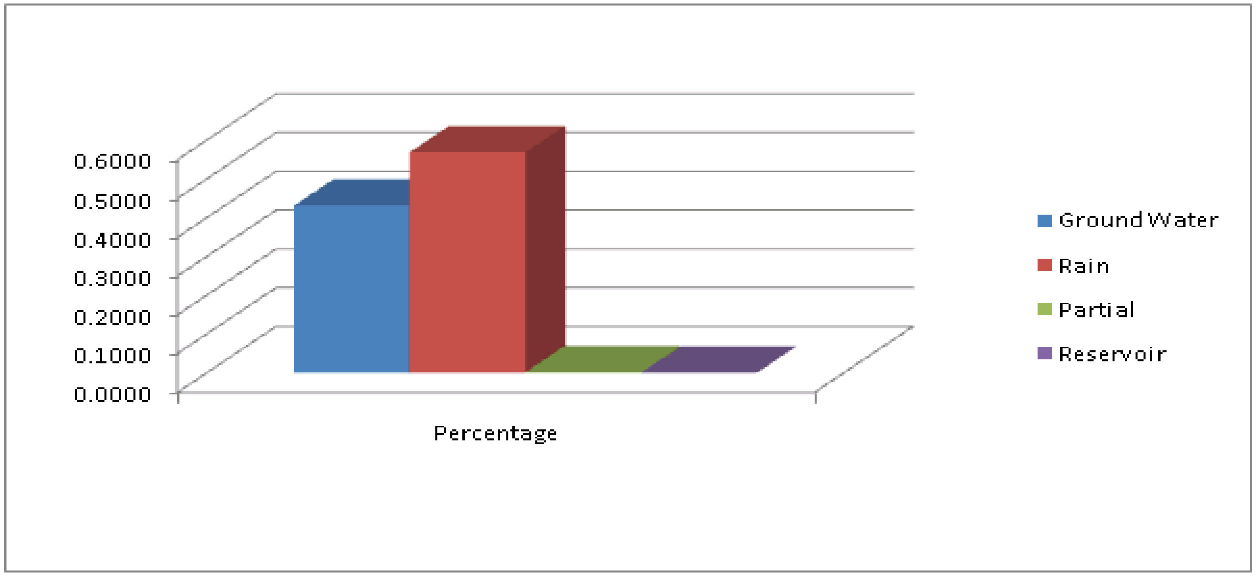

Figure 6-7: The Model Graphical Output of the Utilization

Output of the Utilization Results as Tables and Graphs

The graphical output of the "Model Analyses from 19 years of Data" found on the variable input page is shown in Figure 6-5, with supply table in the right upper corner above the graph. In the upper left corner is the table for the sector frequency distribution of the rain in percentage, based upon the row label volumetric parameters. For example, 91.66 percent of the sector rain is between zero (0) and 500,000 gallons.

Output of Frequencies of Rain

The model output frequency of rain provides the user a frequency table for the piping configuration limitations posed by the configuration to capture the rain. The rain not captured by the piping configuration is considered excess. Table 6-1 shows the frequencies for the sector piping configuration and counts the excess events under the heading "Count of Excess." This table is useful in the design of the configuration because the user utilizes the information from the frequency and the volume count. This tool allows the configuration for the best management practices and the highest probability of capture for the least amount of dollars spent on the Augmentation system.

Table 6-1: Model Output Frequency of the Piping and Rain Events.

Row Labels	Count of Excess
0.00	735296
118,880.78	109
446,130.78	287
773,380.78	66
1,100,630.78	153
1,427,880.78	35
1,755,130.78	91
2,082,380.78	30
2,409,630.78	71
2,736,880.78	12
3,064,130.78	36
3,391,380.78	7
3,718,630.78	32
4,045,880.78	3
4,373,130.78	15
4,700,380.78	5
5,027,630.78	8
5,682,130.78	6
6,336,630.78	6
6,991,130.78	4
7,645,630.78	2
7,972,880.78	1
9,281,880.78	1
10,590,880.78	1
Grand Total	**736277**

Table 6-2 provides the user a summary table of roof runoff utilization over the 19 years of rain records. The table provides the total rain amount in gallons for that sector; maximum, mean, standard deviation; and the percent that the rain collector system could capture.

Table 6-2: Summary of the Sector Piping Constraints.

Sector Collector System Contraints Results (Sub Routine)			
Over 19 yrs	Rain	Rain Capture	Excess
Total (gal)	2,262,625,200.00	1,871,506,984.87	391,118,215.13
Max	4,151,400.00	606,947.69	3,544,452.31
Mean	3,073.06	2,541.85	531.21
St Dev.	45,618.25	30,593.85	22,425.58
Percent	100.00	82.71	17.29

Table 6-3 is a frequency table of annual rainfall for the given year based upon the 19 years of rain records. This table is useful for the user to illustrate normal annual variability in rainfall over the period.

Table 6-3: Data Rain Records Annual Rainfall.

Year	Rain in Inches
1979	69.8
1980	46.1
1981	33.4
1982	62.5
1983	64.3
1984	35.6
1985	35.7
1986	51.7
1987	56.7
1988	61.6
1989	51.8
1990	38.6
1991	57
1992	48.9
1993	50.6
1994	63.3
1995	58.8
1996	55.5
1997	64.7
1998	63.4

The estimated cost for this project is $4,243,618.20. The model includes an interactive amortization schedule, which shows that the annual cost of $18.00 per connection over the next 30 years. This translates to a cost per homeowner of $1.50 dollars per month of equal payments at an interest rate of three (3) percent. There is the possibility of a variety of funding opportunities for the implementation of the Augmentation system, such as direct funding from the federal government water improvement program, municipal bonds for the funding of capital. The payback period for the investment based upon the current wholesale water rate of $3.10 per 1,000 gallons. The savings per year from the augmentation is $276,345.91, thus the system with the four (4) million gallon storage configuration would require a payback period of 15.36 years. This does not take into account increased wholesale water rate increases. This scenario does not provide for increased population or connections to the city service area not in the City of Temple Terrace. The model output estimates and the amortization are in Appendix II.

The Model as a Feasibility Tool for Alternative Sources

This model is a tool for analyzing and evaluating flow, storage and economic considerations of roof runoff and determining the most economical strategy for augmenting a potable water supply using roof runoff. This source strategy may be more viable, considering a recent ruling by the South Florida Water Management District (SFWMD). Water providers can no longer use traditional resources such as the Everglades for their continued water supply per F.A.C. Section 3.2.1. (South Florida Water Management District, 2007a, 2007b). This ruling by the SFWMD has water providers searching for alternative supplies, and this model could be used as a tool for a selection of augmentations to water supplies, along with other options. As this strategy revealed, the key to the storage issue is using the roof runoff as the events occur and processing the runoff as the demand increases.

Current water use, consumption needs and public attitudes, appear to be changing in some parts of the United States due to multi-year droughts combined with increased populations. Communities are beginning to investigate use of alternative supplies such as roof runoff and reuse in the United States; such is the case in parts of Texas. The review of the literature did find many specific papers discussing the effects of trace metal concentration in roof runoff, and many researchers considered roof runoff only as a nonsource pollution–not a potential resource. In the literature worldwide, communities are looking for the sustainability of their communities and their resources. In order to collect and use runoff from roofs, the chemical composition of the runoff from a variety of roofing materials must be analyzed. DRRH is no longer just for developing countries. Rather, many industrialized countries are implementing programs that include DRRH in urban centers. While this area of DRRH is emerging in the United States, there are numerous international studies for developing countries and some industrial countries. Rain precipitation is a random even - temporal and spatial in nature - that may present potential risks interacting with different roofing material in the Southeastern United States. At the time of this investigation and research, the review did not find any similar research in the state of Florida. However, the review found some generalized roof runoff research in the United States and around the world.

This situation of water scarcity is not unique to the investigation region of Tampa Bay Florida. This is a global issue, and with the increasing population, we need to search for alternatives and efficiencies. Rainwater systems such as a community-based system, as presented in the model, offer the capability for storage and using the rainwater immediately, increasing the efficiency and reducing possible evaporation. Florida's latitude creates a unique environment that allows the applicability of the model in most regions. Many of the world's communities are creating decentralized integrative systems versus large pipe centralized systems. Australia developed a strategy to use an integrated urban water management system and takes a comprehensive view of water supply, which includes DRRH, drainage, and sanitation (Coombes, et al., 2002; Mitchell, 2006). Globally and following the Australians' concept, there are some other locations such as the US Virgin Islands and Taiwan, who have all incorporated this strategy of DRRH into their construction code. More states and countries such as Germany are also considering integration and code requirements for new construction (Cheng, et al., 2006; Herrmann & Schmida, 2000).

The System Advantages Contrasted to Individual Units

The advantage of an Augmentation Model is the economy of scale and the unique strategy of transferring collected water directly to the water treatment plant. The transfer strategy of collecting rain while using minimal size storage tanks to transfer water to the water treatment plant while the community is using the same water reduces the overall costs. The reductions in costs are associated with a reduction in the land cost and storage tank size. This same economy of scale allows monitoring of the Augmentation Model to piggyback on pre-existing monitoring programs already in place at the water plant. This immediate transfer accomplishes several objectives, such as removing citizens from water quality monitoring and disinfection of potable water. A strategic objective is removing the issues with individual cisterns and allowing professionals to monitor the treatment process at the water plant. Using the services of water treatment professionals allows a mechanism to ensure the safety of the potable water and compliance to any future regulations.

Another advantage of the Augmentation Model is sectors can be operated individually or combined to meet the needs of the city. This approach also allows for a phased development of sectors coming online with the water treatment plant.

The contrast to the Augmentation system is the individual citizen cistern or system, which must manage water treatment and disinfection. The costs and economics are not to scale to provide saving of the chemicals treatment processes, or the construction of the cistern. This is further complicated by the responsibility of the individual to manage the water treatment. Repairs, maintenance and operation costs would have to be sustained by the individual. There would be additional costs for the installation of backflow valve devices to prevent contamination to the potable water from the city. In the test case, the individual system could only support the home for only a few months of the year. Then there are costs in time to the individual citizen, who has to spend time managing the water treatment process, instead of working in gainful employment or relaxing.

Regulatory and Policy Issues

In the test case State of Florida, there were no statutes or regulatory policies preventing the implementation of the Augmentation system. Other states such as the Texas (TNRCC, 2004) have embraced the DRRH concept. Johnson in 2009, states Arizona is actively promoting rainfall catchment to be installed for all new construction. However, some states in the western part of the United States restrict or forbid rainwater harvesting because they have different water laws. According to the Utah Division of Water Rights, (2009), it is illegal to harvest rainwater unless the property owner has the water rights. Therefore, the implementation of the Augmentation Model might have some regulatory or policy issues depending on the location. There are social and policy behaviors that have not been addressed because they were outside the scope of this research.

The Augmentation System Compared to Aquifer Storage and Recovery

This study has provided a model, which is feasible for smaller communities to implement. The Augmentation Model is an inexpensive alternative compared to another strategy currently being used such as Aquifer Storage and Recovery (ASR). The alternative is a full-scale aquifer storage and recovery (ASR), which requires that potable water be injected typically into a brackish water aquifer where it forms a bubble within the existing aquifer. This allows for storage and allows the potable water to be withdrawn at will. ASR wells are classified as injection wells and are regulated by the Underground Injection Control (UIC) program under the federal SDWA, including chapters 528 F.A.C. Injected water must meet drinking water standards prior to pumping the water into the storage zone. This regulation is justified for protection from contamination of the Floridian aquifer, our major potable water resource.

Some of the considerations for ASR are site-specific due to the topography and the variable geochemical composition of the aquifer. The topography will affect the well depth required for permitting. The geochemical composition of the aquifer presents a challenge. Several studies have found that there has been leaching of arsenic and other metals that co-precipitate in the water-rock interface ,which results in causing the mobilization of metals into the extracted waters (Arthur, et al., 2002). This could require additional treatment of water to ensure it meets the MCLs of the water drinking standards. This possible additional treatment adds cost to recovering waters from the ASR. There are also site-specific efficiencies for reclaiming the potable water that were injected into the aquifer, with recovery that can be 65 to 75 percent of the original volume allotted. For example, the elevation of the site above the aquifer for storage and the TDS of the injected aquifer zone create additional costs to the project.

Current cost estimations for ASR are $2,000,000 per-million-gallons-per-day; this includes testing and permitting (Southwest Florida Water Management District, 2006). This same estimation can be used to estimate the cost of adding additional wells to the current well field. The capturing of roof runoff strategy maximizes the throughput of resources by eliminating expensive ASR; currently the largest ASRs found in the state are 2 MGD and on the average permitting and testing requires a five-year lead-time or more. Then there is the problematic question as to where to find the additional water source. The Hillsborough River cannot supply the surface water that is currently needed to meet the permitted demand of municipalities and regional water supplier. It is not feasible or reasonable to store 458,410,950 gallons at a cost of $ 2M per–million-gallons for a total cost of $229,205,475. The permitting and regulatory issues for this size ASR have not been addressed. The lead times for large scale ASR are unknown at this point.

In contrast to the ASR, this roof runoff strategy and model is based upon actual collected data and historical rainfall data records from the years 1979 through 1998. The user inputs the catchment area in square-feet, number of homes, and 15-minute demand into the model. After the specific location, parameters are entered into the model. The result is calculated as a percentage of demand for this specific site, and this determines the volume available for augmentation. The model calculates at fifteen (15) minute intervals the amount of water that can be used for potable water from roof runoff. This model indicated in the test case that over the 19-year period, 56.93 percent of demand was met.

CHAPTER VII: CONCLUSIONS

This research has provided information and data to the literature on roof runoff water quality on five different roofing materials in a non-arid area. In conducting this research, the following conclusions were reached.

None of the water quality samples collected from the five roofing materials exceeds the primary or secondary drinking water standards. There are preferred roofing materials such as the clay tile, which was found to have absorptive and desorptive properties. The other preferred roofing material is the painted galvanized roofing material, because of decreased concentrations of zinc when compared to the galvanized material. The water quality and model strategy of using the water plant as part of the system avoids most problems associated with individual water supplies and/ or cisterns. Water quality of the roof runoff was of high quality when compared to stormwater water recovery.

The model also illustrated the cost benefits of capturing roof runoff for augmenting the potable water supply. The versatility of the model allows the analyses of individual sector systems, and community systems or a combination the unique ability to examine this alternative source strategy parameters of pipe routing system, cost analysis and feasibility of a system's cost-effectiveness. The model provides a management tool for examining alternative best management practices.

CHAPTER VIII: RECOMMENDATIONS

The study revealed that this is a viable and feasible method of augmenting an existing water supply with the following recommendations.

Continue monitoring the apparatus for changes in water quality and meteorological conditions.

Continue to work with the City of Temple Terrace and the water management district to incorporate the strategy and test a prototype or pilot study sized system potentially in a new development.

Propose a pilot plant to test the efficiency of the model.

Explore further refinements to the model and collect additional data to refine the model.

Provide additional options and improvements for the users based upon their needs.

Future research is needed on the clay tile and other roofing materials to define their water quality aspects.

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APPENDICES

Appendix I: Standards and Analysis

This section contains the various outputs of the analysis.

Table A-1: pH Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	29	29	29	29	29
mean	0.0237	0.7054	0.8857	-0.4098	-0.3701
sample variance	0.4644	0.8876	1.0315	0.6366	0.6404
sample standard deviation	0.6814	0.9421	1.0156	0.7979	0.8003
minimum	-1.61	-1.08	-1.11	-2.6	-1.78
maximum	1.3	2.37	2.64	0.81	1.13
range	2.91	3.45	3.75	3.41	2.91
normal curve GOF					
p-value	.7023	.0100	.0376	.0258	.8013
chi-square(df=3)	1.41	11.34	8.45	9.28	1.00
E	4.83	4.83	4.83	4.83	4.83
O(-0.97)	4	4	3	6	6
O(-0.43)	5	5	7	3	4
O(+0.00)	5	10	8	1	4
O(+0.43)	6	2	3	7	4
O(+0.97)	3	1	1	9	5
O(inf.)	6	7	7	3	6

Appendix I (Continued)

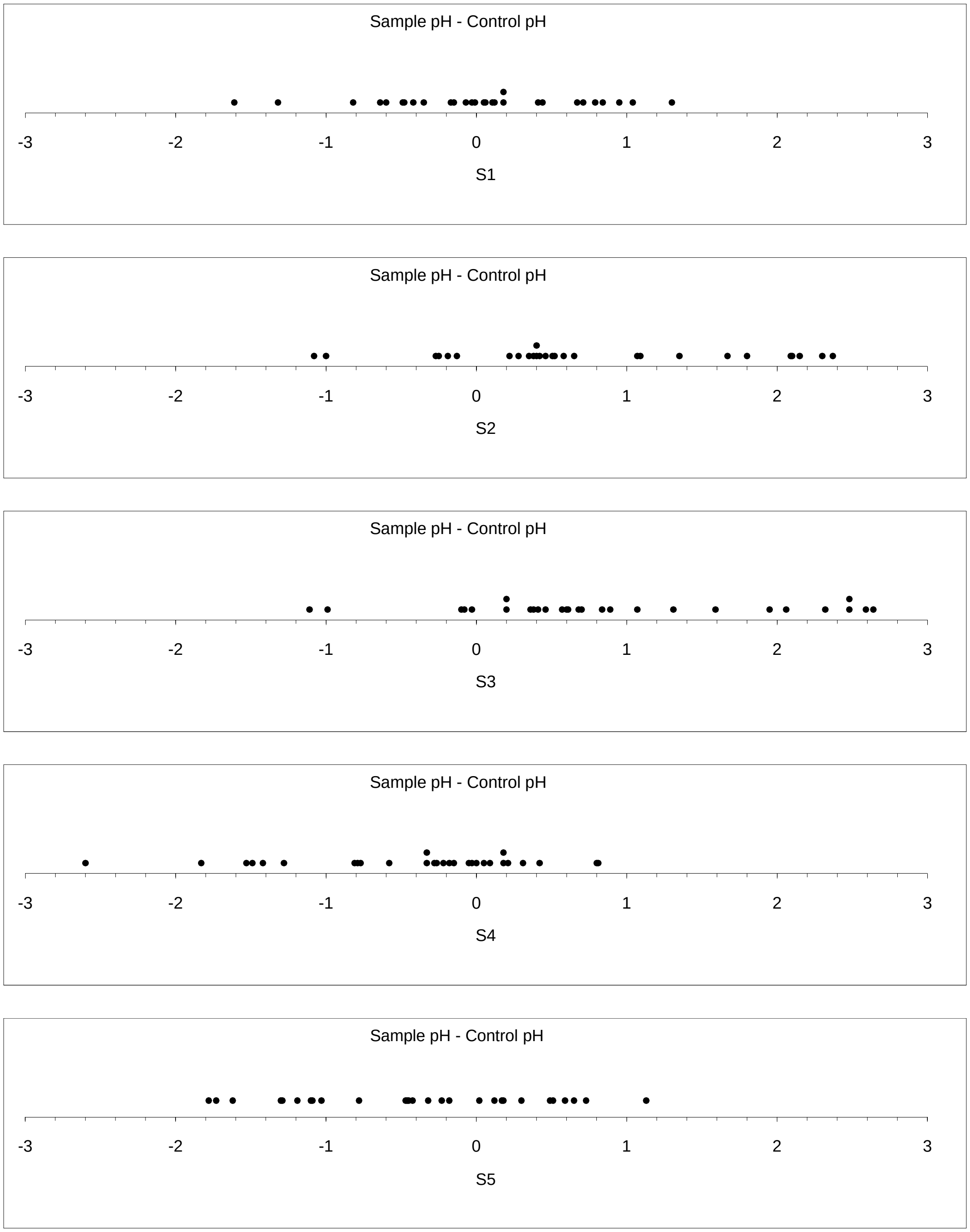


Figure A-1: pH Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-2: pH Paired T-Test Analysis S1 and Control.

0.000000	hypothesized value
6.380690	mean S1
6.357034	mean ConpH
0.023655	mean difference (S1 - ConpH)
0.681438	std. dev.
0.126540	std. error
29	n
28	df
0.19	t
.8531	p-value (two-tailed)
-0.235550	confidence interval 95.% lower
0.282860	confidence interval 95.% upper
0.259205	half-width

Table A-3: pH Paired T-Test Analysis S2 and Control.

0.000000	hypothesized value
7.062414	mean S2
6.357034	mean ConpH
0.705379	mean difference (S2 - ConpH)
0.942127	std. dev.
0.174949	std. error
29	n
28	df
4.03	t
.0004	p-value (two-tailed)
0.347013	confidence interval 95.% lower
1.063745	confidence interval 95.% upper
0.358366	half-width

Appendix I (Continued)

Table A-4: pH Paired T-Test Analysis S3 and Control.

0.000000	hypothesized value
7.242759	mean S3
6.357034	mean ConpH
0.885724	mean difference (S3 - ConpH)
1.015612	std. dev.
0.188594	std. error
29	n
28	df
4.70	t
.0001	p-value (two-tailed)
0.499406	confidence interval 95.% lower
1.272042	confidence interval 95.% upper
0.386318	half-width

Table A-5: pH Paired T-Test Analysis S4 and Control.

0.000000	hypothesized value
5.947241	mean S4
6.357034	mean ConpH
-0.409793	mean difference (S4 - ConpH)
0.797875	std. dev.
0.148162	std. error
29	n
28	df
-2.77	t
.0099	p-value (two-tailed)
-0.713288	confidence interval 95.% lower
-0.106298	confidence interval 95.% upper
0.303495	half-width

Appendix I (Continued)

Table A-6: pH Paired T-Test Analysis S5 and Control.

0.000000	hypothesized value
5.986897	mean S5
6.357034	mean ConpH
-0.370138	mean difference (S5 - ConpH)
0.800264	std. dev.
0.148605	std. error
29	n
28	df
-2.49	t
.0189	p-value (two-tailed)
-0.674542	confidence interval 95.% lower
-0.065734	confidence interval 95.% upper
0.304404	half-width

Table A-7: pH Wilcoxon Analysis S1-Control.

variables:	S1 - ConpH
234	sum of positive ranks
201	sum of negative ranks
29	n
217.50	expected value
46.21	standard deviation
0.36	z, corrected for ties
.7211	p-value (two-tailed)

Appendix I (Continued)

Table A-8: pH Wilcoxon Analysis S2-Control.

variables:	S2 - ConpH
383	sum of positive ranks
52	sum of negative ranks
29	n
217.50	expected value
46.21	standard deviation
3.58	z, corrected for ties
.0003	p-value (two-tailed)

Table A-9: pH Wilcoxon Analysis S3-Control.

variables:	S3 - ConpH
391	sum of positive ranks
44	sum of negative ranks
29	n
217.50	expected value
46.18	standard deviation
3.76	z, corrected for ties
.0002	p-value (two-tailed)

Table A-10: pH Wilcoxon Analysis S4-Control.

variables:	S4 - ConpH
99	sum of positive ranks
307	sum of negative ranks
28	n
203.00	expected value
43.78	standard deviation
-2.38	z, corrected for ties
.0175	p-value (two-tailed)

Appendix I (Continued)

Table A-11: pH Wilcoxon Analysis S5-Control.

variables:	S5 - ConpH
121.5	sum of positive ranks
313.5	sum of negative ranks
29	n
217.50	expected value
46.21	standard deviation
-2.08	z, corrected for ties
.0378	p-value (two-tailed)

Table A-12: TDS Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	29	29	29	29	29
mean	-10.637931	0.155172	10.413793	-8.293103	-7.534483
sample variance	140.980296	67.805419	82.965517	106.098522	75.891626
sample standard deviation	11.873512	8.234405	9.108541	10.300414	8.711580
minimum	-44	-20	-14	-42	-33
maximum	0.5	15	33	2	4
range	44.5	35	47	44	37
normal curve GOF					
p-value	2.82E-07	.3230	.3230	.0001	.0012
chi-square(df=3)	33.28	3.48	3.48	21.28	15.90
E	4.83	4.83	4.83	4.83	4.83
O(-0.97)	4	5	4	4	3
O(-0.43)	2	3	4	1	1
O(+0.00)	3	4	8	2	5
O(+0.43)	4	7	6	10	10
O(+0.97)	16	7	3	11	9
O(inf.)	0	3	4	1	1

Appendix I (Continued)

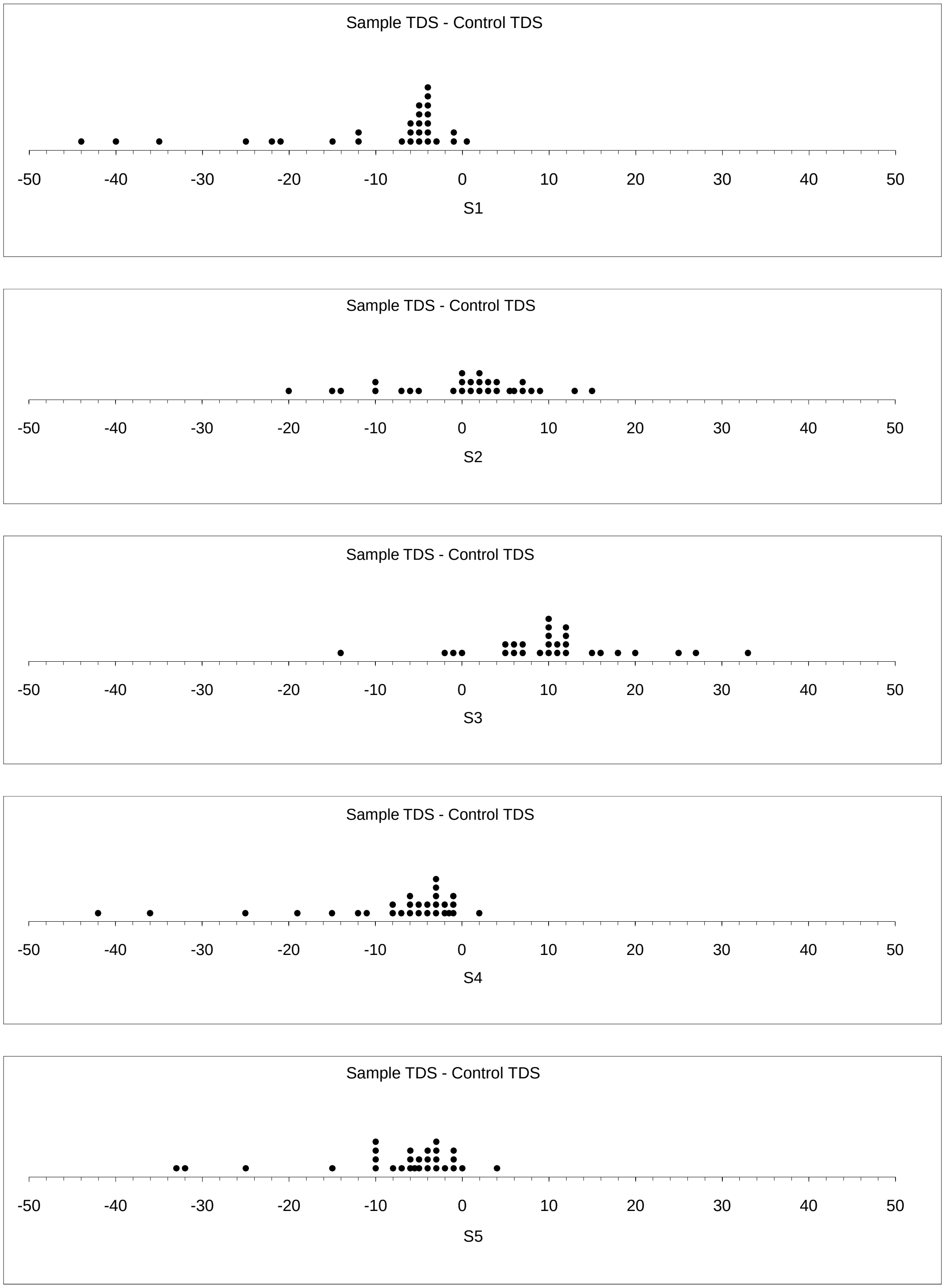


Figure A-2: TDS Frequency Plot Analysis of Material

Appendix I (Continued)

Table A-13: TDS Paired T-Test Analysis S1 and Control.

0.0000	hypothesized value
13.4655	mean S1
24.1034	mean ConTDS
-10.6379	mean difference (S1 - ConTDS)
11.8735	std. dev.
2.2049	std. error
29	n
28	df
-4.82	t
4.48E-05	p-value (two-tailed)
-15.1544	confidence interval 95.% lower
-6.1215	confidence interval 95.% upper
4.5164	half-width

Table A-14: TDS Paired T-Test Analysis S2 and Control.

0.0000	hypothesized value
24.2586	mean S2
24.1034	mean ConTDS
0.1552	mean difference (S2 - ConTDS)
8.2344	std. dev.
1.5291	std. error
29	n
28	df
0.10	t
.9199	p-value (two-tailed)
-2.9770	confidence interval 95.% lower
3.2874	confidence interval 95.% upper
3.1322	half-width

Appendix I (Continued)

Table A-15: TDS Paired T-Test Analysis S3 and Control.

0.000	hypothesized value
34.517	mean S3
24.103	mean ConTDS
10.414	mean difference (S3 - ConTDS)
9.109	std. dev.
1.691	std. error
29	n
28	df
6.16	t
1.20E-06	p-value (two-tailed)
6.949	confidence interval 95.% lower
13.878	confidence interval 95.% upper
3.465	half-width

Table A-16: TDS Paired T-Test Analysis S4 and Control.

0.0000	hypothesized value
15.8103	mean S4
24.1034	mean ConTDS
-8.2931	mean difference (S4 - ConTDS)
10.3004	std. dev.
1.9127	std. error
29	n
28	df
-4.34	t
.0002	p-value (two-tailed)
-12.2112	confidence interval 95.% lower
-4.3750	confidence interval 95.% upper
3.9181	half-width

Appendix I (Continued)

Table A-17: TDS Paired T-Test Analysis S5 and Control.

0.0000	hypothesized value
16.5690	mean S5
24.1034	mean ConTDS
-7.5345	mean difference (S5 - ConTDS)
8.7116	std. dev.
1.6177	std. error
29	n
28	df
-4.66	t
.0001	p-value (two-tailed)
-10.8482	confidence interval 95.% lower
-4.2208	confidence interval 95.% upper
3.3137	half-width

Table A-18: TDS Wilcoxon Analysis S1-Control.

variables:	S1 - ConTDS
1	sum of positive ranks
434	sum of negative ranks
29	n
217.50	expected value
43.51	standard deviation
-4.98	z, corrected for ties
6.48E-07	p-value (two-tailed)

Appendix I (Continued)

Table A-19: TDS Wilcoxon Analysis S2-Control.

variables:	S2 - ConTDS
194	sum of positive ranks
157	sum of negative ranks
26	n
175.50	expected value
38.72	standard deviation
0.48	z, corrected for ties
.6328	p-value (two-tailed)

Table A-20: TDS Wilcoxon Analysis S3-Control.

variables:	S3 - ConTDS
382	sum of positive ranks
24	sum of negative ranks
28	n
203.00	expected value
42.74	standard deviation
4.19	z, corrected for ties
2.81E-05	p-value (two-tailed)

Table A-21: TDS Wilcoxon Analysis S4-Control.

variables:	S4 - ConTDS
6	sum of positive ranks
429	sum of negative ranks
29	n
217.50	expected value
45.10	standard deviation
-4.69	z, corrected for ties
2.73E-06	p-value (two-tailed)

Appendix I (Continued)

Table A-22: TDS Wilcoxon Analysis S5-Control.

variables:	S5 - ConTDS
10.5	sum of positive ranks
395.5	sum of negative ranks
28	n
203.00	expected value
42.56	standard deviation
-4.52	z, corrected for ties
6.10E-06	p-value (two-tailed)

Table A-23: Zinc Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	30	30	30	30	30
mean	-0.099563	-0.113567	-0.054190	-0.035647	1.122243
sample variance	0.021732	0.027803	0.022279	0.021365	0.944698
sample standard deviation	0.147419	0.166741	0.149261	0.146169	0.971956
minimum	-0.5081	-0.5703	-0.4312	-0.4122	-0.0016
maximum	0.0149	0.0175	0.3535	0.1975	3.3669
range	0.523	0.5878	0.7847	0.6097	3.3685
normal curve GOF					
p-value	6.90E-10	2.83E-08	9.10E-08	.0035	9.37E-07
chi-square(df=3)	45.60	38.00	35.60	13.60	30.80
E	5.00	5.00	5.00	5.00	5.00
O(-0.97)	6	4	3	4	1
O(-0.43)	1	3	3	3	15
O(+0.00)	1	1	2	2	7
O(+0.43)	4	5	17	12	0
O(+0.97)	18	17	4	6	2
O(inf.)	0	0	1	3	5

Appendix I (Continued)

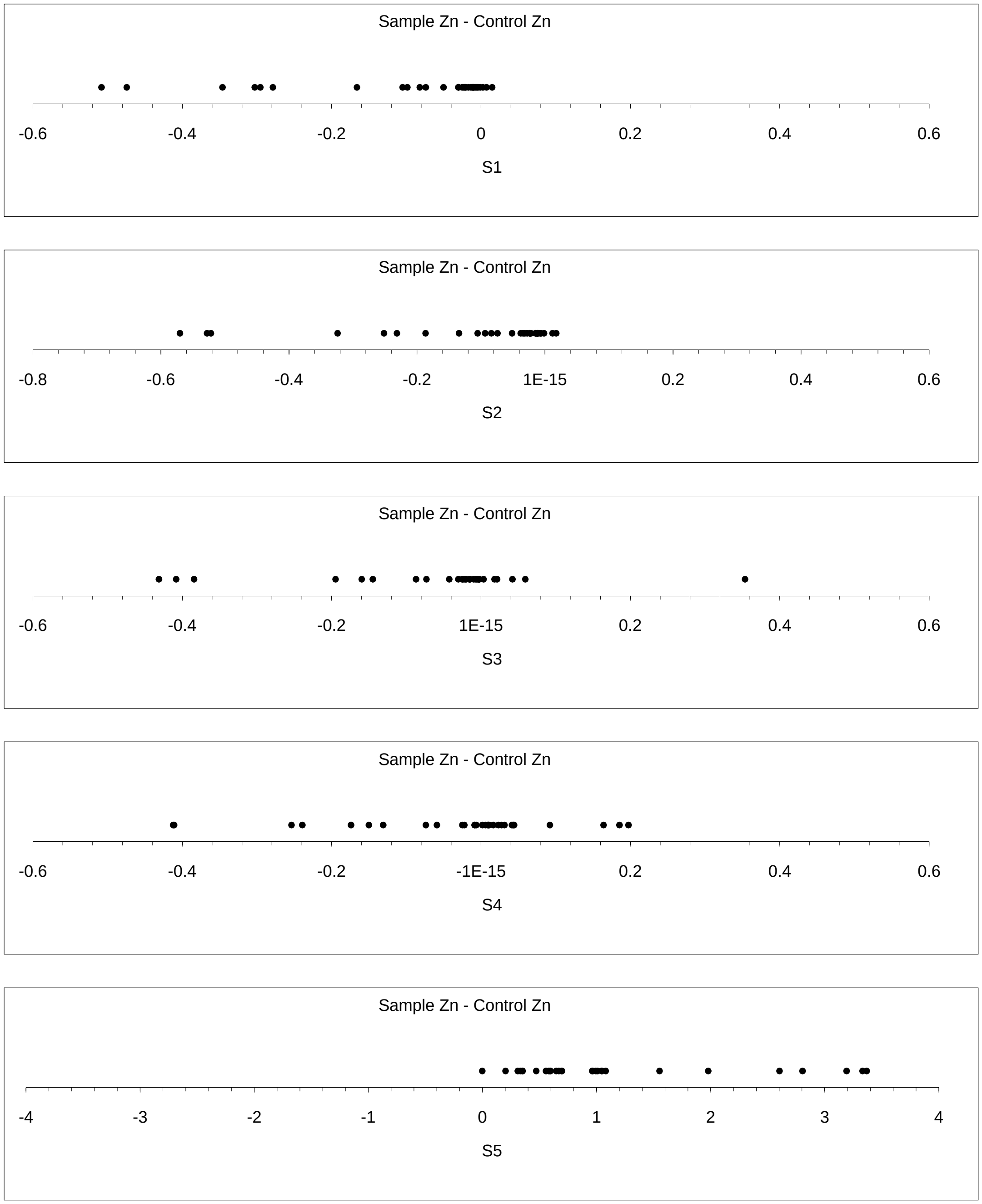


Figure A-3: Zinc Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-24: Zinc Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0743600	mean S1
0.1739233	mean ConZn
-0.0995633	mean difference (S1 - ConZn)
0.1474187	std. dev.
0.0269149	std. error
30	n
29	df
-3.70	t
.0009	p-value (two-tailed)
-0.1546104	confidence interval 95.% lower
-0.0445163	confidence interval 95.% upper
0.0550471	half-width

Table A-25: Zinc Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0603567	mean S2
0.1739233	mean ConZn
-0.1135667	mean difference (S2 - ConZn)
0.1667415	std. dev.
0.0304427	std. error
30	n
29	df
-3.73	t
.0008	p-value (two-tailed)
-0.1758289	confidence interval 95.% lower
-0.0513044	confidence interval 95.% upper
0.0622623	half-width

Appendix I (Continued)

Table A-26: Zinc Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.1197333	mean S3
0.1739233	mean ConZn
-0.0541900	mean difference (S3 - ConZn)
0.1492615	std. dev.
0.0272513	std. error
30	n
29	df
-1.99	t
.0563	p-value (two-tailed)
-0.1099252	confidence interval 95.% lower
0.0015452	confidence interval 95.% upper
0.0557352	half-width

Table A-27: Zinc Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.1382767	mean S4
0.1739233	mean ConZn
-0.0356467	mean difference (S4 - ConZn)
0.1461687	std. dev.
0.0266866	std. error
30	n
29	df
-1.34	t
.1920	p-value (two-tailed)
-0.0902270	confidence interval 95.% lower
0.0189336	confidence interval 95.% upper
0.0545803	half-width

Appendix I (Continued)

Table A-28: Zinc Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
1.2961667	mean S5
0.1739233	mean ConZn
1.1222433	mean difference (S5 - ConZn)
0.9719555	std. dev.
0.1774540	std. error
30	n
29	df
6.32	t
6.57E-07	p-value (two-tailed)
0.7593092	confidence interval 95.% lower
1.4851775	confidence interval 95.% upper
0.3629342	half-width

Table A-29: Zinc Wilcoxon Analysis S1-Control.

variables:	S1 - ConZn
18	sum of positive ranks
447	sum of negative ranks
30	n
232.50	expected value
48.62	standard deviation
-4.41	z
1.02E-05	p-value (two-tailed)

Table A-30: Zinc Wilcoxon Analysis S2-Control.

variables:	S2 - ConZn
16	sum of positive ranks
449	sum of negative ranks
30	n
232.50	expected value
48.62	standard deviation
-4.45	z
8.47E-06	p-value (two-tailed)

Appendix I (Continued)

Table A-31: Zinc Wilcoxon Analysis S3-Control.

variables:	S3 - ConZn
99	sum of positive ranks
366	sum of negative ranks
30	n
232.50	expected value
48.62	standard deviation
-2.75	z
.0060	p-value (two-tailed)

Table A-32: Zinc Wilcoxon Analysis S4-Control.

variables:	S4 - ConZn
213	sum of positive ranks
252	sum of negative ranks
30	n
232.50	expected value
48.62	standard deviation
-0.40	z
.6884	p-value (two-tailed)

Table A-33: Zinc Wilcoxon Analysis S5-Control.

variables:	S5 - ConZn
464	sum of positive ranks
1	sum of negative ranks
30	n
232.50	expected value
48.62	standard deviation
4.76	z
1.92E-06	p-value (two-tailed)

Appendix I (Continued)

Table A-34: Lead Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	30	30	30	30	30
mean	-0.000317	-0.000460	-0.000370	-0.000630	-0.000823
sample variance	0.000005	0.000003	0.000005	0.000004	0.000005
sample standard deviation	0.002306	0.001659	0.002262	0.002009	0.002290
minimum	-0.0054	-0.0043	-0.005	-0.0056	-0.007
maximum	0.004	0.0027	0.0058	0.0022	0.0028
range	0.0094	0.007	0.0108	0.0078	0.0098
normal curve GOF					
p-value	.1870	.0267	.3618	.4936	.2615
chi-square(df=3)	4.80	9.20	3.20	2.40	4.00
E	5.00	5.00	5.00	5.00	5.00
O(-0.97)	6	5	4	4	4
O(-0.43)	4	3	5	5	2
O(+0.00)	3	4	6	5	8
O(+0.43)	4	4	8	4	6
O(+0.97)	9	11	3	8	5
O(inf.)	4	3	4	4	5

Appendix I (Continued)

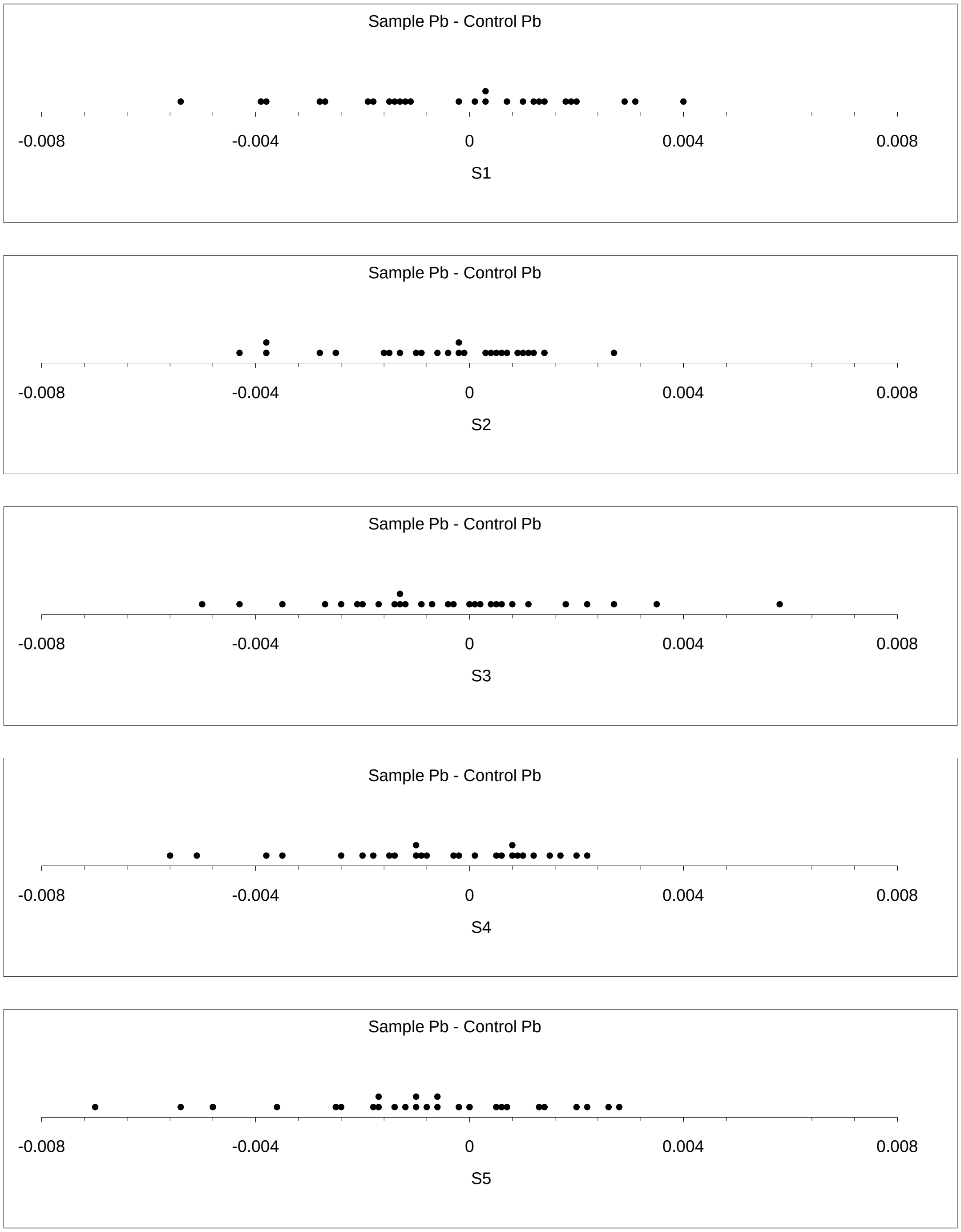


Figure A-4: Lead Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-35: Lead T-Test S1 Analysis and Control.

0.0000000	hypothesized value
0.0027833	mean S1
0.0031000	mean ConPb
-0.0003167	mean difference (S1 - ConPb)
0.0023059	std. dev.
0.0004210	std. error
30	n
29	df
-0.75	t
.4580	p-value (two-tailed)
-0.0011777	confidence interval 95.% lower
0.0005444	confidence interval 95.% upper
0.0008610	half-width

Table A-36: Lead Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0026400	mean S2
0.0031000	mean ConPb
-0.0004600	mean difference (S2 - ConPb)
0.0016587	std. dev.
0.0003028	std. error
30	n
29	df
-1.52	t
.1396	p-value (two-tailed)
-0.0010794	confidence interval 95.% lower
0.0001594	confidence interval 95.% upper
0.0006194	half-width

Appendix I (Continued)

Table A-37: Lead Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0027300	mean S3
0.0031000	mean ConPb
-0.0003700	mean difference (S3 - ConPb)
0.0022622	std. dev.
0.0004130	std. error
30	n
29	df
-0.90	t
.3777	p-value (two-tailed)
-0.0012147	confidence interval 95.% lower
0.0004747	confidence interval 95.% upper
0.0008447	half-width

Table A-38: Lead Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0024700	mean S4
0.0031000	mean ConPb
-0.0006300	mean difference (S4 - ConPb)
0.0020093	std. dev.
0.0003668	std. error
30	n
29	df
-1.72	t
.0966	p-value (two-tailed)
-0.0013803	confidence interval 95.% lower
0.0001203	confidence interval 95.% upper
0.0007503	half-width

Appendix I (Continued)

Table A-39: Lead Paired T-Test S5 Analysis and Control.

0.0000000	hypothesized value
0.0022767	mean S5
0.0031000	mean ConPb
-0.0008233	mean difference (S5 - ConPb)
0.0022901	std. dev.
0.0004181	std. error
30	n
29	df
-1.97	t
.0586	p-value (two-tailed)
-0.0016785	confidence interval 95.% lower
0.0000318	confidence interval 95.% upper
0.0008551	half-width

Table A-40: Lead Wilcoxon Analysis S1-Control.

variables:	S1 - ConPb
206	sum of positive ranks
259	sum of negative ranks
30	n
232.50	expected value
48.59	standard deviation
-0.55	z, corrected for ties
.5855	p-value (two-tailed)

Table A-41: Lead Wilcoxon Analysis S2-Control.

variables:	S2 - ConPb
185	sum of positive ranks
280	sum of negative ranks
30	n
232.50	expected value
48.56	standard deviation
-0.98	z, corrected for ties
.3280	p-value (two-tailed)

Appendix I (Continued)

Table A-42: Lead Wilcoxon Analysis S3-Control.

variables:	S3 - ConPb
165	sum of positive ranks
270	sum of negative ranks
29	n
217.50	expected value
46.21	standard deviation
-1.14	z, corrected for ties
.2560	p-value (two-tailed)

Table A-43: Lead Wilcoxon Analysis S4-Control.

variables:	S4 - ConPb
169	sum of positive ranks
296	sum of negative ranks
30	n
232.50	expected value
48.37	standard deviation
-1.31	z, corrected for ties
.1893	p-value (two-tailed)

Table A-44: Lead Wilcoxon Analysis S5-Control.

variables:	S5 - ConPb
139.5	sum of positive ranks
295.5	sum of negative ranks
29	n
217.50	expected value
46.02	standard deviation
-1.69	z, corrected for ties
.0901	p-value (two-tailed)

Appendix I (Continued)

Table A-45: Cadmium Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	31	31	31	31	31
mean	-0.000010	0.000042	0.000010	0.000003	0.000023
sample variance	0.000000	0.000000	0.000000	0.000000	0.000000
sample standard deviation	0.000137	0.000349	0.000108	0.000143	0.000171
minimum	-0.0003	-0.0003	-0.0001	-0.0003	-0.0002
maximum	0.0004	0.0018	0.0003	0.0003	0.0007
range	0.0007	0.0021	0.0004	0.0006	0.0009
normal curve GOF					
p-value	1.92E-05	8.36E-08	4.04E-05	.0019	.0019
chi-square(df=3)	24.55	35.77	23.00	14.87	14.87
E	5.17	5.17	5.17	5.17	5.17
O(-0.97)	3	1	11	5	2
O(-0.43)	8	3	0	4	9
O(+0.00)	0	17	10	12	10
O(+0.43)	14	6	0	0	0
O(+0.97)	3	3	7	6	6
O(inf.)	3	1	3	4	4

Appendix I (Continued)

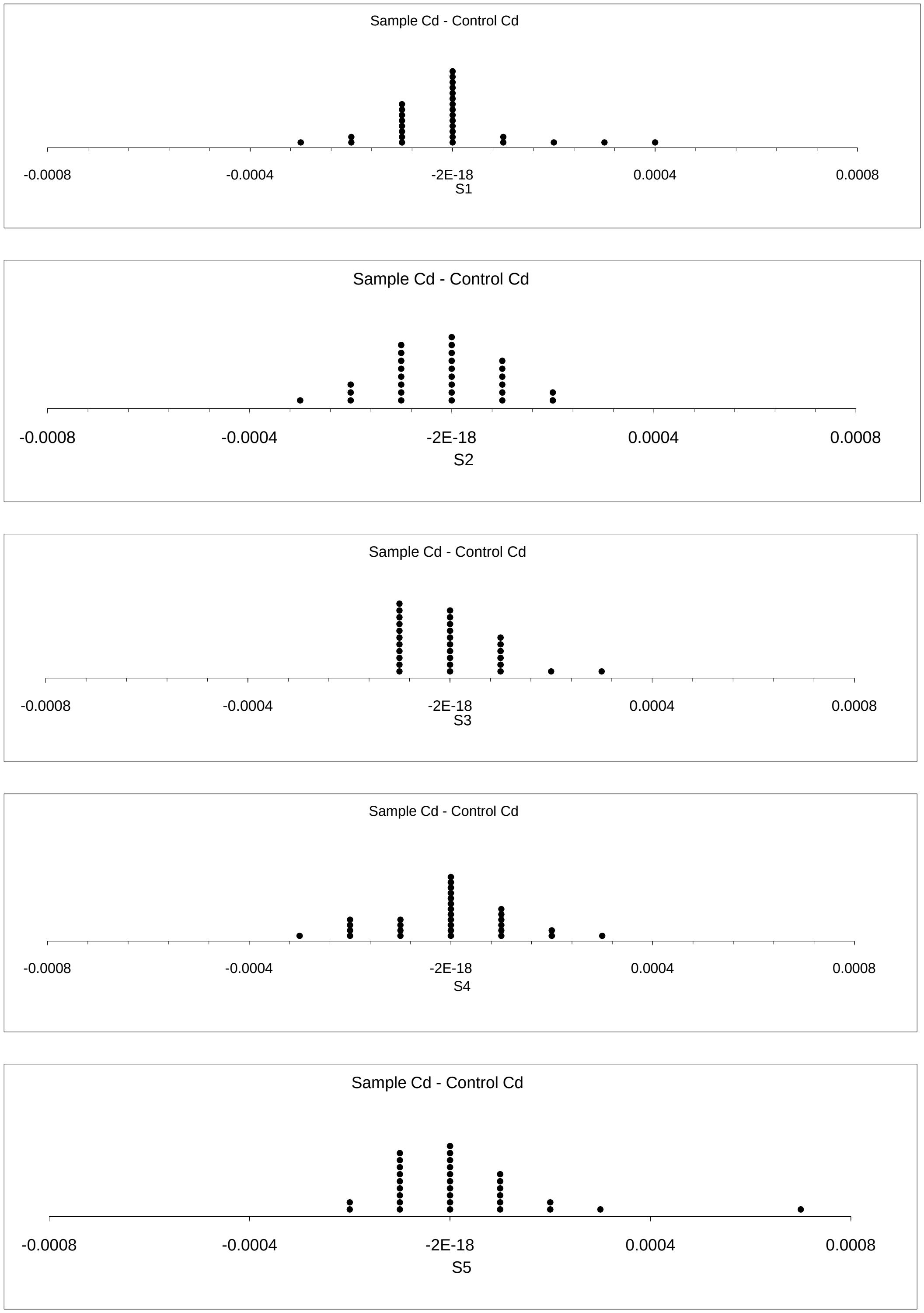


Figure A-5: Cadmium Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-46: Cadmium Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0001000	mean S1
0.0001097	mean ConCd
-0.0000097	mean difference (S1 - ConCd)
0.0001375	std. dev.
0.0000247	std. error
31	n
30	df
-0.39	t
.6979	p-value (two-tailed)
-0.0000601	confidence interval 95.% lower
0.0000408	confidence interval 95.% upper
0.0000504	half-width

Table A-47: Cadmium Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0001516	mean S2
0.0001097	mean ConCd
0.0000419	mean difference (S2 - ConCd)
0.0003491	std. dev.
0.0000627	std. error
31	n
30	df
0.67	t
.5087	p-value (two-tailed)
-0.0000861	confidence interval 95.% lower
0.0001700	confidence interval 95.% upper
0.0001280	half-width

Appendix I (Continued)

Table A-48: Cadmium Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0001194	mean S3
0.0001097	mean ConCd
0.0000097	mean difference (S3 - ConCd)
0.0001076	std. dev.
0.0000193	std. error
31	n
30	df
0.50	t
.6201	p-value (two-tailed)
-0.0000298	confidence interval 95.% lower
0.0000491	confidence interval 95.% upper
0.0000395	half-width

Table A-49: Cadmium Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0001129	mean S4
0.0001097	mean ConCd
0.0000032	mean difference (S4 - ConCd)
0.0001426	std. dev.
0.0000256	std. error
31	n
30	df
0.13	t
.9006	p-value (two-tailed)
-0.0000491	confidence interval 95.% lower
0.0000555	confidence interval 95.% upper
0.0000523	half-width

Appendix I (Continued)

Table A-50: Cadmium Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
0.0001323	mean S5
0.0001097	mean ConCd
0.0000226	mean difference (S5 - ConCd)
0.0001707	std. dev.
0.0000307	std. error
31	n
30	df
0.74	t
.4671	p-value (two-tailed)
-0.0000400	confidence interval 95.% lower
0.0000852	confidence interval 95.% upper
0.0000626	half-width

Table A-51: Cadmium Wilcoxon Analysis S1-Control.

variables:	S1 - ConCd
58.5	sum of positive ranks
94.5	sum of negative ranks
17	n
76.50	expected value
21.12	standard deviation
-0.85	z
.3942	p-value (two-tailed)

Table A-52: Cadmium Wilcoxon Analysis S2-Control.

variables:	S2 - ConCd
116.5	sum of positive ranks
136.5	sum of negative ranks
22	n
126.50	expected value
30.80	standard deviation
-0.32	z
.7454	p-value (two-tailed)

Appendix I (Continued)

Table A-53: Cadmium Wilcoxon Analysis S3-Control.

variables:	S3 - ConCd
121	sum of positive ranks
110	sum of negative ranks
21	n
115.50	expected value
28.77	standard deviation
0.19	z
.8484	p-value (two-tailed)

Table A-54: Cadmium Wilcoxon Analysis S4-Control.

variables:	S4 - ConCd
92.5	sum of positive ranks
97.5	sum of negative ranks
19	n
95.00	expected value
24.85	standard deviation
-0.10	z
.9199	p-value (two-tailed)

Table A-55: Cadmium Wilcoxon Analysis S5-Control.

variables:	S5 - ConCd
124	sum of positive ranks
107	sum of negative ranks
21	n
115.50	expected value
28.77	standard deviation
0.30	z
.7677	p-value (two-tailed)

Appendix I (Continued)

Table A-56: Nickel Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	24	24	24	24	24
mean	-0.000258	-0.000358	0.001208	-0.000354	-0.000196
sample variance	0.000001	0.000001	0.000042	0.000001	0.000001
sample standard deviation	0.000842	0.000879	0.006481	0.001092	0.000981
minimum	-0.0026	-0.002	-0.0032	-0.0041	-0.0033
maximum	0.0011	0.0012	0.0312	0.0008	0.001
range	0.0037	0.0032	0.0344	0.0049	0.0043
normal curve GOF					
p-value	.5724	.8013	1.05E-16	.0117	.0186
chi-square(df=3)	2.00	1.00	77.50	11.00	10.00
E	4.00	4.00	4.00	4.00	4.00
O(-0.97)	2	4	0	3	3
O(-0.43)	6	4	2	1	1
O(+0.00)	4	3	20	4	4
O(+0.43)	4	5	1	8	9
O(+0.97)	4	5	0	7	5
O(inf.)	4	3	1	1	2

Appendix I (Continued)

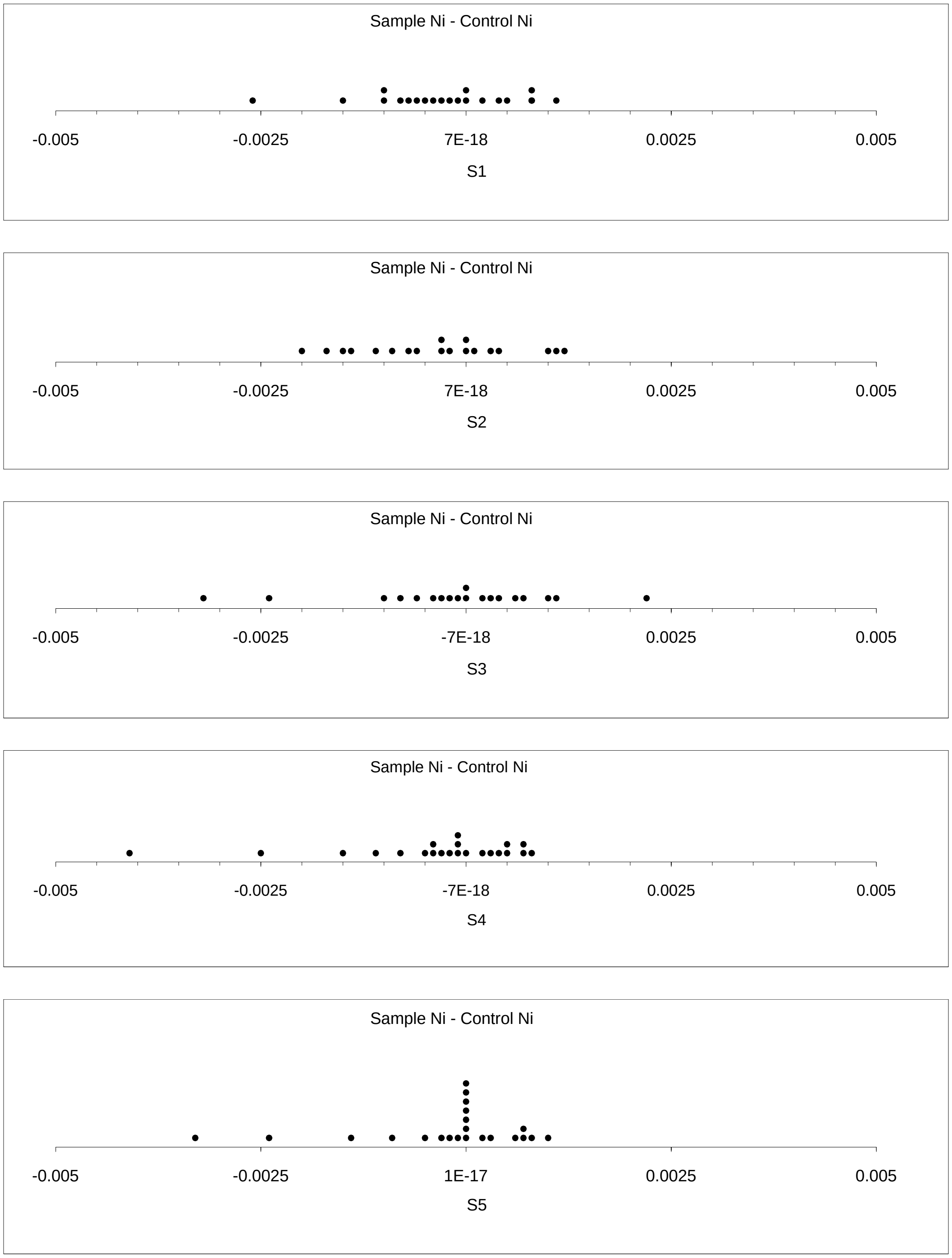


Figure A-6: Nickel Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-57: Nickel Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0017000	mean S1
0.0019583	mean ConNi
-0.0002583	mean difference (S1 - ConNi)
0.0008423	std. dev.
0.0001719	std. error
24	n
23	df
-1.50	t
.1466	p-value (two-tailed)
-0.0006140	confidence interval 95.% lower
0.0000973	confidence interval 95.% upper
0.0003557	half-width

Table A-58: Nickel Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0016000	mean S2
0.0019583	mean ConNi
-0.0003583	mean difference (S2 - ConNi)
0.0008792	std. dev.
0.0001795	std. error
24	n
23	df
-2.00	t
.0578	p-value (two-tailed)
-0.0007296	confidence interval 95.% lower
0.0000129	confidence interval 95.% upper
0.0003712	half-width

Appendix I (Continued)

Table A-59: Nickel Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0031667	mean S3
0.0019583	mean ConNi
0.0012083	mean difference (S3 - ConNi)
0.0064808	std. dev.
0.0013229	std. error
24	n
23	df
0.91	t
.3705	p-value (two-tailed)
-0.0015283	confidence interval 95.% lower
0.0039449	confidence interval 95.% upper
0.0027366	half-width

Table A-60: Nickel Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0016042	mean S4
0.0019583	mean ConNi
-0.0003542	mean difference (S4 - ConNi)
0.0010919	std. dev.
0.0002229	std. error
24	n
23	df
-1.59	t
.1257	p-value (two-tailed)
-0.0008152	confidence interval 95.% lower
0.0001069	confidence interval 95.% upper
0.0004611	half-width

Appendix I (Continued)

Table A-61: Nickel Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
0.0017625	mean S5
0.0019583	mean ConNi
-0.0001958	mean difference (S5 - ConNi)
0.0009809	std. dev.
0.0002002	std. error
24	n
23	df
-0.98	t
.3382	p-value (two-tailed)
-0.0006100	confidence interval 95.% lower
0.0002184	confidence interval 95.% upper
0.0004142	half-width

Table A-62: Nickel Wilcoxon Analysis S1-Control.

variables:	S1 - ConNi
84.5	sum of positive ranks
168.5	sum of negative ranks
22	n
126.50	expected value
30.80	standard deviation
-1.36	z
.1727	p-value (two-tailed)

Table A-63: Nickel Wilcoxon Analysis S2-Control.

variables:	S2 - ConNi
73.5	sum of positive ranks
179.5	sum of negative ranks
22	n
126.50	expected value
30.80	standard deviation
-1.72	z
.0853	p-value (two-tailed)

Appendix I (Continued)

Table A-64: Nickel Wilcoxon Analysis S3-Control.

variables:	S3 - ConNi
136	sum of positive ranks
117	sum of negative ranks
22	n
126.50	expected value
30.80	standard deviation
0.31	z
.7578	p-value (two-tailed)

Table A-65: Nickel Wilcoxon Analysis S4-Control.

variables:	S4 - ConNi
105.5	sum of positive ranks
170.5	sum of negative ranks
23	n
138.00	expected value
32.88	standard deviation
-0.99	z
.3229	p-value (two-tailed)

Table A-66: Nickel Wilcoxon Analysis S5-Control.

variables:	S5 - ConNi
71.5	sum of positive ranks
81.5	sum of negative ranks
17	n
76.50	expected value
21.12	standard deviation
-0.24	z
.8129	p-value (two-tailed)

Appendix I (Continued)

Table A-67: Iron Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	31	31	31	31	31
mean	-0.017303	-0.009474	0.002945	-0.007084	-0.013416
sample variance	0.001091	0.001634	0.003030	0.001945	0.001424
sample standard deviation	0.033028	0.040419	0.055047	0.044098	0.037733
minimum	-0.1273	-0.1261	-0.1	-0.1294	-0.116
maximum	0.0387	0.0526	0.1499	0.0685	0.0411
range	0.166	0.1787	0.2499	0.1979	0.1571
normal curve GOF					
p-value	.2196	.0571	.6348	.4120	.1132
chi-square(df=3)	4.42	7.52	1.71	2.87	5.97
E	5.17	5.17	5.17	5.17	5.17
O(-0.97)	4	6	5	3	5
O(-0.43)	5	3	6	4	4
O(+0.00)	7	3	7	7	4
O(+0.43)	2	10	5	6	5
O(+0.97)	8	6	3	7	10
O(inf.)	5	3	5	4	3

Appendix I (Continued)

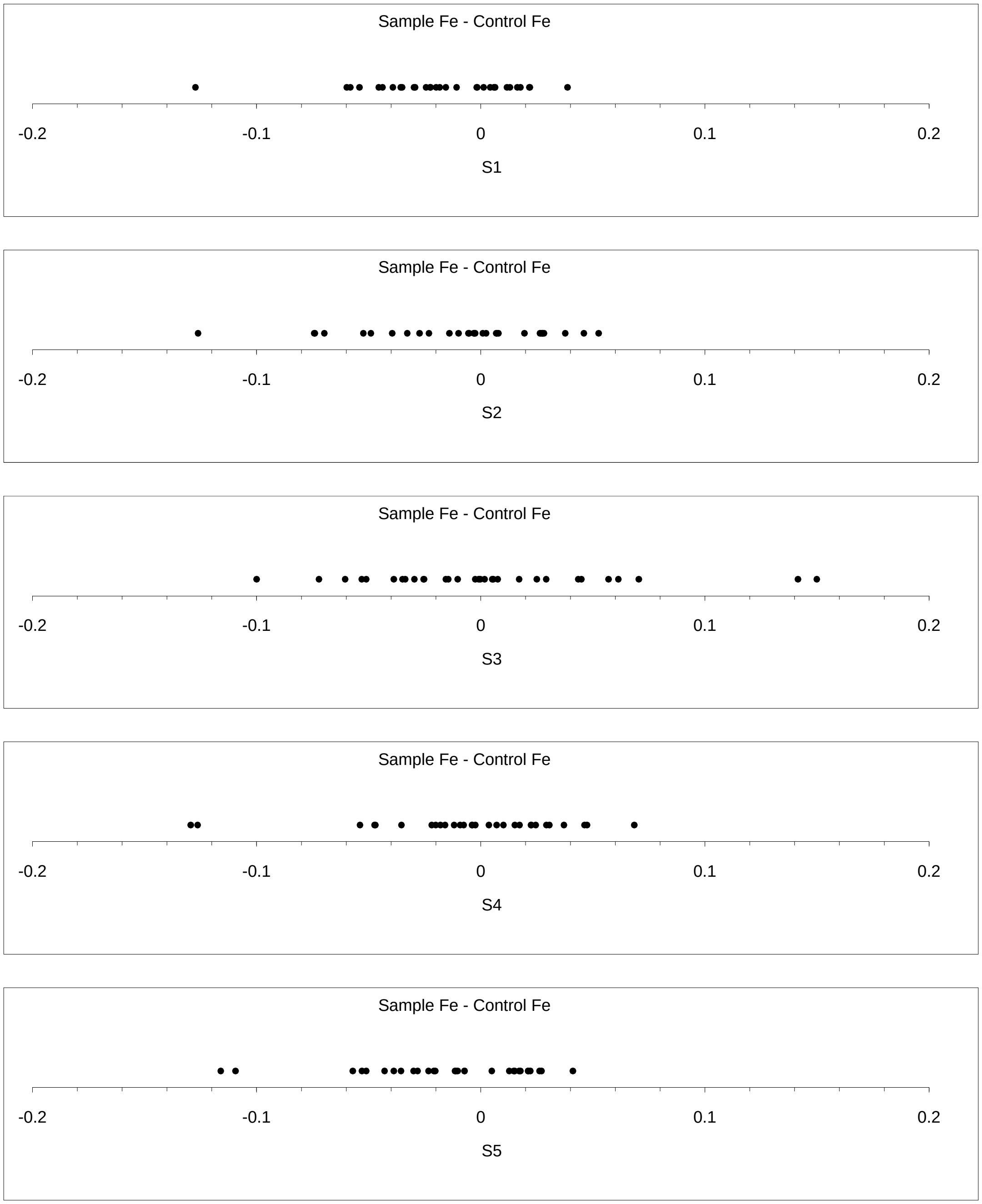


Figure A-7: Iron Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-68: Iron Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0532387	mean S1
0.0705419	mean ConFe
-0.0173032	mean difference (S1 - ConFe)
0.0330278	std. dev.
0.0059320	std. error
31	n
30	df
-2.92	t
.0066	p-value (two-tailed)
-0.0294179	confidence interval 95.% lower
-0.0051885	confidence interval 95.% upper
0.0121147	half-width

Table A-69: Iron Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0610677	mean S2
0.0705419	mean ConFe
-0.0094742	mean difference (S2 - ConFe)
0.0404191	std. dev.
0.0072595	std. error
31	n
30	df
-1.31	t
.2018	p-value (two-tailed)
-0.0243000	confidence interval 95.% lower
0.0053516	confidence interval 95.% upper
0.0148258	half-width

Appendix I (Continued)

Table A-70: Iron Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0734871	mean S3
0.0705419	mean ConFe
0.0029452	mean difference (S3 - ConFe)
0.0550470	std. dev.
0.0098867	std. error
31	n
30	df
0.30	t
.7678	p-value (two-tailed)
-0.0172463	confidence interval 95.% lower
0.0231366	confidence interval 95.% upper
0.0201914	half-width

Table A-71: Iron Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0634581	mean S4
0.0705419	mean ConFe
-0.0070839	mean difference (S4 - ConFe)
0.0440980	std. dev.
0.0079202	std. error
31	n
30	df
-0.89	t
.3782	p-value (two-tailed)
-0.0232592	confidence interval 95.% lower
0.0090914	confidence interval 95.% upper
0.0161753	half-width

Appendix I (Continued)

Table A-72: Iron Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
0.0571258	mean S5
0.0705419	mean ConFe
-0.0134161	mean difference (S5 - ConFe)
0.0377327	std. dev.
0.0067770	std. error
31	n
30	df
-1.98	t
.0570	p-value (two-tailed)
-0.0272566	confidence interval 95.% lower
0.0004243	confidence interval 95.% upper
0.0138405	half-width

Table A-73: Iron Wilcoxon Analysis S1-Control.

variables:	S1 - ConFe
111	sum of positive ranks
385	sum of negative ranks
31	n
248.00	expected value
51.03	standard deviation
-2.68	z
.0073	p-value (two-tailed)

Table A-74: Iron Wilcoxon Analysis S2-Control.

variables:	S1 - ConFe
111	sum of positive ranks
385	sum of negative ranks
31	n
248.00	expected value
51.03	standard deviation
-2.68	z
.0073	p-value (two-tailed)

Appendix I (Continued)

Table A-75: Iron Wilcoxon Analysis S3-Control.

variables:	S3 - ConFe
238	sum of positive ranks
258	sum of negative ranks
31	n
248.00	expected value
51.03	standard deviation
-0.20	z
.8446	p-value (two-tailed)

Table A-76: Iron Wilcoxon Analysis S4-Control.

variables:	S4 - ConFe
226.5	sum of positive ranks
269.5	sum of negative ranks
31	n
248.00	expected value
51.03	standard deviation
-0.42	z
.6735	p-value (two-tailed)

Table A-77: Iron Wilcoxon Analysis S5-Control.

variables:	S5 - ConFe
170	sum of positive ranks
326	sum of negative ranks
31	n
248.00	expected value
51.03	standard deviation
-1.53	z
.1264	p-value (two-tailed)

Appendix I (Continued)

Table A-78: Manganese Descriptive Statistical Analysis Material Surfaces S1-S5.

	S1	*S2*	*S3*	*S4*	*S5*
count	24	24	24	24	24
mean	-0.002908	-0.003513	-0.002925	-0.002146	-0.000842
sample variance	0.000108	0.000113	0.000134	0.000119	0.000160
sample standard deviation	0.010384	0.010634	0.011575	0.010909	0.012666
minimum	-0.0501	-0.0518	-0.0527	-0.0491	-0.0503
maximum	0.0015	0.001	0.0149	0.0163	0.0325
range	0.0516	0.0528	0.0676	0.0654	0.0828
normal curve GOF					
p-value	6.99E-15	6.99E-15	7.52E-13	1.14E-14	5.88E-13
chi-square(df=3)	69.00	69.00	59.50	68.00	60.00
E	4.00	4.00	4.00	4.00	4.00
O(-0.97)	1	1	1	1	1
O(-0.43)	1	1	2	2	1
O(+0.00)	3	3	2	1	3
O(+0.43)	19	19	18	19	18
O(+0.97)	0	0	0	0	0
O(inf.)	0	0	1	1	1

Appendix I (Continued)

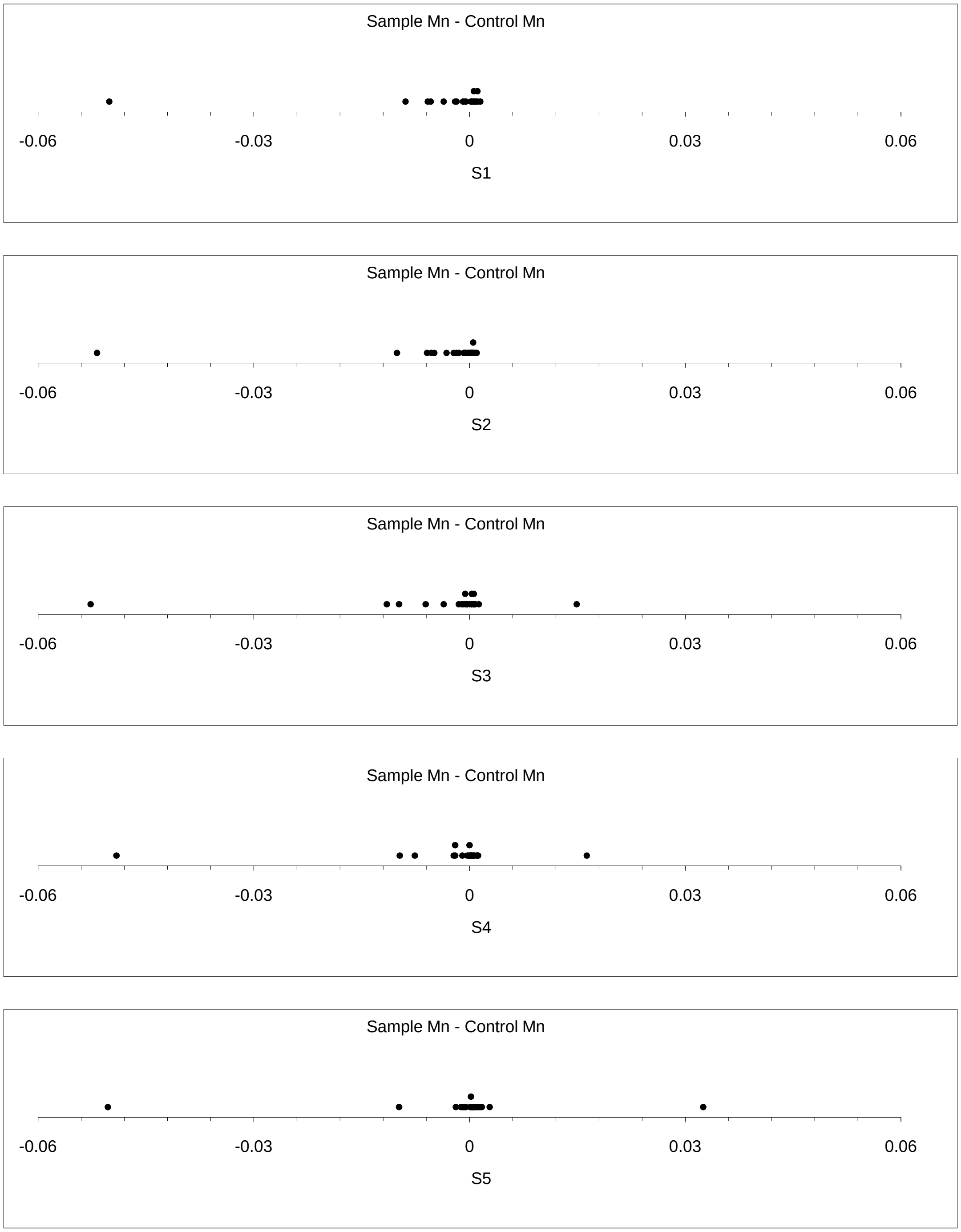


Figure A-8: Manganese Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-79: Manganese Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0036042	mean S1
0.0065125	mean ConMn
-0.0029083	mean difference (S1 - ConMn)
0.0103835	std. dev.
0.0021195	std. error
24	n
23	df
-1.37	t
.1832	p-value (two-tailed)
-0.0072929	confidence interval 95.% lower
0.0014762	confidence interval 95.% upper
0.0043846	half-width

Table A-80: Manganese Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0030000	mean S2
0.0065125	mean ConMn
-0.0035125	mean difference (S2 - ConMn)
0.0106340	std. dev.
0.0021706	std. error
24	n
23	df
-1.62	t
.1193	p-value (two-tailed)
-0.0080028	confidence interval 95.% lower
0.0009778	confidence interval 95.% upper
0.0044903	half-width

Appendix I (Continued)

Table A-81: Manganese Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0035875	mean S3
0.0065125	mean ConMn
-0.0029250	mean difference (S3 - ConMn)
0.0115752	std. dev.
0.0023628	std. error
24	n
23	df
-1.24	t
.2282	p-value (two-tailed)
-0.0078128	confidence interval 95.% lower
0.0019628	confidence interval 95.% upper
0.0048878	half-width

Table A-82: Manganese Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0043667	mean S4
0.0065125	mean ConMn
-0.0021458	mean difference (S4 - ConMn)
0.0109091	std. dev.
0.0022268	std. error
24	n
23	df
-0.96	t
.3453	p-value (two-tailed)
-0.0067524	confidence interval 95.% lower
0.0024607	confidence interval 95.% upper
0.0046065	half-width

Appendix I (Continued)

Table A-83: Manganese Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
0.0056708	mean S5
0.0065125	mean ConMn
-0.0008417	mean difference (S5 - ConMn)
0.0126659	std. dev.
0.0025854	std. error
24	n
23	df
-0.33	t
.7477	p-value (two-tailed)
-0.0061900	confidence interval 95.% lower
0.0045067	confidence interval 95.% upper
0.0053484	half-width

Table A-84: Manganese Wilcoxon Analysis S1-Control.

variables:	S1 - ConMn
125.5	sum of positive ranks
174.5	sum of negative ranks
24	n
150.00	expected value
34.87	standard deviation
-0.70	z, corrected for ties
.4823	p-value (two-tailed)

Table A-85: Manganese Wilcoxon Analysis S2-Control.

variables:	S2 - ConMn
81	sum of positive ranks
219	sum of negative ranks
24	n
150.00	expected value
34.96	standard deviation
-1.97	z, corrected for ties
.0484	p-value (two-tailed)

Appendix I (Continued)

Table A-86: Manganese Wilcoxon Analysis S3-Control.

variables:	S3 - ConMn
88	sum of positive ranks
188	sum of negative ranks
23	n
138.00	expected value
32.37	standard deviation
-1.54	z, corrected for ties
.1225	p-value (two-tailed)

Table A-87: Manganese Wilcoxon Analysis S4-Control.

variables:	S4 - ConMn
115	sum of positive ranks
138	sum of negative ranks
22	n
126.50	expected value
30.66	standard deviation
-0.38	z, corrected for ties
.7076	p-value (two-tailed)

Table A-88: Manganese Wilcoxon Analysis S5-Control.

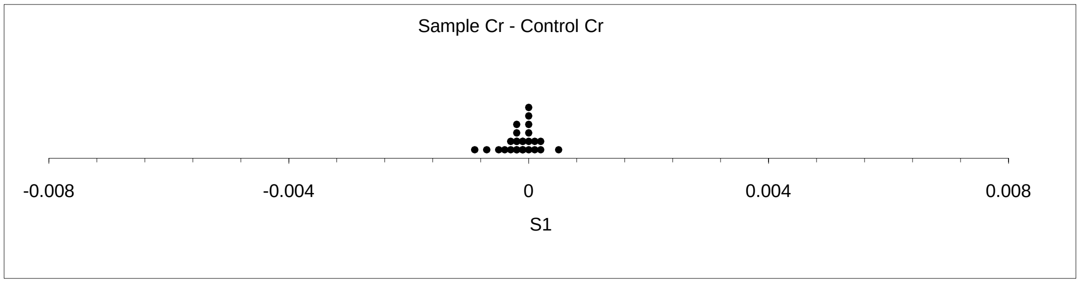
variables:	S5 - ConMn
183	sum of positive ranks
117	sum of negative ranks
24	n
150.00	expected value
34.96	standard deviation
0.94	z, corrected for ties
.3452	p-value (two-tailed)

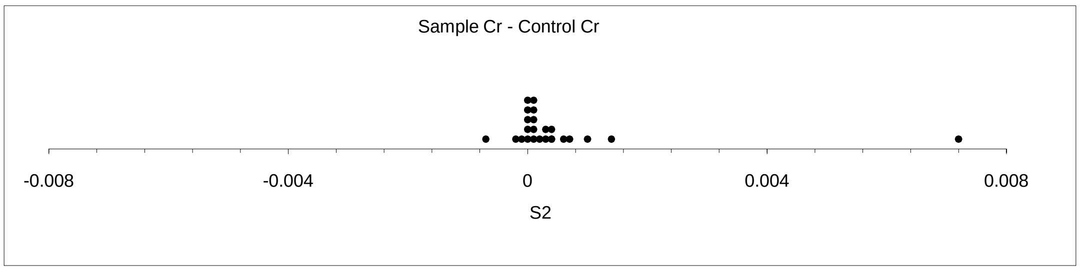
Appendix I (Continued)

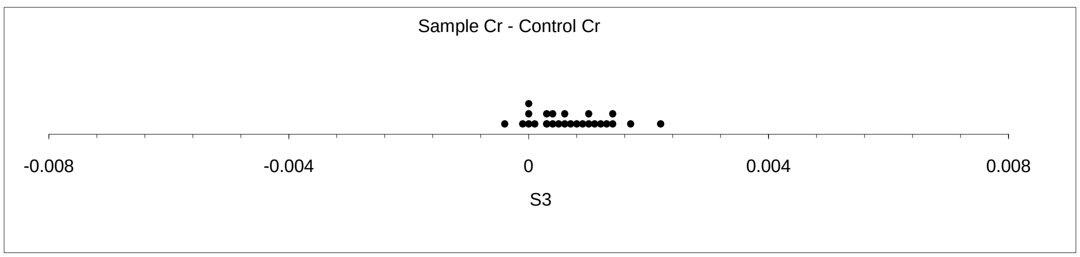
Table A-89: Chromium Descriptive Statistical Analysis Material Surfaces S1-S5.

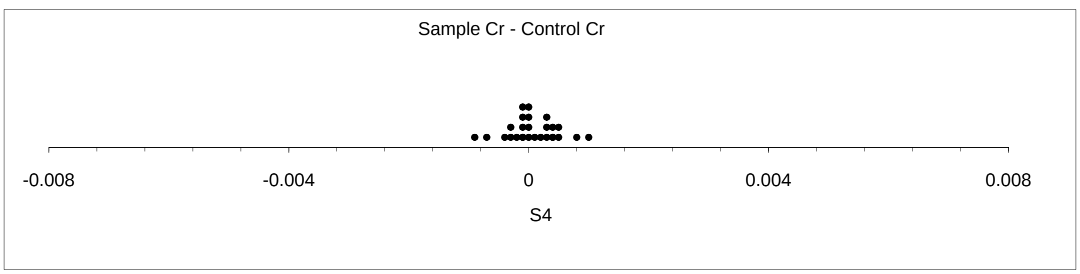
	S1	*S2*	*S3*	*S4*	*S5*
count	31	31	31	31	31
mean	-0.000142	0.000455	0.000648	0.000090	-0.000058
sample variance	0.000000	0.000002	0.000000	0.000000	0.000000
sample standard deviation	0.000280	0.001304	0.000582	0.000393	0.000398
minimum	-0.0009	-0.0007	-0.0004	-0.0009	-0.0011
maximum	0.0005	0.0072	0.0022	0.001	0.0009
range	0.0014	0.0079	0.0026	0.0019	0.002
normal curve GOF					
p-value	.4782	5.76E-18	.4120	.7238	.0239
chi-square(df=3)	2.48	83.39	2.87	1.32	9.45
E	5.17	5.17	5.17	5.17	5.17
O(-0.97)	4	0	5	5	4
O(-0.43)	4	2	6	6	2
O(+0.00)	6	24	7	4	8
O(+0.43)	5	3	2	5	10
O(+0.97)	8	1	6	7	4
O(inf.)	4	1	5	4	3

Appendix I (Continued)









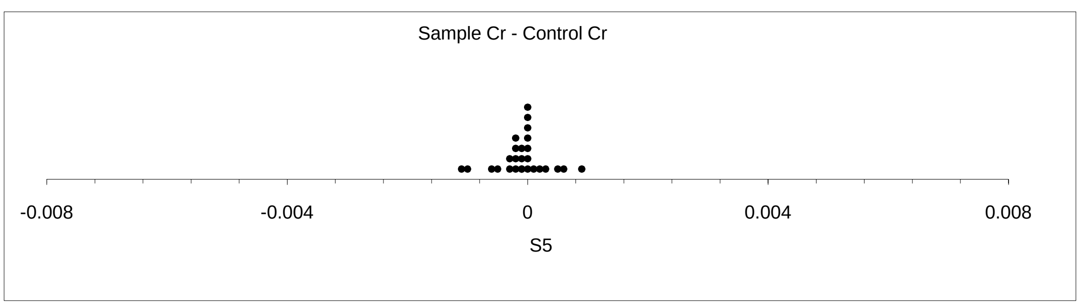


Figure A-9: Chromium Frequency Plot Analysis of Material Surface

Appendix I (Continued)

Table A-90: Chromium Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0006129	mean S1
0.0007548	mean ConCr
-0.0001419	mean difference (S1 - ConCr)
0.0002802	std. dev.
0.0000503	std. error
31	n
30	df
-2.82	t
.0084	p-value (two-tailed)
-0.0002447	confidence interval 95.% lower
-0.0000392	confidence interval 95.% upper
0.0001028	half-width

Table A-91: Chromium Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0012097	mean S2
0.0007548	mean ConCr
0.0004548	mean difference (S2 - ConCr)
0.0013038	std. dev.
0.0002342	std. error
31	n
30	df
1.94	t
.0615	p-value (two-tailed)
-0.0000234	confidence interval 95.% lower
0.0009331	confidence interval 95.% upper
0.0004782	half-width

Appendix I (Continued)

Table A-92: Chromium Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0014032	mean S3
0.0007548	mean ConCr
0.0006484	mean difference (S3 - ConCr)
0.0005819	std. dev.
0.0001045	std. error
31	n
30	df
6.20	t
7.89E-07	p-value (two-tailed)
0.0004350	confidence interval 95.% lower
0.0008618	confidence interval 95.% upper
0.0002134	half-width

Table A-93: Chromium Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0008452	mean S4
0.0007548	mean ConCr
0.0000903	mean difference (S4 - ConCr)
0.0003927	std. dev.
0.0000705	std. error
31	n
30	df
1.28	t
.2102	p-value (two-tailed)
-0.0000537	confidence interval 95.% lower
0.0002344	confidence interval 95.% upper
0.0001441	half-width

Appendix I (Continued)

Table A-94: Chromium Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
0.0006968	mean S5
0.0007548	mean ConCr
-0.0000581	mean difference (S5 - ConCr)
0.0003981	std. dev.
0.0000715	std. error
31	n
30	df
-0.81	t
.4232	p-value (two-tailed)
-0.0002041	confidence interval 95.% lower
0.0000880	confidence interval 95.% upper
0.0001460	half-width

Table A-95: Chromium Wilcoxon Analysis S1-Control.

variables:	S1 - ConCr
63.5	sum of positive ranks
261.5	sum of negative ranks
25	n
162.50	expected value
35.13	standard deviation
-2.82	z, corrected for ties
.0048	p-value (two-tailed)

Table A-96: Chromium Wilcoxon Analysis S2-Control.

variables:	S2 - ConCr
312	sum of positive ranks
39	sum of negative ranks
26	n
175.50	expected value
37.90	standard deviation
3.60	z, corrected for ties
.0003	p-value (two-tailed)

Appendix I (Continued)

Table A-97: Chromium Wilcoxon Analysis S3-Control.

variables:	S3 - ConCr
394.5	sum of positive ranks
11.5	sum of negative ranks
28	n
203.00	expected value
43.61	standard deviation
4.39	z, corrected for ties
1.13E-05	p-value (two-tailed)

Table A-98: Chromium Wilcoxon Analysis S4-Control.

variables:	S4 - ConCr
251	sum of positive ranks
127	sum of negative ranks
27	n
189.00	expected value
40.01	standard deviation
1.55	z, corrected for ties
.1212	p-value (two-tailed)

Table A-99: Chromium Wilcoxon Analysis S5-Control.

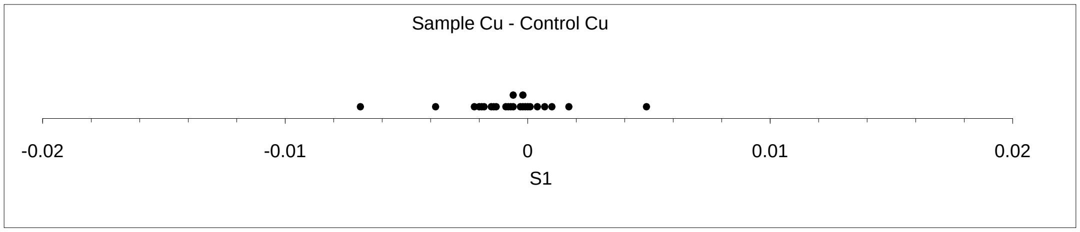
variables:	S5 - ConCr
118	sum of positive ranks
182	sum of negative ranks
24	n
150.00	expected value
33.60	standard deviation
-0.95	z, corrected for ties
.3409	p-value (two-tailed)

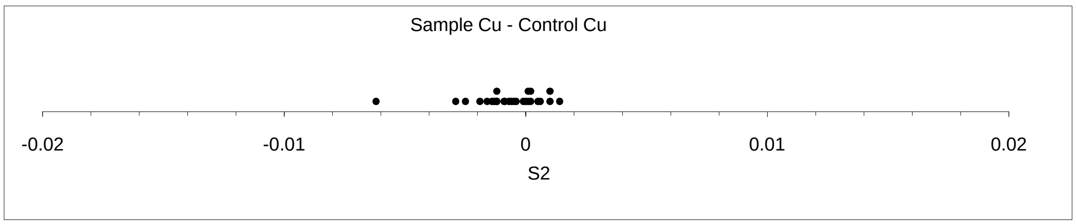
Appendix I (Continued)

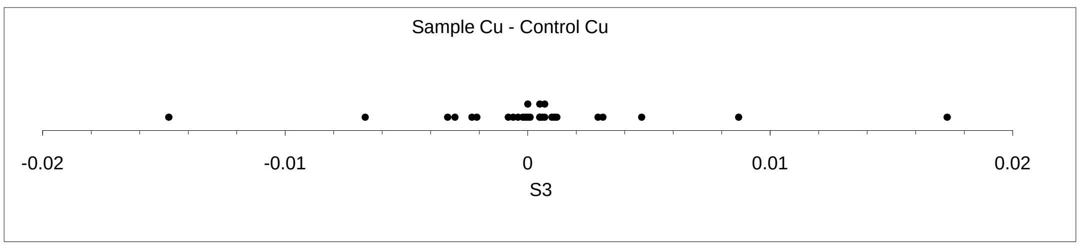
Table A-100: Copper Descriptive Statistical Analysis Material Surfaces S1-S5.

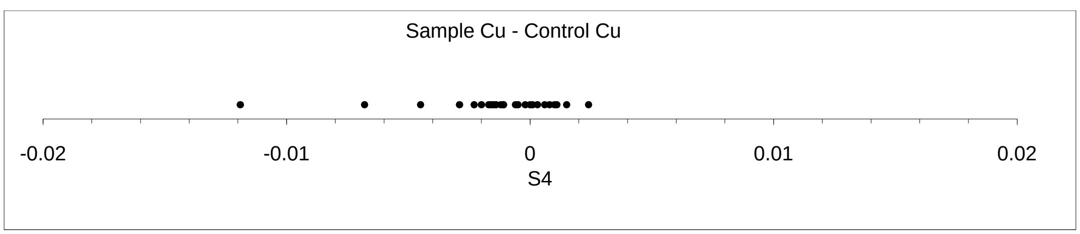
	S1	*S2*	*S3*	*S4*	*S5*
count	31	31	31	31	31
mean	-0.000697	-0.000718	0.000284	-0.001119	-0.001168
sample variance	0.000004	0.000002	0.000024	0.000007	0.000007
sample standard deviation	0.001884	0.001430	0.004879	0.002703	0.002712
minimum	-0.0069	-0.0062	-0.0148	-0.0119	-0.0131
maximum	0.0049	0.0014	0.0173	0.0024	0.0013
range	0.0118	0.0076	0.0321	0.0143	0.0144
normal curve GOF					
p-value	.0098	.0284	.0028	.0140	.0001
chi-square(df=3)	11.39	9.06	14.10	10.61	21.84
E	5.17	5.17	5.17	5.17	5.17
O(-0.97)	2	3	2	3	3
O(-0.43)	5	4	4	2	0
O(+0.00)	7	6	10	7	8
O(+0.43)	11	4	10	7	10
O(+0.97)	4	11	3	10	10
O(inf.)	2	3	2	2	0

Appendix I (Continued)









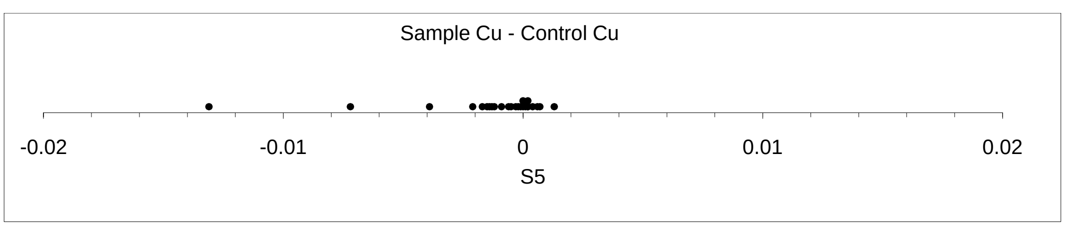


Figure A-10: Copper Frequency Plot Analysis

Appendix I (Continued)

Table A-101: Copper Paired T-Test Analysis S1 and Control.

0.0000000	hypothesized value
0.0058903	mean S1
0.0065871	mean ConCu
-0.0006968	mean difference (S1 - ConCu)
0.0018837	std. dev.
0.0003383	std. error
31	n
30	df
-2.06	t
.0482	p-value (two-tailed)
-0.0013877	confidence interval 95.% lower
-0.0000058	confidence interval 95.% upper
0.0006909	half-width

Table A-102: Copper Paired T-Test Analysis S2 and Control.

0.0000000	hypothesized value
0.0058687	mean S2
0.0065871	mean ConCu
-0.0007184	mean difference (S2 - ConCu)
0.0014299	std. dev.
0.0002568	std. error
31	n
30	df
-2.80	t
.0089	p-value (two-tailed)
-0.0012429	confidence interval 95.% lower
-0.0001939	confidence interval 95.% upper
0.0005245	half-width

Appendix I (Continued)

Table A-103: Copper Paired T-Test Analysis S3 and Control.

0.0000000	hypothesized value
0.0068710	mean S3
0.0065871	mean ConCu
0.0002839	mean difference (S3 - ConCu)
0.0048785	std. dev.
0.0008762	std. error
31	n
30	df
0.32	t
.7482	p-value (two-tailed)
-0.0015056	confidence interval 95.% lower
0.0020733	confidence interval 95.% upper
0.0017895	half-width

Table A-104: Copper Paired T-Test Analysis S4 and Control.

0.0000000	hypothesized value
0.0054681	mean S4
0.0065871	mean ConCu
-0.0011190	mean difference (S4 - ConCu)
0.0027034	std. dev.
0.0004855	std. error
31	n
30	df
-2.30	t
.0283	p-value (two-tailed)
-0.0021106	confidence interval 95.% lower
-0.0001274	confidence interval 95.% upper
0.0009916	half-width

Appendix I (Continued)

Table A-105: Copper Paired T-Test Analysis S5 and Control.

0.0000000	hypothesized value
0.0054194	mean S5
0.0065871	mean ConCu
-0.0011677	mean difference (S5 - ConCu)
0.0027121	std. dev.
0.0004871	std. error
31	n
30	df
-2.40	t
.0229	p-value (two-tailed)
-0.0021626	confidence interval 95.% lower
-0.0001729	confidence interval 95.% upper
0.0009948	half-width

Table A-106: Copper Wilcoxon Analysis S1-Control.

variables:	S1 - ConCu
105	sum of positive ranks
360	sum of negative ranks
30	n
232.50	expected value
48.49	standard deviation
-2.63	z, corrected for ties
.0086	p-value (two-tailed)

Table A-107: Copper Wilcoxon Analysis S2-Control.

variables:	S2 - ConCu
104	sum of positive ranks
361	sum of negative ranks
30	n
232.50	expected value
48.34	standard deviation
-2.66	z, corrected for ties
.0079	p-value (two-tailed)

Appendix I (Continued)

Table A-108: Copper TDS Analysis Wilcoxon S3-Control.

variables:	S3 - ConCu
242	sum of positive ranks
193	sum of negative ranks
29	n
217.50	expected value
46.18	standard deviation
0.53	z, corrected for ties
.5958	p-value (two-tailed)

Table A-109: Copper TDS Analysis Wilcoxon S4-Control.

variables:	S4 - ConCu
122	sum of positive ranks
343	sum of negative ranks
30	n
232.50	expected value
48.56	standard deviation
-2.28	z, corrected for ties
.0229	p-value (two-tailed)

Table A-110: Copper TDS Analysis Wilcoxon S5-Control.

variables:	S5 - ConCu
87	sum of positive ranks
348	sum of negative ranks
29	n
217.50	expected value
46.21	standard deviation
-2.82	z, corrected for ties
.0047	p-value (two-tailed)

Appendix II: Model Development

Hydraulic Model

Conceptually the hydraulic model consists of two elements, one of which is a collection system and the other being a discharge system. The collection system is a gravity flow system and its design is based upon Manning's equation, while the discharge system is based upon Darcy's equation. These calculations are averages used prior to developing the Excel model to examine the potential of such a system.

Collection System

The model requires that following data be collected or estimated from historical records:

- Community population =
- Population /home =
- Total daily demand =
- Total number of lots =
- Lots/ street =
- Total roof area = (usually not available)
- Average lot size =
- Home square footage =
- Roof area/ home =
- Rainfall data =

Appendix II (Continued)

- Rainfall frequency data =
- Capacity of treatment plant/ system =
- Topographic Maps =

The model requires that following calculations be done:

- Calculations of available volume to be collected
- Estimation of the total volume of water that is available /year
- Estimation of total number of homes assuming 2.5-person occupancy
- Area of Total Roof Surface, for example:

  $$\text{Surface Area}_{roof} = \text{No. Homes x 3041 sf/home (Temple Terrace)}$$

- Per capita consumption rate
- Total volume of rainfall available from roof catchment
- Total rainfall received per year

  Annual volume = (annual rainfall ft/yr) total roof area x eff

- Annual consumptive demand

  Cons demand = average daily demand x 365 days/year x pop

- Percentage of demand
- Percentage = total volume available
- Total consumptive demand
- Assessment of rainfall volume to collect

Appendix II (Continued)

The model requires that following constraints be determined:

- Constraints of volume to collect
- Capacity of treatment plant
- Economic capital investment
- Water quality

Rainfall frequency analysis must be done and piping system selection (for example, based upon the data collected, 90% of the time rainfall events in this area are equal to or less than 1 inch-per-hour.)

- Unit volume = intensity (in/hr) x eff x roof area $_{unit}$ x 7.48 gal/cf
- Required capacity of lateral pipe to carry water.
- $Q_{lateral}$ = volumetric rate per unit x connections per length
- Selection of pipe diameter

Manning's Equation Estimated Max Flow Rate

$$V = \frac{1.486}{n} \left({}^{D}/_{4} \right)^{2/3} (S)^{1/2} \quad \text{(Equation B-1)}$$

$$Q = \frac{\pi (D)^2}{4} V \quad \text{(Equation B-2)}$$

$$Q = 30.86(D)^{2.667} (S)^{1/2} \quad \text{(Equation B-3)}$$

Appendix II (Continued)

- Cost of Pipe in Suburban area $7.00/inch diameter-feet of length

For example, assume that the connection included 12 homes and the length of run was 500 feet slope from the map is 7 feet in 500 feet and n = 0.015. The flow from the 12 homes would be:

Q = 26.85 gpm x 12 = 322 gpm or 0.72 cfs (Equation B-4)

The required pipe diameter is calculated from:

$Q = 30.86\ (D)^{2.667}\ (S)^{0.5}$ = 0.54ft = 6.5" or use an 8 inch pipe

Cost @ $7.00/ inch-ft = $56/ft x 500 ft = $28,000

The same approach is used to determine main piping that connects the laterals to the storage and pumping stations. Total connections, slope of pipe, and volume to be transported are established to determine the diameter of the pipe.

For example, assume the change in elevation is 45 feet and there are 500 home connected to the main through laterals. The total flow for a 1 inch/ hour storm would be 13,425 gallons per minute and would require a 30-inch diameter main 6,500 feet long costing $1,365,000.

Appendix II (Continued)

Storage

Storage is controlled by the capacity of the treatment plant.

- Augmentation Demand = Daily Demand x augmentation fraction
- Storage = Volume recovered from selected Units - Augmentation demand

Pumping System

- Daily demand equals capacity of plant.
- Pumping Q = Plant capacity in gallons/ minute
- Total Horsepower required

Pump Requirements for Force Main 16 Θ ” (Equation B-5)

- Power = Q(gpm) x Total Head(static + dynamic) x Pump efficiency

$$P = \frac{Q\ (gpm) x\ Total\ Head\ (ft)}{3960\ x\ Pump\ effiency}$$

Cost

Estimated cost of 59hp pump is \$ 350,000. Note: Various configurations of the piping network strongly influence the Capital Cost of this type of project.

NOTE: Variables for these hydraulic calculations can be found in Table B-1, below.

Appendix II (Continued)

Table B-1: Model Variables for the Hydraulic Calculations.

Known Variables	
Roof Area	3,041.00
Lots per Street	24.00
Map Lots	1,021.00
Average Daily for Florida gal	174.00
Connections	29,000.00
Temple Terrace Daily Demand gd	4,167,400.00
Average Rain Fall in inches	47.38
Conversion Factor cfd to gal	7.48
Conversion Factor gpm to cfsl	0.002228
Monthly Average demand in gallons Temple Terrace	126,690,700.00
Assumption	
Pop Density	2.50
Collection efficiency	0.85
Estimation rate for capital use in Temple Terrace	
Average Rate	143.70
Total Dwellings	11,600.00
Estimated Total Roof Area	35,275,600.00
Average rainfall in cfy	3.95
Total Collection cfy @ 85 percent	118,387,853.23
Total Collection gy @ 85 percent	885,541,142.19
Temple Terrace Annual Demand g/yr	1,520,288,400.00
Roof Runoof Percent of Demand	58.25
Number of Units to Provide 25 Percent	
Annual Volume g/yr	380,072,100.00
Unit Capacity g/unit @ 85 percent	76,339.75
Number of unit	4,978.69
Approximately	5,000.00
90 percent probability Rainfall is 1 inch or less	
Volume 1 inch an duration is 60 minutes @ 85 percent gpm	26.85
Lateral Design Run 500' Slope 7'	
typical lateral is 24 lots gpm Q =	644.49
typical lateral is 12 lots gpm Q =	322.24
typical lateral is 12 lots cfs Q =	0.72
Main Connection Grade (80-45)/6500	
1/2 unit 500 Dwellings gpm	13,426.86
1/2 unit 500 Dwellings cfs	29.92
Storage	
Transfer Rate 25 Percent	1,041,850.00
3000 unit 1"' /hour cfc	646,212.50
3000 unit 1"' /hour gpm	4,833,669.50
Design to Storage	
amount less transfer rate	1,041,850.00
3000 unit 1"' /hour gpm	4,833,669.50
Approximately 4 MDG	3,791,819.50
Capacity 3 MGD at the Water Plant	
Maximum throughput gpm	2,083.00
Pump Requirement for the Forced Main	
Pump Requirement for the Forced Main hp	52.00

Appendix II (Continued)

Row Labels	Count of Reservoir	Percent
0-500000	674856	0.9166
500000-1000000	21105	0.0287
1000000-1500000	17909	0.0243
1500000-2000000	22407	0.0304
Grand Total	**736277**	**100%**

Supply	Percentage	QA
Ground Water	0.4307	736277
Rain	0.5685	
Partial	0.0008	
Reservoir	0.0000	
	100%	**736277**

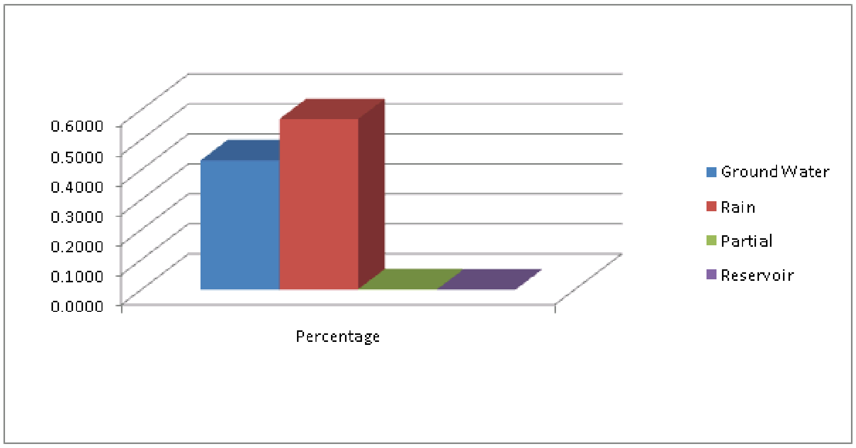


Figure B-1: Rain Model Analyses for Demand

Appendix II (Continued)

Table B-2: Model Cost Schedule Analysis.

City Cost Index				
Tampa	86.7			
Florida ranges 71.6-90.0				
Piping HDPE Type S	Daily Output		Total incl O &P	City Cost Adjusted
6" diameter	400	L.F.	$ 5.30	$ 4.60
8" diameter	380		$ 7.55	$ 6.55
10" diameter	370		$ 9.30	$ 8.06
12" diameter	340		$ 11.70	$ 10.14
14" diameter	320		$ 13.30	$ 11.53
16" diameter	300		$ 15.10	$ 13.09
18" diameter	275		$ 21.50	$ 18.64
24" diameter	250		$ 31.00	$ 26.88
30" diameter	200		$ 47.00	$ 40.75
36" diameter	180		$ 58.00	$ 50.29
42" diameter	175		$ 71.00	$ 61.56
48" diameter	170		$ 89.00	$ 77.16
54" diameter	160		$ 133.00	$ 115.31
60" diameter	150		$ 154.00	$ 133.52
62" diameter	150		$ 165.00	$ 143.06
Water Supply HDPE SDR 21 40' lengths			Total incl O &P	City Cost Adjusted
16" diameter	180	L.F	$ 54.50	$ 47.25
18" diameter	140	L.F	$ 69.00	$ 59.82
Land Costs		ea	Total incl O &P	City Cost Adjusted
		1 acre	$ 20,000.00	$ 17,340.00
Reservoir		ea	Total incl O &P	City Cost Adjusted
				$ -
Prestressed Concrete above ground		ea	Total incl O &P	City Cost Adjusted
4,000,000 gal		1	$ 1,309,350.00	$ 1,135,206.45
6,000,000 gal		1	$ 1,786,400.00	$ 1,548,808.80
8,000,000 gal		1	$ 2,273,600.00	$ 1,971,211.20
10,000.000 gal		1	$ 2,760,800.00	$ 2,393,613.60
Steel not incl fdn.		ea	Total incl O &P	City Cost Adjusted
4,000,000 gal		1	$ 1,114,723.00	$ 966,464.84
6,000,000 gal		1	$ 1,546,606.00	$ 1,340,907.40
8,000,000 gal		1	$ 2,025,179.00	$ 1,755,830.19
10,000.000 gal		1	$ 2,503,752.00	$ 2,170,752.98
Pump		ea	Total incl O &P	City Cost Adjusted
65 hp		1	$ 350,000.00	$ 303,450.00

Appendix II (Continued)

Table B-3: Model Estimated Cost and Payback Period Analysis.

Unit	Collection system	Pipe (in)	Cost	Distance run (ft)	Cost O & P		
1200	connection	8	$ 6.55	100	$ 785,502.00		
50	laterals	14	$ 11.53	1200	$ 691,866.00		
2	Trunk Main	48	$ 77.16	6500	$ 1,003,119.00		
					$ 2,480,487.00	Collection	$ 2,480,487.00
Unit	**Storage (cap. Gal)**		**Cost**		**Cost O & P**		
1	acre		$ 17,340.00		$ 17,340.00		
1	4,000,000		$ 1,135,206.45		$ 1,135,206.45		
					$ 1,152,546.45	Storage	$ 1,152,546.45
Unit	**Main return to Plant**		**Cost**	**Distance run (ft)**	**Cost O & P**		
1	forced	16	$ 47.25	6500	$ 307,134.75		
1	Pumps		$ 303,450.00		$ 303,450.00		
					$ 610,584.75	Plant return	$ 610,584.75
						Total	***$ 4,243,618.20***

Unit	Description	Pay back period	
1200	homes		
2.5	person per home		
143	consumption per capita gallons/day		
365	days per year		
156,585,000.00	gallons/yr		
156,585.00	per/1,000 gal		
89,143.8405	56.93 percent Augmentation saving	Total Cost	$ 4,243,618.20
$3.10	wholesale water cost per 1,000 gallons	Savings per year	$276,345.91
$276,345.91	Saving from the System per year	Pay back period in years of the system	**15.36**

Appendix II (Continued)

Table B-4: Model Loan Schedule Analysis.

Input Summary	
Loan Amount	$ 4,243,618.20
Term (Years)	30
Interest Rate:	3.0%
Loan Year	2007
Number of Users	12000

						Declining Payments	Equal payments
Loan Repayment Schedule	Outstanding Principal	Principal Payment (Annual)	Interest Payment (Annual)	Total Payment (Annual)	PV Annual Payment	Cost per User (Annual)	Cost per User (Annual)
2008	$5,502,025	$183,401	$165,061	$348,462	$338,312	29	23
2009	5,318,625	183,401	159,559	342,960	323,272	29	23
2010	5,135,224	183,401	154,057	337,458	308,821	28	23
2011	4,951,823	183,401	148,555	331,956	294,938	28	23
2012	4,768,422	183,401	143,053	326,454	281,602	27	23
2013	4,585,021	183,401	137,551	320,951	268,792	27	23
2014	4,401,620	183,401	132,049	315,449	256,489	26	23
2015	4,218,219	183,401	126,547	309,947	244,675	26	23
2016	4,034,819	183,401	121,045	304,445	233,332	25	23
2017	3,851,418	183,401	115,543	298,943	222,442	25	23
2018	3,668,017	183,401	110,041	293,441	211,988	24	23
2019	3,484,616	183,401	104,538	287,939	201,955	24	23
2020	3,301,215	183,401	99,036	282,437	192,326	24	23
2021	3,117,814	183,401	93,534	276,935	183,087	23	23
2022	2,934,414	183,401	88,032	271,433	174,223	23	23
2023	2,751,013	183,401	82,530	265,931	165,720	22	23
2024	2,567,612	183,401	77,028	260,429	157,564	22	23
2025	2,384,211	183,401	71,526	254,927	149,743	21	23
2026	2,200,810	183,401	66,024	249,425	142,244	21	23
2027	2,017,409	183,401	60,522	243,923	135,054	20	23
2028	1,834,008	183,401	55,020	238,421	128,163	20	23
2029	1,650,608	183,401	49,518	232,919	121,559	19	23
2030	1,467,207	183,401	44,016	227,417	115,230	19	23
2031	1,283,806	183,401	38,514	221,915	109,167	18	23
2032	1,100,405	183,401	33,012	216,413	103,360	18	23
2033	917,004	183,401	27,510	210,911	97,798	18	23
2034	733,603	183,401	22,008	205,409	92,473	17	23
2035	550,203	183,401	16,506	199,907	87,375	17	23
2036	366,802	183,401	11,004	194,405	82,495	16	23
2037	183,401	183,401	5,502	188,903	77,825	16	23
Total				8,060,467	5,502,025		

ABOUT THE AUTHOR

Robert Carnahan Jr. has been the Chair of the Hillsborough River Board and Technical Advisory Council for the past six of eight years of the appointed council position. He is currently teaching environmental studies and business management as an adjunct professor at Eckerd College.

Carnahan was a graduate of Nova Southeastern University with a MBA and was inducted into Sigma Beta Delta honor society. He is a graduate of Eckerd College with a BA, with distinction, in management.