ABSTRACT

WILLIAMS, NEKESHA BERNADETTE. Relationship between flow regime and aquatic macroinvertebrate abundance in headwater streams in the Piedmont Region of North Carolina. (Under the direction of Dr. Stacy Nelson).

Approximately 85% of the area of watersheds in the Piedmont Region of North Carolina are drained by headwater streams. Headwater streams may also serve as sources or sinks for sediments, nutrients, and biota hence their importance on a watershed scale. Water depth data was collected from eight first order headwater streams for 18 months. In addition, macroinvertebrates were sampled from the study streams three times a year. Hydrographs, created from the water depths collected for each study stream, were analyzed to determine periods of lower and higher hydrologic flow in the stream channels. Based on the hydrographs it was determined that near the end of the growing season, some sub-reaches of the stream channel may cease to flow whereas others exhibit lower levels of water. Conversely, after the growing season, water depths in streams will increase. Four different statistical models were used to characterize the effect that water depths in the headwater streams have on macroinvertebrate abundance. The four models used in the analysis were a full mixed effects model, a reduced model with the stream type variable, a reduced model without the stream type variable and a reduced model with a minimum water depth term. Both the reduced model without the stream type variable and the minimum water depth model were chosen as models that better fit the data. These models indicated that water depths may affect general macroinvertebrate abundance in the study streams. An additional objective of this study was to evaluate the North Carolina Division of Water Quality (NCDWQ) Stream Classification Method for identifying the origins of intermittent and perennial streams. Results from statistical analysis indicated that the NCDWQ’s Stream Classification Method is an effective tool for distinguishing stream types (ephemeral, intermittent, and perennial).

RELATIONSHIP BETWEEN FLOW REGIME AND AQUATIC MACROINVERTEBRATE ABUNDANCE IN HEADWATER STREAMS IN THE PIEDMONT REGION OF NORTH CAROLINA

by

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DEDICATION

To my loving and very supportive family.
To all those who believed in me.
and
To Mrs. Carmen McCoy Harrison
Rest in Peace

BIOGRAPHY

Nekesha B. Williams was born and raised in the Republic of Trinidad and Tobago. Ms. Williams is her mother’s only child and is the first of five children for her father. In 1993, Ms. Williams immigrated to the United States at the age of thirteen where she took up residence in Brooklyn, New York. In 2002, Ms. Williams completed her undergraduate studies at the State University of New York College of Environmental Science and Forestry (SUNY-ESF), where she acquired a Bachelor of Science in Environmental Studies, Biological Applications. During her undergraduate academic career, Ms. Williams served as first the secretary and then as Vice President for the Baobab Society, the only multicultural club on the SUNY-ESF campus at that time. Currently, Ms. Williams is a member of Xi Sigma Pi, the Forestry Honor Society at North Carolina State University, as well as Minorities Striving and Pursuing Higher Degrees (MSPHD’s) in Earth System Science, 2004 Cohort.

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Introduction

Headwater streams are the first and second order (intermittent and perennial) streams distributed throughout a watershed that form the principal connection between the land and higher order streams and rivers. North America, Central Europe, and other regions of the World are becoming more aware of the importance of managing headwater streams in watersheds (Haigh and Krecek 1991, Schreier 2000). Various land use practices occurring within watersheds such as urbanization, agricultural encroachment, and mining have resulted in increased sedimentation, downstream flooding and a decreased capacity to process nutrients such as nitrogen in headwater streams. These ecological functions in headwater streams may be an important factor in the amelioration of non-point source pollution occurring downstream from the headwater areas (Meyer and Wallace 2001, Peterson et al. 2001). The monitoring of water quality downstream of the headwater reaches has included the use of biological indicator species of aquatic macroinvertebrates (Lenat 1987). However, much research is still necessary to understand the role and abundance of aquatic macroinvertebrates within the actual headwater stream reaches, which may represent an increased sensitivity to changes occurring throughout the entire watershed in comparison to larger downstream flows.

Macroinvertebrates inhabiting headwater streams contribute to the watershed stream ecology, making the presence and abundances of these organisms vitally important in assessing ecosystem health and water quality (Gomi, et al. 2002). Thus, understanding macroinvertebrate abundances and their relationship to the geomorphic and hydrologic character of headwater streams are an important step towards recognizing the ecological functions of these streams that influence water quality, water supply, and aquatic biodiversity of watersheds.

Importance of headwater streams

Headwater streams have been traditionally classified as first and second order streams (Rheinhardt et al. 1999). These orders represent small streams that often have been described as located in the uppermost regions of watersheds and representing the origin or source of a river (Plate 1998). However, headwater streams occur throughout a watershed draining small catchments at watershed boundary as well as small catchments that discharge to the main stream of the watershed near its mouth (Personal Communication, J.D. Gregory, 2005). Additionally, headwater streams have also been recognized as areas where a great amount of groundwater recharge occurs within a given watershed (Tognetti 2000, Haigh et al. 2004).

Headwater streams are also an important component of the landscape drainage system. Their high density and variable distribution throughout the watershed allows for nearly complete drainage of the upland areas (Leopold et al. 1964 and Gomi et al. 2002). Approximately 70 to 80% of a watershed's total catchment area may be comprised of headwater streams (Sidle et al. 2000). Parrachini et al. (2000) estimated that headwater streams make up approximately 51% of the total European Union, in which 12% can be found in mountainous regions, and approximately 56% of which are located in forested areas.

Headwater streams provide several additional landscape functions. For example, these environments have been recognized to play an important role in improved water quality, water supply, and the overall ecology of the watershed within which they are located (Meyer and Wallace 2001). Headwater stream catchments may also function as a source or sink for sediments, nutrients, and biota. The movement of these components through or out of a watershed may have an effect on forest ecosystems as well as downstream coastal environments on local, regional, or global scales (Feger et al. 1990, Wilson et al. 1991, and Sidle et al. 2000).

Headwater streams, and the larger streams which they support, are important habitat areas for macroinvertebrates, fishes, and amphibians within watersheds. The macroinvertebrate community is of particular importance as it serves many functions in headwater streams such as decomposition of leaf litter, release of nutrients to downstream consumers and as a bio-indicator of landscape non-point source pollution (Vannote et al. 1980, Wallace and Webster 1996, and Gage et al. 2004). Thus, the roles of headwater streams within a watershed are important to the support and productivity of critical ecosystems both within the specific watershed and to connecting watersheds.

Connectivity to Landscape

Headwater streams are connected to adjacent upland areas within a watershed and as a result may be vulnerable to anthropogenic alterations to the channel, catchment, and riparian zone. These streams are also connected to downstream ecosystems (Pringle 1997, Meyer and Wallace 2001). Changes to one component of the stream network may result in impacts throughout the entire drainage network. Additionally, headwater streams have been investigated for their potential to predict global warming trends. There is an approximately one degree Celsius difference between the temperature of groundwater entering headwater streams and the mean annual temperature for a region. An increase in the groundwater temperature entering a stream not reflected in the surrounding landscape, may suggest possible global warming trends (Vannote and Sweeney 1980, Meyer and Wallace 2001).

Threats and Impacts

Humans have a pronounced influence on headwater streams (Plate 1998 and Burt 2003). These influences include impacts that do not remain within the local watershed boundaries or headwater streams, as these impacts may also have an influence on downstream systems as well as within the landscape (Haigh and Krecek 1991, Meyer and Wallace 2001).

The major anthropogenic impacts to headwater streams include deforestation, land conversion, mining, construction of roads, development, and to a lesser extent air pollution, which leads to increase in acid rain deposition. Air pollution and acid rain have been shown to have adverse effects on many ecosystems, particularly within Norway and Central Europe (Behiem 2000, Haigh and Krecek 1991). Within the boundary of headwater streams, human induced impacts may contribute to degraded water quality and aquatic ecosystems as well as a reduction in water supply (Meyer and Wallace 2001, Haigh and Krecek 1991).

Additional human influence of headwater streams may result from deforestation. Deforestation in the headwaters can result in the narrowing and eroding of stream channels, which may contribute to habitat losses of fish and invertebrates in these streams (Meyer and Wallace 2001). Also, changes to stream hydrology and an increase in the transport of nutrients may also result from deforestation activities. Consequently, changes in hydrology can result in increased flooding frequency, sedimentation in channels and reservoirs, as well as limiting water supply for municipalities as lower discharge to rivers may relate to water scarcity problems and increased water purification costs (Haigh and Krecek 1991).

Charoenphong (1991) reported in Southern Thailand, 14 provinces in the mountainous headwater regions of the country have large-scale issues resulting in the destabilization of soils on steep slopes, creating landslides. This destabilization is the result of conversions of dense forest to rubber plantations and timber harvest practices, leading to deforestation in these areas. Landslides coupled with the additional natural pressures of monsoons, sediment pollution to surrounding streams, and flood damages within the local villages resulted in the loss of hundreds of lives within Thailand villages, as well as damage and loss of property, agricultural land and infrastructures. Flood damages within the affected regions of South Thailand were estimated to be $259 million (US) in addition to a reduction in water supply due to pollution.

In the U.S., mining practices have been noted to have severe impacts on headwater streams. For example, in West Virginia, southwestern Virginia, eastern Kentucky, and eastern Tennessee, a method of mining referred to as mountain-top removal and valley fill, is used to mine coal. This method results in the filling or burial of streams with excess unwanted material sediments or earth. Downstream from the buried streams, in the larger stream network, sedimentation resulting from the mining activities has been noted as a serious problem destroying fish habitat, in-stream vegetation, and reducing water quality (Meyer and Wallace 2001).

Meyer and Wallace (2001) provided case studies where the construction of roads and increased developmental activities may be related to a decrease in drainage density. Headwater streams in watersheds that are developed or urbanized are usually piped and filled over with soil to increase construction area. This practice may reduce the amount of headwater streams in larger stream networks thereby further reducing drainage densities and capacities of the entire network. Additionally, functions important to the ecology and connectiveness of the system such as the retention of organic matter, nutrients, and water, may be greatly reduced (Meyer and Wallace 2001).

Despite the several human impacts to headwater systems, there are also several natural processes acting on these systems. Headwater streams and rivers in Taiwan are geologically young, steep, and receive heavy precipitation, which may lead to landslides. Although these lands are richly forested with no record of human activity, this region experiences frequent flooding and landslides which contribute to heavy debris flows within the stream channels (Cheng et al. 2002). When these natural processes are combined with destructive human activities the impacts on headwater streams may be magnified (Charoenphong 1991).

Catchment Geomorphology

Geomorphology relates to the study of landforms and the processes that create them as well as drainage areas which are formed by physical processes and flowing water (Chang 2003). Watershed geomorphology investigates the geomorphic characteristics of a watershed. Several geomorphic parameters may be calculated once the boundaries of a watershed are delineated. For example, size (drainage area), slope, shape, maximum and minimum elevation, and drainage pattern (Cech 2003). These parameters are very important in describing the behavior of streams within a given catchment area.

The geomorphology of a watershed is also a major determinant of stream flow (Chang 2003). For instance, knowing the shape of the entire watershed (i.e. circular or elongated) can give researchers an idea as to how fast runoff will reach the outlet and the duration of peak flows. The slope of a watershed can determine rate of water flowing over land surfaces as well as the volume of water within stream channels (Ward and Trimble

2004). Morisawa (1962) suggests that key components in the assessment of hydrologic flow behavior in a watershed include shape, relief, drainage area, stream length and frequency of stream channels.

Stream Mapping

Hydrological models and site planning for construction projects require the accurate mapping of stream channels (Heine et al. 2004). Methods with their base in Geographic Information Systems (GIS) technology are becoming more popular in the delineation of channels, watersheds, and the extraction of these characteristics for use in hydrological models (Tarboton and Ames 2001). GIS technology combined with the use of digital elevation models (DEMs) provides an increasingly valuable tool in hydrologic modeling of larger streams channels and networks. However, the ability to delineate headwater streams still presents a challenge as course resolution DEMs have been largely ineffective in detecting the finer “topographic signatures” that are a characteristic of these streams (Heine et al. 2004). However, newer sensors such as the Light Detection and Ranging system (LIDAR) may offer improved results.

Present methods used to map stream networks on the ground, all have varying degrees of accuracy. For instance, the blue lines on the USGS 1:24000 topographic maps created by the United States Geological Survey are used to describe stream networks in a given watershed, however this technique has traditionally proved to be very inaccurate for determining or identifying first order streams. Digital orthophotoquads have evolved as an efficient data source utilized in stream mapping and have resulted in accuracy estimates of up to 100% provided stream channels are not obscured by dense canopy cover (Heine et al. 2004). Another technique used to produce highly accurate stream network maps involves the use of LIDAR data. Results produced from initial uses of LIDAR indicated this procedure was able to effectively locate more stream channels than compared to other existing methods (University of Washington 2004).

Vogt et al. (2003) tested a new procedure for obtaining a drainage network from digital elevation data (i.e. DEMs). The method recognizes the variability in drainage patterns and is based on a variable threshold measurement of contributing area. In this study, researchers used a DEM with a 250-meter grid cell size, along with data on abiotic and biotic variables such as vegetation cover, soil and lithology, climate, and terrain morphology. The authors reported that this procedure can be used to develop drainage networks in addition to watershed boundaries on both a national and continental scale.

Stream Identification

Various ways currently exist in which streams are identified or classified and the method of classification may depend on the study or investigation that is being carried out, as well as who is conducting the research. Hydrologic flow characteristics of headwater streams can be used to classify streams being studied into unique hydrologic regimes known as reaches. Based on the flow characteristics of the headwater stream and the reaches of the stream, the headwater reaches may be further categorized as an ephemeral, intermittent, or perennial stream (Clifford 1966).

Hewlett (1982) defined the three stream types by flow regimes. Ephemeral streams (“dry wash” streams) are exhibit short periods of flow during a storm event or when snow has melted. Intermittent streams (“wet weather” streams) flow during periods of consistent rainfall, with flow lasting usually only a few months during the year. Perennial streams (“live-streams”) maintain water flow within their channels for the most of the year.

Stream orders are determined by the size and position of the stream and stream network within its watershed (Strahler 1957, Hansen 2001). Early work by Richard Horton (1932, 1945) quantified certain geomorphic characteristics of a watershed making it possible to calculate watershed area, drainage density and basin shape as well as provide concepts such as stream ordering to assist in qualitative description of streams. Horton's method of stream ordering involves the designation of unbranched, fingertip tributaries as first order. Second order streams were classified as streams that receive water from only first order tributaries. Finally, third order streams are those that receive tributaries from one or more second order tributaries as well as those from lower orders. In Horton's stream order scheme, the main stem in the network possesses the highest order designation.

Strahler (1957) modified Horton's stream order scheme and the Stahler method is now the most common method of describing or identifying streams based on size and location in a stream network (Hughes and Omernick 1981). Strahler's method of stream ordering assumes that all intermittent and perennial streams are located in defined valleys (Strahler 1957). In Strahler's scheme "fingertip" tributaries are considered exclusively first order streams. In areas where two first order streams connect, a second order stream channel is formed. A third order stream is created from the convergence of two second order streams, and so forth. Similar to Horton's method, the main stem or stream trunk in the river network is considered to represent the location where all water and sediments are discharged. This location is assigned the highest order within the stream network (Horton 1945).

Strahler contributed towards the efforts of quantifying various geomorphic parameters for watersheds by providing a simple non computerized method for determining drainage density and stream length (Morisawa 1957). In Strahler's method, a stream is inserted wherever the V-shape contours indicate the presence of a stream channel (Morisawa 1957). This method was tested against the traditional method, which involves the use of blue lines on maps. Both procedures were also compared to the results from field surveys and it was found that the use of blue lines to determine stream length from topographic maps were the least accurate compared to Strahler's method. However, in other studies Strahler's method was found to not differ greatly from the streams lengths calculated from field measures (Morisawa 1957). The author suggested that the use of blue lines recorded on most maps is inaccurate for measurements of stream lengths.

Parracchini et al. (2000) contributed to headwater research for the European Union by demonstrating that it is possible to estimate the total amount of headwater areas on a continental scale. This study used two procedures to identify headwater streams. The first method identified the smallest headwater streams. In the second method the origin of the stream network is considered to be at the intersection of two first order channels. Both procedures were applied through the development of ARCINFO codes to identify headwater streams for the entire European Union.

Geomorphic relationship studies

Morisawa (1962) quantified the geomorphology of some watersheds in the Appalachian Plateau which includes the Allegheny Mountains division, the unglaciated Allegheny Plateau, and Cumberland Plateau. The objective of this study was to create a mathematical relationship between stream flow characteristics and geomorphic parameters of a watershed. Morisawa (1962) found stream flow to be related to geomorphic characteristics such as stream length, drainage area, basin shape and relief, and frequency of stream channel. This study also suggested "discharge is proportional to the area of a watershed". Thus, as watershed area increases so does the amount of discharge flowing out of the systems. The relationships described in this study can assist in transforming information on watersheds from qualitative to quantitative**.**

Graves (2001), investigated the relationship between stream order and watershed geomorphology. This study used a combination of GIS and multiple linear regression models to analyze the data. It was determined that a model containing variables such as total relief and average slope may be a useful tool for determining stream order without having to incorporate stream data from the higher reaches within the stream network.

Jaegar (2004) investigated the source area-slope relationship that may exist for channel stream head locations and compared seasonal changes in surface water expression in streams underlain by two lithologies, sandstone and basalt. Jaegar discovered that surface water expression varied seasonally between the two lithologies, which suggest that each of the lithologies used in this study possessed different hillslope flowpaths. In addition, the author found that there was not a source area-slope relationship that existed for either lithologies used in this study. The lack of source area-slope relationship was attributed to a variety of geomorphic and physical parameters such as soil, narrow range of slope, bulk density, hydraulic conductivity etc. This study suggests the importance of understanding the environmental variability and the probability of these features representing confounding factors within a study.

Smith (2001) investigated the stream origins of first and zero order catchments in the Piedmont region of North Carolina. The randomly sampled study catchments were located in three different soil systems, which included Felsic Crystalline, Carolina Slate Belt, and Triassic. The author discovered that the geomorphology of first order streams differed among soil systems; therefore, suggesting that geology may be a factor in variability of first order catchments.

The United States Code of Federal Regulations created by the United States Office of Surface Mining and Reclamation (OSM) described conditions for placement of excess rock material in headwater stream valleys requiring that this material be limited to the ephemeral reaches of the watershed (Paybins 2003). Interpretation of this law by the U.S. District Court rulings in 1999 and 2002 permitted the placement of excess material in ephemeral streams. However, the spoil must not be placed within 100 feet of intermittent and perennial streams except when land use after mining activities have been completed is designated as development (Paybins 2003).

Work conducted by Paybins (2003) described the hydrologic and drainage characteristics of intermittent and perennial headwater streams in the coal mining region of southern West Virginia. She studied headwater streams in this region that were not affected by mining activities. The author discovered that points of intermittent and perennial flow within these streams varied with time suggesting that this variability in flow may be attributed to local environmental variables such as antecedent climatic conditions, evapotranspiration and drainage basin conditions. This study also suggests that local conditions within a watershed or drainage basin must be considered when identifying points of origin for intermittent and perennial streams.

Tsuboyama et al. (2000) and Sidle et al. (2000) identified the potential of zero-order basins to contribute to the stormflow and streamflow. Zero-order basins are basins that have no defined channel and drain sporadically throughout a watershed. Tsuboyama and colleagues (2000) in their investigation of zero-order basins indicated that zero-order basins become more responsive as a gradual rate of wetness increases. A conceptual hydrogeomorphic model formulated by Sidle et al. (2000) illustrated the role antecedent moisture conditions of soils can play in the generation of stormflow or runoff. In this model, under dry conditions, very little runoff occurred, and that channel interception and riparian zones through saturated overland flow were responsible for most of the storm flow generated in an area.

Brown et al. (1999), evaluating the role of water from snowmelt on summer flow, found that the snowmelt event water was a contributor to stormflow during dry climatic conditions in headwater catchments. However, this process decreased in importance as catchment size increased. In addition, these authors also found that as moisture content increased or if soil is very wet, zero-order basins became linked with the channel networks in the watershed. This concept may support efforts to protect headwater areas, since this conceptualizes the connectivity between adjacent uplands areas and stream networks (Sidle et al. 2000). Conversions of zero-order basins into channelized flows may further increase the probability of these streams to transport nutrients and heavy metals, thus affecting water quality.

In catchments that have not experienced development, it is believed that transient and saturated areas, which are contiguous to a stream, produce rapid stormflow runoff. This has been demonstrated by attempts to describe the relationship between saturated areas and topography and soil through the use of various mathematical formulas (O’Loughlin 1981). This study found that the size of the contributing area of runoff is dependent on topographic, soil, and flow parameters, and is dependent on idealized slopes. This relationship has also been identified for gradational soil profiles (O’Loughlin 1981).

Aryal et al. (2003), in an investigation to identify the actual portion of the hillslope within a catchment that contributes to streamflow used factors such as topography and other descriptive characteristics including soil, hillslope shape, and rainfall frequencies to predict hydrologic response. The results from this study after examining the study catchments for over 24 years supports the finding of O'Loughlin (1981) who reported that catchment runoff in certain areas of a watershed may be dependent specific relationships within the topography as determined through the generated hillslope. The implication of this study is that additional research is needed to learn more about contributing areas to stream flow in a catchment as well as the need for better management of watersheds given that there is a lot be learned even now about the catchment-stream relationship.

Headwater areas of a watershed, specifically the upper portions of first order streams, may have antecedent soil moisture conditions, which can play a major role in triggering runoff to adjacent channels (Tsuboyama et al. 2000, Sidle et al. 2000, and Aryal et al. 2003). Additionally, various geomorphic variables such as stream length, drainage area and basin shape may have a significant influence on the hydrology of headwater streams (O'Loughlin 1981).

Increased recognition of the importance of headwater streams in the United States and in other parts of the World (i.e. Taiwan) has sparked an interest in increasing our understanding of these relatively under explored systems. Conducting research is very important for the thorough investigation of small first and second order streams to develop a better understanding of how these systems work. Additionally, further knowledge is required for effective regulatory and managerial purposes.

There still remains a great need for further research on headwater streams with respect to their hydrology and how various geomorphic characteristics may influence it. Conducting such research is imperative to the development of headwater stream studies not only in the United States, but throughout the World, as our fresh water quality and supply depends upon it.

Aquatic Macroinvertebrates

Macroinvertebrates are ubiquitous in many aquatic systems throughout the world. Freshwater macroinvertebrates represent less than 3% of all insects possessing aquatic lifestages, however they also represent over 95% of insects found in all freshwater environments (Daly 1984 and Ward 1992). Thirteen orders of insects are known to exhibit aquatic stages as well as semi-aquatic life stages. Orders, such as Ephemeroptera, Tricoptera, Odonata, Plecoptera, and Megaloptera are comprised of species that remain mostly aquatic throughout the life of the organism. The remaining eight orders (Hemiptera, Collembola, Orthoptera, Lepidoptera, Neuroptera, Hymennoptera, Diptera, and Coleoptera) consist of species that are both terrestrial as well as aquatic or semi aquatic (Table 1.1).

Table 1.1 The aquatic association between the thirteen insect orders that exhibit aquatic stages.

ORDER	Aquatic Association
Ephemeroptera	Aquatic
Odonata	Aquatic
Tricoptera	Aquatic
Plecoptera	Aquatic
Megaloptera	Aquatic
Hemiptera	Terrestrial, Some aquatic
Collembola	Terrestrial, Some aquatic
Orthoptera	Terrestrial, Some Semi-aquatic (No Aquatic)
Lepidoptera	Terrestrial, Some aquatic
Neuroptera	Terrestrial, Some aquatic
Hymenoptera	Terrestrial, Some aquatic
Diptera	Terrestrial, Some aquatic
Coleoptera	Terrestrial, Some aquatic

*Table 1.1 partially adapted from Table 1.1 of Ward, 1992

Aquatic macroinvertebrates inhabit a wide variety of environments in both lentic and lotic freshwater systems. Both systems offer a very diverse range of aquatic environments. Lentic systems include lakes, ponds, and even freshwater wetlands such as swamps and wetlands. Lotic systems include streams, rivers, springs and brooks. Despite the differences in structure and zonation between these habitats, all 13 orders of macroinvertebrates have been identified in both environments (Ward 1992).

The bottom substrate of lotic systems, specifically streams, can be divided into two components; the surface benthic area and the hyporheic zone. In addition, macroinvertebrates may be categorized as either surface benthos or hyporheic fauna. Macroinvertebrates that live in the hyporheic zone are exposed to different environmental conditions (i.e. current, light, and lower temperature as depth increases) than surface benthos (Ward 1992). In the past 30 years, the hyporheic zone has acquired a lot of attention with reference to its ecological role and many studies have investigated the relationship between diversity and distribution of macroinvertebrates in the hyporheic zone to environmental parameters such as particulate organic matter (POM) and bacterial activity etc. (Storey and Williams 2004).

River Continuum Concept

Within most aquatic stream systems macroinvertebrate communities may occur along a gradient ranging from the headwaters to lower reaches of a watershed. This gradient has been characterized as the River Continuum Concept (RCC) theory (Vannote et al. 1980, Ward and Trimble, 2004). According to the RCC, macroinvertebrates identified as shredders and collectors tend to be the dominant communities in headwater streams, whereas in mid-order streams (orders 4-6), grazers become abundant. In lower reaches, where the streams flow into rivers (orders > 7), macroinvertebrates identified as collectors become the dominant macroinvertebrate community. However, deviations from the RCC macroinvertebrate distribution patterns may be due to human alteration to these systems (Ward and Trimble 2004).

Few studies have investigated macroinvertebrate communities within headwater streams in comparison to larger streams and rivers (Cole et al. 2003). Meyer and Wallace (2001) suggested that headwater streams may serve as habitats for unique and diverse communities of macroinvertebrates and that learning more about the functions of headwater streams within watersheds may increase the knowledge about the role these streams play in the drainage network and may contribute to better management (Meyer and Wallace 2001 and Price et al. 2003).

Studies conducted by Cole et al. (2003), Price et al. (2003) and others; describe the macroinvertebrate communities of headwater streams under different forest conditions such as managed, old growth, and clearcut forests in an effort to provide additional information in the current knowledge gap pertaining to macroinvertebrate communities in headwater streams. Therefore, the use of macroinvertebrates as indicators of water quality may be very important in these systems (Cole et al. 2003).

Hyporheos

Macroinvertebrates, in addition to being found in the surface benthic zone, may also occupy a niche within the interstitial spaces of the stream bed sediments. This subbenthic zone is known as the hyporheic zone (Ward 1992). Aquatic insects within the hyporheic zone have been found at depths of 30cm or more (Ward 1992). The hyporheic zone is also recognized as an area where both ground water and surface water within the stream channel meet (Bencala 1993). This extent varies dramatically, as this zone may depend on the degree of surface and groundwater interaction (Hancock 2002). Hyporheic zones with larger extents are common in areas of alluvial deposition, composed of coarse sand and gravel usually derived from crystalline rock. Whereas stream bed composition in areas of solid bedrock or compact clay lack a hyporheic zone (Ward 1992).

Macroinvertebrates that dwell in the hyporheic zone are referred to as hyporheic fauna or hyporheos (Ward 1992). Hyporheic fauna are divided into two categories. The first category consists of fauna that are only found in the substrate and are not normally found at the benthic surface or in the water column. For example, certain groups of crustaceans, mites and nematodes are organisms that may be considered permanent residents of the hyporheic zone. The second group is composed of macroinvertebrates that spend part of their lives in the hyporheic zone and the other part of their life in the surface benthos (Ward 1992).

The hyporheic zone may also serve as a potential refuge for macroinvertebrates against disturbances such as drought, flood, and extreme temperatures, as interstitial or pore water may be retained during these periods (Ward 1992). However, conclusive evidence of this use of the resource by macroinvertebrates is currently unavailable. Studies by Del Rosario and Resh (2000) found that although the densities of macroinvertebrates on the substrate surface or in the pooled water had decreased, when baseflow declined and stopped, the hyporheic zone may not have provided a suitable refuge for macroinvertebrates when the stream dried. Despite the lack of evidence supporting the use of the hyporheic zone as a habitat by macroinvertebrates in times of channel bottom drying Del Rosario and Resh (2000) were still convinced that in times of substrate surface drying the hyporheic zone may provide critical habitat functions for macroinvertebrates on the surface allowing for recolonization of the surface waters after a drought. The authors suggested that a lack of drought tolerance may explain the lower taxon densities, richness, and diversity found in intermittent streams as compared to perennial streams.

Palmer et al. (1992) also tested the hyporheic zone capacity to serve as a refuge for macroinvertebrates. However, the authors investigated the use of the hyporheic zone during flooding as opposed to use during drought as in the Del Rosario and Resh (2000) study. Palmer et al. (1992) results could not explain fauna recovery in streams that experienced flooded conditions suggesting that the hyporheic zone may not serve as a refuge during high flows or a source for recolonization for macroinverterbrates (meiofauna) after a stormflow event.

Flow Persistence

Macroinvertebrate communities exhibit variations seasonally and spatially within a stream (Cowell et al. 2004). These variations may be directly related to levels and volumes of water flow within the stream channel. Cowell et al. (2004) discovered that the total percent densities of benthic macroinvertebrates exhibited seasonal variations throughout the year. Percent densities ranged were 37% in the fall, to 33.3% in the winter, 22.9% in the spring and 31.9% in the summer. In addition, this study found streams also varied on a seasonal basis with the winter and spring being the seasons with the most similar macroinvertebrate densities. The authors also suggested that variations may be related to perturbations such as a spring drought, slow colonization by invertebrates, and/or low dissolved oxygen content during the summer season (Cowell et al. 2004).

Price et al. (2003) while studying streams in Cliyoquot, British Columbia discovered that insect communities became dominated by shredders in both clearcut and old-growth forests as stream flow decreased. Intermittent streams in this study possessed more shredders than perennial streams, but less than ephemeral streams. The researchers suggested that this dominance may be attributed to a decline in the other functional feeding groups when stream persistence decreased. In addition, the absolute abundance of shredders was observed to increase as stream flow decreased. Price et al. (2003) also found that 4 to 8-yr old, post-clearcut forests possessed different aquatic communities than old-growth forests. This study provides evidence that stream flow variability affects the species present in macroinvertebrate communities and possibly abundance.

Shivago (2001) also investigated the communities of invertebrates in an intermittent and perennial stream. Two streams were classified based on their flow durations. The intermittent stream possessed a dry period whereas the perennial stream was expected to flow year round. Shivago (2001) found that the mean abundance and number of species were higher in the permanent perennial stream than in the intermittent. However, the faunal composition was largely similar as there was only a slight difference in community structure.

Carla Delucchi (1988) compared community structure of streams with different temporal flow regimes. The researcher suggested that community structure along temporary and permanent streams may be a function of a variety of both abiotic and biotic factors including substrate, stream size, length of dry period, and distance from possible source of colonizers, current speed and seasonal changes. The author found that differences in community structure may be attributed not only to duration of flow in riffles, but to seasonal changes in benthic invertebrate taxa, stream size and when and how long riffles have been dried. Despite the advances of Delucchi (1988), Cowell et al. (2004), and Shivago (2001) there still exists a need to understand differences in community structure in relations to flow regimes.

Macroinvertebrates as bioindicators

Urban development and agriculture represent significant sources of non-point source pollution in the Southeastern United States. Controlling discharges from these areas may also represent an important factor influencing water quality in this region (West 2002 and Potter et al. 2004). Besides water quality, nonpoint source pollution can also affect organisms that inhabit streams by reducing abundances, limiting recolonization, and degrading habitat suitability (Chen et al. 1994, Karr 1999, Potter et al. 2004). The use of macroinvertebrates to monitor the accumulation of heavy metals as well as insecticides in streams has been investigated by other researchers (Muirhead-Thomson 1987, Johnson et al. 1993 and Wallace and Webster 1996). Additional studies have used aquatic insects to assess the level of human induced disturbance to stream and lake systems thus, demonstrating the value of studying macroinverterbrate communities in headwater streams (Wallace and Webster 1996).

Ohio’s Environmental Protection Agency (OEPA) uses biological assessment methods in addition to water samples to classify streams according to one of five different aquatic life habitats (Ward and Trimble, 2004; Table 1.2). The aquatic life habitats are determined by various bioassessment indices such as the qualitative habitat evaluation index (QHEI), the index of biotic integrity (IBI) among others (Karr 1981, Fausch et al. 1984, Karr et al. 1986, Ward and Trimble 2004). However, the QHEI method has certain limitations. For example, streams have watersheds less than 7.77km^2 in area are classified as a limited-resource water habitat, assuming that no important aquatic life inhabit streams of this size. To address this limitation, a headwater habitat evaluation index (HHEI) was created to assess habitats for organisms (macroinvertebrates, salamanders etc.) that may be found in these small streams (Ward and Trimble 2004).

Table 1.2 Description of aquatic life habitats for categorizing streams in Ohio by the OEPA.

Aquatic life habitats	Description
Warm-water habitat (WWH)	The majority of streams and rivers in Ohio that are targeted for management.
Exceptional warm-water habitat (EWH)	Streams and rivers in Ohio that possess “unusual and exceptional” communities of aquatic organisms.
Cold-water habitat (CWH)	Represents streams that sustain cold-water organisms or are stocked with salmonids with the intention of providing a yearly put and take fishery.
Modified warm-water habitat (MWH)	Streams and rivers that have experienced extensive hydro-modifications, to the extent that WWH uses are not attainable. Organisms inhabiting these types of environment are tolerant of poor habitat quality, low dissolved oxygen content, and high suspended solids concentrations.
Limited-resource water habitat (LRW)	This represents streams that have a drainage area less than 3mi^2. In addition includes streams and rivers which do not support a significant combination of aquatic life.

*Table adapted from information provided by Ward and Trimble (2004).

Roy (2003) found that urbanization of a catchment created a shift in macroinvertebrate communities, causing the dominance of more tolerant species of macroinvertebrates and a less diverse macroinvertebrate community in affected catchments. Lenat and Crawford (1994) also observed a similar relationship between urban landcover and macroinvertebrates communities. In the Lenat and Crawford (1994) study, urban streams were found to have lower taxa richness and an increase in tolerant groups of invertebrates, such as the Oligochaeta, when compared to streams that were located in forested and agricultural areas.

Jones and Clark (1987) compared the macroinvertebrate communities of urbanized streams to those of unurbanized streams and found that in less urbanized streams, orders such as Plecoptera, Diptera, Ephemeroptera, Tricoptera, Coleoptera, and Megaloptera, had great representation in the stream. However, in some of the highly urbanized streams the dominant orders were found to be Diptera and Tricoptera. Work by Jones and Clark (1987) suggests that sensitive species become less dominant in urbanized systems whereas tolerant species prevail in these systems.

Summary

Macroinvertebrates in headwater streams both play an integral role in the lotic environments of stream networks. They provide important ecological functions such as litter decomposition and nutrient processing (Gage et al. 2004). Headwater streams provide protection against flooding in addition to providing a site for nitrogen transformation and retention in large watersheds along with other functions (Peterson et al. 2001). Together, understanding headwater streams and macroinvertebrates may help land managers and decision makers to adopt better landuse practices to maintain and improve water quality. Studies such as those conducted by Cole et al. (2003), Price et al. (2003), Cowell et al. (2004) and others have addressed various questions about macroinvertebrates, their communities' structure as well as potential hydrologic influence on their distribution and densities. While some of these studies pertained to headwater streams and may address some questions pertaining to macroinvertebrates in these streams, there is still much more to learn about macroinvertebrates in headwater streams.

The hyporheic zone has gained much attention as more is learned about its connection to the stream and possibly the catchment as a whole. However, current research has yet to establish the linkage between the hyporheic zone, macroinvertebrate communities, and headwater streams. Furthermore, little is known about the impacts that humans have on the hyporheic zone (Hancock 2002)

Maintenance of pristine water quality is essential to the successful ecology and sustainability of our environment. Studies such as those carried out by Jones and Clark (1987), Lenat and Crawford (1994), and Roy (2003) suggest macroinvertebrates are good indicators of water quality within a stream. Understanding what additional functions macroinvertebrates provide, especially in headwater streams is essential.

Technologies such as Geographic information Systems (GIS) and Global Positioning System (GPS), including the use of statistical analysis and digital modeling have contributed to the advancement of hydrological studies. With these techniques, we can investigate relationships between the hydrology of a basin and various geomorphic and environmental variables, accurately map the positions of streams, or delineate a drainage basin or stream networks (Paracchini et al. 2000, Vogt et al. 2003)**.** These techniques have increased the accuracy of certain processes such as stream mapping and delineation deriving such features from digital elevation data, i.e. DEMs (Tarboton and Ames 2001, University of Washington 2004). Despite the many advances in technology to improve the mapping of stream networks, field investigations are still necessary to validate the measurements made with the use of a GIS (desktop analysis) or GPS units (Morisawa 1957 and Hansen 2001). Field reference information is also necessary to compare the observed macroinvertebrate community structure to the expected community structure of a stream for correlative analyses (Lenat 1987). To manage our water resources in a sustainable manner, an understanding of the relationship between macroinvertebrates and headwater streams is necessary for the successful management of our water resources.

There is a limited amount of knowledge pertaining to headwater streams and the abundance of macroinvertebrates inhabiting these environments in the current literature. Even less information is known about the specific hydrology of headwater streams therefore, research is necessary to describe the flow regimes from ephemeral to intermittent to perennial segments and to determine the influence of streamflow characteristics or stream flow duration on macroinvertebrate abundance found in streams.

HEADWATER STREAMS AND MACROINVERTEBRATE RELATIONSHIPS

INTRODUCTION

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The objective of this study was to determine the relationship between headwater streams and macroinvertebrate abundances through repeated field measurements of water depth and seasonal macroinvertebrate collections. The approach used involved statistical analyses to determine the relationship between headwater stream water depths and macroinvertebrate variables such as total taxa, aquatic taxa, terrestrial taxa, abundances, and aquatic abundances for eight headwater streams used in this study. An additional objective also included the analysis of the measured headwater stream water depths to evaluate the effectiveness of the North Carolina Division of Water Quality (NCDWQ) Stream Classification Method (NC Division of Water Quality 1999, 2005).

METHODS

Experimental Design

Eight headwater stream catchments were selected in the Piedmont Region of North Carolina. To reduce the possibility of variations in headwater stream geomorphology influencing the hydrologic regime, all streams were selected within the Felsic Crystalline soil system (Daniels, et al. 1999). Each catchment was composed of one or more ephemeral streams that discharge(s) into one or more intermittent streams that discharge to a perennial stream (i.e. ephemeral-to-intermittent-to-perennial headwater stream network). Additional measures were taken to ensure stability of the stream geomorphology and flow regime:

1. Catchments were located in forested watersheds consisting of forest stands that are all at least 60-70 years of age all met the first criterion.

2. Streams were selected within the study catchments which have been relatively stable and exhibited little or no apparent accelerated channel erosion in recent years.
3. Catchments did not receive any significant runoff from developed areas or impervious surfaces, including road ditch discharge.
4. Study catchments contained either (1) a single first order (intermittent) stream or (2) two or more first order streams draining to a second order stream with a transition from ephemeral to intermittent to perennial and a stream order sequence from first to second to third order.
5. Each catchment represented a replication within the soil system for the comparison of the characteristics of ephemeral, intermittent, and perennial streams and their catchments.

Reach Determination

The headwater streams used in this study were divided into reaches. Visual assessment was used to identify areas where stream geomorphology changed, thus signifying a reach change. For instance, similar geomorphic characteristics such as successive riffle/ pool sequences would identify a reach. Where that sequence of riffle/pool ends, and a run characteristic becomes the prevalent geomorphic characteristic a new reach segment would be designated.

Catchment Delineation

Stream hydrological measurement points were mapped using a Leica submeter accuracy Global Positioning System (GPS) unit. The mapped stream points, along with 20 feet LIDAR DEM for the study areas were used in the ArcGIS application Arc Hydro to delineate the catchment boundaries of the headwater streams used in this study. Catchment area and perimeter were computed in this application.

Study Area

All catchments used in this study were located in Wake County, North Carolina (Figure 2.1). This area is situated within the Piedmont physiographic region in North Carolina, which is considered a transitional area between the Coastal Plain and Mountainous regions of the State. The Piedmont is characterized by gentle slopes with altitudes ranging from 200 feet along the border of the Coastal Plains to 1500 feet at the base of the Mountains (Griffith, et al. 2002). The Piedmont Region is composed of four major geologic units among which soils and geomorphology differ. These include: 1) the Felsic Crystalline terrains; 2) the Carolina Slate belt; 3) the Triassic basins and 4) the mixed Mafic and Felsic rock (Daniels et al. 1999). However, all headwater catchments used in this study were entirely encompassed within the Felsic Crystalline soil system series to minimize variation in soils and geomorphology.

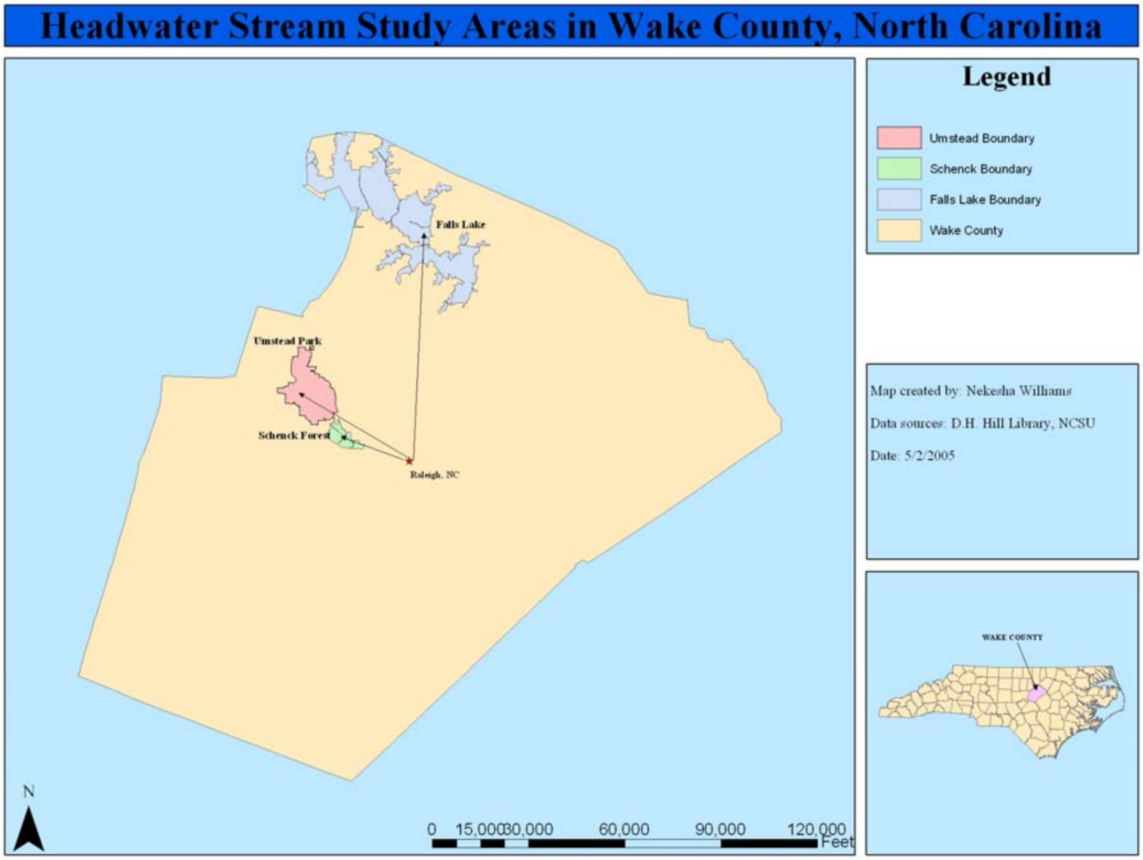


Figure 2.1: Map of the Study areas within Wake County, North Carolina

Geology and Soils

The Felsic Crystalline soil system is found in the central, western Piedmont area and North of Raleigh (Daniels et al. 1999). Its' bedrock is composed of mica schists, mica gneiss, granite and granite gneiss (O'Brien and Buol 1984 and Daniels et al. 1999). Within this soil system the topography of the landscape varies. In the upland areas; broad gentle slopes are common as well as moderate to steep sloping areas possessing narrow convex ridges and steep valley slopes (Daniels et al. 1999). The major soil series that are present within the study catchments also included Cecil, Enon, Georgeville, Madison, Mantachie and

Wake. However, Cecil and Madison appeared to be the two most dominant soil series within this area.

A list and brief description of the soil mapping units found within each study catchment are provided in Table 2.2 and Appendix 1 contain maps of the distribution of soil mapping units for each of the headwater stream study catchments. In addition, the soil types found and described in this study were based on information provided by Wake County Soil Survey (Cawthorn 1970) and the NRCS Official Soil Series Description (OSD) webpage [http://soils.usda.gov/technical/classification/osd/index.html]

Cecil soils are well drained, deep Piedmont soils found on gentle to steep slopes in the upland areas. Soils in this series are formed from gneiss, schists, and acidic rock and are located in the Northern and Central part of Wake County. The water table level is maintained below the solum, permeability classified as moderate and runoff is medium to rapid (Cawthorn 1970, OSD 2005). The taxonomic classification for this soil series is fine, kaolinitic, thermic Typic Kanhapludults (OSD 2005)

Soils in the Enon series are generally deep, well drained soils that possess slow permeability and medium to rapid runoff (OSD 2005). These soils can be found on sideslopes and ridge tops in the Piedmont region that are deep to saprolite and bedrock. The Enon soil series are formed from materials such as diorite, gabbro, diabase, or horneblende gneiss or schist. The taxonomic class for this soil series is fine, mixed, active, thermic Ultic Hapludalfs (OSD 2005).

Another soil series that can be observed in two of the study catchments is the Georgeville soils series. The soils in this series are well drained, deep soils that experience moderate permeability and exhibit a medium runoff rate. The parent material for the

Georgeville soil series is fine grained metamorphic rocks of the Carolina Slate Belt. Georgeville’s taxonomic classification is fine, kaolinitic, thermic, Typic, Kanhapludults (OSD 2005).

The Madison soil series often found in association with Cecil soils due to variability in bedrock geology, is another soil that can be found within some of the study catchments (Daniels et al. 1999). The Madison soil series can be found in fairly small areas in the northern region of Wake County. These are gently sloping to moderately steep, deep well drained soils in the Piedmont uplands. Madison can also be observed on side slopes and on rounded divides (Cawthorn 1970). Permeability of Madison soils are classified as moderate and runoff of water is medium to rapid (OSD 2005). The taxonomic classification of this soil series is fine, kaolinitic, thermic Typic Kanhapludults (OSD 2005).

The Mantachie soil series, found in one of the study catchments is a deep and somewhat poorly drained soil located in the depressions and headwater valleys of the Piedmont. Mantachie soils were formed from alluvium washed from surrounding uplands soils during extensive agricultural use of the piedmont region in the late 1800’s and early 1900’s (Cawthorn 1970). These soils may also experience periods of flooding that may recede quickly or last for long durations. The water tables in Mantachie soils can be as high as 1.0-1.5 feet below the surface in the late winter and spring when precipitation is high. Permeability for this soil series is moderate and runoff is rated as slow. The taxonomic classification for this soil series is fine-loamy, siliceous, active, acid, thermic Fluventic Endoaquepts (OSD 2005).

The Wake soil series is comprised of soils that are shallow, sandy, and excessively drained soils and that are located in upland areas in Wake County, North Carolina.

Relatively resistant granite and gneiss are the parent materials for this soil series producing relatively small units that are much shallower than surrounding soils. Wake soils are highly (rapid) permeable and runoff is characterized as moderate to rapid. The taxonomic classification for this series is mixed, thermic Lithic Udipsamments (OSD 2005).

Climate/Landuse History

The Piedmont of North Carolina experiences a wide range of climatic variability with average maximum summer temperature of approximately 86 degrees Fahrenheit, and average winter temperature of 51degrees Fahrenheit (State Climate Office 2005). Summer presents the greatest amount of rainfall within the month of July, which is characterized as being the wettest month. November is the driest month of the year, with autumn being the driest season. Low pressure storms during the winter and spring contribute to precipitation occurring in those seasons (NC State Climate 2005). Wake County experiences a warm, humid climate where the average annual temperature is 61 degrees Fahrenheit. The average monthly temperatures range from 42° in January to 79° Fahrenheit in July (Cawthorn 1970). Precipitation is well distributed throughout the county, receiving on average 46.9 inches annually. In addition, there are small variations in climate from place to place throughout the county (Cawthorn 1970).

Successional pine (*Pinus taeda*) currently dominates lands once used for agriculture in the Piedmont of North Carolina. In areas that were unsuitable for agricultural purposes hardwoods species are typically dominant species of forest. However, these forest systems have in the past experienced anthropogenic disturbances such as grazing and selective harvesting of timber (Healy 1985 and Taverna et al. 2005).

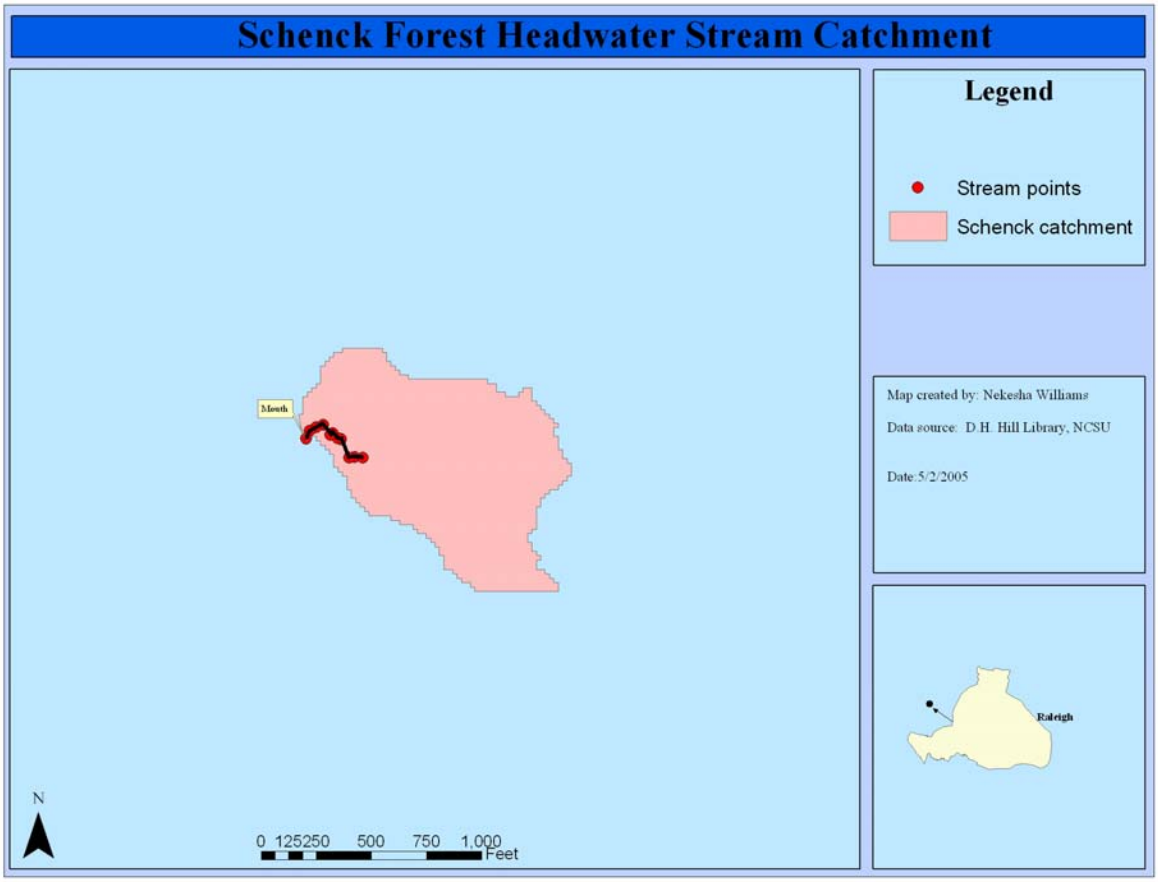
INDIVIDUAL STUDY SITES

Schenck Memorial Forest

Schenck Memorial Forest was established in 1936 in commemoration of Dr. Carl Alwin Schenck who founded the first forestry school in the United States known as the Biltmore School of Forestry located near Asheville, North Carolina. Schenck Forest is a 245-acre multiple use forest system managed by the Department of Forestry and Environmental Resources at North Carolina State University. The Forest is located in the Western portion of Wake County within the city of Raleigh. This area is protected from urbanized development and is used for teaching, research and recreational purposes (NCSU 2005).

The study catchment, containing a single first order stream referred to as Schenck, receives no runoff from the forest trail system or nearby unpaved roads (Table 2.1 and Figure 2.2). The soil type and texture identified within the Schenck Forest catchment included Cecil sandy loam (CeB2, CeC2, CeD, CeF) and Cecil gravelly sandy loam (CgB2, CgC2) (Cawthorn 1970). Table 2.2 and Appendix 1 include a brief description of the soil mapping units and the distribution of soils within each catchment.

The forest stand located in the study catchment is a loblolly pine (Pinus taeda L.) plantation established in 1936 that has a mid-story of successional hardwood species. The stand has thinned several times and parts of it have received several prescribed burns in the past. However, no management activity had occurred in the last several years prior to study establishment and none occurred during the study.



Map created by: Nekesha Williams

Data source: D.H. Hill Library, NCSU

Date:5/2/2005

Figure 2.2: Schenck headwater stream catchment.

William.B. Umstead State Park

Established in 1943 when the federal government deeded the land to North Carolina, this park consists of 5,439 acres of undisturbed land located between the cities of Raleigh, Cary, and Durham. This park like all others in this study provides multiple use benefits such as recreation, education and research to the neighboring communities. The unmanaged forest stands in the Umstead Park consist of two principal forest types: (1) old field pine stands with successional hardwood mid-stories and (2) significantly older mixed hardwood stands.

Two of the eight headwater streams used in this study are located in Umstead Park were used in this study; one on the Northern end (referred to as Umstead 1) and the other on the Southern end of the park (referred to as Umstead 2; Table 2.1). These streams are located in areas that are inaccessible to visitors and receive no runoff from nearby gravel packed roads. Within the Umstead State Park study catchments, the major soil series present are: Cecil, Georgeville, and Wake. Specifically, in the first catchment (Umstead 1), the types/textures included Cecil gravelly sandy loam (CgB, CgB2, and CgC2), Georgeville silt loam (GeB, GeC, and GeD2) and Wake soils (Wke). In the second catchment (Umstead 2), the soil types/textures that is present are Cecil sandy loam (CeF), Cecil gravelly sandy loam (CgB2, CgC2), Cecil clay loam (ClB3, ClC3) and Georgeville silt loam (GeB2, GeC2, and GeD2) (Cawthorn 1970). Table 2.2 and Appendix 1 include a brief description of soil mapping units and the distribution of soils within each catchment.

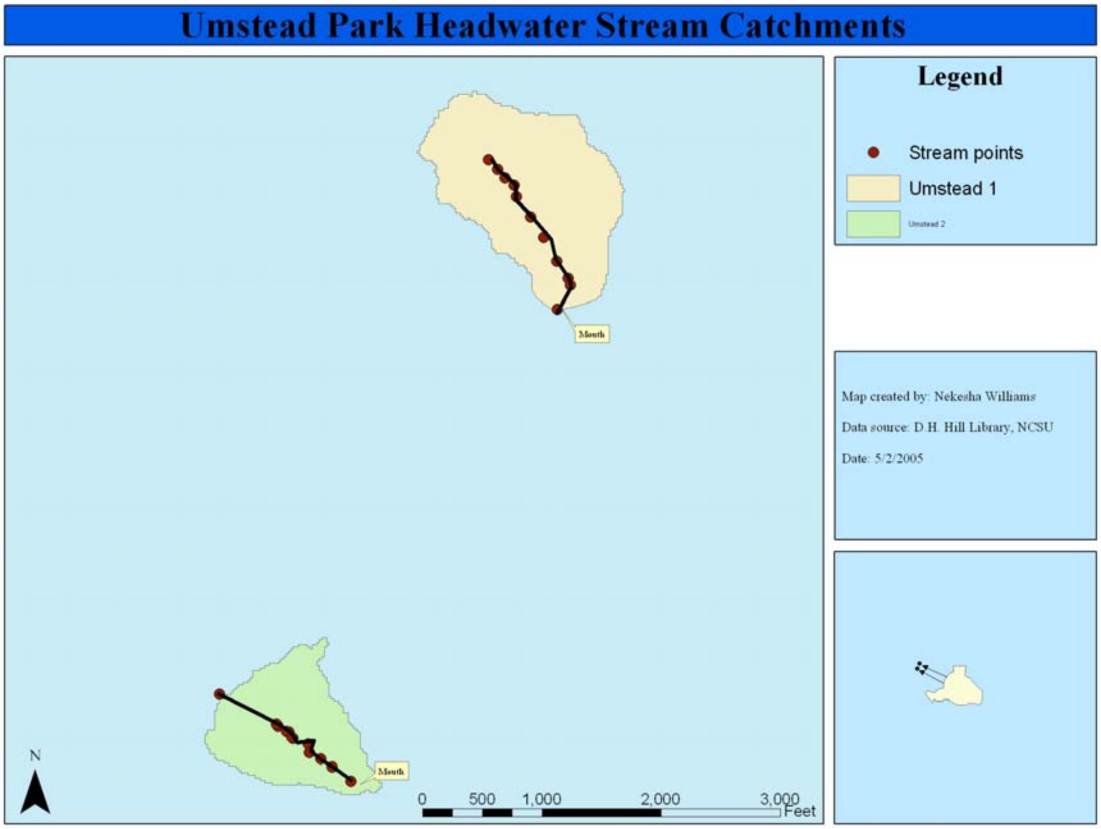


Figure 2.3: Umstead Park's headwater stream catchments.

Falls Lake State Park: B.W. Wells Area

Falls Lake State park is a recreational area that was designated by the state in 1965 and that borders Falls Lake, a large reservoir on the Neuse River. This park exists as a part of the North Carolina State park system within the greater Raleigh area. Similar to the other forests described above, Falls Lake State Park is primarily an undisturbed area that is surrounded by urbanized areas. Five headwater streams (referred to as Falls 1-5; Table 2.1) are located within the 44 acre B.W. Wells Interpretive Area (UNC-Falls Lake, 2005). These streams are situated in areas that are inaccessible to the public and there are no trails adjacent to the streams nor do they receive runoff from nearby gravel pack roads. The forest communities in all five study catchments consists of mixed-age mixed hardwood stands.

In the first study catchment (Falls 1), the soils series with in this catchment are Cecil, Enon, Madison, and Mantachie. The specific soil types/textures include Cecil sandy loam (CeB2, CeC2, CeD, CeF), Cecil gravelly sandy loam (CgB2, CgC2), Cecil clay loam (ClB3), Enon fine sandy loam (EnB2, EnC2), Madison sandy loam (MdE2), and Mantachie (Me) (Cawthorn, 1970).

Falls 2, Falls 3, and Falls 4 study catchments were dominated by the Madison and Cecil soil series. In study catchments labeled Falls 2 and Falls 3, the soil types/ textures that are present are Cecil gravelly sandy loam (CgB2, CgC2) and Madison sandy loam (MdB2, MdC2, MdE2). In Falls 4 the dominant soil series were also Cecil and Madison (Cg, CgC2, MdB2, MdC2, MdE2); whereas in Falls 5 study catchment, the sole soil series/texture present was Madison sandy loam (MdB2, MdC2, MdD2, MdE2) (Cawthorn 1970).

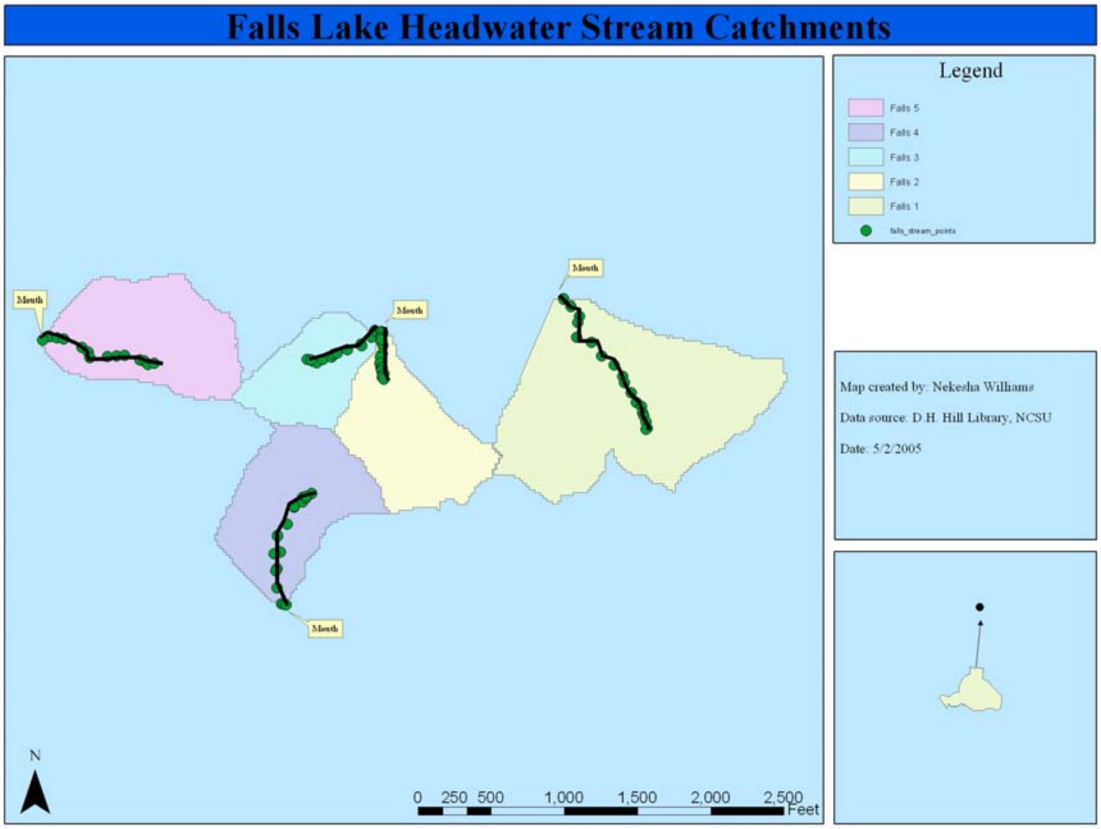


Figure 2.4: Falls Lake headwater stream catchments.

Table 2.1. Headwater stream study sites.

Location	Headwater Stream Name
Schenck Memorial Forest	Schenck
Umstead State Park	Umstead 1
	Umstead 2
B. W. Wells Park (Falls Lake)	Falls 1
	Falls 2
	Falls 3
	Falls 4
	Falls 5

Table 2.2. Basic description of soil types present within study catchments.

Soil Type/Texture[a]	Slope[b] %	Infiltration[c]	Runoff[d]	Study streams[e]
Cecil sandy loam				
CeB2	2 to 6 (eroded)	fair	medium	S1,F1
CeC2	6 to 10 (eroded)	fair	rapid	S1, F1
CeD	10 to 15	fair to good	very rapid	S1, F1
CeF	15 to 45	fair to good	very rapid	S1, U2, F1
Cecil gravelly sandy loam				
CgB	2 to 6	good	moderate	U1
CgB2	2 to 6 (eroded)	fair	medium	S1,U1,U2,F1, F2,F3, F4
CgC2	6 to 10 (eroded)	fair	rapid	S1,U1,U2, F1, F2, F3, F4
Cecil clay loam				
ClB3	2 to 6 (severly eroded)	poor	rapid	U2, F1
ClC3	6 to 10 (severly eroded)	poor	rapid	U2
Enon fine sandy loam				
EnB2	2 to 6 (eroded)	fair	medium	F1
EnC2	6 to 10 (eroded)	fair	rapid	F1
Georgeville silt loam				
GeB	2 to 6	good	medium	U1
GeB2	2 to 6 (eroded)	fair	medium	U2
GeC	6 to10	good	rapid	U1
GeC2	6 to 10 (eroded)	fair	rapid	U2
GeD2	10 to 15 (eroded)	fair to good	very rapid	U1,U2
Madison Sandy Loam				
MdB2	2 to 6 (eroded)	fair	medium	F2, F3, F4
MdC2	6 to 10 (eroded)	fair	rapid	F2, F3, F4
MdD2	10 to 15 (eroded)	fair	very rapid	F4, F5
MdE2	15 to 25 (eroded)	fair	very rapid	F2, F3, F4,F5
Mantachie				
Me	0 to 4	good	slow to medium	F1
Wake soils				
Wke	10 to 25	good	very rapid	U1

a. Soil type/texture: This is a list of the different mapping units for the soil series present in the study catchments.

b. Slope: The percentage slope for the mapping units present and well as their degree of erositivity.

c. Infiltration: This provides the infiltration rank/range for each soil mapping unit.

d. Runoff: This provides information about the level of runoff that a soil unit may exhibit.

e. Study streams: S1: Schenck; U1: Umstead 1; U2: Umstead 2; F1: Falls 1; F2: Falls 2; F3: Falls 3; F4: Falls 4; and F5: Falls 5

Stream Data Collection

Stream flow data were collected on a weekly basis for eighteen months for each stream within each of the eight headwater stream watersheds. A flow or water table measurement point was designated at the approximate longitudinal center of each study sub-reach on each stream. The measurements consisted of measuring depth of flow at the thalweg or depth of the water table below the channel bottom when visible flow was absent. Data collection began in late May, 2003 and ended in early December, 2004. Water table monitoring wells were used to monitor water table levels in the ephemeral reaches of the stream channels. Water table depth in ephemeral reaches were calculated by finding the difference between the water depth inside the well to the top of the well cap (TOC inside) and , the height from nominal ground level to the top of the well cap outside the well (TOC outside).

In the event that stream flow ceased in the stream channels, wells or piezometers were installed and used to measure water table depths in the hyporheic zone. When there was stream flow in the channel (presence of water) at sub-reaches where a riffle/ pool sequence was present, water depths were measured at the deepest point at the closest riffles and pool at the designated measurement location. In sub-reaches where the stream channel was a relatively uniform run, the water depth was measured in the deepest part of the thalweg the designated measurement location.

Tipping bucket raingauges and manual raingauges were installed in open areas relatively close to the study watersheds in order to determine as accurately as possible the amount of rainfall received by the watersheds. Each of the study sites (Schenck, Umstead Park, and Falls Lake) possessed two raingauge stations. The rain gauge data loggers (tipping buckets) were set to record at 0.2mm measurement intervals of rainfall. Water levels in the manual raingauges were read and recorded weekly and data loggers were initially downloaded every 3-4 weeks for approximately two months of the study period. After the initial two months precipitation data was retrieved from data loggers every two weeks throughout the entire study period. This frequency of data collection prevented, large amounts of data loss in the event that equipment malfunctioned or was damaged. In addition, precipitation data (30-year monthly normal) was obtained from the Raleigh/Durham International Airport (RDU). This data was used to compare precipitation accumulated on a monthly basis by the raingauge stations located within the three study areas (Schenck, Umstead Park, and Falls Lake) to determine if these areas received greater or less than the observed monthly normal rainfall based on a 30-year normal rainfall record.

The collection of rainfall and streamflow data assisted in the description of seasonal duration, variability and continuity of base flows within the stream channels. This information may be used to help distinguish between reach types (ephemeral, intermittent, and perennial) and the possible transitional points between the reaches. This information may also prove to be valuable in describing the general abundance of macroinvertebrates collected from these streams.

Macroinvertebrate Data Collection

Benthic macroinvertebrates were sampled five times (SPRING 2003, SUMMER 2003, WINTER 2004, SPRING 2004, SUMMER 2004) in the ephemeral, intermittent, and perennial reaches of each stream by Mr. Larry Eaton, an aquatic biologist, North Carolina Division of Water Quality, Stormwater and Wetlands Branch. Analysis of the macroinvertebrate samples was also conducted by Mr. Eaton. The macroinvertebrate sampling was as follows:

Sampling techniques varied and were dependent on the presence or absence of water in the reach being sampled. The times selected for collection coincided to reflect seasonal difference and variation in flow duration (Personal Communication, Larry Eaton NCDWQ, 2005). The sample periods were:

1. Late January to March (2004)– period when hydrologic base flow is expected to be near the seasonal high in both the intermittent and perennial reaches of sample streams.
2. Late May to early June (2003, 2004)- period where hydrologic base flow is expected to be decreasing due to increasing evapotranspiration.
3. Late August to October (2003, 2004)- This is a period where hydrologic baseflow is expected to be at its seasonal low in perennial streams and have ceased to flow in intermittent streams.

Stream Data Standardization

Datasets were created for precipitation readings from the manual raingauges as well as from the stream flow data. A graph illustrating the pattern of rainfall that occurred in the study areas was generated (Figure 2.9). Water depth measures were categorized based on the measurement type for each sub-reach within a stream. For example, ephemeral and run measurements were coded as 1; a code of 2 was given to pool measurements and 3, to riffle measurements. Hydrographs based on measurement category were created for each stream. For instance, in some cases a stream may have a maximum of four hydrographs (ephemeral wells, pools, riffles, and runs). Secondary hydrographs were created using the stream flow data based on seasonal collection of macroinvertebrates from the headwater streams.

The macroinvertebrate abundances for each stream, separated according to the seasonal collection were organized in a database spreadsheet. Each dataset contained records pertaining to stream points that were allotted for each segment (sub-reach) sampled as well as the total taxa, aquatic taxa, terrestrial taxa, aquatic abundance, and abundance found within a sampled segment. Exploratory Data Analyses (EDAs) were conducted on the datasets, using SAS. Results indicate that the abundances were not normally distributed, therefore, the abundances were log transformed to improve normality. For statistical analysis in SAS, combined datasets containing all headwater streams with the measured water depths for each sampled segment were also added to the database spreadsheet.

The SAS command Proc Corr was used to indicate whether multicollinearity or intercorrelation existed between the independent variables. The detection of multicollinearity between variables in a model is important especially in a study such as this because the importance of an individual variable within a model may not be detected or represented accurately in the results if completely or partially masked by another variable (Steel et al. 1997). The SAS Proc Mixed (mixed effect) was used to evaluate the effects of water depth on the various macroinvertebrate variables (total taxa, terrestrial taxa, aquatic abundance, abundance, and aquatic taxa). This command was chosen due to the presence of fixed and random variables from the data, which needed to be included in the analysis process to determine or consider their effects on macroinvertebrates. Finally, the SAS command Proc Gplot provided scatter plots of the relationships between the independent and dependent variables.

Statistical Approach

Statistical analysis was used to determine the relationship, if any, between headwater stream water depths and macroinvertebrate variables such as total taxa, aquatic taxa, terrestrial taxa, abundances, and aquatic abundances for the eight headwater streams used in this study. In addition, the effectiveness of the North Carolina Division of Water Quality (NCDWQ) Stream Classification Method was evaluated. This field method was developed for the purpose of distinguishing ephemeral channels from intermittent channels (NCDWQ, Internal Guidance Manual 1999).

Table 2.3. A summary of the hydrologic regimes included within a particular statistical models.

Equation (s)	Independent Variables (Water Depths)	Categories Included
Eq. 1	X1, X2, X3, X4	Riffles, Pools, Runs, and Ephemeral wells
Eq. 2, 4	X1	Pool, Runs, Ephemeral wells
Eq. 2, 5	X2	Riffles, Runs, Ephemeral wells
Eq. 3, 6	X_Avg	All categories
Eq. 7	Xp_min	Mimimum WD in Pools, Ephemerals wells, and Runs
Eq. 8	Xr_min	Minimum WD in Riffles, Ephemeral wells and Runs

Statistical Model Development

The original mixed effects model that was designed to determine the relationship between water depths and individual macroinvertebrates, termed the full model was:

$$\mathbf{Y_{ijkl}=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+S_i+T_j+C_k+E_{ijkl}} \qquad \mathbf{(1)}$$

Where:
Y_{ijkl} = macroinvertebrate variable (total taxa, aquatic taxa, terrestrial taxa, abundance, or aquatic abundance.
X_1, X_2, X_3, X_4 = Water depths measures, four weeks prior to macroinvertebrate sample date.
S_i = Stream effect (random effect)
T_j = Stream type (ephemeral, intermittent, and perennial) (fixed effects)
C_k = Type of measurement (ephemeral, run, riffle, pool) (fixed effects)
E_{ijkl} = Error (unknown random effects)

The rationale that guided the development of this model was that macroinvertebrates sampled at a particular time may not be dependent on water depth measurements after the sampling date. Additionally, a simple single date water sample occurring prior to the sample date may not effectively capture the true mean of water depth having the greatest relationship to the macroinvertebrate sample date. However, after consideration, it was decided that water depths collected the week after the macroinvertebrate sample date should be included in the model in order to better represent hydrologic variability of the stream segment sampled. Therefore, water depths collected on the week before and the week after macroinvertebrate collections were averaged for pools, riffles segments. The full model was reduced to include:

$$\mathbf{Y_{ij}=\beta_0+\beta_1X_1+\beta_2X_2+S_i+T_j+E_{ij}} \qquad \mathbf{(2)}$$

and

$$\mathbf{Y_{ij}=\beta_0+\beta_1X_{\_Avg}+S_i+T_j+E_{ij}} \qquad \mathbf{(3)}$$

Where:
Y_{ij} = macroinvertebrate variable (total taxa, aquatic taxa, terrestrial taxa, abundance, or aquatic abundance).
X_1 = Averaged water depths week before and week after macroinvertebrate sample date for pools. (Fixed Effects)

X_2 = Averaged water depths week before and week after macroinvertebrate sample date for riffles. (Fixed Effects)
X_Avg = Average of both X1 and X2.
S_i = Stream effect (random effect) correlation within stream
T_j = Stream type (ephemeral, intermittent, and perennial)
E_{ij} = Error (unknown random effects)

In the case where macroinvertebrates were sampled in an ephemeral or run segment (sub-reach) where a single water depth measurement was collected, the water depths collected on the week before and the week after the sample date were used and the resulting values were repeated in X1, X2, and X_Avg. For example, if the segment was an ephemeral (water table well measurement point) with a measurement value of -23cm, then X1= -23cm, X2=-23cm, X_Avg =-23cm.

Statistical Analysis of these reduced models followed the same methods in evaluating the full models using Proc Corr, Proc Mixed, and Proc Gplot. Proc Corr was used to detect if multicollinearity existed between the independent variables, Proc Mixed was used to determine if a relationship existed between the dependent variable and the independent variables. Proc Gplot provided a scatter plot of the data.

Initial testing of these models resulted in high multicollinearity between the X1 and X2 variables. Nonsignificant relationships were reported between most, if not all, the macroinvertebrates and water depth measurements. However, significant relationships were observed between the dependent variables and the stream type variable. With these preliminary results it was determined that further model reduction was needed in order to describe the relationship between water depths and the dependent variables: The final reduced submodels without the stream type variable were created to analyze the data. Also, to avoid multicollinearity, the independent variables were separated into submodels; where the variables as previously defined. The reduced model resulted in the following:

$$Y_{ij} = \beta_0 + \beta_1 X_1 + S_i + E_{ij} \quad (4)$$

$$Y_{ij} = \beta_0 + \beta_2 X_2 + S_i + E_{ij} \quad (5)$$

and

$$Y_{ij} = \beta_0 + \beta_1 X_{\_Avg} + S_i + E_{ij} \quad (6)$$

The variable stream type was omitted from the final submodels because it was suspected to prevent the true effect that water depth may have on abundances from being detected in the analysis of the data using the previous model(s).

The final model that was developed was the minimum water depth model. The minimum water depth may have a greater influence on the macroinvertebrate abundances that the averaged water depths from the stream sample date a week before and the stream sample date a week after the macroinvertebrate collection date. Therefore, the minimum water depth (pool, riffle, run, ephemeral well) was chosen from water depths the week before and week after the macroinvertebrates were sampled. The resulting water depth was included in this model. The variables of this model include:

$$Y_{ij} = \beta_0 + \beta_1 X_{p\_min} + S_i + E_{ij} \quad (7)$$

$$Y_{ij} = \beta_0 + \beta_1 X_{r\_min} + S_i + E_{ij} \quad (8)$$

Where:
X_{p_min}= Minimum water depth for a pool measurement
X_{r_min} =Minimum water depth for a riffle measurement
S_i = Stream effect (random effect)
E_{ij} = Error (unknown random effects)

Stream Type Validation

The field methodology for determining the origins at intermittent and perennial streams was developed out of a need to accurately identify stream types in the Neuse River Basin with the passing of the Neuse River Basin Riparian Buffer Rules. Therefore, a numerical system for stream classification was developed in order to provide an objective means by which regulators can evaluate and distinguish between ephemeral, intermittent and perennial streams (NCDWQ Internal Guidance Manual 1999). This classification scheme is based upon the absence or presence and degree of development of primary and secondary physical, biological and hydrologic indicators. Based on this evaluation method, first and second order stream reaches that accrue less than 19 points are classified as ephemeral. Intermittent streams may have total points allotted ranging between 19 and 30 points; perennial streams greater than 30 points (NCDWQ 2005).

In this study, the stream classification evaluation was conducted for all stream segments that were sampled for macroinvertebrates and for which water depth measurements were collected. Segments obtaining less than 19 points were coded 1, segments with assigned points' between 19-30 were coded 2 and stream segments with greater than 30 points were assigned a code of 3. To analyze the relationship between stream types and water depths the Proc Mixed procedure was used in SAS. The average water depths the week before and the week after macroinvertebrate sample date for pools (X1) and the averaged water depths the week before and the week after macroinvertebrate sample period (X2), and X_Avg (averaged water depths in pools and riffles the week before and the week after macroinvertebrate sample date) in addition to the minimum water depths were used in the analyses.

These water depths were chosen for use in this analysis because the headwater streams used in this study are very dynamic and given a particular climatic event, there are noticeable changes in flow. Since the stream evaluation points were allotted at specific points in time, it is assumed that the best way to test the validity of the stream classification method is by using the water depth closest to the time of sampling, as well as determining the effects that minimum water depth has on stream type classification. The model that was created to determine the relationship between water depth and stream type (stream points) include:

$$\mathbf{Y_{ij} = \beta_0 + \beta_1 X_x + S_i + E_{ij}} \quad \mathbf{(9)}$$

Where:
$\mathbf{Y_{ij}}$**=** Stream Type (ephemeral, intermittent, and perennial) determined by stream point allocation.
$\mathbf{\beta_1 X_x}$ **=** Water depth variables X1, X2, X_Avg, Xp_min, Xr_min as defined by in the prior models and Table 2.3.
$\mathbf{S_i}$**=** Stream Effect (Random effect)
$\mathbf{E_{ij}}$ **=** Error (unknown random effects)

RESULTS

Hydrologic Variability

Stream flow in the eight headwater streams varied over the eighteen month sample period. Figures 2.5-2.8 illustrate the variability of water depth with time. The hydrologic variability exhibited by the streams can be described as cyclic in nature. During the late spring/early summer months there is a steady decrease in water depths followed by an increase in water levels during the winter season. Occasional peaks in the hydrographs are visible and may be a result of a storm event within the area.

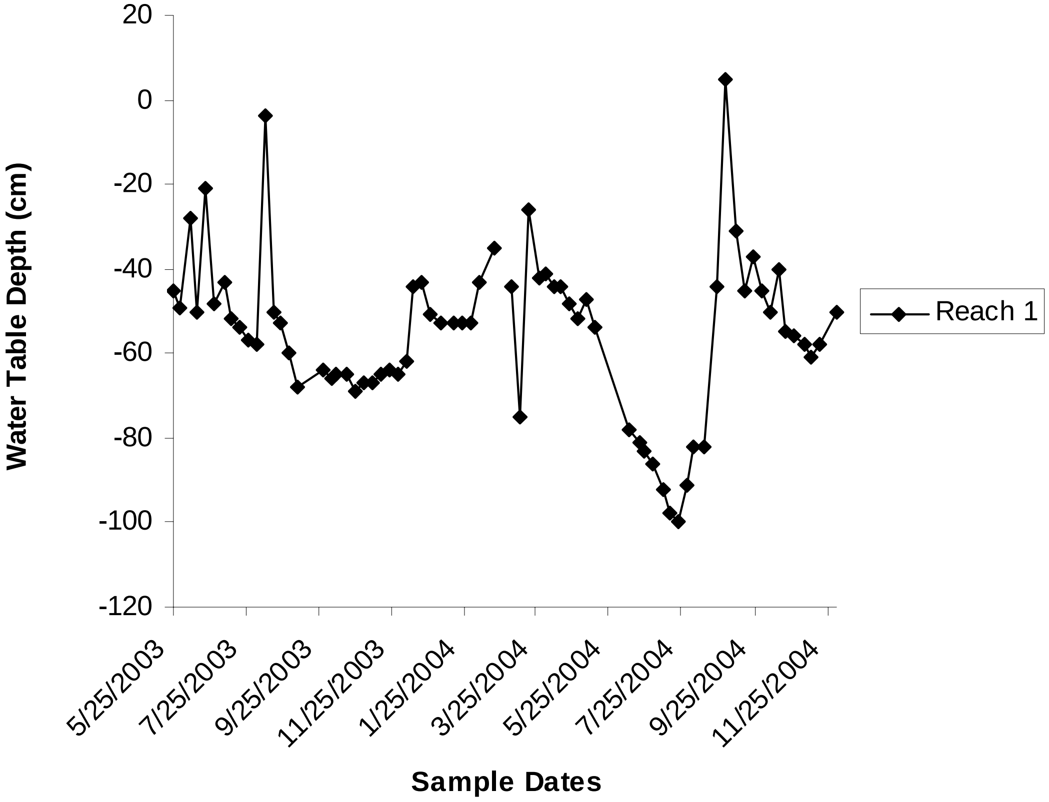


Figure 2.5: Water table hydrograph for ephemeral reach in headwater stream at Schenck Forest.

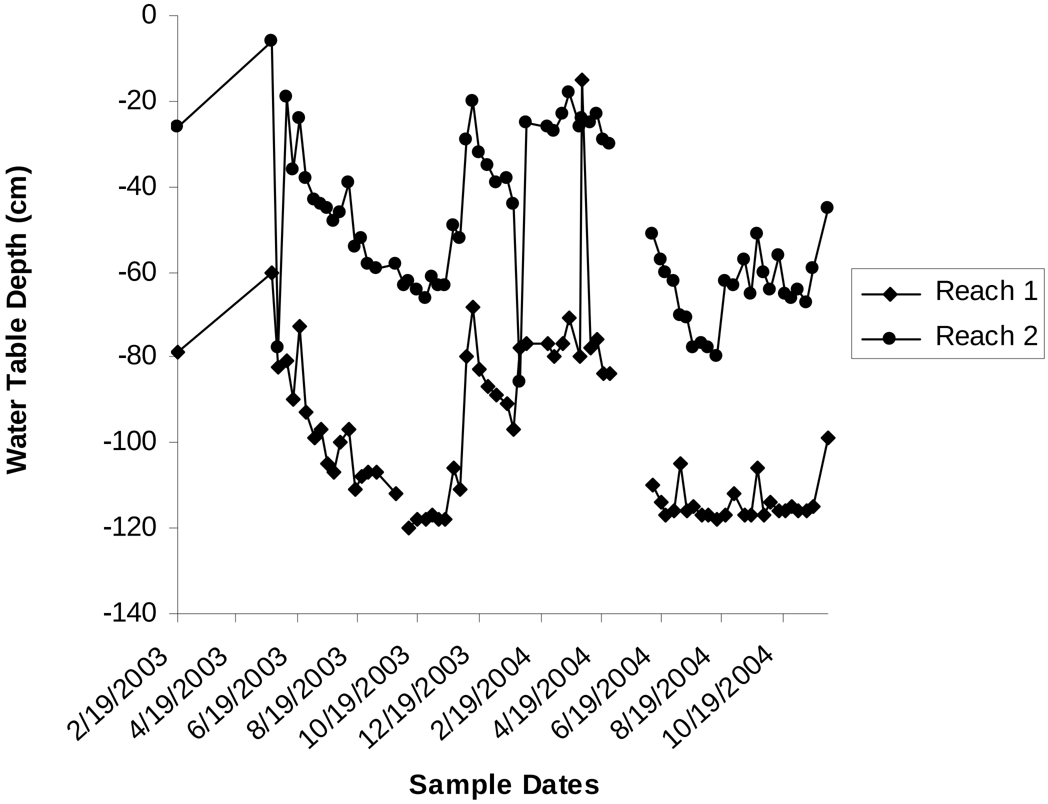


Figure 2.6: Water table hydrograph for ephemeral reach in headwater stream at B.W. Wells section, Falls Lake State Park.

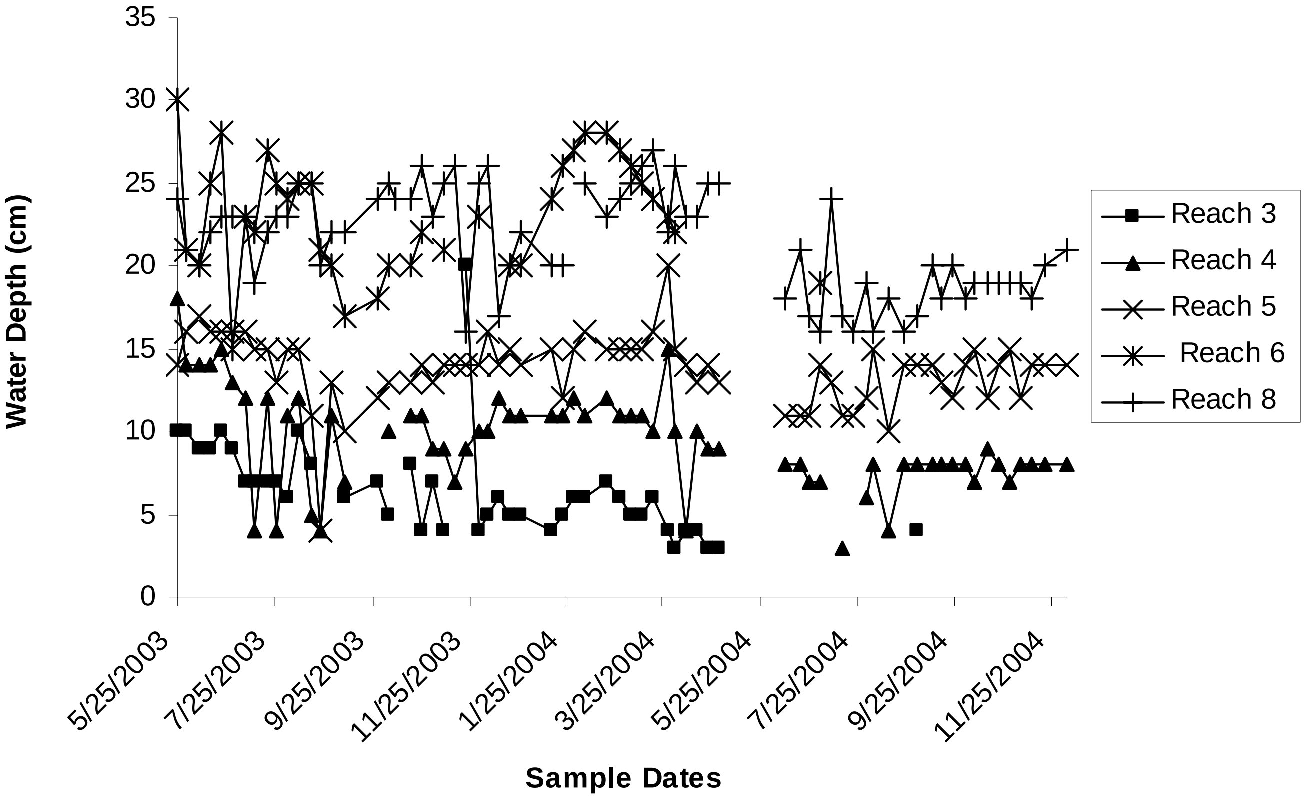


Figure 2.7: Hydrograph for pool water depths for headwater stream at B.W. Wells section, Falls Lake State Park.

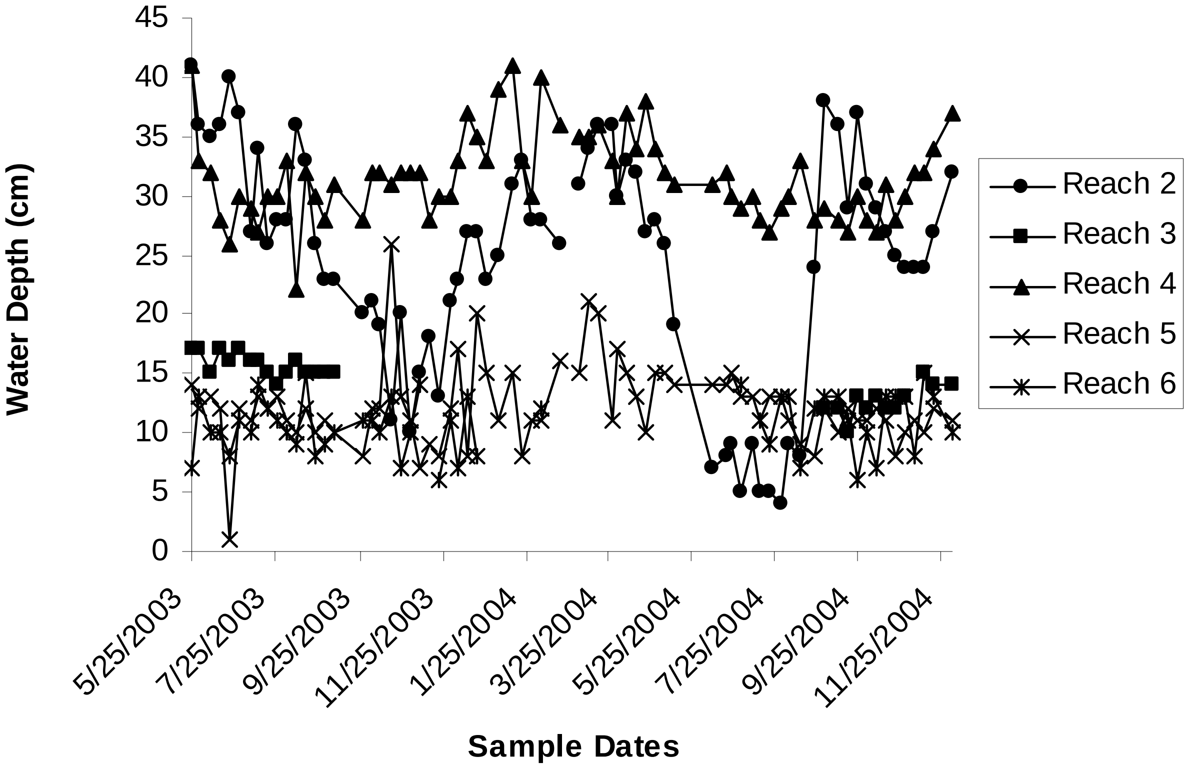


Figure 2.8: Hydrographs for pool water depths for headwater stream at Schenck Forest.

Based on the hydrographs, drying periods or in some cases the lowering of water depths was observed in the headwater streams during the summer and fall seasons in 2003 and 2004 (Figures 2.5-2.8 and Appendix 2). The drying (or lowering of water levels) within the streams is most prominent in the year 2004. Cycles of increased water depths within the stream channels and/or in the hyporheic zones are also noticeable between the summer/fall 2003 and summer 2004 and to some extent late fall in the 2004. Some hydrographs indicated that water levels below the surface in the summer and fall months would slowly increase above the channel surface in the intermittent reaches of the stream as winter approaches

(Appendix 2). However, during the stream flow measurement period very few stream reaches went completely dry for an extensive amount of the time.

Decrease in water levels within the hyporheic zones are best represented in the ephemeral sections of the study streams as well as in some of the sub-reaches classified as runs. For example, in the Schenck 1, Umstead 2 and Falls 1, 2, 4, and 5 the rise and fall of water depths over the eighteen month period are clearly visible. Water depths in pools also indicated this pattern of increasing and lowering of water levels with time (Figures 2.7-2.8 and Appendix 2).

Water depths in some sub-reaches classified as runs or riffles for the most part were very stable, very little variability was exhibited by these segments. However, within the study catchment Falls 1 (F1), water flow in a short intermittent section near the upstream end of the study stream ceased during the summer and fall months, but began again during the winter.

In some of the hydrographs generated for the headwater streams the hydrologic patterns may not be as obvious due to discontinuities. Discontinuities in the hydrographs were the result of missed measurement days or in most cases changes in the stream morphological characteristics due to bedload movement during stormflow events. For instance, hydrographs contain discontinuities for a stream if the stream, which may have first possessed a riffle/pool sequence, then converted to a run segment; this change may be temporary or may be permanent for the duration of the stream flow measurement period (Appendix 2).

Within a stream, similar hydrologic behavior has been observed among the pools, riffles, runs, and ephemerals along a stream. For instance, a lowering of water levels in one pool within a stream may be reflected in the water levels of the other pools along the stream channel being measured. However, on occasions, peaks in the hydrographs may be observed for a single reach in the hydrograph, thus deviating from the suggestion of similar hydrologic behavior among measurement categories within a stream.

Rainfall Pattern

Figure 2.9 illustrates the rainfall levels collected from the manual raingauges on a weekly basis. This graph also compares the amount of precipitation that was received by the study catchments. Precipitation levels between the study areas are highly variable. Greater amounts of rainfall were received in certain catchment areas. Precipitation intensities recorded with the use of a data logger were not included in this analysis due to the possible corruption of the data from malfunction and destruction of equipment.

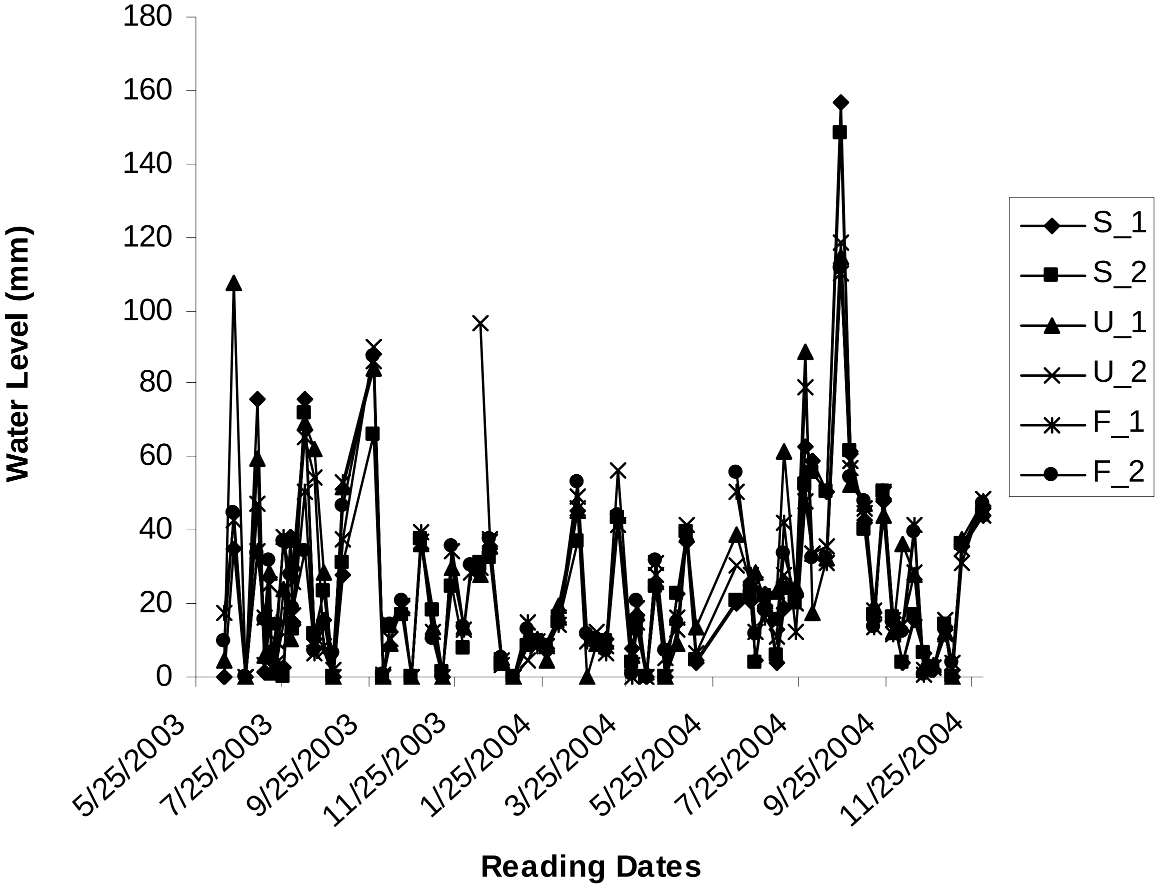


Figure 2.9: Precipitation levels for all manual raingauge stations at all the study areas.

Figure 2.10 is a histogram illustrating precipitation accumulation within the study areas as compared to the 30-year monthly normal precipitation that was recorded at the RDU weather station. In the initial months of the study period, based on the precipitation levels read from the study raingauge stations, it appears that rainfall in these areas exceeded the mean monthly normal precipitation. This trend can be observed during the summer months in 2004 however, during the winter of 2004 (Jan-March) as well as early spring precipitation levels were below normal. Note that in some months, precipitation data was lacking due to the destruction or malfunctioning of some raingauge stations.

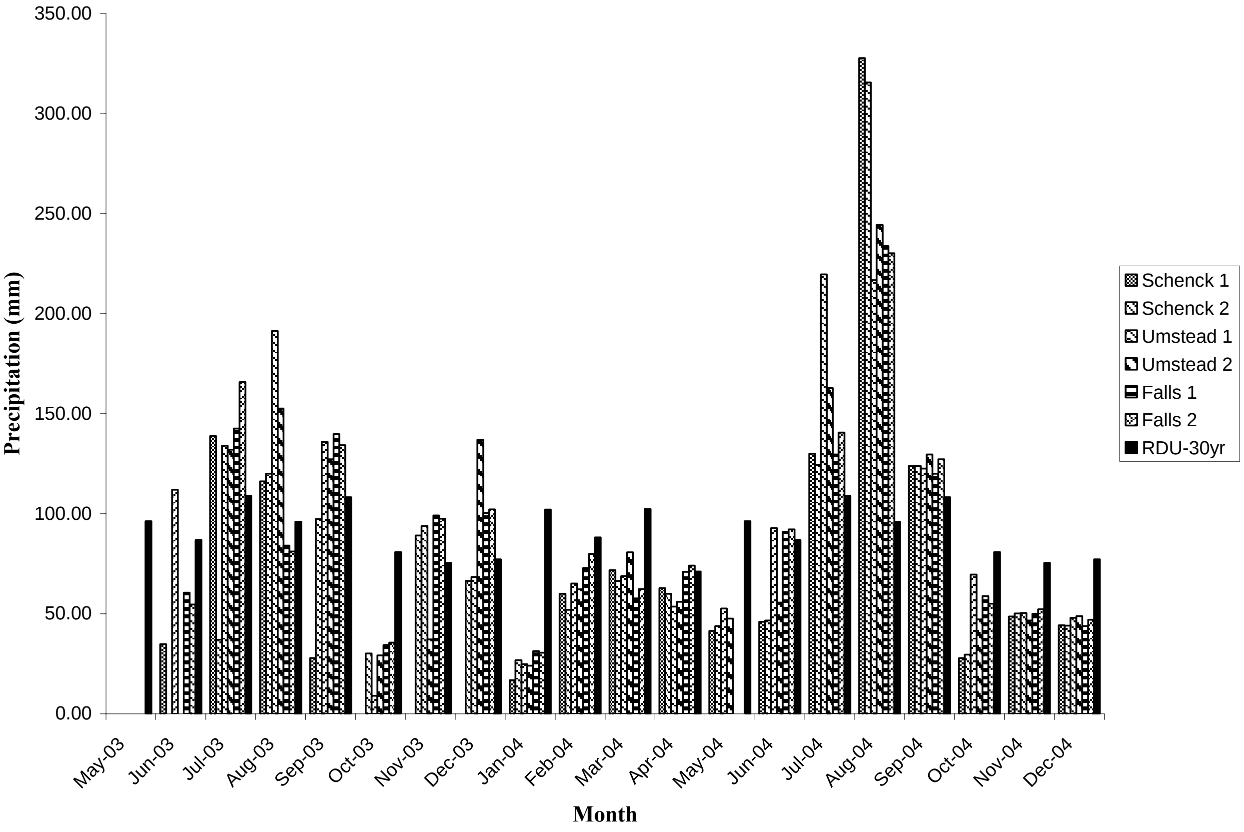


Figure 2.10: Comparison of precipitation accumulation between RDU weather station and study areas.

Statistical Model Analysis

Statistical modeling techniques involved a series of candidate models. A full model included all variables sampled. In addition, reduced and minimum depth models were created to reduce multicollinearity within the dataset. Tables 2.4-2.8 indicate the level of significance that was reported for each model based on the seasonal macroinvertebrate samples.

Table 2.4. Indicates the level of significance between water depths and macroinvertebrates for spring 2003 sample period.

Model	Statistical Test	Spring 2003				
		Abund.[a]	Aq. abund.[a]	Aq. taxa[a]	Ter. taxa[a]	Total taxa[a]
Equation 1	Pearson[b]	0.58-0.94	0.58-0.94	0.58-0.87	0.58-0.94	0.58-0.94
	AIC[c]	139.4	163.8	89.1	102.5	72.0
Stream-type	p-values[d]	0.0131	0.4871	0.0008	0.0348	0.0005
Category	p-values[d]	0.7065	0.0135	<.0001	0.0198	0.0045
X1	p-values[d]	0.2376	0.7551	0.7140	0.3441	0.5957
X2	p-values[d]	0.4647	0.7000	0.8659	0.1253	0.5617
X3	p-values[d]	0.7958	0.5611	0.4519	0.2758	0.4619
X4	p-values[d]	0.6064	0.3665	0.4696	0.3784	0.6926
Equation 2	Pearson[b]	0.52-0.86	0.52-0.87	0.52-0.86	0.42-0.79	0.52-0.86
	AIC[c]	104.8	130.9	86.0	146.9	59.8
Stream-type	p-values[d]	0.0335	0.1324	0.0027	0.6307	0.0002
X1	p-values[d]	0.6851	0.2844	0.1402	0.2668	0.2281
X2	p-values[d]	0.5875	0.9717	0.9571	0.5737	0.4159
Equation 3	AIC[c]	97.8	125.1	93.4	118.5	52.1
Stream-type	p-values[d]	0.0214	0.1356	0.0026	0.6537	0.0003
X_AVG	p-values[d]	0.1828	0.1122	0.0418	0.2734	0.5312
Equation 4	AIC[c]	108.6	132.9	93.4	76.7	68.8
X1	p-values[d]	0.0024	0.0011	<.0001	0.0008	0.0013
Equation 5	AIC[c]	105.4	131.9	91.5	75.3	67.6
X2	p-values[d]	0.0007	0.0012	<.0001	0.0005	0.0011

Table 2.4. , continued

Equation 6	AIC[c]	106.3	131.5	90.9	75.0	67.4
X_AVG	p-values[d]	0.0009	0.0007	<.0001	0.0004	0.0008
Equation 7	AIC[c]	104.5	129.8	87.5	77.2	64.7
Xp_min	p-values[d]	0.0002	0.0002	<.0001	0.0010	0.0001
Equation 8	AIC[c]	**101.6**	**125.2**	**85.3**	**75.2**	**64.3**
Xr_min	p-values[d]	**0.0001**	**0.0001**	**<.0001**	**0.0005**	**0.0002**

a. Abund., Aq. Abund., Aq. Taxa, Ter. Taxa, - These are the abbreviation s for the dependent variables: Abundance, Aquatic abundance, Aquatic taxa, and Terrestrial taxa.

b. Pearson- Pearson's correlation represents the level of multicollinearity between the model's independent variables. A threshold of 0.55 was used to determine multicollinearity. Note that Pearson was not available for all models.

c. AIC- Akaike Information criterion was used to assist in model selection. The smaller the AIC the better the model.

d. p-values- These values were acquired from the statistical analysis of the data using the Proc Mixed command in SAS.

e. Values that are in bold highlights the best fit model for a particular analysis.

Table 2.5. Indicates the level of significance between water depths and macroinvertebrates for summer 2003 sample period.

Model	**Statistical Test**	**Summer 2003**				
		Abund.[a]	**Aq. abund.[a]**	**Aq. taxa[a]**	**Ter. taxa[a]**	**Total taxa[a]**
Equation 1	Pearson[b]	0.68-0.97	0.77-0.94	0.77-0.94	0.68-0.77	0.68-0.96
	AIC[c]	160.6	144.9	88.7	105.1	97.4
Stream-type	p-values[d]	0.6519	0.6185	0.3439	0.4340	0.3793
Category	p-values[d]	0.0805	0.0508	0.0104	0.6747	0.0021
X1	p-values[d]	0.8443	0.0649	0.0254	0.0050	0.6454
X2	p-values[d]	0.4093	0.3331	0.0498	0.0391	0.1451
X3	p-values[d]	0.4898	0.0912	0.0572	0.0015	0.9294
X4	p-values[d]	0.1685	0.0312	0.0038	0.6803	0.9488
Equation 2	Pearson[b]	0.59-0.95	0.50-0.89	0.50-0.89	0.50-0.95	0.59-0.95
	AIC[c]	122.7	114.3	81.0	81.3	77.1
Stream-type	p-values[d]	0.5360	0.6839	0.5250	0.7100	0.4592
X1	p-values[d]	0.8942	0.9462	0.4829	0.9600	0.6789
X2	p-values[d]	0.2834	0.1186	0.2222	0.8700	0.2950
Equation 3	AIC[c]	116.9	109.2	73.6	73.5	69.3
Stream-type	p-values[d]	0.5300	0.7217	0.4668	0.7033	0.3903
X_AVG	p-values[d]	0.0312	0.0067	0.0047	0.7837	0.0018
Equation 4	AIC[c]	120.9	114.7	77.6	72.5	71.6
X1	p-values[d]	0.0004	0.0003	<.0001	0.7472	<.0001
Equation 5	AIC[c]	**119.0**	111.2	74.6	72.3	**69.0**
X2	p-values[d]	**0.0003**	<.0001	<.0001	0.7661	**<.0001**

Table 2.5. , continued.

Equation 6	AIC[c]	119.6	111.8	74.2	72.4	69.3
X_AVG	p-values[d]	0.0003	<.0001	<.0001	0.7529	<.0001
Equation 7	AIC[c]	122.0	114.1	78.1	72.4	73.2
Xp_min	p-values[d]	0.0010	0.0006	<.0001	0.7037	<.0001
Equation 8	AIC[c]	120.3	**108.1**	**74.6**	**72.3**	70.7
Xr_min	p-values[d]	0.0005	**0.0001**	**<.0001**	**0.7387**	<.0001

a. Abund., Aq. Abund., Aq. Taxa, Ter. Taxa, - These are the abbreviation s for the dependent variables: Abundance, Aquatic abundance, Aquatic taxa, and Terrestrial taxa.

b. Pearson- Pearson's correlation represents the level of multicollinearity between the model's independent variables. A threshold of 0.55 was used to determine multicollinearity. Note that Pearson was not available for all models.

c. AIC- Akaike Information criterion was used to assist in model selection. The smaller the AIC the better the model.

d. p-values- These values were acquired from the statistical analysis of the data using the Proc Mixed command in SAS.

e. Values that are in bold highlights the best fit model for a particular analysis.

Table 2.6. Indicates the level of significance between water depths and macroinvertebrates for winter 2004 sample period.

Model	Statistical Test	Winter 2004				
		Abund.[a]	Aq. abund.[a]	Aq. taxa[a]	Ter. taxa[a]	Total taxa[a]
Equation 1	Pearson[b]	0.89-0.98	0.89-0.98	0.89-0.98	0.89-0.98	0.92-0.98
	AIC[c]	82.2	99.8	71.8	83.4	48.1
Stream-type	p-values[d]	0.0160	0.1540	0.1223	0.0916	0.0045
Category	p-values[d]	0.0071	0.0308	0.0950	0.4975	0.0056
X1	p-values[d]	0.1608	0.7067	0.8706	0.4957	0.1279
X2	p-values[d]	0.7067	0.1730	0.0497	0.6398	0.8986
X3	p-values[d]	0.2085	0.1910	0.2424	0.4270	0.4289
X4	p-values[d]	0.1409	0.0492	0.0498	0.5295	0.8940
Equation 2	Pearson[b]	0.62-0.95	0.62-0.95	0.61-0.95	0.62-0.95	0.62-0.95
	AIC[c]	69.4	89.6	66.6	64.5	42.8
Stream-type	p-values[d]	0.3871	0.5287	0.0559	0.3630	0.0202
X1	p-values[d]	0.3271	0.3538	0.7925	0.7624	0.2053
X2	p-values[d]	0.0161	0.0218	0.2594	0.7326	0.7782
Equation 3	AIC[c]	66.6	87.4	60.3	58.2	35.2
Stream-type	p-values[d]	0.3367	0.6730	0.0505	0.2598	0.0129
X_AVG	p-values[d]	0.0037	0.0068	0.0052	0.8803	0.0022
Equation 4	AIC[c]	71.8	93.6	67.1	60.9	41.3
X1	p-values[d]	0.0010	0.0004	<.0001	0.1021	<.0001
Equation 5	AIC[c]	66.0	88.3	67.5	61.9	43.6

Table 2.6. Indicates the level of significance between water depths and macroinvertebrates for winter 2004 sample period continued.

X2	p-values[d]	<.0001	<.0001	<.0001	0.2362	0.0002
Equation 6	AIC[c]	69.0	90.9	62.9	61.0	41.9
X_AVG	p-values[d]	0.0002	<.0001	<.0001	0.1252	<.0001
Equation 7	AIC[c]	70.4	91.0	**64.0**	**59.1**	**41.0**
Xp_min	p-values[d]	0.0002	<.0001	**<.0001**	**0.0379**	**<.0001**
Equation 8	AIC[c]	**64.0**	**83.3**	64.8	59.5	43.3
Xr_min	p-values[d]	**<.0001**	**<.0001**	<.0001	0.0563	0.0003

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a. Abund., Aq. Abund., Aq. Taxa, Ter. Taxa, - These are the abbreviation s for the dependent variables: Abundance, Aquatic abundance, Aquatic taxa, and Terrestrial taxa.

b. Pearson- Pearson's correlation represents the level of multicollinearity between the model's independent variables. A threshold of 0.55 was used to determine multicollinearity. Note that Pearson was not available for all models.

c. AIC- Akaike Information criterion was used to assist in model selection. The smaller the AIC the better the model.

d. p-values- These values were acquired from the statistical analysis of the data using the Proc Mixed command in SAS.

e. Values that are in bold highlights the best fit model for a particular analysis.

Table 2.7. Indicates the level of significance between water depths and macroinvertebrates for spring 2004 sample period.

Model	Statistical Test	Spring 2004				
		Abund.[a]	Aq. abund.[a]	Aq. taxa[a]	Ter. taxa[a]	Total taxa[a]
Equation 1	Pearson[b]	0.98-0.99	0.98-0.99	0.98-0.99	0.98-0.99	0.98-0.99
	AIC[c]	64.2	74.0	30.3	44.3	42.4
Stream-type	p-values[d]	0.1311	0.2706	0.0001	0.9665	0.0401
Category	p-values[d]	0.6519	0.8467	0.0150	0.1724	0.8211
X1	p-values[d]	0.7695	0.7745	0.8481	0.7131	0.7896
X2	p-values[d]	0.3836	0.3414	0.2015	0.8391	0.3352
X3	p-values[d]	0.8675	0.8981	0.1719	0.8340	0.9304
X4	p-values[d]	0.8893	0.6780	0.1611	0.3862	0.6508
Equation 2	Pearson[b]	0.41-0.61	0.41-0.57	0.41-0.57	0.41-0.57	0.41-0.57
	AIC[c]	54.2	62.0	43.0	34.5	34.1
Stream-type	p-values[d]	0.4139	0.3990	0.1632	0.9603	0.1499
X1	p-values[d]	0.8879	0.8732	0.7071	0.1646	0.4891
X2	p-values[d]	0.3605	0.4924	0.4272	0.2176	0.5340
Equation 3	AIC[c]	48.9	55.2	36.4	30.4	26.6
Stream-type	p-values[d]	0.3910	0.3677	0.1334	0.9940	0.1126

Table 2.7., continued.

X_AVG	p-values[d]	0.3045	0.4139	0.2473	0.7449	0.2065
Equation 4	AIC[c]	55.4	63.3	42.5	29.4	30.9
X1	p-values[d]	0.1412	0.1502	0.0606	0.2637	0.0442
Equation 5	AIC[c]	53.4	61.8	41.4	29.9	30.9
X2	p-values[d]	0.0723	0.0988	0.0489	0.6197	0.0509
Equation 6	AIC[c]	53.5	61.6	40.3	30.0	29.1
X_AVG	p-values[d]	0.0714	0.0848	0.0299	0.6270	0.0262
Equation 7	AIC[c]	53.1	**56.3**	40.3	28.7	**26.6**
Xp_min	p-values[d]	0.0514	**0.0500**	0.0120	0.2782	**0.0111**
Equation 8	AIC[c]	**52.5**	59.5	**39.6**	**28.5**	29.8
Xr_min	p-values[d]	**0.0574**	0.0424	**0.0286**	**0.3065**	0.0437

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a. Abund., Aq. Abund., Aq. Taxa, Ter. Taxa, - These are the abbreviation s for the dependent variables: Abundance, Aquatic abundance, Aquatic taxa, and Terrestrial taxa.

b. Pearson- Pearson's correlation represents the level of multicollinearity between the model's independent variables. A threshold of 0.55 was used to determine multicollinearity. Note that Pearson was not available for all models.

c. AIC- Akaike Information criterion was used to assist in model selection. The smaller the AIC the better the model.

d. p-values- These values were acquired from the statistical analysis of the data using the Proc Mixed command in SAS.

e. Values that are in bold highlights the best fit model for a particular analysis.

Table 2.8. Indicates the level of significance between water depths and macroinvertebrates for summer 2004 sample period.

Model	Statistical Test	Summer 2004				
		Abund.[a]	**Aq. abund.[a]**	**Aq. taxa[a]**	**Ter. taxa[a]**	**Total taxa[a]**
Equation 1	Pearson[b]	0.88-0.99	0.88-0.99	0.88-0.99	0.88-0.99	0.88-0.99
	AIC[c]	28.4	25.5	24.1	29.5	24.1
Stream-type	p-values[d]					
Category	p-values[d]					
X1	p-values[d]					
X2	p-values[d]					
X3	p-values[d]					
X4	p-values[d]					
Equation 2	Pearson[b]	-0.04-0.44	-0.05-0.44	-0.05-0.44	-0.05-0.44	-0.05-0.44
	AIC[c]	26.9	26.9	19.8	22.8	19.5
Stream-type	p-values[d]	0.4870	0.4967	0.2977	0.7362	0.2943
X1	p-values[d]	0.5065	0.4239	0.4430	0.3919	0.5636
X2	p-values[d]	0.8761	0.7970	0.9934	0.2780	0.6679
Equation 3	AIC[c]	20.2	20.4	19.9	18.2	10.2
Stream-type	p-values[d]	0.2726	0.2808	0.1253	0.8356	0.1012
X_AVG	p-values[d]	0.4073	0.3234	0.4599	0.6064	0.4386
Equation 4	AIC[c]	26.3	26.2	17.3	**15.5**	15.2
X1	p-values[d]	0.6314	0.4552	0.5615	**0.0336**	0.9301
Equation 5	AIC[c]	**24.8**	**25.1**	**15.0**	18.9	**14.2**
X2	p-values[d]	**0.2131**	**0.2106**	**0.1520**	0.0552	**0.3997**
Equation 6	AIC[c]	25.0	25.3	15.8	21.9	13.3
X_AVG	p-values[d]	0.8065	0.9771	0.5123	0.6848	0.5067

Table 2.8., continued.

Equation 7	AIC[c]	26.4	26.3	17.6	19.8	15.1
Xp_min	p-values[d]	0.6798	0.5123	0.8173	0.0902	0.8398
Equation 8	AIC[c]	25.6	25.9	16.0	19.7	15.6
Xr_min	p-values[d]	0.3570	0.3667	0.0506	0.0854	0.1529

a. Abund., Aq. Abund., Aq. Taxa, Ter. Taxa, - These are the abbreviation s for the dependent variables: Abundance, Aquatic abundance, Aquatic taxa, and Terrestrial taxa.

b. Pearson- Pearson's correlation represents the level of multicollinearity between the model's independent variables. A threshold of 0.55 was used to determine multicollinearity. Note that Pearson was not available for all models.

c. AIC- Akaike Information criterion was used to assist in model selection. The smaller the AIC the better the model.

d. p-values- These values were acquired from the statistical analysis of the data using the Proc Mixed command in SAS.

e. Values that are in bold highlights the best fit model for a particular analysis.

Full Model

The rationale that guided the development of the full model was that water depths prior to the macroinvertebrate sampling may be more important than water depths after the sampling period. This assumption was based on the belief that four weeks prior to the macroinvertebrate sample dates would better represent the hydrologic variability within the stream segments, which may influence macroinvertebrate abundances. When the full model was applied, the results indicated that this may in fact not be the case. Water depths four weeks prior to the macroinvertebrate sample date (X1, X2, X3, X4) showed no significant relationship to the macroinvertebrate abundances collected in stream segments during the spring 2003 sampling. The range of p-values reported by this model during this sampling season was p = 0.1253-0.7958. However, relationships between stream type and all macroinvertebrte variables except for aquatic abundance were significant. The overall range of p-values was p=0.0005-0.0348. The variable, category, was indicated to have a possible influence on aquatic taxa and total taxa, but not macroinvertebrate abundances (Table 2.4).

In the summer 2003 sample period, water depths were indicated to have a possible influence on various abundances. However, stream type, unlike that of the prior season, was not indicated as having an affect on any of the macroinvertebrate abundances. Stream category was shown to have some relationship to aquatic taxa and total taxa, but not with the other dependent variables (Table 2.5).

Results from the winter 2004 sample period indicated significant relationships between X4 (one week prior to sample date), aquatic abundance, and aquatic taxa (p=0.0492-0.0498) as well as X2 (three weeks prior to sampling period) and aquatic taxa (p=0.0497). However, nonsignificant relationships were reported between the abundances and independent variables X1 (water depths four weeks prior to sample date) and X3 (water depths two weeks prior to macroinvertebrate sample date). The range of p-values reported for X1 and X3 were $p=0.1279-0.8706$. Stream type was identified as possibly having an influence on dependent variable such as abundance and total taxa whereas category was observed to be related to abundance, aquatic abundance, and total taxa (Table 2.6).

For the spring 2004 sample period, the full model indicated that water depths four weeks prior to sampling did not explain a lot of the variation in macroinvertebrate variables. Stream type was statistically significant ($p<0.05$) to aquatic taxa and total taxa, but nonsignificant relationships were reported for the other variables. The variable, stream category, was also shown to have a significant relationship with aquatic taxa at a p-value of 0.0150. In the summer 2004 sample period the model did not produce any results for macroinvertebrates sampled in this time (Table 2.8).

Reduced Model with Stream Type

Based on the assumption that water depths the week before and the week after the sampling of macroinvertebrates may best reflect the hydrologic conditions of the sub-reaches sampled for macroinvertebrates, a new reduced model was developed to test this idea. This new model contained fewer variables than the full model and is comprised of two submodels where the water depth variables X1 represents the averaged water depths the week before and the week after macroinvertebrate sample date for pools and X2 represents the averaged water depth the week before and the week after macroinvertebrate sampling for riffles. The necessary adjustments were made for ephemeral and run measurements. The variable X_Avg is the averaged water depth for X1 and X2.

Results from statistical analysis using the reduced model (submodels) with the stream type variable indicated that stream type may influence macroinvertebrate abundance, aquatic taxa and total taxa but, non significant relationships were indicated between averaged water depths X1, X2 and , macroinvertebrate variables during the spring 2003 sampling period. The overall range of p-values for the nonsignificant relationships between X1, X2 and macroinvertebrate variable was p=0.1402-0.9717. However, a significant p-value was reported for X_Avg and aquatic taxa (p=0.0418). For the summer 2003 period, stream type, X1, and X2 were not found to have a potential influence on macroinvertebrate samples, but X_Avg was found to be significantly related to abundance, aquatic abundance, aquatic taxa, and total taxa, but not terrestrial taxa (Table 2.4-2.5).

Analysis of the winter 2004 samples provided evidence that stream type may explain the total taxa of macroinvertebrates whereas X_Avg was indicated to have a possible influence on all abundances except for terrestrial taxa. The variable X2 may be able to explain macroinvertebrate abundance and aquatic abundance for the analyzed samples. For the spring and summer 2004 sampling seasons there were no significant relationships determined between the independent variables and the dependent variables (Tables 2.6, 2.8).

Reduced Model without Stream Type

A further reduced model was used to determine if hydrology (water depths) has an influence on macroinvertebrate variables such as abundance, aquatic abundance, total taxa, aquatic taxa, and terrestrial taxa. The full model and reduced model with the stream type variable included were not successful in answering this question therefore; the reduced model without stream type was developed to analyze the affects of water depth on the dependent variables.

Analysis of samples collected during the spring 2003 sample period using the reduced model (submodels) without the stream type variable indicated that independent variables X1, X2, X_Avg have an influence on all macroinvertebrate variables (Table 2.4). For the summer 2003 and winter 2004 samples, the independent variables were significantly related to abundance, aquatic taxa, aquatic abundance, and total taxa, but not for terrestrial taxa (Tables 2.5-2.6).

For the spring 2004 samples these were significant relationships between X1 and total taxa (p=0.0442) in addition to X2 and aquatic taxa (p=0.0489). The independent variable X_Avg was found to have significant relationships for both aquatic taxa and total taxa. The range of p-values reported for this submodel was p= 0.0299-0.0262. Analysis on the summer 2004 data produced evidence, which suggests that X1 may have an influence on terrestrial taxa where as no other significant relationship was detected by any of the other variables in the other submodels (Tables 2.7-2.8).

Minimum water depth Model

The X_min model is composed of two submodels which is a measure of the minimum water depth for pools, riffles, ephemeral wells, and runs between the week before and the week after macroinvertebrate sampling. Analysis conducted on the spring 2003 samples indicated that the macroinvertebrate variables were significantly related to minimum water depths. The overall range of p-values included p<0.0001-0.0005. For the summer 2003 sampling period, significant relationships were also detected for all macroinvertebrate variables except for terrestrial taxa. The range of p-values for the statistically significant relationships is p<0.0001-0.0005. Whereas the p-values reported for the nonsignificant relationship between minimum water depths and terrestrial taxa was p=0.7387. In the summer of 2004 no significant relationships between minimum depth values and dependent variables were observed using this model (Table 2.4-2.5, 2.8).

Applying the minimum water depth model to the winter 2004 samples, data analysis indicated that all abundances except for terrestrial taxa were significantly related to minimum water depth values. The overall range of p-values for this sampling season was p<0.0001-0.0005. However, a significant relationship was found between minimum water depth in pools and terrestrial taxa (p=0.0379). Whereas in the spring 2004 while there was also no relationship identified between water depths (Xp_min and Xr_min) and terrestrial taxa; aquatic taxa and total taxa were both found to be significantly related to Xp_min. The sub-model Xr_min reported significant p-values for aquatic abundance, aquatic taxa, and total taxa (Table 2.6-2.7).

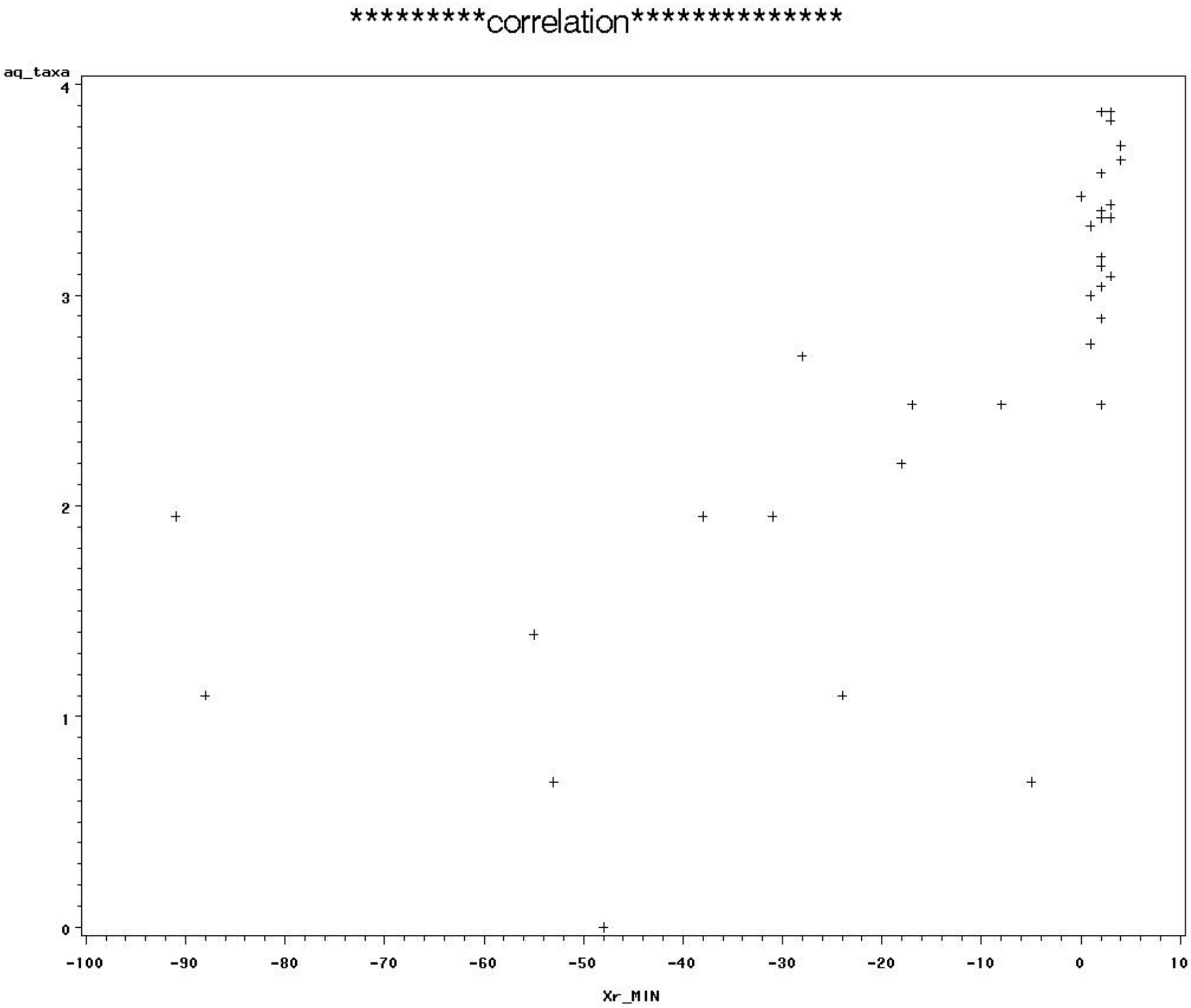

Figure 2.11: The relationship between minimum water depths in riffle (Xr_min) and aquatic taxa for spring 2003 sampling period.

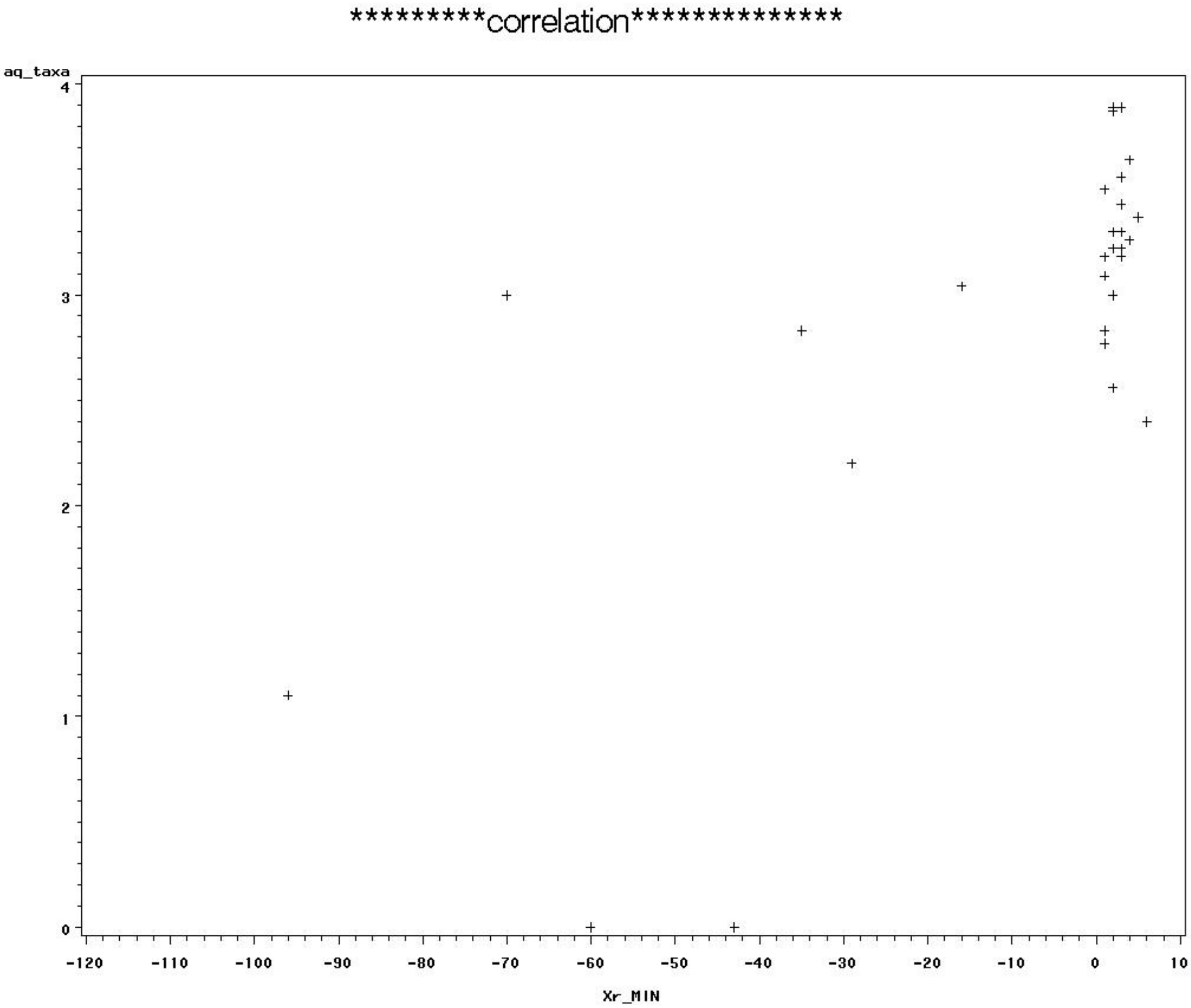

Figure 2.12: The relationship between minimum water depths in riffles (Xr_min) for the summer 2003 sample period.

Model Selection

Statistical analysis of the data indicated that both the reduced submodels without the stream-type variable as well as the minimum water depth model (submodels) are best suited for answering the question of the influence of stream hydrology on macroinverterbrate abundance in the eight headwater streams used in this study. These models were selected as the best fit models due to the lack of multicollinearity or intercorrelation relationships associated with the full model and the reduced model, which included the stream type variable. In addition, the Akaike Information Criterion (AIC) values along with the higher significance levels that were detected with the use of these models were used to evaluate model fit. Results from AIC assessments suggested that the minimum water depth model provided the best fit for this data in most seasons (Table 2.4-2.7).

Multicollinearity issues were detected in the full model and the reduced model containing the stream type variable. With reference to the full model, Pearson correlation reported r -values that exceeded the threshold value of 0.55. This means that there are variables present that may not be contributing to the significance of the model. Correlation between the independent variables in the reduced models with the variables stream type were not as high in some cases as those reported for the full model, yet its inability to predict significant relationships between water depths and macroinvertebrate variables was the reason for not choosing this model as the best fit model. One of the objectives of the study was to determine if water depth affected macroinvertebrates, however with the variable stream type included, it was difficult to determine the connection between water depth and macroinvertebrates.

Both the reduced model without the stream type variable and the minimum values model were chosen as the best models for analysis of the data collected. These models (submodels) were chosen because of their lower AIC values and their ability to detect relationships between water depths and macroinvertebrate variables. The lower AIC values are indicating that the independent variable(s) within the models (submodels) are contributing to the efficiency of the models to detect relationships between the independent variables and dependent variables. Tables 2.4-2.8 AIC values as well as p-values in bold indicating the best model (submodel) for each season and for each macroinvertebrate variable.

Stream Classification Method

Table 2.9 illustrates the level of significance between stream type and water depths during the macroinvertebrate sampling seasons. The data indicated that water depths may be used to validate the efficiency of the stream classification method used by North Carolina regulators, land managers and project managers to identify stream types.

Table 2.9. Relationship between stream types (stream points) and water depth.

Water Depth*	p-values**				
	Spring_03	Summer_03	Winter_04	Spring_04	Summer_04
X1	**0.0022**	**0.0004**	**0.0015**	0.1276	0.9048
X2	**<.0001**	**<.0001**	**0.0003**	0.1574	0.2923
X_Avg	**0.0003**	**0.0002**	**0.0018**	0.1064	0.4154
Xp_min	**<.0001**	**0.0004**	**0.0015**	**0.0307**	0.8654
Xr_min	**<.0001**	**0.0001**	**0.0032**	0.2051	**0.0032**

* These are water depth values used in the model.
** $p<0.05$ indicates significant relationships.
Note that the season used in this analysis corresponds to sampling season.
p-values in bold represents instances where significant relationships were detected in the spring and summer 2004 sampling period

DISCUSSION AND CONCLUSION

Headwater stream variability

Streams in North Carolina have typically exhibited lower hydrologic flow near the end of the growing season, which includes the months of September, October, and November. Conversely, increased water levels within streams at the end of the growing season may be in response to a decrease in uptake of water by vegetation and as a result more water is available to enter the stream (Giese and Mason 1993). During the entire sample period (May 2003-December 2004), lower hydrologic flows were observed during the summer and fall season, whereas in the winter and early spring water levels were higher within the stream channels.

The variability in water depths observed within the headwater streams used in this investigation can be described as seasonal variations and may be attributed to climate, specifically precipitation and evapotranspiration. Occasional peaks in the hydrographs might be attributed to increased rainfall or storm events in the area. Headwater stream catchments are suggested to be very responsive to precipitation, meaning that generation of stormflow is very rapid as a result of precipitation (Ward 1984). Runoff or overland flow generated by precipitation may not be observed in a forested catchment therefore, it has been suggested that areas adjacent to the streams contribute to streamflow in the channel during storm events. This idea is known as the Variable Source Area Concept (Ward and Trimble 2004).

Variable Source Area Concept

The Variable Source Area concept explains that precipitation can infiltrate and move through the soil and produce stormflow, a process or flow pathway called throughflow or interflow. Some of the precipitation received by the area may reach groundwater, but the portion that does not, may move through the soil and accumulate adjacent to stream where the soil may be shallow or along ephemeral draws, eventually becoming saturated and producing saturated overland flow (Ward and Trimble 2004).

Saturated areas adjacent to stream channels were observed in the headwater streams catchment used this study. After a major storm event, it was observed that the areas adjacent to streams became very saturated. Shallow flow from these saturated surfaces moved towards the stream channel eventually flowing into the streams. Saturated overland flow was most visible in the Umstead 1 study catchment along sub-reach five. The soil type adjacent to the sub-reach five was identified as a Wake soil (Wke). This soil is described as having rapid permeability and medium to rapid runoff (OSD 2005). In addition, such a soil possessed bedrock that is only 12 inches below the surface thus, allowing the above soil horizon to become saturated quickly resulting in runoff. Therefore, if interflow is the primary flow path that precipitation takes before it becomes streamflow or stormflow, then the properties of this soil may support this mechanism.

Flooding of the areas adjacent to the channel was observed along reaches 7A, 7B, and 7C of the Falls 1 study catchment during the summer of 2003. This phenomenon may be due to the fact that Mantachie soils underlay these reaches, where low channel gradient and resulted in floodplain development. A defining characteristic of Mantachie soils is that it experiences periodic flooding typically in the late winter and early in the spring (OSD 2005). Persistent rainfall throughout the day resulted in the flooding of this area.

Variability between streams

GIS technology was used to delineate the catchment areas for the study watersheds. The largest catchment was the Umstead 1 study catchment whereas the smallest area was computed for the Falls 3 watershed (Appendix 1). However, based on field observations the Schenck Forest study catchment appeared to be the most responsive to precipitation of all the headwater catchments in this study. A possible reason for this response may be that the forest canopy sheltering the stream is less dense than the other catchment forests. A less dense canopy may allow a greater amount of precipitation to intercept saturated or near saturated surfaces adjacent to the stream channel hence, contributing to stormflow to the stream at a faster rate than the other watersheds. Greater canopy cover may allow for increased evapotranspiration especially during the growing season therefore, less water if any at all may be able to reach the stream channel and generate baseflow (Ward and Trimble 2004).

A potential effect, which may be attributable to possessing a denser vegetative cover over the headwater streams used in this study is that water depths in some of the more intermittent and perennial reaches of streams did not exhibit a lot of variability as compared to the water depths for the Schenck Forest catchment. From visual assessments of the hydrographs water depths for some of the riffles and run sub-reaches of the study streams, e.g. Umstead 1 run water depths and Falls 2 run water depths, showed very little variability in water depths. Thus, suggesting that canopy cover in addition to other variables might be a factor that influences water depths in streams (Appendix 2).

Best Fit Models

Both the reduced model (submodels), without the stream type variable, as well as the minimum water depth model (submodels) provided a better fit of the macroinvertebrate data when compared to the full model and the reduced model with the stream type variable. The range of probability values observed was $p<0.0001$-0.7387. The improved model fit of this data indicated for the most part significant relationships between water depths and macroinvertebrate variables when the other models were not as efficient in reaching the same level of significance. The range of p-values reported by models was p=0.0015-0.9717. Additionally, these models incorporated various hydrologic conditions. For example, the reduced model without the stream type variable included the effects of the averaged water depths sampled the week before and the week after macroinvertebrate sample date may have on the macroinvertebrate. In contrast the minimum water depth model investigated the potential influence that minimum water depths may have on the sampled macroinvertebrates.

These models were also considered to best fit the data because of the lack of multicollinearity. Multicollinearity was reduced from the models by having each submodel consist of a single water depth variable. In addition to reduction of multicollinearity, these models provided lower Akaike Information Criterion (AIC). When comparing models with different numbers of independent variables, AIC serves as a reliable indicator of goodness-of-fit. A lower AIC usually represents a better model when compared to models resulting in a higher AIC. Both the reduced model without the stream type variables as well as the minimum water depth model resulted in a lower AIC than the majority of the other models.

In the reduced model which included the stream type variable, the submodel containing the variables stream type and the averaged water depths for both the averaged pool and riffle water depths the week before and the week after macroinvertebrate sample date (X_Avg) in some cases reported a lower AIC than the models chosen as the best fit models. In addition there were some significant relationships between averaged water depths for both the averaged pool and riffle water depth the week before and the week after macroinvertebrate sample date and a particular macroinvertebrate variable. This model was not selected as the best fit model in those cases because there were implications that stream type may be related to X_Avg. Therefore, if stream type is a component in a model, it may not be necessary to include X_Avg.

Additionally, this submodel was not selected because X_Avg is the averaged water depths in pools the week before and the week after macroinvertebrate sample date (X1) and averaged water depth in riffles the week before and the week after macroinvertebrate sample date (X2) (with the necessary adjustments made for ephemeral and run measurements). Averaging water depths for pools and riffles may not be an environment that is found in stream environments hence, the reason it was not chosen as the best fit in the cases where both a lower AIC and significant relationships were indicated between X_Avg and various macroinverterbrate variables.

Poorest Fit Model

The model with the poorest fit was the full mixed effects model. This model was used to determine the relationship between macroinvertebrate variables and water depths measured four hydrological sample weeks prior to macroinvertebrate sample date. The full model resulted in multicollinearity between the explanatory variables, the inclusion of the categorical variables such as stream type and category also introduced some level of redundancy into the model (Tables 2.4-2.8).

The full model also reported higher AICs when compared to the other models. One of the components for deriving AIC is that this goodness-of-fit criterion takes into consideration model complexity, which is the number of model parameters multiplied by a penalty number of 2 (Steel et al. 1997). The full model possessed more parameters when compared to the other model applied in this study hence a possible reason for the higher AIC values reported for the model.

Medium Fit Model

The reduced model, which included the stream type variable, consists of two submodels, which reported different results. The first submodel includes the variables averaged water depth in pools the week before and week after macroinvertebrate sample date (X1) and averaged water depth in riffles the week before and the week after sample date (X2), and stream type and did not result in a significant relationship between water depths and macroinvertebrate variables. The lack of significance reported by this model in all seasons except for winter 2004 may be explained by intercorrelation between the X1 and X2 variables as well as the possibility that stream type may hinder the model from detecting significant relationships between the water depth and the macroinvertebrate variables. The range of p-values during this season is p=0.01-0.022.

The other submodel included the variable stream type and the averaged water depths in pools the week before and the week after macroinvertebrate sample date and averaged water depth in riffles the week before and the week after macroinvertebrate sample date (X_Avg). In some instances, this model suggested relationships between water depth and macroinvertebrate variables as well as reported the lowest AIC of all the model and sub-models applied in this analysis. However, the averaged water depths in pools and riffles the week before and the week after macroinvertebrate sample date may not be considered a realistic environment that is present in streams whereas riffles and pools are two separate environments that are closely connected with each other but the characteristics of each may not be truly found in an exact combination. Thus, this model was not chosen as a best fit model in the cases where it produced significant results as well as reported a lower AIC than the other models and submodels.

Improvement of Models

To specifically improve the full model (Eq. 1) the four independent variables representing water depths four weeks prior to the macroinvertebrate sampling date could have been averaged into a single averaged water depth variable. By averaging the water depths, multicollinearity between the independent variables would be reduced. The full model may have also been improved by not including variables such as stream type and category. These variables may have introduced some redundancy in the model thus, preventing statistically significant relationships from being detected between water depths and general macroinvertebrate abundance.

With reference to the reduced model with the stream type variable, multicollinearity between the independent variables in the first submodel (Eq. 2) could be addressed by including only a single water depth variable in the model. In addition as in the case of the full model (Eq. 1) it may be necessary to exclude the stream type variable from the model since stream type maybe implied from the hydrological measurements made for the reaches of the headwater streams.

Overall, improvement of models so as to provide a better fit to this data could be accomplished by incorporating coincidental sampling and/or repetitive sampling. Coincidental sampling would necessitate that macroinvertebrates be sampled on the same day that water depths measurement are taken to provide a better estimate of the hydrologic conditions of the stream reaches. This is important because water levels measured in the sub-reach the same day macroinvertebrates are sampled will be an accurate representation of water depths the day of sampling. In addition, repetitive sampling of reaches may be necessary to provide a better assessment of the seasonal variation of macroinvertebrates variables such as the ones used in this analysis. With repetitive and/or coincidental sampling it may be possible to better describe seasonal variations in macroinvertebrates within these headwater streams because changes in stream flow and general macroinvertebrate abundance within channels may be captured if repetitive and coincidental sampling procedures were employed in this study.

Another way in which the models could have been improved is by analyzing relationships between water depths and general macroinvertebrate abundance by creating individual models based on the different hydrologic regimes (riffles, pools, runs, ephemeral wells). This would address the issue of comparing different hydrological regimes in a single model.

Additionally, the statistical models may have been improved by increasing the sample size (i.e. increasing the amount of sub-reaches that were sampled within a stream). Nonsignificant or less significant relationships were reported during the spring and summer 2004 sampling period. The nonsignificant and less significant relationships reported for these macroinvertebrate sampling seasons may be attributed to the fact that fewer sub-reaches were sampled in Spring 2004 and fewer streams (fewer sub-reaches) were sampled in the summer of 2004 (Table 2.7-2.8).

Macroinvertebrates in headwater streams

The results of this study found significant relationships in most macroinvertebrate sampling seasons between water depth and macroinvertebrates in headwater streams, using the minimum water depth model and the reduced models without stream type variable. The range of p-values reported by the minimum water depth model is p<0.0001-0.7387, whereas the overall range of p-values for the reduced model without stream type variable was p<0.0001-0.7661.

The distribution of macroinvertebrates may be affected by water depths, in which shallow water depths have been shown to be the preferred habitat for benthic macroinvertebrates (Wesche 1985 and Gordon et al 2004). For the spring 2003 macroinvertebrate sample period used in this study, minimum water depths in riffles were found to be significantly related to all of the macroinvertebrate variables (p<0.0001-0.0005). Riffles are indicated as having higher densities of benthic invertebrates hence a possible reason why minimum water depth in the riffles submodel reported a greater level of significance when compared to the minimum water depths in pool submodel during that sampling season.

In the summer 2003 sample period similar relationships between minimum water depth in riffles and macroinvertebrates were found, however a nonsignificant relationship was found between minimum water depths and terrestrial taxa. These relationships were also reflected in the reduced model without stream type. A possible explanation for this is that terrestrial taxa usually consist of invertebrates that are found primarily on land and not within aquatic systems therefore, the inclusion of terrestrial taxa within the stream samples may have occurred accidentally. For example, invertebrates from trees or on the banks of the streams may have by chance fallen in the channel at the time of sampling.

The habitats represented by riffles and pools are markedly different. These habitats possess different substrates and diversity of bedforms as well as different velocities (Gordon et al. 2004). Analysis of the winter 2004 macroinvertebrates samples indicated that minimum water depths in riffles could explain the total abundance and aquatic abundance during this sample period whereas the minimum water depths in the pools were indicated as having a possible influence on aquatic taxa, terrestrial taxa, and total taxa sampled from the reaches of the headwater streams. A possible explanation for this may be that during the winter sampling period, when water levels are expected to be high and velocity in the riffles is the greatest therefore, the pools may have been suitable for macroinvertebrates sampled during this season. Clifford (1966) recognized that the geomorphology of the stream is critical for providing habitat to aquatic invertebrates as well as possibly providing a refuge against increased velocity when water is flowing in the channels of intermittent streams.

Sample size may be an important determinant in whether significant relationships between independent and dependent variables can be detected using statistical analysis. The results may also suggest that a decrease in the number of streams sampled during the spring and summer 2004 sampling seasons may have caused the low level or lack of significance that was detected between minimum water depths and macroinvertebrate variables such as aquatic abundance, aquatic taxa, and total taxa. These results may also suggest the possibility of influences from other environmental variables such as temperature, food availability, or precipitation.

The life cycles of macroinvertebrates typically inhabiting headwater streams may provide an additional explanation between the low level of significance that was detected between water depths and macroinvertebrate variables during the spring 2004 sampling period. Griffith and Perry (1993) investigated the distribution of macroinvertebrates within the hyporheic zone and suggested that the variation in density for individual taxa may be a result of taxa life cycle. This means that the life cycle of macroinvertebrates might be a factor influencing variation in the general abundance of macroinvertebrates from season to season.

In the summer of 2004, water depths were not found to have a significant relationship with macroinvertebrates using most models as water depths may have been very low corresponding to the low flows that are characteristic of North Carolina streams near the end of the growing season. The range of p-values include p= 0.0506-0.9934. Furthermore, other factors such as food and temperature (changes in season) may have had a greater influence on macroinvertebrates at that time in addition to water depths. The model results of this study suggest that water depth in the stream channel may have a statistically significant relationship to the general abundance of macroinvertebrates found in headwater streams. The range of p-values reported was p<0.0001-0.0437. However, improvements can be made to the models by incorporation of other environmental factors.

Validation of NCDWQ's Stream Classification Method

An additional objective of this study was to compare conceptual stream type designations to the hydrologic flow measurements taken within the study area over the 18 month hydrologic measurement period and determine if stream water depth could be correlated to the stream points (stream type) assigned to the sampled reaches of the stream. These designations include ephemeral, intermittent, and perennial hydrologic stream reaches. Landuse activities on lands adjacent to headwater streams can affect these streams due to the ecological connection between stream channels and its riparian zone (Haggerty et al. 2004). Habitats for organisms living in the stream as well as degraded water quality may be consequences of altering lands in the headwater regions (Meyer and Wallace 2001). The stream type designations are critical in determining landuse relationships affecting water quality in headwater streams.

Significant relationships were found between stream type and water depths during the spring 2003, summer 2003 and the winter 2004 macroinvertebrate sampling period providing a statistical measure of agreement with the stream classification method implemented by NCDWQ. The range of p-values reported for these sampling seasons were p<.0001-0.0032. Nonsignificant relationships, which ranged in p-values of 0.1064 to 0.9048, were observed at most water depths for macroinvertebrate sample periods spring and summer 2004 macroinvertebrate sampling period. These datasets contained fewer records than the prior three sampling times and suggested poorer relationships in all models results.

The importance of protecting both the water body as well as its associated riparian areas were recognized with the use of Best Management Practices (BMPs) and many states have now established Riparian Management Zones and areas, streamside (special) management zones; stream protection zones and buffer strips (Blinn and Kilgore 2001). In the state of North Carolina one of the more well-known riparian buffer regulations established for the state is the Neuse River Basin Riparian Buffer Rules (NCAC15A02B.0233). A component of this rule requires proper identification of stream types. The definitions of these NCDWQ stream types are:

1. **Ephemeral stream:** Ephemeral (stormwater) stream refers to a feature that carries only storm water in direct response to precipitation with water flowing only during and shortly after large precipitation events. An ephemeral stream may or may not have a well-defined channel, the aquatic bed is always above the water table, and stormwater runoff is the primary source of water. An ephemeral

stream typically lacks the biological, hydrological, and physical characteristics commonly associated with the continuous or intermittent conveyance of water. 15A NCAC 02B .0233(2)(d)

2. **Intermittent stream:** Intermittent stream identifies a well-defined channel that contains water for only part of the year, typically during winter and spring when the aquatic bed is below the water table. The flow may be heavily supplemented by stormwater runoff. An intermittent stream often lacks the biological and hydrological characteristics commonly associated with the conveyance of water. 15A NCAC 02B .0233(2)(g)

3. **Perennial stream:** Perennial stream refers to a well-defined channel that contains water year round during a year of normal rainfall with the aquatic bed located below the water table for most of the year. Groundwater is the primary source for a perennial stream, but it also carries stormwater runoff. A perennial stream exhibits the typical biological, hydrological, and physical characteristics commonly associated with the continuous conveyance of water. 15A NCAC 02B .0233(2)(i)

These definitions were obtained from the North Carolina Division of Water Quality Identification Methods for the Origins of Intermittent and Perennial streams Manual (2005). Based on the hydrograph results compiled over the entire study period (18 months) the water table in all ephemeral streams ranged from 112cm below the surface to 9cm above the surface. The above surface water depth (i.e. stormflow) was measured at Schenck Forest after the Tropical Storm, Charley passed through North Carolina. After that time, water table levels were not recorded above the surface even after extended periods of rainfall. This range supports the NCDWQ's definition of an ephemeral stream.

The range of water depth for intermittent streams was -78cm within the hyporheic zone to over 26cm. One of the defining characteristics of an intermittent stream based on the NCDWQ's definition of an intermittent stream is that such a stream contains water for only part of the year. The range of water depths that were observed for the intermittent reaches in the study streams supports this definition.

Based on the hydrographs for the perennial streams, the range in water depths was 1cm to 45cm. Within the perennial reaches of the stream, water depths did not go below the surface for the duration of the entire sample period (18 months). The range that was observed for the perennial reaches of the headwater streams coincides with the definition of perennial streams.

The results of the statistical models used in this study suggest headwater stream water depths may have a significant relationship to the macroinvertebrate inhabiting those streams abundances found within these streams. The NCDWQ Stream Classification Form (Method) is a valuable and effective tool that can assist regulators and land managers in identifying the intermittent and perennial origins of headwater streams.

EXTENDED DISCUSSION

INTRODUCTION

Headwater streams and Macroinvertebrates

Water levels in headwater streams are a direct result of a highly variable flow regime. This variability may be influenced by climatic as well as other physical factors such as soils and geology. Macroinvertebrate abundances are also observed to vary seasonally and spatially within a stream and such variability may be attributed to water level and volumes in the stream channel (Cowell et al. 2004). Despite the need for detailed information on the hydrology of headwater streams and relationship of macroinvertebrates to hydrology little information exists in the current literature. The objectives of this study were to: (1) describe the hydrologic behavior of eight headwater streams in the Piedmont of North Carolina, (2) discuss the potential influence of water depths in headwater streams, and (3) evaluate the accuracy of the NCDWQ's Stream Classification Method for identifying the origins of intermittent and perennial streams. This study demonstrated that stream flow in headwater streams exhibits seasonal variability in response to many environmental and biological factors. It also revealed that minimum water depths in streams may influence macroinvertebrates inhabiting these environments.

These result suggests that as water depths decrease in riffles and pools this may affect variables such as total macroinvertebrate abundance, aquatic abundance, total and aquatic taxa. Clifford (1966) questions the potential impact that cease of flow in small streams during the summer and early fall may have on macroinvertebrates. It may be assumed from studies such as Cowell et al. (2004), which observed seasonal variability in densities of benthic macroinvertebrates that the macroinvertebrates sampled from the eight headwater streams in this study may have also exhibited such seasonal representation that may be reflected in the macroinvertebrate samples collected from the headwater streams used on this study.

Water depths measured for each stream were correlated to the stream points assigned to stream reaches demonstrating that the stream classification form/method is an effective tool for determining stream type and points of origin for intermittent and perennial streams. In the long-term, accurate headwater stream identification will aid in preventing further loss of headwater streams in the state as well as assist in regulation of landuse activities that can impact stream and river water quality.

Uniqueness of study sites

The headwater streams used in this study are located in protected areas. Umstead Park and Falls Lake Park are component part of the North Carolina state park system. Schenck Forest is not a part of the State's park system and is owned by North Carolina State University. Even though these forest systems are bordered by highly urbanized areas and generally are open to the public; the headwater streams are, for most part, inaccessible to the public. By selecting streams that are located in these protected areas we ensured that the water depths measured and the macroinvertebrates sampled were not influenced by the surrounding landuses. Thus, the hydrological variability observed and the macroinvertebrates sampled were representative samples and behavior of these streams in natural forested watersheds.

Streams in urbanized areas support biological communities that are different from communities in natural watersheds (Klein 1979). If this study was conducted using headwater streams in urbanized watersheds, it may be expected that both the hydrologic response and macroinvertebrates sampled would be different from what was observed for the headwater streams used in this study. In urban areas, stream flow during storm events is described as “flashy”. During a storm event, runoff from impervious surfaces is rapid, which results in flooding in addition to other disturbances (Klein 1979). Lenat and Crawford (1994) observed differences in community assemblages when comparing an agricultural, urban, and forested stream in the Piedmont region of North Carolina. The authors provided evidence that land use had an affect on macroinvertebrates.

Delucchi (1988) listed various physical and biological factors that may influence benthic community structure. Two variables that the author indicated as having an influence on community structure included: (1) how recently the riffle dried and (2) the length of the dry period. Knowing the length of the stream period and the time drying are important because these factors may have potential influences on macroinvertebrate abundance. The onset and the length of drying in streams raise questions about recolonization of macroinvertebrates in streams. Upon initial evaluation of the macroinvertebrate samples that were collected from the headwater streams in this study, the question arose as to recolonization of streams once flow in the stream channel has returned after drying. This question then led to the idea of the hyporheic zone as a potential refuge for macroinvertebrates when channel flow has ceased. However, from research carried out by Del Rosario and Resh (2000) there are still some questions as to the potential role that the hyporheic zone may play in the recolonization of stream channels when flow commences.

Further Research

Many questions have surfaced pertaining to both the hydrology and ecology of headwater streams in North Carolina. With reference to the hydrological questions; some areas that can be further researched are flow pathways in these headwater catchments as well as describing the relationship various the catchment geomorphic properties such as area, shape, slope, and relief to the headwater streams hydrology. Learning more about the different flow pathways within the headwater catchments in addition to the relationship between catchment geomorphology and character of the streams is important. Such knowledge will assist land and watershed managers in understanding the impacts of various landuse activities on the hydrology of headwater regions in watersheds.

Macroinvertebrates have been used as indicators of water quality and stream health. Conducting research that increases knowledge about macroinvertebrate assemblages in headwater streams that have not been influenced by urbanization or land conversion practices is useful. When attempting to assess the impacts of urbanization on water quality in the headwater region of a watershed or river basin, it may be necessary to compare the findings for the urbanized streams to those headwater streams that drain forested watersheds. Studying headwater streams in the forested areas can provide reference information that can be used for comparative purposes.

In addition, when attempting to statistically determine the relationships between water depths and macroinvertebrates, it may be necessary to create individual models based on the hydrologic regimes (riffles, pools etc.). By doing this, the true relationship between water depth and macroinvertebrates may be determined based on hydrologic flow regimes. However, it is recommended that if such models were to be created it would be necessary to increase sample size, possibly in the form of the number of streams sampled or simply the case of sampling more reaches in the eight study headwater streams.

Future Direction

Knowledge about the headwater streams in North Carolina is very limited (Personal Communications, Dr. James D. Gregory). One of the main reasons underlying the initiation of such a project is to address this lack of information on headwater streams in the North Carolina State. Analysis of the data collected for this study emphasizes the need to learn more about these streams and the macroinvertebrate communities, which it supports.

In addition, it is important to not only learn more about headwater streams in the Piedmont region of the state but, also to expand such research into the Blue Ridge/Mountain ecoregion as well as the Coastal Plain. It is estimated that approximately less than 1 percent of headwater streams (ecosystems) have been lost in the inner Coastal Plain due to increased agriculture, hence the importance of researching these sensitive streams (Rheinhardt et al. 1999).

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APPENDICES

APPENDIX 1

Basic Catchment Characteristics:

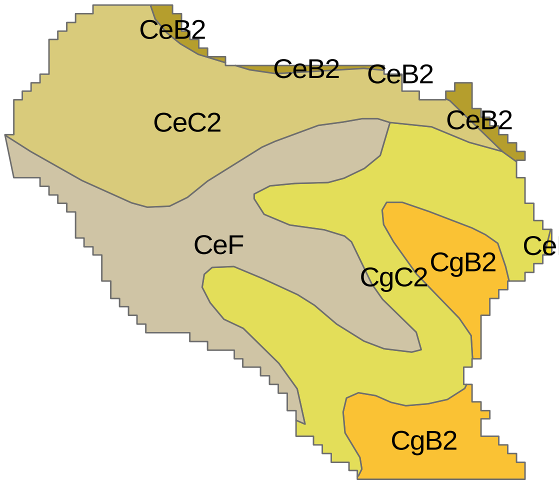
Catchment area and perimeter

Measurement points along individual headwater streams were mapped with the use of aLeica sub-meter accuracy Global Positioning System. These points were imported into GIS where the catchment boundaries were delineated. Catchment area and perimeter were all computed in ARC Map.

Catchment	Area (Acres)	Perimeter (Feet)
Schenck	18.69	5090.41
Umstead 1	44.08	9359.26
Umstead 2	25.52	5959.50
Falls 1	39.42	9519.64
Falls 2	16.69	4836.24
Falls 3	10.89	3717.11
Falls 4	18.09	5036.09
Falls 5	19.08	4636.40

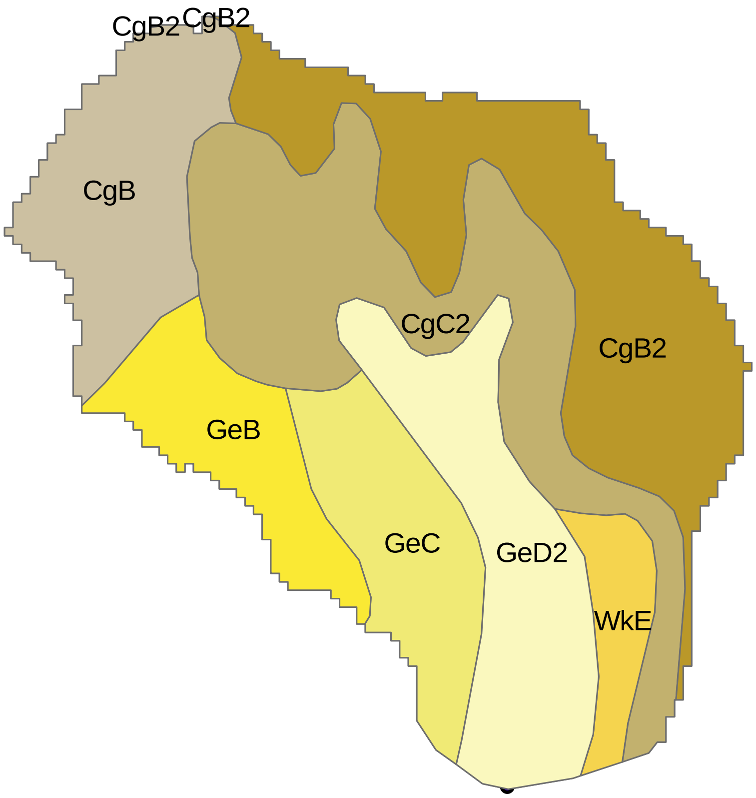
SOIL MAPS:

Distribution of soil types within Schenck Forest catchment
Dominant soil series is Cecil



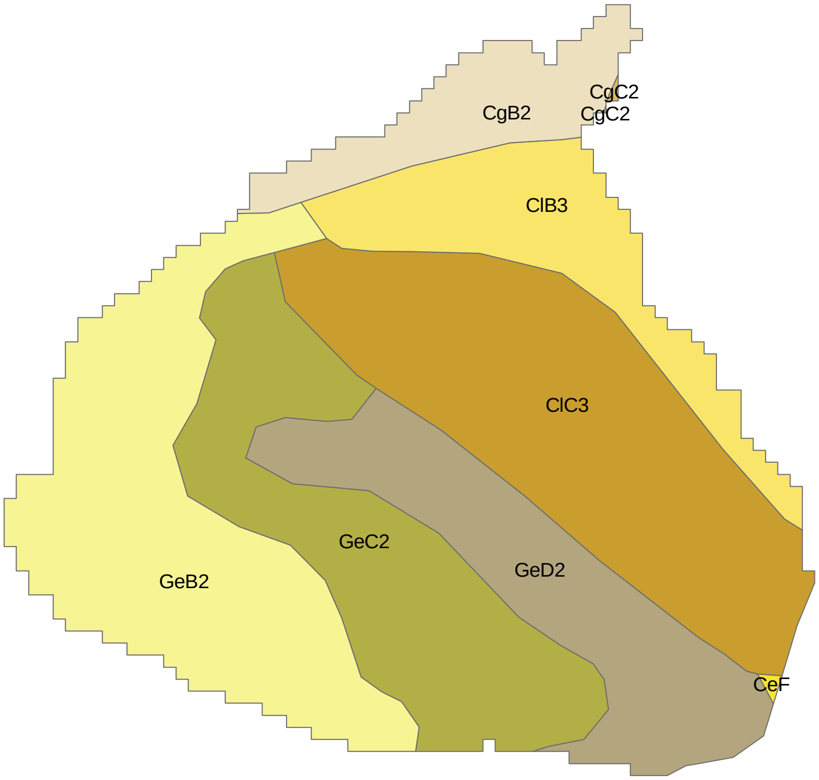
SOIL MAPS:

Distribution of soil types within Umstead 1 catchment
Dominant soil series are Cecil, Georgeville and Wake



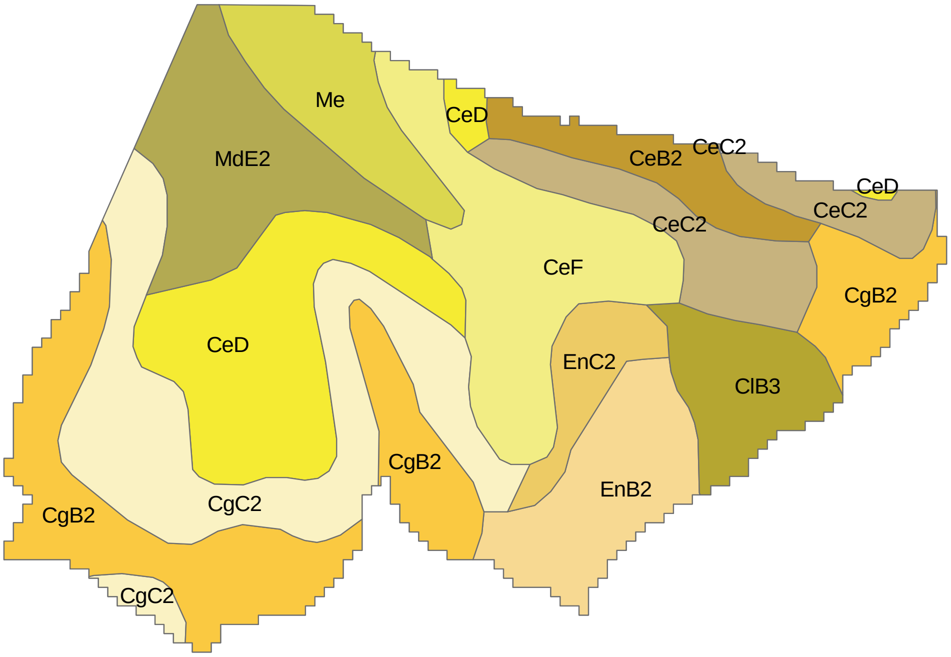
SOIL MAPS:

Distribution of soil types within Umstead 2 catchment
Dominant soil series are Cecil and Georgeville



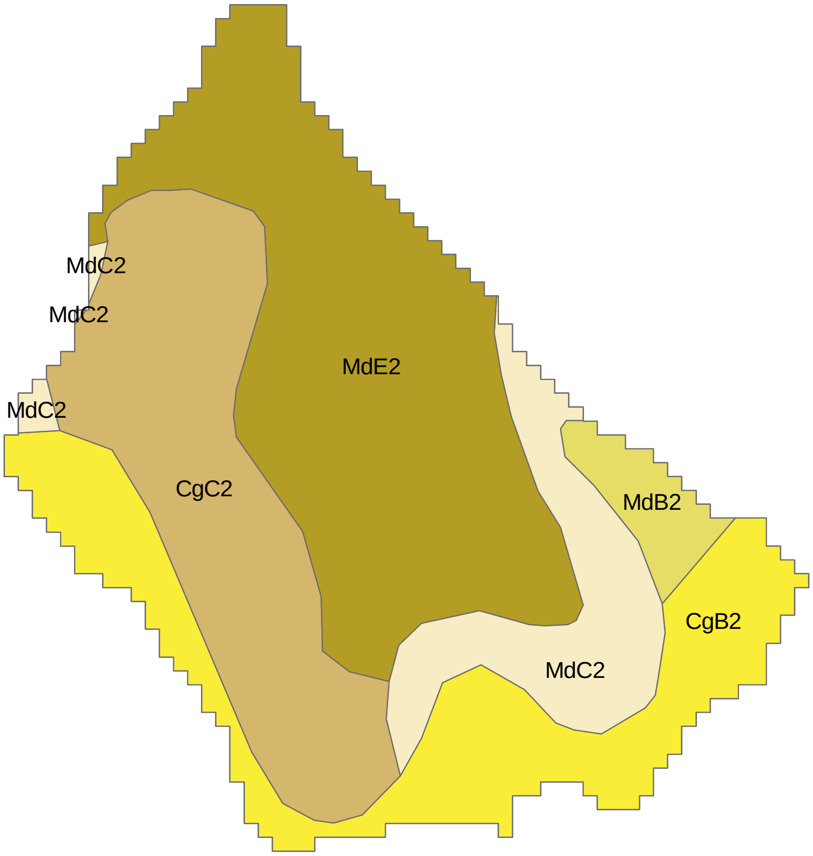
SOIL MAPS:

Distribution of soil types within Falls 1 catchment
Dominant soil series are Cecil, Enon, Madison and Mantachie



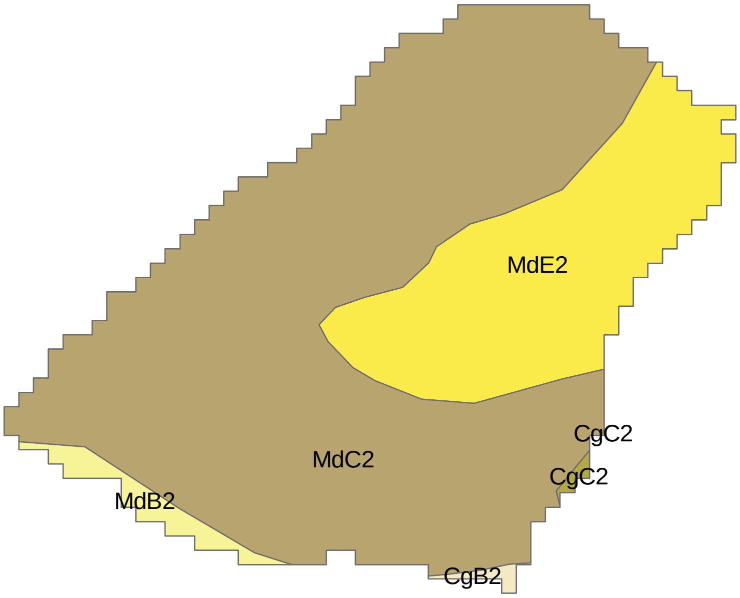
SOIL MAPS:

Distribution of soil types within Falls 2 catchment
Dominant soil series are Cecil and Madison



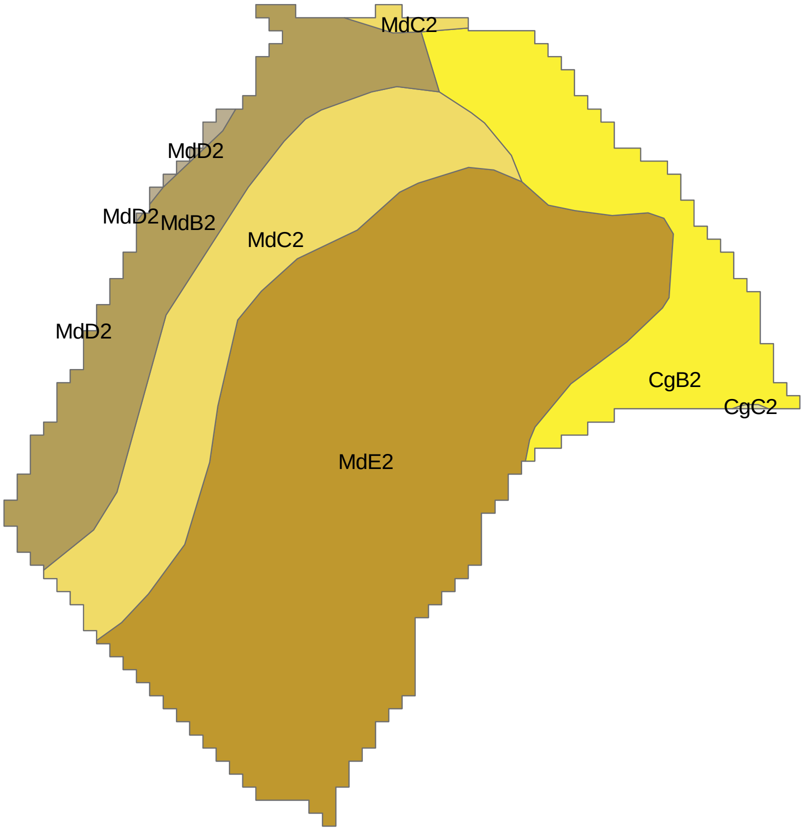
SOIL MAPS:

Distribution of soil types within Falls 3 catchment
Dominant soil series are Cecil and Madison



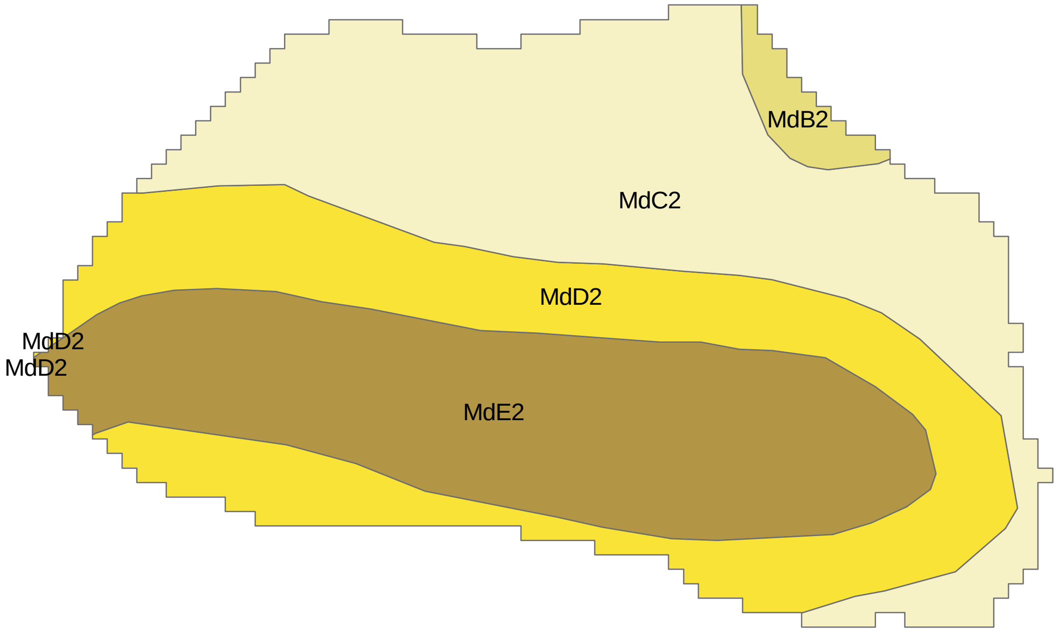
SOIL MAPS:

Distribution of soil types within Falls 4 catchment
Dominant soil series are Cecil and Madison



SOIL MAPS:

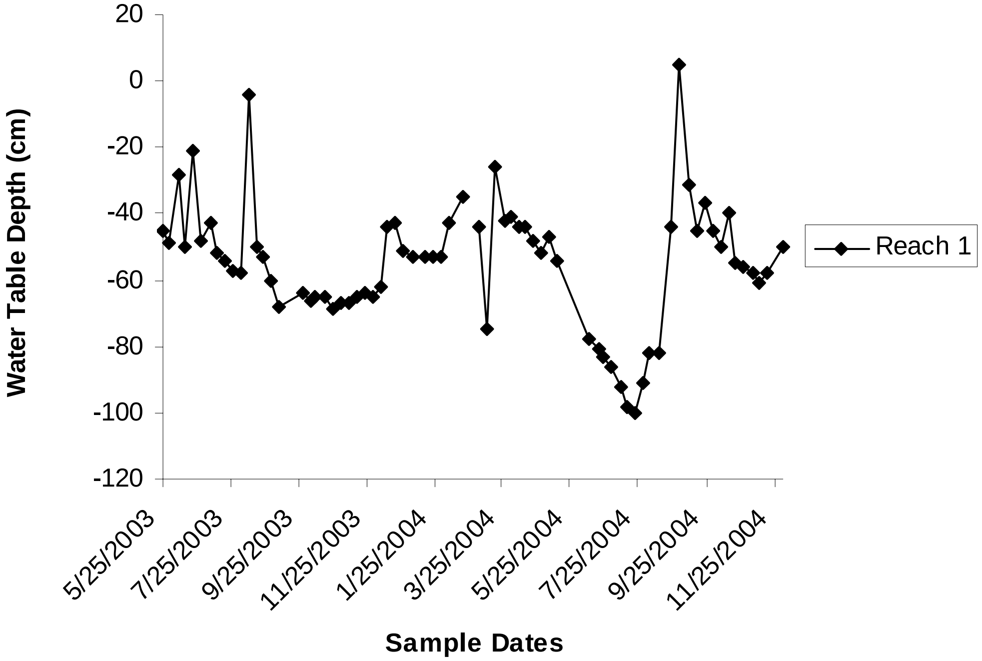
Distribution of soil types within Falls 5 catchment
Dominant soil series is Madison



APPENDIX 2
STREAM HYDROGRAPHS:

Water depths over the 18 months stream measurement period

Schenck Stream Ephemeral Water Table Depths



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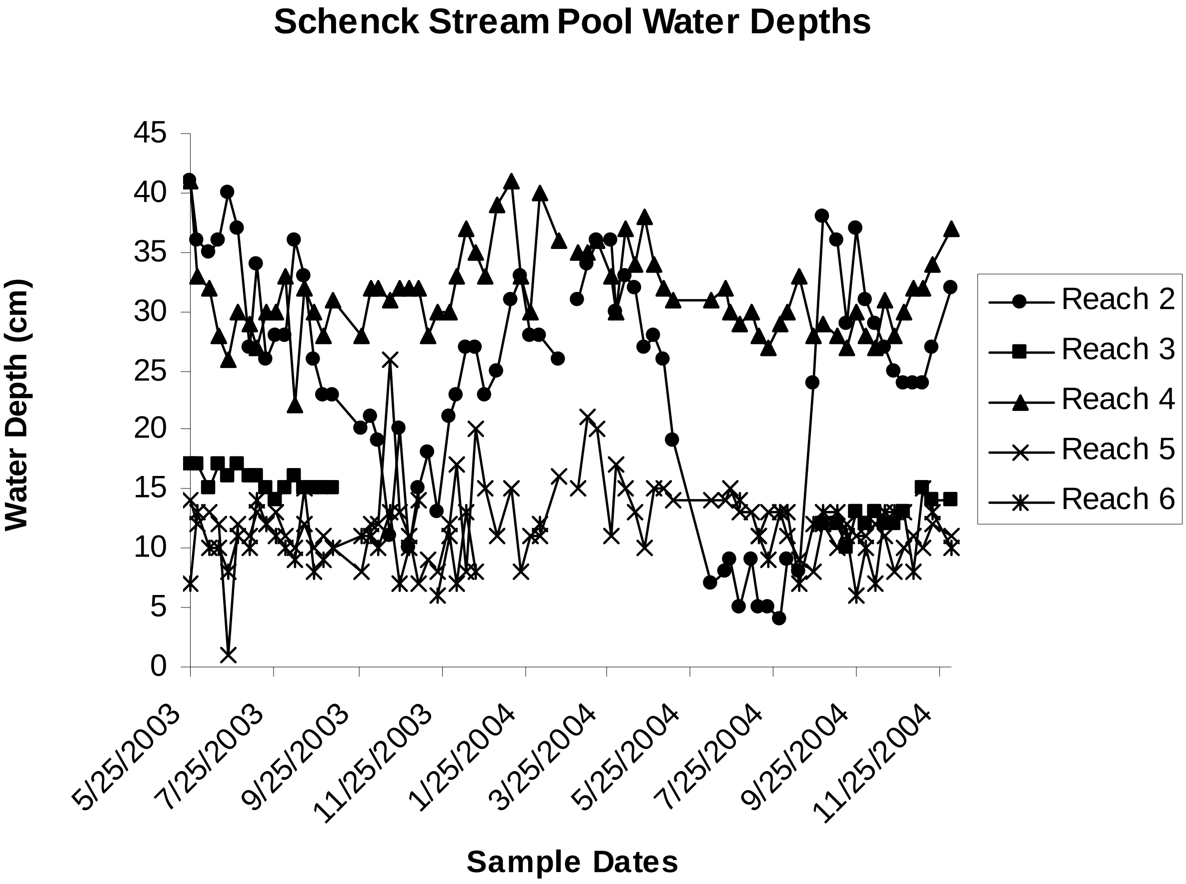
Water depths over the 18 months stream measurement period



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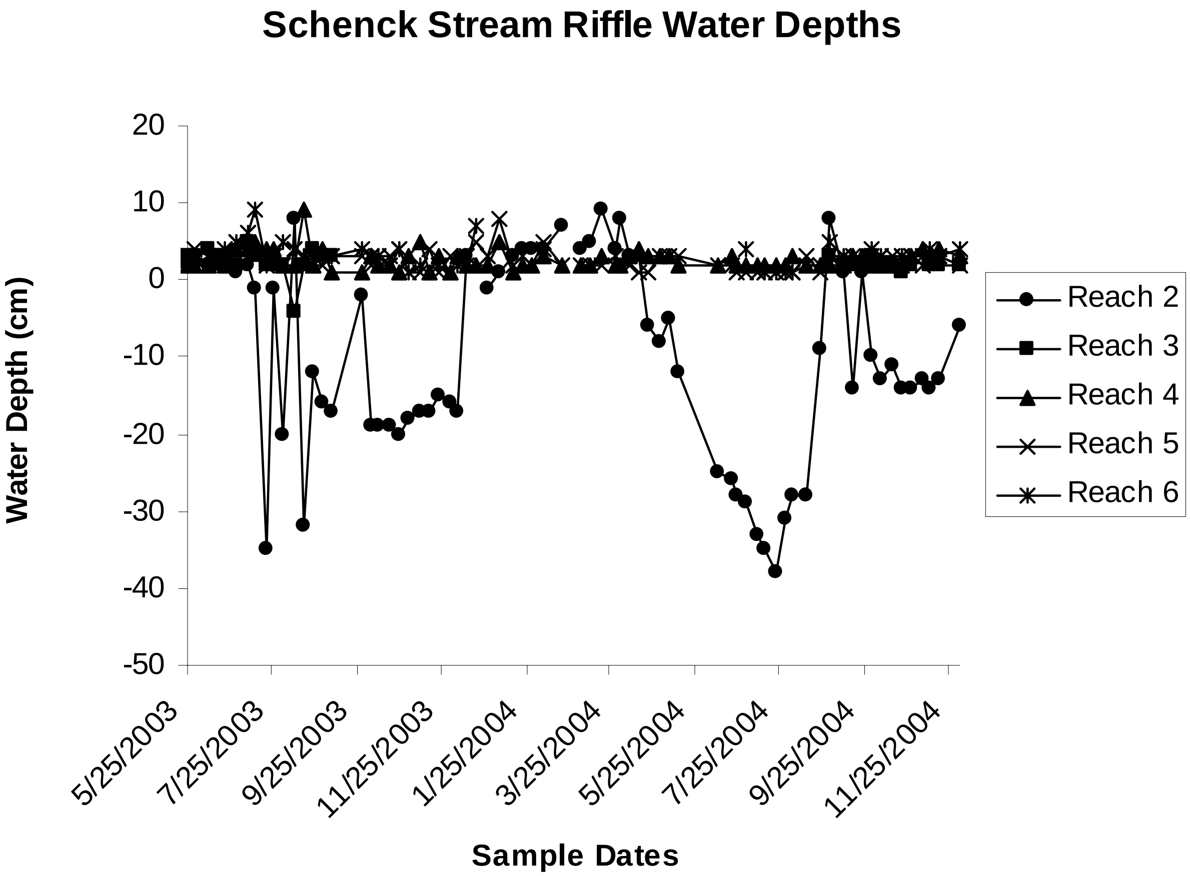
Water depths over the 18 months stream measurement period



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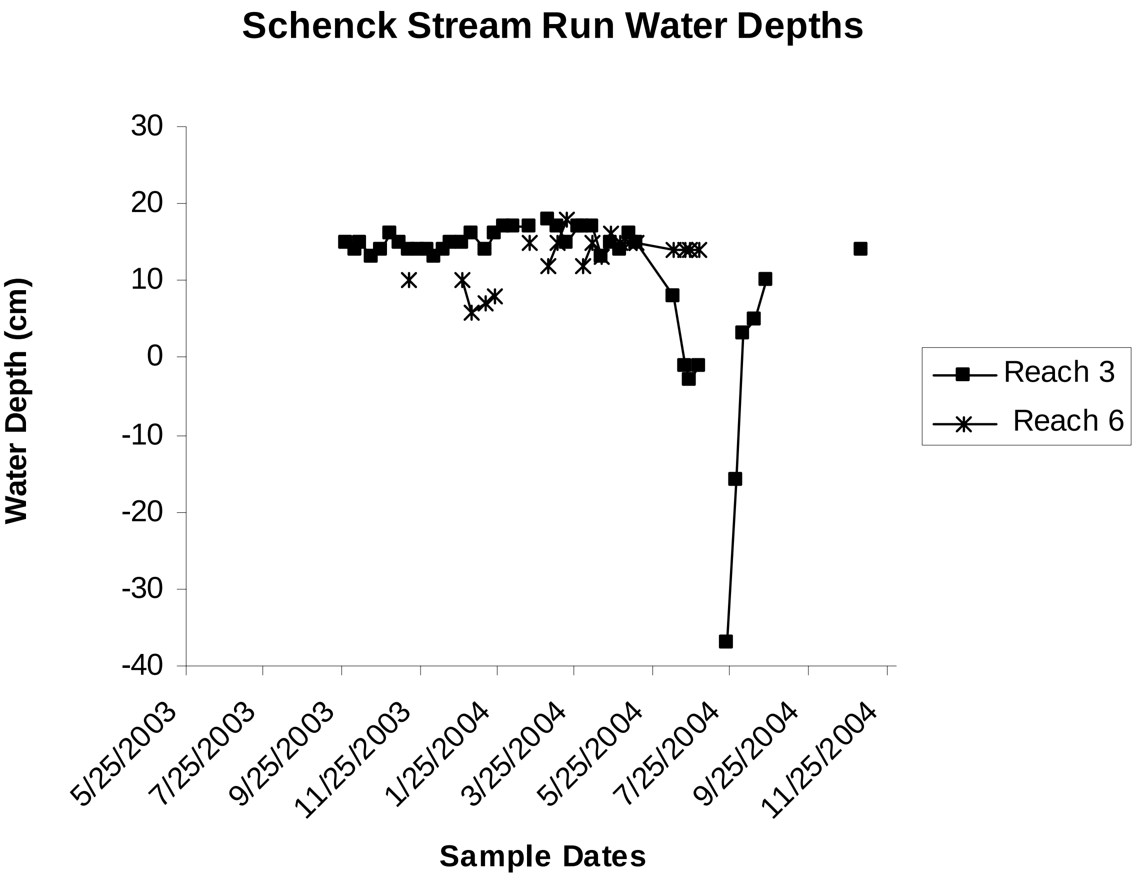

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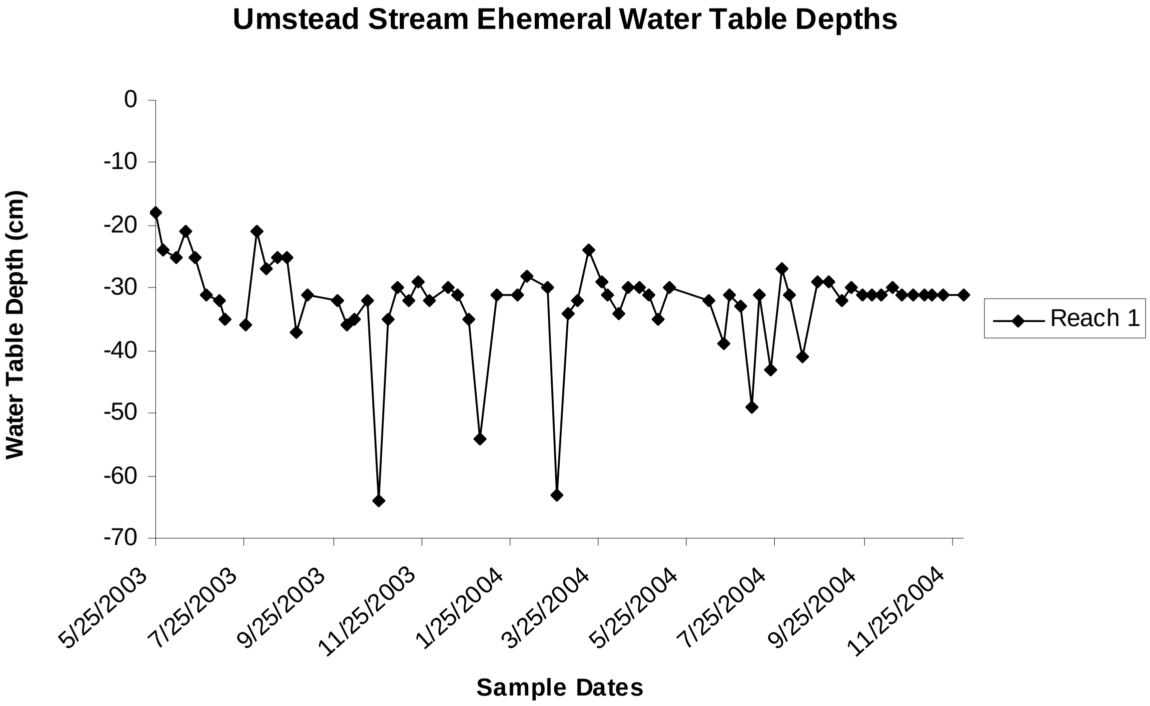
Water depths over the 18 months stream measurement period



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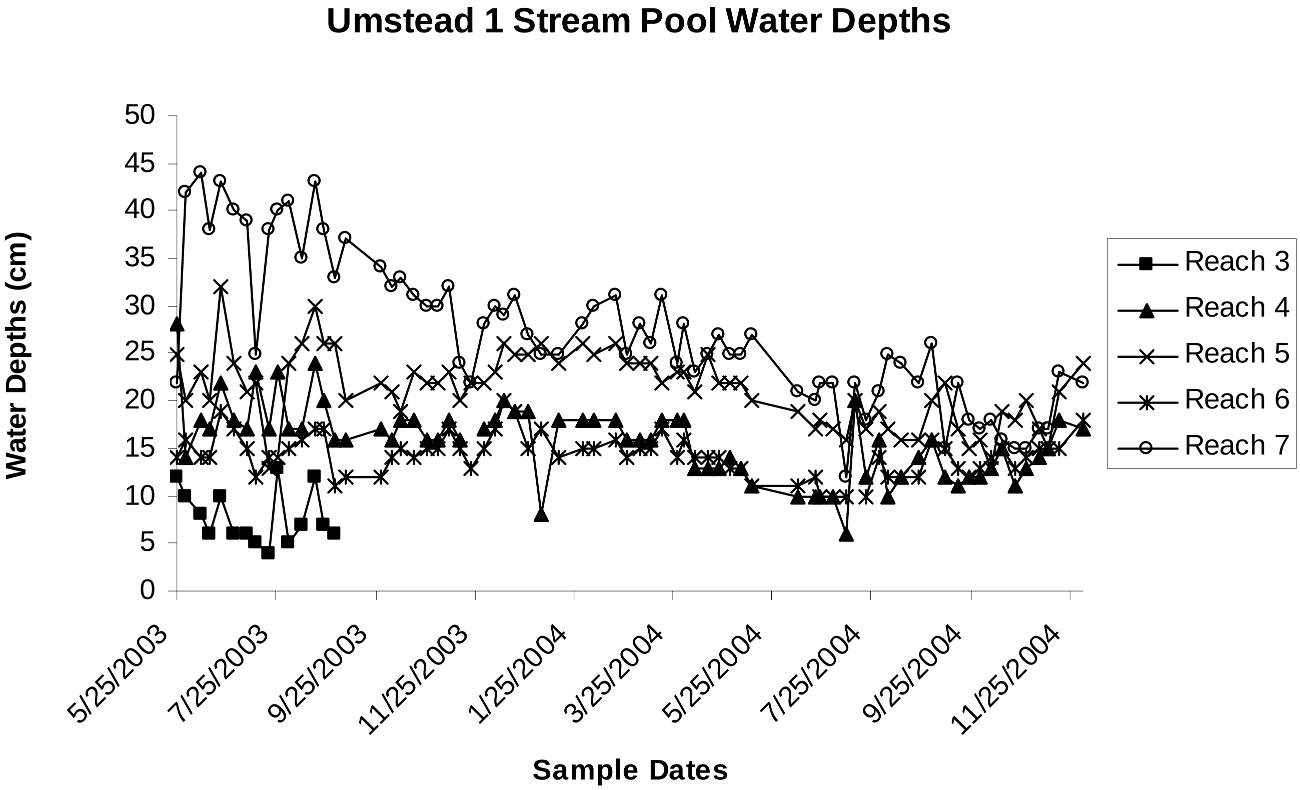
Water depths over the 18 months stream measurement period



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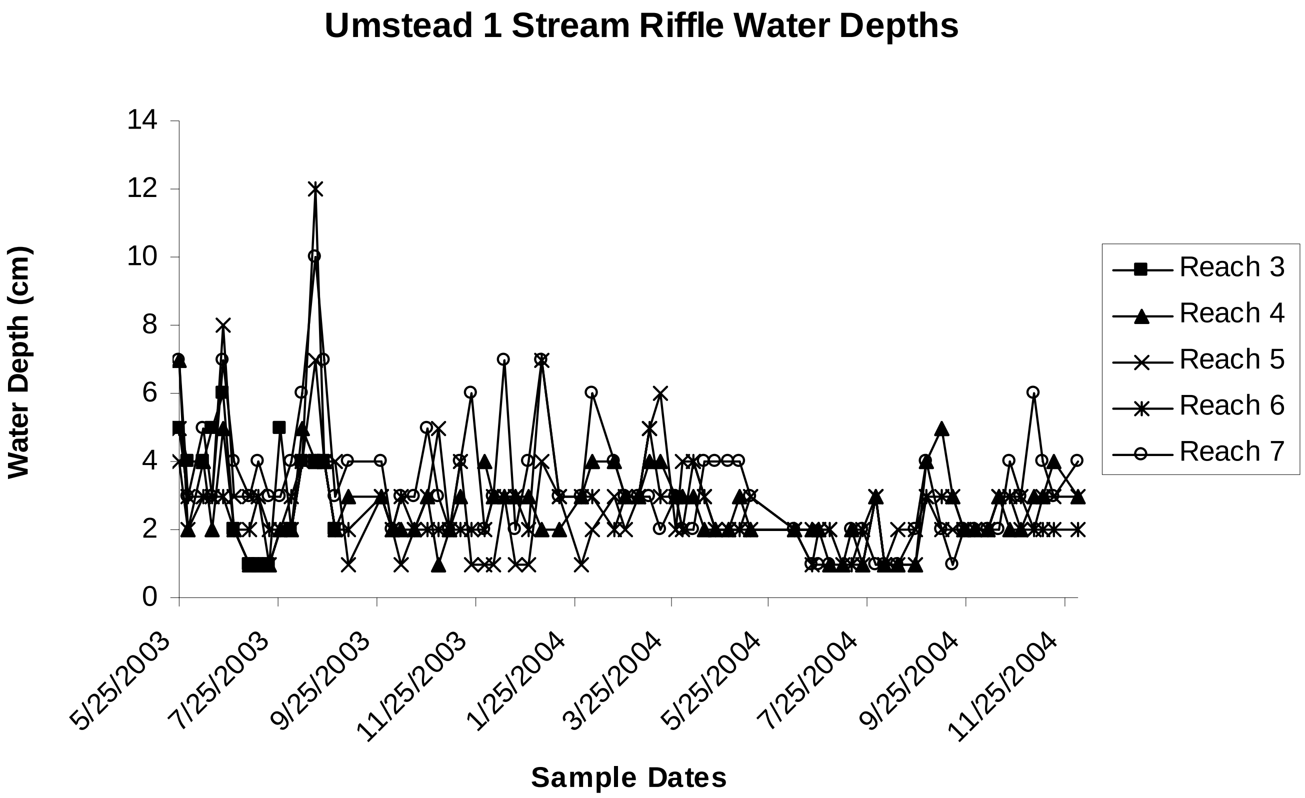
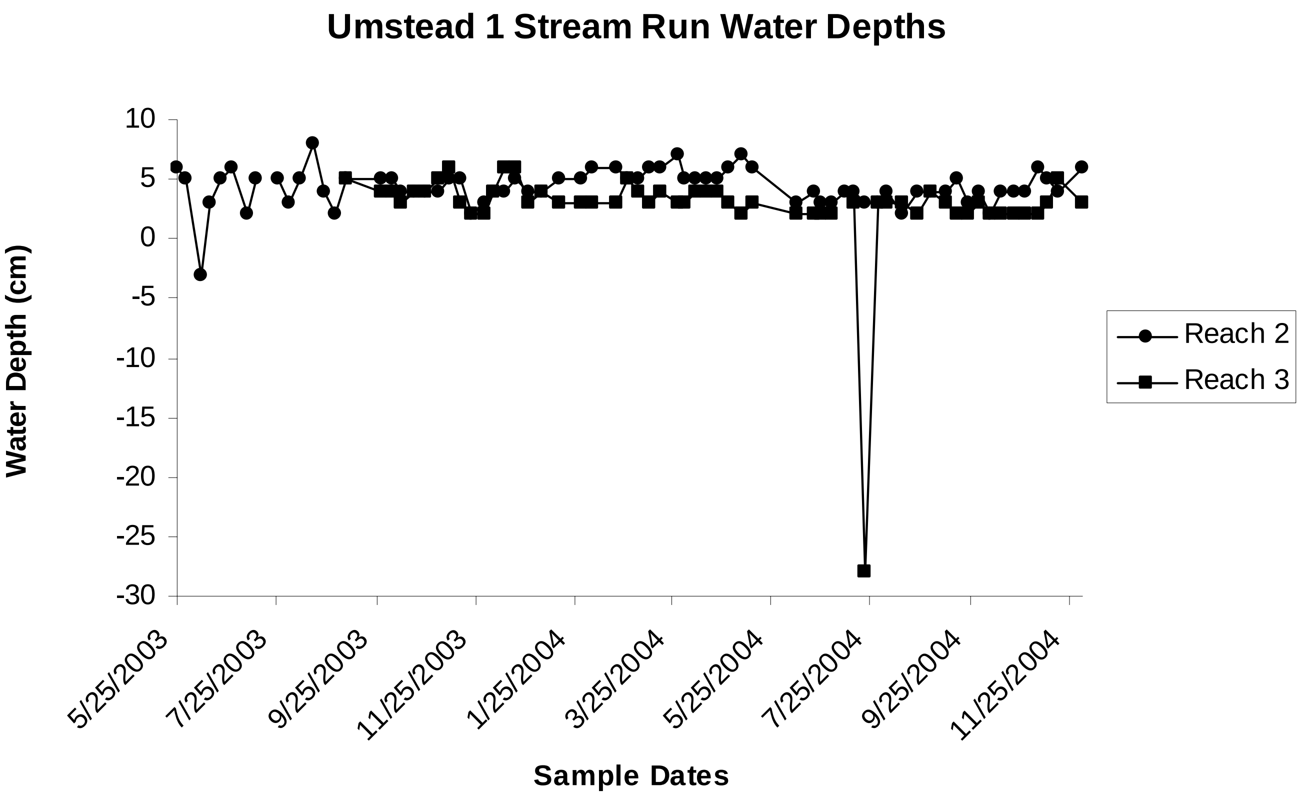
Water depths over the 18 months stream measurement period



STREAM HYDROGRAPHS:

Water depths over the 18 months stream measurement period



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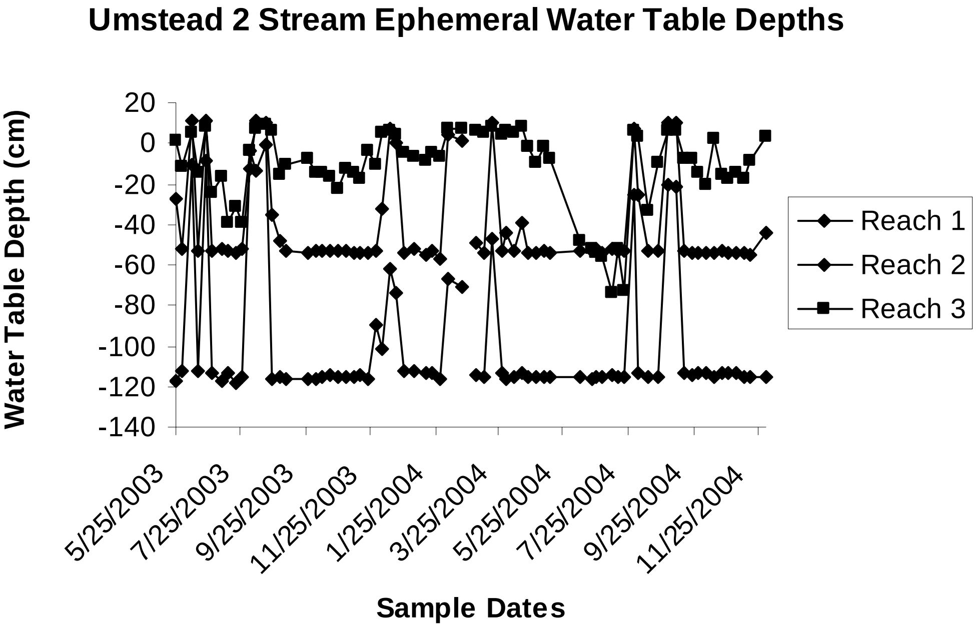
Water depths over the 18 months stream measurement period



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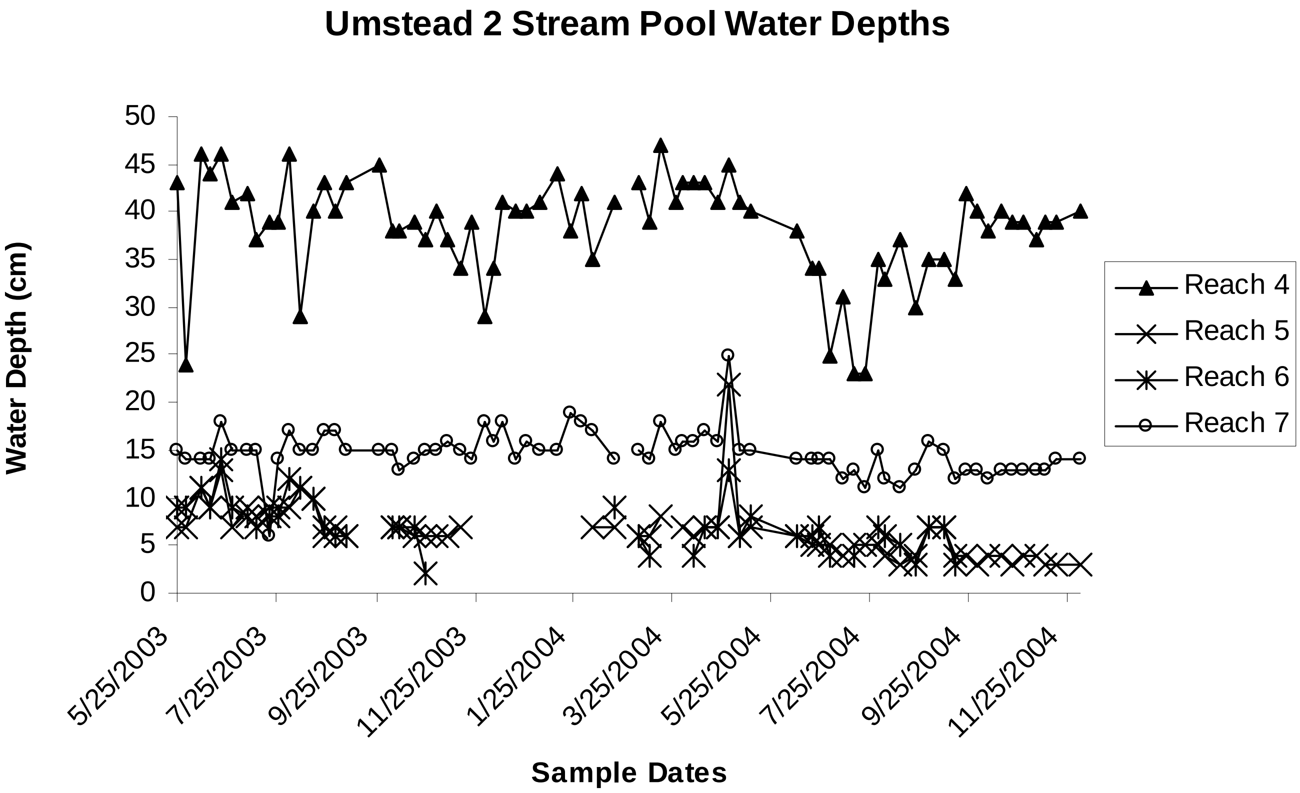
Water depths over the 18 months stream measurement period



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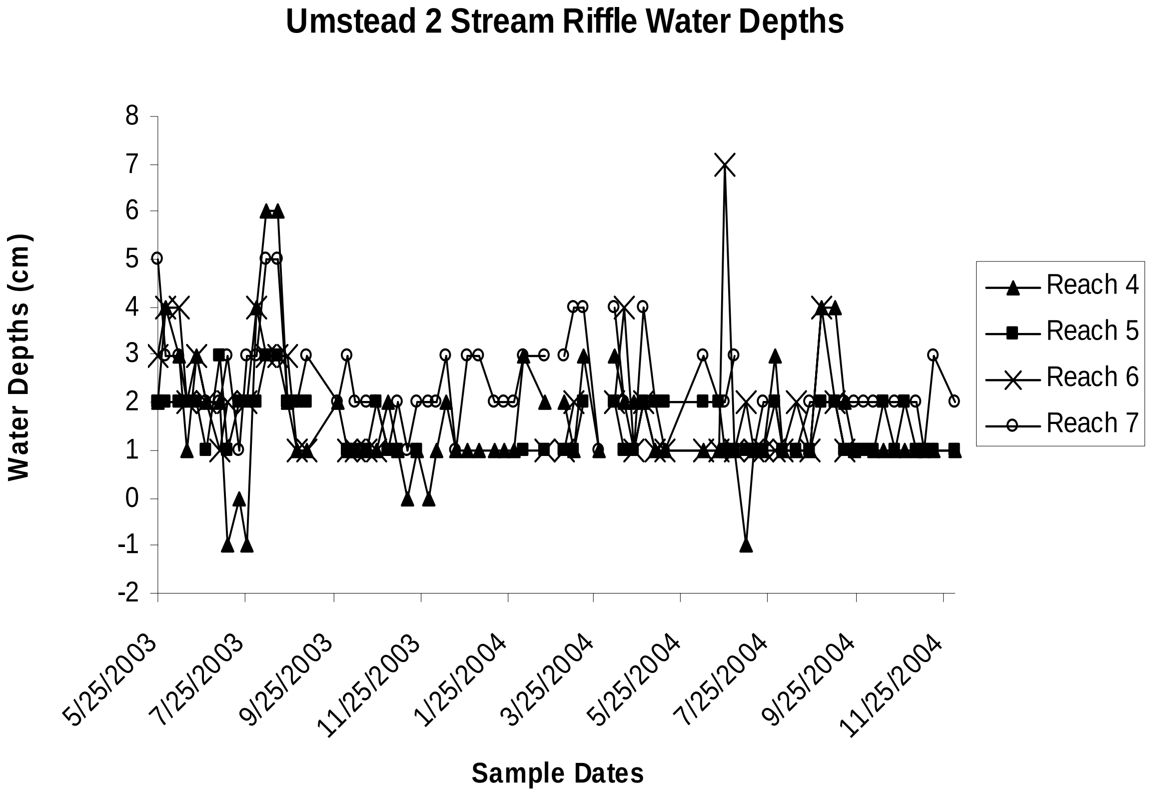
Water depths over the 18 months stream measurement period



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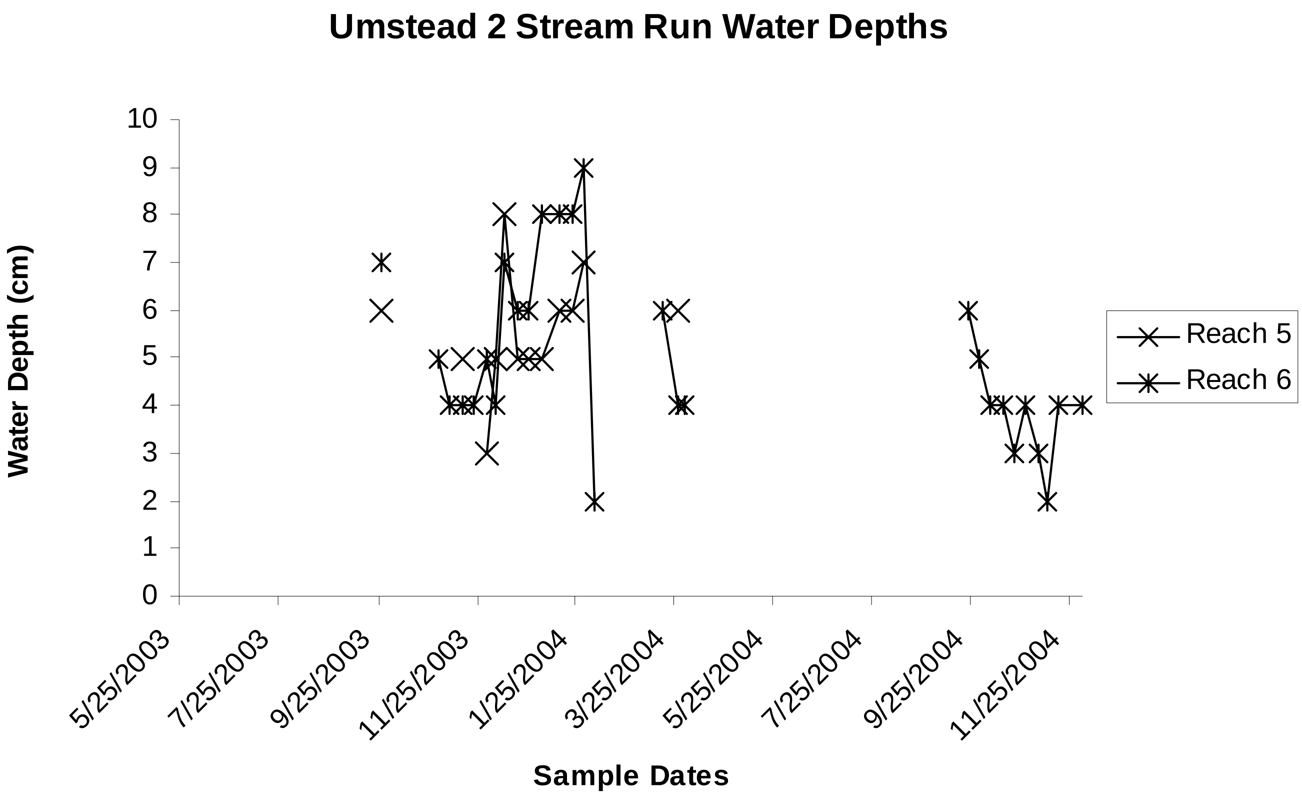

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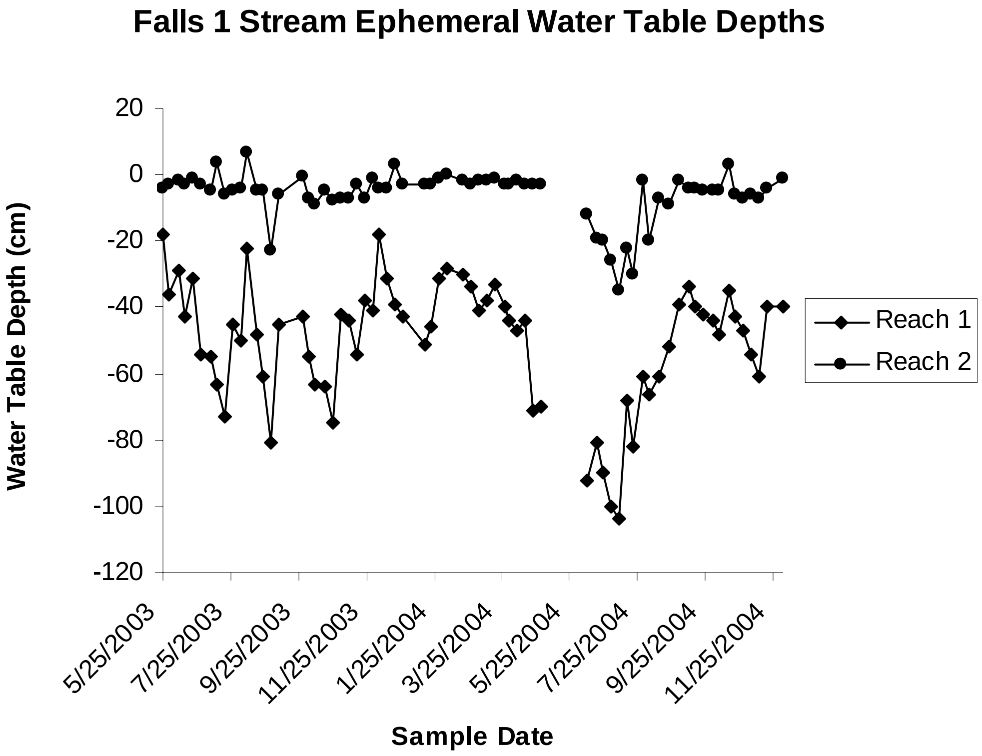

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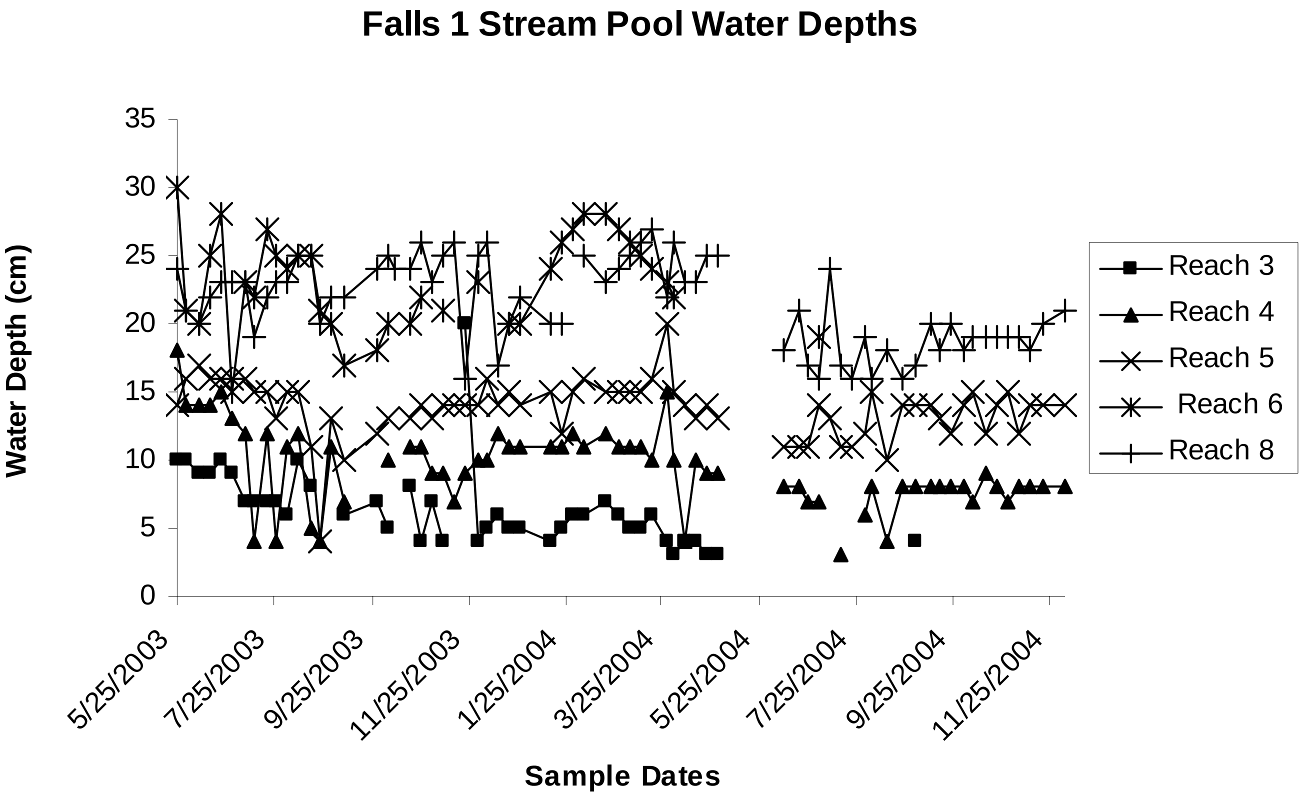
Water depths over the 18 months stream measurement period



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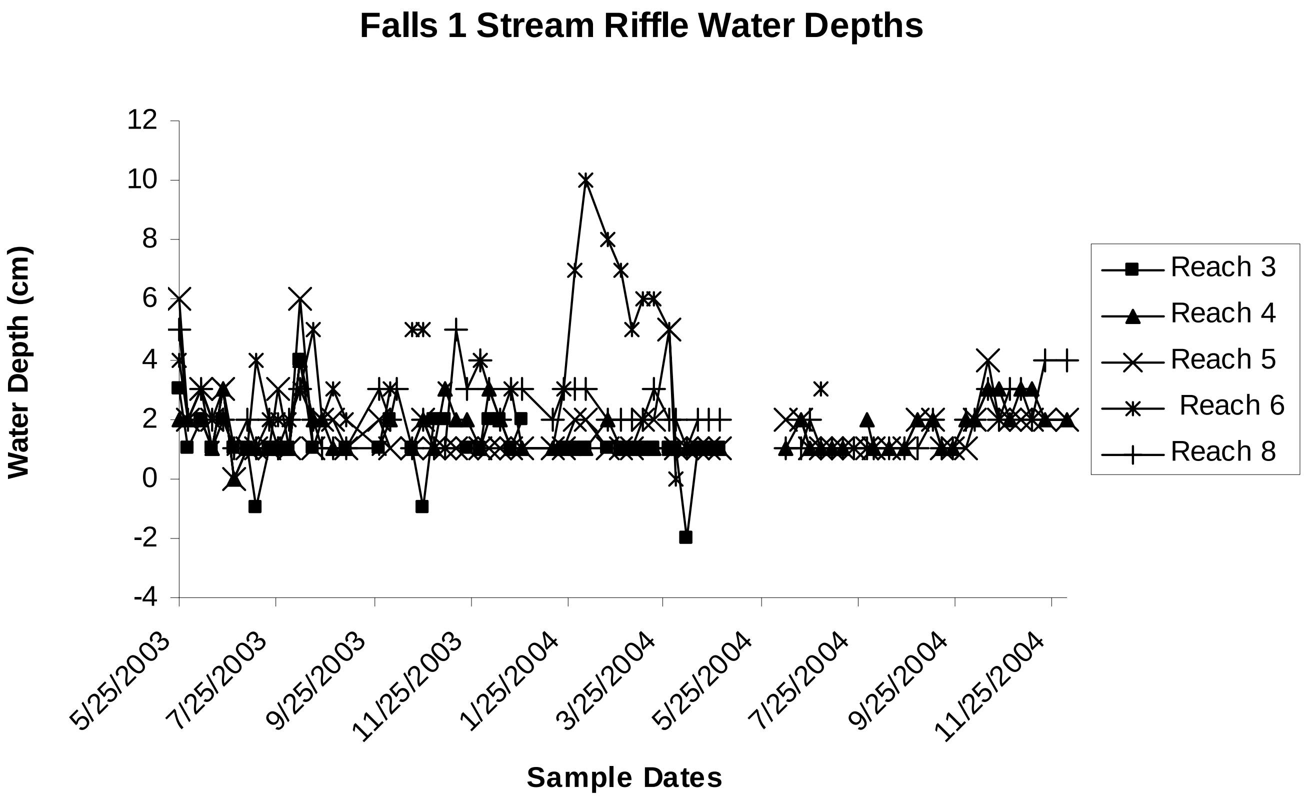

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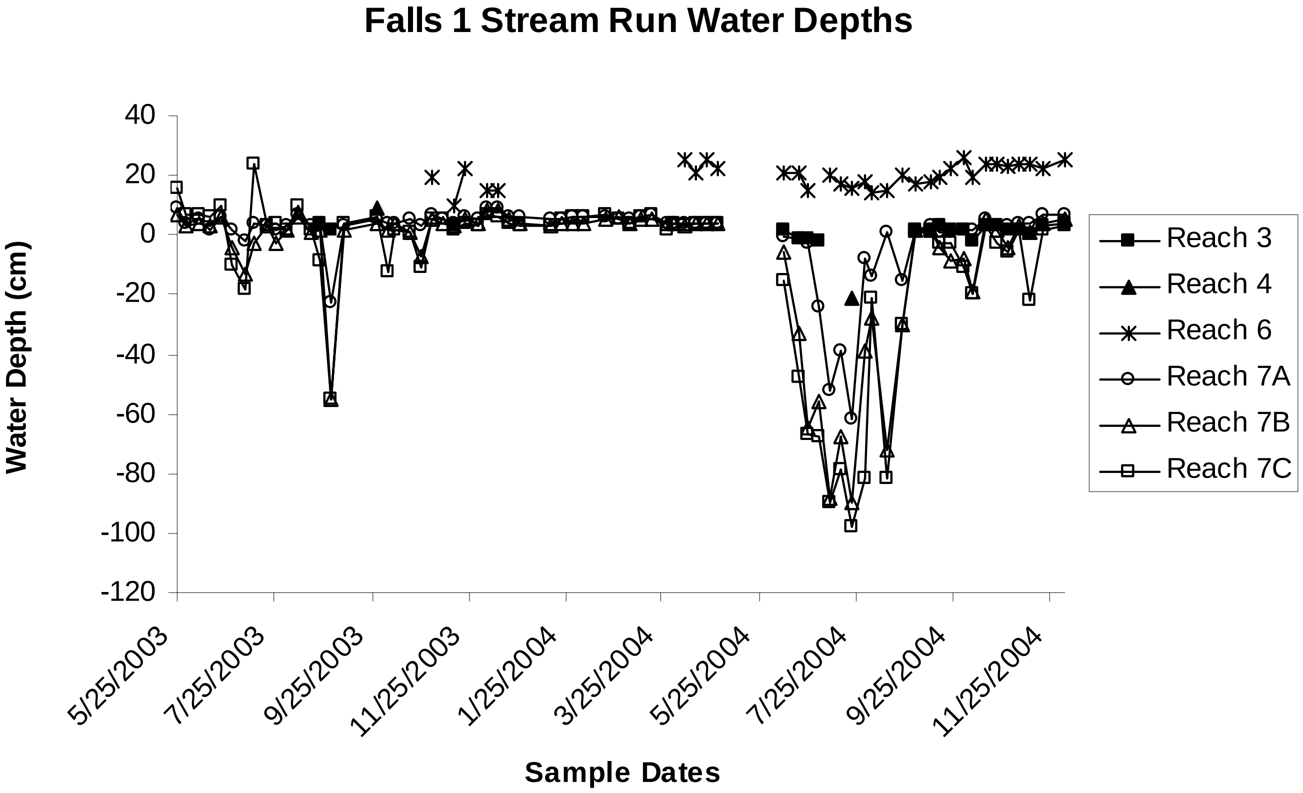

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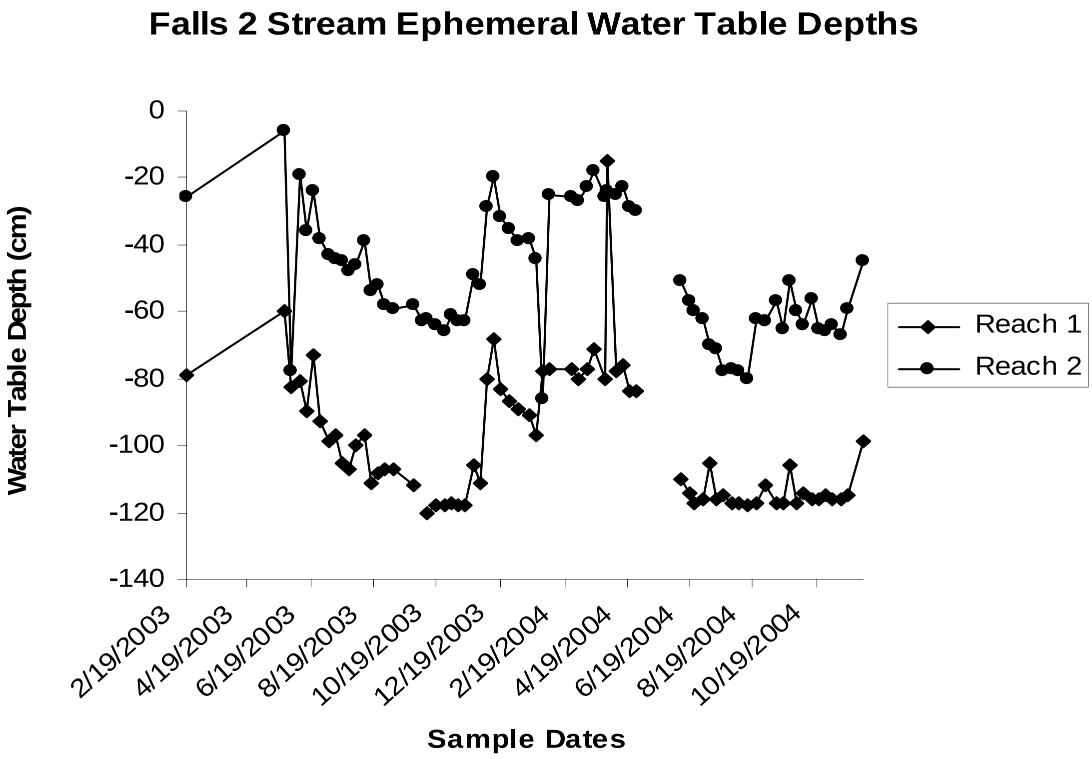

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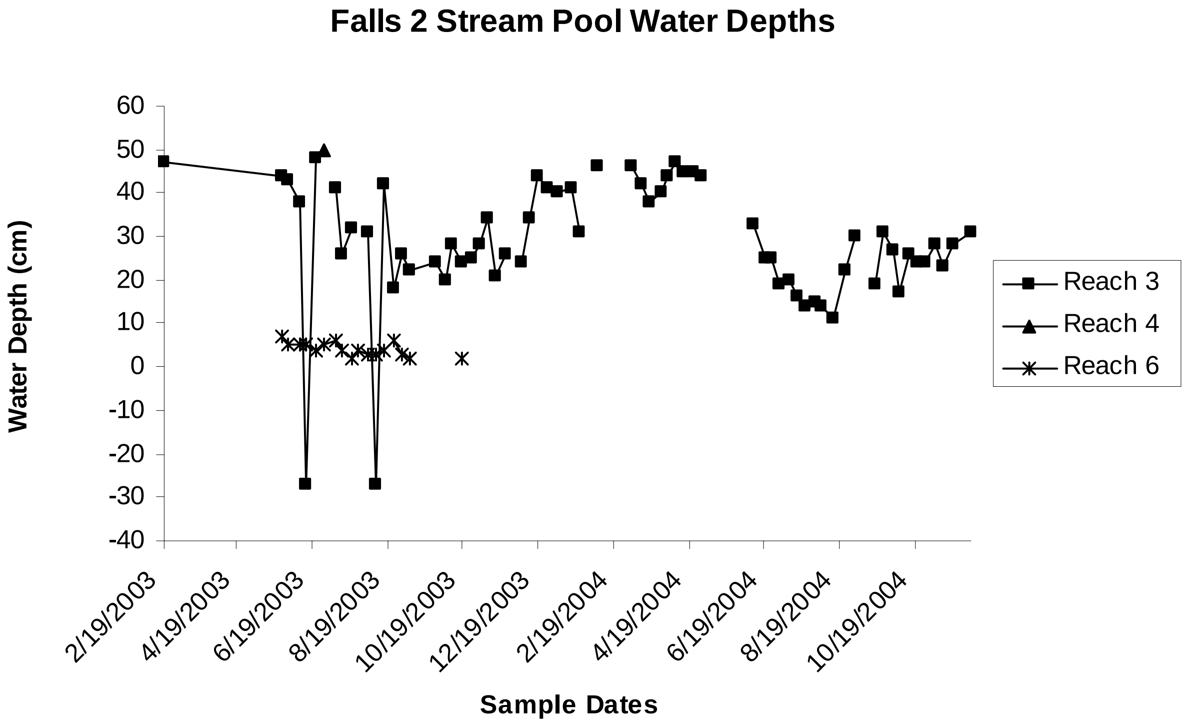
Water depths over the 18 months stream measurement period



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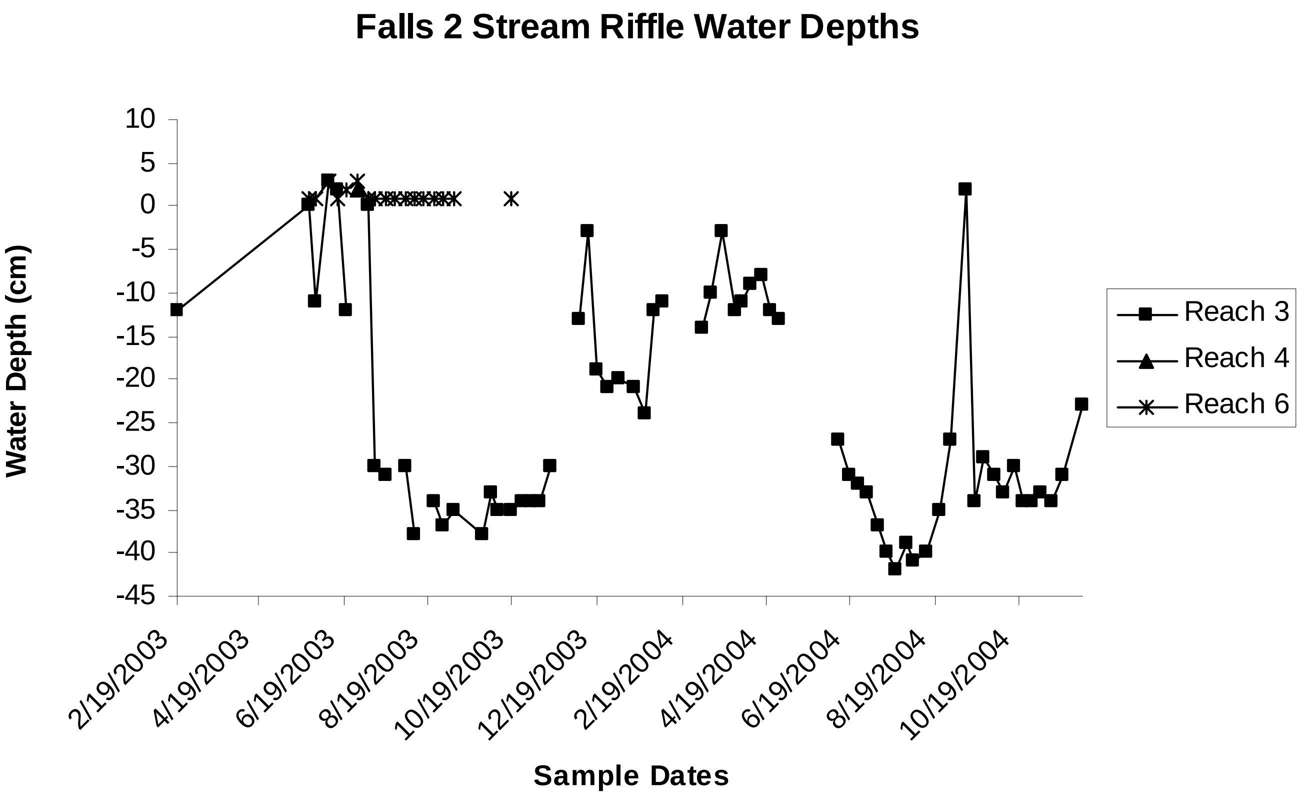

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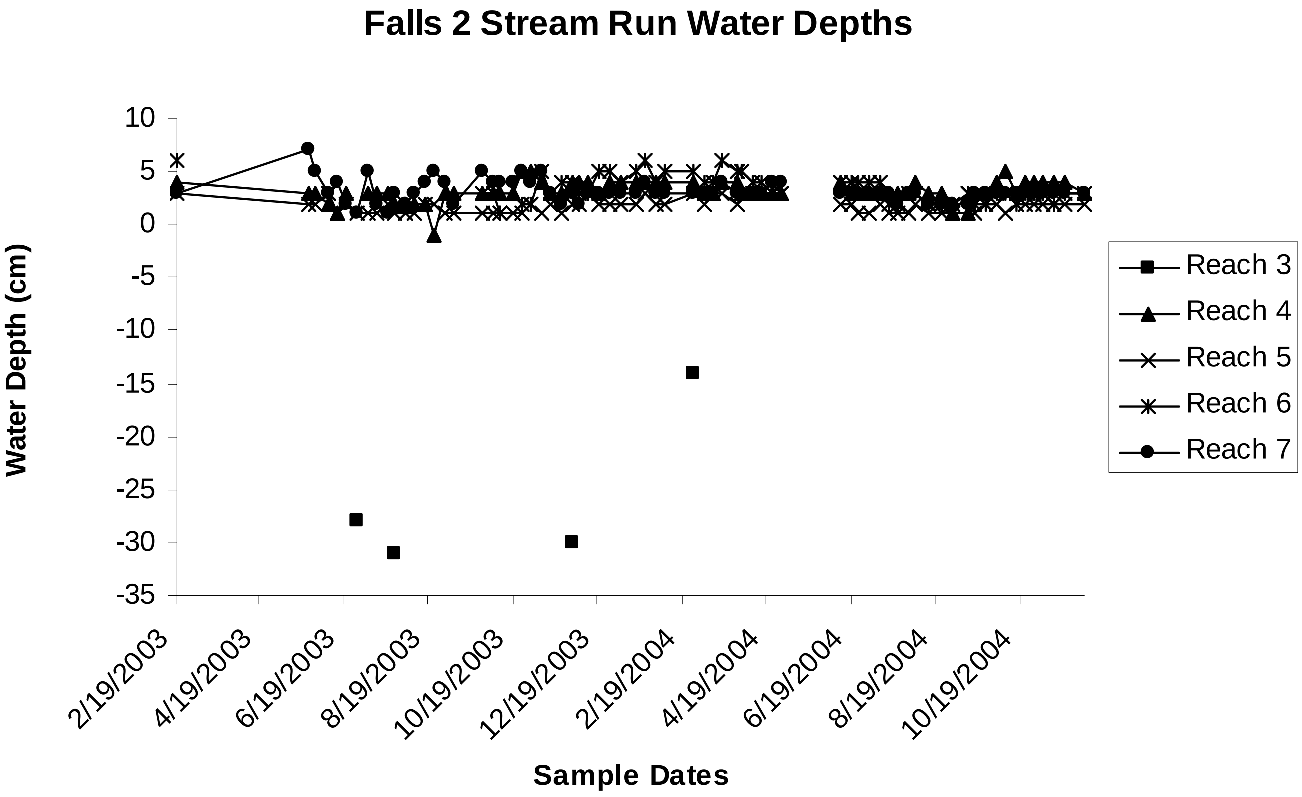

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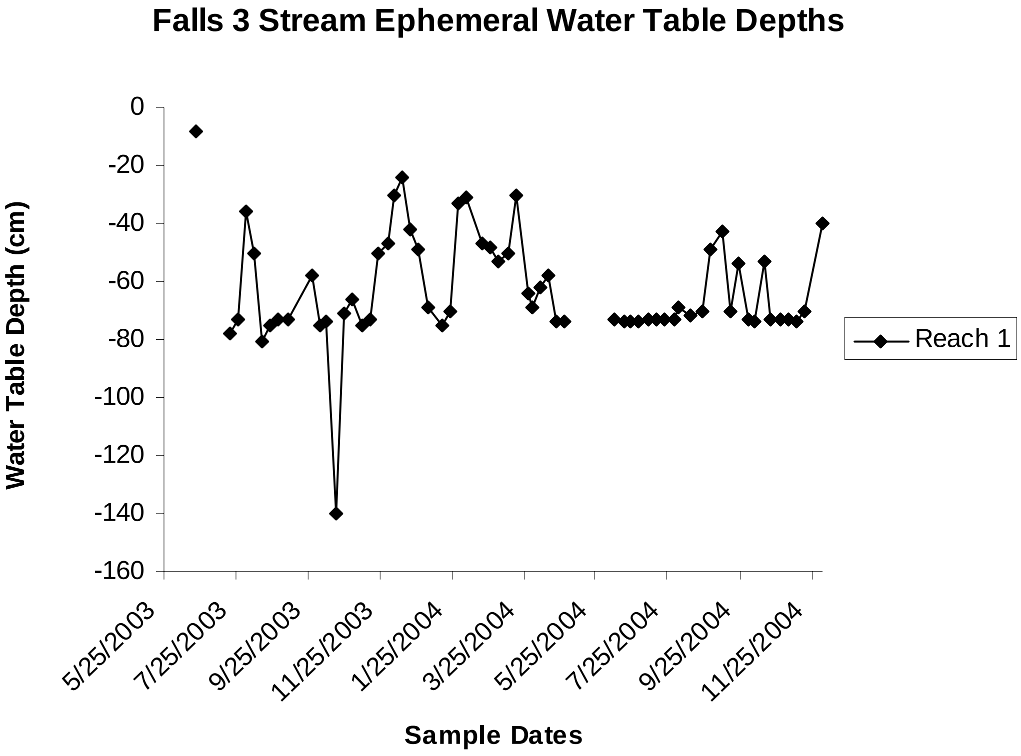

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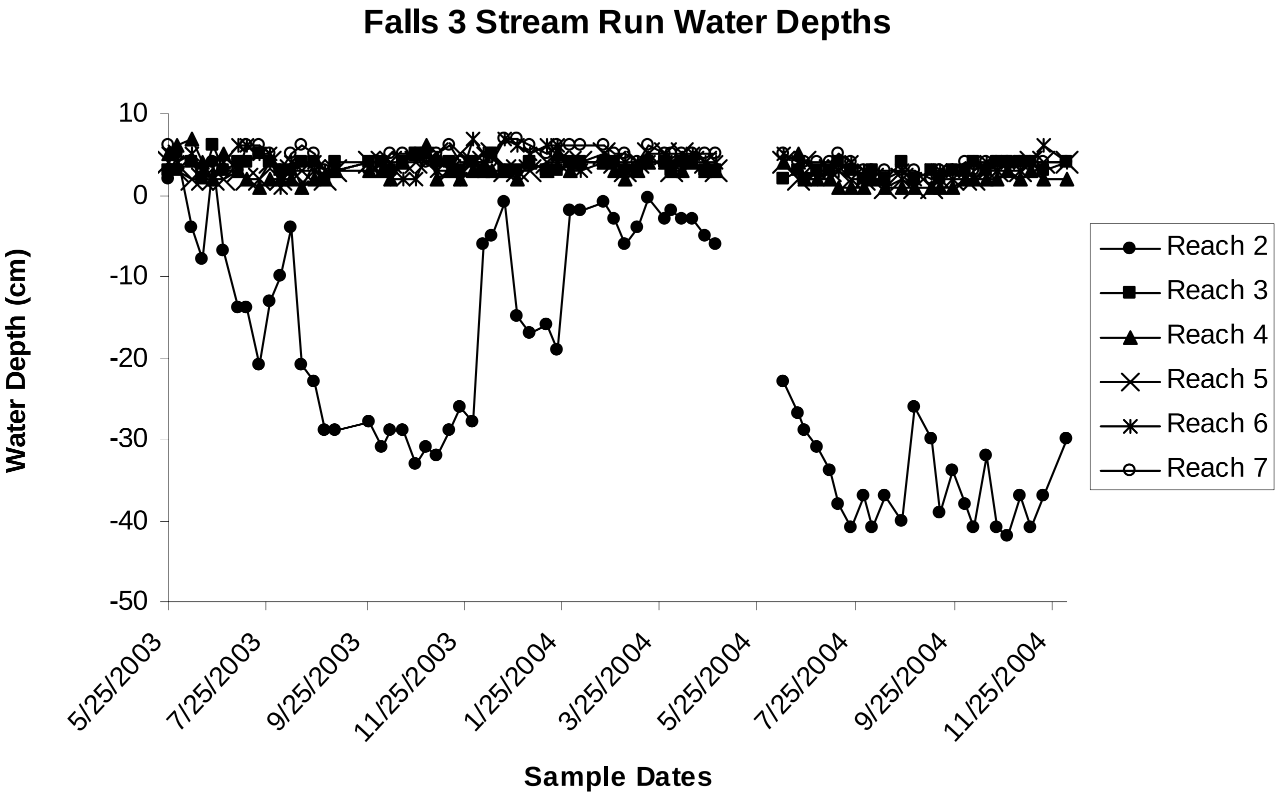

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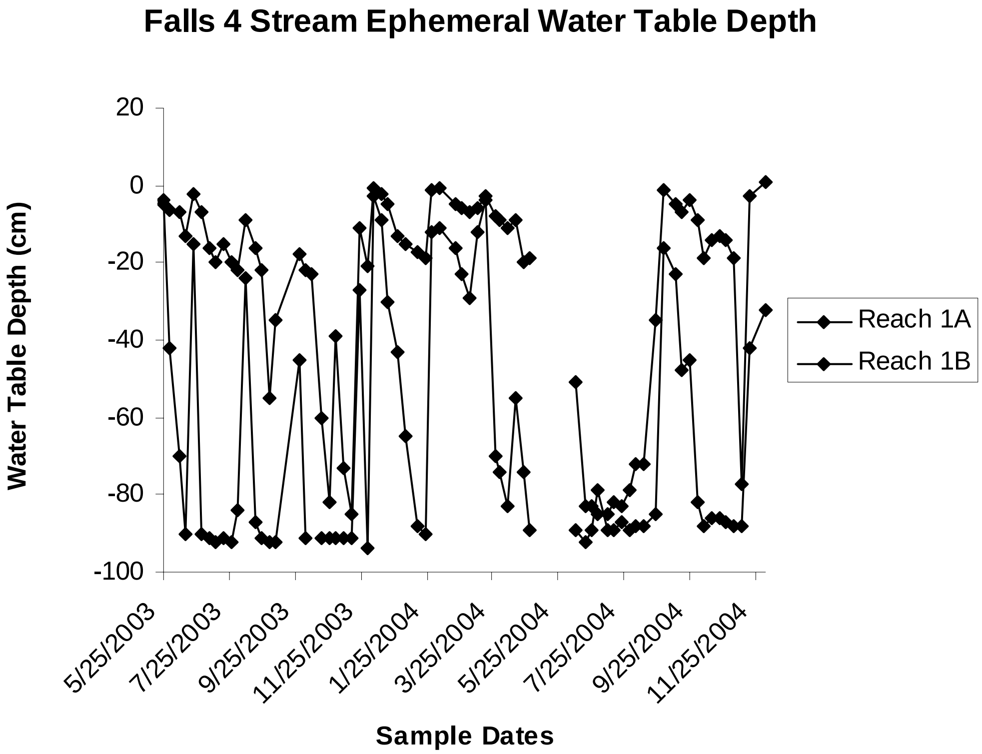

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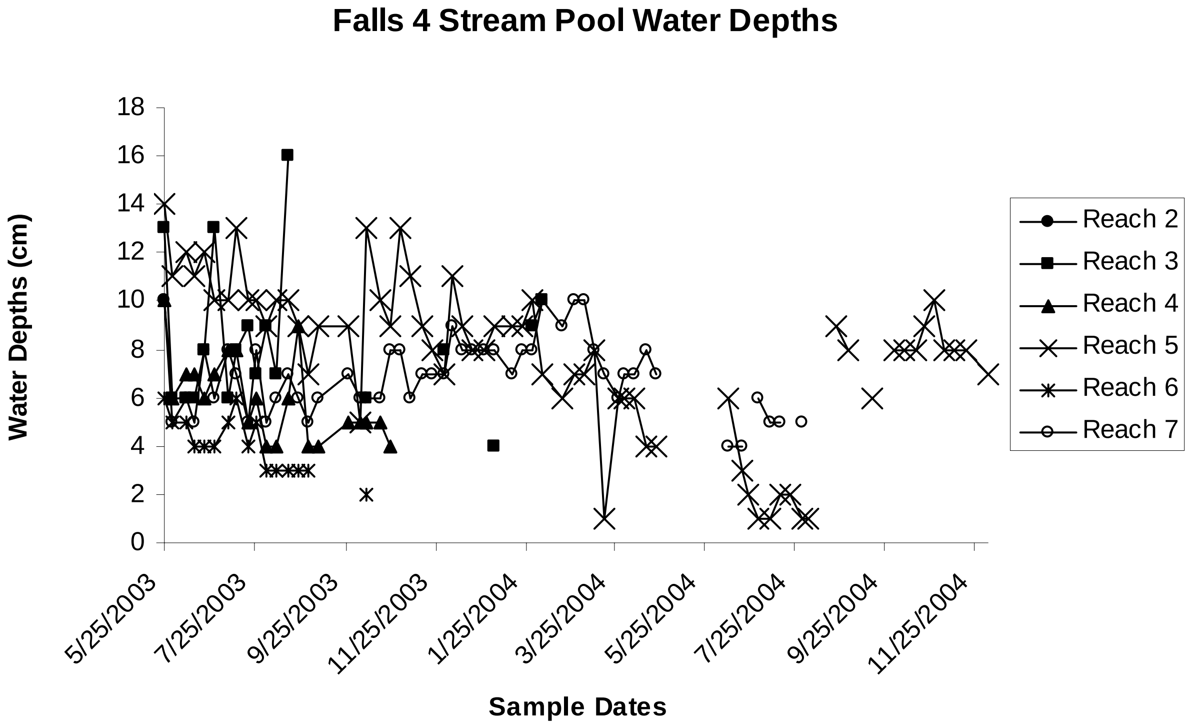

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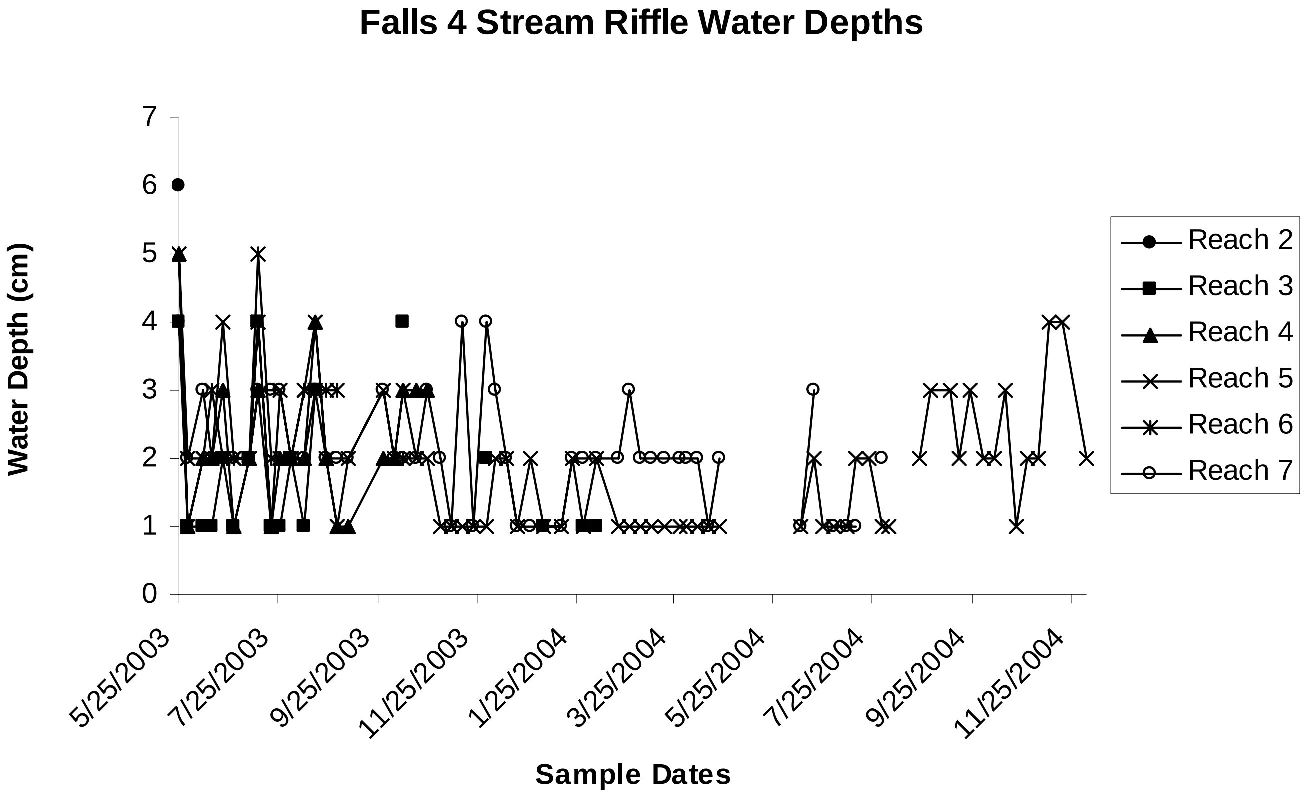

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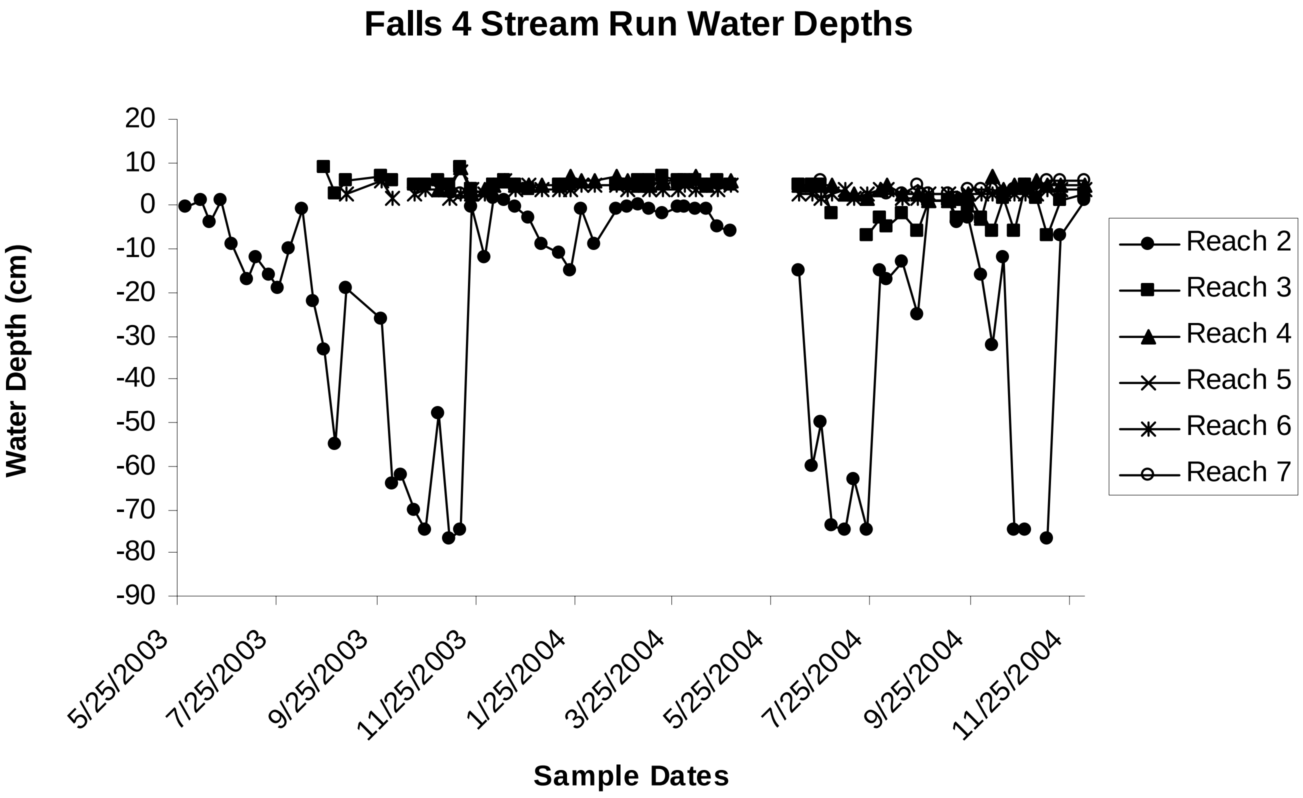

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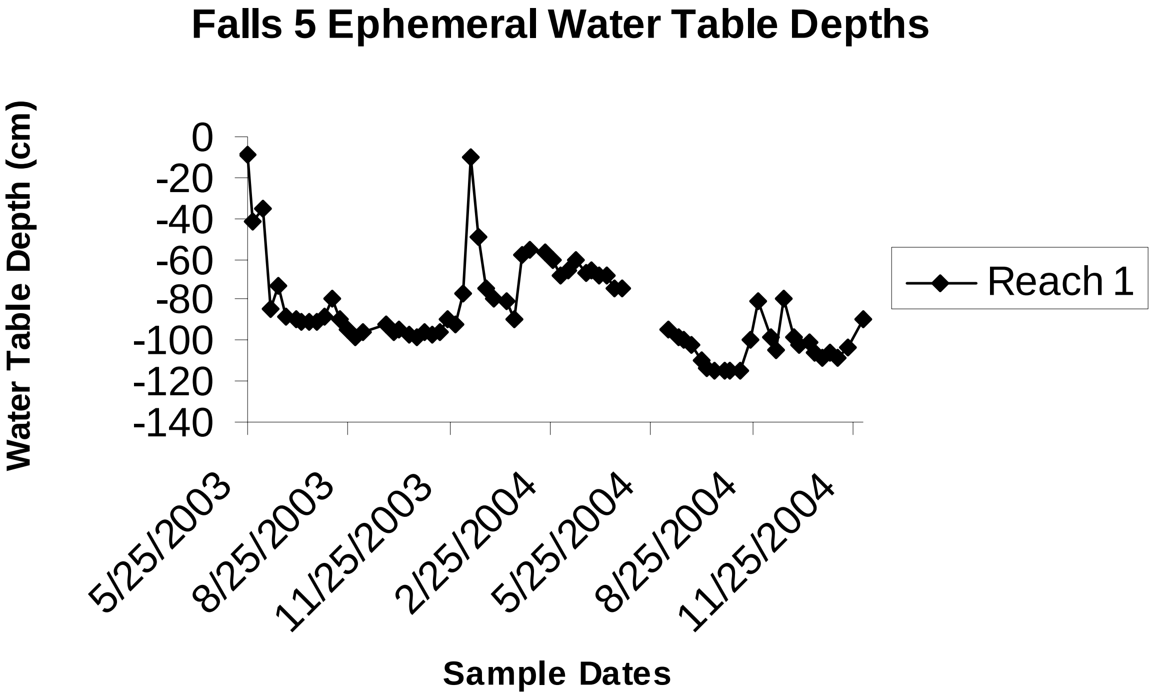

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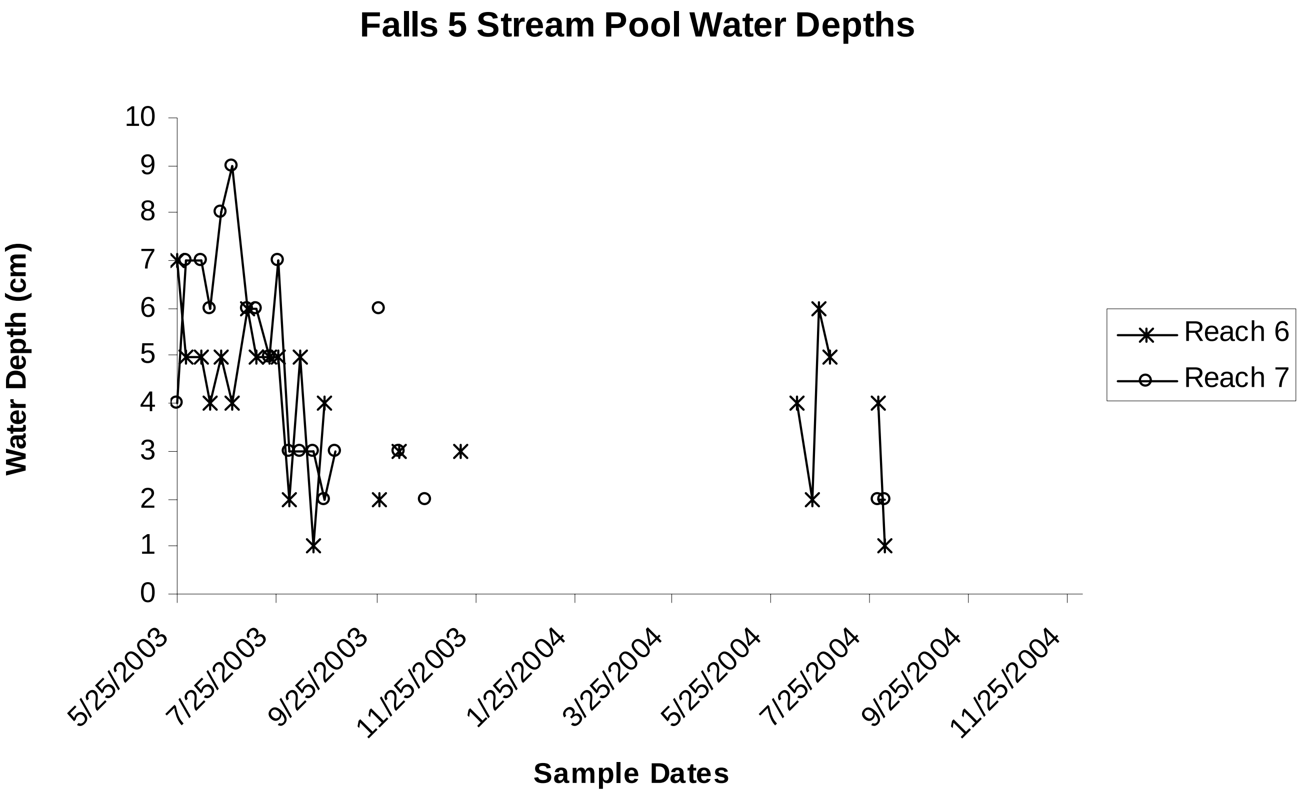

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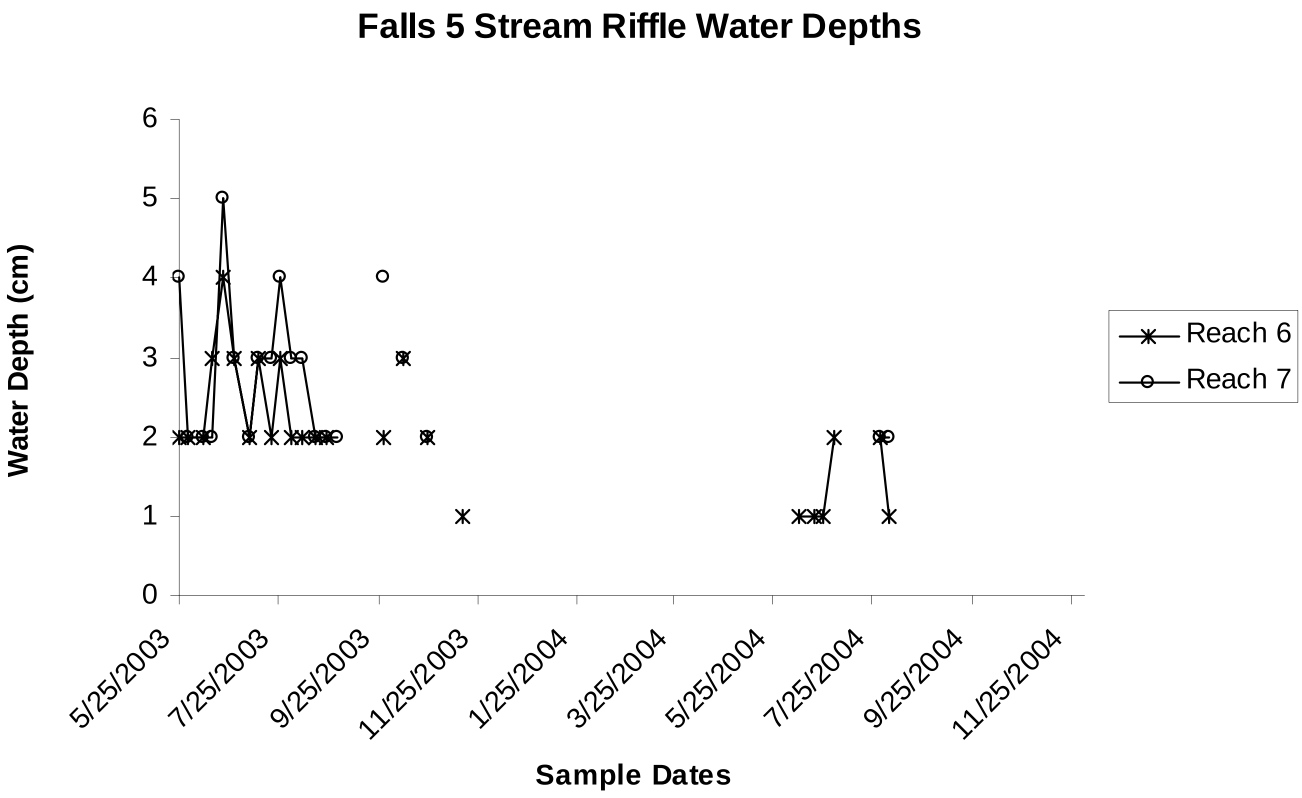

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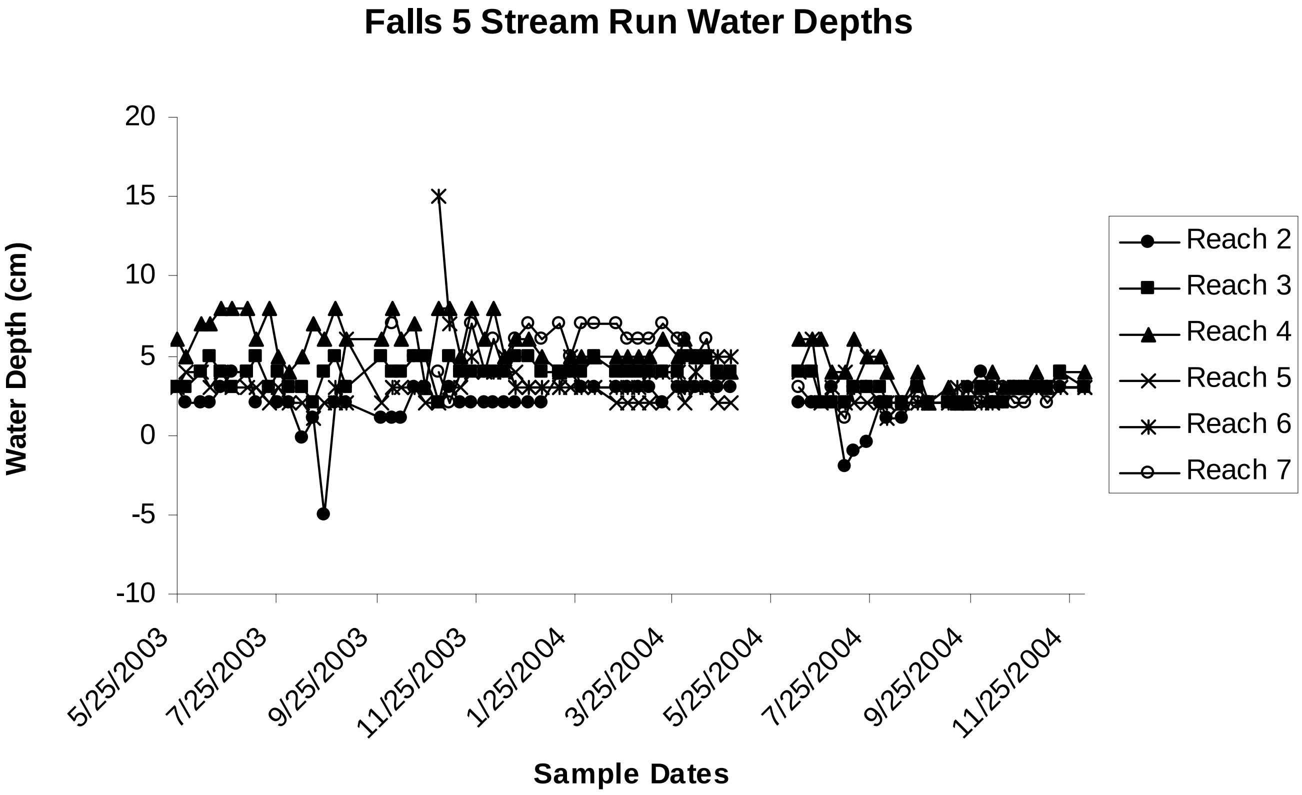
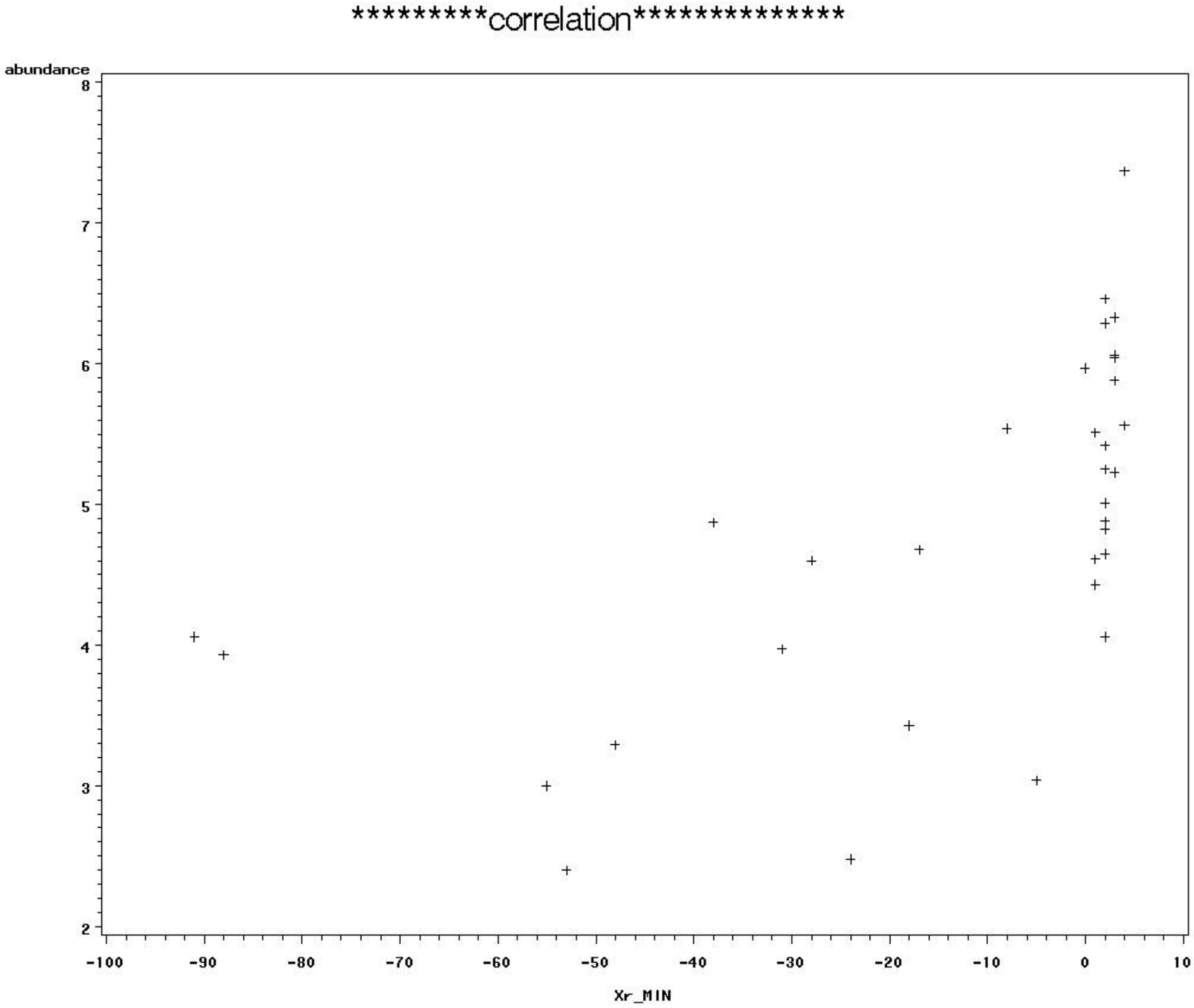


APPENDIX 3

Spring 2003

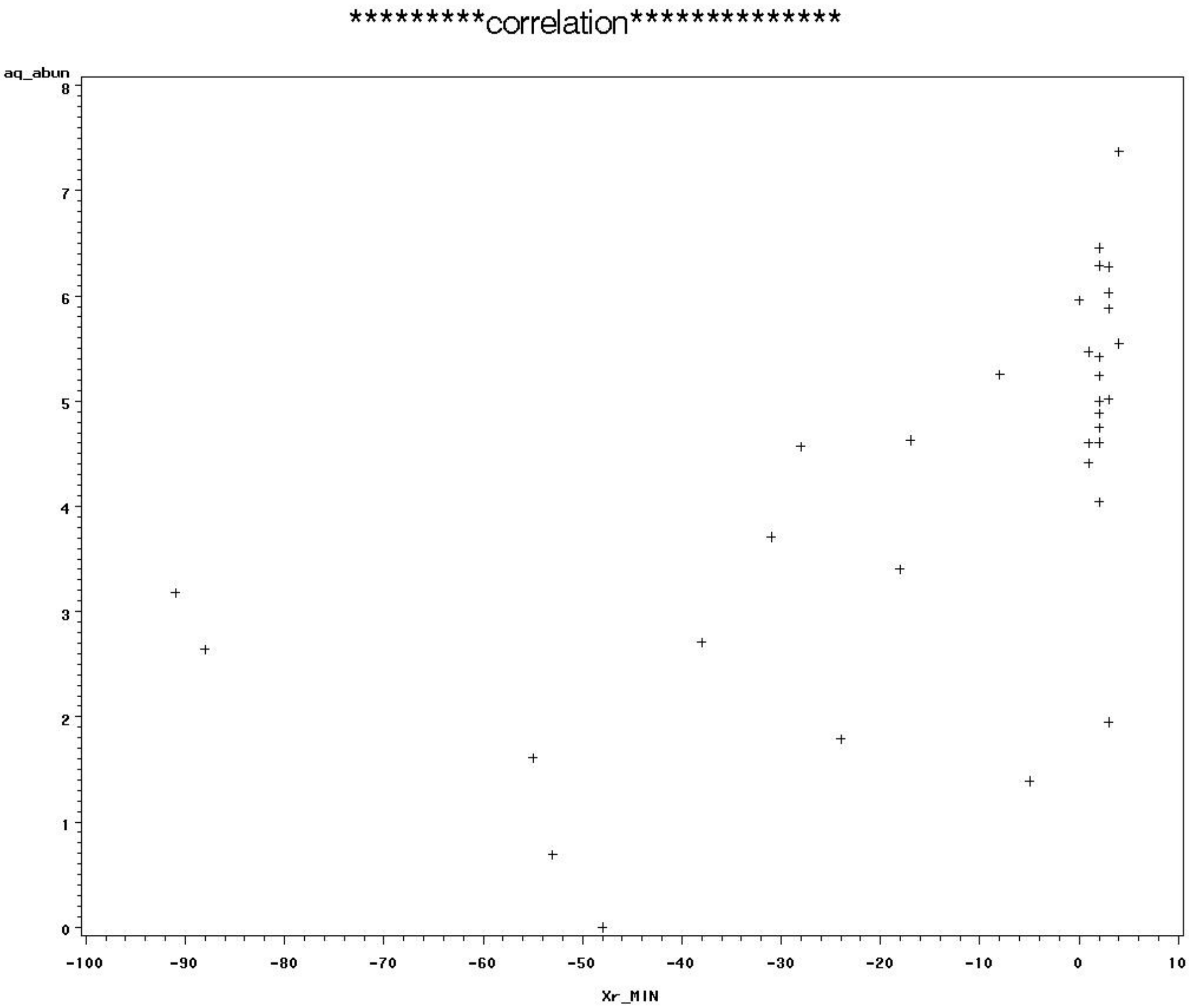
Relationship between general macroinvertebrate abundance and water depths
Plots from Best Fit Models



This figure illustrates the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate abundance ($p=0.0001$). This plot may be interpreted as follows: increase in riffle depths may result in an increase in macroinvertebrate abundance in such an environment.

Spring 2003

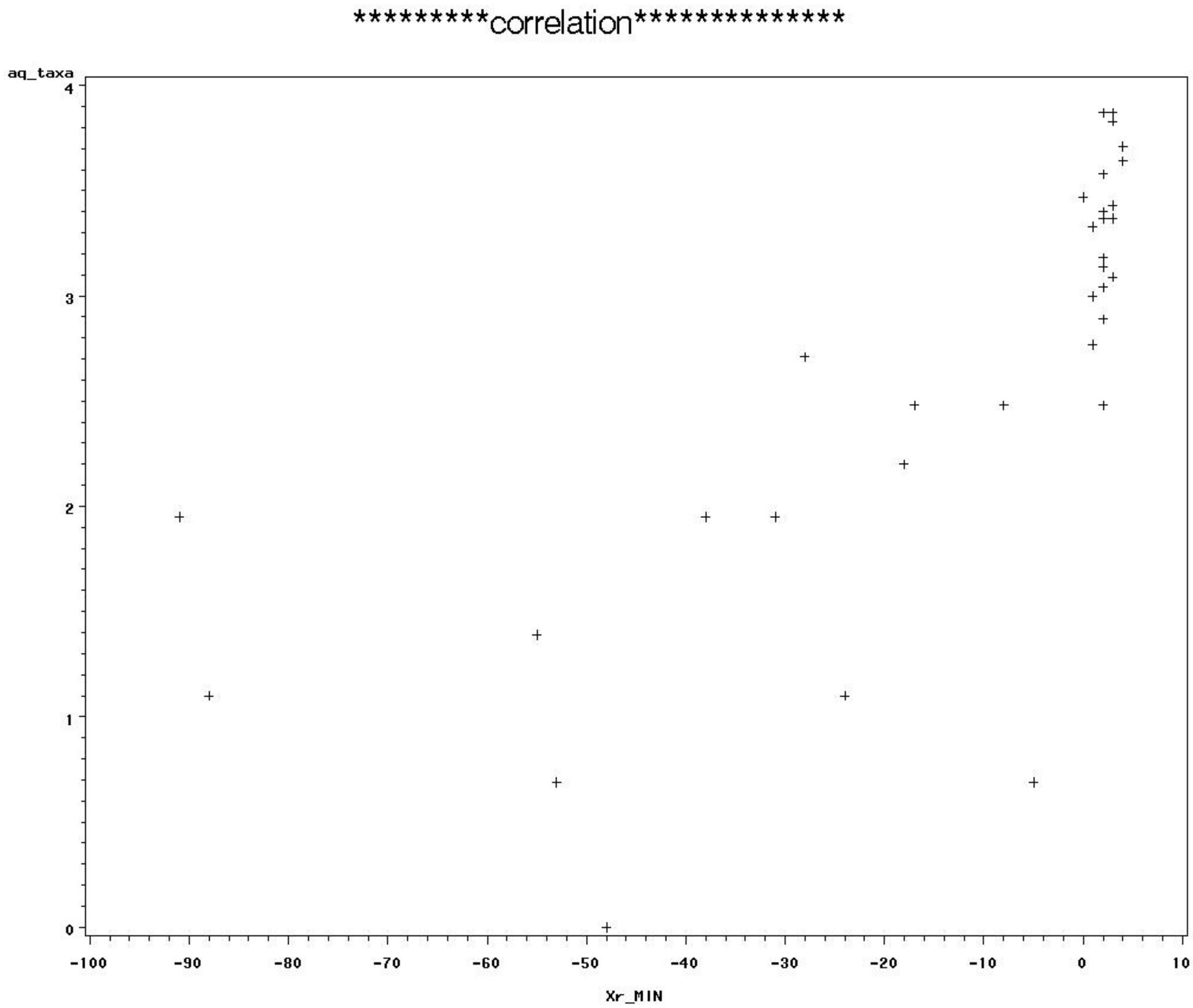
Relationship between general macroinvertebrate aquatic abundance and water depths
Plots from Best Fit Models



This figure illustrates the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate aquatic abundance (p=0.0001). This plot may be interpreted as follows: increase in riffle depths may result in an increase in aquatic abundance in such an environment.

Spring 2003

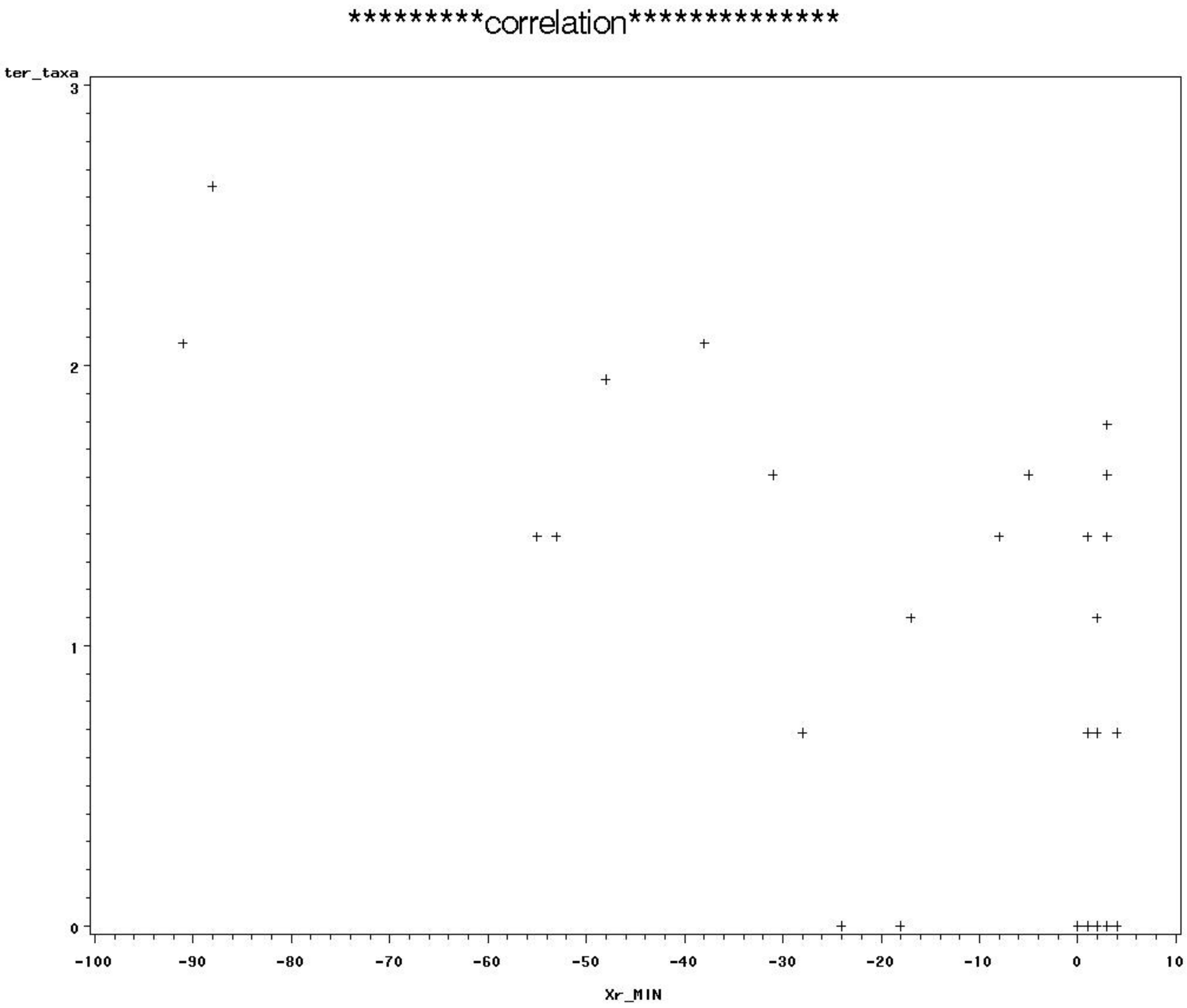
Relationship between general macroinvertebrate aquatic taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate aquatic taxa ($p<0.0001$). This plot may be interpreted as follows: increase in riffle depths may result in an increase in aquatic taxa in such an environment.

Spring 2003

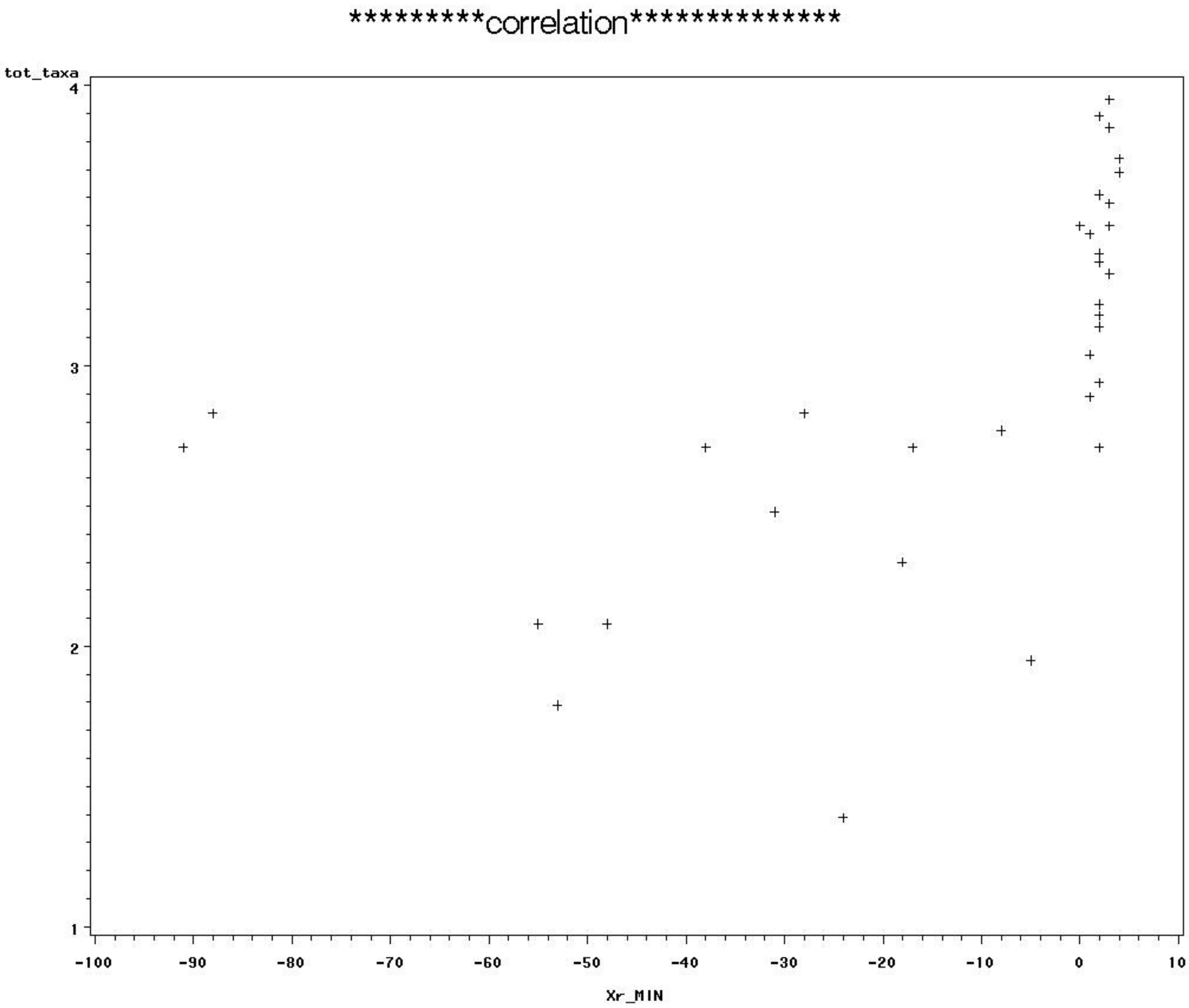
Relationship between general macroinvertebrate terrestial taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate terrestrial taxa (p=0.0005). This plot may be interpreted as follows: decrease in riffle depths may result in an increase in terrestrial taxa in such an environment.

Spring 2003

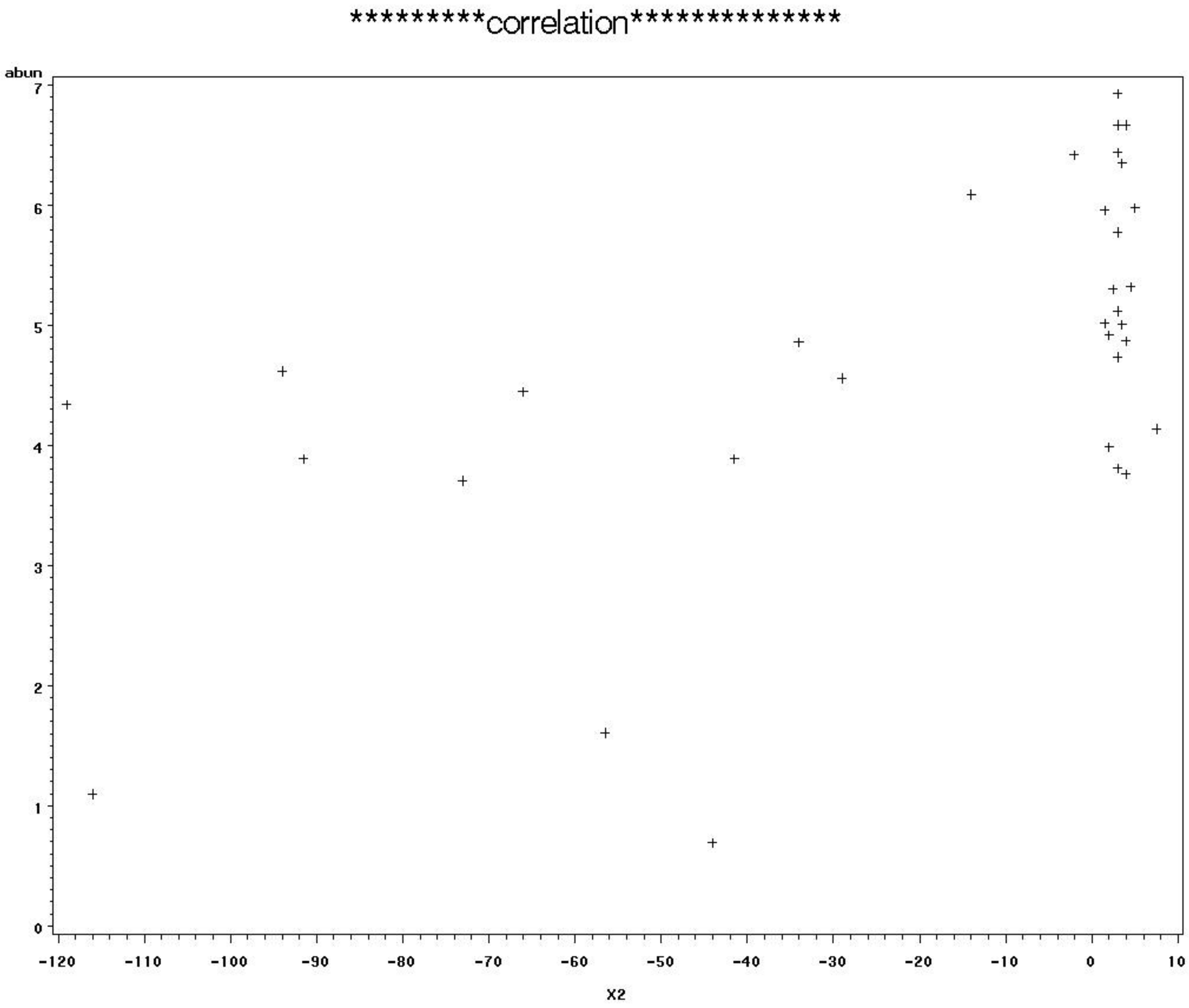
Relationship between general macroinvertebrate total taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate total taxa (p=0.0002). This plot may be interpreted as follows: increase in riffle depths may result in an increase in total taxa in such an environment.

Summer 2003

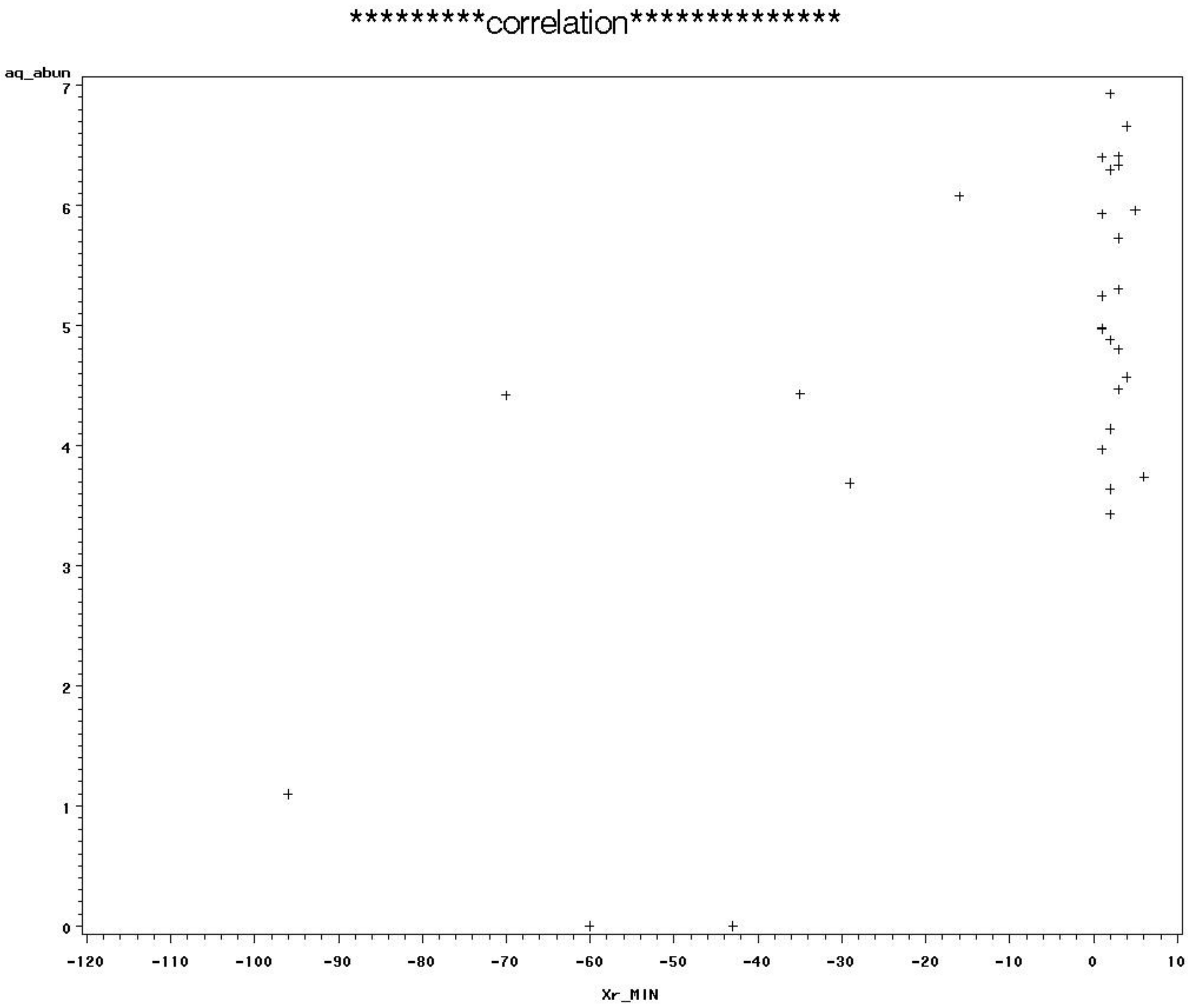
Relationship between general macroinvertebrate abundance and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum averaged water depths in riffles the week before and the week after macroinvertebrate sample date (p=0.0002).

Summer 2003

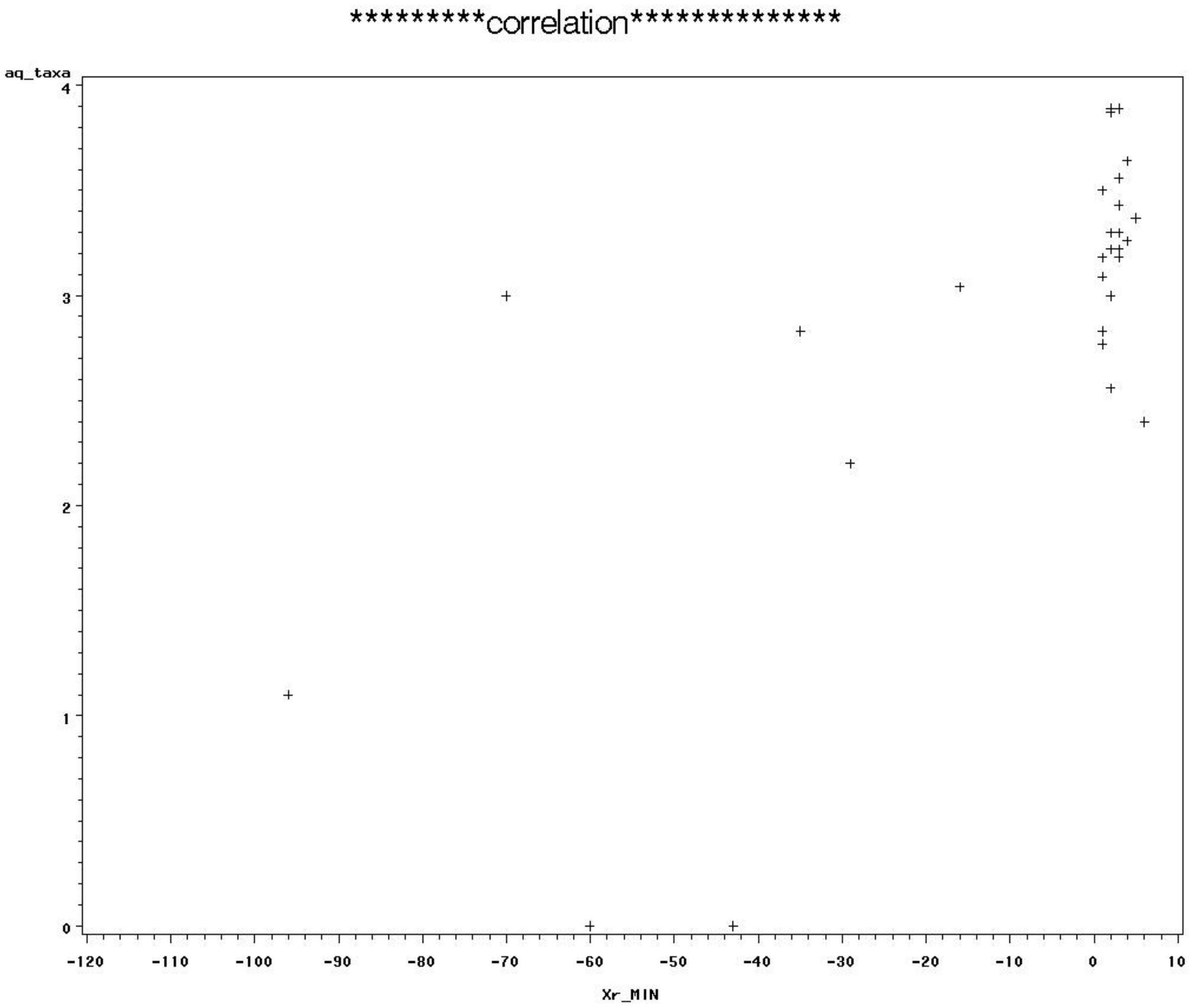
Relationship between general macroinvertebrate aquatic abundance and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate aquatic abundance (p=0.0001). This plot may be interpreted as follows: increase in riffle depths may result in an increase in aquatic abundance in such an environment.

Summer 2003

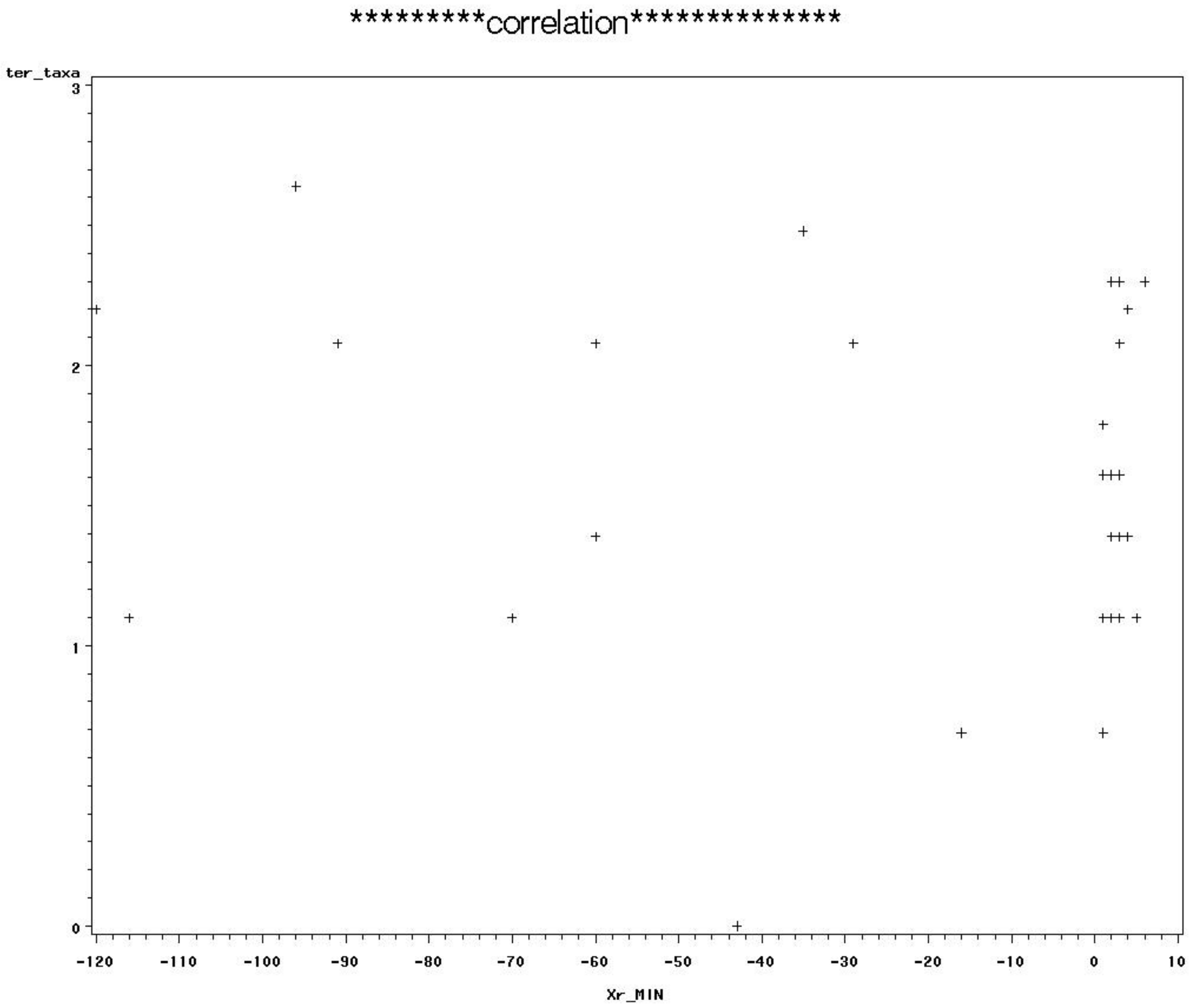
Relationship between general macroinvertebrate aquatic taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate aquatic taxa ($p<.0001$). This plot may be interpreted as follows: increase in riffle depths may result in an increase in aquatic taxa in such an environment.

Summer 2003

Relationship between general macroinvertebrate terrestrial taxa and water depths
Plots from Best Fit Models

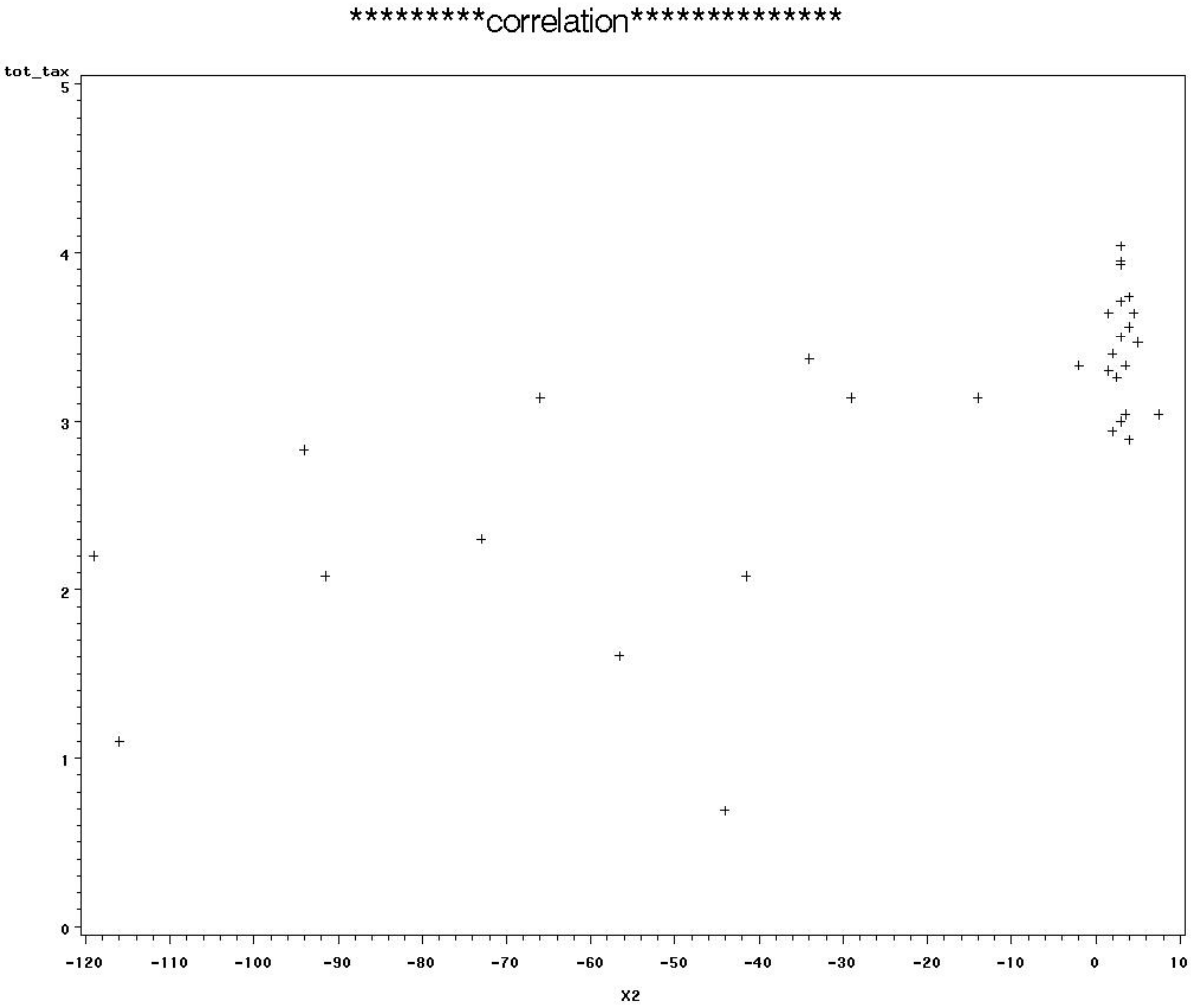


*********correlation**************

In the summer of 2003, terrestrial taxa was not found to be related to water depths (p=0.7387). However, when compared to the other models, this model was considered the better fit model due to its lower AIC value.

Summer 2003

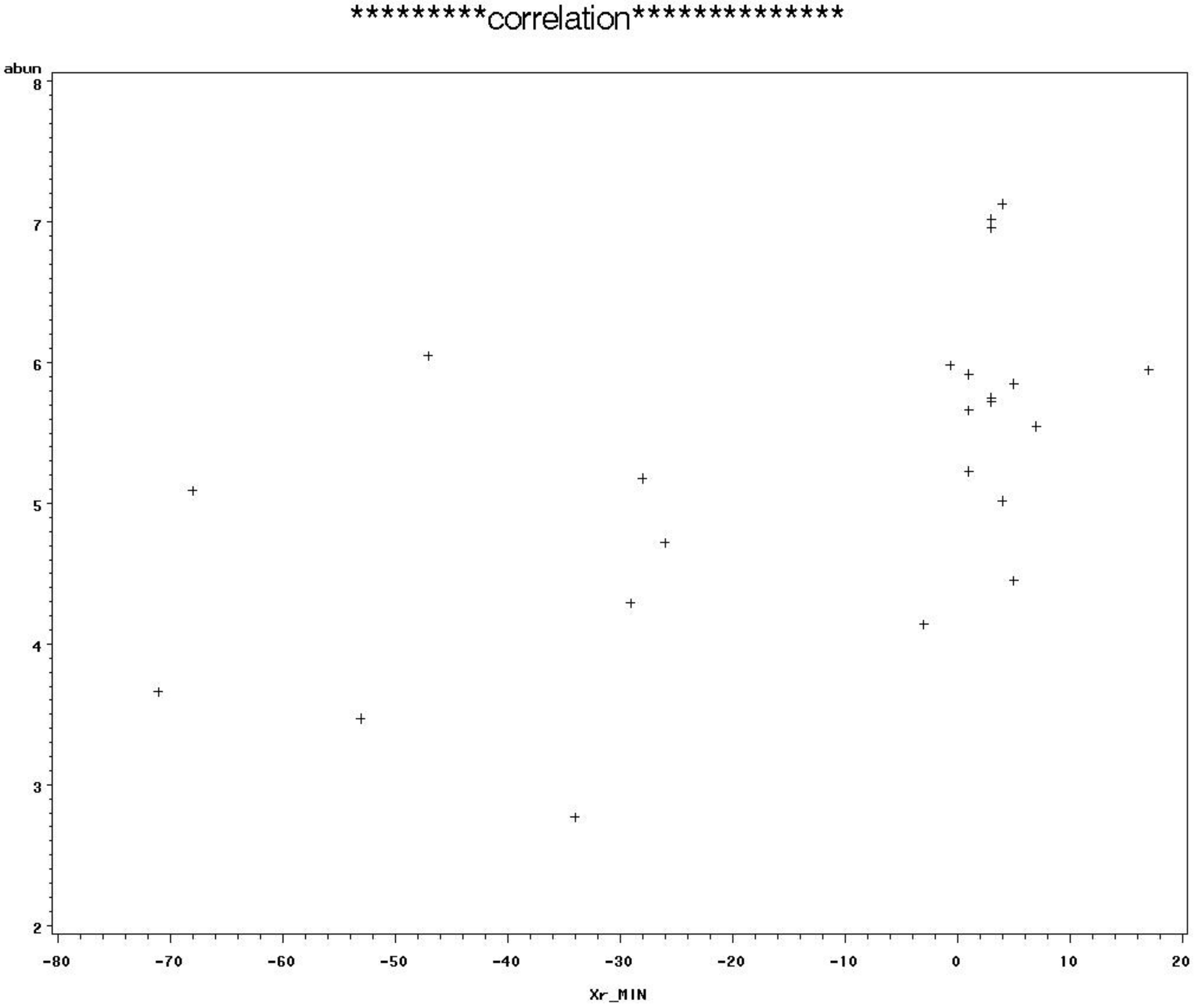
Relationship between general macroinvertebrate total taxa and water depths
Plots from Best Fit Models



This plot illustrates the relationship between averaged water depths in riffles the week before and the week before and the week after macroinvertebrate sample date (X2). In the summer 2003, a significant relationship (p<.0001) was found between independent variable X2 and total taxa.

Winter 2004

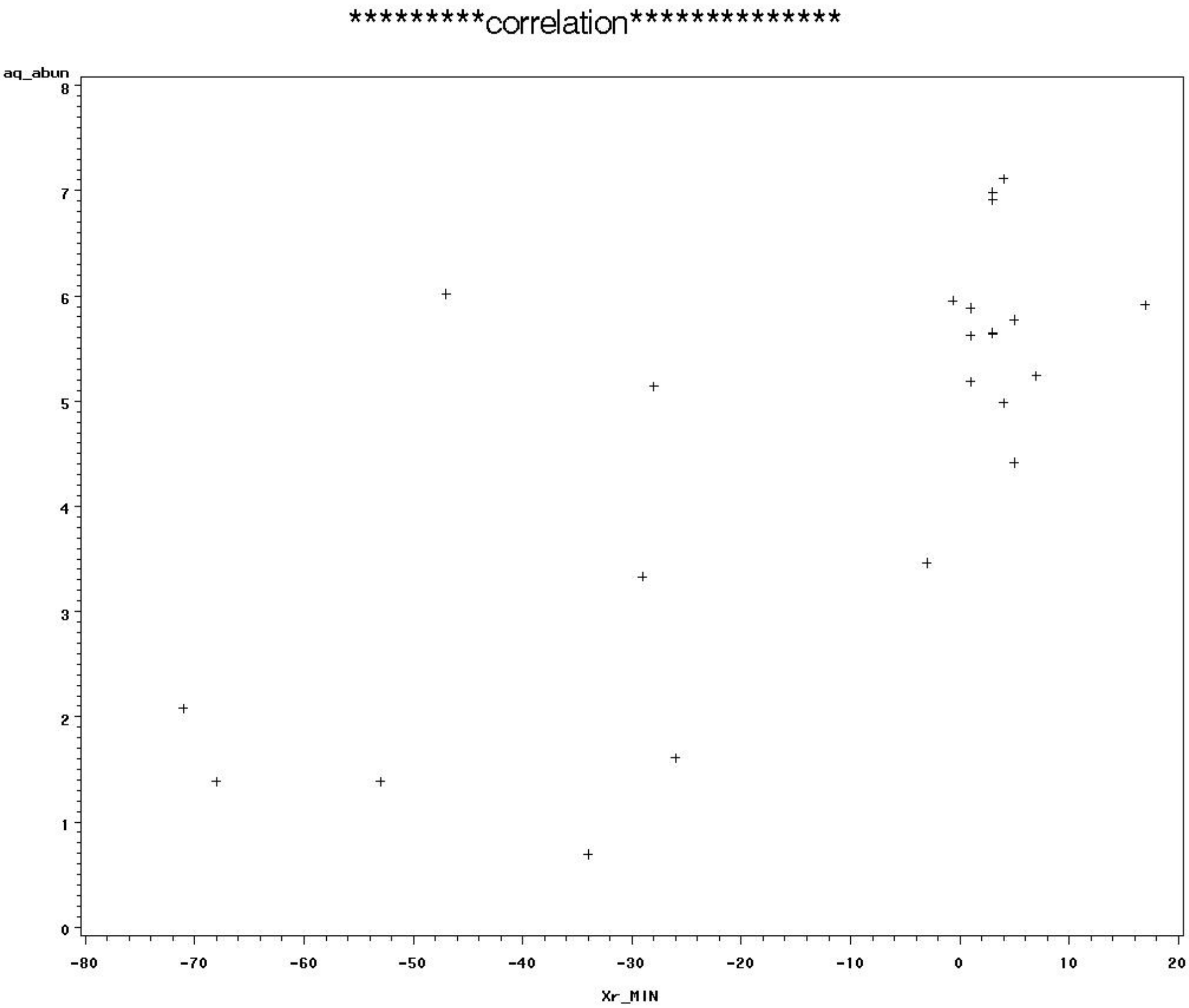
Relationship between general macroinvertebrate abundance and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate abundance ($p<.0001$). This plot may be interpreted as follows: increase in riffle depths may result in an increase in abundance in such an environment.

Winter 2004

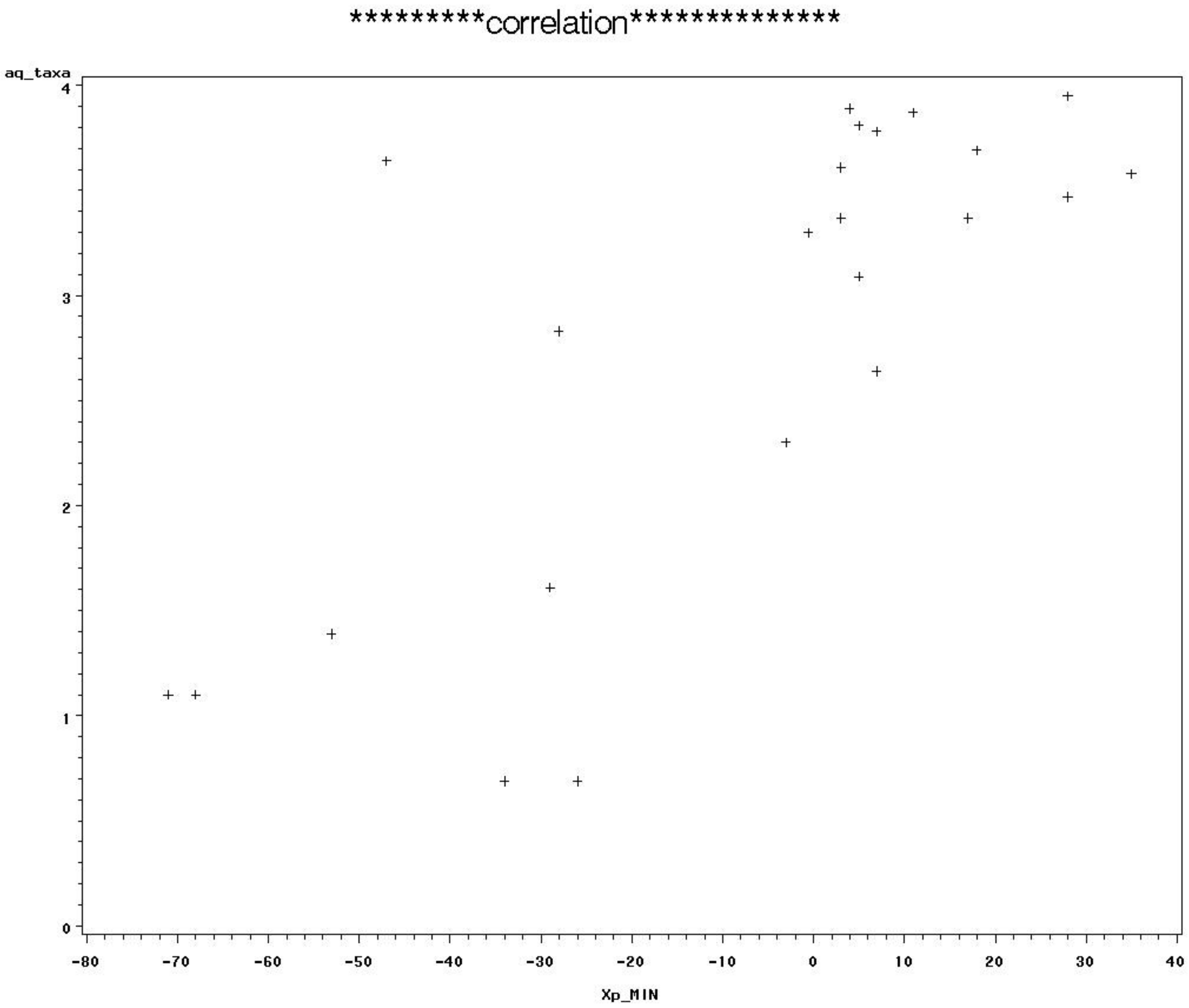
Relationship between general macroinvertebrate aquatic abundance and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffle (Xr_MIN) and macroinvertebrate aquatic abundance (p<.0001). This plot may be interpreted as follows: increase in riffle depths may result in an increase in aquatic abundance in such an environment.

Winter 2004

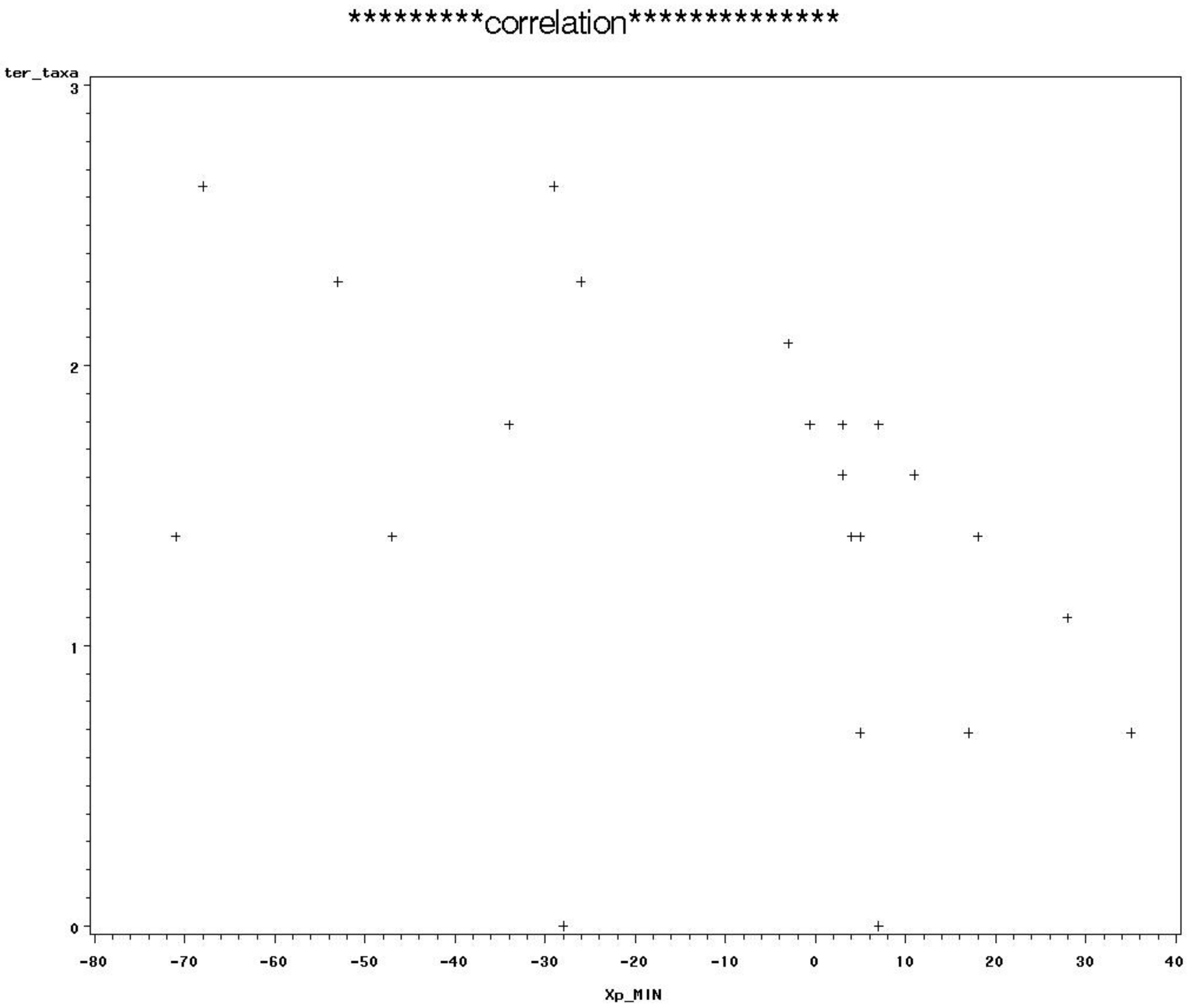
Relationship between general macroinvertebrate aquatic taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in pools (Xp_MIN) and macroinvertebrate aquatic taxa ($p<0.0001$). This plot may be interpreted as follows: increase in pool depths may result in an increase in aquatic taxa in such an environment.

Winter 2004

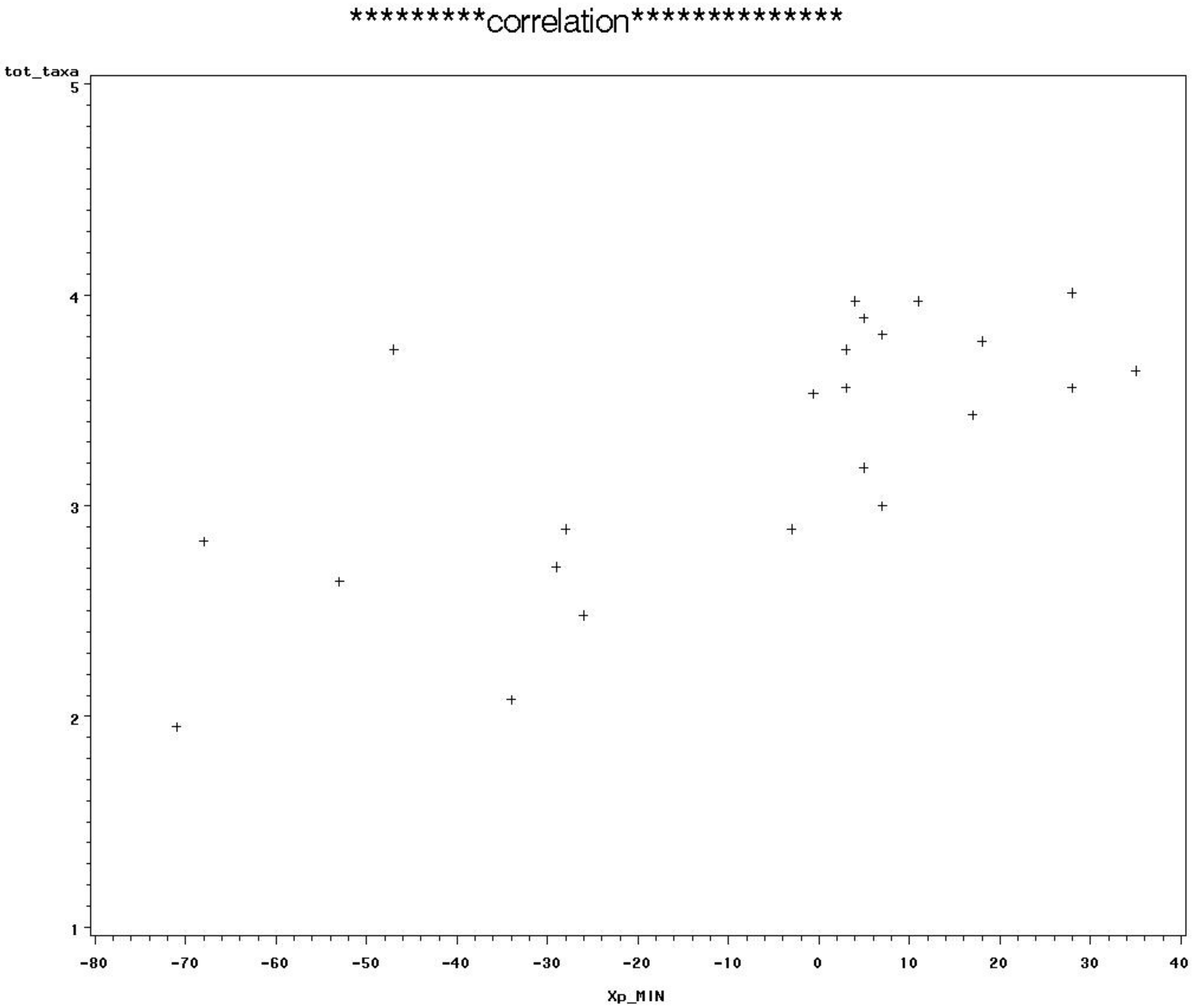
Relationship between general macroinvertebrate terrestrial taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in pools (Xp_MIN) and macroinvertebrate terrestrial taxa (p=0.0379).

Winter 2004

Relationship between general macroinvertebrate total taxa and water depths
Plots from Best Fit Models

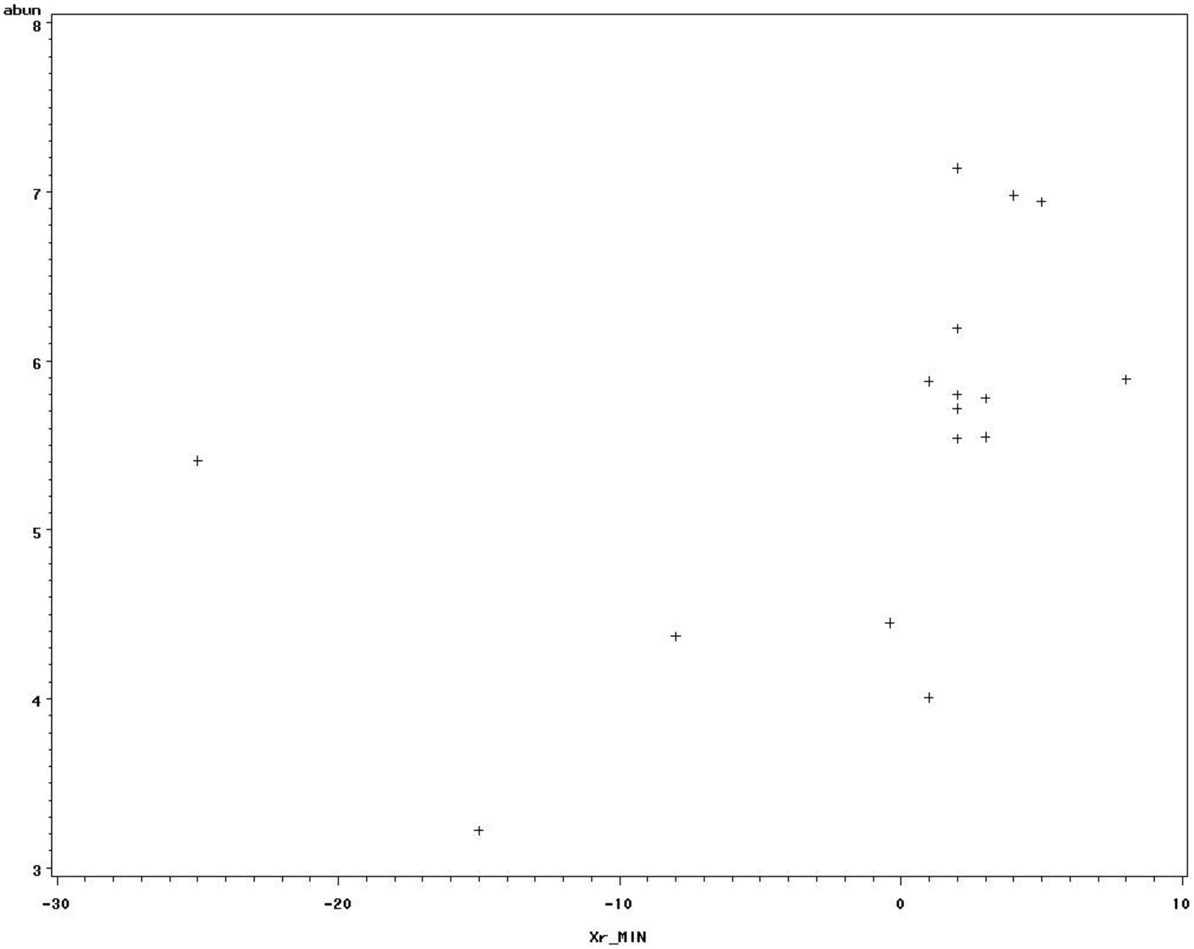


This figure depicts the relationship between minimum water depths in pools (Xp_MIN) and macroinvertebrate total taxa ($p<.0001$).

Spring 2004

Relationship between general macroinvertebrate abundance and water depths
Plots from Best Fit Models

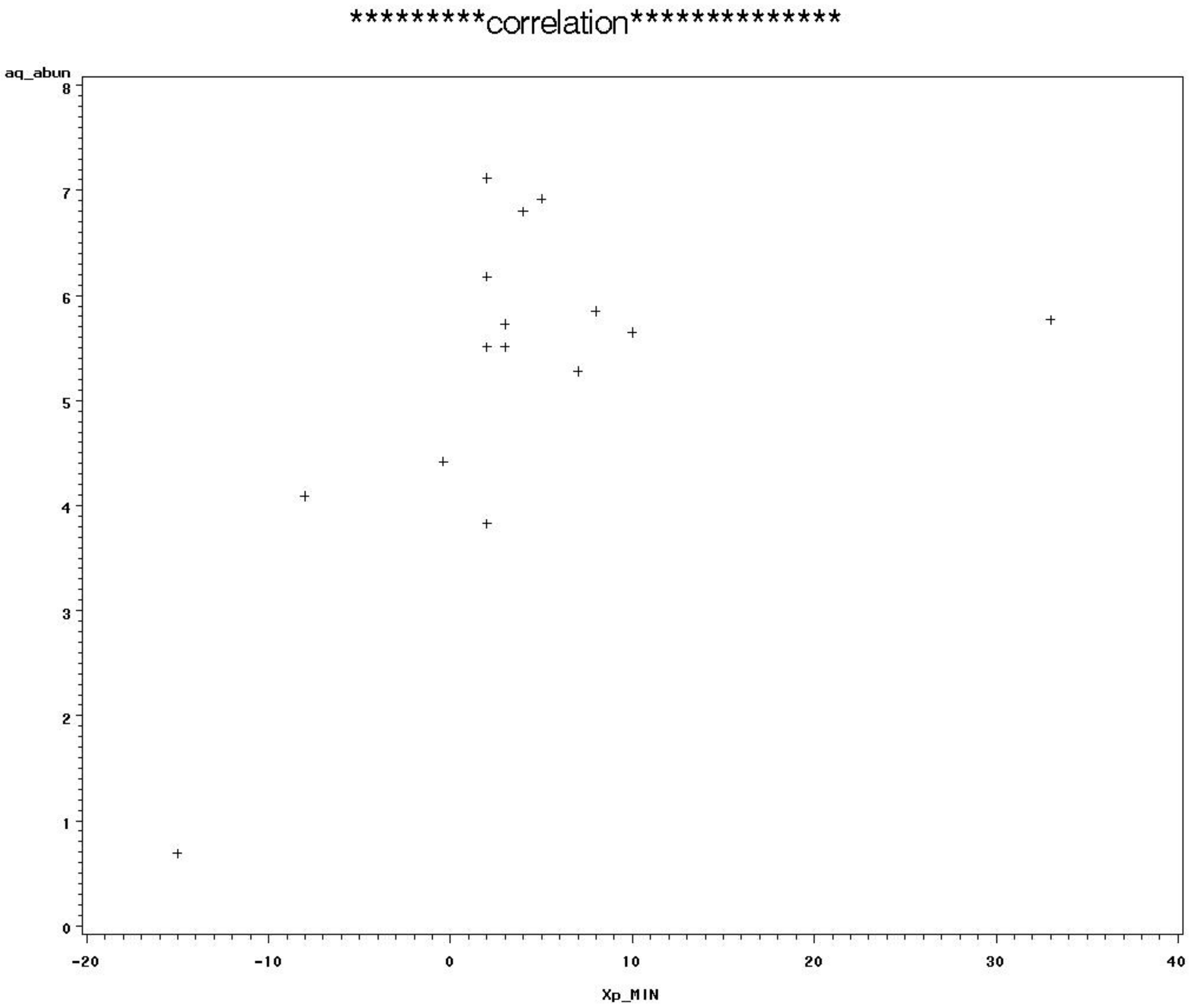
*********correlation**************



This figure depicts the relationship between minimum water depths in riffles (Xr_MIN) and macroinvertebrate abundance (p=0.0574).

Spring 2004

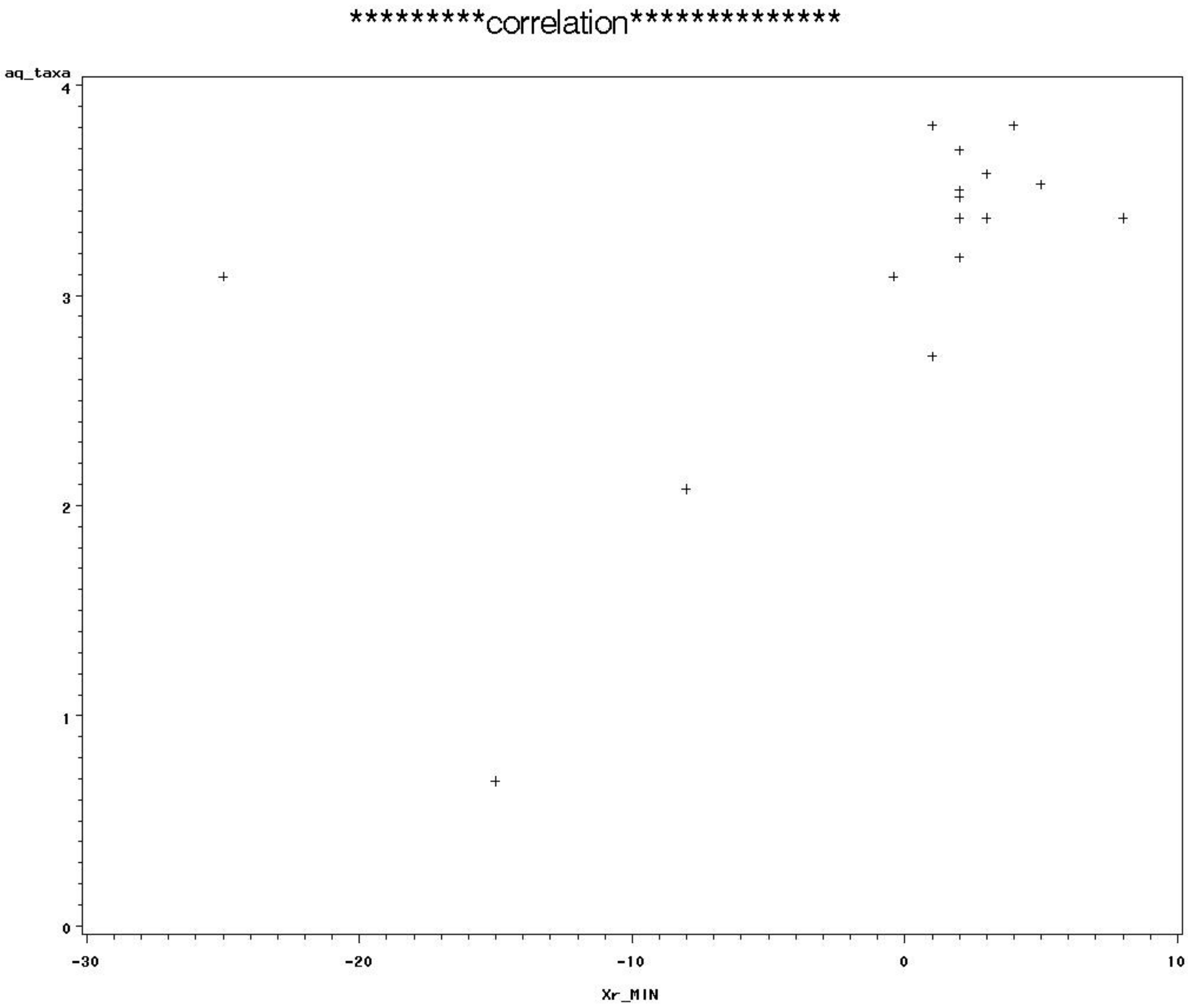
Relationship between general macroinvertebrate aquatic abundance and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in pools (Xp_MIN) and macroinvertebrate aquatic abundance (p=0.0500).

Spring 2004

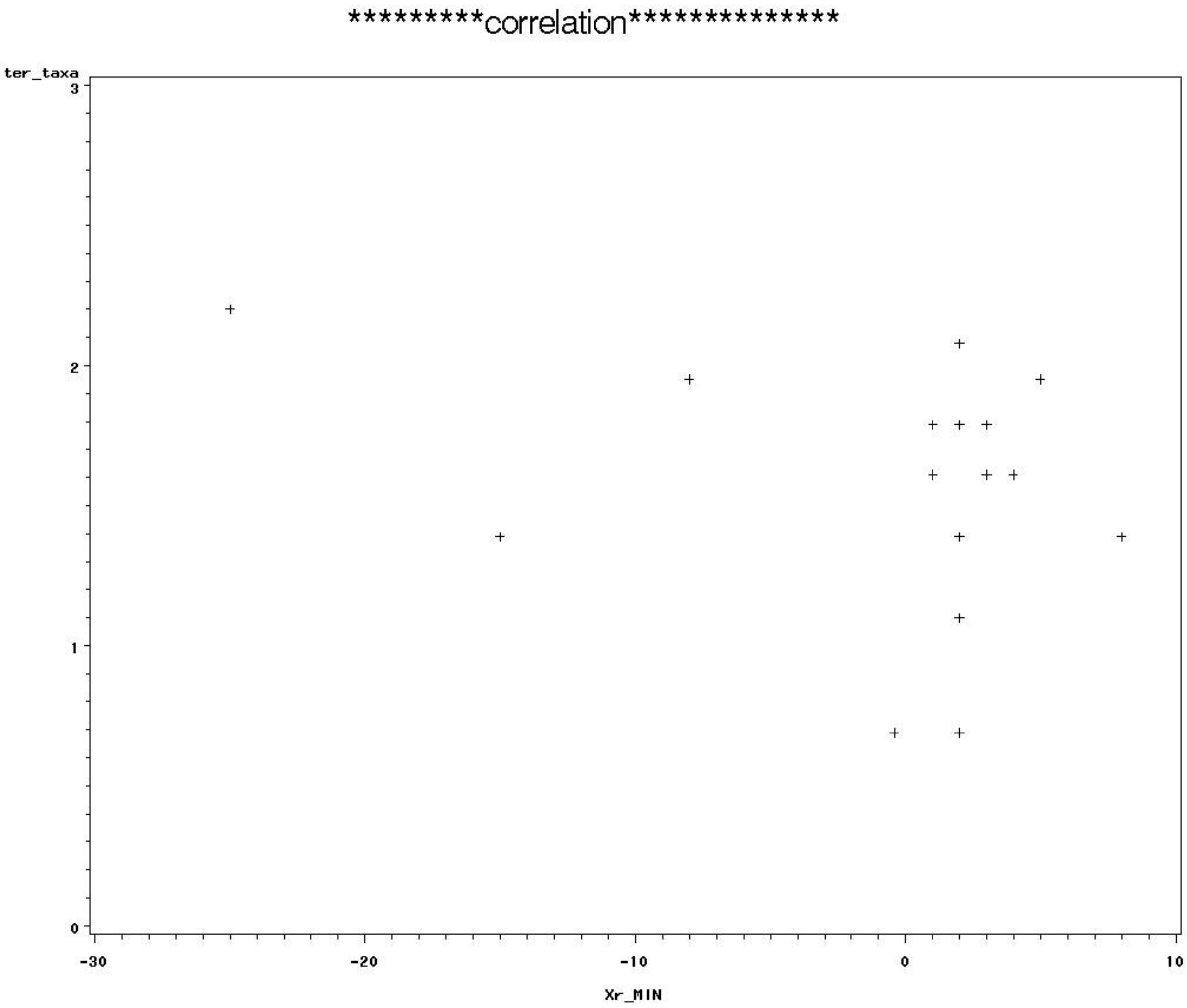
Relationship between general macroinvertebrate aquatic taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffles (Xr_MIN) and macroinvertebrate aquatic taxa (p=0.0286).

Spring 2004

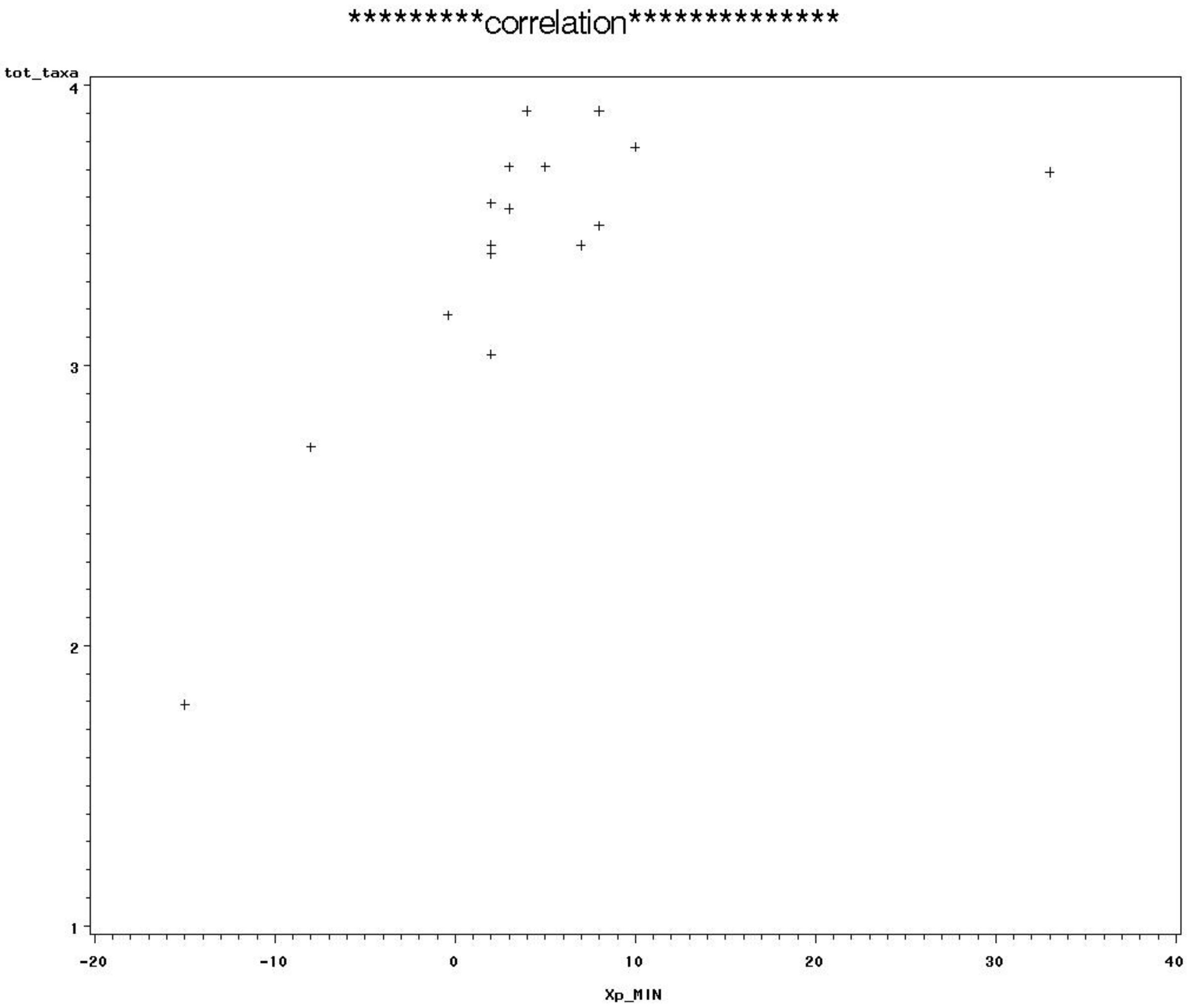
Relationship between general macroinvertebrate terrestrial taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in riffles (Xr_MIN) and macroinvertebrate terrestrial taxa (p=0.3065).

Spring 2004

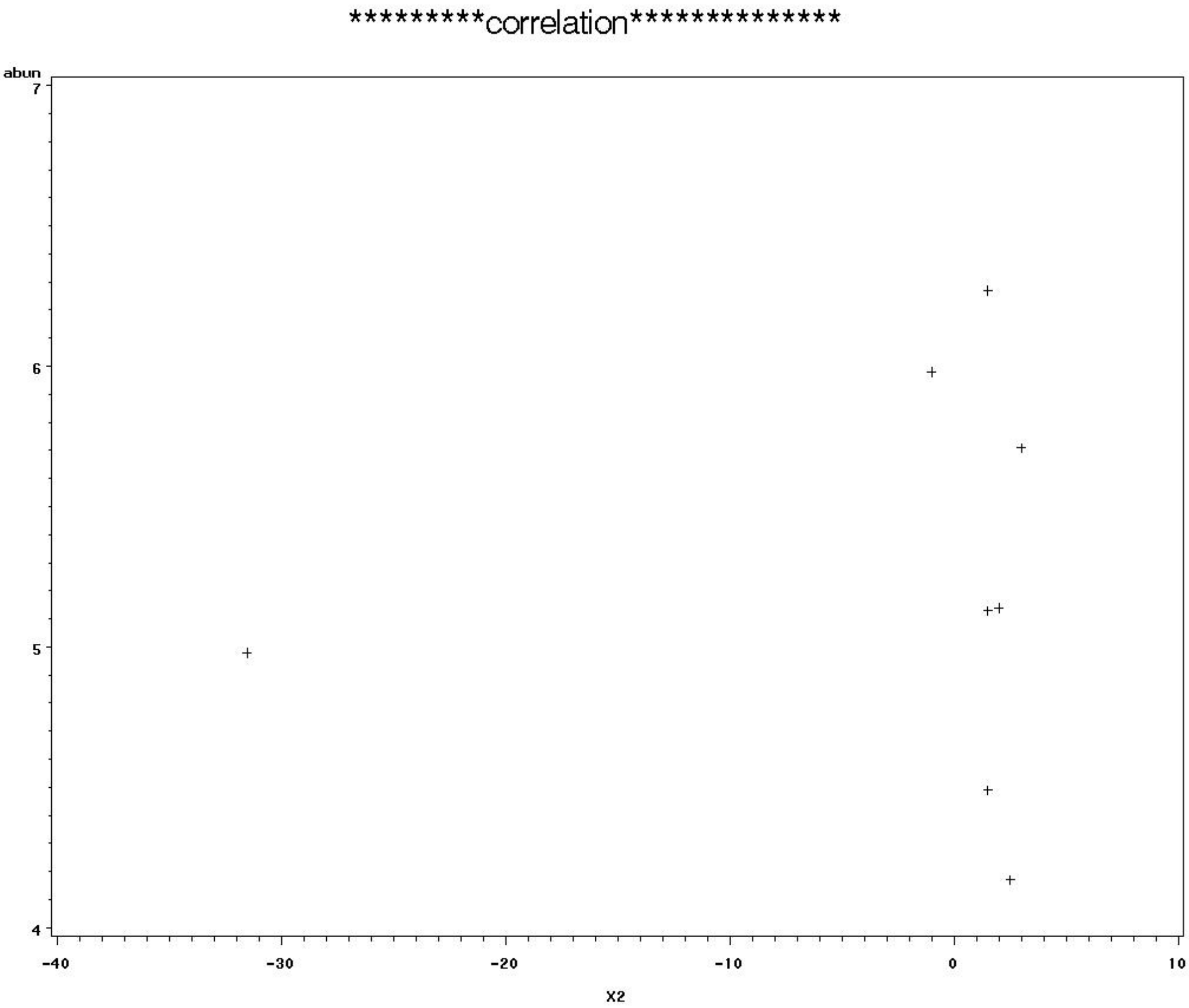
Relationship between general macroinvertebrate total taxa and water depths
Plots from Best Fit Models



This figure depicts the relationship between minimum water depths in pools (Xp_MIN) and macroinvertebrate total taxa (p=0.0111).

Summer 2004

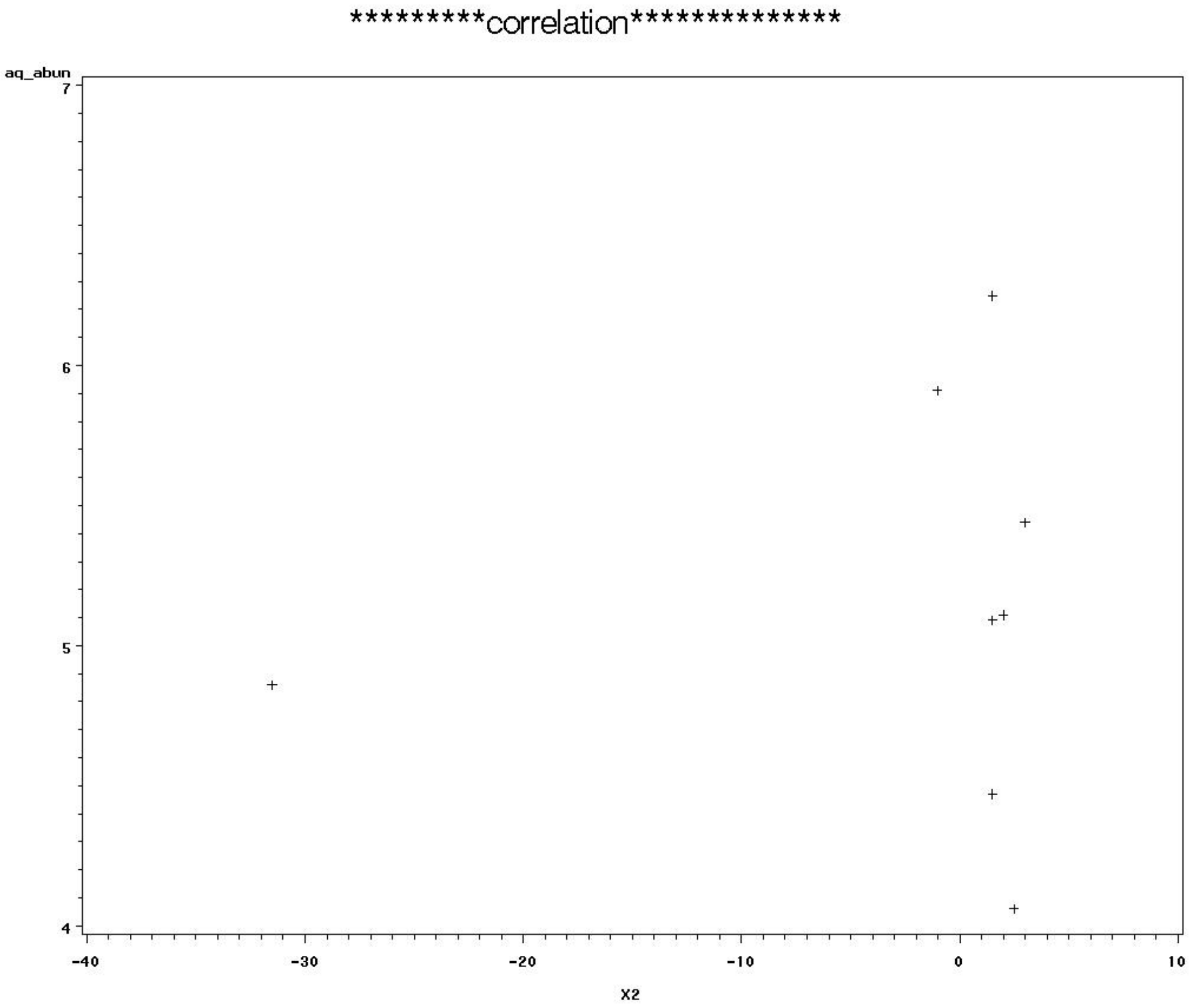
Relationship between general macroinvertebrate abundance and water depths
Plots from Best Fit Models



This plot illustrates the relationship between averaged water depths in riffles the week before and the week before and the week after macroinvertebrate sample date (X2) and abundance (p=0.2131).

Summer 2004

Relationship between general macroinvertebrate aquatic abundance and water depths
Plots from Best Fit Models

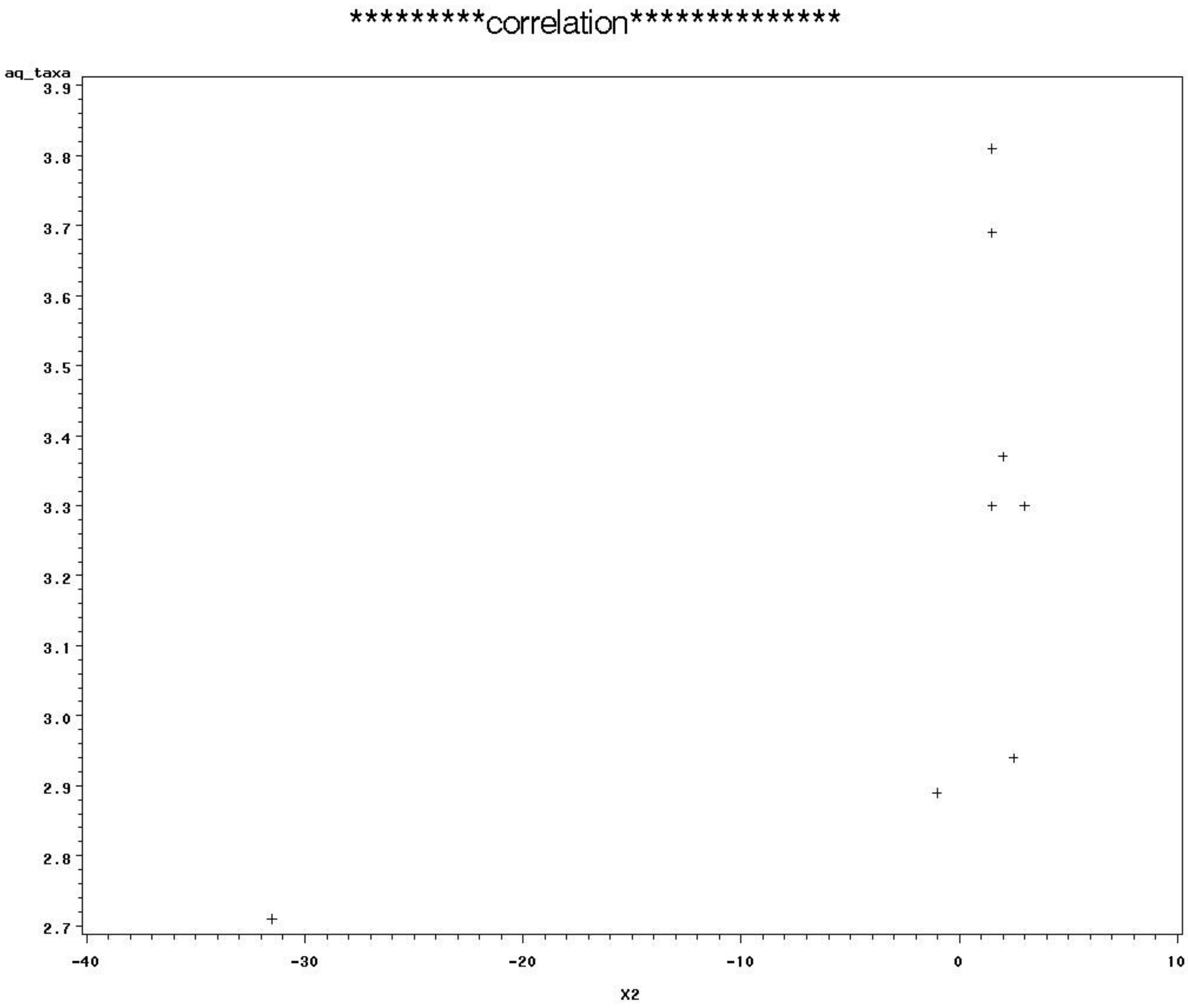


This plot illustrates the relationship between averaged water depths in riffles the week before and the week before and the week after macroinvertebrate sample date (X2) and aquatic abundance (p=0.2106).

Summer 2004

Relationship between general macroinvertebrate aquatic taxa and water depths

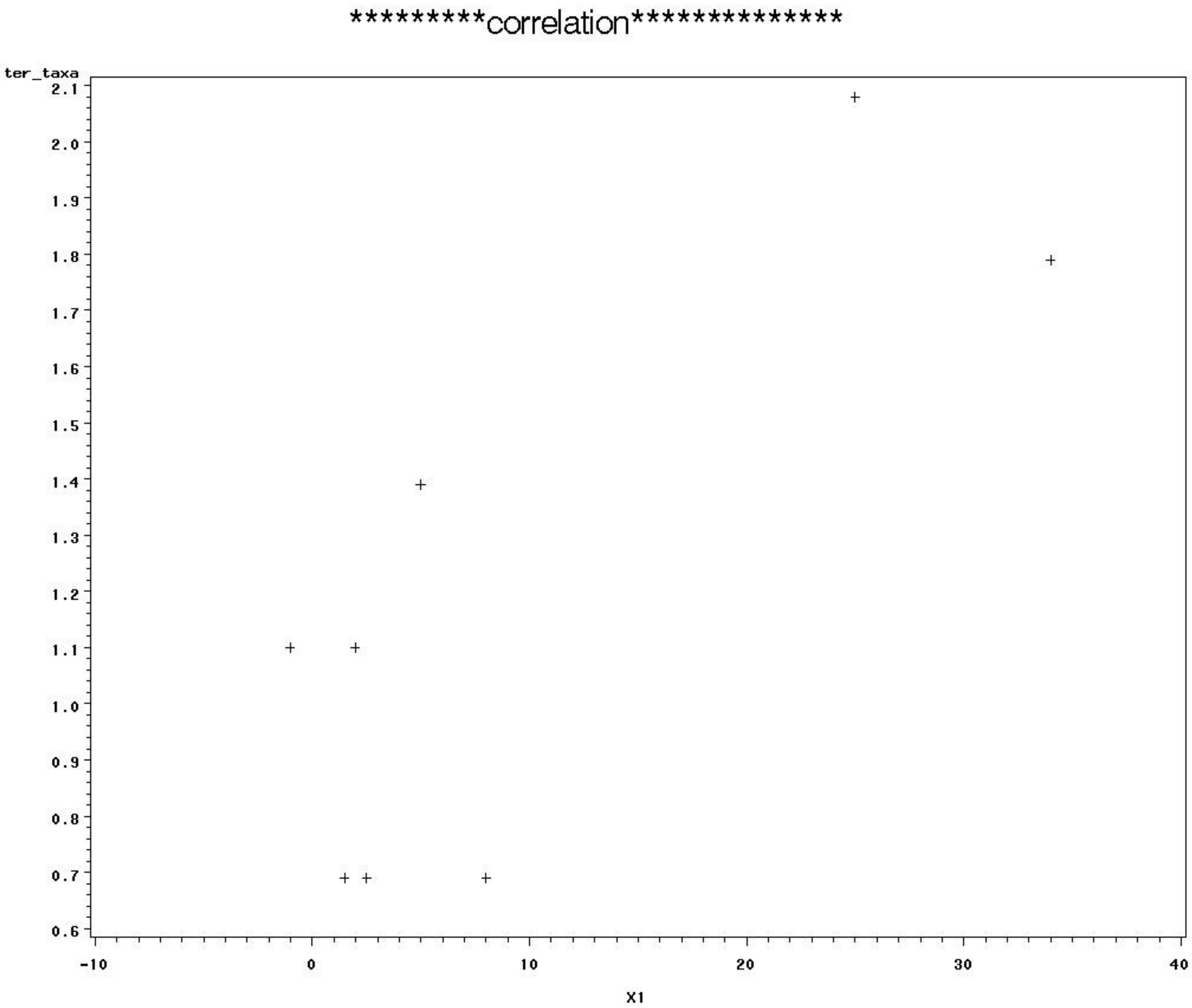
Plots from Best Fit Models



This plot illustrates the relationship between averaged water depths in riffles the week before and the week before and the week after macroinvertebrate sample date (X2) and aquatic taxa (p=0.1520).

Summer 2004

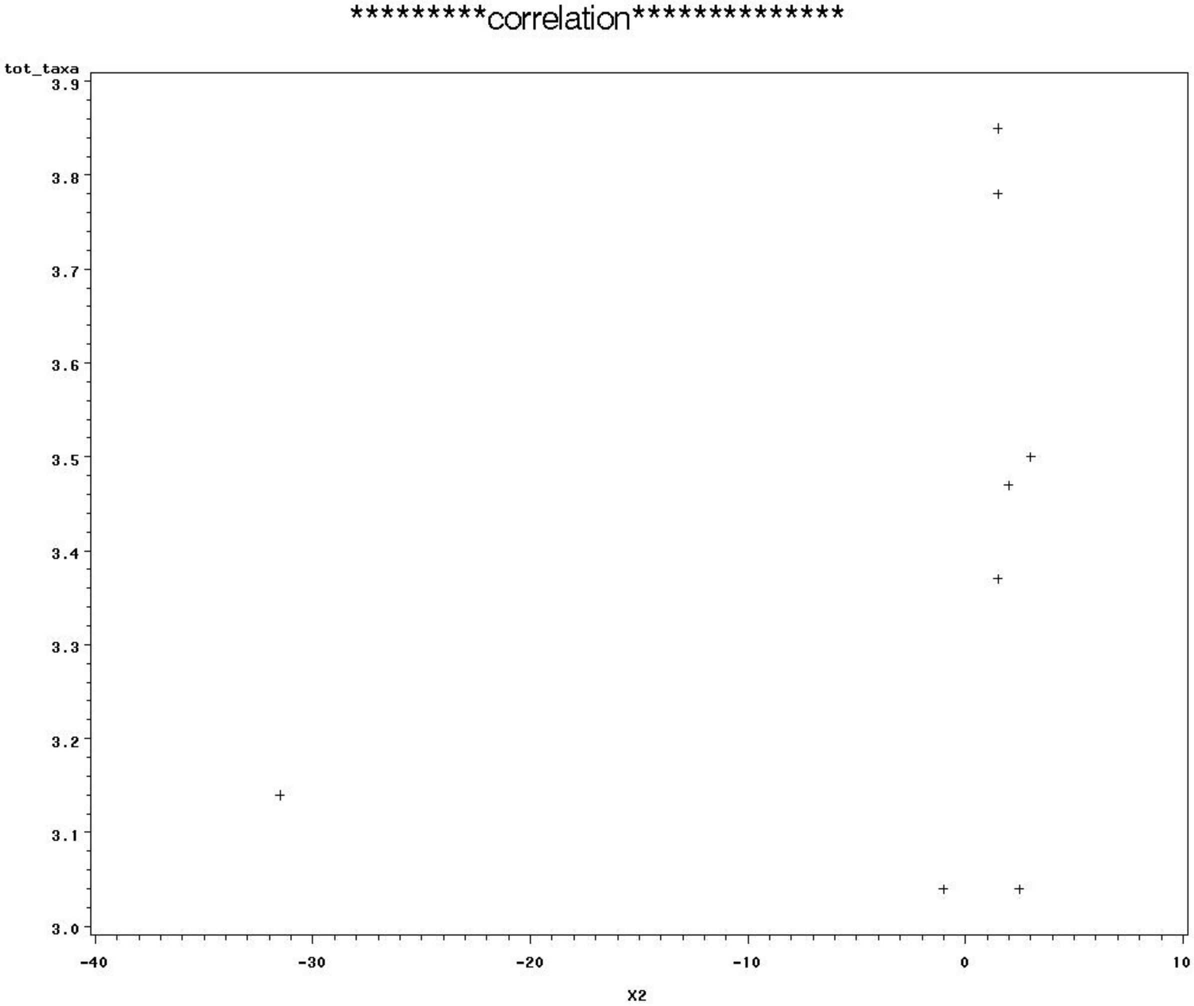
Relationship between general macroinvertebrate terrestrial taxa and water depths
Plots from Best Fit Models



This plot illustrates the relationship between averaged water depths in pools the week before and the week before and the week after macroinvertebrate sample date (X1) and terrestrial taxa (p=0.0336).

Summer 2004

Relationship between general macroinvertebrate total taxa and water depths
Plots from Best Fit Models



This plot illustrates the relationship between averaged water depths in pools the week before and the week before and the week after macroinvertebrate sample date (X2) and terrestrial taxa (p=0.0336).

APPENDIX 4

EVALUATION OF STREAM CLASSIFICATION METHOD

Statistical Analysis Software: SAS Program

The general code used to evaluate NCDWQ's Stream Classification Method is:

```
data Stream_type;
input Stream Stream_type X1;
cards;
1      1      -34.5
1      2      38.5
1      2      16.5
1      3      9.5
2      1      -28
2      1      8
2      2      20
2      3      41.5
3      1      -21
3      1      -16
3      2      43.5
3      3      11.5
4      1      -54.5
4      2      -4
4      3      12.5
4      2      -14
4      3      23
5      1      -31
5      1      48
5      2      26.5
5      3      4.5
6      1      -8
6      2      4.5
6      3      3
6      3      3.5
7      1      -90.5
7      2      -13
7      2      9.5
7      3      7
8      1      -80.5
8      2      3.5
8      3      3.5
8      3      4.5
proc mixed;
class stream stream_type X1;
model stream_type=X1;
random stream;
run;
```