# Hydrologic Characteristics and Flooding Potential of the Meadowbrook Stream Watershed in Sunderland Massachusetts

A Professional Paper Presented by

Colleen B. Samson

Professional M.S. Candidate Wildlife & Fisheries Conservation

Approved as to style and content by:

_______________________________, Chair
(Curtice Griffin)

_______________________________, Member
(Timothy Randhir)

_______________________________, Consulting Member
(Jerry Schoen)

_______________________________________
(Kevin McGarigal, Graduate Program Adviser)

_______________________________________
(Curt Griffin, Department Head Environmental Conservation)

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# I. Abstract

A hydrologic evaluation was conducted for the Meadowbrook stream watershed located in Sunderland, Massachusetts in order to try and determine the cause of basement flooding problems reported by some local area residents, as well as to try and determine if the plan proposed by the Sunderland Conservation Commission to remove woody debris and aquatic vegetation would reduce the flooding problems. An evaluation of hydrologic conditions of the area included both monitoring of stream and groundwater level depth change, stream velocity change, as well as an analysis of other physical features of the watershed led to the conclusion that removing woody debris and aquatic vegetation from the stream would not have the desired effect of reducing basement flooding problems. The results of our evaluation indicated that groundwater level fluctuations were the primary cause of basement flooding problems in the Meadowbrook stream watershed, and that weak relationships displayed by correlation and regression analyses, as well as low levels of influence from other factors evaluated in the watershed indicated that due to the low level of influence between stream and groundwater level flow, attempts to remove woody debris and aquatic vegetation from the stream would not have the desired effect of reducing basement flooding problems. It is our belief that groundwater level fluctuations were due to fluctuations in the aquifer connected to the Connecticut River, but insufficient data at the time prevented us from determining if the aquifer was the actual cause of groundwater level fluctuations.

# II. Introduction

Flooding is a process that can be viewed from a variety of levels. Brooks et al. define flooding as “stream flow that rises above the stream banks and exceeds the capacity of the channel” (Brooks et al., 2003), but flooding is more commonly viewed as large natural disasters that cause damage. The largest scale floods are those events that gain the most notice due to the devastating effects they have on human settlements and the environment. The United States Department of the Interior states that “the great or catastrophic event is infrequent” (United States Department of the Interior, 1968), and “that the most infrequent floods occur under conditions that are not appreciably affected by imperviousness of the basin” (United States Department of the Interior, 1968). Small scale flooding occurs most frequently when stream capacity is exceeded and water flows over the top of stream banks. These small scale floods are often overlooked, unless they negatively affect humans in some way. In between small scale floods and large flooding events are medium level flooding events. These floods are large enough in scale to be recognized by people, but still small enough in scale to be affected by human influences on the environment.

Human alteration to the environment largely affects the rate and severity of floods. Human development negatively affects the natural flow of water through the environment by increasing overland flow due to increased levels of impervious surfaces. This increase in impervious surfaces results in increased runoff rates, and reduced infiltration (Harbor, 1994). This results in less water entering the soil, which not only reduces groundwater levels, but also increases the peak stream flow, which results in flooding. The resulting changes to the natural river flow, not only can negatively affect humans and other organisms (Poff et al., 1997), but can also lead to changes in vegetation composition adapted to reduction in groundwater levels

(Hayashi and Rosenbury, 2002 ).

In order to counteract the damages caused by floods, efforts are made to understand the cause of flooding problems. Poor quality of data and complexity of the factors involving the rate of water transportation through a system makes it difficult to assess. Many flood models have inherent flaws due to the lack of sufficient data (Reed, 2002), not accounting for spatial variation in plot characteristics (Merz, Bardossy, and Schiffler, 2002), assessing flow patterns (Voinov, Voinov, and Costanza, 1999), and variability in soil type, and variability in infiltration rate (Joel et al., 2002). The lack of available data, plus inaccurate models is further complicated by the inability of scientists to communicate the information to the public effectively. One of the problems with educating the public about flood management practices is the assumption that the population in general will seek out and understand flood information (Brown and Damery, 2002). “When trying to educate people about flood mitigation measures, it is important that the information comes from a reliable source, and that it is easy to understand” (Sims and Baumann, 1987).

Brooks et al. (2003) state that “there are essentially three options to reduce and prevent disasters caused by excessive amounts of water: (1) modify the natural system, (2) modify the human system of behavior, and (3) some combination of (1) and (2).” Modifications to the natural system usually take the form of flood control devices such as dams, levees, and channelization. The problem with such control devices is that they often result in what Thompson (1999) refers to as the “flood control paradox.” The flood control paradox is related to people developing a false sense of security due to control devices such as dams and levees, which they view as being able to protect them from future flood inundation (Thompson, 1999). This false sense of security results in a greater level of development in flood prone areas, and eventually worse damages when structures fail (Thompson, 1999). “There are four levels of adjustments that people make when dealing with floods, 1) Modify the Natural Event, 2) Modify damage susceptibility, 3) Modify the loss burden, or 4) Do nothing” (Thompson, 1999).

The concept of adjusting to flooding by altering the Natural Event relates to the construction of devices to alter flood flow, but has the result of giving people a false sense of security, as well as often causing detrimental effects to the environment (Thompson, 1999). Modifying damage susceptibility relates to encouraging people to not build in flood prone areas, but instead giving priority to the river to use the floodplain for flood storage or for other land uses such as parks that would be less negatively affected by a flood event (Thompson, 1999). Modifying the loss burden refers to such actions such as flood insurance and disaster relief that help individuals cope with flood caused destruction to their property, and finally doing nothing refers to those people who choose not to take any action to reduce the effect that flooding has on their lives, but rebuild and wait for the next flood event to occur (Thompson, 1999). “There are many ways to undertake the management of riverine ecosystems, but understanding the human element and making people understand their effect on the riverine ecosystem is an important step in fixing ecosystem degradation” (Groffman et al., 2003).

## Relationship to Hydrology

The hydrologic cycles consists of the processes and components that circulate water through the natural system (Brooks et al., 2003). Water enters the system in the form of precipitation, travels through a variety of pathways, until it returns to the atmosphere to restart the cycle again (Thompson, 1999). As it flows through the system, the rate it travels and the pathway it takes is largely effected by the type of surfaces it flows over. On its journey to the ground, precipitation is slowed by vegetation which stores water on its surface, or returns it to the atmosphere by evaporation or transpiration. Water that enters the ground is either stored in underground aquifers, or slowly makes its way to stream channels, where it flows downstream to join larger water bodies and eventually reenter the atmosphere. Water that lands on saturated, impervious, or compacted soils generally can’t be absorbed, so instead quickly flows overland until it meets up with a stream channel or an area of land that is able to absorb it (Thompson, 1999).

Many factors affect the rate and direction of water flow through the hydrologic cycle. Climate affects the type of precipitation and severity of storms, as well as the type of vegetation present (Brooks et al., 2003). Type and density of vegetation determines the amount of water that reaches the soil surface (Brooks et al., 2003). Plants with larger surface areas or root distribution can often intercept and store more water than less dense vegetation (De la Cruiz and Barten, 2007). Alteration of the environment results in changes to the hydrologic cycle and results in changes in the pathways of flow (Thompson, 1999). Cleared areas now results in a larger amount of water flowing through the system as overland flow until it is either absorbed into the ground at a later location, or enters the stream channel to alter the natural flow rate. Not only are rates of flow altered, but groundwater storage as well. With less water being trapped and slowed by vegetation, less water infiltrates into the ground, so less water is available for groundwater storage (Harbor, 1994). Groundwater storage not only affects the type of vegetation that is able to grow in an area (Webb and Leake, 2006), but also helps maintain stream flow during periods of low precipitation.

Precipitation type and rate, soil type, vegetative cover, topography, and many other factors affect the rate at which water passes through a system, what form it takes, how it is stored or travels, and eventually how it reenters the atmosphere (De la Cruiz and Barten, 2007). The processes are continuous and occur simultaneously throughout the system. “A balance exists where changes in one step of the process will result in alterations in the rest of the system” (De la Cruiz and Barten, 2007). Problems exist where human influence often alters natural or preexisting flow paths. The changes that result causes alterations to the flow, alter preexisting conditions, or change at a rate that the natural system can’t keep up with to retain a balanced state (Poff et al., 1997).

## Flooding in Basements

This study focused on the occurrence of residential basement flooding in the Meadowbrook Watershed of Sunderland, MA.. The goal of the study was to assess and determine the cause of the basement flooding. The two possible factors that were a focus of this research were if the problem was a result of stream conditions, or groundwater conditions. Residents in the area thought that their basement flooding problem was due to the inability of the local drainage ditch (Meadowbrook stream), to adequately transport water from the area as a result of poor maintenance. The lack of maintenance resulted in degraded stream conditions, often caused by vegetation clogging the stream channel, as well as the buildup of sediment. It was suggested by local residents that due to the degraded conditions the stream flow was hindered, and the stream was no longer able to drain the area quick enough to prevent water from backing up into neighboring homes. The second option that we looked at was the level of groundwater in the area which might also have caused basement flooding.

The problem we discovered with trying to determine if groundwater levels were the cause of basement flooding is the need for data and analysis. Most of the papers available on basement flooding were related to basement flooding due to faulty building construction or drainage systems. Due to the lack of preexisting data and approaches, we focus on groundwater monitoring wells to determine groundwater depth, and compared these depth change readings to other measurements in the watershed.

In most areas, groundwater level fluctuations occur on a very small scale and change gradually, often making them difficult to detect and accurately measure (Heathcote, 2009). Groundwater flows from areas of higher saturation to areas of lower saturation due to capillary action (Heathcote, 2009). An example of this is when water is pumped from a well. Groundwater levels become lower in the area surrounding the well, resulting in reduced saturation in the area. Surrounding groundwater responds to the alteration in saturation by flowing across the water table until a new balance is achieved, resulting in this case in a lower water table throughout the rest of the watershed. In the case of the Meadowbrook watershed, large precipitation events result in increased water levels in the Connecticut River. This resulted in a higher saturation level in the river channel, then in the surrounding areas, so water flows through the soil spreading through the watershed until a level of equal saturation is attained. In this way, the water level in the river channel is reduced, but surrounding groundwater levels rise, resulting in basement flooding due to homes being built too close to the water table. Groundwater readings taken during non-storm conditions would result in readings indicating that groundwater levels were too low to affect buildings, but when groundwater levels rise due to large precipitation events, or spring thaw, they rise above normal levels, due to the river's influence on groundwater level change.

## **Focus of the Study**

Residents were concerned about basement flooding problems, or basement flooding that was becoming more frequent over the years. The residents hoped that the Conservation Commission might be able to take some action to reduce the flooding. Looking at the problem, the commission came up with the possibility that the flooding issues may be related to the lack of maintenance of drainage ditches that ran through the area. The commission proposed to remove vegetation and debris in the hope that it would increase water transportation and thus reduce basement flooding. Before undergoing this process though, the commission decided it wanted to look more into the cause of flooding in the area in order to see if water transportation and unmaintained ditches were really the problem, and not some other unknown factor. This project came up so that an evaluation could be made of the area, factors that contribute to potential flooding could be analyzed, and then the results presented to the Conservation Commission so that they could make their final decision about what actions they wanted to take.

## Objectives

We divided this study into four main objectives. (1) Assess the extent of the area contributing to the stream flow; (2) quantify the relationship between surface and groundwater levels; (3) Model runoff at a spatially explicit scale; and (4) study site-specific factors influencing flooding.

## Objective 1: Assess the Extent of the Area Contributing to Stream Flow:

One of the interests was the extent of the watershed that drained into the Meadowbrook stream. By determining the watershed extent, one would better be able to determine areas contributing to the stream. Knowing the location of the watershed boundary allows one to assess factors contributing to stream runoff and potential sources of flooding in a system framework. By knowing the extent of the watershed, we were able to better comprehend what land uses were contributing to flooding along the Meadowbrook stream. The null hypothesis for this objective was that there was no correlation between the watershed area and stream flow. This indicated that as the area of the watershed increased, there would be no alteration in the rate of stream flow, resulting in no connection between watershed size, and flood occurrence.

## Objective 2: Quantify the Relationship Between Surface and Groundwater Levels:

By determining the stream flow capacity, one is able to estimate how much water the stream can transport, and whether the amount is enough to support the town's decision to dredge the stream. In order to determine if the dredging plan would have any beneficial effects towards reducing flooding, one had to determine if the stream was contributing to the flooding problem, and if the stream flow capacity was enough to handle the watershed runoff it drained. The stream assessment survey was conducted year long on stream velocity and depth changes in water level at five different points, as well as a onetime survey of the stream channel length. Data was collected on stream channel shape, vegetation and woody debris levels, as well as sediment levels. ArcGIS map layers were created to run evaluations of stream flow capacity. As part of the assessment to determine if clearing out the brook would reduce flooding problems, groundwater level were monitored by installing two monitoring wells. Readings taken from the wells were used in combination with precipitation and stream height to assess the relationship between changes in groundwater level and watershed flooding. To determine occurrence of flooding in area homes, we used a survey asking residents of the watershed whether their basements were flooding or if they had made any modifications to prevent flooding from occurring. We compared the survey results with groundwater and stream level change data to determine what relationships existed between the various factors affecting the watershed. The null hypothesis was that there was no signification relationship between surface and groundwater. This indicated that as stream flow rate and depth changed, there would be no influence on groundwater level change, indicating that alteration to stream channel makeup would have no significant influence on flooding which was the result of groundwater level change.

## Objective 3: Model Runoff at a Spatially Explicit Scale:

Measurements of land use type as well as soil drainage classification were used by the curve number method to assign values to areas of the watershed. Resulting values were then combined with yearly precipitation values to generate runoff rate measurements. Using the curve number method we were able to determine runoff rates as well as infiltration rates of the watershed. Resulting rates when compared to groundwater depth and surface depth change and flow indicated the relationship between flooding problems and runoff rates.  The null hypothesis was that there was no significant difference in runoff at spatial scales. No difference in runoff rates over the surface of the watershed indicated that changes in watershed size would have no signification effect on runoff rates. Likewise infiltration rates and groundwater level change would not be affected as well, indicating that flooding was occurring independently  of runoff generated by the watershed size.

## Objective 4: Study Site-Specific Factors Influencing Flooding:

The final objective of our study was to conduct a land use analysis. The purpose of this analysis was to determine what factors in the watershed were either contributing to the flooding problem other than the clogged stream conditions or high ground water levels. By looking at land use, we could determine if changes in land use were causing changes in the hydrology of the area. Data was collected from MassGIS online databases, as well as from field observations and resident responses to surveys. Soil type, land use, level of imperviousness, as well as other factors were looked into to determine if they were having an effect on the Meadowbrook stream drainage area that would result in the occurrence of flooding. The null hypothesis for this objective was that site factors were not significantly influencing residential flooding. This hypothesis indicated that factors such as vegetation and woody debris levels, runoff rates, land use type, as well as location of flooding had no direct influence on the occurrence of basement flooding problems.

# III. Literature Review

## 1) Surface Flow

1)

The affect of land use change on hydrology and the application of modeling these changes is a tool for managers and development planning (Harbor, 1994). Increases in development alter hydrology by increasing runoff rates and reducing the amount of infiltration occurring (Harbor, 1994). This results in increased levels of runoff and reduced groundwater infiltration, which could eventually reduce groundwater levels and alter wetland hydrology. Harbor (1994) proposed to use his runoff model to estimate runoff amounts that will occur due to alterations, for the use in development planning, as well as water management practices. By knowing the effect of development beforehand, alternate methods may be taken to reduce development impacts or additional measures may be taken to reduce the impact (Harbor, 1994). Having an estimate of runoff values will give you an idea of whether a flood risk occurs from a development project, and whether that project should be altered to reduce the affect (Harbor, 1994).

2)

Irwin and Whiteley (1983) looked at the effects of land drainage by the creation of tile drainage systems and channels in Ontario Canada, to determine the effect they have on water infiltration, overland flow, and flooding. There are two basic views about drainage. The first is that it will increase overland flow which will result in increased flooding. The second is that high water tables that existed before the land drainage would prevent high infiltration rates so channel construction and drainage systems shouldn't have much effect (Irwin and Whiteley, 1983). Overall channelization of streams and creation of tile drainage systems didn't have much effect on flood occurrence and magnitude (Irwin and Whitely, 1983). Undrained land don't have high infiltration rates, so total runoff rates wouldn't be increased by much anyway (Irwin and Whitely, 1983). Infiltration rates should be higher under the drained system, because soils are better able to absorb water. If channel sections aren't synchronized, the flood events may be reduced due to spread out flow.

3)

Jerald Barnard (1978) looked at the effects of flooding on property values, and methods to reduce the problems that urban development in upstream areas have on properties in lower lying areas of a watershed. Barnard's (1978) study focuses largely on the Ralston Creek watershed, located in Iowa City, Iowa. An analysis of property values of homes in parts of the watershed was conducted to determine how property values decreased based on increases in flood occurrence resulting from increased runoff caused by more impervious surfaces in upland areas. Estimated property values decreased over time for homes located in low lying areas as small scale flood occurrence increased (Barnard, 1978). Cost to property owners also increased due to the need to repair flood damage to property, not just loss of property values due to increased flood risk. Efforts should be made to reduce flood problems due to development both after they occur, as well as before they start (Bernard, 1978). Reduction efforts can take the form of dam installation or removal of homes from flood prone areas. Flood prone lands can be converted to other land uses such as parks or nature areas, where flooding causes less damage. Flood reduction efforts should consider the cost of the repair work. Sometimes it's less expensive to create a dam that may not be able to protect against all levels of floods. Barnard (1978) pushed for development plans that take into account altered drainage patterns in the planning process. Many development plans don't make designs that work with natural runoff patterns and reduced runoff flow. New regulations need to be created and put into effect that prevents people from building in flood prone areas in order to reduce flooding problems Barnard (1978).

4)

Miyata et al. (2009) looked at the effect of forest floor cover on overland flow and soil erosion rates. Their study took place from 2004 to 2006 on a cypress plantation in Mie Prefecture, located in Central Japan. The study involved three plots with different land cover types. Plot A consisted of a sparsely vegetated understory with litter, plot B had a dense fern understory with litter, and plot B,' which was site B with understory vegetation and litter carefully removed. Surface flow rates, soil runoff rates, and soil infiltration rates were analyzed. Vegetation reduced the impact caused by raindrops, thus dropping the soil erosion levels (Miyata et al., 2009). Vegetation also slowed runoff rates, which increased infiltration rates. Plot B' had higher soil runoff rates, but those higher rates were attributed to recent removal of the protective vegetation layer (Miyata et al., 2009). Site A had already lost most of its easily erodible soil layer due to earlier vegetation removal, and site B''s soil erosion rate should eventually reach a similar speed as site A's due to the runoff of the newly vulnerable soil layer (Miyata et al., 2009). Miyata et al. (2009) felt the results of this study are important, because the models they used took into account both changes in vegetation cover as well as soil erosion rates. The models would be useful for practices such as logging, which effect both vegetation cover and the soil of an area. More studies need to be undertaken in order to better understand the effects of vegetation cover on preventing soil loss due to raindrop impact and its effects on reducing overland flow (Miyata et al., 2009).

5)

Bronstert, Vollmer, and Ihringer (1995) look at existing studies on land consolidation in

Germany and tried to determine the effect it had on flood occurrence rate. Land consolidation is the process by which separate areas of land use are altered to produce larger areas of similar land use practices rather than having multiple scattered small scale plots. Land consolidation involves moving roads, redirecting small streams, altering land terraces where crops can be grown, and changing drainage patterns. Runoff and drainage rates could be increase, by such activities as straightening streams and creating more impervious roads, or it could decrease by the creation of water storage areas or winding streams built to slow water movement and store it in arid areas (Bronstert, Vollmer, and Ihringer, 1995). The results of their study were deemed to be inconclusive due to a lack of sufficient data (Bronstert, Vollmer, and Ihringer, 1995). Small scale area practices such as terracing, stream straightening and road construction generally increase runoff production and potentially increase flood occurrence, while consolidation practices would have less of an effect on large scale river watersheds (Bronstert, Vollmer, and Ihringer, 1995). An increase in impervious surfaces due to urbanization was likely to have a larger effect than stream consolidation on flood occurrence rate (Bronstert, Vollmer, and Ihringer, 1995).

6) Komatsu et al. (2011) look at changes in runoff, and daily precipitation values for the period of 1979 to 2007 in the Terauchi watershed, located in Japan. Changes in runoff were analyzed to determine if decreases in forestry practices were resulting in an increase in flood risk. Due to a decrease in timber prices many forestry management practices have stopped or been decreased in Terauchi (Komatsu et al., 2011) . Previous studies have shown that a decrease in management practices have resulted in an increased leaf area index for coniferous trees. Resulting increase in leaf area resulted in a reduced understory vegetation layer, which reduced the amount of infiltration that was occurring, resulting in higher runoff rates (Komatsu et al., 2011). Komatsu et al. conduct similar tests to determine if the results of previous studies were

true. The two factors affecting infiltration rate are the thickness of understory vegetation and decomposition rates of leaf litter (Komatsu et al., 2011). Leaf litter with slowed decomposition rates were almost as good as a thick understory at slowing down runoff rates and increasing infiltration (Komatsu et al., 2011). Infiltration rates for long duration storms on areas with vegetation removed versus areas without vegetation removed were similar, while short term duration storms showed higher infiltration rates for vegetated areas versus non vegetated areas. The difference in infiltration rates may have been due to high infiltration rates of unsaturated soils during short storms versus saturated soil conditions created by long duration storms (Komatsu et al., 2011). Komatsu et al. (2011) did not observe increased runoff rates due to non-managed timber plantations that had been observed during previous studies. Different results may have been observed if hourly precipitation data, which was not available for the period of their study, was used.

7)

An evaluation of historical aerial photo, precipitation, and stream flow data was conducted from 1947 to 1998 to determine the effect of impervious surface increases over time on stream flow in the Accotink Creek subwatershed located in Fairfax, Virginia (Jennings and Jarnagin, 2002). Precipitation data was analyzed to determine if there were any changes in precipitation levels that could have accounted for increases in stream discharge rates. There were no changes in precipitation levels that would account for the increase in stream discharge (Jennings and Jarnagin, 2002). Existing aerial photos were also analyzed and impervious surfaces located in the watershed were manually mapped. Increases in stream flow rates were attributed to increases in impervious surface levels (Jennings and Jarnagin, 2002). As impervious surface levels increased over time stream discharge levels also increased, and this increase could not be attributed to precipitation levels (Jennings and Jarnagin, 2002). There were three main problems with the study, which revolved around mapping imperviousness in the watershed. Sidewalk and single family homes were difficult to make out due to vegetation cover and the quality of the photos, and some compacted sites caused by construction might have been missed (Jennings and Jarnagin, 2002). Jennings and Jarnagin (2002) believed that using aerial photos, precipitation data, and stream discharge rates were helpful tools for managing watershed health. Methods for determining impervious surfaces needed to be standardized in order to allow for comparisons among existing studies (Jennings and Jarnagin, 2002).

8)

Voinov, Voinov, and Costanza (1999) worked on developing a hydrology model that could be used on different spatial scales and still retain accuracy. Often times hydrology models focus only on smaller scale watersheds and don't take into account the effects on larger areas (Voinov, Voinov, and Costanza, 1999). Models that are applied to large areas are often inaccurate as well, due to variations in watersheds flow pattern. Often watershed size in models are increased, but changes in model size do not have the same effect as results for modeling a larger watershed, so the results are often not accurate in displaying natural events. The focus area for the study was the Patuxent Watershed, located in Maryland. The difficulty with developing a hydrology model that can be used on a larger scale than most models take into account, is dealing with the complexity of the many factors that affect hydrologic flow in the watershed (Voinov, Voinov, and Costanza, 1999). They had to determine which factors could be altered or excluded from the model and still have it accurately predict runoff values. The three main parameters that affected the surface flow rate in their model were infiltration rate, horizontal conductivity which controls the baseflow rate, and the length of the water transportation paths represented by the model (Voinov, Voinov, and Costanza, 1999). Voinov, Voinov, and Costanza

(1999) adjusted various factors until they ended up with what they felt was a fairly accurate simulation of hydrologic flow that worked on a small, as well as large watershed scale.

9)

Andrew J. Pearce (1976) looked at the effects of storm length and strength on the production of Hortonian overland flow and its effects on erosion, in order to use the data to design a rehabilitation program for the defoliated areas near Subsbury and Ontario, Canada. Rates and amounts of erosion that were occurring were recorded at four study plots, and then the data was compared to records of storm strength and duration. Storms that occurred the most frequently and contributed the most to erosion in the Sudsbury and Ontario study areas were the results of storms ranging from one to six hours (Pearce, 1976). Pearce (1976) suggests that management practices to reduce erosion should concentrate on protecting against these storms, rather than trying to focus attention on protecting against storms that are more severe, but occur less often.

10)

Joel et al. (2002) looked at differences in runoff/infiltration rates of water on two different sized plots in order to try and determine the effect of plot size on runoff/infiltration estimates. The study took place in Santiago, Chile from March to October 1997. Observations showed that larger sample plot sizes yielded different result than smaller plot sizes (Joel et al., 2002). These  differences were contributed to greater variations in site properties in larger sites than in smaller sites (Joel et al., 2002). Over a larger plot the possibility of greater variation in soil types and infiltration rates is possible. Other factors such as soil depressions and travel time across the plot were also considered to influence infiltration rates, allowing for greater storage and travel times on larger plots (Joel et al., 2002).  For short term rainfall events variations in runoff/infiltration rates were greater than those for longer term rainfall event (Joel et al., 2002).

These differences are important, because in Chile agricultural practices often use surface runoff for crop growth, so accurate estimates are needed for agricultural planning (Joel et al., 2002).

## 2) Infiltration

1)

Rawls, Brakensiet, and Savabi (1989) looked at rangeland infiltration models, and how they do not account for groundcover and canopy cover when calculating the amount of water that can infiltrate into an area. Existing models like the Green Amp. Infiltration model based their infiltration amounts largely on soil properties, such as soil type, and soil particle size, without taking into account the higher infiltration rates found in areas that had either a canopy cover or ground cover as opposed to bare ground (Rawls, Brakensiet, and Savabi, 1989). Due to the missing parameters, infiltration calculations were coming up with inaccurate results. In the hope of reducing or eliminating this problem, Rawls, Brakensiet, and Savabi (1989) analyzed various existing studies and infiltration equations, and came up with an equation that took into account canopy and ground cover.

2)

W. E. Nute (1980), attempted to conducts an infiltration/inflow analyses of ten sewer systems located in the San Francisco Bay Area. The analyses was conducted in order to try and determine the best approach for the sewer systems to take, so that they complied with the Federal Water Pollution Act guidelines. The systems were unable to handle excess flow due to large rain events, which resulted in the discharge of improperly treated wastewater into outflow water bodies. The evaluation was being conducted in order to determine the best way (the cheapest versus the most effective) to upgrade the existing systems so that they would be able to handle large storm flows, which exceed the average flow amounts the systems were designed to handle

(Nute, 1980). Data was unavailable for the period of study caused by various recording problems existing with the systems. Hydrology infiltration/inflow calculations were used in order to determine the flow of water through the system in a similar way that it is measured in a hydrology system with unknown elements. Additions to the equation had to be made in order to account for leaks into the system due to the poor grade of materials that were used to upgrade some of the system in the mid-1950s (Nute, 1980). The overall conclusion was that the standards of acceptable discharge in place were not reasonable for storm driven wastewater events, and that the standards for untreated discharge had to be modified into more realistic terms before the most cost efficient modifications could be completed in order to meet the no untreated wastewater discharge guidelines (Nute, 1980).

3)

Soil tillage practices and their effect on soil organic carbon (SOC) concentrations were analyzed to see the effect on infiltration rate (Franzluebbers, 2002). SOC affects water infiltration rates, as well as soil aggregation, which affect the growth potential of plants in soil (Franzluebbers, 2002). By using different tillage methods the amount of SOC retained in the soil varies. Conventional tillage versus no tillage was looked at to try and determine how these tillage practices affected SOC, and thus water infiltration rates. Twenty-four soil cores were collected from two different sites located in close proximity to each other. The cores for each site were either left intact, or the soil particles were mixed in order to distribute SOC throughout the sample. Four different treatments were applied to each sample and results were recorded. Survey results indicated that greater stratification as well as greater total levels of SOC in soil samples increased the infiltration rates (Franzluebbers, 2002). By looking at SOC content, land management plans can be made in order create soil tillage practices that will improve soil water properties, such as infiltration (Franzluebbers, 2002).

4)

Lipiec et al. (2006) looked at four different tillage methods and their effect on soil pore size of Eutric Fluvisol soils in Pulawy, Poland. Tillage methods included no tillage, conventional tillage, as well as harrowing to 5 cm every year, and finally harrowing to 5 cm for five years followed by harrowing to 20 cm on the sixth year (Lipiec et al., 2006). These tillage practices were repeated from 1979 to 1997, with tests conducted in 1997. Pore size distribution, areal porosity, stained porosity, and infiltration rates were recorded for each sample. Results showed that conventional tillage practices that had larger soil pores had higher infiltration rates and water storage capacities than the other tillage practices evaluated for this study (Lipiec et al., 2006). The results showed different pore sizes for the various tillage methods, which results in different infiltration rates as well as different water storage capacities (Lipiec et al., 2006). These factors become important in the content of water availability for plants, as well as groundwater recharge, and rates of erosion (Lipiec et al., 2006).

5)

M. D. Dukes et al. (2006) looked to promote the practice of increasing the amount of storm water that infiltrates into urban areas, by encouraging people to maintain soil infiltration rates by reducing the amount of compaction that is occurring on construction sites. In order to prove their hypothesis that construction reduces infiltration rates, a series of study plots were set up that compared different amounts of compaction or non compaction, and then factors that influence infiltration rates were looked at. Construction equipment did cause compaction that greatly reduced infiltration rates as compared to non compacted sites (Dukes et al., 2006) . In order to prevent reduced rates of infiltration as much as possible, areas of property under construction should be set aside in order to maintain the original non-compacted state (Dukes et al., 2006). These areas would serve as places where infiltration would still be occurring at a higher rate, so that the amount of runoff that could be produced would not be as high as it would if the entire site was compacted due to construction practices (Dukes et al., 2006).

6)

An experiment was conducted looking at vegetation cover on hillsides in parts of the Cache National Forest in Northeastern Utah (Singh, 1969). Differences in infiltration rate and soil runoff was looked at for plots with different vegetation types. Infiltration rates of plots with a mixture of wyethia and grasses were compared to plots with just grasses for vegetation. Resulting measurements generated by the experiment showed that wyethia had slightly higher infiltration rates than the grass plots (Singh, 1969). Rates were not considered a great enough difference to distinguish one land cover as significantly better than the other (Singh, 1969). Soil erosion measurements showed a similar result. Wyethia had higher initial soil erosion present in the runoff, but the grass plots overall had a higher soil erosion level (Singh, 1969). Similar to infiltration rates, soil erosion levels were not significantly different among the two land practices (Singh, 1969). This study was designed to look at infiltration rates and soil erosion levels from rain events in order to try and reduce damaging runoff flows and high erosion levels generated by steep slopes, Teja stated that more studies should be done looking at specific vegetation types in order to get a better understanding of how vegetation cover effects infiltration and soil runoff.

7)

Land use practices were looked at to determine their effect on infiltration rates (Bharati et al., 2002). Experimental plots were established along Bear Creek in Story County, Iowa. These plots were used to compare infiltration rates under grazed pastures, cropped fields, and multi species buffer zones. The results of the experiments showed that multi species buffer zones that had been established for six years had greater infiltration rates than cropped fields, or pastures

(Bharati et al., 2002). The study was based on the idea that greater infiltration in soils resulted in healthier soils, so the higher infiltration rates in multi species buffer zones meant that those areas had higher quality soils (Bharati et al., 2002). The purpose of this experiment was to see if by using these practices to increase infiltration, non point source pollution could be reduced, and less toxins would enter into streams.

8)

Kumar et al. (2012) conducted experiments from a period of 2002 to 2007 to determine the effect of land use on the rate of infiltration. Four study sites were set up with varying land uses, cattle continuously present, cattle rotated through a series of plots, grass buffers, and agroforestry (Kumar et al., 2012). Results showed that the agroforestry areas had the highest rates of infiltration among the four study plots (Kumar et al., 2012). Kumar et al. suggested that these higher infiltration rates were due to not only the vegetation slowing down the water, but also due to larger soil pore spaces caused by rotting tree roots that created larger channels for water to flow into. The area that had the lowest rate of infiltration were those were cattle continuously kept in (Kumar et al., 2012). This was due to greater compaction caused by the presence of the cattle. Kumar et al. hoped that with their research, they would be able to determine which land use practices would reduce the amount of runoff, by determining which land use practices had the highest infiltration rates.

9)

Merz, Bardossy, and Schiffler (2002) look at the effectiveness of infiltration modeling methods. Study plots were set up on a grass field located in the Upper Rhine Valley of Karlsruhe, Southwest Germany. Sprinkler infiltration results were compared to double ring model infiltration results. They discovered that one of the major components affecting the model results was the variation in the study site (Merz, Bardossy, and Schiffler, 2002). Spatial variation of a study site and its effect on infiltration measurements are well known, but most models don't have a way of factoring that variation into infiltration calculations (Merz, Mardossy, and Schiffler, 2002). Merz, Bardossy, and Schiffler concluded that due to similar results obtained from detailed survey methods versus less detailed survey methods, the less detailed survey methods should be used since they both yield similar results, and the less detailed surveys take less time.

10)

Corradini, Morbidelli, and Melone (1998) looked at the influence of run-on on the rate of Hortonian overland flow. Run-on is the process by which runoff from up slope areas infiltrates into pervious down slope areas (Corradini, Morbidelli, and Melone, 1998). Simulations of the rates of run-on on slopes comprised of two types of soils were run. Soils types used for the study were a combination of a clay loam soil, and a sandy loam soil that were randomly generated to create natural variability in the generated slope. Results were then compared to real data collected from a site located in Monte del Lago, Italy. Results of the study showed that run-on rates do play an important role in infiltration rates of storm events (Corradini, Morbidelli, and Melone, 1998). Run-on rates effect estimates of overland flow generation, but they are rarely accounted for in existing equations (Corradini, Morbidelli, and Melone, 1998). Estimates of overland flow are often higher than actual amounts due to not taking into account run-on rates (Corradini, Morbidelli, and Melone, 1998). The effects of run-on were more influential for short duration small scale storms, and had a lesser influence as storm size and duration increased, due to saturation of soil layers (Corradini, Morbidelli, and Melone, 1998).

## 3) River Ecology and Management

1)

Actions should be taken towards restoring natural river flows altered by human activities to predevelopment conditions (Poff et al., 1997). River ecosystems have been altered by human activities such as damming and channelization to reduce flooding and harness resources, by unintentional means such as increased runoff rates due to increased impervious surfaces, and altered organism habitat due to the construction of dams (Poff et al. 1997). Altered conditions negatively affect humans and other organisms alike. Flooding patterns are altered in frequency and strength, as well as river shape and makeup of plant communities due to altered flow. In order for the flooding problem to be reduced and the diversity of native species to be recovered, efforts have to be made to reduce the impact that humans have had on the river environment (Poff et al., 2007). This can be done by looking at natural flooding patterns for an area, and trying to duplicate these conditions if possible (Poff et al., 2007). Many studies focus on a single or few species when they look to restore "ideal" conditions, while these conditions may favor one or a few groups of organisms, managed flood or river flows rarely benefit all or even the majority of organisms present (Poff et al., 2007). The best way to go about recreating natural river conditions is to further study the natural state of the river, and then look towards restoring flow patterns that take into account all the organism in the area not just one or two species (Poff et al., 2007).

2)

Gergel, Dixon, and Turner (2002) look at the practice of flood control using levees and management options that consider the effects of levee removal. There were two main foci of this study, which were to determine the effects of levees versus other factors in influencing flood characteristics and to determine what effects levees had on abundance and distribution of flood tolerant and intolerant species. 100 study plots were set up in three different areas along the Wisconsin River. Water regimes included sites that were located inside the levees, sites that were located outside the levees, and sites that had not been levied. On site evaluations, were conducted as well as using data to predict alterations in flow variables, such as depth and land coverage for simulated levee removal. Setback levee areas had similar characteristics to areas that weren't levied, due to being set back enough that characteristics of the flood plain were not altered as much as areas where levees were located along stream channels (Gergel, Dixon, and Turner, 2002). Vegetation was similar in these areas to pre-levee conditions as well as due to the retention of natural flooding conditions (Gergel, Dixon, and Turner, 2002). Vegetation was effected by levees due to alterations in ratio of flood-tolerant versus flood-intolerant species. Flood-intolerant species were higher behind levees then they would be if the levees didn't exist. Flood characteristics were also affected by the location and type of levee that was used (Gergel, Dixon, and Turner, 2002). Levee removal had different results based on the land topography surrounding the levied river section (Gergel, Dixon, and Turner, 2002). Flow and height differed based on the steepness of the topography. Priority should be given to removing levees that run adjacent to the channel, rather than removing levees that were set back in the floodplain, because mainline levees created greater alterations in flow patterns and set back levees not only had lower effects on floodplain vegetation concentration and hydrology, but also vegetation allowed to grow in the zones between the river and the levee helped to protect levees from damage due to large flooding events (Gergel, Dixon, and Turner, 2002).

3)

John Boardman (1995) looked at the history of flooding and erosion in the South Downs, England, and what has caused it to occur. Local farmers of the area blame increased levels of rainfall as the source of flooding problems, but land use practices are the more likely cause of erosion and flooding in the area (Boardman, 1995). Land practices from 1976 to 1993 switched from pastures to heavier growth of cereal crops over time. The practice of raising winter cereal crops removed organic material from the soil, and that combined with steep slopes and poor soil quality eventually led to large runoff events of both water and soil into down slope areas. These flooding events resulted in damage to property which led to concern among residents in the flood prone areas. Flood mitigation measures were taken to reduce flooding, such as the building of dams, ditches, and instillation of drainage pipes, but due to the characteristics of the area, poor planning, and the amount of soil eroding into the flood prone areas, flood mitigation measures largely failed. Many farmers in the area still refuse to take responsibility for the flooding events, but recent changes in management practices may have had beneficial effect towards reducing the problem (Boardman, 1995). Occurrences of residents suing farmers for poor farming practices and resulting flood damage has resulted in some farmers changing their land use practices because of a need to prevent future flooding events. Changes in farming policies have also caused some farmers to change their land use practices as incentives are being given for switching from heavy growth of cereal, and pushing more towards switching land use practices to pastures. Land use incentives may not specifically be designed for flood mitigation, but they may have the desired effect of reducing runoff and erosion from local area farms that are causing flooding problems (Boardman, 1995).

4)

Tapsell et al. (2002) looked at the social effects of flooding and how to calculate the non-monetary effects floods have on people, so that defense measure can be modified. Flood mitigation measures often only focus on the loss of property and rarely go further to try and fix other non monetary problems residents have suffered as a result of flooding (Tapsell et al., 2002). Factors consisting of health issues such as stress, and loss of mementos are not calculated into damages incurred by flooding. Existing records of flood victims were looked at, as well as records from 2002 flood victims in England. Records showed that flood victims experienced health problems due to the stress of living through the flood event and the poor conditions afterwards, but also due to the loss of treasured mementos and cramped living conditions (Tapsell et al., 2002). Tapsell et al. (2002) tried to create an equation that calculated the non monetary affects that flooding has on people. Such factors as preexisting health, living situation, family structure, and amount of money individuals had, were looked at as part of the equation. More effort needs to be made to look at the social and non physical effect of flooding, so that flood management practices can focus more on the effects to people when mitigation actions are taken, rather than looking at just the monetary cost of property damage (Tapsell et al., 2002)

5)

Flood management practices in the UK were looked at and the flaws of the various efforts made to educate the public about the risks of flooding were discussed (Brown and Damery, 2002). There is an imbalance between technical flood management practices, and the social dimension of flood management (Brown and Damery, 2002). Under technical flood management practices the majority of flood management effort is put into the technical end of the problem, focusing effort on the creation of maps and models that show flood prone areas. The problem with this view is that while the knowledge may be understood from a professional standpoint, the assumption that the population in general will seek out and understand the information is often overlooked (Brown and Damery, 2002). Maps of flood prone areas are misunderstood by the public who will assume that since they are not in the flood prone areas, they are safe from flood events. The inability of the maps to accurately predict where flooding will occur is not taken into account by residents, who are often surprised and unprepared when flooding does occur in their area. The problem of the social dimension of flood management is that it often focuses too much on the human aspect of the flooding problem, and often isn’t put into practice. The social dimension of flooding focuses on educating the public about potential flood problem. The problem with the social dimension of flooding is that it assumes that the public has the same understanding of flooding problems as authorities, and that the public will go out of its way to learn about flooding problems. Management practices have to be altered to further balance the technical understanding of flooding with the social aspect of flooding (Brown and Damery, 2002). Flood data has to become more accurate in the way it is presented to the public, and a greater effort has to be made in order to educate the public about the risks of flooding and measures that can be take (Brown and Damery, 2002).

6)

An evaluation of flood risk estimations, and the factors used to determine areas that are prone to flooding was conducted (Reeds, 2002). The purpose of this study was to determine what factors exist to draw data from in order to make more accurate predictions of flood prone areas. Many flooding models have inherent flaws due to a lack of sufficient data (Reeds, 2002). More accurate predictions of flooding in an area could be made if more data for the specific site was available, but in many cases no such data exists. History of flooding events usually don’t go back far enough to serve as a useful source for predicting flood occurrence, and often rainfall data and stream flow gauging stations don’t exist within areas so it is difficult to determine the causes of floods, and when they will occur again. Some authorities suggest that data can be acquired from similar catchments when no data is available in an area, but similar soil type, topography, and climate are required in order to get accurate results. While many factors exist that effect the rate and severity of flooding, most models still do not take into account all data that is available, and are unable to accurately predict the occurrence and severity of floods. Many models right now depend on recorded data, scientific methods, and professional judgment in the flood mapping process (Reeds, 2002).

7)

Booth et al. (2004) looked at the affects of human alteration on stream health in the Puget Sound area of Washington State. Their evaluation was designed to try and determine the mindset of local residents towards stream health, as well as determine what affect they had had on local stream conditions in an effort to try and determine where efforts should be made to try and restore stream conditions. While effort should be made to restore stream conditions, due to limited resources and continued influences of alterations trying to repair some stream sections would be a futile effort (Booth et al., 2004). Efforts should be made to protect and restore streams that have been minimally affected by land alteration (Booth et al., 2004). Additional efforts can be put towards restoring stream conditions in areas where degradation was more severe, but the benefit gained from such practices as well as the budget available should be taken into consideration (Booth et al., 2004). Due to lack of funding, efforts should be made to first protect areas where degradation is the lowest, before efforts are made to restore more altered locations (Booth et al., 2004). When efforts are made to restore areas, research should be conducted beforehand to determine the cause of the degradation. Due to budget constraints of rehabilitation efforts, Practices like fish rearing that try to restore populations in degraded systems should be limited (Booth et al., 2004). Efforts instead should focus on determining the cause of altered stream conditions, and restoring those conditions wherever possible (Booth et al., 2004)

8)

Walsh et al. (2005) looked at the affects of urban land alteration on stream habitat and function. The urban stream syndrome refers to negative changes to stream environments that are associated with urban development. Increases in impervious surfaces and drainage systems of urban areas alter natural stream flow conditions, often changing the rate, duration, and height of stream flow. Altered flow rates along with contaminants carried by waters draining urban areas alter species populations of streams draining the areas. More sensitive species such as macroinvertebrate populations decrease, and other more tolerant species sometimes increase and take their place. The problem with efforts to manage or restore degraded streams is complicated, because while it may look like one factor is contributing to the degradation of the stream, often multiple factors are working together to cause alterations (Walsh et al., 2005). Actions taken to fix one problem, and which don't address the other problems, will often result in no improvement to the stream. In order to improve the stream systems, efforts should be made to identify the source of the problem, then help bring understanding to residents as to the importance of the stream environment for reasons other than just managing flood drainage (Walsh et al., 2005). Ways to manage for water transportation, as well as creating healthy functioning stream systems needs to be the goal of management practices (Walsh et al., 2005).

9)

Groffman et al. (2003) conducted a review of studies concerning the effect of urbanization on riparian ecosystems. Increases in urban development create changes in riparian environments by altering the rate of water transference through an ecosystem (Groffman et al., 2003) . Various studies were looked at, including ones based out of Georgia and Maryland that show that increases in urban development results in increased runoff rates, which alter natural flow patterns. By altering or bypassing natural runoff pathways, infiltration rates are decreased, which results in lower groundwater tables and altered chemical processes. Reduced groundwater tables result in less water available for plant use, resulting in alteration of vegetation communities and the organisms that rely on them. Efforts should be made to encourage people to appreciate the vegetation of river ecosystems, in the hope that by encouraging appreciation for river communities, residents might reduce impacts caused by urban environments (Groffman et al., 2003). There are many ways to undertake management of riverine ecosystems, but understanding the human element and making people understand their affects on the riverine ecosystems is an important step in fixing ecosystem degradation (Groffman et al., 2003).

10)

Sims and Baumann (1987) looked at increasing public awareness of flood damage and damage prevention measures in four towns in Virginia. The focus of the study was to try and increase flood awareness and reduce flood damage in flood prone cities by increasing resident awareness of the problem and the efforts that can be taken to reduce damages to property. Four different levels of effort were used in educating town residents about flooding. These efforts ranged from no measure taken to inform the public, to brochures, and brochures with the addition of radio, television, and public service announcements. Additional factors such as age, gender, education and incomes were also recorded to see if they played a part in mitigation efforts. Results showed that the three towns that were sent brochures about flood mitigation effects had a greater increase in public awareness than the town that received no information. Against their predictions, the town with the highest level of effort had the lowest levels of improvement among the three brochure towns (Sims and Baumann, 1987). After evaluating the other factors involved in the study it was determined that this reduced response may be due to lower levels of income than the other two towns (Sims and Baumann, 1987). Level and cost of effort does not necessarily produce better results (Sims and Baumann, 1987). Positive results were received in all three cases. Cost of efforts might not produce a greater gain, so cost of the effort should be balanced with the expected increase in response. It is important to make sure that information sources are easy to understand, and that they come from a reliable source if you want people to trust the information they are given (Sims and Baumann, 1987).

## 4) Surface and Groundwater Interaction

1)

Vervier et al. (1992) conducted a study on how surface water groundwater interactions are controlled by ecotone permeability. Groundwater surface water interactions are controlled by three types of filters. The biochemical filter is made up of biological organisms that create chemical reactions that influence groundwater stream flow interactions, such as breaking down organic material. The second filter is the photic filter, which refers to physical differences in groundwater and streambed processes due to the amount of light that is present in the interface. The amount of light affects what organisms can live in the area, and also creates different chemical reactions. The final filter that affects surface-groundwater flow is the mechanical filter, which refers to particle size. Water and nutrient flow between groundwater and surface water is largely affected by soil texture. Finer texture soil such as sand and clay create smaller pores for water to travel through, which slows down groundwater flow. Larger particles such as gravel have larger pores, which allow water to travel much faster. Knowing how groundwater and surface water are moving in an ecosystem are very important to understanding how water flows in the system, and as part of coming to an understanding of the effect of system particle size as mechanical filters greatly effect that flow potential (Vervier et al., 1992).

2)

The relationship between groundwater and surface water flow was looked at to determine how these interactions affect animal and plant life in surrounding areas (Hayashi and Rosenberry, 2002). Groundwater provides baseflow to water bodies, which largely determines stream height and temperatures, especially during periods where there is no flow caused by precipitation or snow melt. Groundwater is frequently affected by land use cover. Removal of trees and other vegetation often results in higher rates of runoff, and less groundwater recharge. Similarly groundwater levels effect the types of plants that can grow in an area. The higher the groundwater table, the less moisture intolerant species you find in the area. Groundwater-vegetation interactions have an effect on streams by controlling the amount of runoff, as well as sediment that enters the stream system. Nutrient levels are partially controlled by ground water as varying levels of nutrients enter into the stream system with groundwater flow. Finally animal composition is affected by stream flow groundwater interactions. Groundwater flows often alter stream temperatures, making areas less or more suitable for fish species. Overall Hayashi and Rosenberry (2002) drew attention to the close relationship between ground and surface water in order to show that the two elements are closely related, and often determine or are determined by the characteristics of surrounding areas.

3)

The relationship between surface water and groundwater alteration was analyzed, to determine how alteration affects vegetation of riparian systems in the South Western United States (Webb and Leake, 2006). Existing data for riparian areas showing changes in vegetation levels over time were analyzed. These changes in vegetation level were related to land use practices to determine the affect of ground water use and surface water damming and diversion on vegetation levels. Webb and Leake had mixed results for their study. In some areas where ground water removal and surface flow alteration occurred vegetation levels were reduced due to decreased water availability. In other locations alteration of natural water regime by drainage and diversion had no affect on vegetation levels. Vegetation either increased or remained the same. In areas where vegetation increased, some of the vegetation was non-native species, but in other areas native species still flourished. Increases in native vegetation despite ground water withdraw may have been due to four factors, winter flooding, increased levels of precipitation, longer growing seasons, and increased levels of carbon dioxide in the atmosphere (Webb and Leake, 2006). If changes aren't made, vegetation levels may decrease in the future (Webb and Leake, 2006). Future management practices should look towards reducing groundwater level lowering, and simulated floods should be allowed in regulated areas to promote the growth of native species (Webb and Leake, 2006).

4)

Luc Lambs (2004) looked at the relationship between groundwater and surface water at the joining of two rivers. Two study sites were set up, one located in France and one in India. Groundwater and stream channel measurements were recorded by looking at stream characteristics including temperature, vegetation, and groundwater level change. Based on the results of the study, Lambs (2004) determined that groundwater surface water mixing had an effect on the type of local vegetation present. Based on the vegetation present at a particular site groundwater influence as well as flow history can be determined based on type of species present, as well as its moisture tolerance level (Lambs, 2004). Groundwater doesn't enter into streams throughout the entire channel, but periodically emerges in various locations and alters the chemical and physical characteristics of the stream where it does (Lambs, 2004). Areas where two rivers meet are more complex then they appear, because not only do you have two rivers meeting with different properties, but you also have the influence of a third river, the groundwater river, that plays a part in the stream makeup (Lambs, 2004). By studying these relationships, Lambs hoped to further understand the interactions of groundwater and surface water flow, and the influence it has on local vegetation.

5)

Marios Sophocleous (2002) summarized current knowledge of groundwater surface water interactions and the various factors that influence them. Groundwater surface water interactions can be grouped into two basic categories, natural influences and human caused influences. Natural influences on groundwater surface water interactions include such factors as climate, topography, soil type, and vegetation. A river or stream location is a watershed influences the rate of flow as well as the number of sources contributing to that flow. A natural balance exists between surface and groundwater where surface flow contributes greatly to the immediate flow after a storm, while groundwater flow helps maintain stream flow by being a constant source of flow. Flow isn't a one way direction from groundwater to the stream. Often water is exchanged from one source to another depending on which source has the lower level at the time. When stream flow is high after storms groundwater is often recharged, while if stream flow is low due to dry periods, groundwater often recharges stream flow (Sophocleous, 2002). The second influence on groundwater surface water interactions are human induced alterations. These alterations come in the form of alterations in stream or groundwater heights either due to water removal from groundwater wells for irrigation, or additions to the stream due to sewer discharge. These human changes cause alterations in the groundwater stream water balance, which alter natural flow patterns. In order for groundwater surface water flow to be better understood, multiple dimensions of science need to be combined to get a more accurate picture of what is occurring in stream systems (Sophocleous, 2002).

6)

Dunne and Black (1970) looked at storm water flow in relationship to subsurface versus surface flow in northern Vermont. The goal of the study was to try and determine the flow of water in a small watershed due to inaccurate results reflected by precipitation models. Subsurface flow played a very small part in storm hydrographs for their study area. Both naturally occurring and simulated storms yielded large amounts of overland flow or direct rainfall into streams, with little contribution by subsurface flow. Subsurface flow didn't really play a role in storm flow until much later in the storm when it reemerged as overland flow, and at that point it didn't have much effect on the hydrograph (Dunne and Black, 1970). Low subsurface flow levels were contributed to high water tables which created saturated conditions, so instead of most of the precipitation being absorbed it just ran off as surface flow. Results of the study were compared to the results of a similar study done in Vermont and it was found that subsurface flows contributed largely to the hydrograph of that study, which was located on highly permeable soils. Methods of modeling runoff based on infiltration theory are not always accurate, as the variation in results between their study and other studies in the Vermont area show (Dunne and Black, 1970). Other newer models may create more accurate results because they take into account other factors concerning the study area (Dunne and Black, 1970).

7)

Urbano et al. (2006) looked at subsurface flow modeling using SECOFLOW_3D. The goal was to get a better understanding of groundwater subsurface flows in unconfined areas by using this model. The advantage of the SECOFLOW_3D model is that it allows the water to find its own outlet to surface flow, rather than having a predefined outlet point (Urbano et al., 2006). Problems that exist with the model is that it requires more calculations and tends to be less stable then models that base their calculations on a fixed grid. Simulations altering features of the model to produce different results. Results were then compared to flow data from the Loosahatchie River in Tennessee. Results showed variations between modeled results using SECOFLOW_3D, and actual stream discharge measurements. Urbano et al. accounted these variations as due to possible groundwater discharge sources upstream of the measured areas that were not accounted for or that sources of water removal such as draining or pumping may have altered measurements (Urbano et al., 2006). In order to better understand ground water surface water interactions in transition zones, further research and model alteration needs to be conducted (Urbano et al., 2006).

8)

Guggenmos et al.(2011) tried to determine locations where interactions between groundwater and surface water were occurring in Wairarapa Valley, New Zealand. Determining areas where surface water and groundwater are interacting in a watershed will help with management of water resources, by determining areas where pollution may be entering or flowing through a system (Guggenmos et al., 2011). Knowledge of pollution transportation paths is important for the Wairarapa Valley due to intensified agricultural practices which have resulted in reduced water quality. Locations of groundwater-surface water interaction were determined by using hydrochemistry, and the multivariate statistical method to analyze existing data for the watershed and group data based on similar chemicals found in water samples. Guggenmos et al. (2011) made the assumption that if surface water-groundwater sources shared a similar chemical makeup, then those sources were assumed to be linked by surface water-groundwater flow. This assumption may not be correct, due to potential similarities in site conditions which result in grouping between unconnected sites (Guggenmos et al., 2011). Due to this assumption they suggest that other factors should be considered as well in order to support results of using hydrochemistry and multivariate statistics (Guggenmos et al., 2011). These methods can provide an inexpensive approach to determine relationships between groundwater and surface water by using only water quality data (Guggenmos et al., 2011).

9)

Devito, Hill, and Roulet (1996) looked at the differences that morphology and geology have on water hydrology in two swamps located in the Canadian Shield. The study looked at groundwater level change, stream discharge, and precipitation inputs from 1990 to 1992 in two conifer swamps. Results of the study showed similar hydrology during the wetter periods of the year, but during the dryer summer months, both swamps had varying hydrology patterns due to till depth. Of the two sites, the site with the deeper till maintained its connection to upland wetland flow, while the site with the shallower till got cut off from the upstream connection. Low levels of groundwater flow due to shallow bedrock caused the shallow tilled site to develop sporadic responses to rainfall due to lack of connection with upland flow. The deeper tilled swamp remained more stable, due to it maintaining a connection to groundwater flow with upland areas. This study is important when considering wetland hydrology, because even though both swamps are classified the same, the classification fails to take into account the variations that exist in the hydrology between the two sites (Devito, Hill, and Roulet, 1996). Differences in hydrology could become a problem if management practices designed for one site are implemented in the other site that may respond in unpredicted ways due to differences in hydrology (Devito, Kill, and Roulet, 1996).

10)

Morrice et al. (1997) looked at the effects of soil type and stream characteristics on the nutrient transportation in a hydrologic system. Three study sites were set up in New Mexico. The first site, located in Aspen Creek possessed sandstone-siltstone soils which have fine grained particles and low conductivity rates. The second site was located in Rio Calaveras, and had medium grained volcanic tuff soils which possessed medium conductivity rates. The final site was located in Gallina Creek and possessed course grained granite/gneiss soils which possessed high conductivity rates. A series of wells and piezometers were set up to monitor rates of Bromide transportation in soils. Results showed direction and rate of Bromide transportation between groundwater and stream sampling locations. Soils with larger particle sizes had higher rates of Bromide transportation than soils with finer grained particles (Morrice et al., 1997). Tests of seasonal differences in hydrology flow rates also revealed higher Bromide transportation rates during seasons with higher hydrology inputs (Morrice et al., 1997). Direction of flow between stream and groundwater sources was able to be determined due to Bromide transportation through groundwater-stream systems. Nutrient transportation between surface and groundwater is important when analyzing the health and functioning of a stream system (Morrice et al., 1997).

# IV. Methods

## 1) Baseline Condition:

Figure 1 represents a simplified version of the processes that occur in the hydrologic cycle. In the cycle water enters the system in the form of precipitation. It can then take a variety of different paths which determine the rate it is transported through the system. When water first enters the system, it has three main paths that it can take. It can land on vegetation which slows its path to the ground and returns some of the water to the atmosphere by transpiration. It can land on the ground surface, which depending on level of saturation, vegetation cover or imperviousness can result in infiltration into the ground, or flow overland until unsaturated areas are reached and infiltration occurs, or it can flow overland until the stream channel is reached. Finally, it can land directly on the stream channel and immediately contribute to flow. Water that enters the ground through infiltration either gradually makes its way to the stream channel, often at a slower rate than overland flow, or reemerges at a down slope area to contribute to surface flow if bedrock or saturated conditions are reached. All these processes occur simultaneously, and are affected by a variety of different factors including soil, vegetation, and land use type, as well as level of compaction of soils.

## 2) Assess the Extent of the Area Contributing to Stream Velocity:

In order to determine the area of the watershed contributing to stream velocity, we used the United States Geological Surveys Massachusetts Stream Stats Website (2012). Stream monitoring stations were used for the outlet point of each drainage area calculation. The resulting maps of drainage area for each monitoring point were then entered into ArcGIS 9.3. ArcGIS 9.3 was then used to calculate the total drainage area contributing to each monitoring station’s stream velocity. Resulting watershed area was than analyzed to determine if it had any influence on flood occurrences.

## 3) Quantify the Relationship Between Surface Water and Groundwater:

### A) Scatter and Time Series Analyses:

For our project we looked at the various factors that influenced the stream velocity throughout the Meadowbrook Stream watershed and measured them where possible. Groundwater wells were installed to monitor the changes in groundwater level. Stream monitoring stations were set up to monitor depth change as well as velocity change over the course of our study period, and stream transects were walked to classify level of stream vegetation and woody debris that existed in the watershed so we could determine if they had any effect on flooding problems. Additional factors such as soil type, precipitation levels, and land use types were gathered from online databases. Field surveys involving the monitoring of stream level, stream velocity, and groundwater level change were started on April 19th 2009 and ran for a year until April 29th 2010.

Measurements were taken at each of the sites every two to three days except for during the winter, once stream monitoring sites froze over and it became impossible to monitor changes in flow and depth. Resulting data from the monitoring sites were analyzed to determine if a relationship existed between groundwater and surface water depth change, as well as to try and determine if either of these factors had an effect on flooding problems that were occurring in the Meadowbrook watershed. For comparison purposes a correlation analysis was run in order to determine if a relationship existed between the monitoring points (Table 1). This correlation analysis compared each of the stream monitoring sites, as well as the groundwater monitoring sites on a one to one basis in order to determine the strength of influence between each of the sites. Results closer to one indicated a strong relationship between the two variables, indicating that depth changed in a similar fashion, while results closer to zero indicated that no relationship existed between the two points. Results from the correlation analysis (Table 1) were compared to stream and well monitoring locations (Figure 2), to determine if results from the correlation equation showed an accurate representation of possible velocity influences in the Meadowbrook watershed, or if resulting high correlation values were due potentially to other factors, or just similar depth change rates. While results from the correlation analysis indicated that a strong relationship existed between the points, other factors such as distance between sites had to be taken into account so that a inaccurate relationship weren't assumed just because resulting data from monitoring sites had similar changes in stream depth.

In addition to conducting a correlation analysis of depth change data for groundwater and surface water monitoring sites, an analysis was conducted of resulting depth change, as well as velocity change data. Data was entered into Excel spreadsheets, and then scatter plots were created that compared monitoring sites based on zone locations (Figure 2). The resulting scatter plots were than analyzed to see what kind of trend could be determined that was not apparent by looking at correlation data by itself. For the purpose of our velocity comparisons, velocity data for stream monitoring point two (S2), as well as for stream monitoring point three (S3), were excluded from the analysis due to lack of measurable velocity over the course of the study period. After scatter plots were created comparing stream and groundwater depth change as well as stream velocity change over the course of our study period, time series graphs were created as well for the same point groupings. Time series graphs were used to compare changes in stream and groundwater depth over the course of the study period to determine if any trend existed that was apparent in resulting data.

### B) Indicators of Hydrologic Alteration:

In order to get an understanding of the flow pattern for the Meadowbrook Stream Watershed, we used the Nature Conservancy's Indicators of Hydrologic Alteration (IHA) modeling program. The IHA creates graphs of estimated flooding based on daily stream flow data. Flow measurements were taken at each of the stream monitoring stations (Figure 2) every two to three days. Flow measurements were conducted using the Global Water FP101 Flow Probe. The probe was slowly moved vertically through the water column for a period of forty seconds, in order to get the average velocity rate for each section of the stream. Velocity data was then combined with stream channel profiles that were created by extending a line parallel across the stream. Height measurements were taken every six inches from the line to the base of the stream, and then digital images were created using Google Sketchup Version 8 (Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7). Stream flow was then calculated by combining stream area measurements calculated using Google Sketchup Version 8 with stream velocity data. We then entered the data into the IHA program, and the IHA projected values for days with missing data based on flow trends. The IHA then took the resulting data and created flow graphs categorizing the stream flow into levels of strength. We then analyzed the resulting graphs to determine seasonality of flow and if any relationship existed between the five sites. After graphs were generated for each of the sites, stream monitoring site two (S2) and stream monitoring site three (S3) were removed from the analysis due to lack of measureable flow for the duration of the study period. The resulting analysis consisted of looking at each of the three remaining sites to determine periods of high and low flow, as well as flow trends.

### C) Simple and Multiple Regression Analyses:

In addition to creating time series and scatter plots to analyze stream depth change trends over the course of our study period, we also conducted two types of regression analysis for depth change data from stream monitoring sites, as well as groundwater monitoring sites. The two types of regression analysis used to analyze the data for the Meadowbrook watershed were a simple regression analysis as well as a multiple regression analysis. The simple regression analysis similar to the correlation analysis determines the strength of the relationship between two variables. The difference between the two analysis is that correlation analysis compares the strength of the relationship between the two variables with neither of the variables having a dominant role over the other variable, while with the regression analysis one variable is considered to be the dependent variable, and the other variable is considered to be the independent variable which is presumed to influence the dependent variable in some way.

Like the simple regression analysis, the multiple regression analysis also compares variables to determine the strength of the interaction between them, the difference between the analyses is that while the simple regression analysis consists of a comparison between one dependent and one independent variable, the multiple regression analysis consists of an analysis between one dependent variable, and multiple independent variables. With the multiple regression analysis, the independent variables were considered to interact with each other in some way, resulting in different slopes than those values calculated by using the simple regression analysis. In order to determine the level of influence of the independent variables for the simple as well as multiple regression analysis, stream and groundwater depth change values were entered into Excel spreadsheets and then a regression analysis was conducted for each of the equations. Resulting data was put into the $y = a + b*x$ format where, Y is the dependent variable (also located on the Y axis of the graph), a is the value of the intercept, b is the slope of the independent variable, and x is the independent variable (located on the X axis of the graph). The resulting equation for the multiple regression analysis was similar to the simple regression analysis, except that each additional independent variable accounted for by the equation was added to the equation with its' slope value.

Independent variables and dependent variables were determined by their location in the watershed (Figure 2). Sections of the watershed were divided into zones based on the location of groundwater and stream monitoring wells in relationship to each other, and then each monitoring point located the furthest downstream in each zone were considered to be the dependent variable, with all other variables being independent variables. Similar equations were set up for simple regression equations as well based on the same zones, except that multiple equations were created for each zone in order to compare each of the variables to each other and determine their influence on other points of each zone. Since stream monitoring point five (S5) was not located close enough to any of the other monitoring sites to be considered part of their zone, it was compared to the other stream monitoring sites to see if a relationship existed. Once regression equations were completed for each zone comparison, an analysis of the resulting slope values for each independent variable was analyzed for each equation. Independent variables with slopes closer to one or negative one were considered to have a strong influence on the dependent variable, while variables with slopes closer to zero were considered to have a weak influence on the dependent variable. In addition to considering the slope for each independent variable, graphs had to be analyzed as well to determine if the slopes generated by the regression analysis accurately reflected the data, or were skewed by the influence of other variables. Outlier points were removed from the graphs before the regression analysis was run in order to prevent resulting slope values from becoming skewed. Correlation values (Table 1) were also considered when analyzing the result of the regression analysis to determine if the points had a strong relationship, or if the resulting relationship represented by the data was showing an effect that was not a true cause/effect relationship.

### 4) Model Runoff at a Spatially Specific Scale:

In order to determine the effect of land use cover on surface water flow generation we used the Curve Number method to calculate runoff and infiltration rates for the Meadowbrook watershed. In order to calculate infiltration and runoff for the Meadowbrook watershed, we first had to determine the watershed boundary ( Figure 8). This was done by using the U.S. Geological Survey's StreamStats website (2012). Once we selected the outlet point of the stream that we were interested in delineating, the program delineated the watershed for us. We then loaded the watershed boundary into ArcGIS 9.3 in order to manipulate our maps of interest so we could calculate the Curve Number values for our study area. The two maps that we used in order to determine the Curve Number values for our study were the Commonwealth of Massachusetts's MassGIS-Land Use (2005) data layer, which was the most current map of land use for the area at the time of our study (2011). In addition to land use, we were also interested in soil drainage classification. MassGIS did not possess a map of soil drainage classification for the Meadowbrook study area. A digital copy of the soil drainage classification for the study area was obtained from the National Resource Conservation Service (Mott and Fuller 1967). We then georeferenced the digital copy of the map we received using MassGIS 9.3 in order to accurately reference it to the physical location of our watershed (Figure 9). The resulting map gave a rough estimation of the location of soil types in the area, with some distortion due to the inability of the maps to be rectified at the time of their creation. We then used ArcGIS 9.3 and clipped the Land Use layer as well as the Soil Drainage Classification layers in order to create polygons showing areas of land use type broken down by drainage type for the study area (Figure 10). Curve number values were than assigned to each polygon based on a combination of the land use type and soil drainage classification. Once Curve Number values were assigned to each polygon the storage factor for each polygon was calculated by using the equation:

$$St = (1000/CN) - 10$$

Where: St = Storage factor
CN = Curve Number

Once the storage factors were calculated, we than calculated the Runoff value for each polygon. Runoff values were calculated using the equation:

$$Q = ((P-0.2St)^2)/(P+0.8St)$$

Where: Q = Runoff (inches)
P = Yearly Rainfall Total (inches)
St = Storage Factor

No precipitation monitoring stations were available for the Meadowbrook watershed, so daily rainfall values were downloaded from the National Oceanic and Atmospheric Administration's website for precipitation monitoring station GHCND:USC00190120 located in Amherst, Ma. (2012). Daily precipitation data was then totaled in order to determine total precipitation for the year which was used to calculate runoff values. Finally, we calculated infiltration values for the watershed by subtracting the runoff values for the entire year from the yearly precipitation total. Resulting data was then used to create two maps for analysis purposes. The first map showed runoff values in monotone values (Figure 11), showing the range of runoff values that existed over the entire watershed. The second map of runoff values (Figure 12) showed runoff values classified into five categories. Runoff data was categorized into five separate ranges in order make comparison of runoff levels easier.

### 5) Site Specific Factors Influencing Flooding:

The final portion of our data analysis for the Meadowbrook stream watershed involved conducting a survey of local residents to determine if they were having basement flooding problems, and then looking at the results to determine if certain areas were more prone than other to flooding. Data collection from residents consisted of a survey that was distributed to just over 100 residents located mostly in the lower portion of the Meadowbrook watershed where flooding complaints originated. The surveys consisted of asking residents if they had basement flooding problems, if they had made any modifications to prevent or reduce basement flooding problems, as well as asking for any additional data that residents felt would be relevant to determining potential flooding sources. Results from those resident surveys were then entered into ArcGIS 9.3 to create a map layer indicating where each of those sites were located, and rating them on a scale of yes, no, and sometimes (Figure 13). Residents who experience flooding problems were classified in the yes category, resident who didn't experience flooding problems were classified in the no category, and residents who experience flooding that was classified as insignificant levels due to rarity of occurrence and minimal moisture level, or contributed flooding to broken pipes were grouped in the sometimes classification. Resulting flooding locations were first analyzed to determine if a particular area of the watershed was more prone to flooding than other regions of the watershed. Survey results were then compared to additional watershed layers including soil drainage classification, land use type, runoff values, as well as distance from the stream to determine if any of these factors could have been considered to play a part in flooding problems. In addition to data layers downloaded from the Commonwealth of Massachusetts MassGIS website (2011), additional data layers were created for analysis purposes from the results of field surveys. In addition to groundwater and stream depth change surveys, stream vegetation and woody debris levels were also recorded through the Meadowbrook watershed. Vegetation levels were rated on a scale of one to four, with one being little to no vegetation present (0-15%), two being vegetation present, but in very low levels (15-50%), three being vegetation present and mostly filled the stream channel (50-85%), and four being vegetation present that filled or mostly filled the stream channel (85-100%). Woody debris levels were also analyzed on the same scale. Upstream vegetation and woody debris levels in relationship to resident survey respondents were then analyzed to see if there was a common trend between flood prone and non flood prone houses.

# V. Results and Discussion

## 1) Baseline Condition:

The Meadowbrook stream watershed (Figure 8) was located in Sunderland, Massachusetts and drained an area approximately 728 acres in size. The northernmost portion of the drainage basin started at the base of Mt. Toby, and discharged into the Connecticut River at its southernmost end. Land use types for the watershed consist primarily of forested areas in the North-Eastern portion of the watershed, with the rest of the watershed consisting of a mixture of agricultural lands, a few small commercial areas, and the remainder consisting of a mixture of residential districts consisting of multi-family homes, residential lots between one quarter to one half acre in size, and lots larger than a half acre in size (Figure 14). Soil drainage classification (Figure 9) of the area consisted largely of well drained to excessively drained soils in the Northern portion of the watershed, with some poorly drained areas locations immediately surrounding the stream. Soil drainage classification became damper in the southernmost parts of the watershed, with a mixture of poorly drained, moderately well drained, and well drained soils the further south we went.

The Meadowbrook watershed was drained by one main stream channel (Figure 2), that started out as three first order streams. The right branch of the watershed was made up of two first order stream that meet up and become a second order stream before it meet up with the left branch of the watershed to form the main stem of the stream (Figure 2). Velocity rates for the watershed measured over the course of the monitoring period range from zero feet per second to 2.34 feet per second. Average velocity rates over the course of the year for each station are 0.47 feet per second for stream monitoring station S1, zero feet per second for stream monitoring station S2, 0.04 feet per second for stream monitoring station S3, 0.60 feet per second for stream monitoring station S4, and 1.75 feet per second for stream monitoring station S5.

In addition to other factors affecting flooding potential of the Meadowbrook watershed, the watershed was largely affected by the occurrence of an aquifer, which underlies a large portion of the southern end of the watershed (Figure: 15). The aquifer extends for a long range along the borders of the Connecticut River in areas both connected to the Meadowbrook watershed, as well as areas upstream and downstream as well. The portion of the aquifer that runs underneath the Meadowbrook watershed was classified as a medium yield aquifer, which is able to generate between 100 to 300 gallons per minute of water (Commonwealth of Massachusetts, 2011). In relationship to groundwater level change, the aquifer was affected much more by variations in the height of the Connecticut River, than it was by any sort of changes in stream depth or flow rates. Fluctuations in groundwater level change as a result of fluctuations in the aquifer level were determined to be the cause of basement flooding problems for the Meadowbrook watershed.

### 2) Assess the Extent of the Area Contributing to Stream Flow:

A comparison of drainage areas for each stream monitoring point versus average stream velocity rate indicated that there was no relationship between the size of the drainage area, and the velocity rate for each stream section. In order of drainage size stream monitoring point S1 had the smallest total drainage area of 310,700 meters$^2$ (Figure 16), followed by stream monitoring point S3 at 394,200 meters$^2$ (Figure 17), stream monitoring point S2 at 1,668,900 meters$^2$ (Figure 18), stream monitoring point S4 at 2,303,900 meters$^2$ (Figure 19), and finally stream monitoring point S5, which had the largest drainage area of the five points at 2,872,700 meters$^2$ (Figure 20). When compared to average velocity rates for the five stream monitoring points, stream monitoring point S2 has the lowest velocity rate of zero feet per second, followed by stream monitoring point S3 at 0.04 feet per second, stream monitoring point S1 at 0.47 feet per second, stream monitoring point S4 at 0.60 feet per second, and finally stream monitoring point S5 at 1.75 feet per second. Based on these results we can accurately say that drainage area did not contribute to stream velocity rate, because despite stream monitoring point S3 having a larger drainage area that overlapped with stream monitoring point S1, stream monitoring point S1 still had a higher velocity rate than stream monitoring point S3 (Table 2). The same can be said for a comparison of stream monitoring point S1 and stream monitoring point S2. While the drainage areas for these two points didn't overlap, stream monitoring point S2 had a larger drainage area than stream monitoring point S1, but stream monitoring point S1 had the higher average velocity rate. Based on these results, some other factor was influencing stream velocity rate, other than the size of the drainage area contributing to each point.

## 3) Quantify the Relationship Between Surface Water and Groundwater:

### A) Correlation Analysis:

Evaluation of correlation analysis results (Table 1), indicated that there was a strong relationship between groundwater monitoring point W1 and groundwater monitoring point W2 (Figure 2). In addition to strong correlation values between groundwater monitoring point W1 and groundwater monitoring point W2 there was also a strong correlation between these two points and stream monitoring point S5. When looking at the physical distance between stream monitoring point S5 and groundwater monitoring point W1 and groundwater monitoring point W2, it appears that the relationship displayed was due to a similar factor affecting all three sites that did not affect the other stream monitoring points. Fluctuations in stream monitoring point S5 that had high correlation values with the groundwater monitoring points were contributed to the location of stream monitoring point S5 just upstream of the outlet point to the Connecticut River.

The low lying location of stream monitoring point S5 in the watershed put it close to groundwater level, so fluctuations in stream level greatly resembled fluctuations in groundwater level.

Correlation values indicating the strength of the relationships between stream monitoring points showed a few strong relationships between some of the stream monitoring points, but those relationships were considered to be due to other factors that may have had a similar influence on stream monitoring data other than the separate sections of the stream having an influence on each other (Table 1). Some correlation results such as those between stream monitoring point S2 and stream monitoring point S3 showed a strong correlation between the two points. An analysis of correlation values for the stream monitoring points showed that those points with strong relationships were mostly located further away from each. Overall correlation analysis results showed the potential relationship between groundwater monitoring points to be much stronger than those between stream monitoring points. Based on these results, it was determined that the primary factor causing basement flooding in the watershed was groundwater level change, and that due to low correlation between stream monitoring points, alteration of one section of the stream would result in a low level of influence on other sections of the stream

### B) Scatter Plots:

Scatter plot graphs generated comparing stream depth change indicated that there were strong linear relationships for all stream monitoring points (Figures 21, 22, 23, 24, and 25). Out of the five stream monitoring points, stream monitoring point S2 and stream monitoring point S3 showed the strongest relationship (Figure 22). Similarity of stream depth change rates may have been due to the shorter distance between these two monitoring points versus the other stream monitoring points (Figure 2), or due to similar influences of the surrounding area, such as bank steepness or streamside land use. Scatter plot graphs were also generated comparing stream velocity rate change for stream monitoring point S1, stream monitoring point S4, and stream monitoring point S5 (Figure 26, 27, & 28). The resulting scatter plots showed a fairly weak relationship for all three velocity monitoring points. Of the three resulting scatter plots, stream monitoring point S1 had the strongest relationship with stream monitoring point S5. Results indicated that upstream flow rates had little influence on downstream flow rates. We came to this conclusion due to stream monitoring point S1 and stream monitoring point S5 having the strongest relationship with each other despite being located the furthest away from each other, as well as due to having such low velocity rates for stream monitoring point S2 and stream monitoring point S3 that we were unable to get readings for them during the monitoring period (Figure 2). Due to stream monitoring point S3 being located between stream monitoring point S1 and stream monitoring point S4, both of which had measurable velocities, it was determined that upstream velocity rate did not have an influence on downstream velocity.

The final scatter plot analysis was of groundwater monitoring point depth change. The scatter plot generated of groundwater monitoring point W1 versus groundwater monitoring point W2 indicated that there was a strong linear relationship between the two wells (Figure 29). When comparing the results of the scatter plots for groundwater level change versus stream level change, the relationship between groundwater monitoring point W1 and groundwater monitoring point W2 had a stronger relationship than all of the stream monitoring points, except for stream monitoring point S2 versus stream monitoring point S3, which also possessed and $R^2$ value of 0.87. When you compare the distance between stream monitoring point S2 and stream monitoring point S3, versus the distance between groundwater monitoring point W1 and groundwater monitoring point W2, the distance between groundwater monitoring points is larger than that between the stream monitoring points, indicating that the groundwater depth change may have had a stronger relationship than stream depth change (Figure 2).

### C) Indicators of Hydrologic Alteration (IHA):

Results from the Indicators of Hydrologic Alteration (IHA) analysis showed greatly different flow rate changes for stream monitoring point S1 (Figure 30), stream monitoring point S4 (Figure 31), and stream monitoring point S5 (Figure 32). Of the three stream monitoring points, stream monitoring point S1 had the most stable flow rate, with flow rates staying within the same range for periods of months on end for most of the year. Stream monitoring point S4 had the most erratic flow of the three stream monitoring points. Stream flow rates shifted erratically both within months, as well as throughout the year. Stream monitoring point S5 showed flow patterns that were similar to both stream monitoring point S1 and stream monitoring point S4. Stream monitoring point S5 showed more consistent flow rates than stream monitoring point S4, though flow rates were not as stable as those produced by stream monitoring point S1. Despite longer periods of consistent flow rates than stream monitoring point S4, stream monitoring point S5 also experienced periods of more rapid stream flow rate change than stream monitoring point S1.

In addition to changes in stream flow rate fluctuations over the course of the year, the rate of stream flow also varied between the three stream monitoring points (Figures 30, 31, and 32). Of the three stream monitoring points, stream monitoring point S1 possessed the smallest variation in stream flow rate, which ranged from 0 to 0.9 cf/sec. Stream monitoring point S4 had the largest variation in stream flow, as well as the highest flow rates, which ranged from 0 to 2.2 cf/sec., and stream monitoring point S5 fell in between stream monitoring point S1 and stream monitoring point S4 with flow rates that fell between 0 and 1.7 cf/sec. Variations in flow rates could have been caused by a variety of factors, including influence of groundwater level change, channel shape, or streamside land use just to name a few (Figures 3, 6, and 7).

### D) Time Series:

The time series graph for zone one (Figure 2) depth change of stream monitoring point S1 versus groundwater monitoring point W1 showed a similarity in line shape, though overall peak height and width was different for both points (Figure 33). The results of the time series showed that groundwater monitoring point W1 had a larger overall depth change than stream monitoring point S1, revealing that groundwater fluctuations were occurring at a greater scale than stream level fluctuations. The time series graph of zone two (Figure 2) comparing stream monitoring point S2, stream monitoring point S3, stream monitoring point S4, and groundwater monitoring point W2, showed similar results to that of the zone one time series (Figure 34). Overall groundwater level fluctuations recorded for groundwater monitoring point W2 were larger than stream depth fluctuations recorded for the three stream monitoring points. Stream depth comparisons for stream monitoring point S2, stream monitoring point S3, and stream monitoring point S4 showed the strongest similarity between stream monitoring point S2 and stream monitoring point S3. Stream monitoring point S4 has a similar overall shape as those of stream monitoring point S2 and stream monitoring point S3, but fluctuations in stream depth occurred at a faster rate, possibly due to outside influences, such as streamside land use, or bank steepness (Figures 4, 5, and 6).

In addition to the time series graphs generated for the points of zone one and zone two (Figure 2), a time series graphs was also created comparing the depth change of stream monitoring point S2 and stream monitoring point S3 in order to compare the depth change of the two channels before they met up to form the main stem of the stream (Figure 35). Results of the time series graph showed very similar depth change for the two stream monitoring points. Depth change for stream monitoring point S2 and stream monitoring point S3 were almost identical. There were some variations between the two points, stream monitoring point S2 occasionally had greater changes in depth than stream monitoring point S3, but this may have been due to the upstream influence of two stream channels on stream monitoring point S2, while stream monitoring point S3's depth change was only being affected by upstream drainage from one stream channel (Figure 2).

A time series graph was created comparing the depth change of all five stream monitoring points (Figure 36). The results of the time series graph showed that stream monitoring point S2 and stream monitoring point S3 had the most similar rate of depth change of the five points. Stream monitoring point S4 showed the fastest stream depth change, while stream monitoring point S5 showed the least overall change in stream depth, as well as having the most gradual rate of change of the five stream monitoring points. Overall depth change throughout the course of the study period were similar for most of the stream monitoring points, variations in rate of depth change for the stream monitoring points may have been due to a variety of influences, such as bank steepness, streamside land use, as well as groundwater level change.

A time series was created showing the depth change of stream monitoring point S5 versus groundwater monitoring point W1 and groundwater monitoring point W2 (Figure 37). The results of the time series indicated that groundwater level depth change was much larger than stream level depth change. A comparison of the time series of stream monitoring point S5 versus groundwater monitoring point W1 and groundwater monitoring point W2 (Figure 37) to that of the five stream monitoring points (Figure 36) revealed that depth change for stream monitoring point S5 more closely resembled the shape of the two groundwater monitoring points than it resembled the rate of change of the other four stream monitoring points, despite the groundwater monitoring points' depth change being larger than the stream level depth change. The similarity in shape between stream monitoring point S5 and groundwater monitoring point W1 and groundwater monitoring point W2 showed a larger effect of groundwater level influence on stream monitoring point S5 than that experienced by the other stream monitoring points, possibly due to its lower elevation, which placed in closer to groundwater level.

The final time series comparison of depth change was for groundwater monitoring point W1 versus groundwater monitoring point W2 (Figure 38). The results of this time series indicted that the overall depth change for the two steam monitoring points was very similar despite the difference in elevation of the two points as well as the total distance between them (Figure 2). When compared to the stream monitoring points, the only points that seem to have a depth change rate as close as that of the two groundwater monitoring points was that of stream monitoring point S2 and stream monitoring point S3 (Figure 35). When you take into account the distance of the two groundwater monitoring points, and the similarity of the depth change, the results show that the groundwater monitoring points had a strong relationship with each other. This indicated that groundwater level fluctuations were much more consistent throughout the watershed than stream level fluctuations.

In addition to time series of stream depth change, time series were also created showing the change in the velocity rate of stream monitoring point S1 (Figure 40), stream monitoring point S4 (Figure 41), and stream monitoring point S5 (Figure 42). The results of these time series indicated that stream velocity rates were very different for the three stream monitoring points. Stream monitoring point S4 had the fastest fluctuations as well as the most variations in stream velocity rates over the course of the year. Stream monitoring point S1 had the most constant overall change in velocity rate for the course of the study period, with changes in flow rate staying within a similar rate for longer periods than the other two monitoring points. Stream monitoring point S5 was similar to stream monitoring point S1 in that it possessed overall a more gradual velocity rate change over the course of the study period, but unlike the other two stream monitoring points, the velocity rate for stream monitoring point S5 changed at a slower rate than that of stream monitoring point S1 and stream monitoring point S4.

### E) Simple Regression Analyses:

A simple regression analysis was conducted to analyze the relationship between the monitoring points of zone one (Figure 2). The resulting equation for the simple regression analysis was $S1= -78.95 + 0.26*W1$. This equation showed that for a one inch increase in groundwater monitoring point W1, there was a 0.26 inch increase in stream monitoring point S1. The resulting relationship between stream monitoring point S1 and groundwater monitoring point W1 showed us that groundwater level was changing at a much higher rate than stream water level. Simple regression analyses were also conducted comparing the monitoring points located in zone two (Figure 2). These points consisted of stream monitoring point S2, stream monitoring point S3, stream monitoring point S4, as well as groundwater monitoring point W2. The results of these simple regression analyses showed that of the three monitoring points, stream monitoring point S2 had the strongest relationship with stream monitoring point S4 (Table 3). When looking at the correlation values of stream monitoring point S2, stream monitoring point S3, and groundwater monitoring point W2 when compared to stream monitoring point S4, correlation results show weak to medium strength relationships between the points (Table: 2). When you also take into account the low P-value scores for the three simple regression equations, the results of these simple regression equations become insignificant, indicating that any strong relationships that were indicated by the simple regression analyses were probably due to a similarity in data, rather than any relationship between the monitoring points (Table 3).

In addition to the simple regression analyses comparing the monitoring points of zone one and zone two (Figure 2) additional analyses was conducted comparing all of the stream monitoring points to stream monitoring point S5 (Table 3). Results from the simple regression analyses showed that of the four stream monitoring points, stream monitoring point S1 and stream monitoring point S4 both had the highest, as well as an equal level of influence on stream monitoring point S5. When you look at the correlation values between stream monitoring points S1, S2, S3, and S4 versus stream monitoring point S5, the resulting correlation values are fairly weak, except for those between stream monitoring point S2 and stream monitoring point S5 (Table 1). When the distance between these two points are taken into account, the strength of the relationship between stream monitoring point S2 and stream monitoring point S5 appears to be due to similarity in data, rather than a cause-effect relationship between the two points. Overall simple regression analyses results for stream monitoring points S1, S2, S3, and S4 versus stream monitoring point S5 are insignificant, showing no true relationship between the points, especially when P-values are taken into account (Table 3).

### F) Multiple Regression Analyses:

A multiple regression analysis was conducted looked at the relationship between the points of zone two (Figure 2). This analysis compared the influence of stream monitoring point S2, stream monitoring point S3, and groundwater monitoring point W2 on the depth change of stream monitoring point S4. The results of this equation indicated, that of the three monitoring points, the point with the largest level of influence compared to stream monitoring point S4, was stream monitoring point S2 (Table 4). Results showed that for every one inch increase in stream monitoring point S2 there was a 1.14 inch increase in stream monitoring point S4, which showed that the downstream point, S4's depth changed at a higher rate than stream monitoring point S2. The resulting multiple regression equation also showed that for a one inch increase in groundwater monitoring point W2, there was a .002 inch increase in stream monitoring point S4. These results indicated that there was a very low level of interaction between stream monitoring point S4 and groundwater levels in the area. Results of correlation analyses for the points of zone two showed a fairly strong relationship between stream monitoring point S2 and stream monitoring point S4, but the relationship between stream monitoring point S3 and groundwater monitoring point W2 versus stream monitoring point S4 showed medium to weak level results (Table 1). When you also take into account the P-value for stream monitoring point S2 versus stream monitoring point S4, indications that there was a strong relationship between any of the points in zone two appear to be due to similarity in data, rather than any true cause-effect relationship between the points.

The final multiple regression analysis that we conducted was between stream monitoring point S1, stream monitoring point S2, stream monitoring point S3, and stream monitoring point S4 versus stream monitoring point S5 (Figure 2). The results of this multiple regression analysis indicated that of the four upstream monitoring points, the point with the strongest interaction with stream monitoring point S5 was stream monitoring point S1 (Table 4). Results indicated that for a one inch increase in the upstream points, there was only a very small increase in stream monitoring point S5, anywhere from 0.04 to 0.39 inches. Correlation values also indicate medium to low level of interaction between stream monitoring point S5 and all of the other stream monitoring points, except for stream monitoring point S2, which had a fairly strong relationship (Table 1). The results of this multiple regression analysis indicated that there was a very low level of influence between stream monitoring point S5 and the other stream monitoring points, and that stronger relationships were probably due to similarity in data, rather than the influence of one point on the other.

### 4) Model Runoff at a Spatially Specific Scale:

A curve number analysis was conducted for the Meadowbrook watershed. Areas of the Meadowbrook watershed were assigned curve number values which ranged from thirty to ninety-five (Figure 42). The majority of the watershed fell into the forty-five to ninety-five range, with the lower half of the watershed falling mostly into the sixty-six to eighty-four range. Higher curve number values of eighty-six to ninety-five were mostly found around the stream channels. Survey locations had higher curve number values that fell into the sixty-six to ninety-five range, with most locations falling into the seventy-seven to eighty-four range. High curve numbers values resulting from the curve number analysis indicated that low levels of infiltration were occurring. Low infiltration rates were not considered large enough to be the cause of groundwater level rise that was the result of basement flooding.

Similar to the curve number map, the runoff maps generated showed high levels of runoff for most of the watershed (Figures 6 and 7). The majority of runoff values fell in the range of forty-three to fifty inches. Areas where lower runoff levels occurred were located in the upper north-east section of the watershed, and had values ranging from thirty-one to forty-one inches. Runoff values for areas located alongside the Meadowbrook stream largely fell into the forty-eight to fifty inch category, with a few locations falling into the forty-five to forty-seven inch category. All survey respondents both those with flooding problems, and those that didn’t have flooding problems fell almost evenly into either the forty-five to forty-seven inch category, or the forty-eight to fifty inch category. Flood prone homes as well as non flood prone homes fell almost evenly between both of these areas, resulting in no clear indication as to whether runoff levels were the cause of flooding in these areas, since homes that were located in similar runoff levels had mixed flooding results.

### 5) Site Specific Factors Influencing Flooding:

For our study we sent out over 100 surveys to resident of the Meadowbrook stream watershed, mostly in the downstream area where flood occurrences had already been reported at some of the homes. Of the greater than 100 surveys we sent out, only seventeen people responded to inform us if flooding was occurring in their homes. Of those seventeen respondents, nine said they experienced flooding, five said they did not have any flooding problems, and the remaining three respondents were put into the category of sometimes, because their flooding events either consisted of very infrequent periods of moisture in the corner of their basements, or occurred vary rarely and were thought to have been due to broken water pipes by the resident in question (Table 5). Survey results did not give any clear indication of specific areas where flooding was occurring (Figure 13). Areas where flooding was occurring were often located close to areas where no flood problems had been detected at the time, so no immediate physical area could be determined to be the source of flooding problems.

One of the first features that we looked at to determine the cause of flood prone areas was the map of land use type (Figure 43). Classifications of land use by themselves were not a good indication of the occurrence of a possible cause of the flooding problem. Land use type for all resident respondents were classified as different levels of residential districts, except for one location which was classified as intensive agricultural cropland by the land use map. Land use type for the different flood prone areas showed no clear indication that any of the levels of development were the cause of flooding problems. Areas with flooding problems, as well as areas without flooding problems occurred on multi-family lots, smaller lots that were between one quarter to one half acre in size, as well as on lot that were larger than a half an acre in size. For those homes that were flooding, five of them occurred on lots that were one quarter to a half acre in size, and four of them occurred on lots that were larger than a half acre. After looking at land use type for survey respondent locations, we looked at land use type of the areas located immediately upstream. Once again results were mixed. For five of the flood prone areas, upstream land use type was classified as residential plots between one quarter and a half acre in size, while the other four had a land use type of residential plots larger than a half acre in size. These results showed that many of the flood prone areas appeared to have been located in areas with smaller lot sizes. The problem we faced was that results for the houses that didn't experience flooding also show similar upstream land use types. Of the five respondents who said their homes did not experience flooding, three of them had upstream land uses of residential lots between one quarter and a half acre in size, one of them had land use classified as multi-family residential housing, and the final one had an upstream land use of intensive agriculture cropland. Based on these results, it appeared that land use type was not the cause of basement flooding problems since greater development in upstream areas did not result in higher levels of flooding in downstream areas.

In addition to looking at land use type, we also took into consideration the soil drainage classification of the survey area (Figure 44). An analysis of soil drainage classification yielded similar results to that of land use type. Soils drainage classification results for areas of survey respondents indicated that soils were classified as poorly drained, well drained, or moderately well drained. Of the soils that were classified as poorly drained three were locations that had flooding problems, three were locations that didn't have flooding problems, and a single location was classified as sometimes having flooding problems. With those sites that were located in the well drained areas, all three sites were listed as having flooding problems. Based on these results, soil drainage by itself can't be considered to be the factor that was causing flooding in the watershed because some of the areas with well drained soils had flooding problems, while some of the sites located on poorly drained soils did not experience flooding problems.

As the final portion of our resident survey response analysis, we compared resident survey responses to field evaluations of vegetation (Figure 45) and woody debris (Figure 46) levels in stream channels throughout the Meadowbrook watershed. The maps that resulted from the collected data on vegetation levels in upstream portions of the stream in relationship to survey respondents indicated that most of the homes had upstream vegetation levels that fell into the category of four, indicating that vegetation was present and filled eighty-five to one hundred percent of the stream channels. Out of all the survey respondents, there were only four homes that had a different category of upstream vegetation level, and those homes fell into the level two classification, with vegetation present in small amounts, occupying only fifteen to fifty percent of the stream channel. Of those homes that had high levels of upstream vegetation, three didn't experience any flooding problems, eight had flooding problems, and two sometimes experienced flooding problems. For the four sites that fell into the fifteen to fifty percent upstream vegetation levels, two did not experience flooding problems, one had experienced flooding problems, and one sometimes experienced flooding problems. Based on this data, a large number of homes had flooding problems that were located downstream of areas with higher stream vegetation levels, but it was still difficult to determine if these higher upstream vegetation levels were the cause of flooding problems in downstream homes. The problem still existed where there were still homes that had similar upstream vegetation levels, but different flooding results. While flooding levels may have been higher in areas where vegetation levels where higher than in areas where vegetation levels were lower, it was still difficult to determine if there was a pattern that exists due to the lack of residents who responded to flood surveys.

The second half of the field survey involved looking at woody debris levels in areas upstream of homes for residents who responded to the flooding survey (Figure 46). The results of the woody debris analysis showed similar results as that of the vegetation survey where homes that experienced flooding problems and home that didn't experience flooding problems both had similar upstream woody debris levels, but they also differ slightly in the range of values. Woody debris levels fell into a wider range of categories than vegetation survey results. One home had upstream woody debris levels that fell into the level four category of eighty-five to one hundred percent, twelve had woody debris levels of three that fell into the fifty to eighty-five percent category, four had woody debris levels of two that fell into the fifteen to fifty percent category, and no homes had upstream woody debris levels that fell in the level one category of zero to fifteen percent. Results from the woody debris survey showed that the upstream woody debris levels for residents who responded to the survey fell mostly in the level three category. Of these twelve respondents, six had flooding problems, three did not have any flooding problems, and the final three only sometimes experienced flooding problems. These results once again showed inconclusive data due to homes that experienced flooding problems having similar conditions to homes that didn't experience flooding problems. Looking at both vegetation levels and woody debris levels simultaneously didn't aid in the determination of flood causes as well, because those areas with high levels of vegetation and high levels of woody debris were not always the sites that were flooding.

# VI: Conclusion

The purpose of this research project was to conduct an analysis of the Meadowbrook stream watershed to try and determine if the proposed plan to remove vegetation and woody debris from the stream channel would result in reduced basement flooding problems of local area residents.  In addition to trying to determine if removing woody debris and aquatic vegetation from the stream channel would result in reduced flooding problems, we also conducted an analysis of other factors in the watershed that might have been the cause of the basement flooding problems. Based on the results of our study, we felt that groundwater level rise was the cause of basement flooding.

In order to determine if woody debris and aquatic vegetation levels were contribution to flooding problems, and if their removal would reduce those flooding problems, we conducted an analysis of the stream flow rate, stream depth change, groundwater depth change, and additional factors that we thought might have had an influence on flood occurrence. We then combined the results from these analyses with flooding locations reported by area residents. A review of the results of the analysis of the physical features in the Meadowbrook watershed showed that the land cover consisted primarily of agricultural fields and various levels of residential lots. Both these land uses can result in increased stream flow after precipitation events, as well as reduced groundwater storage due to the compaction of soils and reduced vegetation levels. While increased runoff rates may lead to greater stream flow, it also often resulted in larger quantities of water making its way to the stream in a shorter period of time, and can also sometimes lead to stream flooding. While the occurrence of stream flooding may cause some surface flooding problems, the reduction in groundwater storage due to the higher surface flows indicated that increased levels of impervious surfaces and reduced levels of vegetation were probably not the source of the problem associated with basement flooding. Instead, it seemed that the problem we were facing dealt more with groundwater levels than with surface flooding problems.

Our analysis of soil drainage classification in relationship to resident flood surveys indicated mixed results. The Meadowbrook watershed contained a range of different soil drainage classifications, many of which fell into categories of less well drained soil types. When looking at this data, it indicated that a large part of the watershed was classified as having some level of poorly drained soils. These naturally wet conditions were thought to have been part of the problem, possibly indicating areas of poor building conditions that were present before buildings were constructed. The problem with our survey results was that some of the areas that were classified as having poorly drained soils did not have flooding problems. Based on these results, we could not label soil drainage classification as being the cause of flooding problems. A similar statement can be made about runoff values. Runoff values calculated for the watershed indicated high levels of runoff for survey areas. Runoff values for most of the survey locations were between forty-five and fifty inches of rain over the course of the year. When compared to the total rainfall amount for the year of fifty-one inches, that meant that the majority of the rainfall was resulting in overland flow, rather than infiltration and groundwater flow or groundwater storage. Based on these results, the possibility of groundwater flooding caused by large levels of infiltration seemed unlikely.

After analyzing runoff results, we than tried to determine if the influence of stream drainage might have been the cause of groundwater level change that might have resulted in basement flooding. With this in mind, we conducted both a correlation analysis to determine the strength of the relationship between stream monitoring points and groundwater monitoring points, groundwater monitoring points and groundwater monitoring points, as well as stream monitoring points and stream monitoring points. The results of the correlation analysis indicated that a large portion of the points were considered to have a weak relationship. Based on the results of these correlation analyses, results of regression analysis could not be considered to have a strong relationship even if regression analysis indicated that a strong relationship existed between points. The results of the remaining correlation analysis that did indicate a strong relationship between points was not considered to represent a true relationship between points, due to the distance between points that resulted in a strong correlations. When you compared the results of the correlation analysis (Table 1) to the location of the monitoring points (Figure 2) those points that showed a strong relationship were often points that were located at greater distances from each other than points that had low correlation values. High correlation values between points that were distant from each other were largely considered to be the result of similarity in data rather than any real relationship between points.

Regression analyses, both simple as well as multiple, had largely the same results as the correlation analysis. While some results such as the high influence between stream monitoring point S1 and groundwater monitoring point W1 seemed to indicated that there was a strong influence of upstream groundwater monitoring points on stream levels flow (Table 3), other analyses such as the results of the simple regression analysis (Table 3) that indicated equal levels of influence on stream monitoring point S5 by both stream monitoring point S1 and stream monitoring point S4 showed that not all relationships reflected by the regression analysis seemed to reflect plausible situations. These results, when combined with low and possibly misleading correlation results indicated that for the most part stream monitoring points were not interacting with stream monitoring points, groundwater monitoring points were not interacting with groundwater monitoring points, and stream monitoring points were not interacting with groundwater monitoring points. Based on these results removing woody debris and aquatic vegetation from the stream channels would not have any great affect on reducing groundwater levels, or indicate that possible higher runoff levels affecting stream flow would result in groundwater level change.

Looking at the general shape of stream depth change and groundwater depth change trend lines indicted a general similarity to most depth change results. Stream and groundwater levels seemed to change at relatively the same rate, but overall depth change varied between sites. The overall comparison of stream depth change versus groundwater level change indicated that groundwater level depth changed much more than stream level depth changed. This difference in depth change indicated that some factor seemed to have had a greater influence on groundwater level change than it did on stream level change. Based on this occurrence, we proposed that groundwater level rise was the cause of basement flooding in the Meadowbrook watershed, and have attributed groundwater level rise to fluctuations in the aquifer underlying the Meadowbrook area.

Comparing all the factors on the assumption that groundwater level rise was the cause of flooding problems in the watershed resulted in no prime factor that was contributing to the problem. Based on correlation analyses and regression analyses, stream velocity rate or stream depth change were not contributing to groundwater level rise, due to low correlation results between stream monitoring points and groundwater monitoring points. Runoff rate as well could not be classified as the cause of groundwater level rise, due to high levels of runoff rates resulting in low infiltration rates. Land use and drainage classification were not much help either, due to the occurrence of homes with flooding problems as well as homes without flooding problems in areas with similar drainage classifications as well as similar land use type. A poor drainage classification for a large part of the study area may point to the actual cause of flooding problems. When all these factors are taken into account, it was largely assumed on our part that basement flooding problems were the result of fluctuations in groundwater level as the result of fluctuations in the aquifer located in the study area (Figure 15). Unfortunately we cannot state that this is the actual cause of the flooding problems due to lack of knowledge about the level of fluctuation in aquifer height due to fluctuations in the Connecticut River, as well as due to variations in aquifer height due to variations in bedrock depth as well as soil type.

## Policy Recommendations

Based on the results of the Meadowbrook stream analysis, and the low influence of stream level on groundwater level change, the proposed plan to remove woody debris and aquatic vegetation for the purpose of increasing stream flow and reducing basement flooding problems will probably not have the desired effect. Stream flow is affected by a variety of factors. The removal of woody debris from the left or the right branch of the Meadowbrook stream may possibly increase flow rate in those sections of the stream, but faster stream flows and no aquatic vegetation or woody debris could also result in increased erosion rate and decreased stability of stream banks, altered organism habitats, as well as potentially increased stream flooding downstream until a balance is achieved. We also have to face the possibility that clearing woody debris and vegetation from the left and right channels of the Meadowbrook stream might not result in any large changes in velocity rate due to the lack of measurable flow that was occurring at the time of our survey, as well as the low level of elevation change between the beginning of the Meadowbrook stream and the main stem of the channel. This possibility is supported by the lack of influence of the size of drainage areas on stream flow. Clearing woody debris and aquatic vegetation from the main stem of the Meadowbrook stream especially in areas alongside locations of flood prone houses may increase transportation of water through these sections into further downstream areas, but the potential of groundwater level rise as being the cause of basement flooding, and the low level of interaction between stream and groundwater level change means that even if stream flow is increased and more water is transported out of the watershed, flooding problems probably wouldn’t be reduced. Based on these reasons, we feel that both the time and the effort spent to perform these clearing actions would not result in the desired results the Conservation Commission was hoping to achieve.

Since our results indicate that stream clearing actions might not have the desired affect that the Conservation Commission is trying to achieve, other steps are necessary to try and achieve a solution to the basement flooding problems. It is our suggestion, that if the Conservation Commission wishes to continue trying to determine the cause of the flooding problems in the Meadowbrook watershed that additional research needs to be conducted. Basic data sources needed to evaluate the influence of various features of the hydrologic cycle were either not readily available for interpretation, or existing data was not up to date. It is our suggestion, that if the Conservation Commission intends to pursue this project at a more detailed level, that additional basic site characteristics need to be collected that were not available at the time of our study. Precipitation monitoring data was not available for our study area due to no precipitation monitoring stations being located in the town of Sunderland. Precipitation data had to be collected from an Amherst monitoring site as the closest available data source. While Sunderland and Amherst are fairly close together, physical features of the watershed could result in some differences between Sunderland and Amherst precipitation rates. Soil drainage maps were not readily available as well. A copy of soil drainage classifications for the town of Sunderland had to be digitized and then georeferenced because no electronic version of this data existed for analysis at the time of our study. The existing soil drainage classification map was old as well, dating from 1967. In addition, know errors were present, due to the inability of the map to be rectified at the time of its creation, leading to the stretching of soil drainage classifications, and possible the incorrect assignment of soil drainage classifications to watershed areas. In addition to looking at physical characteristics of the hydrologic cycle, a greater evaluation of possible human causes of flooding could also be looked into as well, such as age and location of water pipes, that might possible be leaking and contributing to basement flooding problems.

In addition to physical data that needs to be collected and updated, a more extensive knowledge of sites where flooding was actually occurring would be necessary in order to more accurately interpret the cause of the flooding problems. Of the just over 100 surveys that we sent out, only seventeen people responded. Based on these results it was difficult to determine the actual areas where flood problems were occurring, but also difficult to compare flooding locations to collected data, because the sampling size was so small as to make most results unreliable. If a greater resident response could be achieved, then interpretation of data might lead to more conclusive answers. Until these measures are taken, finding a cure for those people who are suffering from basement flooding problems will be difficult. At this point, the best solution may be to work on advising people who are planning new construction projects to take high groundwater levels into account. New basements can be constructed at shallower depths, hopefully raising them above the groundwater level rather than at traditional depths where they would have a higher change of having flooding problems.

Overall, if groundwater level rise due to the influence of the aquifer located under the Meadowbrook stream is the problem, then reducing basement flooding problems is going to be very difficult. Alteration of stream level or stream flow will have little influence on the scale of groundwater change, when aquifer levels are being controlled by changes in the Connecticut River. The only option in this case is for residents to come to the conclusion that no alternative exists that might reduce flooding in their homes. If the aquifer is in fact the cause of basement flooding due to groundwater level change, than one of the best options at this time would be to conduct a field evaluation to determine actual depth of the aquifer throughout the watershed.

The overall goal in this case of flood management should be getting the residents to understand the current flood risk potential of the area they are living in. Flood hazards can occur anywhere, but especially in low lying areas (Federal Emergency Management Agency, 2013). Residents of the Meadowbrook Watershed need to consider that they are both located in low lying areas connected to the Connecticut River floodplain, as well as living in an area that has dug drainage ditches in order to create areas both dry enough for agriculture as well as building. It was known at the time of the creation of the town that the area was wet, but efforts to create buildable conditions didn’t take into account other methods of flooding rather than just surface flooding. While a solution to the flooding problem may not be available for some residents, there are option that can be taken to reduce damages created by basement flooding. Furnaces, water heaters and electrical panels can be raised off of the ground to reduce chances of damage by flood waters, sump pumps can be installed to reduce water level rise, and basement walls can be sealed with waterproofing compounds (Federal Emergency Management Agency, 2013). While waterproofing compounds may not eliminate all flooding problems, they may reduce flooding in some instances.

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# VIII. Appendix

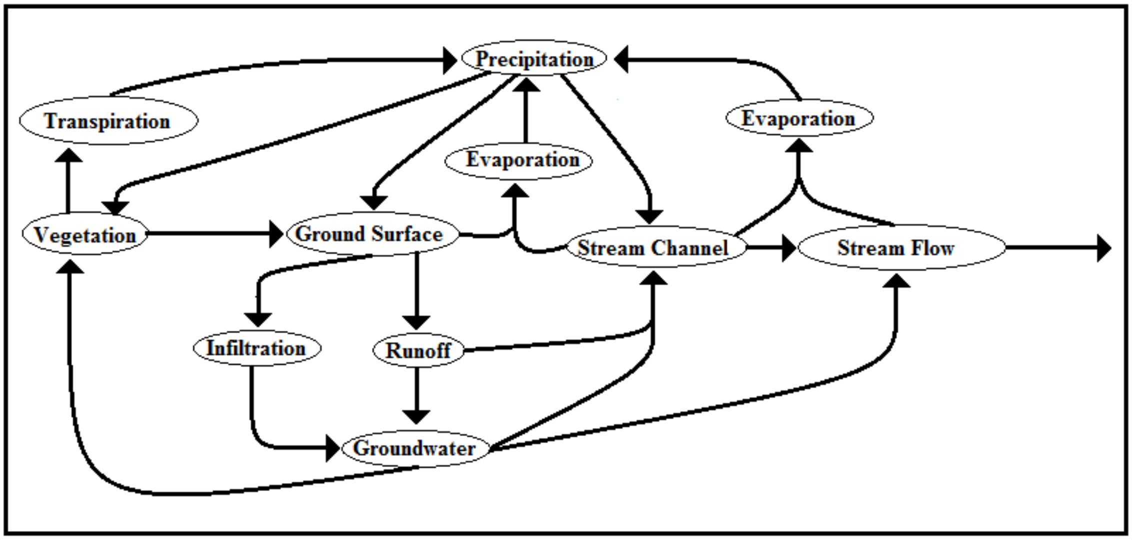


**Figure 1**: Watershed System

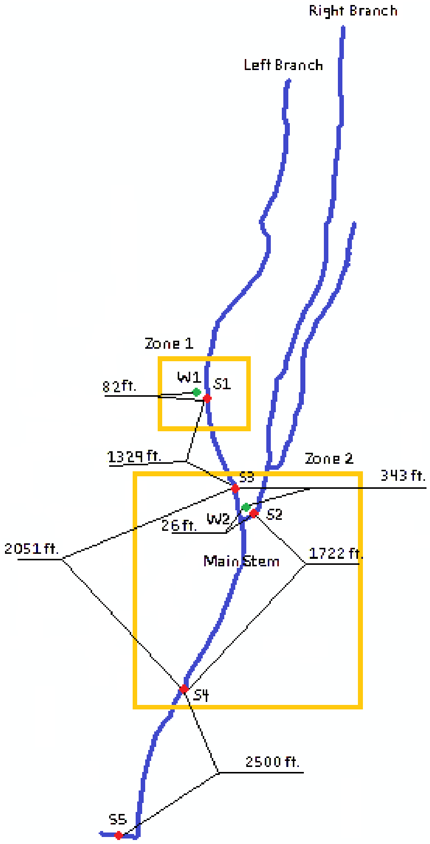


**Figure 2**: Approximate locations of stream and groundwater monitoring sites.

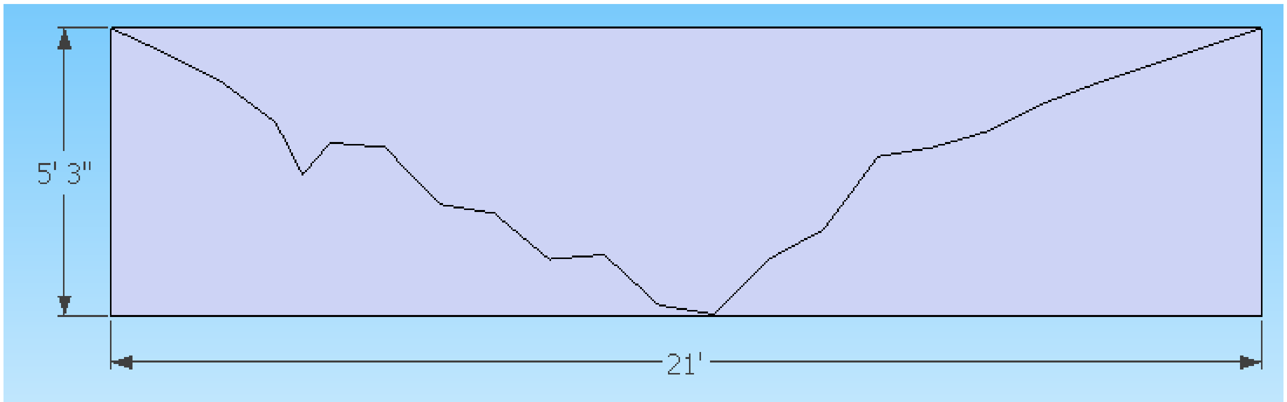


**Figure 3:** Stream monitoring point S1 stream profile.

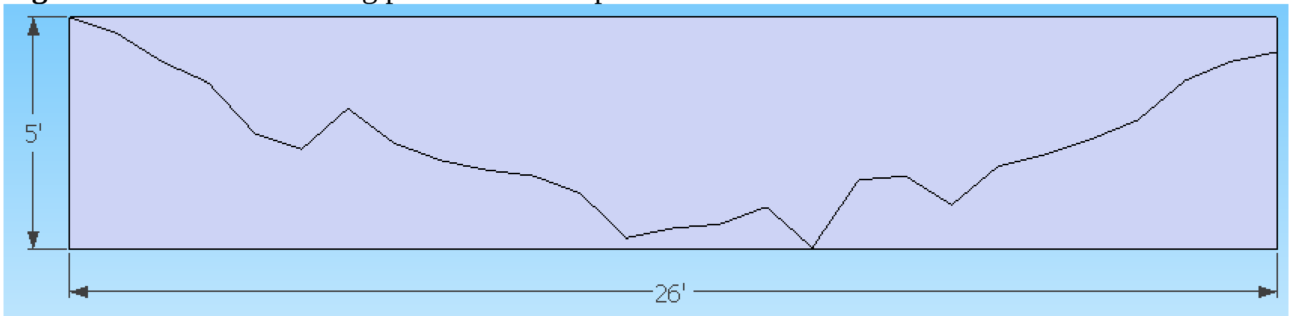


**Figure 4:** Stream monitoring point S2 stream profile.

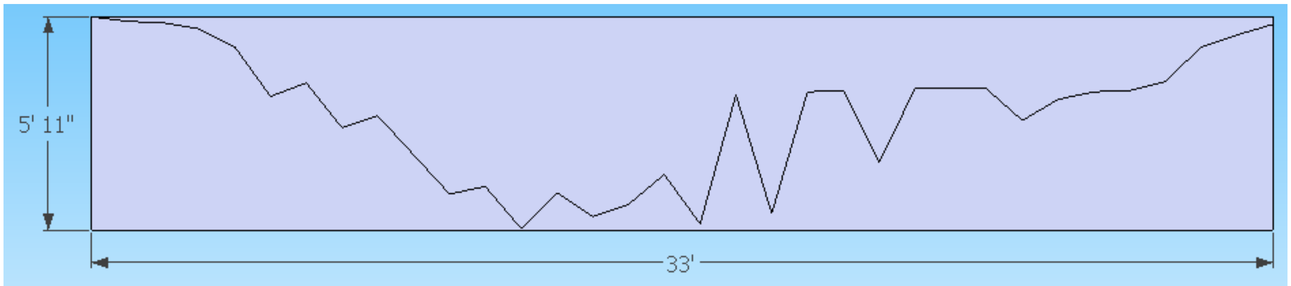


**Figure 5:** Stream monitoring point S3 stream profile.

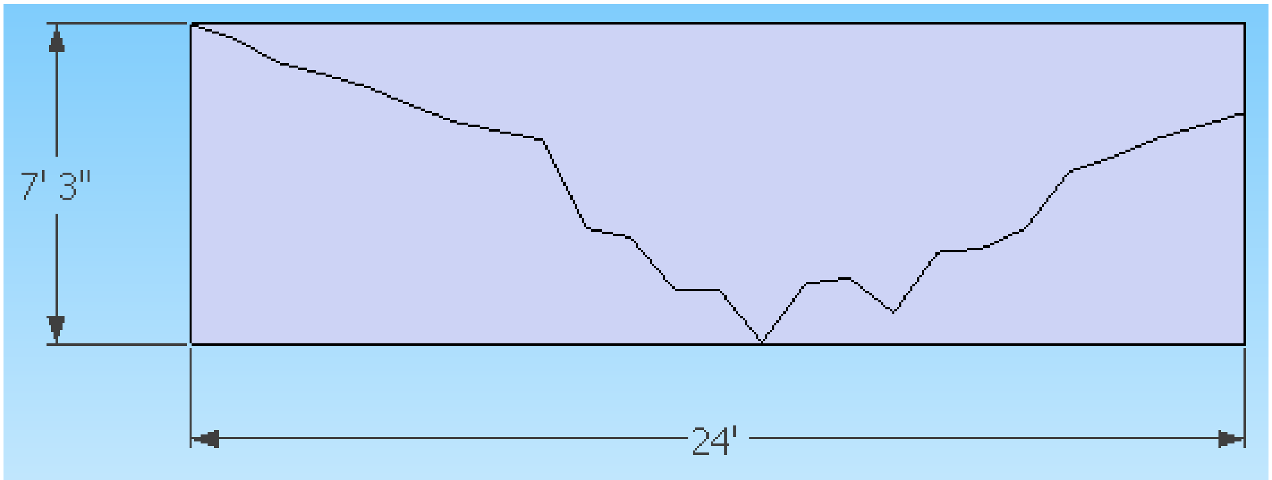


**Figure 6:** Stream monitoring point S4 stream profile.

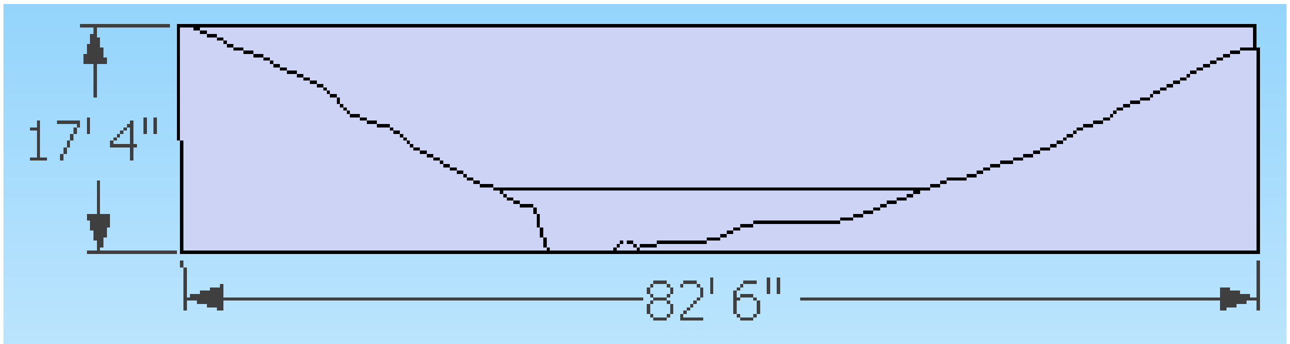


**Figure 7:** Stream monitoring point S5 stream profile.

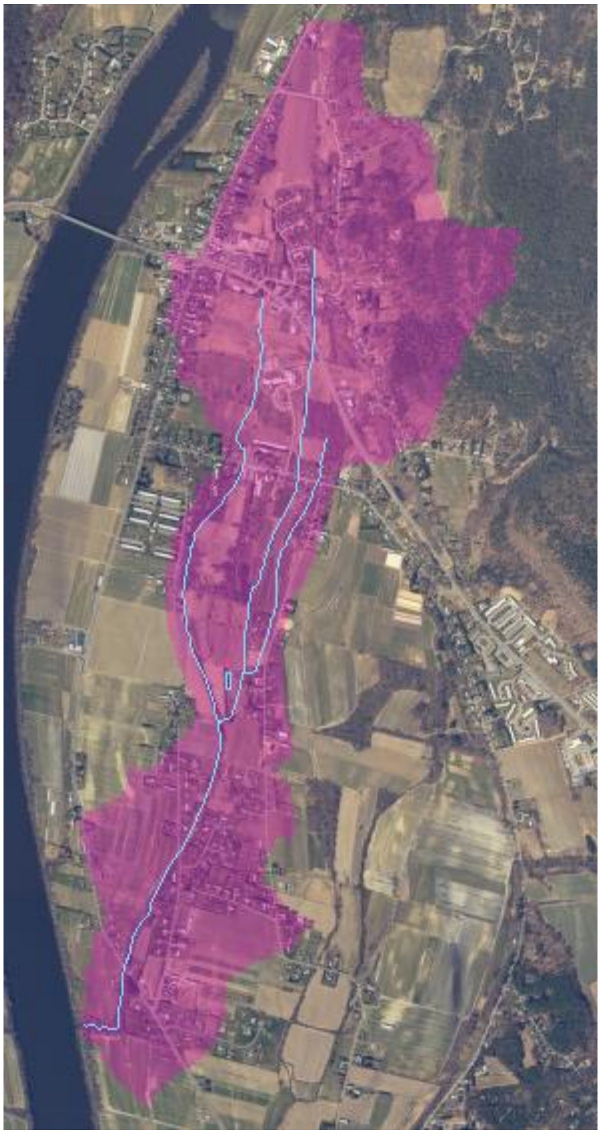


**Figure 8:** Meadowbrook Watershed

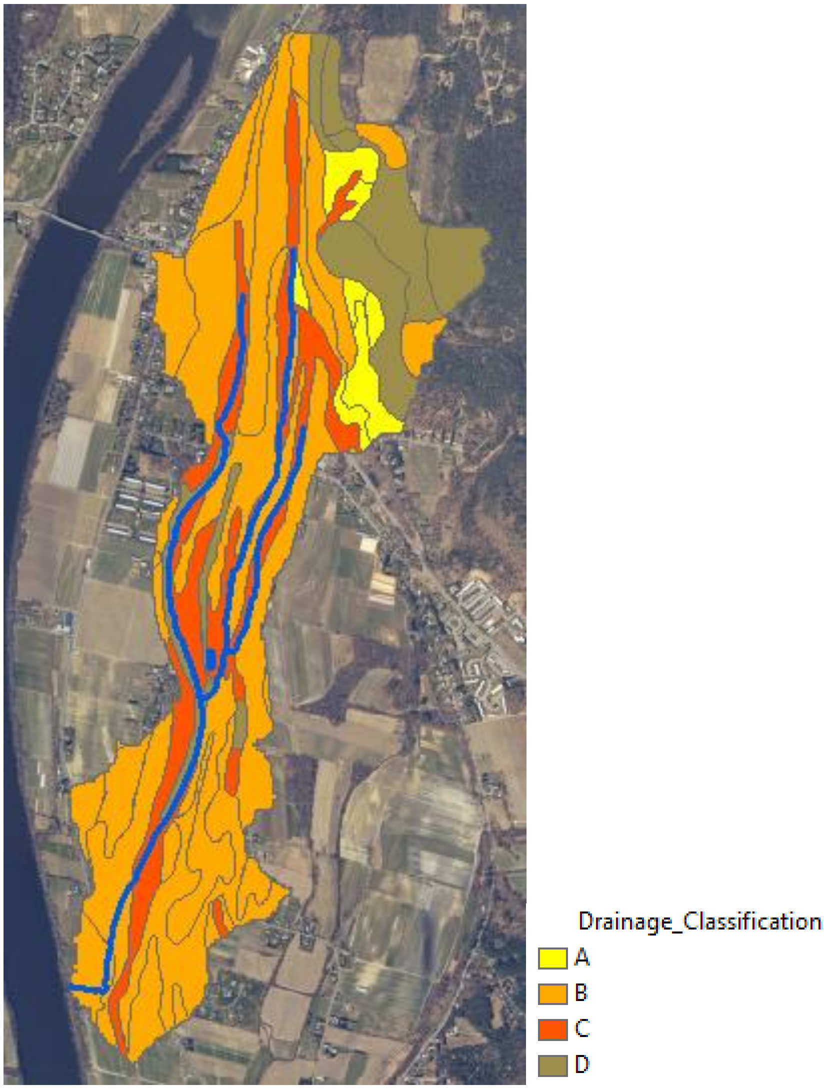


**Figure 9:** Watershed soil drainage classification

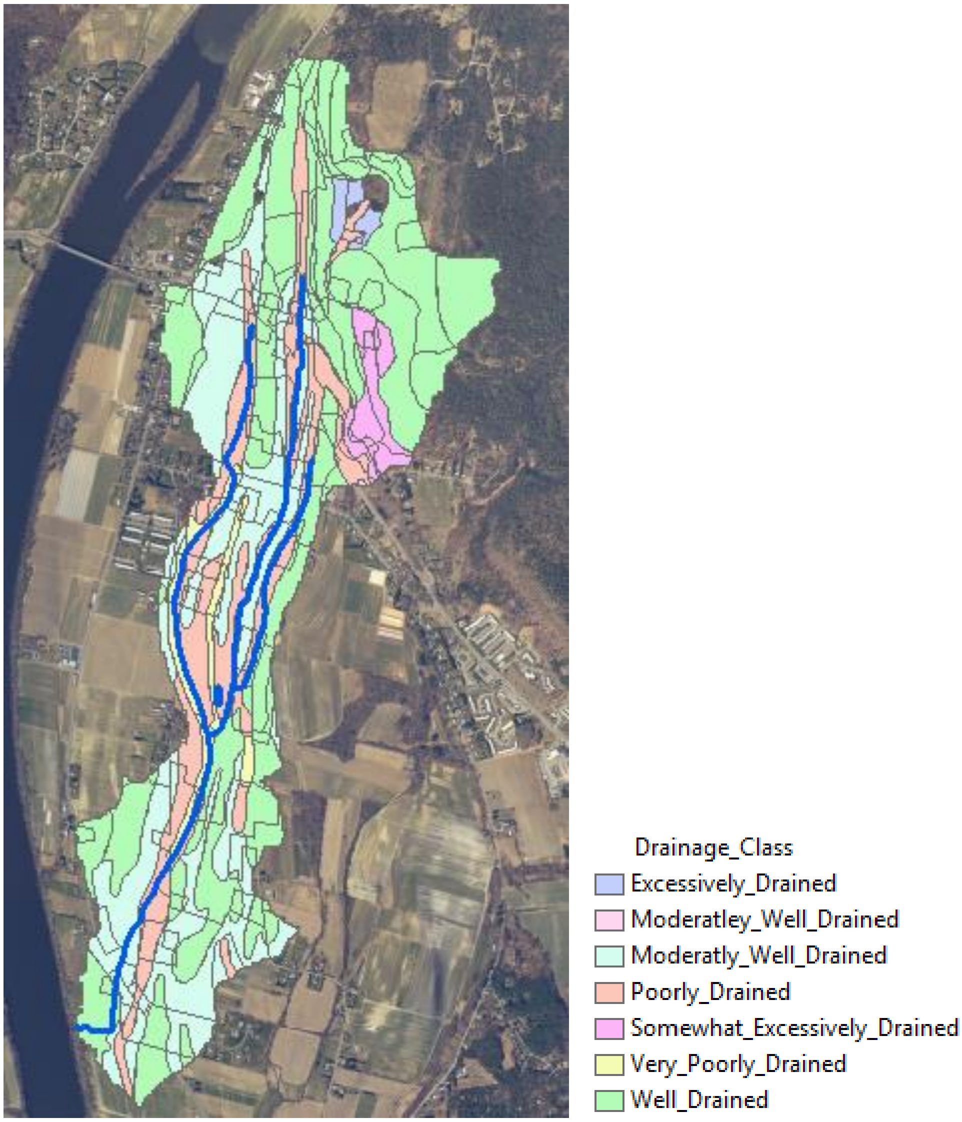


**Figure 10:** Land use by soil drainage classification

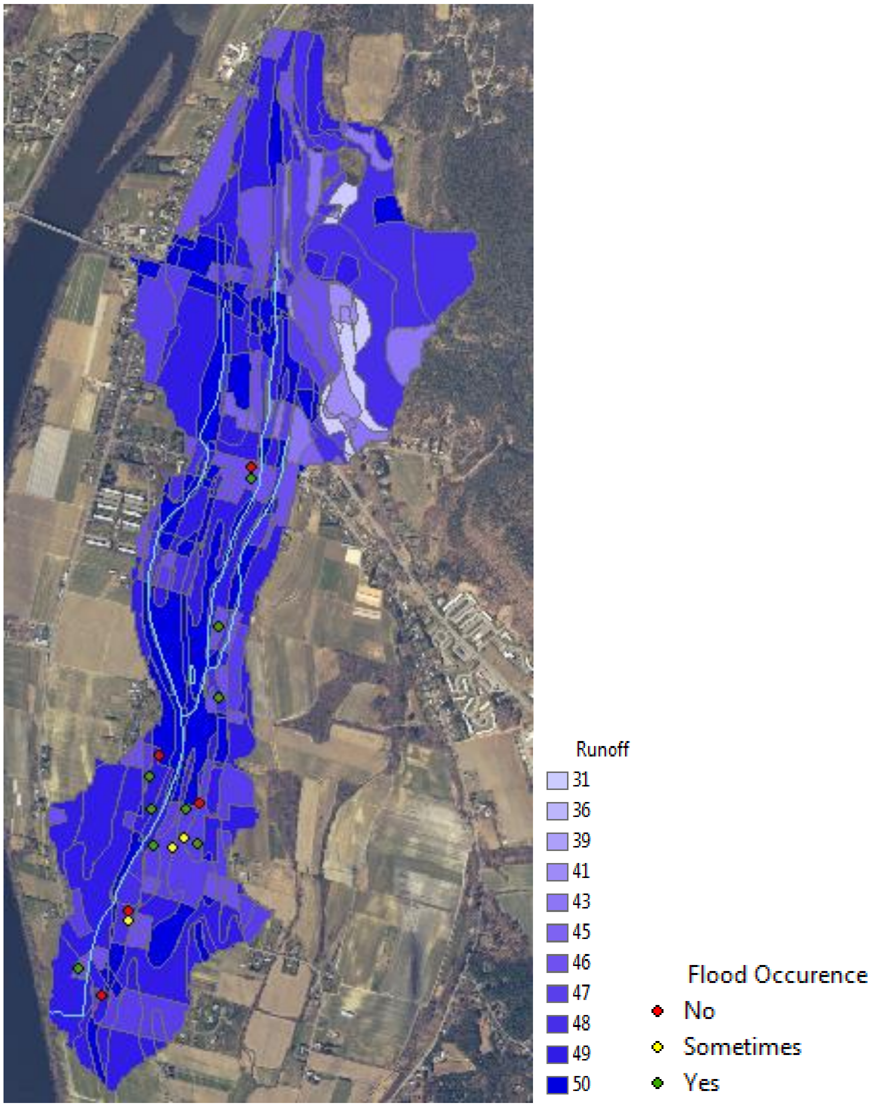


**Figure 11**: Runoff value range

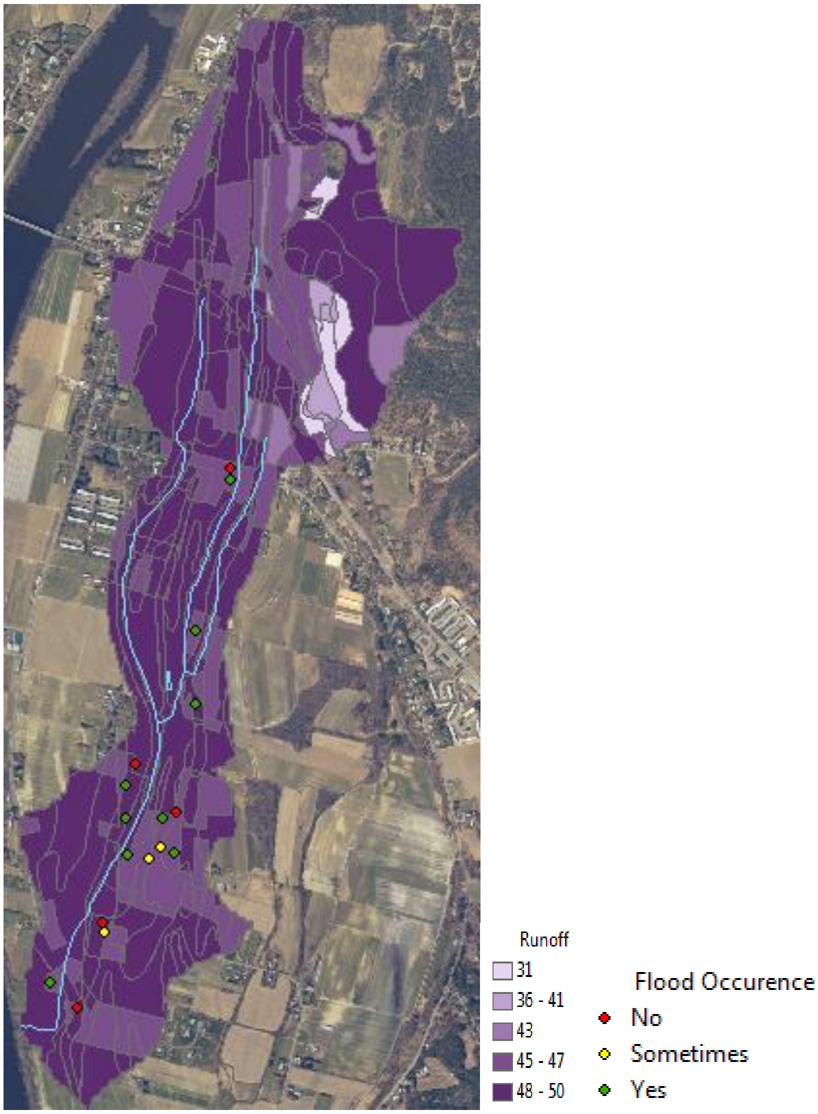


**Figure 12:** Runoff values 5 category

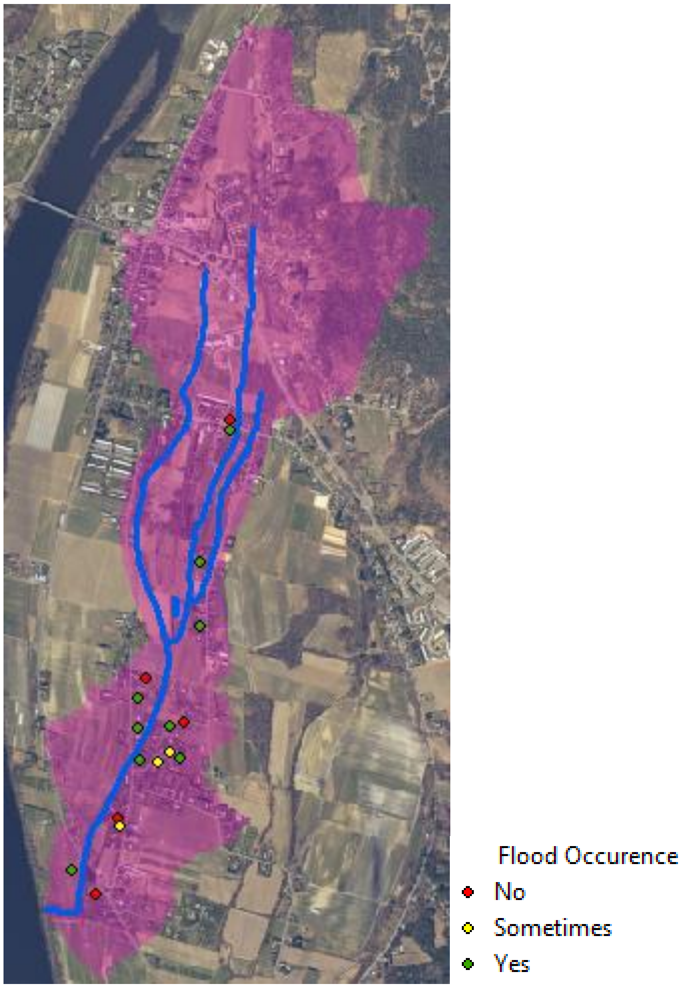


**Figure 13:** Site assessment: flooding survey response locations

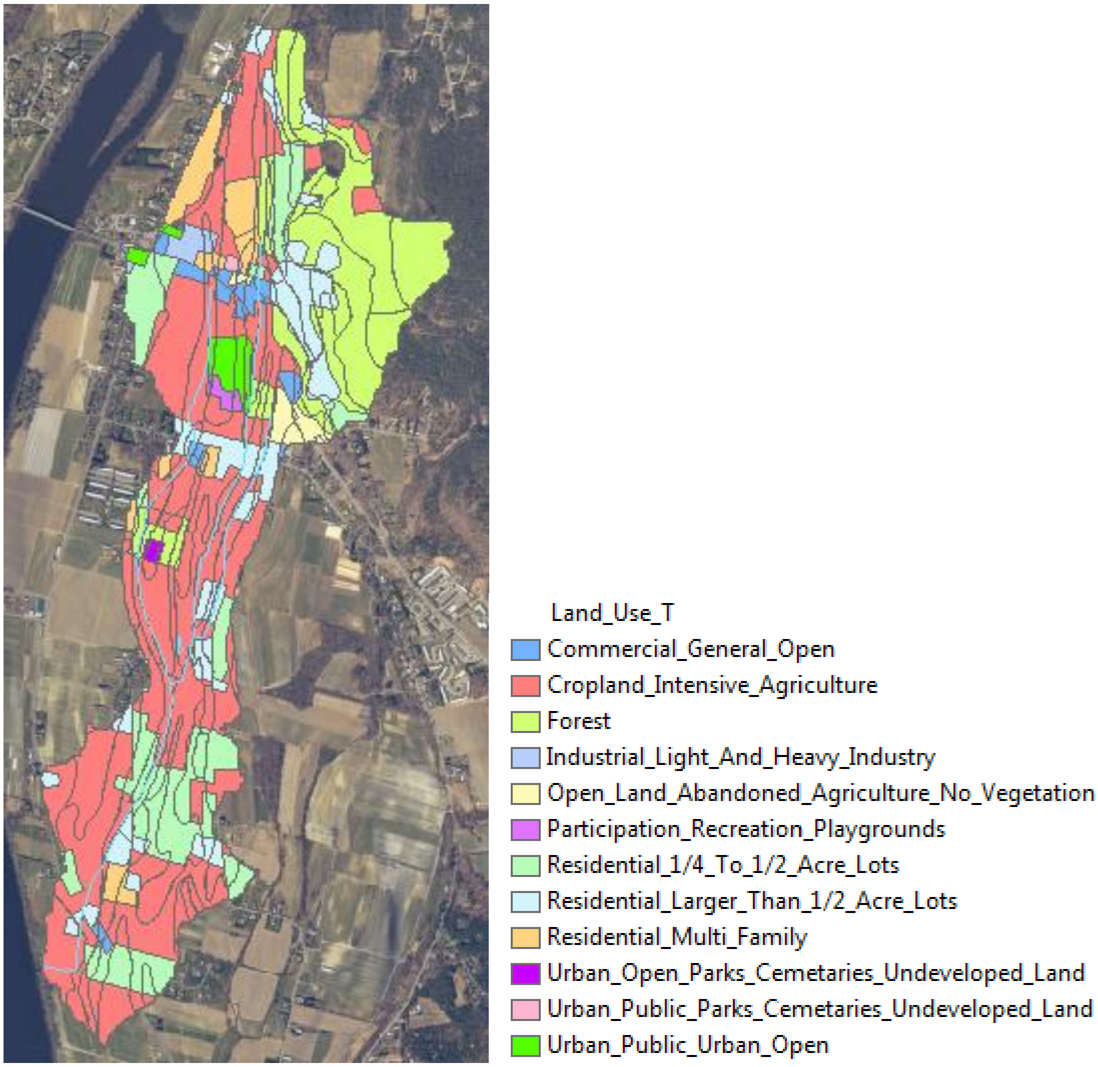


**Figure 14:** Land use type

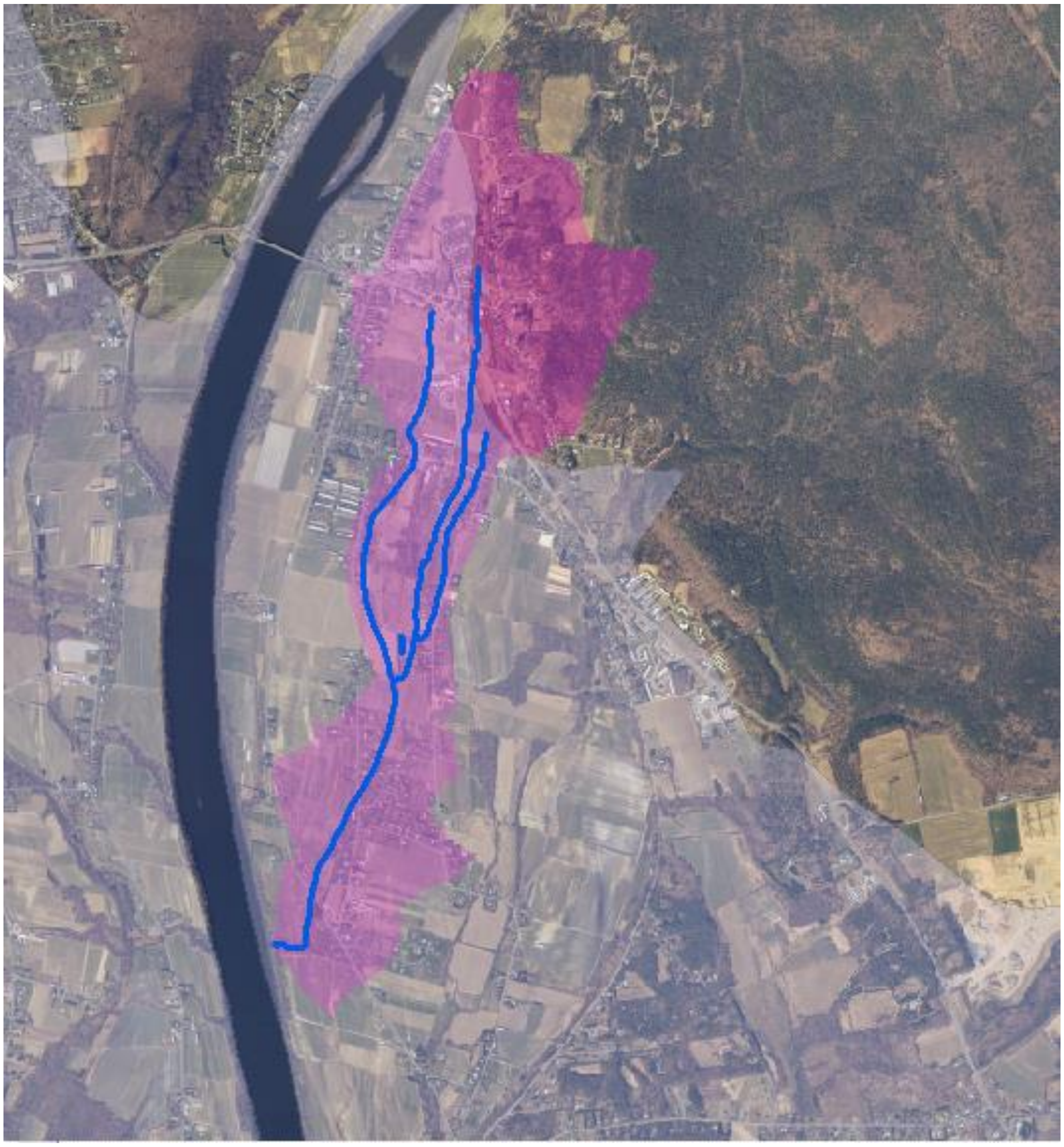


**Figure 15:** Aquifer location vs. watershed location

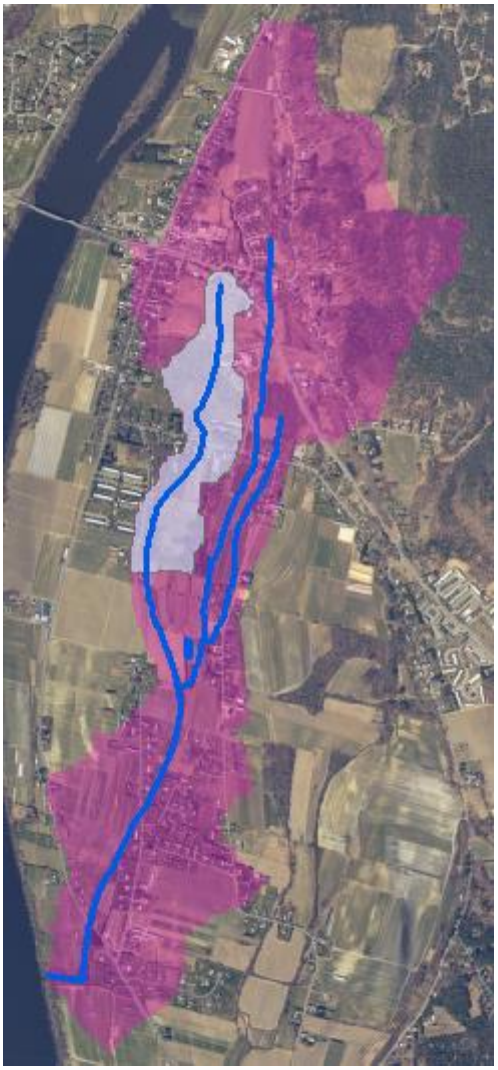


**Figure 16:** Drainage area for stream monitoring point S1

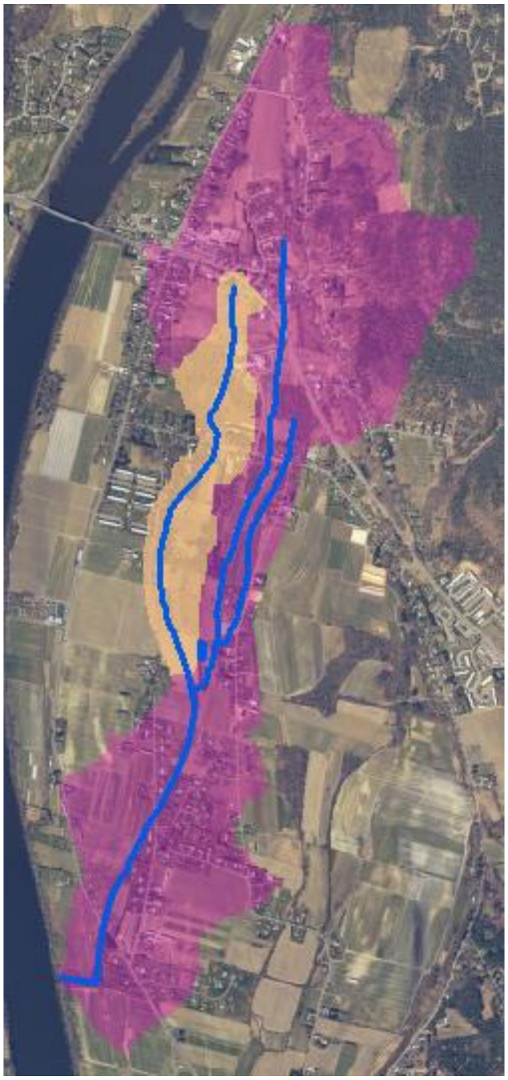


**Figure 17:** Drainage area for stream monitoring point S3

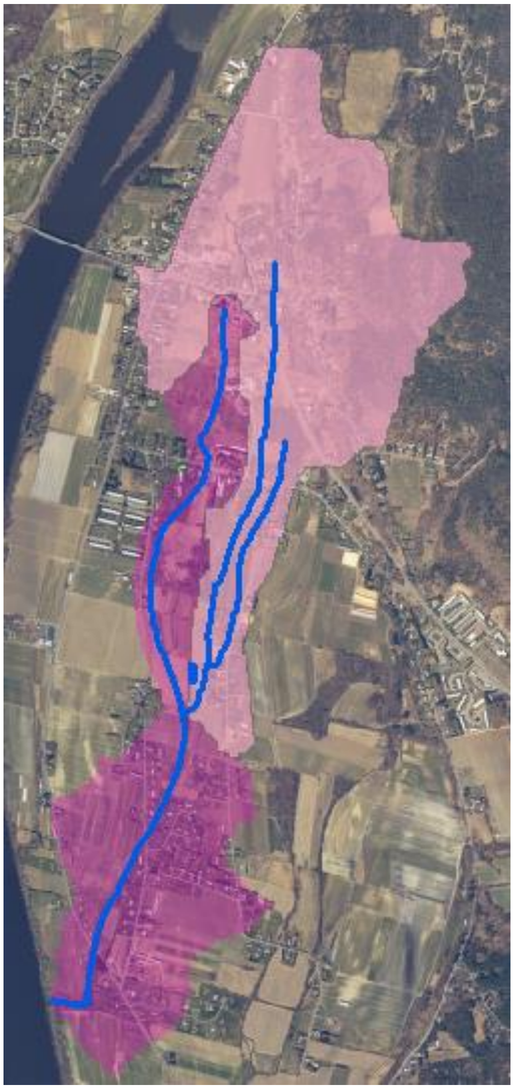


**Figure 18:** Drainage area for stream monitoring point S2

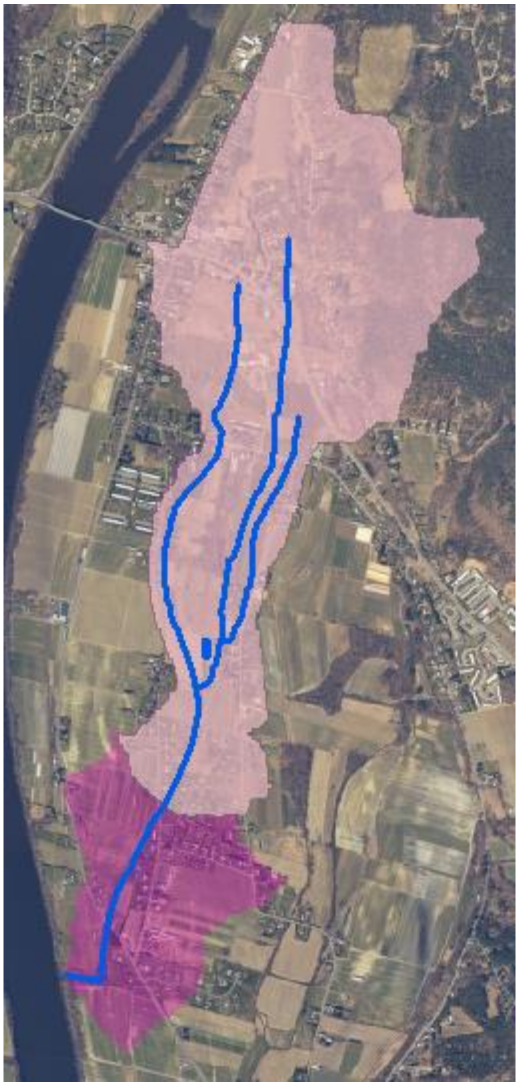


**Figure 19:** Drainage area for stream monitoring point S4

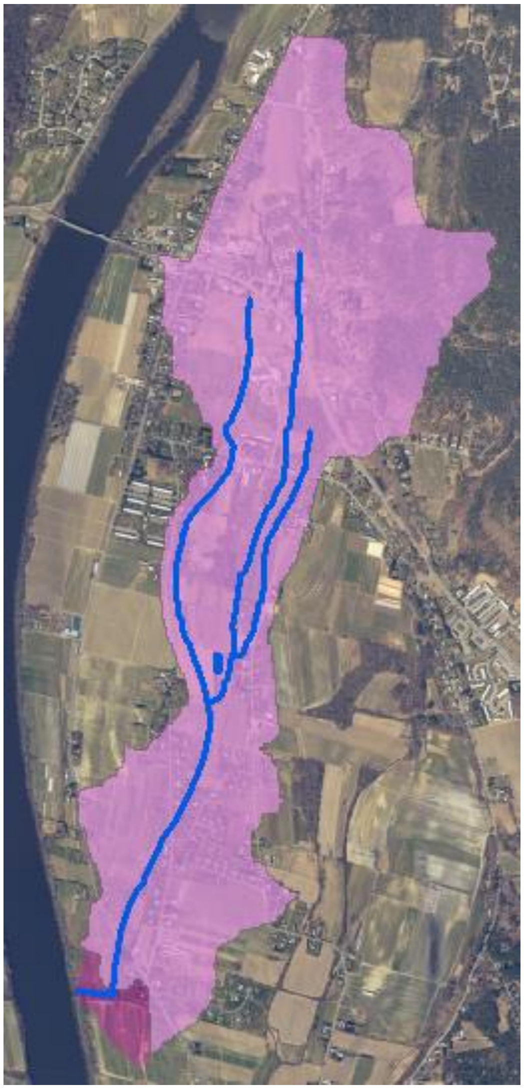


**Figure 20:** Drainage area for stream monitoring point S5

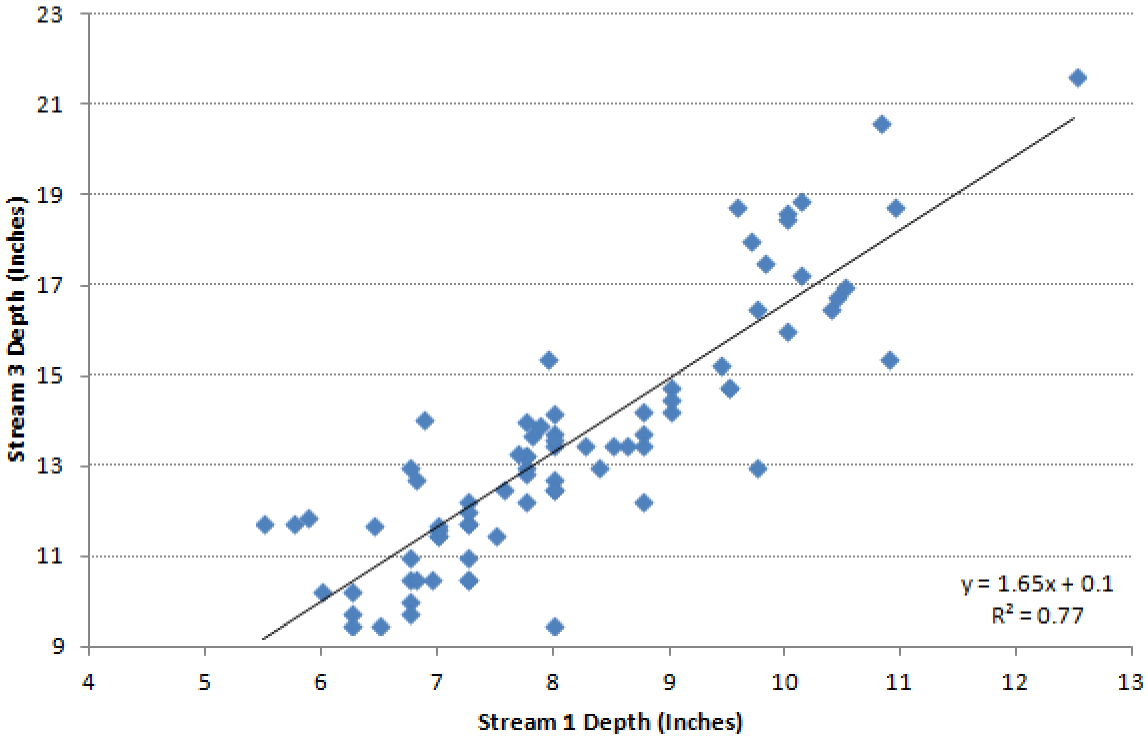
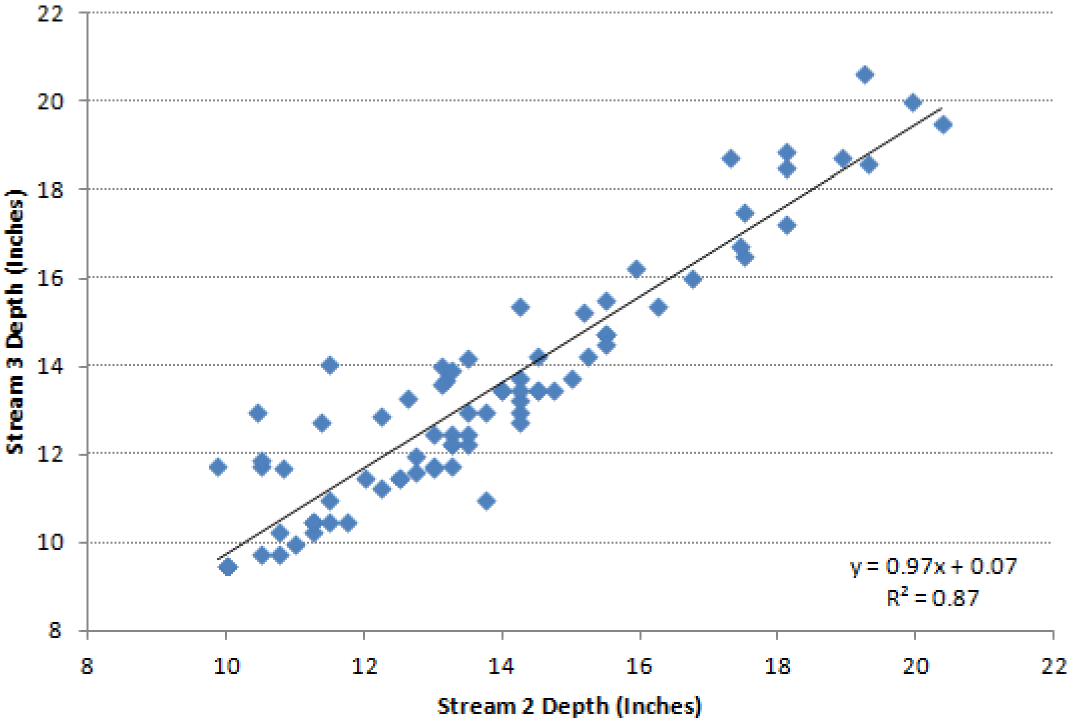


**Figure 21:** S1 depth change vs. S3 depth change 2009



S5

**Figure 22:** S2 depth change vs. S3 depth change 2009

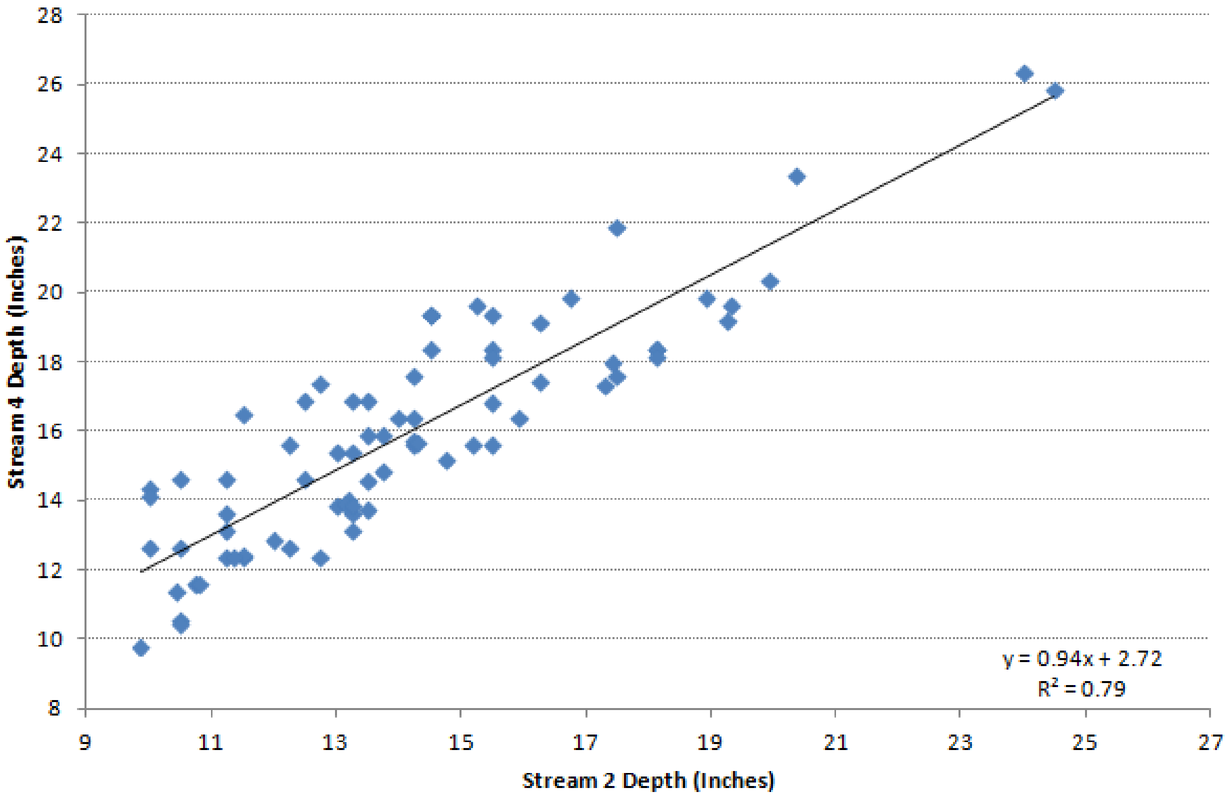


**Figure 23:** S2 depth change vs. S4 depth change 2009

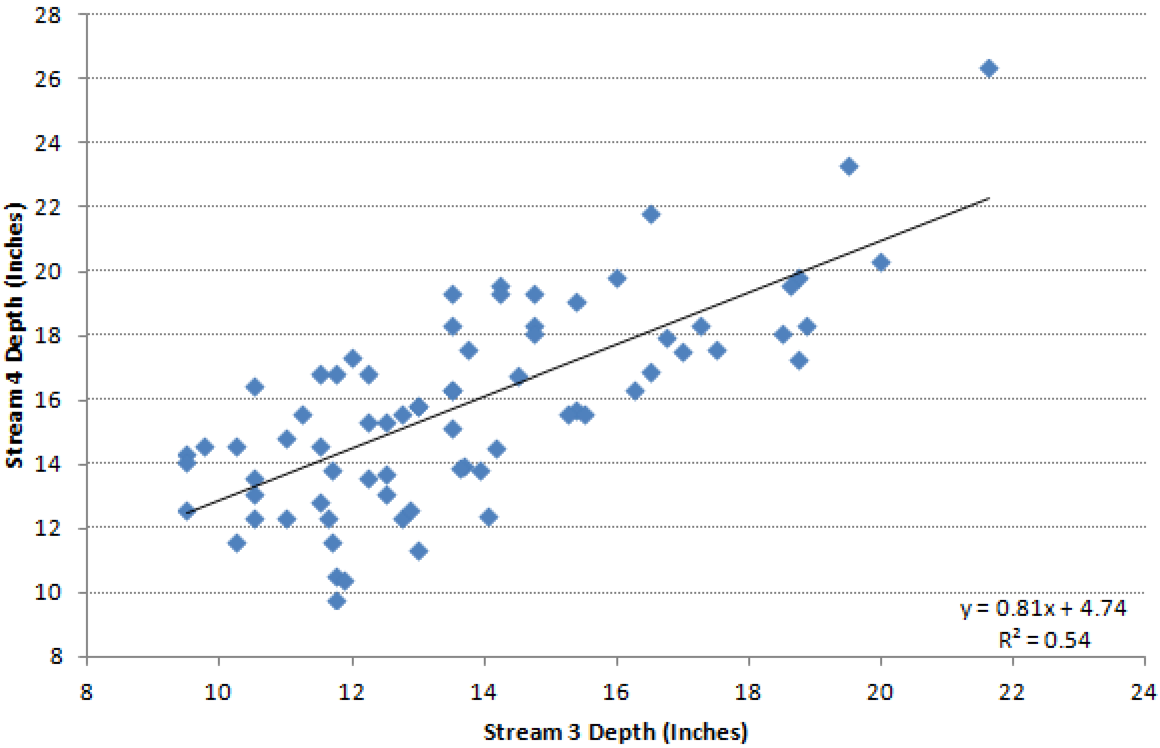


**Figure 24:** S3 depth change vs. S4 depth change 2009

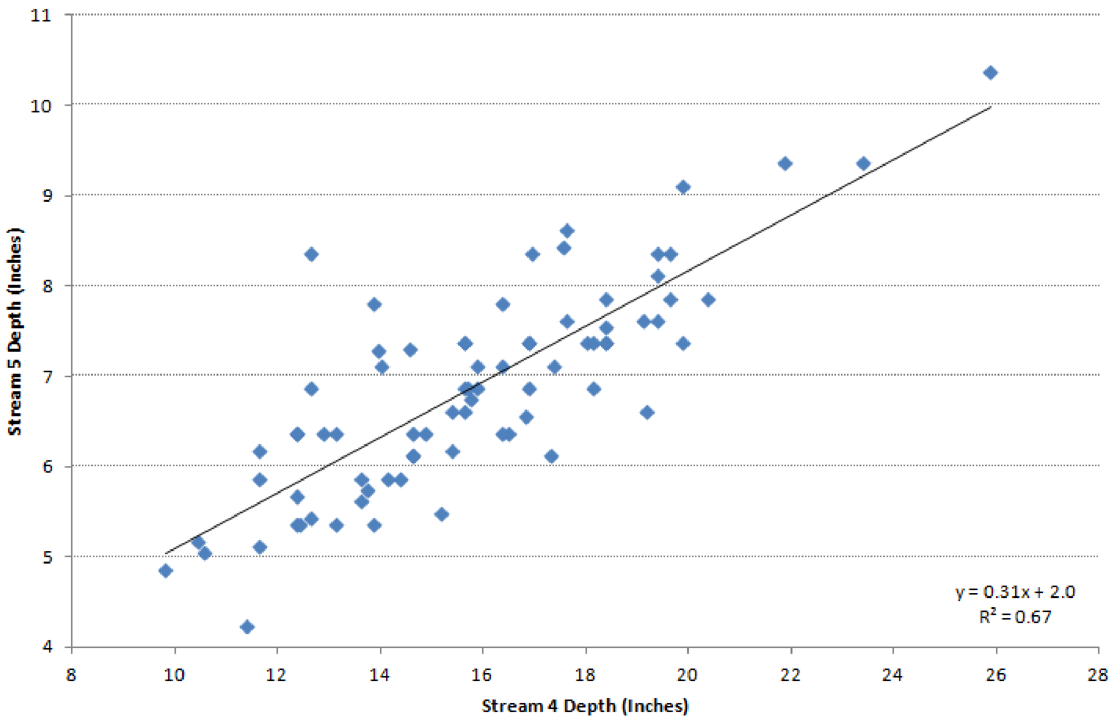


**Figure 25:** S4 depth change vs. S5 depth change 2009

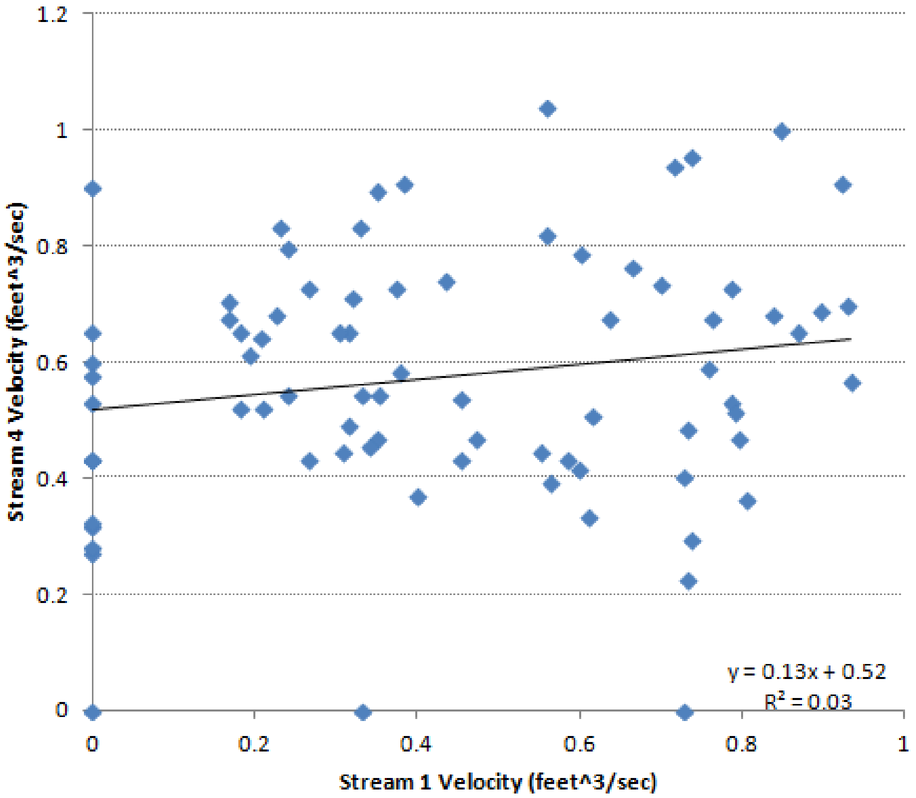


**Figure 26:** S1 velocity change vs. S4 velocity change 2009

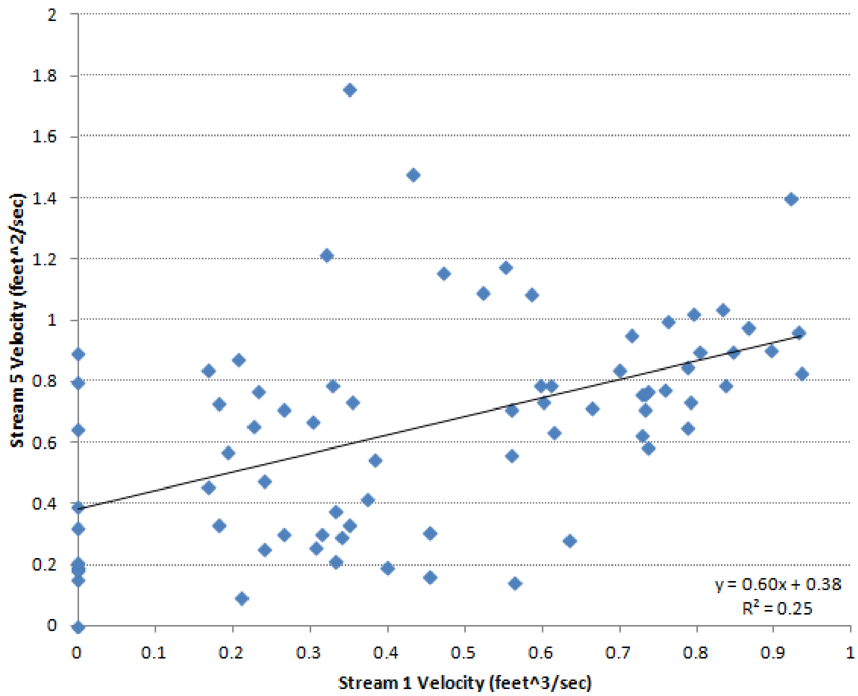


**Figure 27:** S1 velocity change vs. S5 velocity change 2009

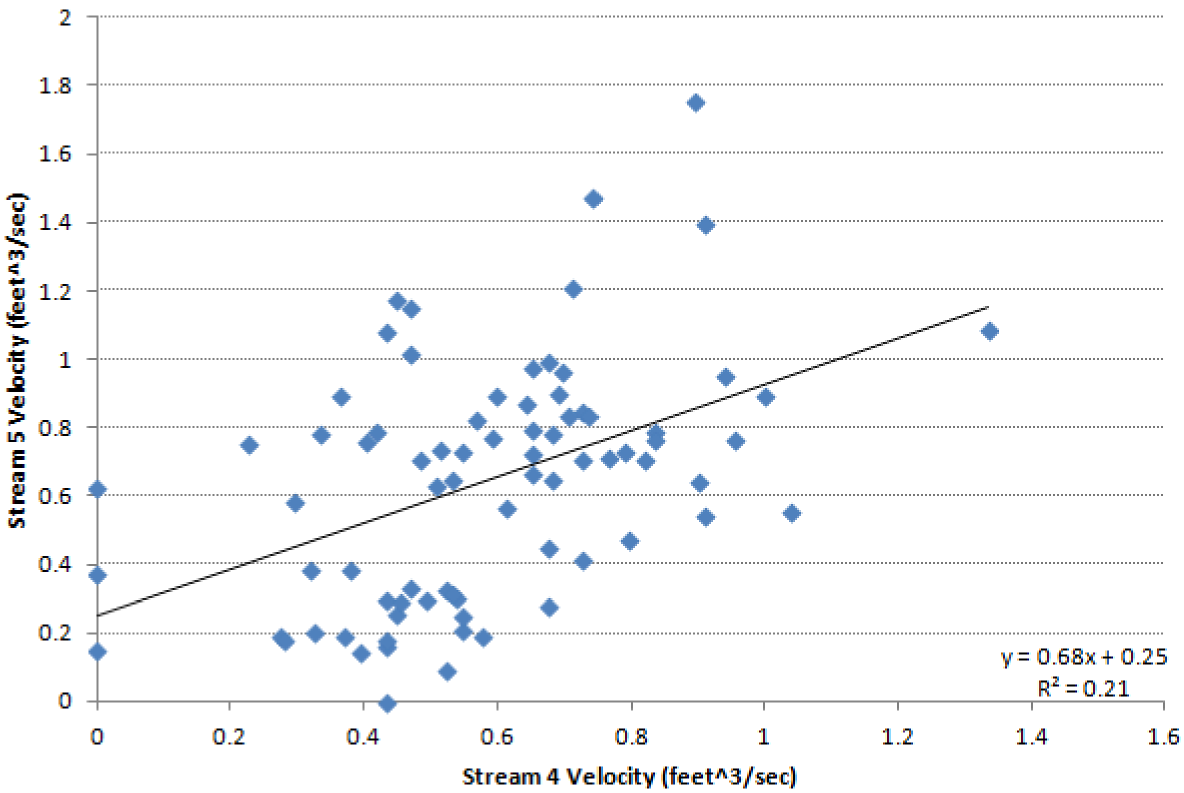


**Figure 28:** S4 velocity change vs. S5 velocity change 2009

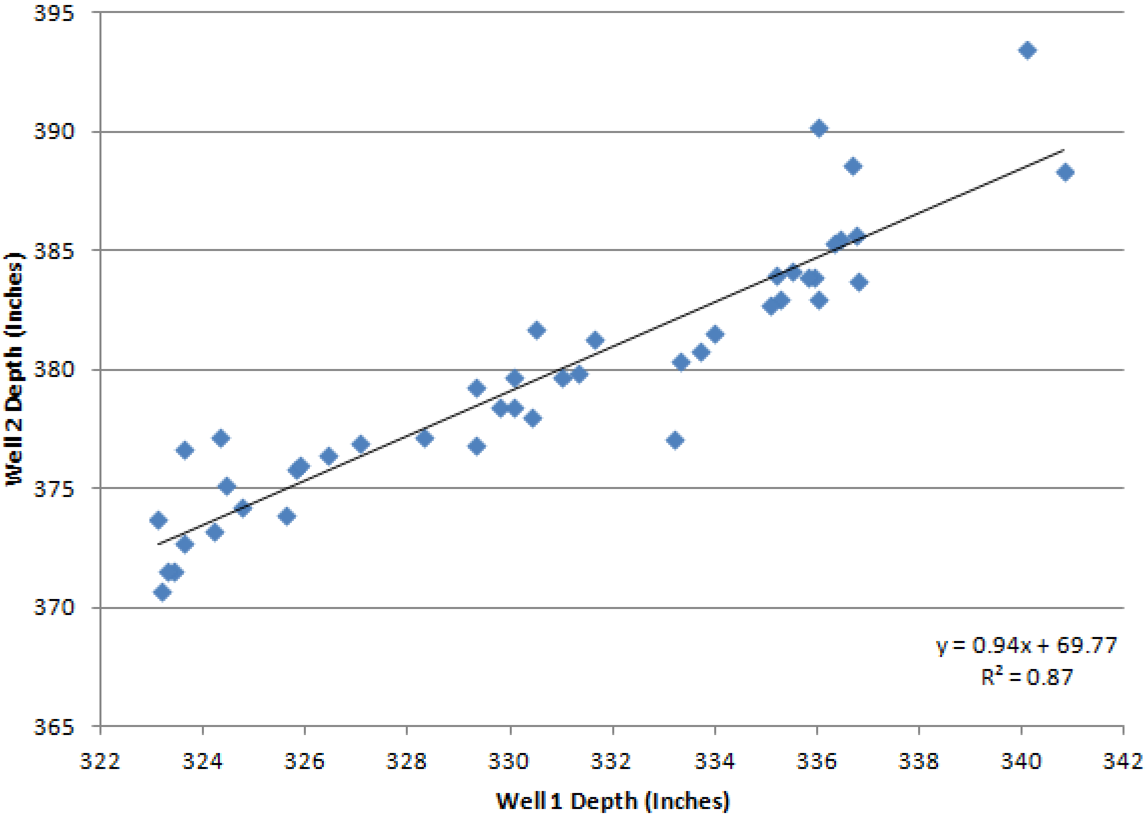


**Figure 29:** W1 depth change vs. W2 depth change 2009

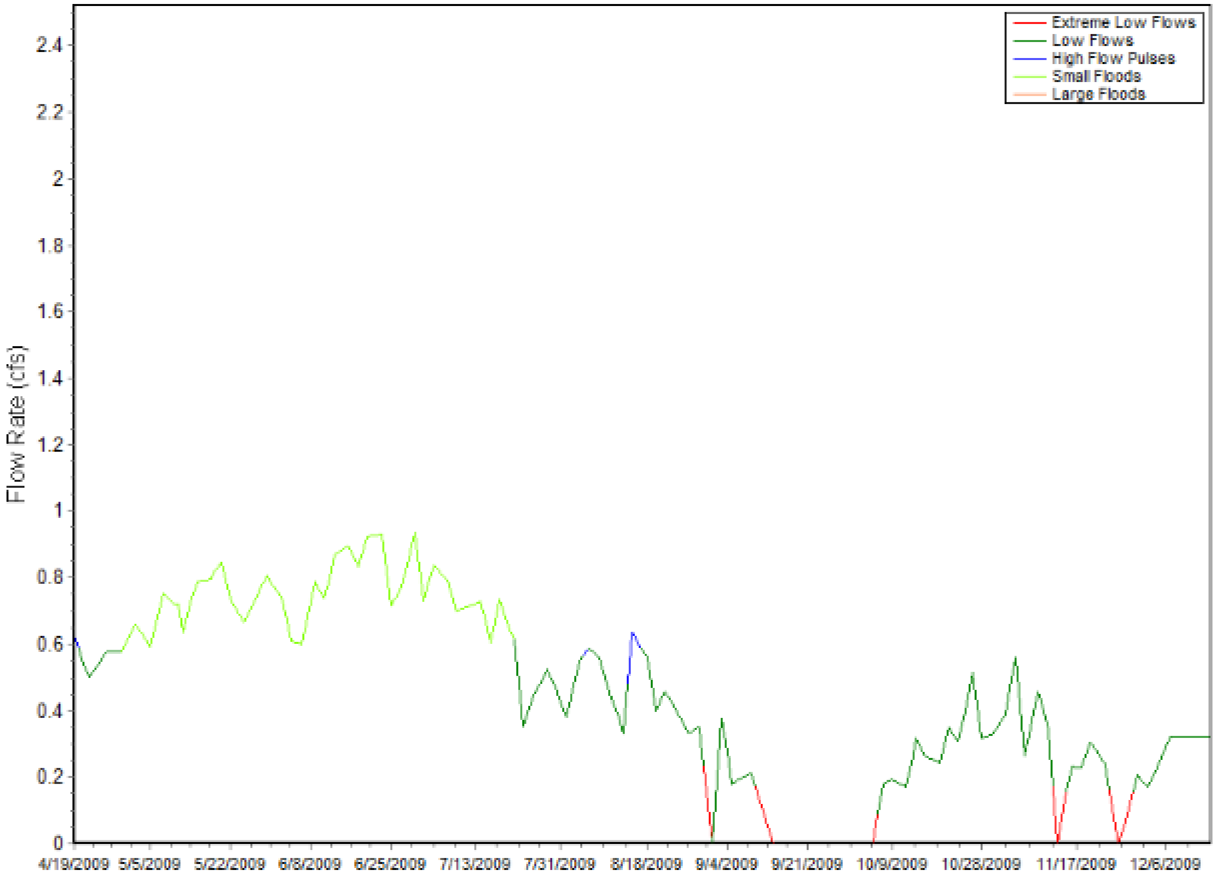


**Figure 30:** IHA S1 stream flow 2009

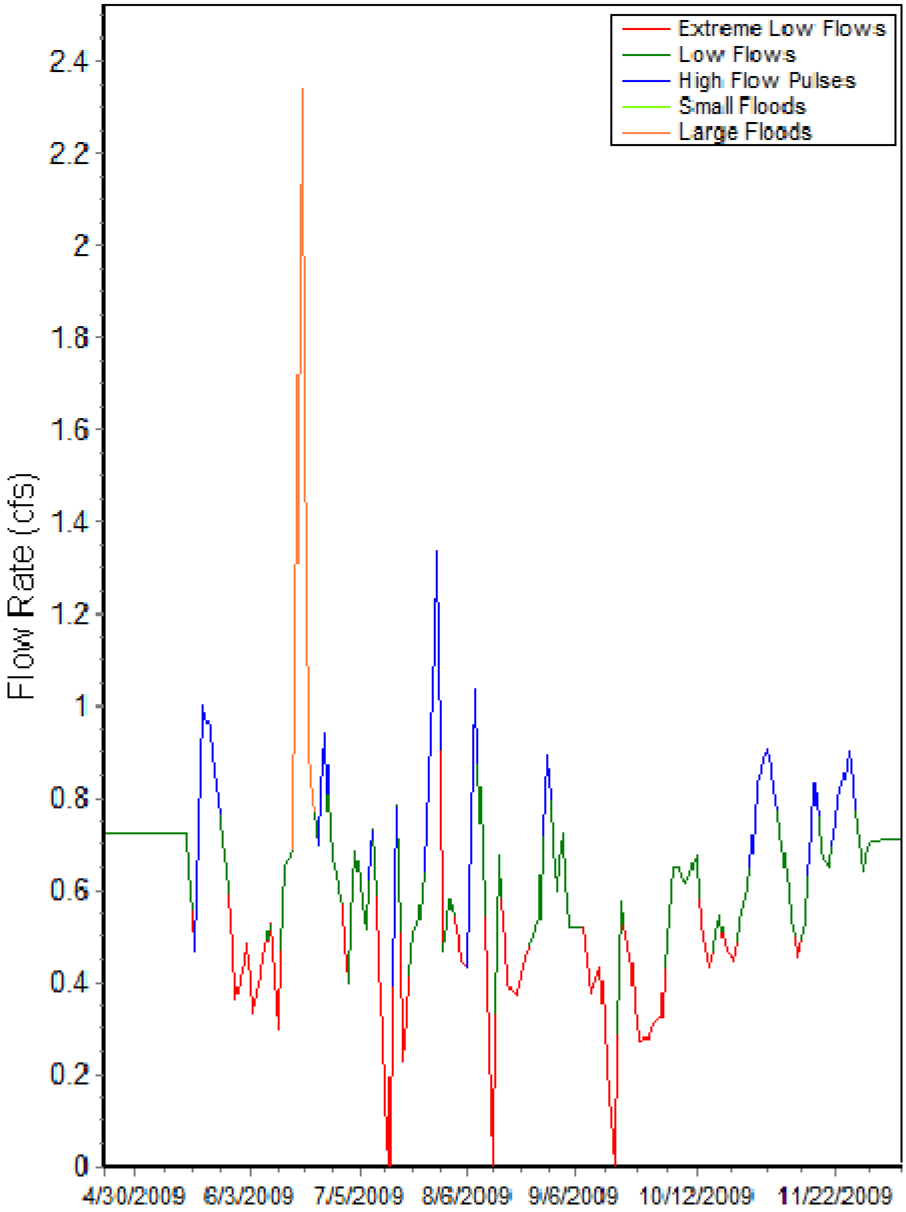


**Figure 31:** IHA S4 stream flow 2009

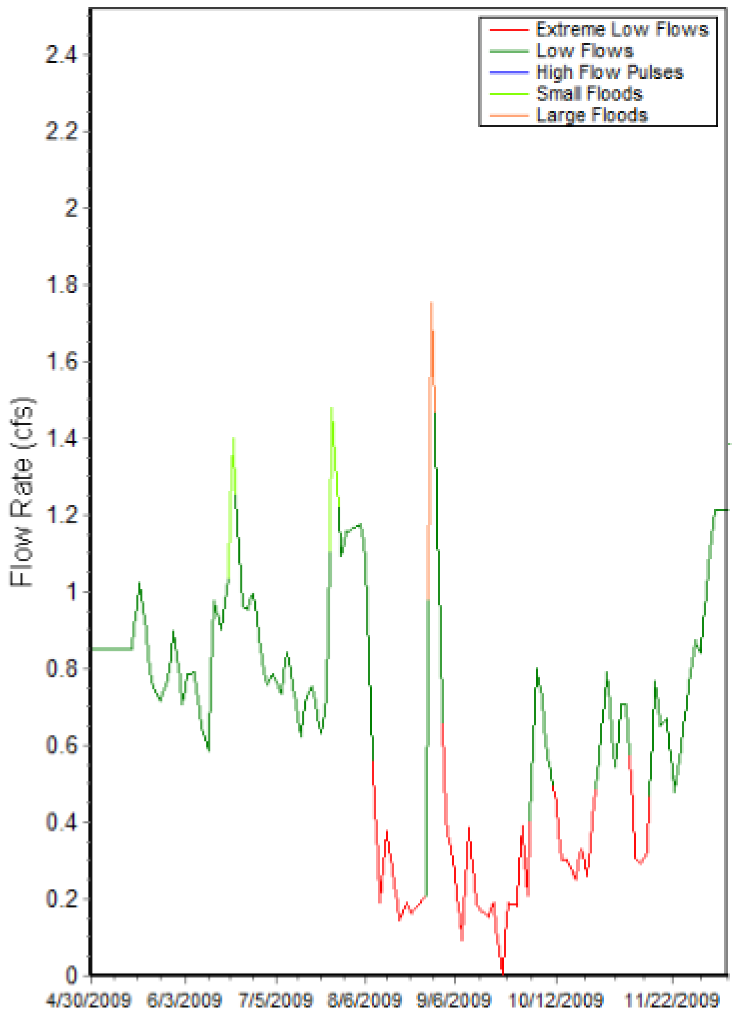


**Figure 32:** IHA S5 stream flow 2009

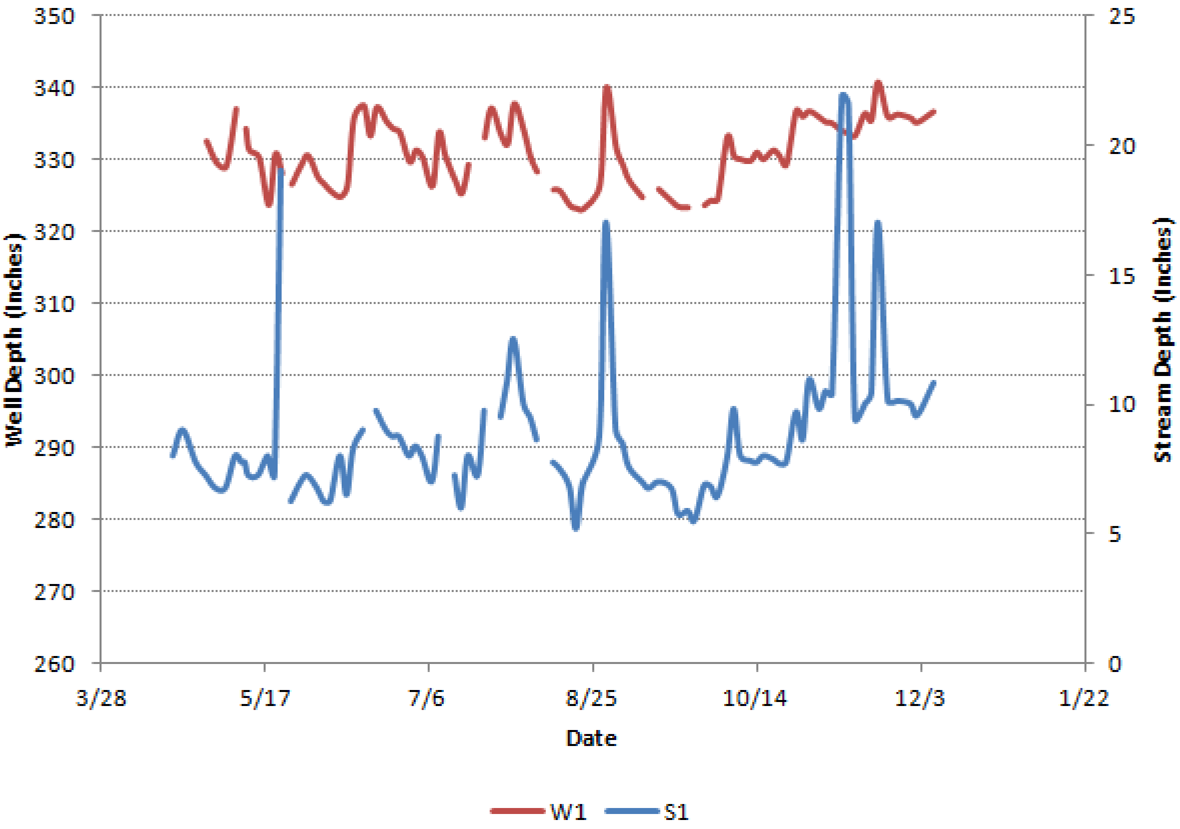


**Figure 33:** S1 vs. W1 depth change 2009

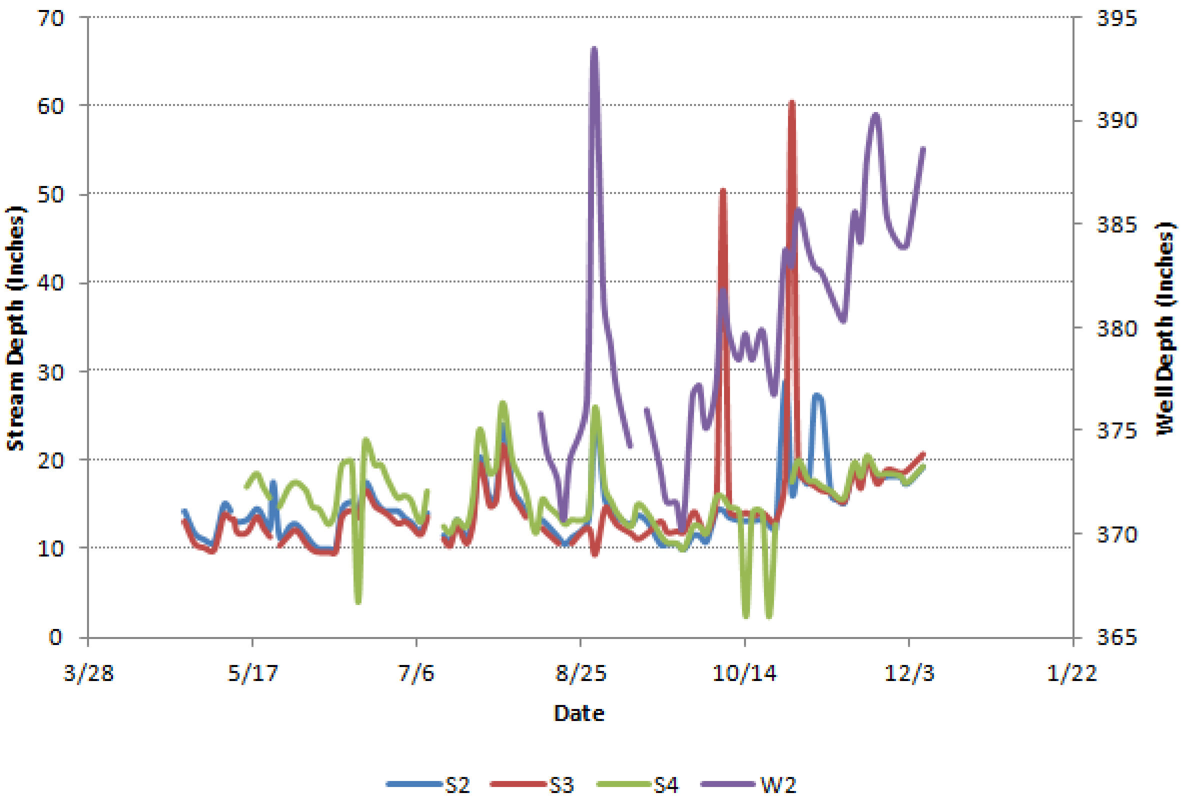


**Figure 34:** S2, S3, & S4 vs. W2 depth change 2009

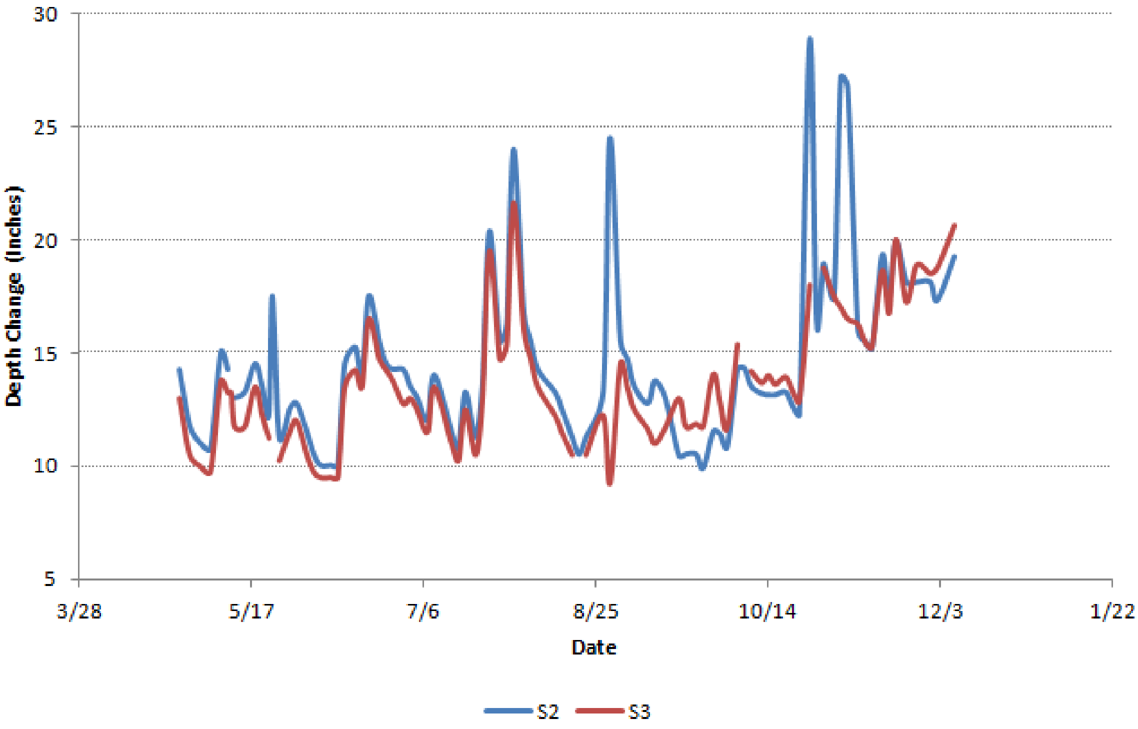


**Figure 35:** S2 vs. S3 depth change 2009

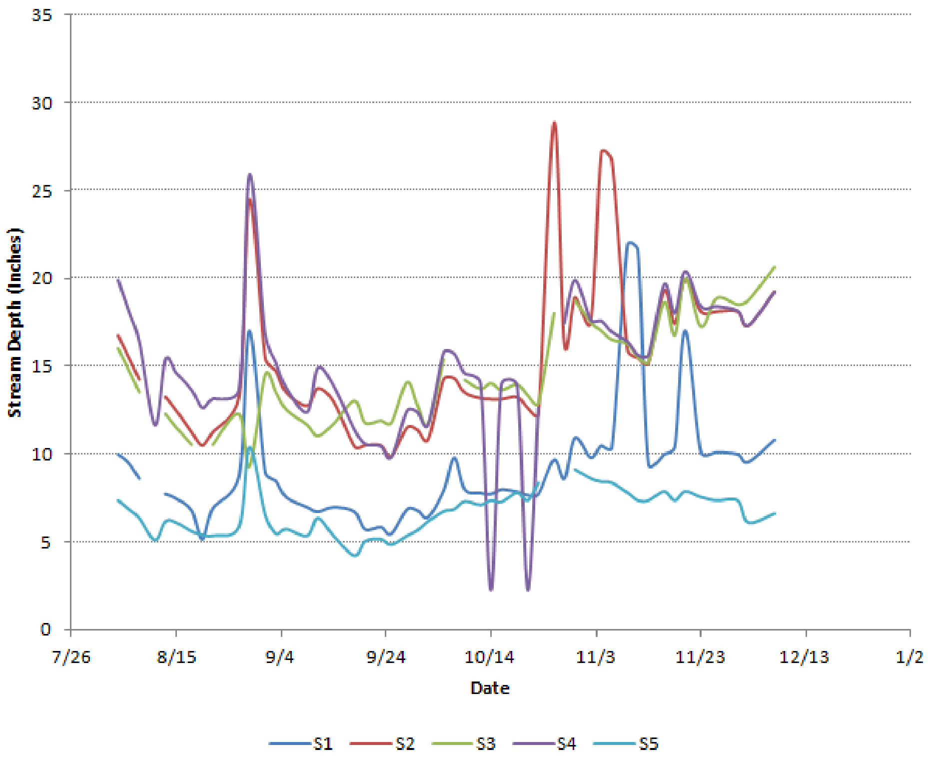


**Figure 36:** All stream depth change 2009

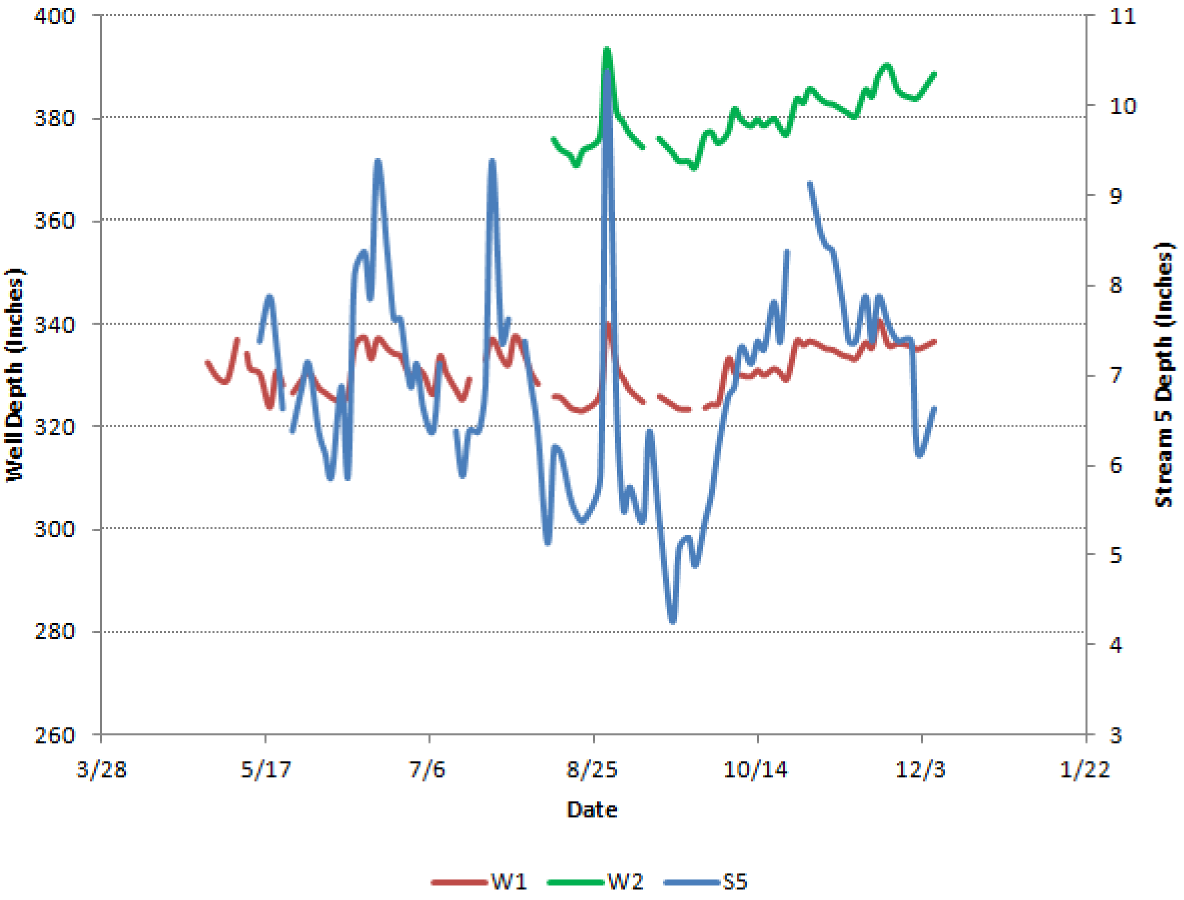


**Figure 37:** S5 depth change vs. W1, & W2 depth change 2009

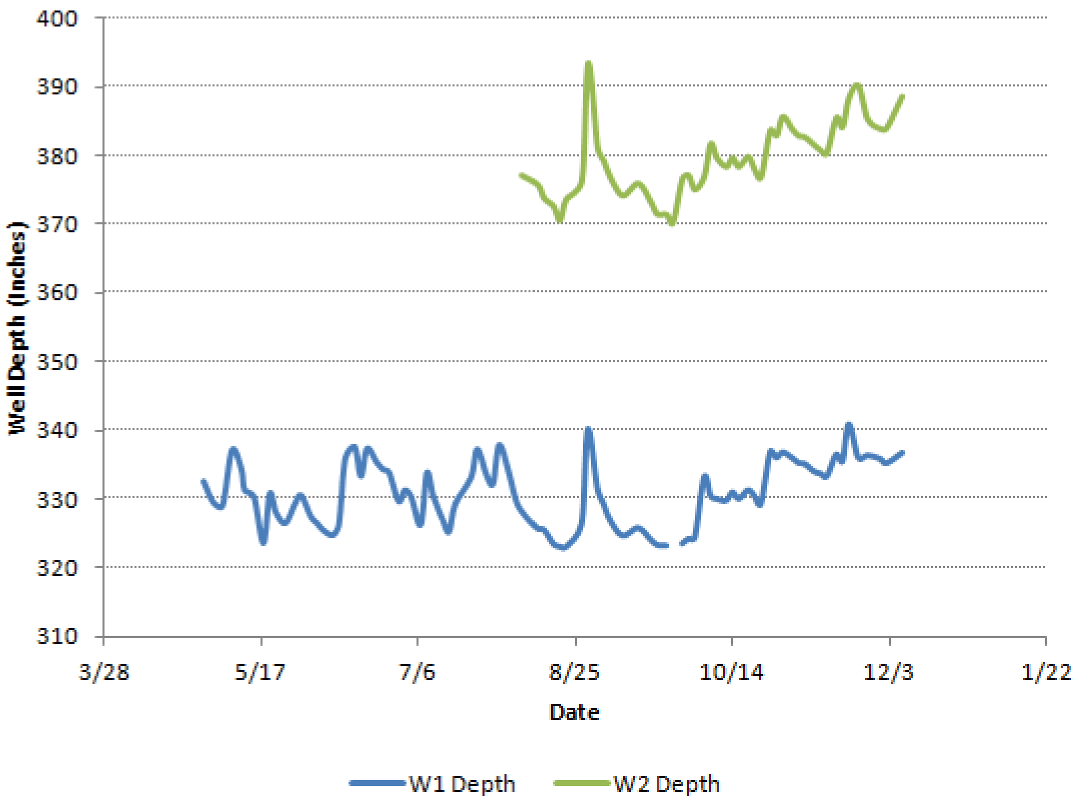


**Figure 38:** W1& W2 depth change 2009

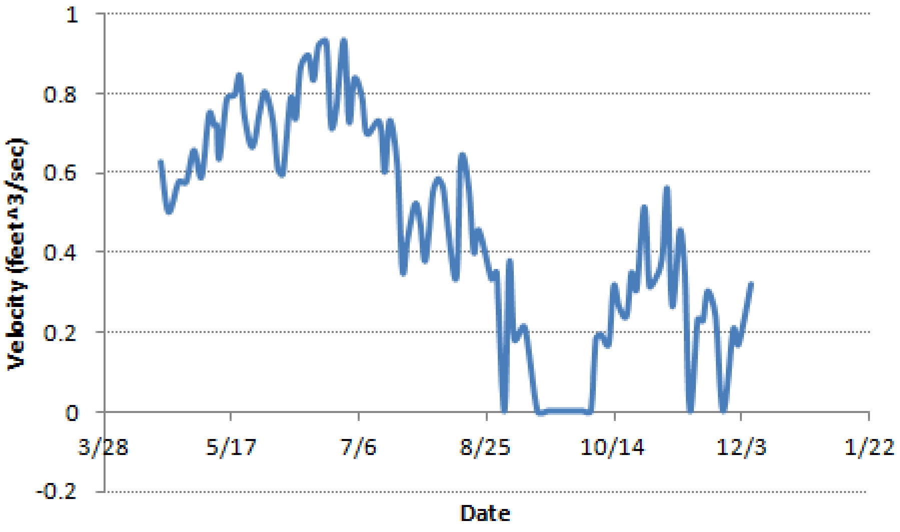


**Figure 39:** S1 velocity 2009

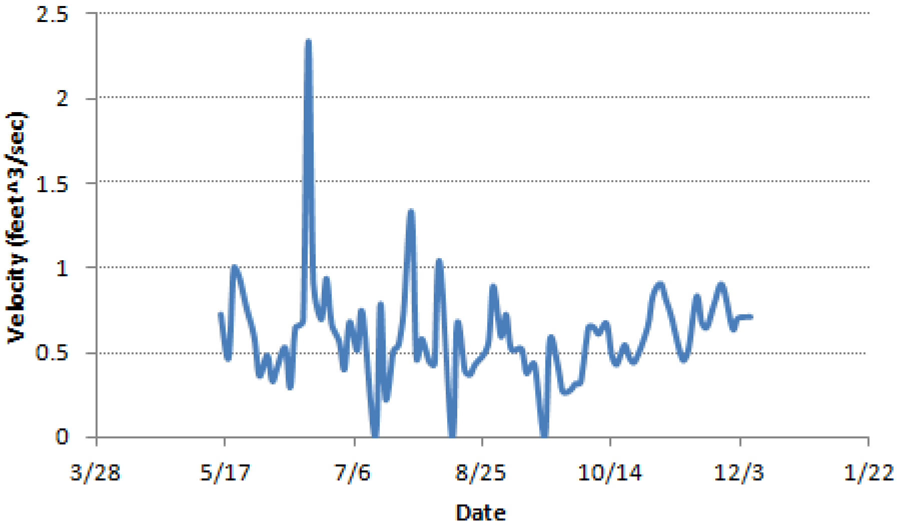


**Figure 40:** S4 velocity 2009

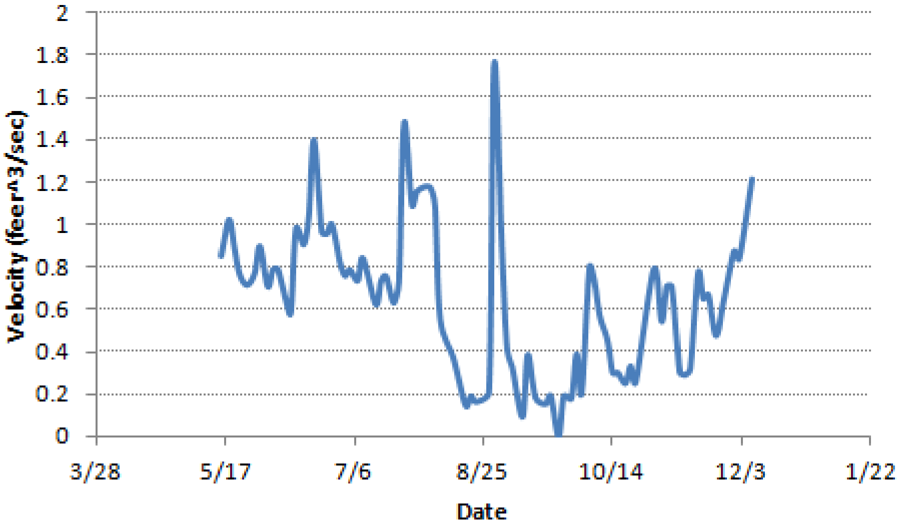


**Figure 41:** S5 velocity 2009

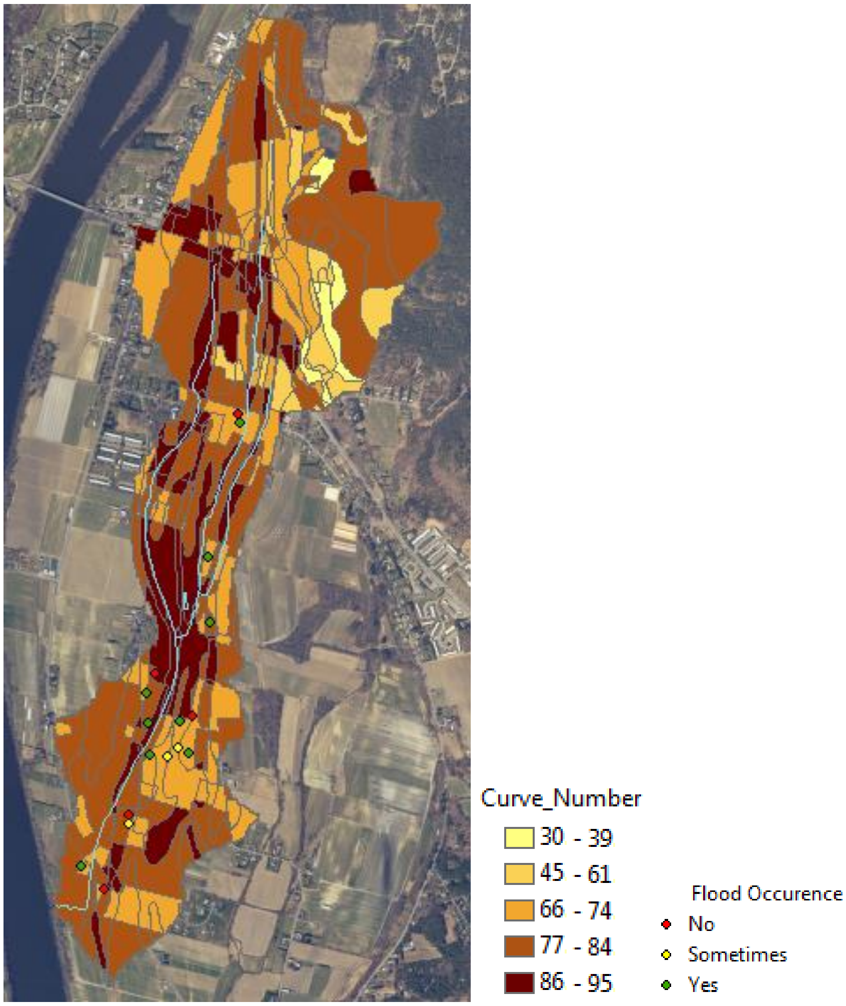


**Figure 42:** Meadowbrook watershed curve number values

**Figure 43:** Site assessment: land use type

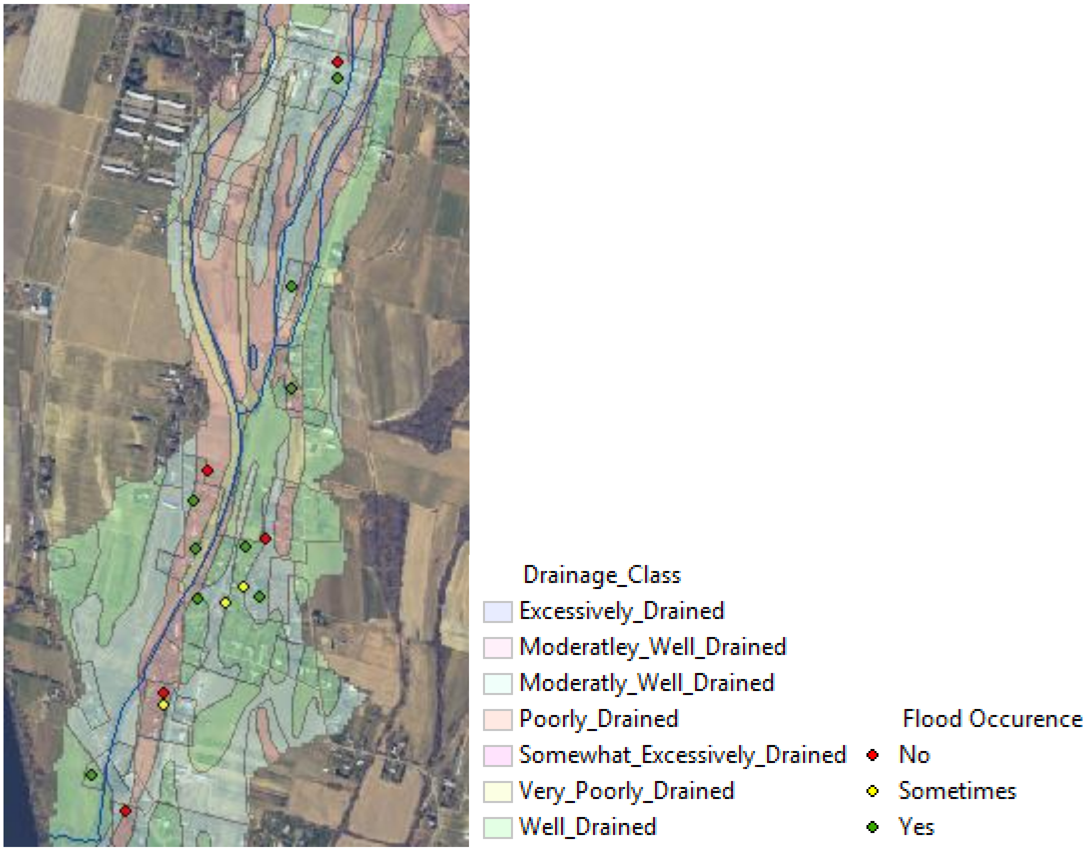


**Figure 44:** Site assessment: drainage classification

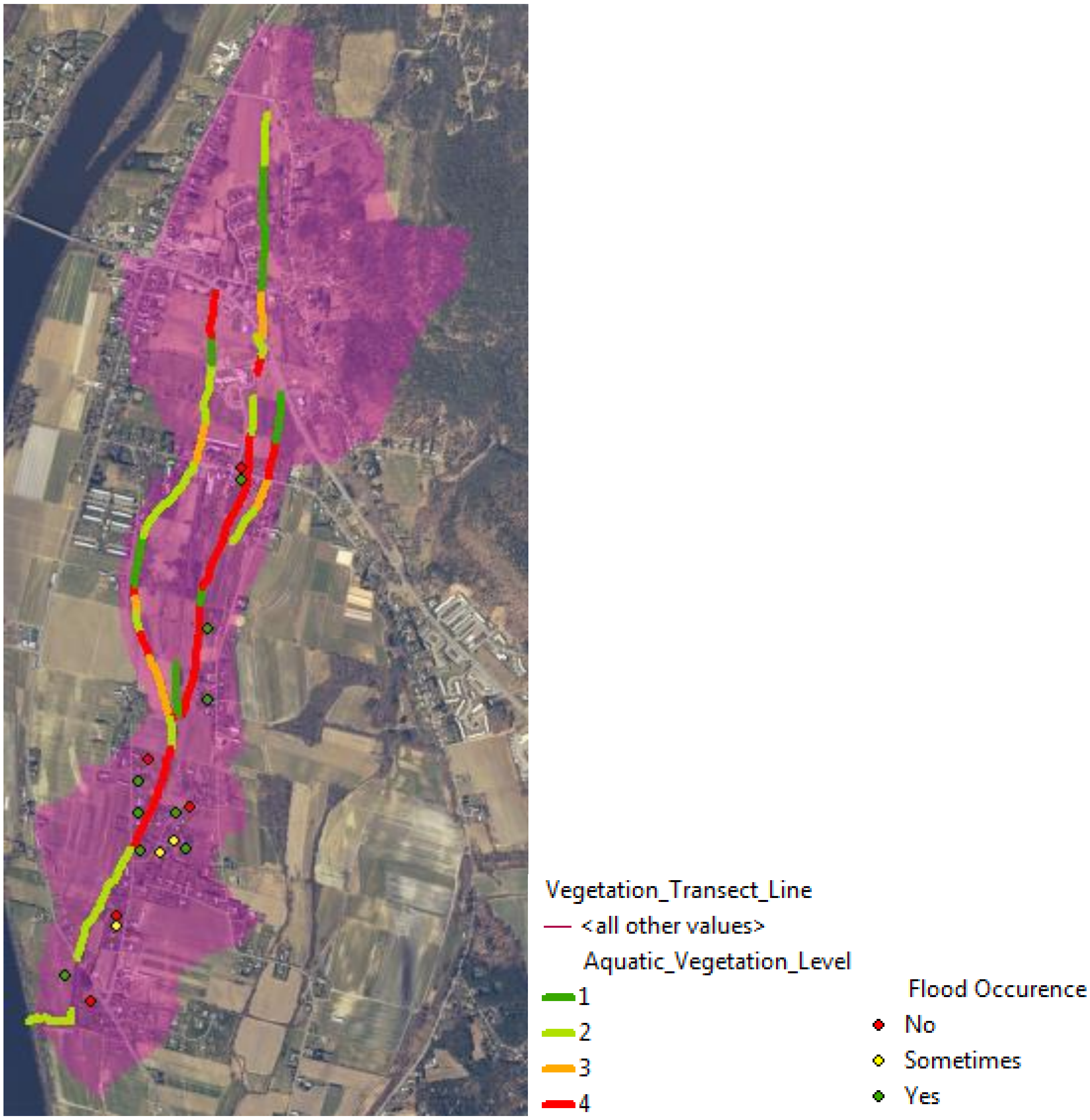


**Figure 45:** Site assessment: vegetation level

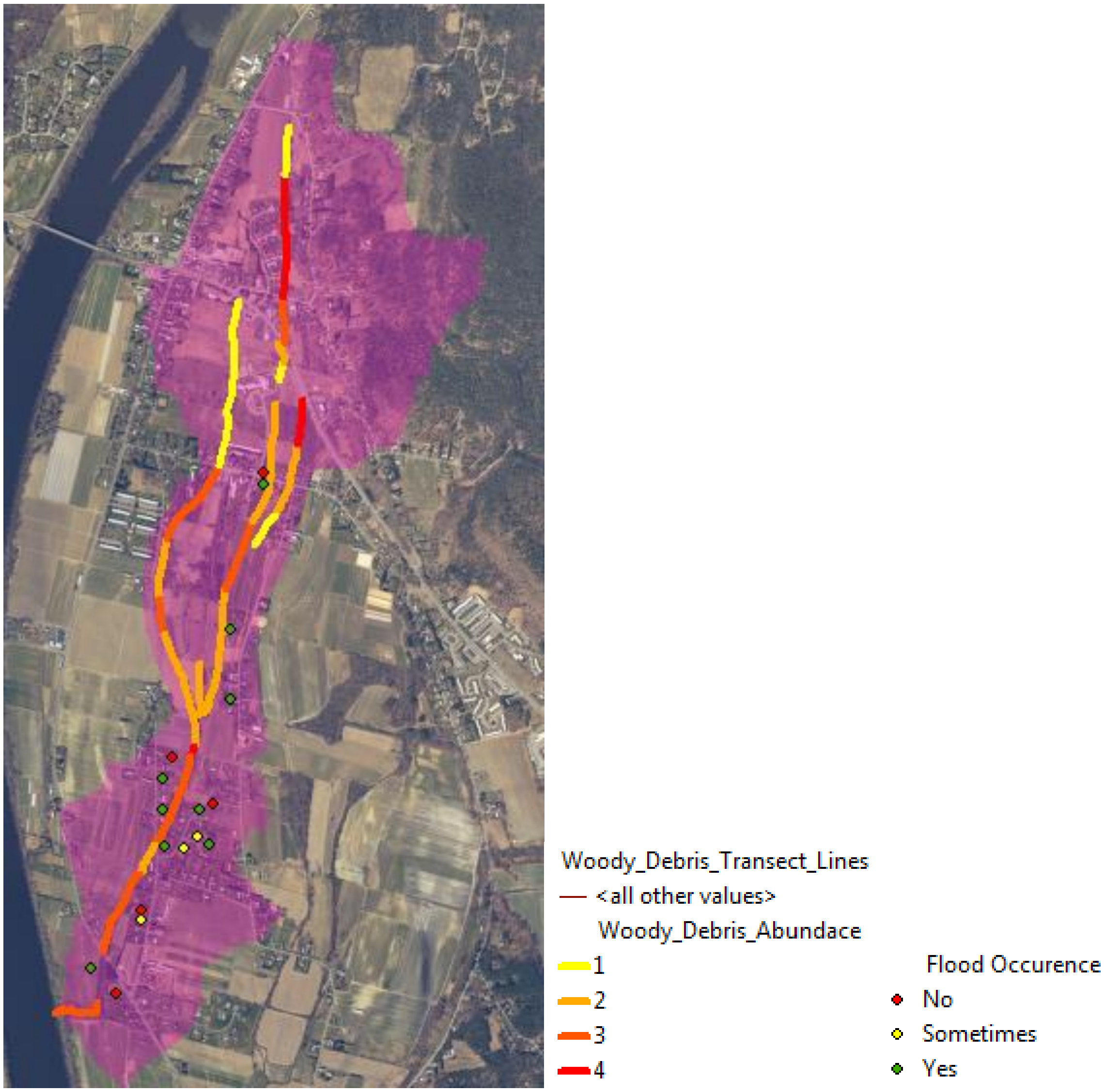
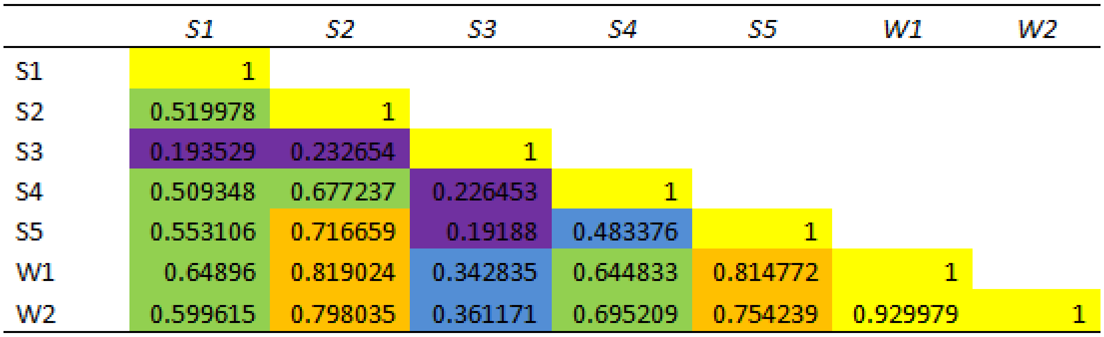


**Figure 46:** Site assessment: woody debris abundance

**Table 1: Correlation Values**



| | S1 | S2 | S3 | S4 | S5 | W1 | W2 |
|---|---|---|---|---|---|---|---|
| S1 | 1 | | | | | | |
| S2 | 0.519978 | 1 | | | | | |
| S3 | 0.193529 | 0.232654 | 1 | | | | |
| S4 | 0.509348 | 0.677237 | 0.226453 | 1 | | | |
| S5 | 0.553106 | 0.716659 | 0.19188 | 0.483376 | 1 | | |
| W1 | 0.64896 | 0.819024 | 0.342835 | 0.644833 | 0.814772 | 1 | |
| W2 | 0.599615 | 0.798035 | 0.361171 | 0.695209 | 0.754239 | 0.929979 | 1 |

### Table 2: Drainage Area vs. Average Stream Velocity

| Monitoring Station ID | Drainage Area (Meter^2) | Average Velocity (Feet^3/sec) |
|---|---|---|
| S1 | 310,700 | 0.47 |
| S2 | 1,668,900 | 0 |
| S3 | 394,200 | 0.04 |
| S4 | 2,303,900 | .60 |
| S5 | 2,872,700 | 1.75 |

### Table 3: Simple Regression Analysis

| Dependent Variable | Independent Variable | Linear Equation | R^2 | Adjusted R^2 | T stat | P Value |
|---|---|---|---|---|---|---|
| S1 | W1 | S1 = -78.95 + 0.26*W1 | 0.63 | 0.63 | 11.48 | 2.85E-18 |
| S2 | S3 | S2 = 1.73 +0.9*S3 | 0.87 | 0.87 | 22.96 | 1.05E-36 |
| S3 | S1 | S3 = 0.096 +1.65*S1 | 0.77 | 0.77 | 16.11 | 1.6E-26 |
| S4 | S2 | S4 = 2.72 +0.94*S2 | 0.79 | 0.78 | 16.55 | 1.39E-23 |
| S4 | S3 | S4 = 5.06 +0.79*S3 | 0.54 | 0.53 | 9.2 | 8.79E-14 |
| S4 | W2 | S4 = -185.54 +0.53*W2 | 0.85 | 0.85 | 15.2 | 1.9E-18 |
| S5 | S1 | S5 = 2.8 +0.49*S1 | 0.47 | 0.46 | 7.81 | 4.04E-11 |
| S5 | S2 | S5 = 3.04 +0.27*S2 | 0.47 | 0.46 | 8.05 | 1.04E-11 |
| S5 | S3 | S5 = 3.69 +0.23*S3 | 0.35 | 0.34 | 6.34 | 1.59E-08 |
| S5 | S4 | S5 = 2.8 +0.49*S4 | 0.47 | 0.46 | 12.33 | 1.04E-19 |

### Table 4: Multiple Regression Analysis

| Dependent Variable | Independent Variable | Linear Equation | R^2 | Adjusted R^2 | T stat | P Value |
|---|---|---|---|---|---|---|
| S4 | S2, S3, W2 | S4 = 1.4 +1.14*S2 -0.24*S3 + .002*W2 | 0.95 | 0.95 | S2 = 8.58<br>S3 = -2.11<br>W3 = 0.03 | S2 = 6.53E-10<br>S3 = 0.04<br>W3 = 0.98 |
| S5 | S1, S2, S3, S4 | S5 = 2.82 +0.39*S1 +0.08*S2 -0.07*S3 +0.04*S5 | 0.49 | 0.46 | S1 = 4.97<br>S2 = 1.43<br>S3 = -0.89<br>S4 = 1.23 | S1 = 0.02<br>S2 = 0.16<br>S3= 0.38<br>S4 = 0.22 |

**Table 5: Site Specific Results**

| Flood Occurrence | Soil Drainage | Distance from Brook (Meters) | Land Use Type | Runoff Values | Infiltration Values | Upstream Vegetation Level | Upstream Woody Debris Level |
|---|---|---|---|---|---|---|---|
| Sometimes | Moderately Well Drained | 156.65 | Residential ¼ to ½ Acre Lot | 46.8 | 4.38 | 85-100% | 50-85% |
| No | Poorly Drained | 83.34 | Cropland Intensive Agriculture | 49.59 | 1.6 | 85-100% | 85-100% |
| Yes | Moderately Well Drained | 222.2 | Residential ¼ to ½ Acre Lot | 46.8 | 4.39 | 85-100% | 50-85% |
| Sometimes | Moderately Well Drained | 133.78 | Residential ¼ to ½ Acre Lot | 46.8 | 4.39 | 85-100% | 50-85% |
| No | Moderately Well Drained | 37.64 | Residential Larger Than ½ Acre Lot | 45.95 | 5.24 | 85-100% | 15-50% |
| Yes | Poorly Drained | 83.34 | Residential Larger Than ½ Acre Lot | 48.14 | 3.06 | 85-100% | 15-50% |
| No | Moderately Well Drained | 148.57 | Residential ¼ to ½ Acre Lots | 46.8 | 4.39 | 85-100% | 50-85% |
| Yes | Well Drained | 103.12 | Residential ¼ to ½ Acre Lot | 46.8 | 4.39 | 85-100% | 50-85% |
| Yes | Poorly Drained | 98.92 | Residential ¼ to ½ Acre Lots | 48.48 | 2.71 | 85-100% | 50-85% |
| Yes | Poorly Drained | 40.3 | Residential ¼ to ½ Acre Lots | 48.48 | 2.71 | 85-100% | 50-85% |
| Yes | Well Drained | 46.88 | Residential ¼ to ½ Acre Lots | 46.8 | 4.39 | 85-100% | 50-85% |
| No | Poorly Drained | 90.96 | Residential Multi Family | 48.14 | 3.06 | 15-50% | 50-85% |
| Sometimes | Poorly Drained | 116.37 | Residential Multi Family | 48.14 | 3.06 | 15-50% | 50-85% |
| No | Poorly Drained | 74.19 | Residential ¼ to ½ Acre Lots | 48.48 | 2.71 | 15-50% | 50-85% |
| Yes | Well Drained | 40.65 | Residential Larger Than ½ Acre Lots | 45.95 | 5.24 | 15-50% | 50-85% |
| Yes | Moderately Well Drained | 42.28 | Residential Larger Than ½ Acre Lots | 45.95 | 5.24 | 85-100% | 15-50% |
| Yes | Moderately Well Drained | 31.37 | Residential Larger than ½ Acre Lots | 45.95 | 5.24 | 85-100% | 15-50% |