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I am submitting herewith a thesis written by Christopher Scott Howley entitled "The Relationships Among Culvert Characteristics and Culvert Sedimentation." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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The Relationships Among Culvert Characteristics
and Culvert Sedimentation

A Thesis
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Master of Science
Degree
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Christopher Scott Howley
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Abstract

The purpose of this study was to investigate the relationships among various culvert characteristics and their effect on sediment deposition in culverts. The analysis included obtaining site specific field data, watershed modeling, culvert modeling, and data interpretation.

Field data was acquired for 39 culvert locations scattered across the City of Knoxville. The locations were selected based on previous maintenance records and a good distribution of characteristics subject to evaluation. The data collected included slopes, culvert material types, culvert sizes, culvert lengths, headwater depths, upstream channel conditions and downstream channel conditions. Obtaining this information required a detailed site inspection including surveying, culvert and sediment measuring, and a visual inspection and site evaluation. In addition, hydrologic and hydraulic models were also used to evaluate culvert site characteristics at study locations. The information from field investigation as well as model output was evaluated by graphical depictions and statistical comparisons. Also, data were evaluated for culvert locations that had a minimal amount of sediment build up versus those culverts with a significant sediment buildup.

Findings revealed that six of the characteristics evaluated showed some relationship with culvert sedimentation. Culvert characteristics were divided into three tiers of influence. Each tier was analyzed and assigned a

numerical value in order to develop a maintenance index. This index is proposed for use in evaluating whether a culvert, existing or proposed, may be prone to sediment deposition problems. Recommended research includes the relationship between debris and culvert sedimentation, the effect of the sediment yield from a watershed on culvert sedimentation, the relationship between the seasonal rainfall effects and culvert sedimentation, and additional statistical analysis on the data compiled within this study.

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1.0 INTRODUCTION

Maintenance of stormwater infrastructure is a topic not often taken into consideration in stormwater municipal management programs, which typically only include activities such as operation and design. Engineers who design the stormwater systems as well as the communities are both responsible for stormwater system maintenance, but rarely recognize or fully understand the problems that arise if maintenance is neglected. In most cases, management emphasis on resource allocation invests in other areas such as new development because of the increase to the tax base and growth of the community that results. Existing stormwater problems are often neglected under an emphasis on new infrastructure development with implementation of stormwater management plans. While in fact, the most important components of a stormwater management plan may be the maintenance of the stormwater infrastructure.

Maintenance of the stormwater system is required for larger municipalities by federal and state law under the National Pollutant Discharge Elimination System (NPDES) stormwater program. The City of Knoxville in Tennessee is mandated to implement a stormwater management program because the city is designated as a NPDES Phase I permittee. Many of the activities required by the NPDES permit pertain to implementation of water quality best management practices (BMP), however maintenance is an integral part of any stormwater management plan. Maintenance activities include ditching,

unclogging drains, street sweeping, cleaning curb inlets and flushing of storm systems. The majority of the stormwater system can be cleaned on an as-needed basis in response to direct calls from citizens. The remainder of the maintenance performed is done for problem areas or as problems are identified by City of Knoxville personnel (CDM 1993).

Very few stormwater management programs exist that contain preventative maintenance schedules. Maintenance is not often seen as an important issue by municipal decision makers and consequently the resources assigned to maintenance tasks are often minimal. Supporting this observation, Chandler (2001) completed a survey of 95 counties and municipalities with populations greater than 2,500 across the state of Tennessee to obtain information about Tennessee's stormwater maintenance programs. The survey indicated over 61 percent of the respondents reported that less than 20 percent of the annual stormwater and street budget is used for stormwater activities. In addition the survey showed that 40 percent of stormwater problems are attributed to needed stormwater maintenance. One conclusion determined from the survey results was that stormwater maintenance in Tennessee is given a low priority. Because limited funds and considerations are devoted to stormwater problems, a better understanding of maintenance issues is warranted.

The City of Knoxville's Engineering Department uses a database to log property owner requests for stormwater services. The database allows each request to be designated into a category related to the type of problem reported. An evaluation of 703 on-going problems was quantified to determine the number of problems that are related to stormwater system maintenance. Twenty nine percent of the requests were reported specifically as blocked drainage. An additional 45 percent of the requests were divided into the categories flooding lawn, flooding street, and flooding structure. These categories are more general, however many of the requests in these categories will be resolved by maintenance activities. Therefore between 29 and 74 percent of the property owner requests were in reference to a stormwater maintenance problem (COK SRD 2002). With maintenance being such a large portion of the workload, improved evaluation of maintenance is desired for effective scheduling.

Culverts are a very important part of the overall stormwater system. Culverts frequently replace open channels when land use development occurs in urban areas. This is the typical situation created by many roads (Debo and Reece 1995). Residential areas, particularly those that are older rely on a ditch and culvert stormwater system to collect and convey stormwater. Commercial, business, and industrial areas typically utilize a closed stormwater system, where stormwater is collected by strategically placed catch basins and conveyed through a series of pipes. The greater the density

of these urban land use types, the greater the likelihood that the storm systems will be closed stormwater systems and interconnected with one another. Therefore for this thesis, evaluation of culverts will be based on watershed land use primarily consisting of residential areas (COK LDM 2003).

Sediment deposition in culverts occurs as sediment laden stormwater passes through a culvert; the sediment falls out of suspension and collects. As sediment collects within a culvert, the capacity of the culvert decreases. This decrease in the capacity of the culvert ultimately can lead to flooding. Unlike the affect of debris, sediment can be deposited in a culvert very quickly or very slowly over time and in some cases can be automatically removed or scoured by the velocity of water through the culvert. Common origins of sediment are erosion from construction projects, erosion of the lining of ditches or creeks, and erosion occurring from typical land uses (FHWA HDS 2001). If a culvert becomes blocked or filled with sediment, less stormwater flow can pass, therefore causing the stormwater flow to back up. The backup of stormwater can cause flooding of yards, houses and businesses, and if the stormwater overtops the road then an additional hazard to drivers is created. This type of culvert failure can have very serious results including property damage, personal injury, or even death (Debo and Reece 1995).

Many characteristics of the culverts, the areas surrounding the culvert, and some hydraulic and hydrologic properties also have an influence on the

sediment accumulation potential of a culvert. Some characteristics such as the culvert slope and velocity impact sedimentation in culverts. Many other characteristics may be related to the sedimentation potential, including slope of the upstream and downstream channel, the size of the culvert, immediate upstream and downstream conditions, inlet improvements, culvert material type, and culvert condition. Some of the hydraulic and hydrologic properties include inlet or outlet control conditions, flow rate, and overtopping condition. These culvert characteristics can be used to identify their impact on sedimentation (Debo and Reece 1995; OACWA 1998).

Communities differ in methodology used to determine maintenance needs of the stormwater system. Unfortunately, very few communities take a proactive approach to resolving maintenance needs of the stormwater system due to a lack of manpower and equipment caused by budgetary constraints. The City of Knoxville has a few programs established to manage maintenance problems. They consist of the City of Knoxville's Public Service Department's maintenance crews, the Capital Improvements Program, and ad hoc task forces and committees. The Public Service Department is responsible for implementing small drainage projects and system maintenance. The Capital Improvements Program is for larger stormwater projects but competes for funding against all types of municipal projects. Task forces and committees are formed which often are used to direct the previous two programs (Johnson 2003; COK LDM 2003).

With limited resources available, the necessity of intelligent utilization of these resources is of paramount importance for the maintenance and preservation of the drainage infrastructures. Hard decisions of maintenance versus replacement or relocation require collection and analysis of the data available to best allocate these expenditures. This thesis will attempt to correlate the size, slope material and other variables in a category of culverts (roadway cross drains) with the observed maintenance conditions. Using these culvert locations as models for the various other culverts will allow decisions to be made regarding both the maintenances of existing systems, and the desired requirements for future installations of drainage infrastructure.

Relatively little information is currently available about stormwater maintenance problems. Understandably, velocity is accepted as the primary contributing factor that affects sedimentation in culverts (FHWA HDS, 2001). I suggest that other culvert or watershed characteristics also impact sedimentation of culverts primarily hydraulic culvert control, upstream channel condition and upstream channel slope.

The objectives of this research are to 1) evaluate the City of Knoxville's current maintenance practices in conjunction with maintenance records, and 2) correlate different types of site conditions and culvert design metrics with the level of sediment accumulation within a variety of culvert locations. This

project will analyze data to gain a better understanding of the causes and solutions of the maintenance problems of culverts. Specifically, this thesis will provide:

- an analysis of culvert conditions, sediment build up, watershed size, pipe material type, slope, and other factors or characteristics contributing to or relating to sediment build up in culverts, and
- a maintenance index that can be used to predict or better evaluate maintenance needs.

2.0 BACKGROUND

2.1 Storm System Maintenance

Maintenance of the storm system is an integral part of any stormwater management plan. Maintenance can be divided into three main categories: removing sediment and debris from pipes, repair/retrofit of existing pipes, ditches, etc., and replacement of existing pipes that may be damaged or do not have adequate capacity (Debo and Reece 1995). Lack of maintenance often can result in situations where the stormwater system is no longer sufficient to convey the design flows intended for the drainage system.

Maintenance problems often lead to flooding, erosion, property damage and hazards to the public. Removal of sediment and debris are also the most frequent types of maintenance and therefore of principle concern.

2.2 Culvert Failure

Deterioration of culverts can occur for several different reasons. Structural problems can lead to significant problems for a culvert. Concrete culverts that experience structural problems begin with cracking and spalling, and can ultimately collapse. Metal culverts can experience deflection, bending or total collapse. Structural problems often lead to serious flooding problems, however durability problems of culverts are more likely to lead to the culvert failure. Corrosion and abrasion are the two main mechanisms that cause durability problems (FHWA CIM 1986). Corrosion occurs from soils that

surround culverts and water that goes through them. Chemicals within the soils and in the stormwater remove the coatings from the metal culverts and increase the corrosive action. Corrosion is typically associated with metal pipes, however reinforced concrete pipes can also be subject to corrosion if water can reach the reinforcing steel. In addition, soil and stormwater acidity as measured by pH can accelerate the rate of deterioration. Abrasion occurs when stormwater laden with sand, gravel, stones, etc. passes through a culvert and wears down the wall or lining of the pipe. This process can remove the protective coating from metal pipes and can expose the reinforcing steel on reinforced concrete culverts. Corrosion and abrasion work together to compound the rate of deterioration.

2.3 Flooding

Providing for the appropriate design flows in culverts is very important. Reduced capacity of these systems can be caused by debris blockages, culvert damage and/or sedimentation. Problems of this nature can compromise the integrity of the stormwater system. Culverts not functioning properly can lead to the flooding of homes, businesses, and road. In addition to the potential damage of adjacent properties, heavy financial losses, or even worse, loss of human life could result from improperly functioning culverts. Properly designed and maintained stormwater systems are imperative to prevent these problems from occurring (Debo and Reece 1995).

2.4 Sediment

Erosion is a naturally occurring phenomenon, which is caused by precipitation, wind, and running water. The most common type of erosion that affects the maintenance of culverts is created by stormwater. Erosion from stormwater can occur in several different manners and magnitudes. Soil erosion involves three different actions: detachment, transport, and deposition of particles (Haan et al. 1994). It typically begins with raindrops landing on bare soil, where the impact of the raindrop contacting the ground begins the transport of sediment. This type of erosion is referred to as impact or raindrop erosion. As the raindrops combine together to create shallow overland flow or sheet flow, sheet erosion will occur in areas primarily transporting soil particles. The sediment that is transported in this area, the interrills, is a result of the impact erosion caused by the raindrops. As stormwater accumulates, small channels, called rills, are created in the bare soil. Impact erosion no longer occurs in the area of the rills because the depth of flow in the rills is sufficient to absorb the energy from the raindrops. Interrill erosion continues to occur between the individual rills and contributes to the rill flows. When the depth of the rills is sufficient, the shear force of the water causes soil detachment. This rill erosion increases the amount of sediment in transport as well as the size of the rills. As the depth of flow and the velocity increase, the rate of rill erosion also increases. The steepness of the slope is a critical factor, which affects the magnitude of rill erosion (Haan et al., 1994; FHWA CRP 1995).

As stormwater combines, the water flows through ditches or swales to creeks, streams and rivers. As erosion occurs, sediment is transported by the flow of water in these conveyances. Additional erosion occurs in waterways when the velocity of water is greater than the resistance to the shear forces of the lining of the conveyance, known as gully erosion or for larger conveyances, channel erosion (FHWA CRP 1995). Significant changes in size, slope, shape, material lining and direction can influence the velocity of the sediment-laden water. The velocity of the water becomes slower, causing sediment deposition. Many of these changes occur at culverts, and are therefore common locations where sediment build up occurs. Sedimentation in pipes reduces the hydraulic conditions of the system, often increasing the future risk of sedimentation as well as increased probability of flooding (FHWA HDS 2001).

2.5 Debris

Trash, brush and other debris are also frequently transported by stormwater. This floating debris is different from sediment because it is not deposited by gravity, but by encountering obstructions or settling after flows subside. Smaller storm events often do not create maintenance problems from trash, brush and debris. These smaller storms occur at relatively frequent intervals and typically stay within the banks of the ditches and creeks. Natural debris from trees and other vegetation does not usually accumulate between these

storm events. Larger storms, which do not occur as frequently, cause the ditches, creeks, streams and rivers to reach much higher levels than small storms allowing the stormwater to pick up and transport the debris. Trash and debris will be caught on bridges, culverts, trees and other vegetation as they are carried through waterways. Accumulation of debris at a culvert results in flooding, culvert damage and/or roadway flooding. The best time to resolve debris problems is during the culvert design phase. If debris problems are anticipated because of watershed characteristics, then a debris control device is typically recommended. In addition to preventing flooding problems debris control devices help keep drift and sediment off the road, it provides a safety factor in the design and it also can prevent damage to the culvert (FHWA DC9 1971). Debris control devices also allow maintenance to be performed on a scheduled basis as opposed to an “emergency” basis reducing overall maintenance needs and therefore reducing maintenance costs.

Debris control is typically considered into three different methods (FHWA HDS 2001). The first is interception, which involves obstructing or catching the debris before it can enter a culvert. The second is deflection, which involves a device that deflects the debris away from the culvert for collection at a later time. The third method is passage through the culvert. This typically accomplished with the installation of an oversized culvert. Debris control devices, if properly designed and installed, can be useful in protecting

inlets from blockage by floating debris. However, some debris control devices such as a trash rack are sometimes incorrectly designed and/or installed.

This leads to collecting and retaining debris within the trash rack, which leads to flooding. Debris control devices can be susceptible to debris accumulation on the device itself, which may reduce the flow rate of the system. Even well designed debris control structures will not function correctly, if maintenance is not performed.

2.6 Design Standards

The City of Knoxville through the Stormwater and Street Ordinance provides minimum criteria for development within the city limits. The development criteria for stormwater systems specifically relates to the peak flow discharge. All storm systems must be designed, at a minimum, to accommodate a 10-year return frequency design storm. Roadways designated as either local or collector must be designed for the 25-year return frequency design storm. Roads classified as arterial must be designed for the 50-year return frequency design storm. Stormwater systems designed where a backup could flood a building or home must be designed to prevent flooding for the 100-year return frequency design storm. The downstream drainage system must also be evaluated to handle to 2-year and 10-year storms to a downstream location. This location is either the second road crossing or a blue line stream indicated on a USGS quadrangle map. In addition, any pipe or culvert under a city street must be constructed of reinforced concrete. These are the main

requirements specified in the City of Knoxville's Stormwater and Street Ordinance regulating the design of stormwater systems and culverts (COK SSO 2003). The City of Knoxville has an additional document containing some design parameters called the Land Development Manual. This guide provides additional information concerning development criteria in addition to the requirements specified in the Stormwater and Street Ordinance. In the design section of the Land Development Manual, additional criteria are given as recommendations. One recommendation specifies 3 fps as the pipe flow velocity and slope greater than one percent to provide a self-cleaning condition. Pipes proposed with steep slopes or pipes with high velocity flows may require additional hydraulic calculations, which could result in the need for additional outlet erosion control measures (COK LDM 2003).

In addition, checklists are also provided in the Land Development Manual, which are used by the plans review staff to evaluate development plans. The checklist related to drainage includes additional criteria for new installations. Catch basins and pipes must have a logical flow path; pipe slopes cannot be too flat or too steep; a high velocity pipe must prevent hydraulic grade line problems; and pipe outlets must be sufficiently stabilized to prevent erosion (COK LDM 2003).

Little or no criteria have been developed to minimize the maintenance problems in culverts. The criteria recommended in the Land Development

Manual are often not included in new development plans. The plans review staff has some ability to make the recommendations of the Land Development Manual into requirements on a case-by-case basis. Additional requirements not related specifically to design or installation of stormwater systems can have an impact on the maintenance of culverts located downstream from construction or a newly developed site (McGinley 2003).

Construction is a major contributor of sediment to the stormwater system. Regulations for erosion and sediment control are required for all construction projects. In an effort to make sure that the erosion and sediment controls on typical sites are properly installed, the developer's engineer must approve the installation before site work begins. This mechanism reduces the downstream sediment impact. In addition, permanent water quality ponds are typically installed on most new development sites. These ponds provide extended detention for small storms, which aids in the removal of sediment from the given site and therefore; they can serve to prevent downstream sedimentation (COK SSO 2003).

2.7 Construction Erosion and Sediment

Even though some erosion occurs naturally, there are many factors that can influence the rate or magnitude of erosion. Changes in land use, the slope, ground cover, and the pathways of runoff are some of the primary characteristics that affect the rate of erosion. All of these characteristics are

typically associated with construction projects. Construction projects are well known as major sources of sedimentation. Sediment loads from construction sites have been reported to be as high as 50 tons per acre per year while post construction amounts of runoff are orders of magnitudes less than this amount (Debo and Reece 1995).

As the use of an area of land changes, the drainage changes both across the land and to offsite drainage systems. This can occur for several reasons. Most land use changes have one or more of the following outcomes that affects the rate of runoff; they include: denuding of site for construction (removal or reduction of trees, bushes and other vegetation); installation of impervious surfaces (buildings, parking lots, driveways, sidewalks, etc.); increases in the on site slopes of the land; and alterations of the natural flow path (Viessman et al. 1989).

On most construction sites the first order of business is to clear the site. This involves the removal of trees, bushes and other vegetation as well as the topsoil. The lack of ground cover exposes the site to erosion. Impact erosion and runoff erosion occur even in a moderate rainstorm. In addition to the erosion occurring very easily, the total surface area of the construction site that will contribute to the sedimentation is very large. Sediment runoff from construction sites can contribute over 1000 times the quantity of sediment as compared to a forested area. This erosion can pose serious problems to the

downstream stormwater system, particularly the creeks, streams and rivers. The characteristics of construction sites are also very common in agricultural locations and the comparisons between the two areas are very similar. Agricultural areas typically have large open areas where the ground has no cover and the exposed soil is often very loose due to tilling of the ground. These areas are also very susceptible to impact and runoff erosion. Even with the similarities, construction sites can produce 10 to 20 times the amount of sediment as agricultural uses (ASCE 1992).

After the construction site has been cleared and graded to the finished elevations, buildings are constructed, parking lots are built, sidewalks are installed and grass and landscaping are placed on the site to complete the development process. The change in the ground cover from a natural area containing trees, bushes and grass to rooftops, pavement, concrete and sporadically placed landscaping, cause tremendous increases in the volume and rate of runoff as well as the velocity of runoff (Viessman et al. 1989).

As mentioned previously, construction projects usually attempt to maximize the useable area for buildings, parking lots, etc. While maximizing the usable area of a construction site, the stormwater system has to be relocated. This occurs by moving the ditches, swales and other open channels to the perimeter of the development or by routing the water through pipes to cross the site, often collecting water from the parking lots, buildings, etc. The onsite

changes to the flow of water increases the velocity of the water, which causes an increase in the peak flow of the stormwater (Debo and Reece 1995). This causes two problems. The first is that as the velocity of the stormwater increases, the erosion potential of downstream unlined open channels increases. Increased erosion leads to sedimentation, which leads to stormwater maintenance problems. The second problem is that as the peak flow of stormwater runoff increases, the downstream stormwater system may not be able to carry the additional runoff. The downstream system therefore becomes undersized because of the additional runoff from the developed site.

Sedimentation causing problems or failures in culverts can often originate in the upstream ditches. The ditch line is subject to severe erosion if the velocities through the channel become greater than the lining can withstand. Erosion of this nature is very common throughout large watersheds. It is nature's way of resizing channels. The type of material that erodes from ditch lines is often larger in particle size than the erosion in other areas. The larger particles that can include rocks often settle out within a culvert creating maintenance problems (ASCE 1992; FHWA CIM 1986).

Another contributor to ditch line erosion are detention ponds. Detention ponds are common Best Management Practice (BMP) used to attenuate the peak flow from a developed site. The pond is designed to collect the stormwater from the developed site and hold the water in the pond while

releasing the water at a peak rate determined for the predevelopment condition. This method is effective in minimizing the localized effect of the peak runoff rate for a given statistically occurring storm. One drawback on the use of a detention pond is that even though the post development peak flow rate from the site has been reduced to a predevelopment condition, the volume of runoff from the site is substantially increased. Erosion problems down stream of the outlet to the detention ponds are still very common because the pond will release the stormwater at the predevelopment flow rate more frequently and for much longer periods of time than before the development was built. For these reasons the ditches, swales, creeks and streams downstream of detention ponds are very susceptible to erosion problems (ASCE1992).

Rainfall patterns affect culvert maintenance problems. Low intensity, long duration storms often do not have the high impact raindrop forces to cause erosion compared to intensity storms. Also sheet erosion is less common and therefore small amounts of sediment are transported (FHWA CRP 1995). In addition, the frequency at which storms occur may relate to the frequency at which maintenance needs to be performed. The seasonal variation of rainfall intensity can be very dramatic. Rainfall amount is a factor influencing sediment deposition in a culvert. If a storm occurs that creates high velocity flow, the culvert can be scoured of the sediment (FHWA HDS 2001). The rainfall patterns that provide this effect are unpredictable and often occur at

varying intervals, therefore, weather patterns are difficult parameter to use in determining maintenance requirements. Figure 2.1 displays the irregularities of rainfall across the seasons and year to year. This graph represents the average daily rainfall total for the City of Knoxville's rain gauges.

Watershed characteristics are a combination of all of the aspects of the land that contributes drainage to a specific point. Soil types play a significant role because of both the infiltration rates characteristic of the soil as well as the erodability of the soil. As erosion increases the sedimentation rates throughout the drainage system will increase. Land use is also a major watershed factor. Land use affects the rate and amount of runoff due to increases in the imperviousness of the land cover (Viessman et al. 1989).

The greater amount of runoff can increase erosion and therefore sedimentation. In addition, land use changes such as simply cutting down the trees in a wooded area will also expose more area to erosion. The construction process occurring in a watershed is probably the most severe land use change. Even though it occurs for a relatively short period of time, the construction process can be very damaging to downstream storm systems. The actual affect on the downstream system depends on both rainfall patterns and on site erosion and sediment controls (ASCE 1992).

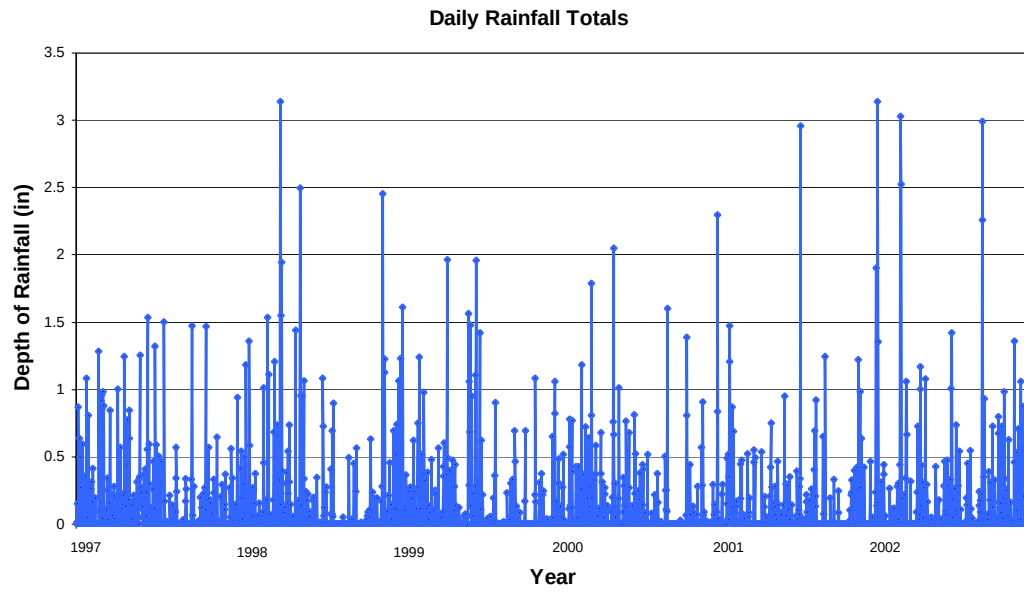


Figure 2.1. Daily rainfall totals for the period 1997 through 2002

2.8 Review of Stormwater System Cleaning Methods

Several methods using various types of equipment exist to remove sediment and debris in stormwater pipe systems. The method selected to perform the sediment and debris removal typically depends upon the financial capability of the owner of the stormwater system and the allowable amount of debris, sediment and other material that can remain in the system.

Many years ago hand augers were commonly used to clean sediment and debris from stormwater and sanitary sewer systems. The device was comprised of a cutting tip placed at the end of a shaft, with a handle to turn the device. The process was accomplished by a person entering a catch basin or manhole and inserting the auger, usually upstream, to reach the blockage in the pipe. Extension rods were added, as needed, to reach the areas of concern. The method was often only effective for blockages that occurred a short distance from an available entry point. This tool could also be very dangerous for the operator of the auger if the obstruction in the line was blocking a considerable amount of water. When the blockage was loosened or removed, the water and debris could flow through the pipe at a high velocity, often forcing the auger and extension back toward the operator. This device was dangerous and very slow at removing blockages and also relied entirely on manpower for its operation (Hudson 2002).

A major improvement on the hand auger was a continuous semi-flexible rod used to replace the hand auger extensions. The flexible rod was wound around a mandrill and the mandrill was mounted on a trailer. An engine attached to the mandrill provided the turning power for the auger. As the auger was inserted into the pipe, the engine provided the power to rotate the auger and effectively drilled out material that caused the blockage. The operator did not have to work in a confined space. This device is known as a rodding machine and is very similar in concept to the smaller plumbing snakes. The City of Knoxville used a rodding machine for many years as the principle method for cleaning pipes until more modern equipment was purchased. The rodding machine is still available for the City of Knoxville to use as a backup maintenance tool (OSCWA 1998; Farley 2002).

Another method of cleaning pipes is by flushing sediment and debris with water. One way to do this is by creating a wave of water to send through storm pipes. This method can be accomplished by inflating a device to temporarily plug a pipe immediately upstream of a section that is to be cleaned. Water is then used to fill the pipes upstream of the plug. When the pipes are filled with a sufficient amount of water to create the flush wave, the plug is rapidly deflated, often with the assistance of a vacuum pump. The force of the flush wave washes through the pipes removing some sediment and other materials contained within the pipe. A downstream location is selected to collect and remove the washed out sediments and other debris

and prevent them from continuing through the storm system. An open area is ideal, i.e., a swale, detention pond or sediment trap. If a suitable open location is not available, then a second inflatable device can be installed at a downstream location, where the sediment-laden water would be pumped out to an above-ground constructed sediment trap. This method is an iterative process, after each flush wave passes through the system, the upstream plug is re-inflated and the pipe filled with water again for the next flush wave (COK BMP 2003). This method or a similar variation is occasionally used by the City of Knoxville for storm pipe maintenance.

Improved technology has provided the stormwater industry with devices that can remove sediment and other blockages much better than the previous methods as well as operate at greater speeds. Currently, the main device that municipalities and contractors use to clean stormwater pipes is a combination sewer cleaner. The combination sewer cleaner is equipped with two main system components, the flushing system and the vacuum system. The flushing system includes an onboard reservoir to hold water, a high-pressure water pump, a high-pressure hose, and a variety of hose tips. The vacuum system includes a vacuum mechanism, a large storage compartment, and a large diameter vacuum pipe. The combination sewer cleaner is set up at a location that is downstream of the blockage or sediment that is to be removed. The vacuum and the flushing hose are both located on the same end of the truck. Before beginning the flushing procedure, a tip is

selected for the flusher hose. There are a variety of different tips, but the basic conceptual design of the tips are the same. The tips have a set of jets that thrust the pressurized water backwards, which propels the tip forward. There is often a second set of jets that thrust the pressurized water forwards, which is used to break up material or blockages. The front jets are not as powerful as the rear so as not to hinder the propulsion of the tip. Other tips are relatively small and narrow with rear facing jets only. This type of jet would be used to ram into a blockage allowing the rear jets to break away material when the tip has rammed deep enough into a blockage. After a tip has been selected and installed, the hose is inserted into the pipe with the blockage. The vacuum pipe is then lowered to the outlet of the blocked pipe. There are several notches at the end of the vacuum, which enables the system to vacuum sediment and debris without the pipe adhering to the ground by suction. The high-pressure water pump is then turned on to propel the tip and hose forward. The rear facing jets have two purposes, one of which as already mentioned is to propel the tip forward; the second purpose is to force the sediment, rocks, and other debris back through the pipe. When the debris begins coming out of the pipe, then the vacuum system is turned on to collect the material. The process of moving the hose up and down the pipe is iterative but is necessary to break up the debris. The hose also has to be frequently reeled back to the vacuum location, to pull debris for the vacuum removal. This method is highly effective for cleaning pipes and appears to be the most common one used today in urban areas. The

combination sewer cleaner is the primary method used by the City of Knoxville maintenance crews for cleaning pipes (OACWA 1998; Farley, 2002).

Other alternative equipment and techniques are also used for cleaning pipes, but are not as commonly used the techniques previously described. Alternate equipment or techniques include: cable or bucket machine, sewer ball, or by hand tools. A cable or bucket machine involves a cable pulling a device through a pipe, which collects sediment as it pulled. Sediment is removed after each pull through the pipe until the pipe is clean. A sewer ball is a ball that is smaller than the diameter of the pipe than is inserted at an upstream location in a pipe. Water is used to force the ball through the pipe and sediment/debris is force out as well. This method is more common in Europe (OACWA 1998). Using hand tools for sediment removal is sometimes the only option. In larger pipes, alternative equipment becomes ineffective for sediment removal.

2.9 City of Knoxville Current Programs for Maintenance

The primary provider of general maintenance of the stormwater systems throughout the City of Knoxville is the Public Service Department. The Public Service Department, in conjunction with the Engineering Department, receives requests for resolution of drainage problems or for specific maintenance tasks. The majority of the work performed by the Public Service

Department crew is based on property owner complaints. The maintenance crews are primarily responsible for flushing storm pipes and catch basins as well as re-establishing ditch lines. In addition to the property owner requests, areas of known problems are maintained on a regular basis or after significant rainfall (COK LDM 2003; Hudson 2003).

The City of Knoxville also has a Capital Improvements Program. This program is a multi-year plan of public infrastructure improvements, which can include stormwater projects. The Engineering Department recommends projects to be included in the program. Each project in the program competes for funding on an annual basis. A second program called the Neighborhood Drainage Program has an annual budget of \$250,000 specifically designated for drainage improvement projects. Projects selected for these programs typically are of a magnitude that is greater than the Public Service Department is equipped to handle. Some of the funded projects include cleaning of box culverts under Northshore Drive and the installation of low flow diverters, relining of the twin eighty four inch metal pipes under Papermill Drive, the evacuation and demolition of flooding houses on Emily Ave, and the removal of a house above a failed pipe and replacement of the pipe. Projects of this nature are funded each year through one of these programs (COK LDM 2003; Johnson 2003).

Task forces have also been formed to address stormwater problems for specific areas. A First Creek Task Force was formed after severe flooding occurred in 1998. The task force was responsible for making recommendations on how to handle the flooding problems. This included requesting funding for and the implementation of specific projects including bridge replacements, sediment removal from culverts, and evacuations. This task force also worked with the Army Corps of Engineers to help find solutions for the areas problems (Johnson 2003).

Many of the programs established in the City of Knoxville provide for alleviation of a single specific problem or localized area of problems. In addition, the programs use a relatively small portion of the work forces and funding on maintenance related activities. A more efficient use of available programs and resources is needed.

2.10 Maintenance Evaluation

Is maintenance necessary? I think that everyone would agree that maintenance is necessary. Anyone who sees a pipe that is completely full of sediment, has logs, branches and other debris completely blocking the inlet, or has a dumpster or other large object that partially or completely prevents water from passing through a pipe should realize that maintenance is needed. The real question is how often is maintenance needed? Funding is an important component in determining how often maintenance is performed.

Several different methods can be used to determine the frequency at which a storm system is serviced.

One method of determining what pipe systems need to be maintained and what level of problems are being caused, is through a complaint process. This method allows community residents and property owners to inform the local stormwater managers of the locations where the storm system has problems. A survey was conducted in Tennessee, which determined the methods municipalities use to prioritize maintenance. Over 35% of the respondents indicated that maintenance priorities were determined on a complaint basis (Chandler 2001). This reactive method of evaluating drainage issues usually means that a problem has already occurred, which means that the roads could have flooded, houses could have flooded, or even worse public safety could have been compromised. This method requires that complaints be taken by phone, internet or some other communicative source. These complaints have to be organized so that an inspector can evaluate the problem during an onsite investigation. The organization of the complaints by geographic area, by watershed, or by severity of the situation is very important. The fact that this method of taking complaints is based on a problem that has already occurred, typically in response during a rain storm, means that the number of complaints will spike each time a significant rain occurs. If a severe rainstorm occurs, the number of complaints reported is much greater. The inspectors that evaluate the drainage problems are

usually not able to handle the large inflow of complaints. Therefore, the timeframe that it takes from the time a complaint is received in to the time that it has been evaluated may depend on the magnitude of the rainstorm or even the duration of the rainy season. This can create long spans of time between a problem occurring and a problem being resolved.

Difficulties can also occur with this method of investigating drainage problems when receiving information from members of the community. The average person does not have a good understanding about drainage and therefore may have a difficult time explaining the drainage problems they have experienced. Additionally, there is a possibility that the drainage problems could be exaggerated to get a quicker response from the stormwater managers or because of concerns that next time it rains, the drainage problem could be worse. Regardless, obtaining as much information from the people who witnessed a drainage problem is imperative to determining a solution. Obtaining pictures or video footage taken during the storm event can also be helpful in determining a solution. The onsite inspector is responsible for determining the validity of the complaint and determining a conceptual solution. Even if other methods are used to identify and investigate drainage problems, a complaint process is still necessary. Drainage problems from blockages or system failures can occur quickly and without notice, regardless of when maintenance was last performed. This is

the primary method used for prioritizing maintenance activities for the City of Knoxville (Debo and Reece 1995; Hudson 2003).

Recording locations and frequency of maintenance is an important part of managing a community's stormwater system. The locations in the community determined to be problem areas because of frequent or regular drainage complaints or because of frequent maintenance need to be addressed specifically. The stormwater manager determines areas that have frequent maintenance needs and categorizes these locations in a different manner than the rest of the stormwater system. Chandler (2001) conducted a survey in Tennessee that determined methods different municipalities use to prioritize maintenance. In this survey, over 24% of the respondents indicated that maintenance was performed after significant storms. Types of maintenance problems that require a frequent maintenance interval are usually caused by debris. Many systems are prone to having a tremendous amount of debris buildup at the inlet of pipes due to a wooded landscape of the watershed, due to a grate or grating system used to collect or divert debris from entering a stormwater pipe opening, or due to the human factor, where people regularly dump trash, debris or other items that can block an inlet, further down in the watershed. These locations where blockages are predictable are best managed with a proactive approach to maintenance. After each significant rainfall, each of the locations designated as "problem spots" need to be inspected and maintained (Debo and Reece 1995). Taking

this approach saves time and money because the maintenance action is taken automatically without waiting for a complaint to be made. This can prevent flooding problem and property damage from occurring from subsequent stormwater flows (Farley 2002).

Communities that have high levels of stormwater management funding have the ability to take a proactive approach to a community's maintenance needs. Creating a stormwater inspection/maintenance schedule can provide a very economical and efficient method of identifying the maintenance needs for the community. The locations inspected are based on the regular inspection schedule for the locations. Chandler (2001) found in a Tennessee survey that over 34% of the municipalities indicated that maintenance activities were performed based on routine scheduling. The methodology involves sending an inspector out acting as a scout to determine the maintenance needs of the stormwater system before maintenance crews are deployed. The inspector can determine whether there is a need to perform the maintenance, if no maintenance is needed, it saves the time the maintenance crew would have taken to drive to the location and setup the equipment. The inspector would use condition standard for recommending maintenance. For instance a condition standards could be stated that if the pipe is greater than one-third obstructed with sediment or debris, then maintenance is needed. Obtaining this information with the use of an inspector can be a significant cost savings while still providing a proactive stormwater maintenance service. Inspection

of the entire storm system should be made at a minimum of once every 10 years and some other storm features such as catch basins should be inspected twice yearly (Debo and Reece 1995).

Many of the drainage complaints that are made to the stormwater managers state “There was no problem until the new development was built...” (Johnson 2003). This statement might very well be the case because some problems are created due to the change in land use and land cover from new development (impervious area and vegetation removal), while other problems are created due to lack of maintenance in the downstream system. Problems occurring from maintenance issues can be caused from neglect of the system before development begins, sedimentation originating from new development during the construction phase of a project, or more likely a combination of both. An option to minimize the impact of new development as well as reduce the cost to the taxpayer for stormwater maintenance would be to require the developer to perform some level of downstream maintenance to the storm system at the completion of the development. This effort would in no way reduce the need or requirements for on-site erosion and sediment control best management practices. The determination of how far downstream maintenance would be required, as well as the level of maintenance, depends on several variables. A few variables to be considered include: size of the watershed, size of the development, and size of the downstream system and topographic characteristics. During the design phase of most new

developments, the design engineer evaluates the downstream system using these same characteristics as well as minimum site development regulations to identify the impact of the new development on the existing downstream system. During this analysis very little consideration, if any, is given to the conditions of the downstream system or to the maintenance needs of the system. It is generally assumed to be in proper functioning condition. This misrepresentation of the conditions of the storm system in conjunction with altered runoff conditions from a developed site could be a significant factor in problems that occur after a development has been completed. The downstream impact study for most sites located in the City of Knoxville is required to analyze the downstream storm system until the system reaches the second road crossing or the system reaches a blue line stream, whichever comes first (COK SSO 2003). The same criteria could be used with consideration to downstream maintenance requirements for developments. Performing maintenance in this manner is very beneficial to minimize the impact of construction and development and to minimize the complaints generated near a new development. This work would save the taxpayers money, could prevent flooding and property damage, and could potentially prevent litigation for other legal cost due to downstream problems. One major drawback to this method is that it would not be popular with developers even though it has the potential to prevent legal action against them. The common view of developers is the stormwater manager should maintain stormwater systems regardless of the development, and that the additional costs would

make the project too expensive. Other problems requiring developers to maintain the downstream system are the land rights of the adjacent property owners. Easements may exist on the properties designating a location for drainage; however property owners typically do not want their properties altered by developers and often do not want new developments to be constructed. Therefore, many homeowners could attempt to prevent a development from being built by denying access to their property (McGinley 2003).

Common sense tells us that every community uses some combination of these maintenance methods. Even with the most proactive approach of determining maintenance needs, all communities have problem areas that are given special attention or additional consideration. In addition, most communities have some variation of complaint driven stormwater evaluation procedure. Each method has its share of pros and cons mainly in regard to cost of implementation and resources used versus the quality of stormwater maintenance service provided.

2.11 General Culvert Design Procedure

Culverts are often seen as a simple pipe system, when they are actually some of the most complex hydraulic conditions because of the variety of flow conditions that can occur. There are typically considered to be six flow types for culverts. The flow types are based on depth of water at the inlet and outlet

of a culvert as well as the slope characteristics. However, the more important distinction is the division of the flow types into either an inlet control or outlet control condition. Two of the flow types are inlet control and four are outlet control (Sturm 2001). The following culvert design procedure consists of typical methodology for sizing a culvert. It is understood that many complex situations exist that would require more analysis than is presented in this section. This procedure should however, provide guidelines for the majority of culvert designs, where calculation use is determined primarily on either inlet or outlet flow conditions.

There are seven basic steps that must be completed for each culvert design. Culvert design is an iterative design procedure; therefore the steps presented here are often repeated several times for a given design. The procedure is a combination of hand calculations, charts and nomographs used to evaluate a culvert. Other methods for designing or evaluating a culvert exist, which include direct calculations for the entire procedure as well as software programs. The software programs can be relatively easy to use but the methods used are not always fully understood by the user. The direct calculating procedure is complex, takes a long time and can be confusing. Using the charts and nomographs in conjunction with some simple equations can yield good values in a straightforward manner.

The seven basic steps that follow a general culvert procedure are as follows:

Step 1. determine design data; Step 2. trial culvert size; Step 3. calculate assuming inlet control; Step 4. calculate assuming outlet control; Step 5. compare HW values for step 3 and 4 (the higher HW governs); Step 6. try an alternate culvert size and repeat step 3; and Step 7. compute outlet velocity.

2.11.1 Step 1 - Determine Design Data (Considerations)

The first step in culvert design is to determine the constraints that affect the design. The primary factor is to know or determine the given design flow for the culvert. The design flow is determined with hydrological calculations or hydrological models. The calculations or model determined flow rate in part by a design storm frequency that is often specified by local government ordinance. Many geometric and physical constraints need to be determined and/or surveyed as well. They include the available slope, the length needed for the culvert crossing and the maximum headwater allowable based on roadway overtopping elevations or potential u/s flooding. The headwater depth is a measurement of the distance from the inlet culvert invert to the height of water above the inlet. Other information that may dictate design parameters includes the maximum allowable velocities in the receiving open channel, the culvert material type which may also be dictated by local government ordinances, the cross-sectional shape and the entrance conditions (ASCE 1992).

2.11.2 Step 2 - Trial Culvert Size

After the initial site and background information is determined, a trial culvert size is selected. The method for selecting a trial culvert size can vary, however there are three common methods that are frequently used. An arbitrary culvert size and shape, or an educated guess based on experience can be a good starting point. An approximating equation such as dividing the flow rate by ten and resulting in a trial cross-sectional area can be used. A third method involves using an inlet control nomograph with the design flow value and an assume headwater divided by diameter value of 1.5 to calculate a trial diameter. Regardless of the method selected for the initial culvert size, the final culvert size selected should not be affected. However, the better the trial culvert size, the fewer iterations of the design procedure will be required; thus speeding up the culvert design process (ASCE 1992).

2.11.3 Step 3 - Calculate the Headwater Depth Assuming Inlet Control

Two possible conditions exist for inlet control, unsubmerged and submerged. The unsubmerged inlet condition occurs when the depth of water at the culvert inlet is not deep enough to submerge the crown of the culvert. This condition is usually considered unsubmerged when the headwater depth divided by the culvert diameter is less than a range of 1.2 to 1.5 (Sturm 2001). Also, the slope of the culvert invert is generally steep enough so to sustain supercritical flow conditions. When these conditions occur the culvert will act similar to a weir (ASCE 1992). The submerged inlet condition occurs when

the headwater divided by the depth is greater than a range of 1.2-1.5. In this condition, the culvert will not flow full and it will act like an orifice. Submerged condition is generally the condition designed for in order to take advantages of the hydraulic benefit of an increased discharge capacity with the increase in headwater depth (Sturm 2001).

The orifice coefficient varies with hydraulic head on the culvert as well as the culvert type and material and entrance geometry. Rating curves for inlet control have been created for several culvert materials, shapes and inlet configurations. Nomographs were developed empirically and were created by pipe manufacturers, the Bureau of Public Roads, and the Federal Highway Administration (Figure 2.2). They can be used to assist with calculating the flow condition for both unsubmerged and submerged conditions and are the recommended method used for culvert design (ASCE 1992).

Nomographs provide the headwater depth with minimal calculation. The input includes trial culvert size, the design flow rate, inlet conditions, and diameter or width of the culvert. The appropriate lines are drawn on the nomograph, which yields a value equal to the headwater divided by the culvert diameter or width. This value is multiplied by the diameter or width providing the headwater depth (FHWA HDS 2001).

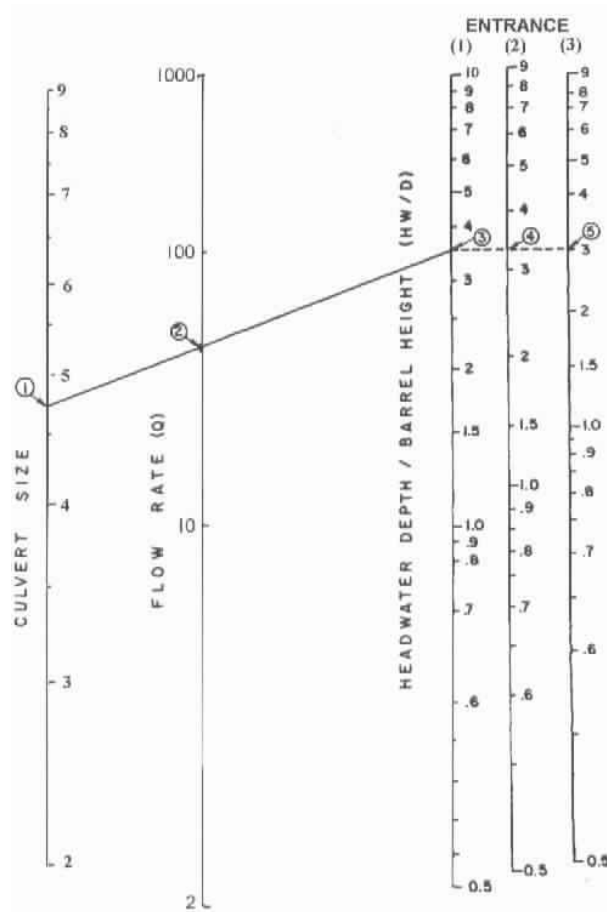


Figure 2.2. Nomograph for culvert design (FHWA HDS 2001)

The headwater depth obtained from the nomographs is evaluated with the original design criteria. If the headwater depth is acceptable for the location then outlet control needs to be checked. If the headwater depth is not acceptable then a new trial culvert size needs to be selected and the inlet control procedure needs to be repeated until an acceptable headwater depth is calculated (ASCE 1992).

If nomographs are unavailable or do not exist for a design situation, then equations exist to calculate both unsubmerged and submerged conditions directly. These equations could be used obtaining similar results. Calculating the headwater with this method requires that the equations for both unsubmerged and submerged conditions be calculated for a series of flows. The flows must be plotted into curves including plotting a transition zone tangential to each flow curve. Using the nomographs prevents applying this additional step. The nomographs were developed to include the transition zone and will there for yield results directly, which is why they are recommended over direct calculations, for use in culvert design (FHWA HDS 2001).

2.11.4 Step 4 - Calculations Assuming Outlet Control

Outlet control will govern if the headwater is deep and the slope is sufficiently flat and the culvert is sufficiently long. The tailwater condition also governs outlet controls, where the tailwater is defined as the depth of water measured

from the invert of the culvert outlet to the water surface elevation. There are three main conditions considered when evaluating outlet control. They are when: 1) the culvert flows full such that the inlet and outlets are submerged, and the outlet tailwater submerges the culvert outlet; 2) the headwater submerges the top of the culvert and the culvert is unsubmerged at the outlet; and 3) the headwater submerges the top of the culvert and the slope is subcritical and the tailwater depth is lower than the pipe critical depth (ASCE 1992). Several variations of these primary conditions exist, however the design procedure takes those variations into consideration.

The basis for the outlet control procedure assumes that the final culvert diameter accepted in the inlet control procedure is used for the first iteration of the outlet control procedure. The first step is to determine the tailwater depth. The method of determining the tailwater depends greatly on the situation. For many situations, normal depth calculations for the receiving open channel are calculated to determine the tailwater depth or elevation. However, if a backwater effect occurs at a downstream location, a backwater elevation must be determined. In addition, field observations or measurements such as proposed culvert discharge into a pond might also produce the appropriate tailwater value. Next, the critical depth value must be determined. This value can be obtained from a curve on a chart developed for a specific culvert size and material type. The critical depth value is displayed as a function of the design flow. In no circumstance can

the critical depth value be greater than the culvert diameter. Figure 2.3 indicates a typical critical depth chart. The procedure follows with the calculation of the average diameter of the culvert, and the critical depth, followed by the calculation or determination of the tailwater depth. The greater of these two values controls and will be used to determine the headwater elevation. An outlet control nomograph is then used to determine the total losses through the culvert. The nomograph provides the losses based on the design flow rate, the entrance loss coefficient for the given inlet condition, the length of the culvert which includes consideration of the roughness, and the culvert size. If the culvert material type is different than the one represented in the nomograph, then a length correction is made based on the Manning's n value on the nomograph versus the actual Manning's n value (FHWA HDS 2001). In some cases one or more variables may be outside of the ranges for the nomographs. In those cases direct equations should be used which are based on the principle of the conservation of energy (Bernoulli's Equation) (ASCE 1992). Finally the headwater depth is calculated. The headwater depth is equal to the sum of the outlet invert elevation, the total energy losses, and the greater of tailwater comparison mentioned above minus the inlet invert elevation (FHWA HDS 2001).

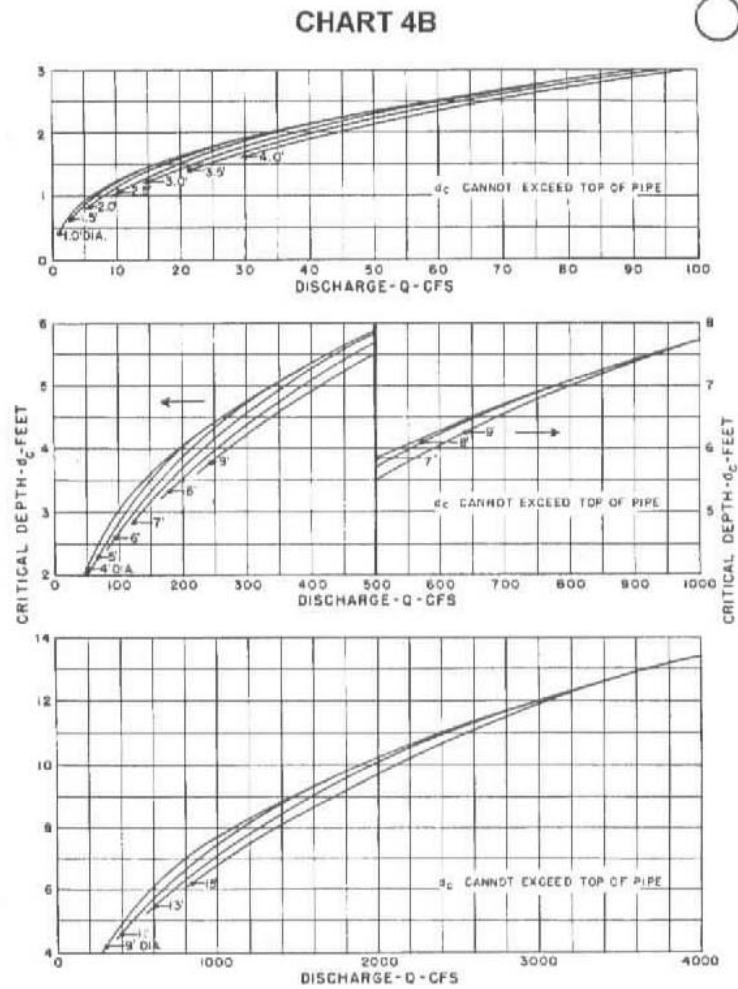


Figure 2.3. Critical depth charts (FHWA HDS 2001)

2.11.5 Step 5 - Compare Headwater Values

The headwater values should be compared for both the inlet control procedure and the outlet control procedure. The method that yields the greatest headwater value is the method that controls for the design storm and is therefore the control used. If the inlet control headwater value is higher, then the culvert sizing is complete. If the outlet control headwater value is higher, then additional steps need to occur (ASCE 1992).

2.11.6 Step 6 - Try Alternate Culvert Size

If the headwater depth for outlet control is greater than the headwater depth for inlet control and does not meet the design criteria, then repeat step 4 with an alternate size culvert or modified culvert characteristics (ASCE 1992). Typically a larger culvert will need to be selected because inlet improvements provide only a minimal flow increase when a culvert is in outlet control (FHWA HDS 2001). This iterative process must continue until an acceptable headwater value is determined. When the headwater elevation is deemed acceptable then the last trial pipe selected is used. Once outlet control has been established, there is no need to re-run the new trial culvert sizes through the inlet control procedure (ASCE 1992).

2.11.7 Step 7 - Compute Outlet Velocity

Determination of the outlet velocity is dependant on whether the culvert is in inlet control or outlet control. For inlet control the velocity is calculated based on the assumption that normal depth flow occurs at the outlet (FHWA HDS 2001). This is accomplished by using Manning equation, which takes into consideration the flow rate, the cross-sectional area of the culvert, the roughness related to the material type, and the slope of the culvert. The normal depth is calculated from Manning equation and then the normal depth is used to calculate the flow area (ASCE 1992). The flow rate divided by the flow area yield the velocity at the outlet.

For outlet control, determining the velocity at the culvert outlet is dependent on the depth of the tailwater. If the tailwater is higher then the diameter of the culvert then the velocity calculation is simply the flow rate divided by the cross-sectional area of the culvert. If the tailwater elevation is lower then the top of the culvert then the greater of the critical depth and the tailwater elevation is used. This value is used to determine the flow area. The flow rate divided by the flow area provides the velocity for the outlet of the culvert (ASCE 1992). The velocity at the outlet of the culvert should be compared to the erosion potential of the channel in the most critical area just downstream from the culvert outlet. The use of energy/velocity dissipaters should be used when required to prevent scour at he culvert outlet (ACP 1998).

When roadway overtopping is allowed to occur at a culvert location, a design may need to include calculations for the flow across the roadway. A roadway that has water overtopping it acts similar to and is modeled like a broad-crested weir. If roadway overtopping is considered or evaluated with a culvert design, then an additional step would be included in the culvert design process. An iterative approach occurs to determine the division of flow between the culvert flow and the flow across the roadway (Sturm 2001). There are often limits of maximum depths of flow across roadways for a given design storm and should be considered in the allowable design criteria.

The preceding procedure provides a general culvert design method. This method or a similar variation is commonly used for culvert design. However, culvert design software programs are readily available and should provide equivalent results. The models have the ability to provide quick results and can evaluate numerous variations for a given design. In addition, many programs can also provide performance curves that can aid in evaluating many different design situations (Debo and Reece 1995). The only potential problem with using a software program is that a designer may not understand how the program determined the results.

2.12 Culvert Design and Maintenance Considerations

The process of culvert design often ends after a size has been determined. Consideration in a design to prevent or reduce the need for routine

maintenance with respect to sediment removal can be incorporated into many designs. Some guidelines are available to provide assistance when designing to prevent maintenance. Many of these guidelines are essentially based on the concept that if the velocity of the stormwater in a pipe reaches a specific velocity, then scour will occur removing sediment from the pipe. Other design alternatives can reduce the maintenance needs of a culvert. In addition to specific design modifications to a culvert, there are also structural and non-structural Best Management Practices (BMPs) that can aid in reduced maintenance design.

There are several different resources that provided suggested guidelines to ensure velocities intended to prevent or minimize sediment build up in storm systems. (Debo and Reece 1995) suggests a minimum velocity of 2.5 feet per second when the culvert is flowing partially full to ensure a self-cleaning condition. ASCE (1992), the Design and Construction of Urban Stormwater Management Systems, states that the minimum slope should be capable of producing a velocity of at least 2 to 3 feet per second when the sewer is flowing full. COK LDM (2002), the City of Knoxville's Land Development Manual specifies the minimum design velocities should be at least 3 feet per second to ensure that a storm drainage system has some capability for self-cleaning, with a recommended target slope of 1% or greater. ACP (1998), the Concrete Pipe Design Manual suggests that a minimum velocity of 3 fps is typically specified based on the specific gravity found in debris-laden

stormwater. AASHTO (1991), the Model Drainage Manual says 3 fps as a minimum velocity at design flow.

OACWA (1998), the Municipal Stormwater Toolbox for Maintenance Practices takes a somewhat different approach to specifying pipe scour minimums.

These values were determined from optimization models used to develop allowable slopes for various pipe sizes as follows: 1) 2.1% for 8-12 inch pipes; 2) 0.9% for 13-24 inch pipes; and 3) 0.3% for 25-47 inch pipes. These guidelines for each pipe size provide slopes, which, in application, correspond to velocities recommended to scour a culvert. Assuming that the pipes are flowing full and the pipe friction is consistent with concrete pipe or corrugated metal pipe, the following are ranges of velocities corresponding to the slopes listed above: 1) 2.7 - 6.6 feet per second for 8-12 inch pipes; 2) 2.5 - 6.8 feet per second for 13-24 inch pipes; and 3) 2.2 - 6.2 feet per second for 25-47 inch pipes.

When using velocity-based guidelines in a culvert design, it is difficult to fully understand exactly how to apply the standards. The majority of the guidelines specify a minimum velocity for the culvert. Some of the guidelines do not specify when or how often the minimum scour velocities need to occur to provide a self-cleaning culvert. The resources that provide a designation, when the culvert is “flowing full”, are suggesting that this scour velocity will not need to occur frequently, as this velocity will not occur until the culvert is

flowing at least $\frac{1}{2}$ full. Velocities are much smaller when the flow depth is low. The lower flow depths are typical of storm flows that occur frequently. Storms required to meet or exceed the minimum velocity would occur infrequently. This concept for designing a self-cleaning culvert is widely accepted, however application of the approach is not well established and can be somewhat subjective. The guidelines produced by the Municipal Stormwater Toolbox for Maintenance Practices are based conceptually on the same velocity based approach but provide an easy method for implementation. In addition, models were produced to backup the use of their method (OACWA 1998).

The greater the velocity of a culvert relates to a greater scour of a culvert, however there are other considerations that need to be addressed. Scour is critical for self-cleaning culverts, however, as the velocities of water increases through a culvert, the impact at the outlet of the pipe increases. The linings of the ditches downstream of a culvert are not always capable of handling the velocities of water that are created by the culvert, which is another reason that the velocities should always be calculated as indicated in Step 7 of the culvert design procedure in the previous section. High velocity stormwater results in severe erosion immediately downstream of the culvert outlet. However, the benefits of having a “self-scouring” culvert far outweigh the negative attribute of high outlet velocities. Improvements can be made to the outlet of the culvert and/or to the downstream system to reduce the velocities

and prevent the erosion problem. These improvements are in the form of energy dissipaters or armoring of the channel. Examples of these devices include headwalls, velocity dissipaters, and lining the downstream ditches. Many popular methods for lining the channel include riprap, concrete, and geotextile matting. Even if the guidelines for a scouring culvert design cannot be met due to topography or grade problems, the velocity should still be calculated as a means of determining the maintenance needs of the culvert post-construction (ASCE 1992). Some pipe material types have maximum allowable velocities for their use. Corrugated metal pipe should not be used if the velocity is greater than 10 feet per second. Reinforce concrete as well as some other pipe material types do not have a specified maximum velocity (Debo and Reece 1995).

It is possible to alter the inlet of a culvert to improve the capacity. Inlet improvements of culverts reduce the entrance losses. The primary driving factors for culverts in outlet control are headwater depth, tailwater depth, and culvert barrel characteristics. When culverts are in outlet control, the entrance conditions are only a small portion of total losses. Therefore, inlet improvements are typically not considered for culverts in outlet control unless they are very inexpensive to implement. Culverts operating in inlet control have the greatest ability to improve flow capacity with an inlet improvement. The primary levels for inlet improvements are the bevel-edged, side-tapered, and the slope-tapered inlets (Debo and Reece 1995).

The first level of inlet improvement is the easiest and least expensive method. This method involves using a bevel-edge at the inlet into the culvert. A bevel is essentially a transition between the face of the culvert and the inside of the culvert. Typically, the bevel is a straight but a rounded transition can have the same affect. Adding a bevel to a square-edge inlet culvert design can increase the culvert capacity by five to twenty percent. Culverts flowing in outlet control are not improved much with inlet improvements, however if the cost is minor it is recommended to use a bevel-edge for all culverts (Debo and Reece 1995).

The second level of inlet improvement is the side-tapered method. This type of inlet involves a widening of the face area (opening) of the culvert by tapering the sidewalls. Two possible control points result in the culvert. One is at the face of the culvert and the other is at the throat. The face is the open area of the culvert inlet. The throat is the location at the end of the taper where the culvert diameter becomes uniform. The greatest improvement in capacity requires the control location to occur in the throat for the design discharge (TxDOT 2002). Tapered inlets improve culvert performance, primarily by reducing the contraction at the inlet control section. Calculating performance curves for culverts with tapered inlets helps to assure that the designer is aware of how the culvert will perform over a range of discharges (FHWA HDS 2001). Replacing a square-edge inlet of a culvert with a side-

tapered inlet can improve the flow capacity by twenty five to forty percent (Debo and Reece 1995). In addition, depressing or lowering the throat section of the culvert or installing a depression upstream of the side-tapered inlet can provide additional flow rate benefits. Some inlet configurations also depress the inlet below the streambed to further improve the flow capacity. Edge conditions are normally improved first and then inlet depression is considered. As mentioned previously use of tapered inlets are not recommended on culverts flowing in outlet control because the simple beveled edge provides the same benefit at a substantially lower cost (FHWA HDS 2001).

The third level of inlet improvement is the slope-tapered method. This method incorporates the efficient flow characteristics of side-tapered inlets with more of the depression area or fall located at the throat section. An increase in head is provided with a lowered culvert, and a fall provided in the enclosed entrance pipe section (Debo and Reece 1995). This design technique uses elevation head to force the flow into the culvert entrance. An advantage over the standard side-tapered inlet method is that there is more head available at the throat. Also, the face sections of these inlets are larger than the face sections of equivalent depressed side taped inlets (FHWA HDS 2001). The tapered inlet section is at a steeper slope than the culvert. Therefore, a bend is also required to transition into the culvert. This provides for the possibility of three different control sections, the face, the bend and the

throat. The bend section typically will not control if general design guidelines are followed. The face is typically oversized so that the throat section will provide the control (Debo and Reece 1995). With proper design a slope-tapered inlet passes more flow at a given headwater elevation than any other culvert configuration (FHWA HDS 2001). In fact, slope-tapered inlet improvements can have greater than 100 percent increase in flow capacity as compared to a standard culvert with a square-edged inlet (Debo and Reece 1995). However, slope-tapered improvements are not generally practical for culverts because of their complexity. Construction difficulties are inherent and can often produce undesirable outcomes. Additionally, this configuration has a tendency to allow sediment deposition resulting in undesired maintenance problems. The improvement is also limited by the minimum slope allowable in the main portion of the culvert. As similar to the side-tapered method, the slope tapered method is not used with culverts in outlet control (FHWA HDS 2001).

Design of an improved inlet is similar in concept to the standard culvert design. A different set of nomographs is used to provide headwater, capacity and size relationships. The improved inlets provide options to improve existing culvert locations as well as minimize the size needed for a new culvert installation (FHWA HDS 2001). Additional factors to consider are that, if a culvert size is reduced in the design process due to an improved inlet, then the culvert should be rechecked to verify that the culvert does not revert

to outlet control. In addition, improved inlets can become serious maintenance problems from debris becoming lodged between the face and throat of the culvert. The use of culvert inlet improvement should not be used in areas where significant amounts of debris are expected (TxDOT 2002). As was mentioned that slope-tapered inlets have the negative attribute of allowing sediment deposition, however beveled edge and side-tapered inlets have the potential to reduce/prevent sediment deposition. Inlet improvements have the benefit of increased capacity of the culvert. This increase within in the culvert not only relates to the flow, but also relates to an increased velocity for a given storm. The increased velocity can aid in scour of the culvert (Debo and Reece 1995).

3.0 METHODS

3.1 Study Area Description

The study area was the City of Knoxville located in east Tennessee near the Junction of the Holston River and the French Broad River. Figure 3.1 indicates the Knox County in which the City of Knoxville is located. Knoxville is the third largest city in the state and it has a population of 173,890 according to the 2000 census figures. The City of Knoxville is approximately 100 square miles in size (COK FF 2003). The Knoxville area is a good choice for study area because of the availability of geographic information systems (GIS) mapping, which provides contour maps at two foot intervals, planimetric information including houses, streets and parking lots, and a storm system inventory. In addition, the maintenance record for Knoxville's stormwater system includes the date that maintenance took place as well as to the nature of the maintenance. The distribution of locations selected for this project are well distributed across the Knoxville.

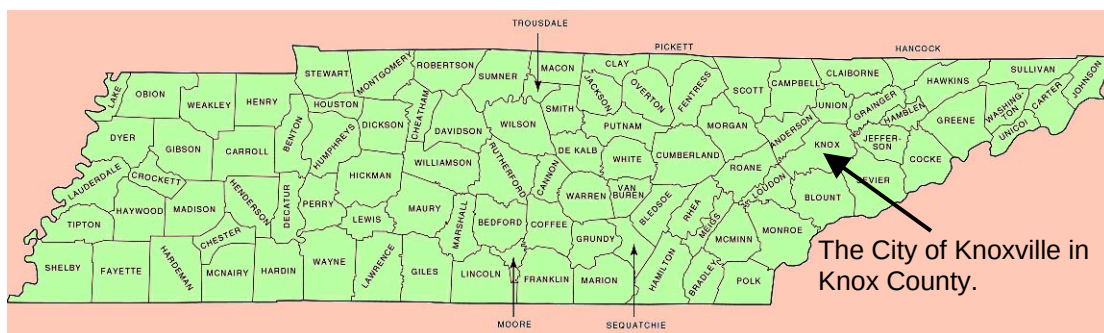


Figure 3.1. City of Knoxville location map (Moore et al. 2004)

3.2 Knoxville's Stormwater Maintenance Records

A work order is the first step in the process that provides information regarding specific maintenance of stormwater systems. The City of Knoxville's Engineering Department writes a variety of work orders for stormwater problems in response to problems or requests from the community. One type of work order often written is to clean and remove sediment and debris from pipe systems. Work orders consist of a brief description of the work required as well as a map indicating the specific locations in which to perform the described work. These work orders are sent to another Knoxville department, the Public Service Department. This department is responsible for implementing the work orders received from the Engineering Department. After the Public Service Department completes the work, the work order is turned in and the date completed is recorded in a database.

3.3 Criteria for Data Inventory Selection

A variety of criteria were used to determine which location to use for this thesis. Possibly the most important criterion was whether the pipes had been cleaned out completely. Unfortunately, the process and existing records could not supply this information; therefore, some assumptions had to be made. In order to analyze the data collected for this project, it was assumed that the pipes indicated on the work orders were thoroughly cleaned of sediment and debris. The public service department typically uses a

combination sewer truck, which is sometimes assisted by mechanical equipment or high-pressure fire hoses for this purpose. With the use of this type of equipment it is fair to assume that the storm systems are cleaned of sediments and debris. Due to the nature of most storm systems, it is very difficult to confirm that the material has been completely removed from the system. The systems are often only accessible from a catch basin or junction box and are sometimes very deep. This prevents a visual confirmation of the conditions inside the pipes. Because of this primary limitation, culverts or cross-drains were selected for analysis in this project. Culverts span relatively short distances and typically can be visually inspected at either the inlet or outlet side to determine the conditions inside the pipe. This enables the Public Service Department crew to visually determine whether the culvert has been successfully cleaned. In the case of cross-drains, it is reasonable to assume that the culverts were thoroughly cleaned. In addition, past observations and associations with the crews responsible for executing these work orders further supports the proposition that the cleaning was accomplished in a thorough manner.

An additional reason for selecting culverts was to have the ability to compare one storm system to another. Storm systems consist of many sections of pipes connected to each other by catch basins and junction boxes. Pipes are typically different sizes and often connect to each other at many different angles. It would be very difficult to compare one storm system to another

because of the difficulty of finding two similarly configured storm systems. In addition, according to the City of Knoxville's policy, the City is not responsible for maintenance of storm systems on private property, and many portions of storm systems are located on private property. This is not the case with cross-drains. Cross-drains are all configured in a very similar manner, and therefore a comparison of one location to another has more meaning than a typical storm system. Cross-drains are also typically located on public property, which means the City is responsible for the maintenance of these culverts.

The individual locations were selected by first going through the work orders submitted by the Engineering Department from 1994 to 2000. The work orders that involved cross-drains that could be used in this project were photocopied for further review. One hundred and thirty eight locations were selected for possible inclusion for this project. As part of this review process, locations were divided into small, medium, and large culvert sizes in an attempt to have a practical distribution of culverts. In addition to having a good distribution of culvert sizes, a variety of watershed sizes, sediment deposition amounts, and culvert configurations was also found. Differences in pipe material type were also used to obtain additional common factors that could influence the way culverts perform.

The work orders for the different locations have an attached GIS map with one feature being the stormwater inventory. The stormwater inventory is basically a rough schematic of the pipes and catch basins within the stormwater system. Pipes are labeled with sizes and material types, but the pipe symbols are not drawn to scale and are only approximately located. The inventory is based on field investigations originating in the early 1990's. This inventory is typically the best information available, but must be field verified for accuracy. Therefore, each of the 138 locations was field investigated before selecting project locations.

Many criteria were used to select locations that would be appropriate for the project. One criterion was that the location was actually a cross-drain; a pipe that had an inlet and outlet separated by a road, free from a complex of other pipes and catch basins. Another criterion that assisted the selection process was to choose an assortment of cross-drains with varying levels of sediment. If all of the cross-drains were thoroughly clean or if they were all completely full, the analysis would be meaningless. An effort was made to select locations where some of the culverts were very clean, some moderately clean, and some full of sediment.

Some of the pipe systems were not selected for the project because during field inspection they were found to have problems or conditions that made them undesirable. Several locations had pipe networks or other configuration

of pipes and catch basins that were not reflected on the maps. In some other locations the pipes were not found at all or the pipe had a structural failure. Some culverts were thought to be undersized or were in problem areas, and were therefore maintained very often. Culverts that are maintained very frequently do not allow sufficient time to accurately measure the conditions and time frames between maintenance activities. In addition, much of the maintenance for these locations is done automatically and the maintenance records may be sporadically available.

Pipe material types also affected the selection of the specific locations selected for the project. The main material types used in cross-drains are corrugated metal pipes (CMP) and reinforced concrete pipes (RCP). A relatively new material type used for storm pipes, high density polyethylene (HDPE), is not allowed for installation under roadways according to the City of Knoxville's policy and was therefore not able to be evaluated. A variety of pipe materials types would be desirable to determine if the material types have a significant effect on the maintenance of a culvert.

The overall intent is to identify the time frame between when the culvert was thoroughly cleaned and the exact time when the sedimentation was measured. In order to determine this time frame the Public Service Departments database was evaluated. In some cases the records of work orders were not available. Because no records could be found, some

potential locations were eliminated from the study. After all locations had been visited and referenced in the Public Service Department database a final dataset of 39 locations was selected for use in the study (COK RFS 2003).

3.4 Data Collection

There are many factors that could affect the deposition of sediment in culverts. The main areas that were weighed for analysis in this project included the following:

- hydraulic conditions dictating either inlet or outlet control of the culvert,
- physical hydraulic characteristics at the entrance of the culvert and at the outlet of the culvert,
- roughness of the culvert as determined by the culvert material type,
- conditions of the culvert,
- flow conditions of the culvert, and
- physical characters of the pipe such as the slope and size.

These factors required a significant amount of site investigation and data collection for each location. A variety of equipment was required to collect the field data needed to compare and evaluate the selected culverts.

3.4.1 Level Surveys

An automatic level mounted on a tripod and a survey rod was used to determine the slope of the culvert by measuring the relative elevation difference between the culvert inlet and the outlet. Using this level requires two people. One person holds the rod at the needed location and the second

person sights the rod through the instrument. The length of the culvert was also measured using either a roll-tape or a 100' long tape measure depending on the site conditions. The culvert length was measured to the nearest one-half foot. During the time frame of field data collection, an additional piece of equipment was obtained to replace the automatic level. A self-leveling rotary laser level with receiver was able to replace the automatic level, and required only one person to operate the equipment. The laser level still requires the use of a tripod and survey rod. The laser level is secured to the tripod and activated. The rod is placed at the needed location and the receiver moved up or down the rod until the device indicates the relative elevation. The amount of sediment in the bottom of the culverts often prevented the survey rod from being placed directly at the invert of the culvert. In the locations where sediment existed, the survey rod was placed at the centerline of the flow path and a reading was taken. A steel probe rod was then pushed through the sediment until the probe rod hit the bottom of the culvert. The probe rod was marked, removed from the sediment and then measured. This measurement was used to adjust the rod reading for the invert measurement of the culvert.

In addition to surveying the elevations of the culvert inverts, the elevation where the water would overtop the embankment was also recorded. This location was typically the roadway for each of the site locations. In some of the locations, the low point was the curb line or a build up of soil on the side

of the road. The overtopping elevation is used to calculate the maximum headwater (HW) elevation available for the culvert analysis.

3.4.2 Sediment Measurements

One of the primary tasks of this project was to obtain a measurement of the amount or depth of the sediment in the culvert. In fact, the majority of the analyses will be based on this determination of sediment. The location along the culvert with the greatest build up of sediment is considered the critical location. This critical area is considered to be the “bottleneck” of the system and therefore the sediment depth of these areas is used in the analysis of the culverts. Sediment measurements were obtained at both the inlet and the outlet of the culvert regardless of which was greater. Typically, in the case of round or oval culverts the sediment was measured by pushing a probe rod through the sediment at the center of the culvert until the probe rod hit the invert of the culvert. The probe rod was marked and removed. The probe rod was measured to determine the depth of sediment. If the culvert was rectangular, multiple measurements were made to establish an average depth of sediment. If more than one culvert was present at a location, the depth of sediment in each culvert was measured independently of the other. Four culvert locations consisted of more than one pipe/opening for the culvert location. In these multiple barrel locations, the sediment deposition may not have been uniformly deposited in each barrel of the culvert location. In these locations an approximation or an average was taken for each set of barrels.

In several cases the sediment was laden with rocks of various sizes. The rocks prevented the probe rod's insertion through the sediment. In these instances a distance was measured from the top of the sediment to inside top or crown on the culvert. This distance was subtracted from the total height of the culvert, which results in the depth of sediment. At a few of the sites, the greatest depth of sediment was not located in the inlet or outlet, but at a location in middle-reaches of the culvert. In these situations the sediment type typically consisted of a variety of large rocks. A direct measurement could not be made; therefore an estimate of the sediment depth was made. The estimate was based on a visual inspection and/or a photograph zoomed in on the sediment and was compared to the height of the culvert. This type of situation requiring estimation occurred at only four of the sites.

The sediment found within the culverts was evaluated for the size of the material present. The material was classified into ranges based on the D_{50} particle size. D_{50} refers to the maximum size for the smallest of one half of a given sample of the material. This size should also correspond to the median diameter of the sediment (Haan et al. 1994). Four ranges have been established to categorize sediment type. These ranges were setup after all initial site visits were made and were based on a review of the field notes and photographs. The field notes depicted a visual account of the material in the culvert. The ranges selected for the sizes occurred at apparent divides in the material types and are as follows:

- D₅₀ size of the material is less than 0.25 inch
- D₅₀ size of the material is greater than 0.25 inch and less than 2 inches
- D₅₀ size of the material is greater than 2 inches and less than 5 inches
- D₅₀ size of the material is greater than 5 inches and less than 10 inches

3.4.3 Culvert Characteristics

The material type used for the culverts is mainly reinforced concrete pipe and corrugated metal pipe. In a few locations it was apparent that extensions were added to the culverts. The extensions were not always installed with the same material type. Some of the pipes were extended with vitrified clay pipes or smooth walled steel pipes. Current standards for Knoxville require the installation of reinforced concrete pipes under the road for long-term durability and structural support. Therefore the locations having metal pipe underneath the roads is decreasing, but several location were still located for use in this study. All of the material types found in the study locations were recorded during the site visit. The main purpose for documenting material types was to determine a roughness value that is required for the hydraulic analysis of the culvert.

An addition culvert characteristic related to the conditions of the culvert was identified. Culverts often have damage, wear, alignment problems, or durability problems. These problems occur both over time and as a result of the installation. A spotlight was used to view the inside of the pipes. The culverts were categorized into three main classes. The first class refers to

culverts that have both good alignment of the joints of the pipe sections through the length of the culvert and that the surface of the material is in good condition. The later criterion typically is in reference to the level of rust on the corrugated metal pipes. The second class includes culverts that may have some minor alignment problems with the joints of the culvert and/or are showing some signs of rust or surface durability problems. The third class, which is most noteworthy, deals with pipes that had significant misalignment of the pipe sections of the culvert and/or culverts that have rust or durability problems that could affect structural stability or erosion of bedding or backfill material. This again refers to corrugated metal pipes that have rusted to a level where soil or other material that surround the culvert is subjected to the high velocities that occur. The problems of misalignment and durability can alter the hydraulics of the culvert by increasing the friction component of the system, and also by creating a situation where debris can become caught in the misaligned pipe section or in a hole rusted through in the bottom of the culvert.

There are a variety of sizes and shapes of the culverts that are being evaluated in this study. The majority is round with some being box shaped or arched. Measuring the size of the culverts is straightforward for clean culverts. A tape measure was used to measure the height from the invert to the crown of the pipe, and the width was also measured in case of box culverts or arched pipes. In locations where sediment was present, a probe

rod was pushed through the sediment to the invert of the culvert and the sediment depth was measured. Then the height was measured from the sediment to the crown and the values were added together. In locations with round culverts where sediment consisted of rocks, which prevented the probe rod from being inserted, the diameter was obtained by simply measuring horizontally across the culvert. In one of the locations the invert of the culverts could not be identified. The large box culvert had sediment, which consisted of rock and was not a standard size. In this location, the height of the culvert was measured from the lowest cross sectional elevation across the face of the culvert to the crown of the culvert. The culvert diameters or heights and widths were measured to the nearest inch.

3.4.4 Drainage Conveyance Characteristics

During the original data collection process, the slope of the ditch line immediately downstream of the culvert was not surveyed. At that time it had not been determined that this slope was also needed. GIS was used to determine most of these down stream slopes. The mapping system has contour at two-foot intervals. The distance was measured digitally on the mapping system between the pair of contour lines closest to the outlet of the culvert. From this information the slope was calculated. In several of the locations, the downstream area was either very flat or was subject of other downstream pipes that prevented having a measurable pair of contour lines. In these locations an additional site visit was required to obtain this slope.

Two locations were surveyed at a measured distance apart (typically 20 feet) and the slope was calculated.

An additional characteristic that was assessed deals with the transition or angle of flow between the channel and the culvert. This hydraulic channel condition is sorted based on the degree of this offset angle. The groups used for these parameters are as follows:

1. The alignment of the flow line between the culvert and the ditch line is primarily straight, or less than 15 degrees off the centerline of the flow,
2. The alignment of the flow line between the culvert and the ditch line is 15 to 30 degrees off the centerline of the flow,
3. The alignment of the flow line between the culvert and the ditch line is greater than thirty degrees and less than 60 degrees off the centerline of the flow, or
4. The alignment of the flow line between the culvert and the ditch line is greater than 60 degrees off the centerline of the flow.

The alignment category was assessed for the primary or greatest flow that approaches or recedes from the culvert. The determination of the angle of alignment was based on a field observation as well as careful review and measurement of the GIS mapping for the given area.

3.5 Data Records

Photographic records were also made at each site for future information or verification. Four pictures were taken at the typical site. A picture was taken upstream and downstream of the culvert, as well as of the inlet and outlet. Additional photographs were taken at some of the locations of the inside of

the culverts to depict either the sediment amount or type, or the alignment of the culvert.

The date that the sediment depth was measured was recorded. This date, in combination with the date of the last maintenance of a culvert, was used to determine the time frame that produced the observed sediment.

During each of the site visits a comparative evaluation was made to verify that the field conditions were the same as the expected conditions shown on the work order map. This comparison related to the size and the material type of the culvert. If the information in the field corresponded to information on the map, then nothing out of the ordinary was expected. However, if the information was different, further investigation was needed. The fact that the information may be different, in itself may not be meaningful, but could be an indicator that something at the site could have been altered. The stormwater pipe inventory on GIS may have some incorrect information on the system, however many of the “mistakes” on the system are actually locations that were not updated after a physical change was made to the storm system. In locations where differences were found in the field that did not match the maps, further information was needed. The Public Service Department’s database was consulted to see if records existed identifying a pipe replacement at the site location. Another site indicator that required further evaluation of the Public Service Department’s database was observable

linear asphalt patches which could indicate a culvert replacement. These two evaluations were used in conjunction with each other, which resulted in finding that a few culverts had been replaced. Those locations are still being used for this study with the assumption that the culverts were thoroughly clean the day they were newly installed.

3.6 Watershed and Hydraulic Modeling

The analysis portion of the study required several additional pieces of information to be used for analysis, including:

- the areas of the watershed,
- peak flow discharge from each location for the two-year frequency storm,
- the velocities through the culverts for the two-year frequency storm,
- determination of inlet or outlet hydraulic control for the culvert, and
- the roadways overtopping potential for the two-year frequency storm.

The first step in the process of obtaining this information required a hydrologic analysis of each of the watersheds surrounding the culvert sites. The watershed modeling software selected to perform these analyses was Technical Release Fifty-Five (TR55), version 2.0. This software package is issued by the National Resource Conservation Service (NRCS) formally known as the Soil Conservation Service (SCS). The methodology behind this software has been in use since 1975. This software requires two main data inputs. The first input is the curve number (CN), which is a calculation that determines a numerical value to represent the land use, land cover, and soil characteristics of the watershed. The second input is the time of

concentration (ToC), which is a value determining that rate at which water drains from the extent of the watershed to the point of interest. Peak flow is computed from the CN and ToC inputs as runoff from the watershed.

The runoff CN is a representative number that determines the runoff potential from a watershed. This number is calculated based on the land use makeup of the watershed in conjunction with the soil characteristics. The first step to determine the runoff curve number requires knowing the watershed area. The watersheds were drawn out by hand on GIS contour maps. The maps used were obtained in two different manners. Small watersheds where the maps would fit on 8.5 by 11 inch paper were specifically printed for this project. The larger watersheds were pieced together from copies of large pre-printed maps originating from the GIS. The inventory of stormwater features on the maps aided in the delineation of the watersheds. Pipe networks often can better describe the destinations of the runoff in many areas, which provide better information to create more accurate watershed boundaries. Once the watersheds were determined, areas were calculated with a digitizing area-line meter. This device is used by encircling the watershed boundary line, which allows the device to calculate the area. In each of the watershed the area was calculated two or three times to verify the measurement. An average was taken of the closest two values.

The next step in the method for determining the runoff CN required designating various areas into similar categories. The categories represented land cover or degree of imperviousness and were designated by a specific CN. For use in the study, the watershed land cover information was compiled from the GIS maps. The majority of the areas are urbanized locations and therefore the CN variations are relatively small. For this reason CNs were calculated based on only the following land uses and descriptions as provided by the software. Open space in good condition refers to areas that are in undeveloped locations such as lawns, park etc., which have at least a 75% grass cover. Paved streets and roads refer to the area taken up by paved roads including curb and gutter. Commercial and business refers to areas that are typically considered to have 85% impervious ground cover. Residential districts refers to area or specifically neighborhoods where the average lot size is approximately one-eighth acre, one-fourth acre, one-third acre, one-half acre or one acre. Each of these residential subgroups has a curve number to describe each residential size. Each watershed was divided into the appropriate category according to the percentage of the watershed that each represented. This was done with a combination of reasonable estimates and some area measurements determined with the digitizing area-line meter. Open space areas were drawn on the GIS maps as general boxes in areas that did not show any development; these areas were determined with the digitizing area-line meter. The roads were typically estimated based on an overview of the amount of roads in the watershed and

by estimating a standard width of a road. Urban watersheds typically have around five percent roads. The majority of the watersheds in the study were primarily residential, however some of the watersheds did include some areas that were business or commercial. These locations were also boxed in on the GIS maps and the areas were determined with the digitizing area-line meter. The final CN category used in this watershed analysis was the residential locations. There were five different sizes for the residential developments. The residential areas on many of the maps indicated only one typical size of residential properties and therefore an average lot's area was measured and the corresponding residential subcategory was used. The locations of the residential areas were not drawn on the map as some of the other categories. Instead, the residential category was typically the percentage remaining after the percentages of other categories were determined.

The final step to determine the runoff CN requires the soil type or types of the watershed. A general soils map for the Knox County area, produced by the United States Geological Survey (USGS), was used which had the county divided into ten different groups of soils. A map of the study sites was superimposed over the soils map to determine the soil groups that make up the watersheds. Each of the watersheds was composed of one of five different soil groups, which are as follows: 1) Fullerton-Clarksville; 2) Dewey-Decatur; 3) Litz-Sequoia; 4.) Tellico-Alcoa; and 5) Fullerton-Dewey.

Each of these soil groups was referenced in the TR55 manual and a hydrologic soil group (HSG) was determined. The four HSGs classified are A, B, C, and D, which are defined from best draining to worst draining, respectively. All of the soil groups were rated HSG “B” except Litz-Sequoia, which was rated as a HSG “C.”

Both the land use category percentages and the HSG values are used together to determine the runoff CN. The percentages of each category area are input into the software package in the appropriate soil group position, where a weighted average is calculated to determine a single numeric value to represent the runoff characteristics of the watershed.

ToC is the most sensitive component of the TR55 program. ToC is the time that it would take for a drop of water landing in the hydraulically most remote location to reach the point of interest. The watershed characteristics that affect the time of concentration are the surface roughness, channel shapes and sizes, and most importantly the channel slopes. TR55 breaks the time of concentration calculations into three categories, sheet flow, shallow concentrated flow and channel flow. Sheet flow is basic flow over plane surfaces in the headwater of a stream. Sheet flow is shallow flow that is generally less than 0.1 foot deep.

Shallow concentration is a flow type that occurs as the depth of sheet flow increases in depth and begins to form more defined groups of water flow without going in a channel. Channel flow begins in areas where there is a defined channel. These are usually areas that can be identified by aerial photography, are surveyed cross-sections or are blue lines on a USGS quadrangle sheet. The GIS mapping was also used to aid in calculating the time of concentration. The flow pathways were indicated on the maps. Each reasonably long path was evaluated to determine the longest hydraulic pathway. When the pathway is selected, it is divided into the three categories referenced above. The sheet flow length was determined as the distance from the hydraulically most remote point to a point within three hundred feet that has an apparent grade change that is steeper. The ground cover in these areas was assumed to be dense grass. The length of the sheet flow line was measured on the map using a roll-a-tape with a digital readout and scale. Using the contours on the map, the elevation difference was determined and the average slope was calculated for that segment of the time of concentration. The shallow concentrated flow length was determined by the distance from the end of the sheet flow length to the location along the flow path where a defined channel begins. This segment of ToC uses the surface characteristic paved or unpaved, which is used to evaluate the friction effect on the flow. The shallow concentrated flow can be broken into further segments, which can each contain a paved and an unpaved surface type. The slope is calculated in the same manner as with the sheet flow. The

channel flow segment of the ToC has its length measured from the end of the shallow concentrated flow to the point of interest. The channel flow segment can be separated into multiple sections if the need arises. The channel flow is calculated by determining a representative channel shape and size from which a cross-sectional area is calculated, a wetted perimeter is calculated, and a Manning's "n" determined. For the study group a Manning's "n" of 0.03 was used for all of the open channel portions of the channel flow calculations. The slope is calculated the same way as the other two flow segments. TR55 uses the information for each of the flow segments to determine a velocity and from that, a time is calculated. The addition of the time for each segment provides the time of concentration (USDA 1986).

3.7 Hydrological Analysis

TR55 uses the graphical peak discharge method to calculate the peak flow from the runoff of a watershed. This method uses the information previously described for the evaluation. The watershed area, the runoff CN and ToC are model inputs for this method. Two of additional pieces of information are needed for the model to run. One piece of information is the rainfall distribution. TR55 has four different rainfall distributions that are specified for the various areas of the United States. The majority of the areas across the county are subject to the type II rainfall distribution, including the Knoxville area. The type II rainfall distribution is basically a synthetically derived rainfall distribution that interpolates the design storm rainfall amount into a

distribution over a 24-hour period, with the peak of the rainfall occurring at approximately 12 hours. The second piece of information needed is the rainfall amount for the 2-year 24-hour frequency storm. The storm magnitude that was used for the study was the 2-year storm. The 2-year storm is a relatively frequently occurring storm whose flow is typically considered to remain within the banks of the creeks and ditches. It is also considered to be relatively powerful for the rainfall contributed. In the Knoxville area the 2-year frequency storm is 3.3 inches of rainfall over a 24-hour period (COK SSO 2003).

The watershed analysis used in this study conformed to the guidelines specified in the TR55 manual with a few exceptions. The graphical peak discharge method requires that the watershed be homogeneous so that it can be described with one runoff curve number. In addition, the graphical peak discharge method requires that only one main stream exist or that if more than one stream exists then all streams must have similar times of concentration. These criteria were met by most of the watersheds, however some of the very large watersheds did have multiple streams with different ToC and also had a greater variety of land uses resulting in a broader range of contributing runoff CN (USDA 1986).

The TR55 model is based on open and unconfined flow overland or in channels. Watersheds that contain storm systems require additional care

when estimating the ToC. Storm systems typically only carry a portion of a large storm event and the remaining flow finds overflow locations such as streets, lawns etc. Therefore, additional considerations for velocity determination should be made in flow paths that have storm systems. This limitation was not perceived as being a problem because the only storm of interest for the study was the 2-year frequency storm event and the 2-year frequency storm rainfall amount is the value used for the ToC calculations.

3.8 Culvert Hydraulic Analysis

The hydraulic analysis of the culvert locations was performed using a program called Culvert Master, version 2.0 produced by the company Haestad Methods. The Culvert Master program's primary reference for performing hydraulic design, analysis or sizing of culverts is the Federal Highway Administration's (FHWA) publication HDS No. 5, Hydraulic Design of Highway Culverts (Haestad Methods 2003). This is the same reference that the Federal Highway Administration's culvert software, HY8 is based. HY8 has been used nationally and has been available for many years. The results from both programs are typically very similar.

The analysis tool of the Culvert Master software was used because the culvert locations used in this study are existing facilities. The peak flow discharge from the 2-year frequency storm determined by the hydrologic modeling is a key initial input (Section 3.7). The majority of the physical

information about the culvert properties needed for input into the software was obtained from the site investigations (Section 3.4). The size and shape of the culvert was input, which provided the cross-sectional flow area as well as information for the weir and orifice calculations. The material type of the culvert is entered to provide the Manning's "n" friction coefficient that describes the friction resulting from the walls of the culvert. In seven of the sites the condition of the pipe was rated poor because of either misaligned pipe segments of the culvert or due to excessive rust in the metal culverts. For these locations the standard software determined Manning's "n" friction coefficients were not used. Instead adjusted Manning's "n" friction coefficients were manually input into the program. A value of 0.017 was used for the reinforced concrete pipes with misaligned pipe segments and a value of 0.027 was selected for the damaged corrugated metal pipes. In one of these locations the material type consisted of both vitrified clay pipe and corrugated metal pipe. The vitrified clay pipe was badly spalled and would have been assessed a value of 0.020, however the corrugated metal pipe was still the controlling material type so the value remained unchanged (Debo and Reece 1995).

Multiple culverts at one location can also be accounted for, but is only appropriate if the culverts are the same size and shape and have the same inlet and outlet invert elevations. In most locations with double culverts, each culvert was input separately creating two individual culverts. Even though the

culverts appear to have been installed as equal culverts, constructed conditions rarely are able to accomplish design specifications exactly. General survey information about the culvert including the inlet and outlet invert along with the length of the culvert provides the basis to calculate the slope of the culvert. Typically the invert of the outlet was given a value of ten and all other elevations were relative to that elevation. Inlet treatment can affect the hydraulic conditions of the culvert. The program provides an entrance condition or treatment selection list, which is available varying for material type and/or shape of the culvert. For example, round concrete pipes have inlet conditions such as projecting, groove end with headwall, etc. A concrete box culvert or a round corrugated metal pipe would have a different selection of inlet treatments. The inlet treatment of the culvert is directly related to the entrance loss values used in calculating the flow through the pipe.

Multiple options are available to depict the ditch line downstream of the culvert. The two options that were applicable for the culvert location in this study are for a free outlet condition or a specified downstream channel. Most of the locations required a specified downstream channel. A trapezoidal shaped cross-section was selected as the typical channel type for all of the culvert locations that required a downstream channel. The Manning's "n" was assumed to be 0.03 representing grass with some weeds or earth bottom and rubble sides (Debo and Reece 1995) which appeared to be consistent with

the typical field condition. Two to one side slopes for the trapezoidal channel were also the standard input. The bottom width of the channel was estimated based on photographs showing the culvert outlet and a portion of the downstream ditch line. The known width of the culvert in conjunction with the photographs provides a reasonable estimate for the bottom width of the channel. The bottom elevation of the channel was generally the same as the relative elevation for the outlet of the culvert. In cases where the downstream ditch elevation was higher than the invert of the outlet of the culvert, then the higher elevation was used.

Culverts can pass only a certain amount of stormwater. As the flows increase the water backs up increasing the level of the water. When the water backup to a sufficient level the water will overtop the roadway. This overtopping elevation was surveyed during the site evaluation and is input into the software, assuming that the roadway, curb line, etc. is acting like a broad crested weir. The weir coefficient of 3.33 was selected for use in the weir equation as recommended for the initial estimate for broad crested weirs (Lindeburg 1999). However, the sensitivity of this value was evaluated and significant deviations were not observed. The length of the weir was estimated from the photographic records and area contour maps.

The conglomeration of inputs provides sufficient information for the program to run. The program provides a significant number of results including

upstream water depth (head water, HW), downstream water depth (tail water, TW), hydraulic profile information, inlet and outlet control properties, and culvert performance curves. However, the results needed from Culvert Master for this study are inlet and outlet control determination for each site, an indication of whether overtopping occurs for the two-year frequency storm at each site, and the maximum velocities expected in each culvert location for the 2-year frequency storm.

3.9 Data Analysis

The data collected was displayed graphically and is presented in the next chapter. In addition to a graphical display, a significance factor was determined to better evaluate the data. Some of the data sets were standard x-y plots and regression was used to develop trends for the data as well as the statistical significance of the data. Other groups of data were displayed graphically, where on the x-axis values represented one of two data groups. The y-axis was numerically based. A t-test for two variables assuming unequal variances was used to determine the data averages and the statistical significance of the data (Devore and Peck 1986). The significance was determined using one tail. The remaining groups of data were also displayed graphically, where on the x-axis values represented three or more data groups. An ANOVA single factor analysis was used for these data to determine the data averages and the statistical significance of the data (Devore and Peck 1986).

3.10 Maintenance Index Development

A maintenance index was developed using the results from the data obtained for the culvert characteristics. After the analysis of the data was completed, the characteristics that showed signs of influence on sediment deposition were selected for use in the maintenance index. A trial and error process in conjunction with apparent breaks in the data were used to formulate an equation. This maintenance index equation provides a value used to predict culvert sedimentation.

4.0 RESULTS

4.1 Data Overview

The collected data as described in the Methods chapter were compiled and displayed in tabular form. Work orders collected for this study were distributed throughout Knoxville (Figure 4.1). The Figure 4.1 map has small circles which denote a work order location. Table 4.1 provides a list of the addresses close to the locations for the selected culverts in this study, based on culvert maintenance work order information. The work order location column designates how the sites will be cited. In most cases it is simply the street name where the culvert is located. In some locations where there is more than one location on a street, they are listed as 1, 2, etc.

Graphs were generated that describe the relationship between a variable and the percentage of sediment deposition in a culvert. The percentage of sediment deposition in a culvert requires an interval of time to be included to make the data comparable. Therefore, three maintenance intervals were selected and used as categories in each of the graphs. The maintenance interval is the time period between the last recorded maintenance of a culvert location to the date that the sediment data were collected. These categories were decided upon because sediment deposition typically increases over time and comparing locations where the maintenance interval was multiple years different from one another did not seem to be appropriate. The three categories are maintenance intervals less than 3.7 years, 3.7 to 4.7 years and

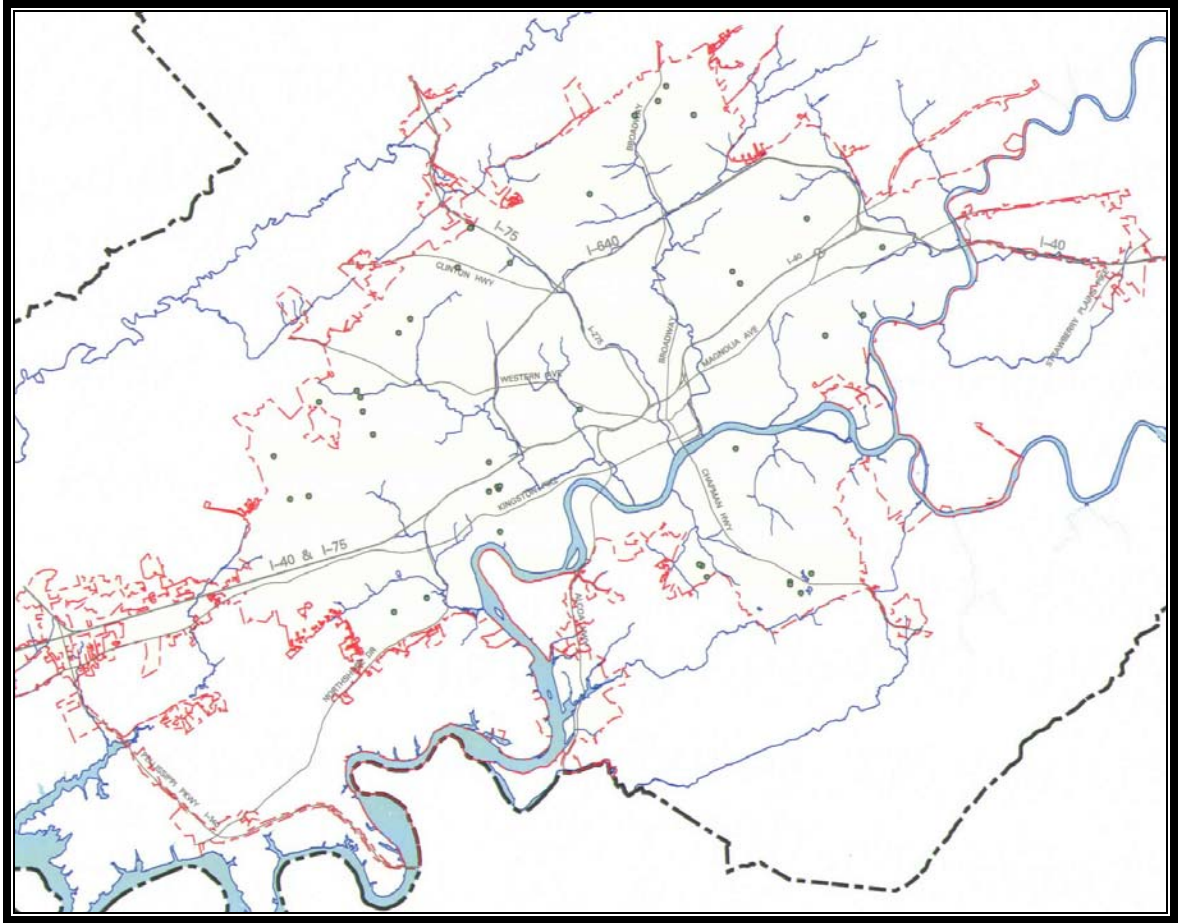


Figure 4.1. Graphical location of work order sites

Table 4.1. Location of work orders in the Knoxville study area

Closest Street Address	Numerical Address	Work Order Location Street
Arrowhead Trl	525	Arrowhead Trail
Boyd's Bridge Pk	3219	Boyd's Bridge Pike
Camelia Rd	5113	Camelia Road
Cecil Ave	2912	Cecil Avenue
Cecil Johnson Rd	2041	Cecil Johnson
Crosby Dr	4316	Crosby Drive
Fruend St	4633	Fruend Street
Hillview St	601	Hollywood Road/Hillview Road
Ingersoll Ave	740	Ingersoll Avenue
Jacksboro Pk	5703	Jacksboro Pike
Jackson Rd	1842	Jackson Road
Lakewood Dr	300	Lakewood Drive
Longwood Dr	4023	Longwood
Lyle Ave	4241	Lyle Avenue 1
Lyle Ave	4300	Lyle Avenue 2
Lyle Ave	4301	Lyle Avenue 3
Maple Dr	1517	Maple Drive
McKamey Rd	3900	McKamey Road
Murray Dr	214	Murray Drive 1
Murray Dr	300	Murray Drive 2
North Hills Blvd	3001	North Hills Blvd
Oak Rd	5729	Oak Road
Piney Grove Church Rd	1308	Piney Grove Church Road
Pleasant Ridge Rd	5811	Pleasant Ridge Road
Plymouth Dr	4401	Plymouth Drive
Proctor St	1504	Proctor Street
Robinson Rd	2425	Robinson Road
Rotherwood Dr	7024	Rotherwood Drive
Silva Dr	5000	Silva Drive
Sparrow Dr	4325	Sparrow Drive
Sullivan Rd	4606	Sullivan Road
Thrall Dr	3717	Thrall Drive
Toxaway Dr	7325	Toxaway Drive
Treemont Dr	1700	Treemont Drive
Valley Ave	1123	Valley Avenue
W Red Bud Rd	216	W Red Bud Road 1
W Red Bud Rd	300	W Red Bud Road 2
Westland Dr	6604	Westland Drive
Woods-Smith Rd	2100	Woods-Smith Road

greater than 4.7 years. The overall time frame range for all locations in this study was 1.8 to 6.2 years. The maintenance interval ranges were selected based on apparent breaks in the data. Table 4.2 displays the maintenance interval data. Approximately 23 percent of the locations had a maintenance interval of less than 3.7 years, 41 percent had a maintenance interval of 3.7 to 4.7 years and 35 percent had a maintenance interval greater than 4.7 years. The “less than 3.7 years” category had a somewhat lower percentage of the total number of locations to limit the range of the time interval.

The 39 culvert locations provided a wide variety of conditions and sediment quantities. To further evaluate the parameters that influence sediment deposition, it was important to also compare the locations that had minimal sediment deposition and the locations that had significant sediment deposition. The culverts that were specified as having minimal sediment deposition were those with less than 10 percent of the culvert filled with sediment. The culverts that were specified as having significant sediment deposition were those with greater than 50 percent of the culvert filled with sediment. Ten locations met the “minimal sediment deposition” criteria and seven locations met the “significant sediment deposition” criteria and both are listed in Table 4.3.

Each of the results for the culvert characteristics were presented graphically using the complete data set. Additionally, statistical analysis was also

Table 4.2. Time frame since last maintenance

Work Order Location Street	Date of last maintenance	Date of Data collection	Number of Days	Number of years since last maintenance
Arrowhead Trail	10/2/1997	4/5/2002	1646	4.5
Boyd's Bridge Pike	1/24/1997	12/10/2002	2146	5.9
Camelia Road	10/10/1997	12/10/2002	1887	5.2
Cecil Avenue	3/4/1997	12/10/2002	2107	5.8
Cecil Johnson	9/8/1997	8/9/2003	2161	5.9
Crosby Drive	5/20/1997	8/9/2003	2272	6.2
Fruend Street	1/13/1999	11/27/2002	1414	3.9
Hollywood Road/Hillview Road	11/12/1998	11/25/2002	1474	4.0
Ingersoll Avenue	2/25/1998	11/27/2002	1736	4.8
Jacksboro Pike	5/9/2000	12/10/2002	945	2.6
Jackson Road	9/16/1997	8/19/2003	2163	5.9
Lakewood Drive	5/9/2000	11/27/2002	932	2.6
Longwood	10/10/2001	8/16/2003	675	1.8
Lyle Avenue 1	3/9/1999	11/25/2002	1357	3.7
Lyle Avenue 2	3/9/1999	11/25/2002	1357	3.7
Lyle Avenue 3	3/9/1999	11/25/2002	1357	3.7
Maple Drive	11/19/1999	8/16/2003	1366	3.7
McKamey Road	7/8/1999	8/9/2003	1493	4.1
Murray Drive 1	12/2/1998	8/19/2003	1721	4.7
Murray Drive 2	12/2/1998	8/19/2003	1721	4.7
North Hills Blvd	12/13/1997	12/10/2002	1823	5.0
Oak Road	6/3/1997	12/10/2002	2016	5.5
Piney Grove Church Road	7/31/1998	4/16/2003	1720	4.7
Pleasant Ridge Road	2/24/1999	8/16/2003	1634	4.5
Plymouth Drive	9/27/1999	8/17/2003	1420	3.9
Proctor Street	12/31/1998	11/25/2002	1425	3.9
Robinson Road	10/14/1999	12/10/2002	1153	3.2
Rotherwood Drive	8/26/1999	11/25/2002	1187	3.2
Silva Drive	11/6/1998	8/17/2003	1745	4.8
Sparrow Drive	8/20/1998	8/17/2003	1823	5.0
Sullivan Road	3/2/1999	8/16/2003	1628	4.5
Thrall Drive	6/29/1998	8/16/2003	1874	5.1
Toxaway Drive	5/28/1997	4/16/2003	2149	5.9
Treemont Drive	4/24/1997	8/16/2003	2305	6.3
Valley Avenue	3/6/2000	8/17/2003	1259	3.4
W Red Bud Road 1	10/21/1999	11/27/2002	1133	3.1
W Red Bud Road 2	10/21/1999	11/27/2002	1133	3.1
Westland Drive	9/8/2000	11/25/2002	808	2.2
Woods-Smith Road	4/28/1999	1/9/2003	1352	3.7

Table 4.3. Minimal and significant sediment deposition locations

Minimal Sediment Deposition		Significant Sediment Deposition	
Location	% Sediment	Location	% Sediment
Arrowhead Trail	0.0%	Boyd's Bridge Pike	74.8%
Cecil Avenue	0.0%	Jackson Road	100.0%
Crosby Drive	0.0%	Lyle Avenue 1	95.6%
Ingersoll Avenue	8.9%	North Hills Blvd	55.7%
Longwood	0.0%	Thrall Drive	52.0%
Maple Drive	0.0%	Toxaway Drive	75.2%
Murray Drive 2	0.0%	Treemont Drive	68.5%
Oak Road	0.0%		
Robinson Road	0.0%		
Rotherwood Drive	4.0%		

conducted for the complete data set. The data for the minimal and significant sediment deposition locations, which were also included in the original data set, were separated out and presented in tabular form for further consideration in evaluating the culvert characteristics.

4.2 Analysis of Culvert Information

The culvert information section includes the results of physical or measured properties of the culverts (Table 4.4) and were described in section 3.4.3. Approximately 31 percent of the locations had corrugated metal culverts and 69 percent had concrete culverts. The culverts were found mainly to be round in cross-sectional shape, however, several were also arches and rectangular-shaped. The culverts ranged in size from 12 inch to 48 inch for round culverts, 28 inch to 58 inch for arched culverts and 48 inch to 216 inch wide for rectangular/box culverts. The designation of the culvert sizes into categories resulted in approximately 49 percent of the culverts classified as small, 33 percent as medium and 18 percent as large. The culverts were measured directly, which produced a variety of lengths. The lengths ranged from 20.5 feet to 88 feet. The condition of the culvert was divided into three categories: good condition, poor condition and bad condition. The good condition culverts accounted for approximately 46 percent of the locations; the poor condition culverts accounted for 31 percent; and the bad condition culverts accounted for 18 percent of the culverts. The condition of

Table 4.4. Culvert properties per work order location

Work Order Location Street	Material Type	Culvert Size (inches)	S,M,L	Culvert Length (feet)	Culvert condition
Arrowhead Trail	CMP	15	S	52	bad
Boyd's Bridge Pike	RCP	24	M	50.5	fair
Camelia Road	RCP	2- 48	L	37	fair
Cecil Avenue	RCP	18	S	36.5	good
Cecil Johnson	CMP	18	S	20.5	good
Crosby Drive	CMP	18	S	34.5	bad
Fruend Street	RCP	15	S	32	fair
Hollywood Road/Hillview Road	RCP	15	S	32	fair
Ingersoll Avenue	RCP	15	S	32	bad
Jacksboro Pike	RCP	18	S	32	good
Jackson Road	CMP	15	S	21.5	-
Lakewood Drive	RCP	18	S	37	good
Longwood	CMP	58 x 35	L	35	bad
Lyle Avenue 1	RCP	12	S	24	-
Lyle Avenue 2	RCP	18	S	29	fair
Lyle Avenue 3	CMP	15	S	33.5	fair
Maple Drive	RCP	15	S	32	fair
McKamey Road	Concrete	216 x 39	L	26	good
Murray Drive 1	RCP	18	S	64	good
Murray Drive 2	RCP	24	M	88	good
North Hills Blvd	CMP	24	M	41	bad
Oak Road	RCP	24	M	48	good
Piney Grove Church Road	CMP	30	M	75	fair
Pleasant Ridge Road	Concrete	72 x 36	L	38.5	good
Plymouth Drive	RCP	24	M	36	good
Proctor Street	Concrete	2- 96x60	L	62	good
Robinson Road	RCP	24	M	32	good
Rotherwood Drive	RCP	2- 36	M	48	good
Silva Drive	RCP	36	M	32	good
Sparrow Drive	CMA	28 x 18	M	49	fair
Sullivan Road	CMA	29 x 17	M	50	bad
Thrall Drive	CMP	30	M	36.5	bad
Toxaway Drive	RCP	15	S	36	fair
Treemont Drive	CMP	15	S	48.5	fair
Valley Avenue	RCP	48	L	55	good
W Red Bud Road 1	RCP	21	S	35	good
W Red Bud Road 2	RCP	18	S	36	fair
Westland Drive	Concrete	48 x 48	L	25	good
Woods-Smith Road	RCP	2- 30	M	45.5	good

approximately 5 percent of the culverts could not be evaluated because of the excessive amount of sediment in the culvert.

Three graphs were produced from the data presented in Table 4.4. The culvert material type, size categories of culverts and the condition of culverts with respect to the sedimentation of the culvert are each shown in Figure 4.2, 4.3, and 4.4, respectively.

The culvert material type graph indicates the relationship between the corrugated metal and concrete material types and the percentage of sediment in the culvert (Figure 4.2). Three series are displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 24.1 percent for concrete culverts. Statistical analysis of this category of data was not possible because only one corrugated metal value was available. The corrugated metal culvert sediment disposition amount for the single location was 0.0 percent. The mean sediment deposition amount for the “3.7 to 4.7 years” category was 37.1 percent for corrugated metal culverts and 28.3 percent for concrete culverts. This category shows a decrease in the mean percentage of sediment deposition from corrugated metal culverts to concrete culverts. The differences between these culvert materials were not statistically significant ($p = 0.40$). The mean sediment deposition amount for the “greater than 4.7 years” category was 46.6 percent for corrugated metal culvers and 26.1

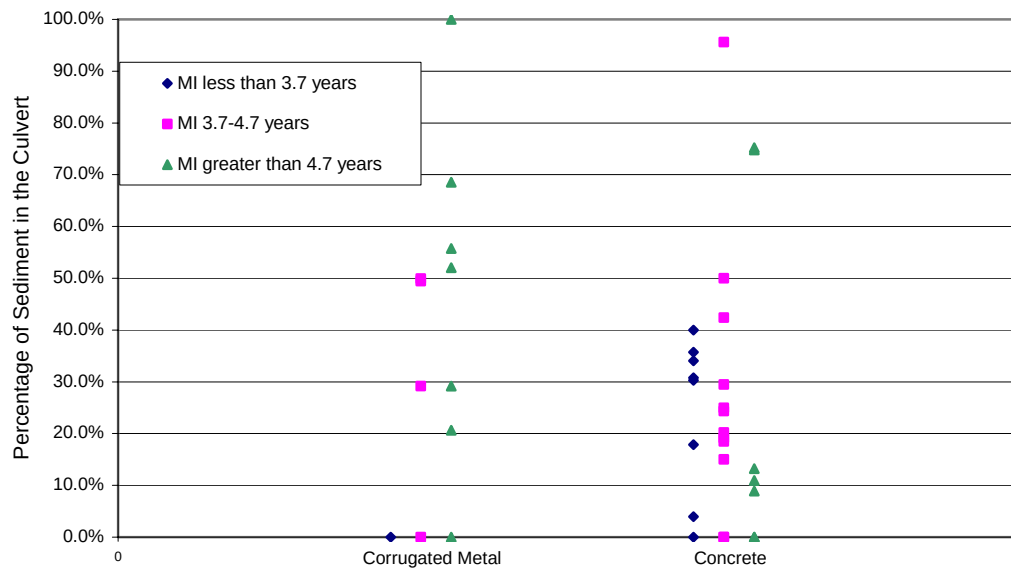


Figure 4.2. Material type graph versus sediment deposition

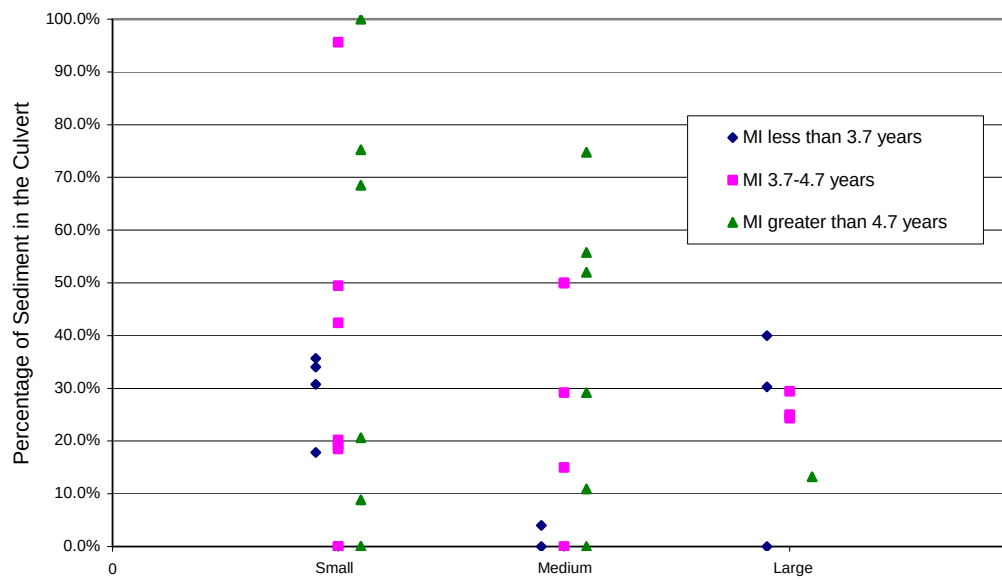


Figure 4.3. Size categories of culverts versus sediment deposition

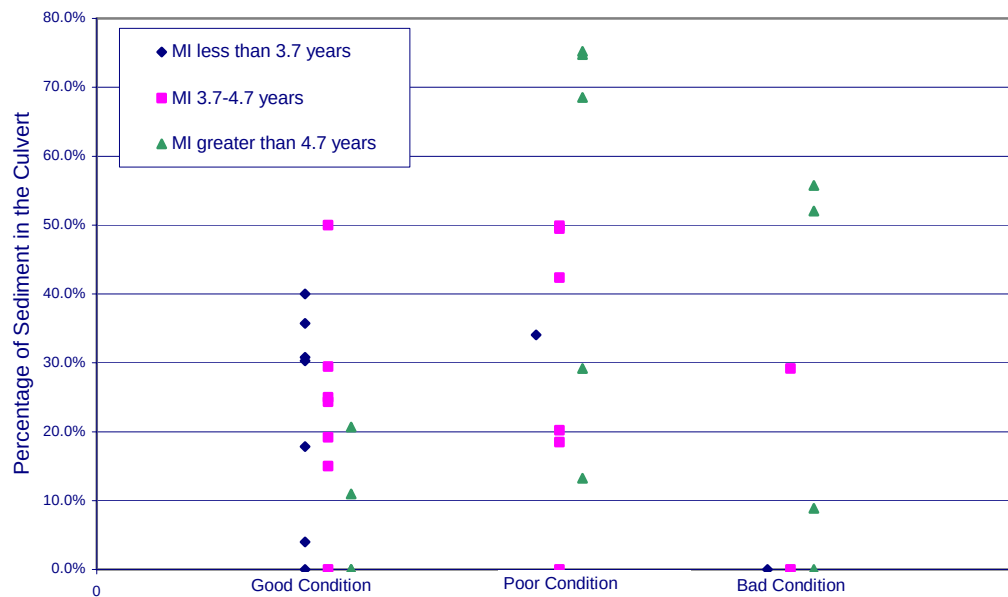


Figure 4.4. Condition of the culvert versus sediment deposition

percent for concrete culverts. This category shows a decrease in the mean percentage of sediment deposition from corrugated metal culverts to concrete culverts, and was marginally significant ($p = 0.14$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.5.

The graph on size categories of culverts, Figure 4.3, indicates the relationship between the small, medium and large culvert size categories and the percentage of sediment in the culvert. Three series are displayed based on the maintenance intervals. The mean sediment deposition amount for the

Table 4.5. Material type for selected data

Culvert Material Type	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
CMP	30%	43%
Concrete	70%	57%

“less than 3.7 years” category was 29.6 percent for small culverts, 2.0 percent for medium culverts, and 39.0% for large culverts. There was a significant decrease in the mean percentage of sediment deposition from small to medium culverts, but then a substantial increase in the percentage of sediment from medium to large culverts. The differences among the sizes of culverts were marginally statistically significant ($p = 0.13$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 30.7 percent for small culverts, 28.8 percent for medium culverts, and 26.3 percent for large culverts. There is a slight decrease from small to medium to large culverts in the percentage of sediment deposition, however the trend was not statistically significant ($p = 0.97$). The mean sediment deposition amount for the “greater than 4.7 years” category was 39.0 percent for small culverts, and 37.1 percent for medium culverts. Only one large culvert was available in this category, which had a sediment deposition value of 26.3 percent. There is a slight decrease from small to medium to large culverts in the percentage of sediment deposition, however this trend was also not statistically significant ($p = 0.80$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.6.

The analysis on culvert condition of culverts indicated relationships among good condition, poor condition, and bad condition categories, and the percentage of sediment in the culvert (Figure 4.4). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 22.7 percent for culverts in good condition. There was only one culvert in poor condition and only one culvert in bad condition in this category. The culvert in poor condition had a sediment deposition value of 26.3 percent and the culvert in bad condition had a sediment deposition value of 0.0 percent. Due to the lack of records in the poor and bad condition groups there was not sufficient information to evaluate the statistical significance of the data. The mean sediment deposition amount for the “3.7 to 4.7 years” category was 23.3 percent for culverts in good condition, 30.1 percent for culverts in poor

Table 4.6. Culvert size designation for selected data

Culvert Size Designation	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Small	50%	57%
Medium	40%	43%
Large	10%	0%

condition, and 14.6 percent for culverts in bad condition. There was an increase in the mean percentage in sediment deposition between the differences of good and poor culvert conditions, but then a significant decrease between the differences of poor and bad culvert conditions. This category of data was not statistically significant ($p = 0.56$). The mean sediment deposition amount for the “greater than 4.7 years” category was 7.9 percent for culverts in good condition, 52.2 percent for culverts in poor condition, and 29.2 percent for culverts in bad condition. There was a substantial increase in the mean percentage of sediment deposition from good to poor, but then a significant decrease from poor to bad. Differences between culvert conditions were statistically significant ($p = 0.07$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.7.

Table 4.7. Culvert condition for selected data

Culvert Condition	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Good	50%	0%
Poor	10%	43%
Bad	40%	29%

* Two locations designated in the “significant sediment deposition” category have unknown culvert conditions.

4.3 Analysis of Slopes for Culvert and Adjacent Channels

The slope information section includes the results for the slope of the culvert and the surrounding channels (Section 3.4.4). Table 4.8 shows a listing of the culvert locations with the following corresponding information: 1) slope of the culvert; 2) slope of the upstream channel; and 3) slope of the downstream channel.

The culvert slopes ranged from negative 0.8 percent to 17.5 percent. The upper end of this range is somewhat misleading. The second highest slope in this range was 8.1 percent, and the average of the data set of culvert slopes was 3.7 percent. The upstream channel slopes ranged from negative 0.9 percent to 22.0 percent. The upper end of this range is also somewhat misleading. The second highest slope in this range was 13.9 percent. The average of the data set for the upstream channels was 5.2 percent. The downstream channel slopes ranged from negative 8.7 percent to 15.9 percent. The lower end of this range may provide misleading results. The second lowest slope in this range was negative 0.9 percent, and the average of the data set of culvert slopes was 4.4 percent.

Three graphs were produced from the data presented in Table 4.8 including the culvert slope, the slope of the channel upstream of the culvert, and the slope of the channel downstream of the culvert with respect to the sedimentation of the culvert (Figure 4.5, 4.6, and 4.7, respectively).

Table 4.8. Slope of culvert with upstream and downstream channel slopes

Work Order Location Street	Culvert Slope	U/s Slope	D/S Slope
Arrowhead Trail	17.5%	4.5%	15.9%
Boyd's Bridge Pike	4.1%	5.5%	2.1%
Camelia Road	0.0%	0.8%	2.1%
Cecil Avenue	4.0%	5.8%	14.5%
Cecil Johnson	3.7%	7.0%	13.2%
Crosby Drive	7.9%	13.8%	10.3%
Fruend Street	5.7%	6.1%	5.3%
Hollywood Road/Hillview Road	4.9%	3.8%	3.9%
Ingersoll Avenue	2.9%	3.8%	7.5%
Jacksboro Pike	2.1%	4.8%	3.9%
Jackson Road	4.0%	5.5%	-8.7%
Lakewood Drive	2.8%	10.0%	3.9%
Longwood	0.3%	1.5%	2.9%
Lyle Avenue 1	6.0%	4.3%	3.8%
Lyle Avenue 2	4.6%	9.7%	4.3%
Lyle Avenue 3	8.1%	8.5%	7.4%
Maple Drive	3.5%	1.9%	13.5%
McKamey Road	2.5%	2.1	2.6%
Murray Drive 1	1.5%	7.4%	-0.9%
Murray Drive 2	5.6%	-0.9%	4.0%
North Hills Blvd	3.9%	6.3%	2.9%
Oak Road	4.9%	3.6%	5.4%
Piney Grove Church Road	-0.8%	0.0%	5.2%
Pleasant Ridge Road	1.1%	1.8%	2.3%
Plymouth Drive	1.8%	2.8%	2.0%
Proctor Street	0.5%	1.2%	4.7%
Robinson Road	6.3%	4.5%	3.6%
Rotherwood Drive	1.4%	1.3%	3.4%
Silva Drive	1.3%	2.3%	2.8%
Sparrow Drive	2.7%	7.3%	2.3%
Sullivan Road	1.7%	4.2%	2.2%
Thrall Drive	7.2%	13.9%	9.4%
Toxaway Drive	1.3%	4.7%	4.1%
Treemont Drive	3.5%	22.0%	0.2%
Valley Avenue	3.3%	3.2%	1.7%
W Red Bud Road 1	4.1%	2.0%	2.1%
W Red Bud Road 2	4.8%	9.4%	4.3%
Westland Drive	1.7%	1.6%	1.1%
Woods-Smith Road	1.7%	3.6%	1.4%

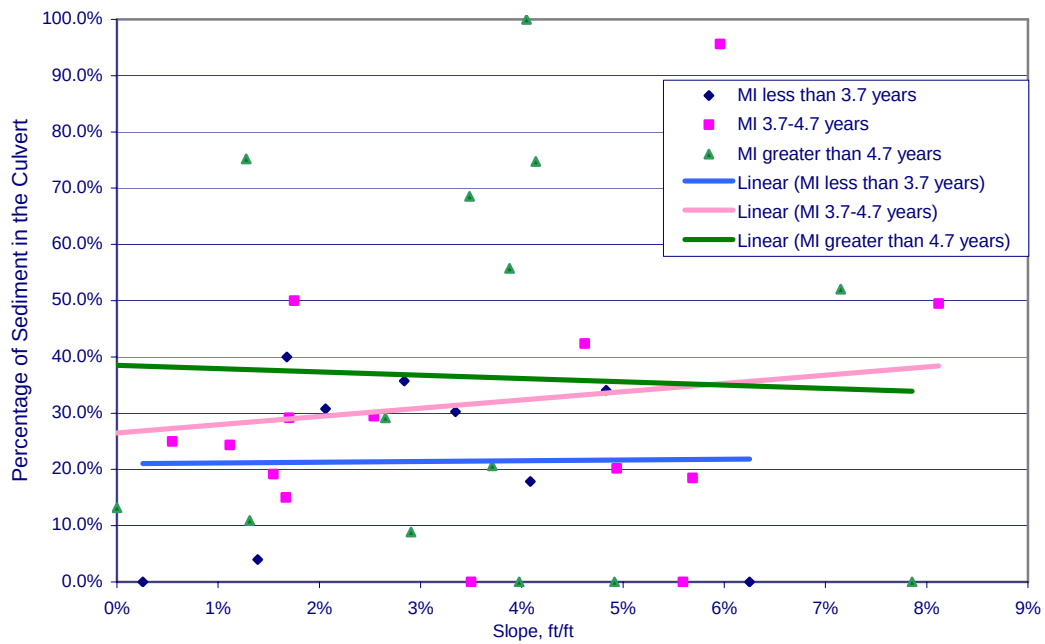


Figure 4.5. Slope of the culvert versus sediment deposition

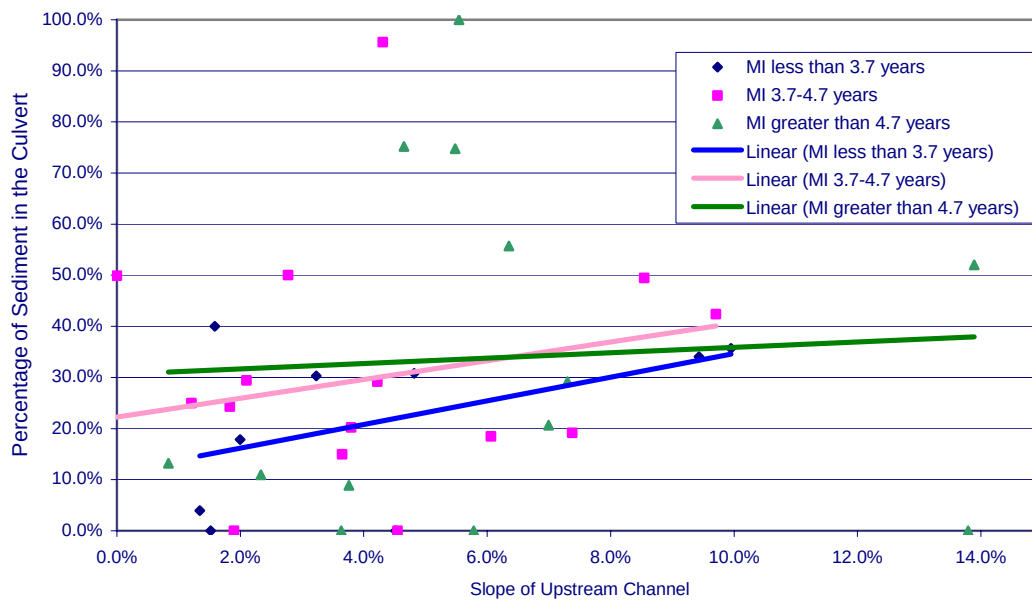


Figure 4.6. Upstream channel slope versus sediment deposition

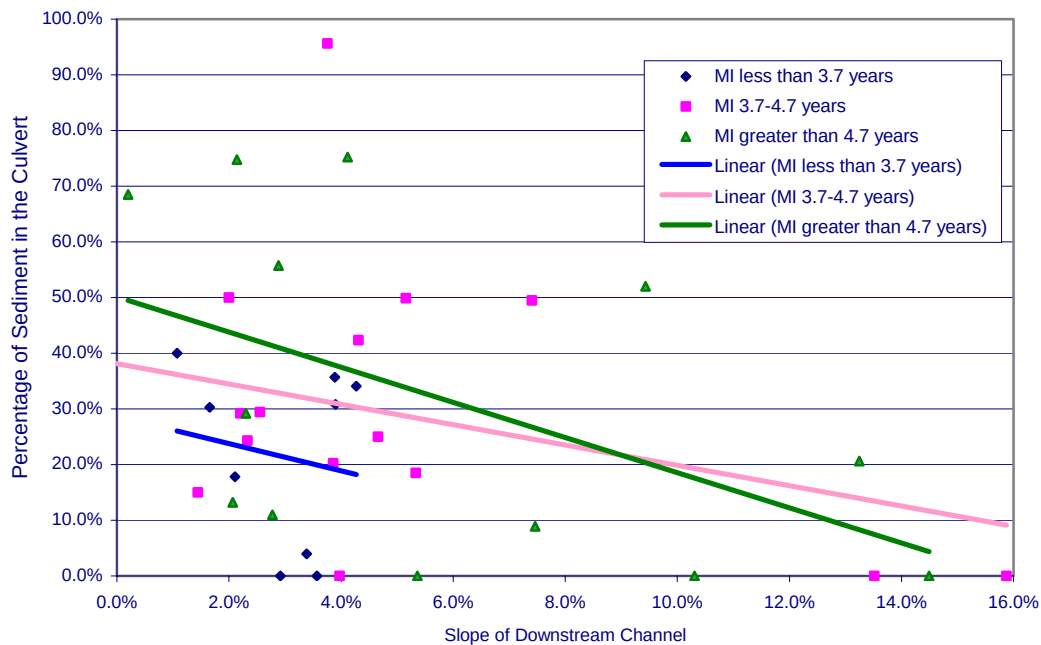


Figure 4.7. Downstream channel slope versus sediment deposition

The culvert slope graph indicated the relationship between the slope and the percentage of sediment in the culvert (Figure 4.5). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval data. The trend for the maintenance interval “less than 3.7 years,” showed nearly a level line, but there were a slightly increasing percentage of sediment in the culvert with an increase in culvert slope. However, this trend was not statistically significant ($p = 0.97$). The trend for maintenance interval “3.7 to 4.7 years,” provided a line showing an increase in the amount of sediment in the culvert as the slope increases. This trend was also not statistically significant ($p = 0.49$). The trend for maintenance interval “greater than 4.7

years,” provided a line showing a decrease in the amount of sediment in the culvert as the slope increases, but this was also not statistically significant ($p = 0.90$). The Arrowhead Trail culvert location data point was removed from the data set because the value was so far removed from the remaining data.

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.9. If the slope value of 17.5 percent were removed from the minimal sediment deposition data because it is much larger than any of the other slope values, then the average slope would be 4.1 percent.

The graph for the channel slope upstream of the culvert indicated the relationship between the channel slope and the percentage of sediment in the culvert (Figure 4.6). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval. The trend line for the maintenance interval “less than 3.7 years,” showed a line with a significantly increasing percentage of sediment in the culvert as the upstream slope increases. This trend was marginally statistically significant ($p = 0.20$). The trend line for maintenance interval “3.7 to 4.7 years,” provided a very similar line at a similar slope. This line, plotted against the percentage of sediment in the culvert, showed a greater amount of sediment for this increased maintenance interval.

Table 4.9. Culvert slope for selected data

	Minimal Sediment Deposition Locations		Significant Sediment Deposition Locations	
	Range	Average	Range	Average
Culvert Slope	0.3% - 17.5%	5.4%	1.3% - 7.2%	4.3%

However, this trend was not statistically significant ($p = 0.41$). The trend line for maintenance interval “greater than 4.7 years,” also provided a line showing an increase in the amount of sediment in the culvert as the upstream slope increases. This line is not as steep as the previous two trend lines and even crosses the maintenance interval line for the “3.7 to 4.7 years” category at a point when the upstream slope value was approximately 5.8 percent. This trend was also not statistically significant ($p = 0.40$). The majority of the trend lines showed an overall greater amount of sediment in the culvert as the maintenance intervals increase. The Treemont Drive location data point was removed from the data set because the value was so far removed from the remaining data.

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.10. If the upstream slope value of negative 0.9 percent were removed from the minimal sediment deposition data, then the average slope would be 4.1 percent. These data include only the locations that met the criteria for minimum or significant sediment deposition. These data are also

Table 4.10. Upstream channel slope for selected data

Upstream Channel Slope %	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Range	-0.9% - 13.8%	4.3% - 22%
Average	4.0%	8.9%

included in the general graphs but were separated from the original data set for further consideration.

The graph for the channel slope downstream of the culvert indicated the relationship between the downstream channel slope and the percentage of sediment in the culvert (Figure 4.7). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval. The trend line for the maintenance interval “less than 3.7 years,” showed a line with a significantly decreasing percentage of sediment in the culvert as the downstream slope increased. This trend was not statistically significant ($p = 0.67$). The trend for maintenance interval “3.7 to 4.7 years,” provided a very similar line at a similar slope. This line, plotted against the percentage of sediment in the culvert, showed a greater amount of sediment for this maintenance interval than the previous maintenance interval. However, this category of data was marginally statistically significant ($p = 0.22$). The trend for the maintenance interval “greater than 4.7 years,” also provided a line showing a decrease in the amount of sediment in the culvert as the downstream slope increased.

This line was slightly steeper than the previous two trend lines and even crosses the maintenance interval line for the “3.7 to 4.7 years” category at a point when the downstream slope was approximately 9.5 percent. This trend was highly significant ($p = 0.01$). The majority of the trend lines showed an overall greater amount of sediment in the culvert as the maintenance intervals increased. The Jackson Road location data point was removed from the data set because the value was so far removed from the remaining data.

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.11. If the downstream slope value of negative 8.7 percent were removed from the significant sediment deposition data, then the average slope was 3.2 percent.

4.4 Analysis of Site Conditions

The site conditions section included conditions for upstream and downstream channels as well as the amount and type of sediment in the culverts. This information was based on visual inspection, from analysis of GIS mapping, or

Table 4.11. Downstream channel slope for selected data

Downstream Channel Slope %	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Range	2.9% - 15.9%	-8.7% - 9.4%
Average	8.1%	2.0%

by measurements taken at the site. Table 4.12 and Table 4.13 showed a listing of the culvert locations with the following corresponding information:

- Upstream hydraulic condition
- Downstream hydraulic condition
- Upstream channel condition
- Downstream channel condition
- Depth of sediment deposition in the culvert
- Type of sediment
- Percentage of the culvert filled with sediment

The hydraulic conditions for both the upstream and downstream channels were divided into four groups described in section 3.4.4. These groups were designated with letters in the Table 4.12 and were related to the following items:

AA = 0 to 15 degrees off the centerline of the culvert
BB = 15 to 30 degrees off the centerline of the culvert
CC = 30 to 60 degrees off the centerline of the culvert
DD = 60 to 90 degrees off the centerline of the culvert

For the upstream hydraulic conditions, approximately 56 percent of the culvert locations had an offset angle between 0 to 15 degrees measured from the centerline of the culvert to the actual channel alignment. About 3 percent of the channels were 15 to 30 degrees offset. Around 13 percent of the channels were 30 to 60 degrees offset and about 28 percent were 60 to 90 degrees offset. For the downstream hydraulic conditions, approximately 77 percent of the culvert locations had an offset angle between 0 to 15 degrees measured from the centerline of the culvert to the actual channel alignment. Around 15 percent of the channels were 30 to 60 degrees offset and about 8 percent of the channels were 60 to 90 degrees offset.

Table 4.12. Upstream and downstream channel information

Work Order Location Street	Upstream Hydraulic Cond.	Downstream Hydraulic Cond.	Immediate u/s conditions	Immediate d/s conditions
Arrowhead Trail	DD	AA	B	B
Boyd's Bridge Pike	AA	AA	B	C
Camelia Road	AA	AA	C	B
Cecil Avenue	AA	AA	B	A
Cecil Johnson	DD	AA	B	B
Crosby Drive	DD	AA	B	C
Fruend Street	AA	AA	B	B
Hollywood Road/Hillview Road	DD	AA	B	B
Ingersoll Avenue	AA	AA	B	C
Jacksboro Pike	AA	AA	A	B
Jackson Road	DD	AA	B	C
Lakewood Drive	AA	AA	B	B
Longwood	AA	AA	D	D
Lyle Avenue 1	CC	CC	A	B
Lyle Avenue 2	AA	AA	A	B
Lyle Avenue 3	AA	AA	B	B
Maple Drive	DD	CC	C	B
McKamey Road	AA	AA	D	C
Murray Drive 1	DD	AA	D	C
Murray Drive 2	DD	AA	C	D
North Hills Blvd	AA	AA	A	D
Oak Road	AA	AA	C	C
Piney Grove Church Road	CC	AA	B	C
Pleasant Ridge Road	CC	CC	B	B
Plymouth Drive	AA	AA	C	B
Proctor Street	AA	AA	B	B
Robinson Road	CC	CC	C	A
Rotherwood Drive	DD	AA	D	D
Silva Drive	AA	AA	B	B
Sparrow Drive	AA	AA	D	B
Sullivan Road	AA	AA	B	B
Thrall Drive	DD	CC	C	B
Toxaway Drive	AA	AA	B	A
Treemont Drive	AA	AA	C	C
Valley Avenue	AA	AA	C	B
W Red Bud Road 1	BB	CC	B	D
W Red Bud Road 2	DD	DD	B	D
Westland Drive	CC	DD	A	A
Woods-Smith Road	AA	DD	C	C

Table 4.13. Sediment information

Work Order Location	Sediment Buildup (ft)	Type of Sediment	% of culvert filled
Arrowhead Trail	0.00	none	0.0%
Boyd's Bridge Pike	1.40	1	74.8%
Camelia Road	1.24	1	13.2%
Cecil Avenue	0.00	none	0.0%
Cecil Johnson	0.39	1	20.7%
Crosby Drive	0.00	none	0.0%
Fruend Street	0.30	1	18.5%
Hollywood Road/Hillview Road	0.32	1	20.2%
Ingersoll Avenue	0.18	1	8.9%
Jacksboro Pike	0.52	1	30.8%
Jackson Road	1.00	2	100.0%
Lakewood Drive	0.58	1	35.7%
Longwood	0.00	none	0.0%
Lyle Avenue 1	0.91	1	95.6%
Lyle Avenue 2	0.66	1	42.4%
Lyle Avenue 3	0.62	1	49.5%
Maple Drive	0.00	none	0.0%
McKamey Road	0.96	3	29.5%
Murray Drive 1	0.37	1	19.2%
Murray Drive 2	0.00	none	0.0%
North Hills Blvd	1.09	2	55.7%
Oak Road	0.00	none	0.0%
Piney Grove Church Road	1.25	4	49.9%
Pleasant Ridge Road	0.73	2	24.3%
Plymouth Drive	1.00	4	50.0%
Proctor Street	1.25	2	25.0%
Robinson Road	0.00	none	0.0%
Rotherwood Drive	0.25	1	4.0%
Silva Drive	0.50	4	10.9%
Sparrow Drive	0.50	4	29.2%
Sullivan Road	0.50	3	29.2%
Thrall Drive	1.29	1	52.0%
Toxaway Drive	0.88	1	75.2%
Treemont Drive	0.81	2	68.5%
Valley Avenue	1.37	1	30.3%
W Red Bud Road 1	0.41	1	17.8%
W Red Bud Road 2	0.56	1	34.1%
Westland Drive	2.00	2	40.0%
Woods-Smith Road	0.85	2	15.0%

The channel conditions for both the upstream and downstream channels were divided into four categories. These four categories relate to the ground cover or channel stabilization technique in the channel/ditch line immediately upstream or downstream of the culvert. The designations in Table 4.12 relate to the following items:

- A = Channel cover is primarily earthen or gravel
- B = Channel cover is mainly grass
- C = Channel cover is tall grass, weeds, or heavy vegetation
- D = Channel is lined with rip-rap or concrete

For the upstream conditions, approximately 13 percent of the culvert locations had a channel with exposed areas of earth or gravel in the channel. About 49 percent had established grass-lined channels in the approach to the culverts. Around 25 percent had channels that were overgrown with tall grass, weeds or brush and about 13 percent were stabilized with either concrete or rip-rap. For the downstream conditions, approximately 10 percent of the culvert locations had a channel primarily covered with exposed areas of earth or gravel in the channel. About 49 percent had established grass-lined channels in the approach to the culverts. Around 26 percent had channels that were overgrown with tall grass, weeds or brush and about 15 percent were stabilized with either concrete or rip-rap.

The sediment depth was measured at the location the maximum depth of sediment within the culvert. The depths ranged from 0.0 to 2.0 feet. In some of the culverts, the maximum sediment depth was located within the culvert

and could not be directly measured. The locations where these culvert sediment depths were estimated included:

Piney Grove Church Road
Plymouth Drive
Silva Drive
Sparrow Drive
Sullivan Road

The size of the sediment observed in the culvert was separated into four groups as indicated in section 3.4.2. These items displayed in Table 4.13, correspond to numbers and were referenced as follows:

- 1 = D_{50} size of the material is less than 0.25 inch
- 2 = D_{50} size of the material is greater than 0.25 inch and less than 2 inches
- 3 = D_{50} size of the material is greater than 2 inches and less than 5 inches
- 4 = D_{50} size of the material is greater than 5 inches and less than 10 inches

Approximately 21 percent of the locations were found to be clean, having no sediment in the culvert. About 46 percent of the locations had a D_{50} sediment size of less than 0.25 inches. Around 18 percent of the locations had a D_{50} sediment size between 0.25 inch and 2 inches. Roughly 5 percent of the locations had a D_{50} sediment size between 2 inch and 5 inches. The remaining ten percent had a D_{50} greater than 5 inches.

Five graphs were produced from the data presented in both Table 4.12 and Table 4.13. The upstream hydraulic condition, the downstream hydraulic condition, the upstream channel condition, the downstream channel condition,

and the sediment classification with respect to the sedimentation of the culvert are each shown in Figures 4-8, 4.9, 4.10, 4.11, and 4.12, respectively.

The upstream hydraulic condition indicated the relationship between the hydraulic condition and the percentage of sediment in the culvert (Figure 4.8). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 24.2 percent for the offset angle of 0 to 15 degrees, 20.0 percent for the offset angle of 30 to 60 degrees, and 19 percent for the offset angle of 60 to 90 degrees. There was a slight decrease in the mean percentage of sediment deposition as the offset angle increased, however, this was not statistically significant ($p = 0.95$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 32.4 percent for the offset angle of 0-15 degrees, 56.6 percent for the offset angle of 30 to 60 degrees, and 7.9 percent for the offset angle of 60 to 90 degrees. There was a significant increase in the mean percentage of sediment deposition as the offset angle increased from the 0 to 15 degree data group to the 30 to 60 degree data group, but then a substantial decrease from the 30-60 degree data group to the 60 to 90 degree data group. This category of data was statistically significant ($p = 0.01$). The mean sediment deposition amount for the “greater than 4.7 years” category was 33.6 percent for the offset angle of 0 to 15 degrees and 43.2 percent for the offset angle of 60 to 90 degrees. No data were available in this category

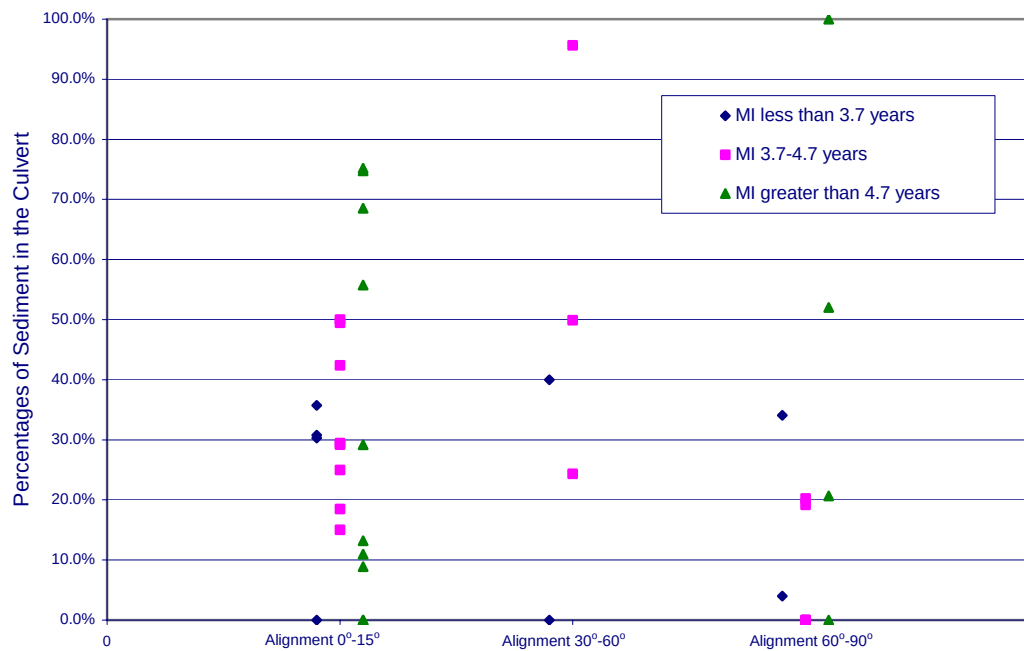


Figure 4.8. Upstream hydraulic conditions versus sediment deposition

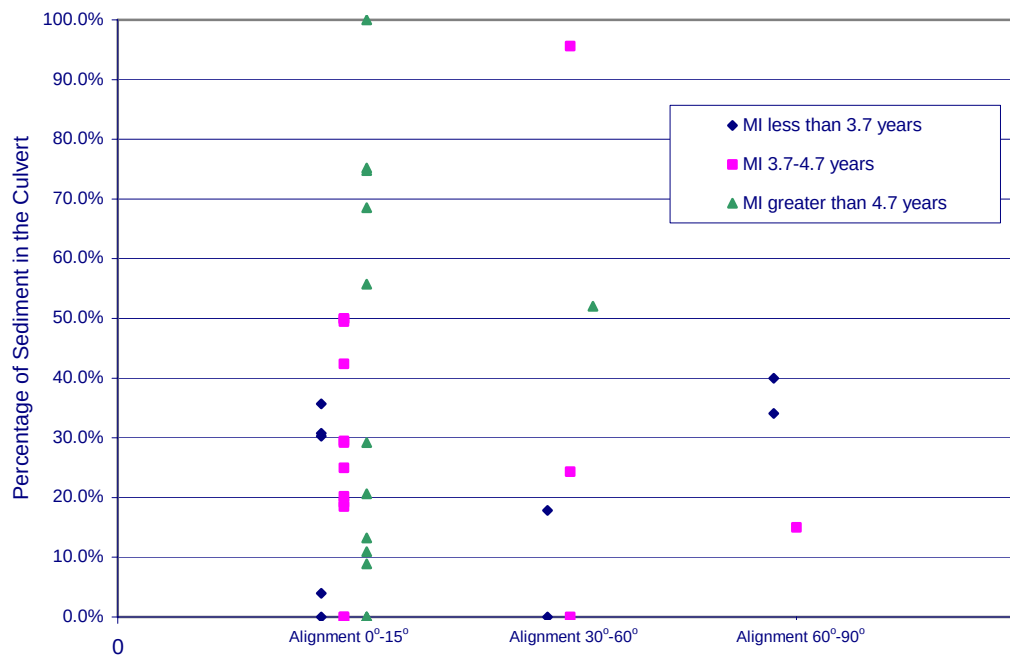


Figure 4.9. Downstream hydraulic conditions versus sediment deposition

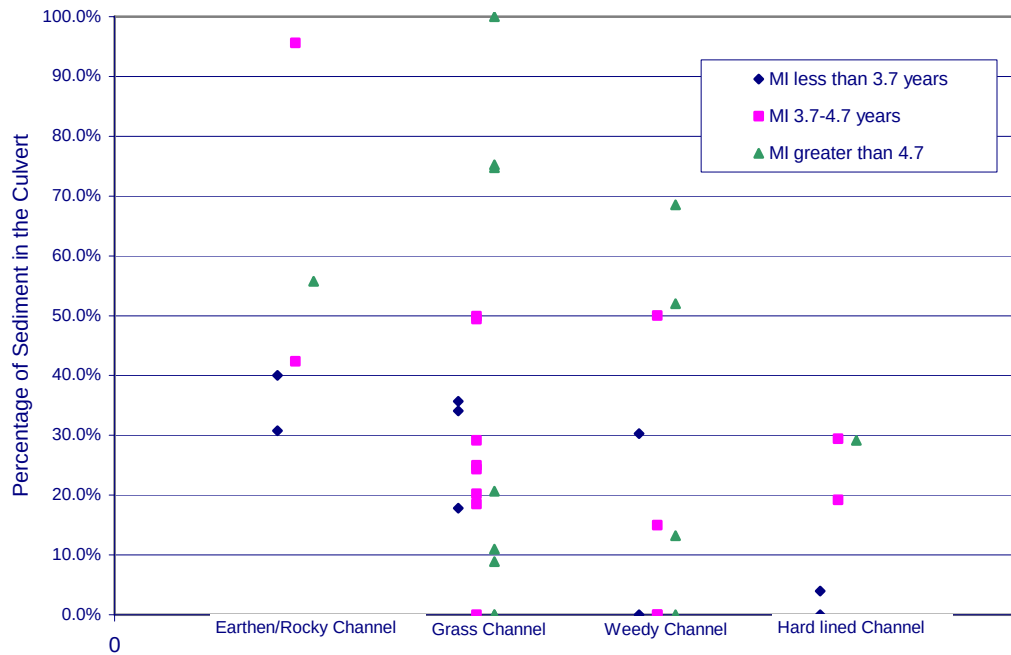


Figure 4.10. Upstream channel conditions versus sediment deposition

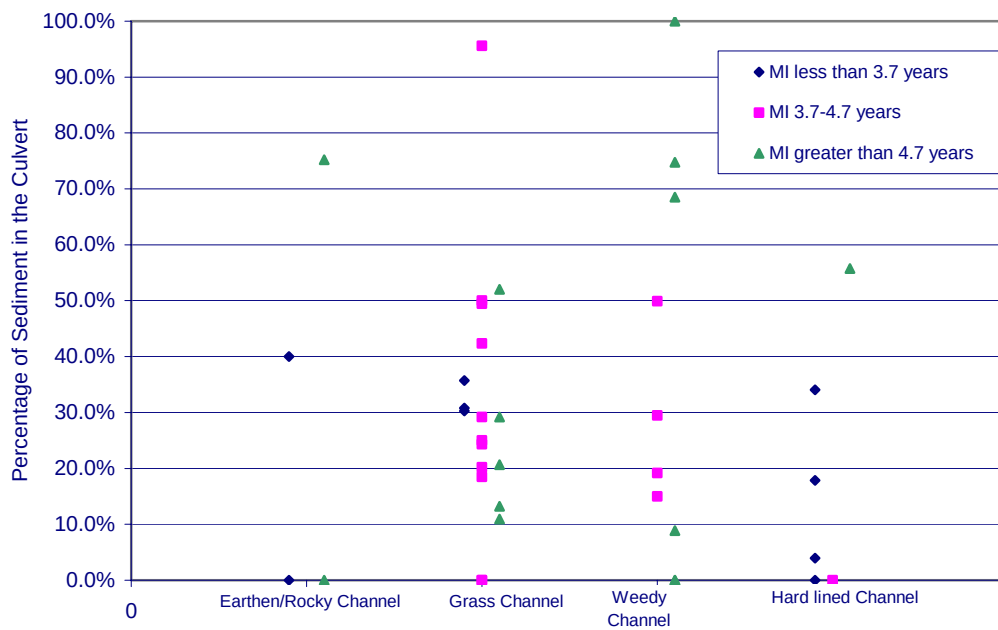


Figure 4.11. Downstream channel conditions versus sediment deposition

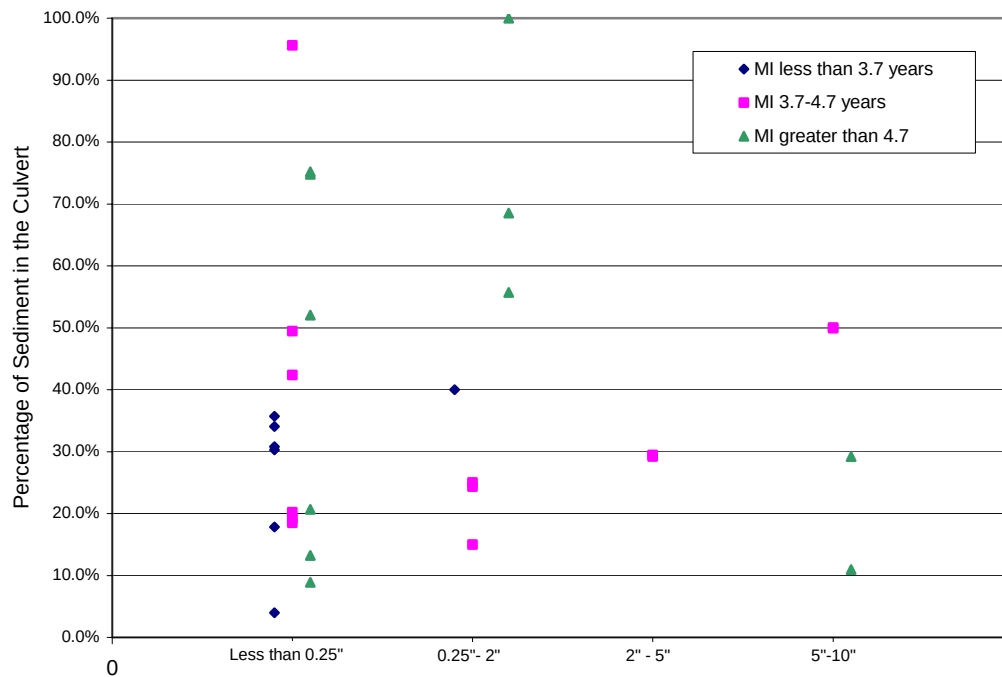


Figure 4.12. Sediment size designation versus sediment deposition

for the offset angle 30 to 60 degrees offset. There was an increase in the mean percentage of sediment deposition as the offset angle increased, however, this trend was not statistically significant ($p = 0.65$). The category for offset angle between 15 to 30 degrees was not included in the graph or results because only one data point that fell in that range.

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.14.

Table 4.14. Upstream channel hydraulic condition for selected data

Degree of offset from the culvert to the upstream channel	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
0 - 15	4	4
30 - 60	1	1
60 - 90	5	2

The downstream hydraulic condition graph indicated the relationship between the downstream hydraulic condition and the percentage of sediment in the culvert (Figure 4.9). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 21.7 percent for the offset angle of 0 to 15 degrees and 8.9 percent for the offset angle of 30 to 60 degrees. Only one value was available for the offset angle of 60 to 90 degrees, which was a sediment deposition amount of 37.0 percent. There was a significant decrease in the mean percentage of sediment deposition as the offset angle increased from the 0 to 15 degree data group to the 30 to 60 degree data group, but then a significant increase from the 30 to 60 degree data group to the 60 to 90 degree data group. This category of data was marginally statistically significant ($p = 0.20$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 27.8 percent for the offset angle of 0 to 15 degrees, 30.0 percent for the offset angle of 30 to 60 degrees, and 15.0 percent for the offset angle of 60 to 90 degrees. There was an increase in the mean percentage of sediment deposition as the offset angle increased from the 0 to 15 degree data group to the 30 to 60 degree data group, but then a decrease

from the 30 to 60 degree data group to the 60 to 90 degree data group. This category of data was not statistically significant ($p = 0.65$). The mean sediment deposition amount for the “greater than 4.7 years” category was 35.2 percent for the offset angle of 0 to 15 degrees. Only one value was available for the offset angle of 30 to 60 degrees, which was a sediment deposition amount of 52.0 percent. No data were available in this category for the offset angle 60 to 90 degrees. There was an increase in the mean percentage of sediment deposition as the offset angle increased, however, the change was not statistically significant ($p = 0.65$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.15.

The upstream channel condition graph indicated the relationship between upstream channel condition and the percentage of sediment in the culvert (Figure 4.10). Three series were displayed based on the maintenance

Table 4.15. Downstream channel hydraulic conditions for selected data

Degree of offset from the culvert to the downstream channel	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
0 - 15	8	4
30 - 60	2	1
60 - 90	-	2

intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 35.4 percent for earthen/rocky channel conditions, 29.2 percent for grassy channel conditions, 15.1 percent for weedy channel conditions and 2.0 percent for hard lined channel conditions. There was a decrease in the mean percentage of sediment deposition as the upstream channel condition progressed from an earthen or rocky condition to a grassy condition to a weedy condition to a hard lined condition. These data approached statistical significance ($p = 0.11$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 69.0 percent for earthen/rocky channel conditions, 27.1 percent for grassy channel conditions, 16.2 percent for weedy channel conditions and 24.3 percent for hard lined channel conditions. There was a decrease in the mean percentage of sediment deposition as the upstream channel condition progressed from an earthen or rocky condition to a grassy condition to a weedy condition, however from the weedy condition to the to a hard lined condition, there was an increase in the mean percentage of sediment deposition. This category of data was statistically significant ($p = 0.07$). The mean sediment deposition amount for the “greater than 4.7 years” category was, 36.3 percent for grassy channel conditions and 33.4 percent for weedy channel conditions. Only one sediment deposition value was available for both earthen/rocky channel conditions and for hard lined channel conditions, which were 55.7 and 29.2 percent respectively. There was a decrease in the mean percentage of sediment deposition as the upstream channel condition progressed from an earthen or rocky condition to a grassy

condition to a weedy condition to a hard lined condition; however, this trend was not statistically significant ($p = 0.95$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.16.

The downstream channel condition graph indicated the relationship between downstream channel condition and the percentage of sediment in the culvert (Figure 4.11). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 20.0 percent for earthen/rocky channel conditions, 32.3 percent for grassy channel conditions, and 14.0 percent for hard lined channel conditions. No data were available in this category for weedy channel conditions. There was an increase in the mean percentage of sediment deposition as the upstream channel condition progressed from an earthen or rocky condition to a grassy condition, however from a grassy condition to the

Table 4.16. Upstream channel conditions for selected data

Condition of the upstream channel	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
Earth/gravel	-	2
Grassy	4	3
Weedy/heavy veg.	4	2
Rip-rap/concrete	2	-

to a hard lined condition, there was a decrease in the mean percentage of sediment deposition. This category of data was not statistically significant ($p = 0.38$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 32.2 percent for earthen/rocky channel conditions and 28.4 percent for weedy channel conditions. No data were available in this category for grassy channel conditions. Only one sediment deposition value was available for hard lined channel conditions, which was 0.0 percent. There was a decrease in the mean percentage of sediment deposition as the upstream channel condition progressed from an earthen or rocky condition to a weedy condition to a hard lined condition, however the trend was not statistically significant ($p = 0.48$). The mean sediment deposition amount for the “greater than 4.7 years” category was 37.6 percent for earth/rocky channel conditions, 25.2 percent for grassy channel conditions and 42.0 percent for weedy channel conditions. Only one sediment deposition value was available for hard lined channel conditions, which was 55.7 percent. There was a decrease in the mean percentage of sediment deposition as the upstream channel condition progressed from an earthen or rocky condition to a grassy condition, however from a grassy to a weedy condition to a hard lined condition, there was an increase in the mean percentage of sediment deposition. This trend was not statistically significant ($p = 0.83$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.17.

The sediment classification graph indicated the relationship between the type of sediment found in the culvert and the percentage of sediment in the culvert (Figure 4.12). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 25.4 percent for the D_{50} is less than 0.25 inch group. Only one sediment deposition value for the D_{50} is between 0.25 and 2 inch group was available, which was 40.0 percent. No data were available in this category for D_{50} is between 0.25 and 2.0 inch group and for the D_{50} is between 5.0 and 10.0 inch group. There was an increase in the mean percentage of sediment deposition as the sediment size increased, however this trend was not statistically significant ($p = 0.32$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 40.9 percent for D_{50} less than 0.25 inches group, 21.4 percent for the D_{50} between 0.25 and 2.0 inch group, 29.3 percent

Table 4.17. Downstream channel conditions for selected data

Condition of the downstream channel	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
Earth/gravel	2	1
Rip-rap/concrete	3	1
Grassy	2	2
Weedy/heavy veg.	3	3

for the D_{50} between 2.0 and 5.0 inch group and 49.9 percent for the D_{50} between 5.0 and 10.0 inch group. There was a decrease in the mean percentage of sediment deposition as the sediment size increased from a D_{50} less than 0.25 inch group to a D_{50} between 0.25 and 2.0 inch group. Then there was an increase in the mean percentage of sediment deposition as the sediment size increased, but the trend was not statistically significant ($p = 0.51$). The mean sediment deposition amount for the “greater than 4.7 years” category was 40.8 percent for D_{50} less than 0.25 inches group, 78.8 percent for the D_{50} between 0.25 and 2.0 inch group, and 20.1% for the D_{50} between 5.0 and 10.0 inch group. No data were available in this category for the D_{50} between 2.0 and 5.0 inch group. There was an increase in the mean percentage of sediment deposition as the sediment size increased from a D_{50} less than 0.25 inch group to a D_{50} between 0.25 and 2.0 inch group. A decrease in the mean percentage of sediment deposition was observed with increase in sediment size ($p = 0.13$).

Evaluation of the data previous noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.18.

4.5 Analysis of Hydrologic Characteristics

The hydrologic model section includes the necessary hydrologic elements to run the analysis as well as selected outputs from the model. This information

Table 4.18. Sediment size for selected data

D ₅₀ size of the sediment in the culvert	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
No sediment	8	-
less than 0.25 inches	2	4
0.25 to 2 inches	-	3

was determined by evaluation and measurement of GIS mapping and USGS soils maps. Table 4.19 shows a listing of the culvert locations with the following corresponding information:

- Watershed area
- Watershed curve number
- Hydrological Soil Group
- Time of Concentration
- Watershed Slope
- Flow for a 2-year storm

Watershed areas were determined as described in Section 3.6. The watershed areas were as small as 0.81 acres and as large as 787.7 acres. The second largest watershed size was 329.8 acres. The average watershed size was 62.5 acres after removing the 787.7-acre watershed value. This value was removed from the average because it was excessively large in comparison to the other values. The watershed CN ranged from 65 to 89, which are representative values for the land use and land cover for each watershed. The average CN value for all of the watersheds was 75.1. HSG was either a B or C. None of the watersheds evaluated was HSG A or HSG D. HSG B accounted for about 71.8 percent of the watersheds and the remaining 28.2 percent of the watersheds were HSG C. The time of

Table 4.19. Information associated with watershed modeling

Work Order Location Street	WS Area acre	Curve No. (CN)	Hydrologic Soil Group (HSG)	t _c hrs	Watershed Slope	2-yr flow, Q (cfs)
Arrowhead Trl	1.8	71	B	0.24	11.1%	2
Boyd's Bridge Pk	47.9	69	B	0.33	6.1%	35
Camelia Rd	177.0	79	B	0.41	3.0%	217
Cecil Ave	13.0	76	B	0.19	11.2%	19
Cecil Johnson Rd	5.8	65	B	0.27	7.3%	3
Crosby Dr	5.2	71	B	0.38	8.2%	4
Fruend St	1.7	80	C	0.13	8.2%	4
Hillview St	3.8	88	C	0.13	8.1%	11
Ingersoll Ave	7.0	80	C	0.16	6.2%	14
Jacksboro Pk	2.8	73	B	0.27	5.2%	3
Jackson Rd	3.0	71	B	0.13	7.5%	4
Lakewood Dr	5.9	82	C	0.33	6.4%	9
Longwood Dr	226.6	69	B	0.46	6.0%	140
Lyle Ave 1	0.8	84	C	0.17	10.2%	2
Lyle Ave 2	0.8	84	C	0.17	10.2%	2
Lyle Ave 3	0.8	84	C	0.12	11.4%	2
Maple Dr	2.4	80	C	0.28	8.3%	4
McKamey Rd	787.7	72	B	0.70	3.2%	473
Murray Dr	0.8	69	B	0.49	2.2%	1
Murray Dr	5.9	68	B	0.20	4.5%	5
North Hills Blvd	38.9	73	B	0.41	5.0%	33
Oak Rd	73.5	71	B	0.29	9.9%	66
Piney Grove Church Rd	33.9	72	B	0.75	0.5%	20
Pleasant Ridge Rd	142.8	75	B	0.31	4.6%	158
Plymouth Dr	38.9	71	B	0.40	5.7%	30
Proctor St	329.8	79	B	0.64	3.3%	319
Robinson Rd	143.4	72	B	0.37	3.8%	121
Rotherwood Dr	326.7	74	B	0.48	1.9%	275
Silva Dr	25.6	81	C	0.40	6.0%	35
Sparrow Dr	16.0	70	B	0.38	7.0%	12
Sullivan Rd	199.6	68	B	0.26	5.4%	154
Thrall Dr	19.9	69	B	0.24	10.4%	17
Toxaway Dr	5.9	73	B	0.21	5.9%	7
Treemont Dr	10.1	89	B	0.20	6.3%	27
Valley Ave	60.2	71	B	0.25	6.1%	58
W Red Bud Rd	21.7	81	C	0.40	4.5%	30
W Red Bud Rd	2.5	82	C	0.31	8.1%	4
Westland Dr	266.3	72	B	0.49	2.4%	195
Woods-Smith Rd	107.0	72	B	0.34	4.1%	95

concentration through the watersheds ranged from 0.12 hours to 0.64 hours. The average ToC for the watersheds is 0.325 hours. The watershed slope, which is the effective average slope of the ToC flow path, had a slope ranging from 0.5 to 11.4 percent. The average watershed slope for all of the watersheds was 6.3 percent. The calculated flow for the 2-year storm provided a range of flows from 1 cfs to 473 cfs. The second highest flow value was 319 cfs. The average 2-year flow for the analysis was 56.2 cfs after removing the 473 cfs value from the data. This value was removed from the average because it was disproportionately large in comparison to the other values.

Four graphs were produced from the data presented in Table 4.19. The watershed area, watershed slope, hydrologic soil group, and the 2-year flow rate with respect to the sedimentation of the culvert are each shown in Figures 4.13, 4.14, 4.15, and 4.16, respectively.

The watershed area graph indicated the relationship between the size of the watershed and the percentage of sediment in the culvert (Figure 4.13). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval data. The linear trend lines for all three of the data sets displayed a decrease in the percentage of sediment in the culvert as the size of the watershed increases. The linear trend line for the maintenance interval

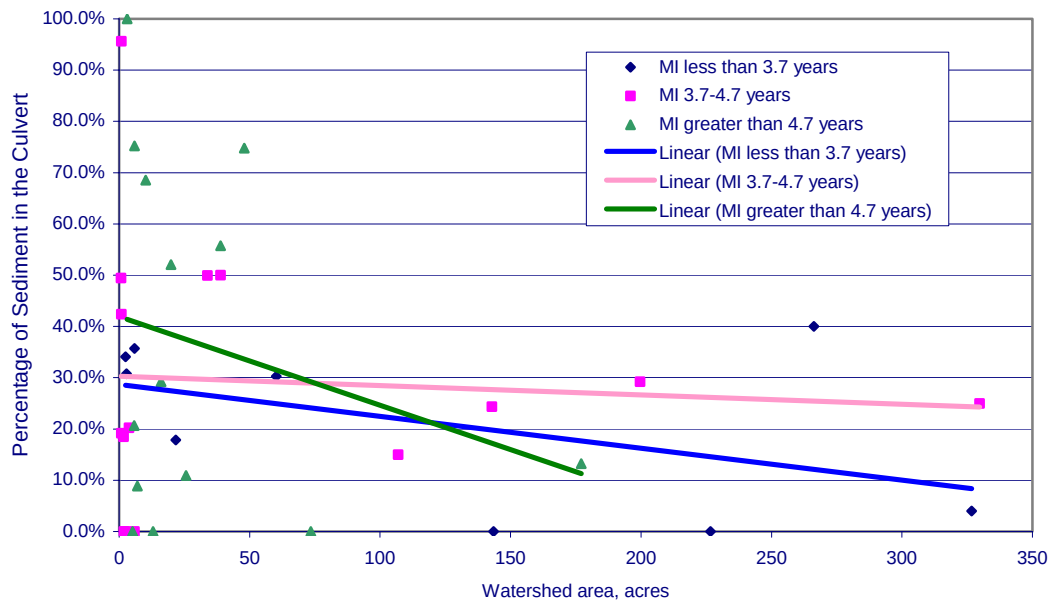


Figure 4.13. Watershed area versus sediment deposition

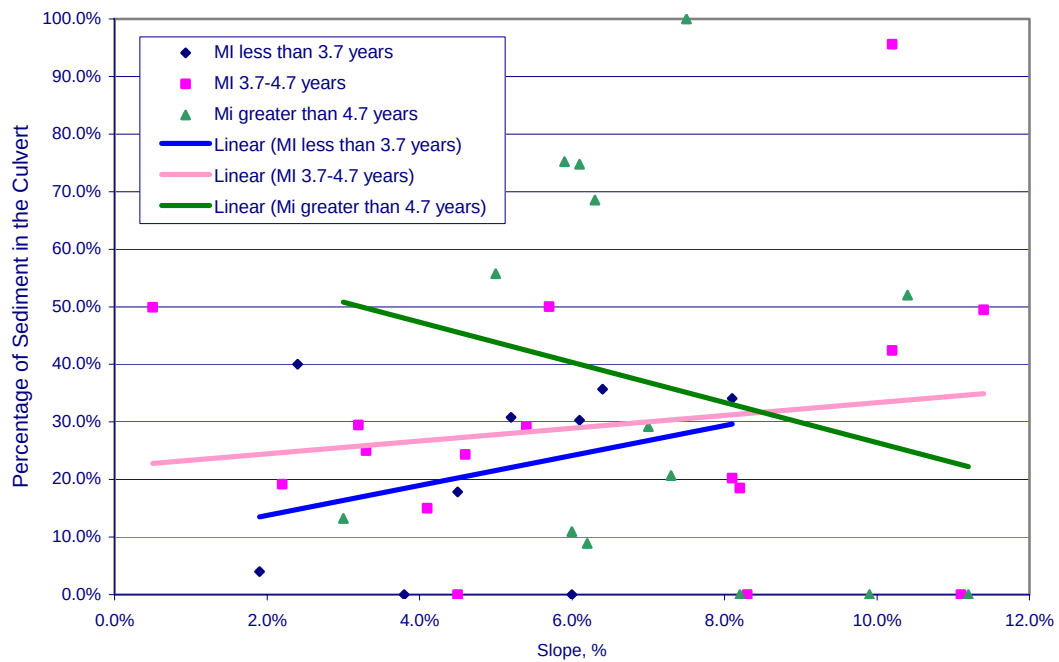


Figure 4.14. Watershed slope versus sediment deposition

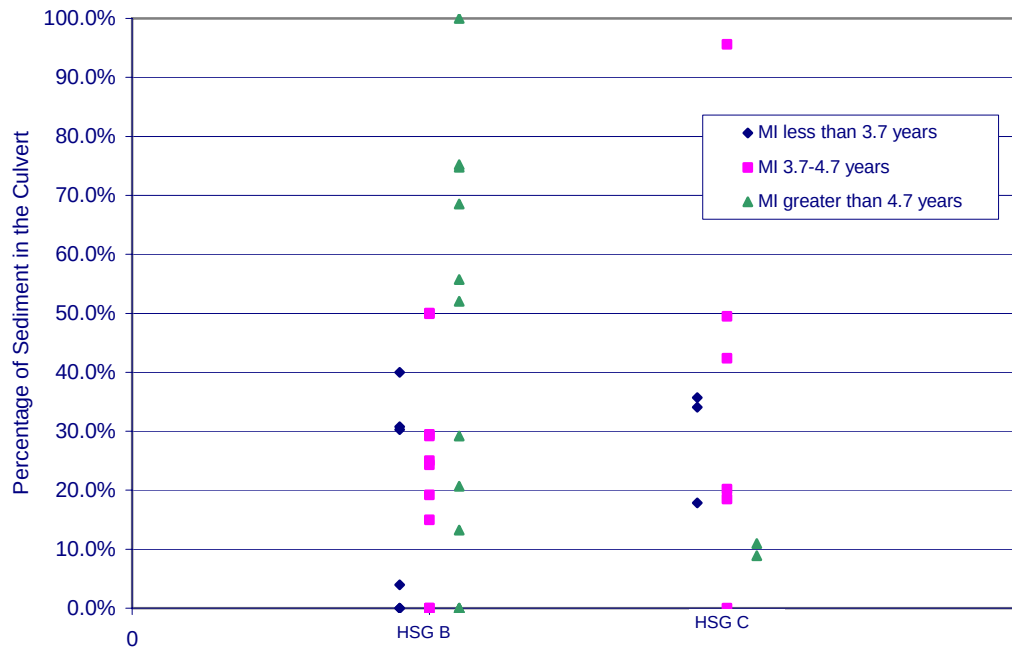


Figure 4.15. Hydrologic soil group versus sediment deposition

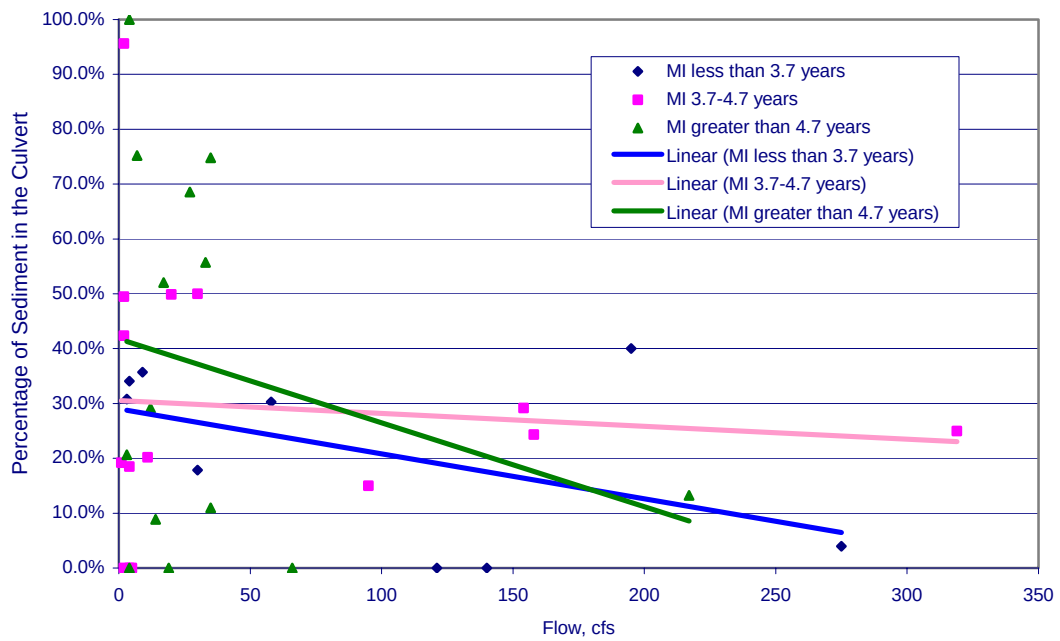


Figure 4.16. Watershed discharge at Q2 versus sediment deposition

“greater than 4.7 years” had a steeper slope than the other two trend lines and even crossed the other trend lines. The data point for the McKamey Road location was much larger than the other data points and was therefore not included in the graph. The “less than 3.7 years” category of data was marginally statistically significant ($p = 0.18$). The “3.7 to 4.7 years” and the “greater than 4.7 years” trends were not statistically significant ($p = 0.91$ and 0.42).

Evaluation of the data previous noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.20.

The watershed slope graph indicated the relationship between the average slope of the watershed’s hydraulically longest flow path and the percentage of sediment in the culvert (Figure 4.14). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval. The linear trend line for both the maintenance interval “less than 3.7 years” and “3.7 to 4.7 years”

Table 4.20. Watershed size for selected data

Watershed Size (acres)	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Range	1.8 -326.7	0.81 - 47.9
Average	80.5	18.1

exhibited an increase in the percentage of sediment in the culvert as the slope of the watershed increases, however, these trends were not statistically significant ($p = 0.40$ and 0.57). The linear trend line for the maintenance interval “greater than 4.7 years” demonstrated a decrease in the percentage of sediment in the culvert as the slope of the watershed increases. This trend was also not statistically significant ($p = 0.44$).

Evaluation of the data previous noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provides the results in Table 4.21.

The HSG graph indicated the relationship between the HSG type and the percentage of sediment in the culvert (Figure 4.15). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 17.5 percent for HSG B and 29.2 percent for HSG C. There was an increase in the mean percentage of sediment deposition from the HSG B to the HSG C ($p = 0.13$).

Table 4.21. Watershed slope for selected data

Watershed Slope	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Range	1.9% - 11.2%	5.0% - 10.4%
Average	7.1%	7.3%

The mean sediment deposition amount for the “3.7 to 4.7 years” category was 24.2 percent for HSG B and 37.7 percent for HSG C. There was an increase in the mean percentage of sediment deposition from the HSG B to the HSG C. This trend was also marginally statistically significant ($p = 0.20$). The mean sediment deposition amount for the “greater than 4.7 years” category was 40.8 percent for HSG B and 9.9 percent for HSG C. There was a clearly significant decrease in the mean percentage of sediment deposition from the HSG B to the HSG C ($p = 0.01$).

Evaluation of the data previous noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.22.

The watershed discharge indicated the relationship between the flow rate for the 2-year storm and the percentage of sediment in the culvert (Figure 4.16). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval. The linear trend lines for all three series exhibited a

Table 4.22. Hydrologic soil group for selected data

Hydrologic Soil Group	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
B	8	6
C	2	1

decrease in the percentage of sediment in the culvert as the flow rate increased. The linear trend line for the maintenance interval “3.7 to 4.7 years” was flatter line than the other two trend lines. The data point for the McKamey Road location was much larger than the other data points and was therefore not included in the graph. The “less than 3.7 years” trend was marginally statistically significant ($p = 0.18$). The “3.7 to 4.7 years” and the “greater than 4.7 years” categories of data were not statistically significant ($p = 0.85$ and 0.39).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.23.

4.6 Analysis of Culvert Hydraulics

The hydraulic model section included results obtained after completing hydraulic modeling at each culvert location (Section 3.8). Table 4.24 shows a listing of the culvert locations with the following corresponding information:

- Hydraulic culvert control

Table 4.23. Design flow for selected data

2-year Flow (cfs)	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
Range	2 - 275	2 - 35
Average	65.0	17.9

Table 4.24. Results from the hydraulic modeling

Work Order Location Street	Inlet or Outlet control	Velocity (ft/s)	Overtopping 2-yr storm
Arrowhead Trail	Inlet	8.4	N
Boyd's Bridge Pike	Outlet	5.4	Y
Camelia Road	Outlet	10.2	N
Cecil Avenue	Inlet	10.4	N
Cecil Johnson	Outlet	2.4	Y
Crosby Drive	Inlet	6.9	N
Fruend Street	Inlet	9.9	N
Hollywood Road/Hillview Road	Inlet	10.5	Y
Ingersoll Avenue	Inlet	8.2	Y
Jacksboro Pike	Inlet	6.4	N
Jackson Road	Outlet	0.0	Y
Lakewood Drive	Inlet	9.3	N
Longwood	Outlet	8.1	Y
Lyle Avenue 1	Inlet	2.6	N
Lyle Avenue 2	Inlet	1.6	N
Lyle Avenue 3	Inlet	2.1	N
Maple Drive	Inlet	8.3	N
McKamey Road	Inlet	9.0	N
Murray Drive 1	Outlet	0.3	N
Murray Drive 2	Inlet	10.7	N
North Hills Blvd	Outlet	4.4	Y
Oak Road	Inlet	17.1	Y
Piney Grove Church Road	Outlet	6.4	N
Pleasant Ridge Road	Inlet	11.6	N
Plymouth Drive	Inlet	9.9	Y
Proctor Street	Outlet	3.9	Y
Robinson Road	Inlet	15.4	Y
Rotherwood Drive	Inlet	11.7	Y
Silva Drive	Inlet	9.3	N
Sparrow Drive	Inlet	6.3	N
Sullivan Road	Outlet	6.4	Y
Thrall Drive	Inlet	4.4	N
Toxaway Drive	Outlet	5.4	Y
Treemont Drive	Outlet	4.7	Y
Valley Avenue	Inlet	4.6	N
W Red Bud Road 1	Inlet	11.9	Y
W Red Bud Road 2	Inlet	2.3	N
Westland Drive	Inlet	9.3	N
Woods-Smith Road	Inlet	11.1	Y

- Design Velocity
- Roadway overtopping for the 2-year storm

The hydraulic culvert control refers to whether the culvert is operating in inlet or outlet control. Approximately 71.8 percent of the locations were in inlet control and the remaining 28.2 percent were in outlet control. The design velocity is the speed the stormwater passes through the culvert for the 2-year storm. Values for velocity range from 0.0 fps to 17.1 fps.

The average velocity calculated for this range was 7.4 fps. In about 56.4 percent of the locations, the stormwater did not overtop the roadway during a 2-year storm. In the remaining 43.6 percent of the locations stormwater overtopped the roadway.

Three graphs were produced from the data presented in Table 4.24. The hydraulic culvert control, the design velocity, and the 2-year overtopping condition with respect to the sedimentation of the culvert are each shown in Figures 4.17, 4.18, and 4.19, respectively.

The hydraulic culvert control graph indicated the relationship between the hydraulic culvert control, either inlet or outlet control and the percentage of sediment in the culvert (Figure 4.17). Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 24.1 percent for inlet control conditions;

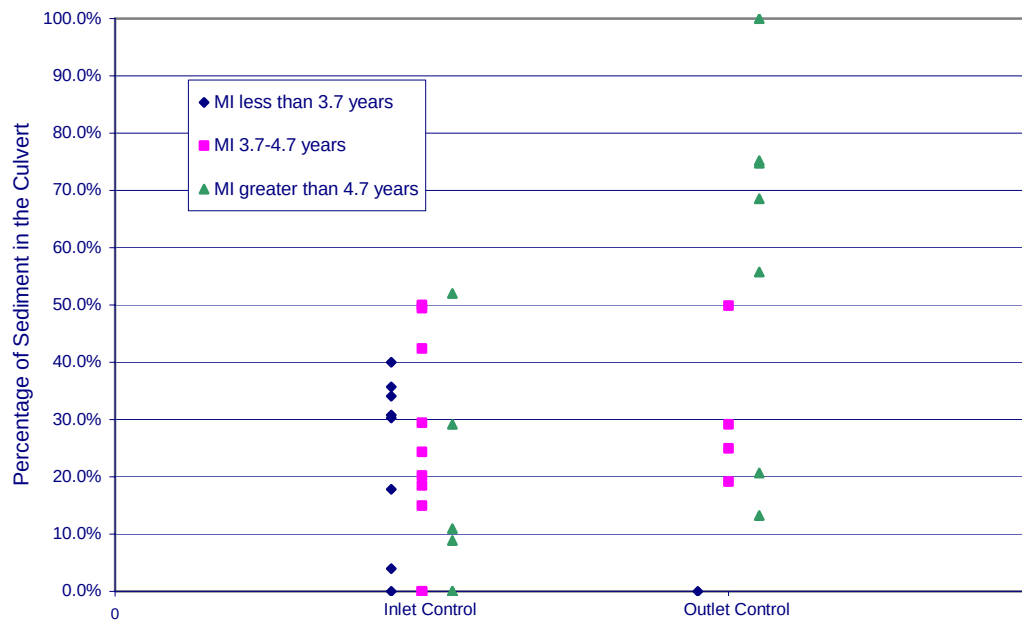


Figure 4.17. Hydraulic culvert control versus sediment deposition

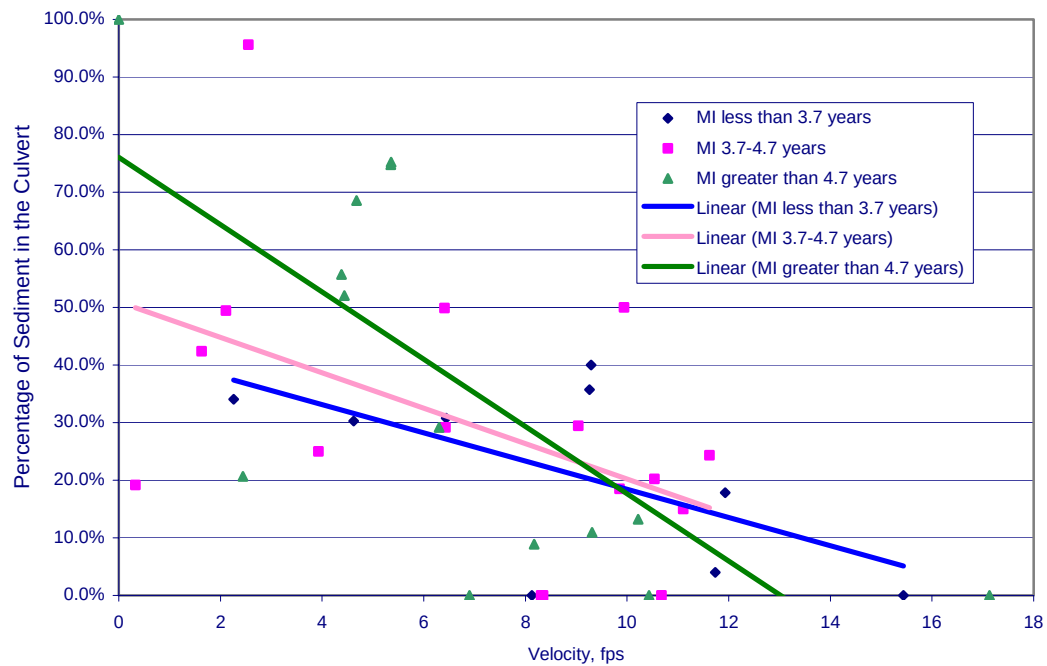


Figure 4.18. Design velocity versus sediment deposition

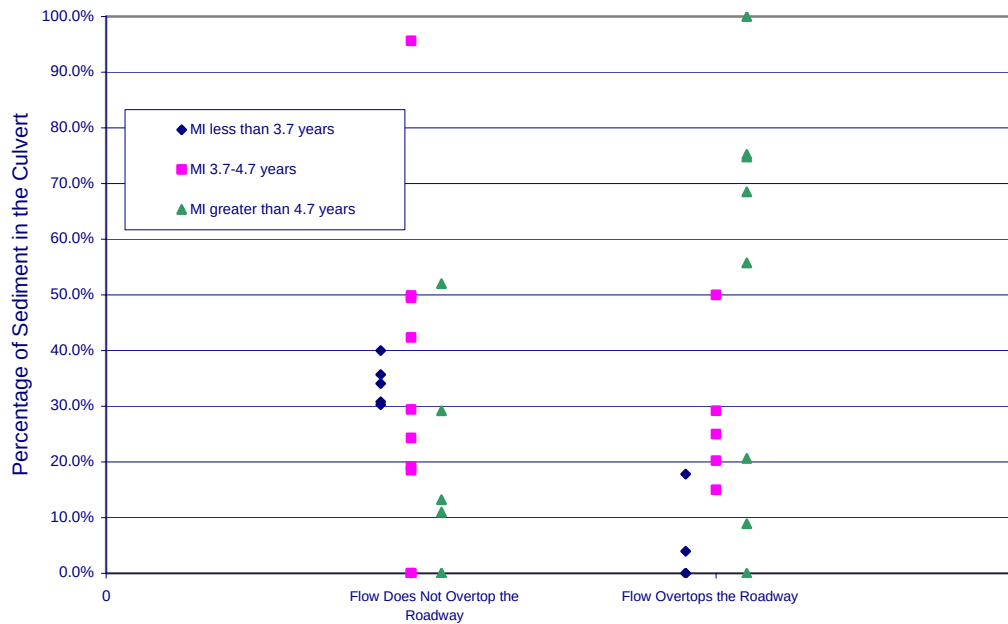


Figure 4.19. Roadways overtopped versus sediment deposition

unfortunately, because there was only one outlet control value available, statistical comparison were not possible. The outlet control sediment deposition amount was 0.0 percent. The mean sediment deposition amount for the “3.7 to 4.7 years” category was 22.7 percent for inlet control conditions and 30.8 percent for outlet control conditions after removing one significantly outlying point. There was an increase in the mean percentage of sediment deposition from inlet culvert control to outlet culvert control ($p = 0.19$). The mean sediment deposition amount for the “greater than 4.7 years” category was 14.4 percent for inlet control conditions and 58.3 percent for outlet control conditions. There was a substantial and significant increase in the mean

percentage of sediment deposition from inlet culvert control to outlet culvert control ($p = 0.01$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.25.

The graph for the culvert design velocity indicated the relationship between the velocity of the stormwater for a 2-year storm and the percentage of sediment in the culvert (Figure 4.18). Three series were displayed based on the maintenance intervals. In addition, linear trend lines were also shown corresponding to the appropriate maintenance interval. The linear trend lines for all three maintenance interval categories displayed a decrease in the percentage of sediment in the culvert as the velocity increased. The steepness of the trend lines increased as the maintenance interval increased. The maintenance interval “less than 3.7 years” and “3.7 to 4.7 years” intersected with maintenance interval “greater than 4.7 years” when the

Table 4.25. Hydraulic culvert control for selected data

Hydraulic Culvert Control	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
Inlet	9	2
Outlet	1	5

velocity was between 9 fps and 10 fps. The value of the percentage of sediment in the culverts also increased with an increased maintenance interval. The “less than 3.7 years”, “3.7 to 4.7 years”, and the “greater than 4.7 years” categories of data were statistically significant ($p = 0.08, 0.06$, and 0.00 , respectively).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.26. If the velocity of 0 fps was removed from the significant sediment deposition data set then the average velocity increased to 4.5 fps.

The graph for roadways overtopped indicated the relationship between conditions where stormwater overtopped or does not overtop the roadway during a 2-year storm event and the percentage of sediment in the culvert. Three series were displayed based on the maintenance intervals. The mean sediment deposition amount for the “less than 3.7 years” category was 34.2 percent for roadways not overtopped and 5.5 percent for overtopped

Table 4.26. Design velocity for selected data

Design Velocity fps	Minimal Sediment Deposition Locations	Significant Sediment Deposition Locations
Range	6.9 fps - 17.1 fps	0 fps - 5.4 fps
Average	10.5 fps	3.8 fps

roadways. There was a decrease in the mean percentage of sediment deposition from roadways not overtopped compared to overtopped roadways. This trend was highly significant ($p = 0.002$). The mean sediment deposition amount for the “3.7 to 4.7 years” category was 29.9 percent for overtopped roadways and 27.9 percent for roadways not overtopped. There was a slight but non-significant decrease in the mean percentage of sediment deposition from roadways not overtopped compared to overtopped roadways ($p = 0.43$). The mean sediment deposition amount for the “greater than 4.7 years” category was 17.6 percent for overtopped roadways and 50.5 percent for roadways not overtopped. There was a substantial and significant decrease in the mean percentage of sediment deposition from roadways not overtopped compared to overtopped roadways ($p = 0.03$).

Evaluation of the data previously noted as locations with either “minimal sediment deposition” or “significant sediment deposition” provided the results in Table 4.27.

Table 4.27. Roadways overtopped for selected data

Overtopping roadway for the 2-year storm	Number of Minimal Sediment Deposition Locations	Number of Significant Sediment Deposition Locations
Overtops	5	5
Does not overtop	5	2

5.0 SUMMARY and CONCLUSIONS

The project required the collection of field information from numerous culvert locations, which represented many culvert site features and characteristics including culvert condition, sediment build up, watershed size pipe material, slope and several other factors. Data for these culvert characteristics were analyzed and the results presented. The results will now be summarized for their meaningfulness and for their possible inclusion in a maintenance index used to predict or evaluate culvert maintenance needs. The summary of results follow in Section 5.1 through 5.6. Development of a “maintenance index” is described in Section 5.7.

5.1 Culvert Information

5.1.1 Material Type

The mean sediment deposition for the corrugated metal culverts was greater than for the concrete culverts. The results for the “3.7 to 4.7 years” and “greater than 4.7 years” indicated that the mean sediment deposition was less in concrete culverts. However, the level of statistical significance was only modest for the “greater than 4.7 years” and less so for the “3.7 to 4.7 years” data. The contrast between locations with minimal versus significant sediment locations provided some additional support for these observations: 70 percent of the minimal sediment deposition locations had concrete culverts. However, data from the significant sedimentation locations did not show much distinction between material types.

5.1.2 Culvert Size Designation

The culvert size did not provide a relationship between small, medium and large culvert designations and sediment deposition. The results in both the "3.7 to 4.7 years" and the "greater than 4.7 years" categories indicated that as culvert size increased from small to medium to large, the mean sediment deposition was less, however these data were not statistically significant. The "less than 3.7 years" data had some significance, but the results were inconsistent (had an "up-down" effect) and did not suggest any relationship for the data. An "up-down" effect occurs when data expected to be generally increasing, has both increases and decreases across the data set. The contrast between locations with minimal versus significant sediment locations provided unanticipated values. The minimal sediment deposition group had 50 percent small culverts, 40 percent medium culverts and only 10 percent large culverts. The data for the significant sediment locations had 0 percent large culverts, 43 percent medium culverts and 57 percent small culverts. These data do not provide insight to a relationship between sediment and culvert sizes.

5.1.3 Culvert Condition

The culvert condition did not provide a relationship between the good, poor, and bad culvert conditions and the sediment deposition amount. The results for all three maintenance interval categories yield greater values for the mean

sediment deposition when comparing good condition to poor condition culverts indicating that as condition worsens that sediment deposition increases. However, the mean sediment deposition value was lower for the bad culvert conditions, which was unexpected. In fact, in two of the maintenance interval categories the bad culvert group's mean sediment deposition was less than for good culvert condition. The change in roughness of the culvert as the conditions degrade should reduce the velocity and therefore should result in increased levels of sediment deposition. Also, for the conditions of misaligned culvert sections and rust through the culvert, debris would be prone to getting caught on the damaged material or misaligned culvert sections. These blockages should result in reduced velocity and flow, increasing the possibility of sediment deposition. These data, however did not support these expectations. The contrast between locations with minimal versus significant sediment locations showed that the minimal sediment deposition group had only 50 percent of the locations in the good culvert condition group and 40 percent were in the bad culvert condition group. The significant sediment deposition group found 0 percent in good condition, however, only 29 percent were in the bad culvert condition group. These data provide little support for the notion that culvert condition plays a role in the sediment accumulation.

5.2 Slope Information

5.2.1 Culvert Slope

The slope of the culverts did not indicate any relationship to sediment deposition. The trend lines for each of the three maintenance interval categories had very small slopes. Each of the lines was not statically significant from a flat line. Therefore, one could conclude that the slope was not directly related to sediment deposition. This is unexpected because traditional ideology and hydraulic equations relate increased slope to increased velocity. The contrast between locations with minimal versus significant sediment deposition showed that the minimal sediment deposition group had an average slope of 5.4 percent while the significant deposition group had an average slope of 4.3 percent. This small difference in slope between these two different groups also did not support a relationship between culvert slope and sediment deposition.

5.2.2 Upstream Channel Slope

The slope of the upstream channel did not show a relationship between the channel slope and sediment deposition. All three trends showed an increase in sediment deposition as the upstream slope increased. Also, there was increased sediment deposition as the maintenance intervals increased. The trends indicated that as the slope increased, the sediment deposition increased, however the statistical significance of the data did not support this interpretation. The contrast between locations with minimal versus significant

sediment locations provided some support for a increase in upstream slope relating to an increase in sediment deposition. The minimal sediment locations had an average upstream channel slope of 4 percent and the significant sediment locations had an upstream channel slope of 8.9 percent. The significant sediment locations had an average channel slope of more than double the average channel slope of the minimal sediment locations.

5.2.3 Downstream Channel Slope

The trend data for the downstream channel slope indicated that as the slopes increased the sediment decreased. Also as the maintenance interval increased the sediment percentage increased for the slopes between 0 percent and 9 percent. In addition, there was some statistical support for these results. The contrast between locations with minimal versus significant sediment locations provided some additional support for these observations: the minimal sediment locations had an average downstream slope of 8.1 percent. The significant sediment locations had an average downstream slope of 3.2 percent. The significant sediment deposition group's downstream channel slope was about 2.5 times less than that of the minimal sediment deposition group. These data were consistent with the interpretation of the data for the upstream slope.

5.3 Site Condition Information

5.3.1 Upstream Hydraulic Condition

The upstream hydraulic conditions displayed no relationship between the hydraulic conditions and the sediment deposition. Each of the maintenance interval categories displayed different patterns of data. The "less than 3.7 years" category had lower mean sediment deposition as the offset angle increased. The "3.7 to 4.7 years" category had greater mean sediment deposition and then lower mean sediment deposition as the offset angles increased, an "up-down" effect. The "greater than 4.7 years" category had greater mean sediment deposition as the offset angle increased, however data were available for only two offset angle groups. Each of the three categories represented completely different characteristics from each other, which suggest that there is no relevance to this data. The contrast between locations with minimal versus significant sediment data showed no significant support for the upstream hydraulic trends.

5.3.2 Downstream Hydraulic Condition

The downstream hydraulic conditions displayed no relationship between the hydraulic conditions and the sediment deposition. Each of the maintenance intervals displayed different patterns of data. The "less than 3.7 years" category had lower mean sediment deposition as the offset angle increased to the 30 to 60 degree offset group and then had a greater mean sediment deposition as the offset angle increased to the 60 to 90 degree offset group, a

“down-up” effect. The "3.7 to 4.7 years" category had greater mean sediment deposition and then lower mean sediment deposition as the offset angles increased, an “up-down” effect. The "greater than 4.7 years" category had a greater mean sediment deposition as the offset angle increased, however values were available for only two offset angle groups. Each of the three categories represented completely different characteristics from each other, which suggest that there is no relevance to these data. The contrast between locations with minimal versus significant sediment data showed no significant support for the downstream hydraulic trends.

5.3.3 Upstream Channel Condition

There was no relationship between the upstream channel condition and sediment deposition. The maintenance interval "less than 3.7 years" and "greater than 4.7 years" categories showed a lower mean sediment deposition amount for each of the four channel condition groups as they transitioned from earthen to grassy to weed to hard lined. The maintenance interval "3.7 to 4.7 years" category had a “down-up” effect. The data in the categories "less than 3.7 years" and "3.7 to 4.7 years" showed some significance. The contrast between locations with minimal versus significant sediment data showed the minimal sediment deposition group had zero locations in the earthen or rocky channel group and the significant sediment deposition group had zero locations in the hard lined channel group. This could suggest a relationship between eroded condition and sediment

deposition as well as reduced sedimentation with well stabilized channels, however the remaining distribution of data for these groups provide no indication to support for the results.

5.3.4 Downstream Channel Condition

The downstream channel conditions showed no relationship to sediment deposition. This culvert characteristic was not evaluated as a source of sediment, but as an indicator of the velocities in the culvert. Earthen and hard lined channels suggest high velocities, and weedy or grassy conditions suggest permissible velocities, which are typically lower. The "less than 3.7 years" category showed lower mean deposition amounts for both the earthen and hard lined channel groups than for grassy condition. This suggested that earthen and hard lined channels were indicators of low sediment amounts, however the data were not significant. In addition, no data were available for the weedy group. The "3.7 to 4.7 years" category showed that the weedy channel group mean sediment deposition was greater than the hard lined group and the earthen channel group had an even greater mean sediment deposition. There were no data available for the grassy channel condition. The "greater than 4.7 years" category had the hard lined channel condition with the highest mean sediment deposition amount, followed by weedy, earthen, and grassy conditions in decreasing order. Each of the trends displayed a different pattern of data and therefore, the results also do not suggest any correlation to the culvert sedimentation. The contrast between

the minimal and significant sediment deposition locations data shown in Table 4.17 was also not consistent with expected or actual results.

5.4 Sediment Size

The size of the sediment found in the culvert did not provide a relationship between the sediment size and the sediment deposition. The results from the maintenance interval categories were not consistent with one another when comparing the mean sediment deposition for each of the size groups.

The "less than 3.7 years" category only had two groups of data but did show an increase in sediment deposition with an increase in sediment size. The "3.7 to 4.7 years" category had a "down-up" effect in the data and the "greater than 4.7 years" category had an "up-down" effect in the data. Therefore, the sediment size correlation did not appear to be purposeful and did not provide any indication of a relationship between the sediment size and the percentage of sediment deposition. The contrast between locations with minimal versus significant sediment provided no support data for the sediment size trends.

5.5 Hydrologic Model Information

5.5.1 Watershed Area

The watershed areas data revealed a relationship between size of the watershed and culvert sediment deposition. All three trends showed a decrease in the sediment deposition with an increase in the watershed size.

The maintenance intervals "3.7 to 4.7 years" and "greater than 4.7 years" did

not show a high level of statistical significance for the data. The maintenance interval "less than 3.7 years" showed some statistical significance for the data. The contrast between locations with minimal versus significant sediment data showed that the minimal sediment deposition group had an average watershed size of 80.5 acres and the significant sediment deposition group had an average watershed size of 18.1 acres. The minimal sediment deposition group had an average watershed size more than four times that of the significant sediment deposition group. These results support the trends for the watershed area data.

5.5.2 Watershed Slope

There was no correlation between the watershed slope and sediment deposition. The maintenance intervals "less than 3.7 years" and "3.7 to 4.7 years" categories both displayed trends indicating an increase in sedimentation with an increase in slope. The maintenance interval "greater than 4.7 years" category showed a trend that indicated a decrease in sediment deposition with an increase in slope, however none of the trends were statistically significant. The minimal and significant sediment deposition locations data had average watershed slopes of 7.1 percent and 7.3 percent, respectively, which did not support a relationship between the watershed slope and the percentage of sediment deposition.

5.5.3 Hydrologic Soil Group

There was no relationship between the HSG designation and sediment deposition. The mean sediment deposition amount was greater for the C soils than the B soils for maintenance intervals "less than 3.7 years" and "3.7 to 4.7 years". The maintenance interval "greater than 4.7 years" had the opposite results. Each of the three categories of maintenance intervals had some statistical significance to the data presented. The maintenance interval "greater than 4.7 years" had the greatest statistical significance. The contrast between locations with minimal versus significant sediment data showed very similar results for both locations, providing no support for a trend.

5.5.4 Watershed Discharge

Flow rate was found to have a relationship with the culvert sediment deposition. Each of the trends had decreased sediment deposition as the flow increased. The data for the "3.7 to 4.7 years" and "greater than 4.7 years" categories were not significant, however the data for the maintenance interval "less than 3.7 years" had some significance. The contrast between locations with minimal versus significant sediment data showed that the minimal sediment deposition group had an average flow of 65.0 cfs and the significant sediment deposition group had an average flow of 17.9 cfs. The minimal sediment deposition group had an average flow of more than three times that of the significant sediment deposition group. These results support the trends for the watershed area data.

5.6 Hydraulic Model Information

5.6.1 Hydraulic Culvert Control

A correlation was found between the hydraulic culvert control and culvert sediment deposition. The results for both the “3.7 to 4.7 years” and the “greater than 4.7 years” categories indicated less sedimentation for culverts in inlet control and both data sets showed some significance. The “less than 3.7 years” category lacked sufficient data to provide results. The contrast between locations with minimal versus significant sediment data showed that 90 percent of the minimal sediment locations had inlet culvert control and that 71 percent of the locations in the significant sediment locations had outlet culvert control. These data were consistent with and supported the interpretation of the data trends.

5.6.2 Design Velocity

There was a definitive relationship observed between velocity and the sediment deposition. The velocity trends showed that as the velocity increased the sediment deposition decreased. Also, as the maintenance interval increased, there was an increase in sediment deposition to a velocity of about 9 fps. These trends were highly statistically significant. The contrast between locations with minimal versus significant sediment data showed that the average velocity for minimal sediment was 10.5 fps, and was 3.8 fps for significant sediment deposition. These results also were highly supportive of the trends.

The velocity trends support a decrease in sediment deposition with an increase in velocity; however, the actual values of the velocities needed to provide self scouring capabilities were different from expected values. Most references suggested scour velocities between 2.5 and 3.0 fps (section 2.12). The data suggest that these values were low. An interesting fact to recognize was that 6 out of the 7 significant sediment locations had a velocity greater than 2.5 fps, and 5 out of 7 had velocities greater than 4.3 fps. Additionally, the lowest velocity for minimal sediment locations was 6.9 fps. The second lowest value was greater than 8.1 fps. Further evaluation of the velocity graph suggest that velocity values between 6.9 and 8.1 fps represent a minimum range of velocities required for self-scour or low maintenance culverts, when velocities are calculated from flows for a 2-year frequency storm.

5.6.3 Roadway Overtopped

A relationship between overtopped roadways and sediment deposition was not found. The average sediment deposition for the "less than 3.7 years" category was 34.2 percent for roadways not overtopped and was 5.5 percent for overtopped roadways and the data were highly significant. The average sediment deposition for the "greater than 4.7 years" category was 17.6 percent for roadways not overtopped and 50.5 percent for overtopped roadways, which was opposite the trend of the "less than 3.7 years" category.

These data were highly significant. The average sediment deposition data for the "3.7 to 4.7 years" category was not significant and the values were very similar for both the roadways not overtopped and for overtopped roadways groups. The contrast between locations with minimal versus significant sediment data did not support the relationship between overtopped roadways and sediment deposition.

5.7 Maintenance Index Development

After evaluating all of the data, it was apparent that much of it did not support expectations. However, some of the data supported expectation and could provide useful information in a prediction model. The culvert characteristics that appeared to have some significance included:

- Design Velocity
- Hydraulic culvert control
- Downstream slope
- Material type
- Watershed area
- Design Flow

These data could be used to assess sediment deposition potential of culverts with the creation of a maintenance index for culvert maintenance. Each of these characteristics was ranked based on the significance of the results and sorted out into three tiers of importance. Velocity was alone in the first tier because velocity proved to be the most significant characteristic and would be a primary factor in a maintenance index. The second tier includes hydraulic culvert control and downstream slope. Both of these characteristics appeared

to rank similarly to one another, with respect to trends and level of significance. The third tier includes material type, watershed area, and flow. These characteristics also appeared to rank similarly to one another, however the trends and level of significance was less than in the second tier. An equation was developed using these characteristics to determine a value corresponding to potential sediment accumulation in culverts. The equation adjusts each of the characteristics in the appropriate tier to control its influence on the result. Also the numerical values assigned to the variable were based on breaks in the data displayed on the graph, as well as on a trial and error process used to evaluate the original field sediment data.

The velocity component, VF, of the equation was based on various ranges of velocities determined from apparent breaks in the velocity graph data and trends. Values were determined for the ranges and are presented in Table 5.1.

The hydraulic culvert condition, IO, was placed into the equation based on

Table 5.1. Velocity factor

Velocity fps	VF
0-2	0.00
2-4	0.33
4-8	0.66
10<	1.00

either an inlet control culvert which uses a value of 1.0 or an outlet control culvert which uses a value of 0.0. The downstream slope component, DS, of the equation was based on various ranges of slopes determined from apparent breaks in the downstream slope graph data and trends. Values were determined for the ranges and are presented in Table 5.2.

The material type (MT) was included in the equation based on either a concrete culvert which uses a value of 1.0 or a corrugated metal culvert which uses a value of 0.0. The watershed area, WA, value was based on different ranges of watershed areas and is presented in Table 5.3. The ranges were determined based on a review of the watershed area graph and trends.

The flow component, QF, corresponds to different ranges of flows and is presented in Table 5.4. The ranges were determined from apparent breaks in the data from the flow graph and trends.

These six components together could be used to formulate a representative value that corresponds to a level of sediment deposition potential. The

equation, $\left[\frac{MT + WA + QF}{3} \right] * 0.2 + \left[\frac{IO + DS}{2} \right] * 0.3 + [VF] * 0.5 =$, uses these

culvert characteristics to determine a maintenance index (MI) value from 0.0 to 1.0. The value represents the expected level of sediment deposition or maintenance expected at a culvert location with 0.0 requiring the most

Table 5.2. Downstream slope factor

Downstream slope %	DS
0-3	0.33
3-5	0.66
5<	1.00

Table 5.3. Watershed area factor

Watershed Size Range acres	WA
0-25	0.33
25-125	0.66
125<	1

Table 5.4. Flow factor

Flow cfs	QF
0-12	0.00
12-35	0.25
35-75	0.50
75-200	0.75
200<	1.00

maintenance and 1.0 requiring the least maintenance. The equation was developed based on the results from this project and was also used to evaluate these same culvert locations. The results from this equation for the culvert location data are shown in Table 5.5 along with the contributing culvert characteristics. The culvert locations are arranged in increasing order, corresponding to the percent sediment deposition in the culvert. The results were broken down into three categories for interpreting the MI value. These ranges were determined from the actual sediment deposition percentages for the culvert locations in combination with apparent breaks in the results. MI values greater than 0.8 indicated that the culvert should require infrequent maintenance and may in some cases have self-cleaning capabilities. A MI value of less than 0.55 indicated that a culvert would require frequent maintenance and/or inspection. MI values between 0.55 and 0.8 were borderline locations. Locations in this range were indeterminate with regard to predicting maintenance needs.

The last column of Table 5.5 indicated numbers highlighted in yellow corresponding to locations that met the criteria for infrequent culvert maintenance. The numbers indicated in blue are the locations that are predicted to require frequent maintenance. This grouping of data indicates that the MI provides a reasonable prediction of the maintenance needs for a culvert. The MI values for culverts with less than 20 percent sediment deposition, met the criteria for low maintenance in 75 percent of the locations.

Table 5.5. Maintenance index (MI) components and results

Work Order Location Street	Material Type	WS Area acre	2-yr flow (cfs)	D/S Slope	Hydraulic Control	Velocity (ft/s)	% filled	Indicies Value
Arrowhead Trail	M	1.83	2	15.9%	Inlet	8.35	0.0%	0.82
Cecil Avenue	C	12.95	19	14.5%	Inlet	10.43	0.0%	0.91
Crosby Drive	M	5.17	4	10.3%	Inlet	6.9	0.0%	0.82
Longwood	M	226.59	140	2.9%	Outlet	8.13	0.0%	0.67
Maple Drive	C	2.35	4	13.5%	Inlet	8.31	0.0%	0.89
Murray Drive 2	C	5.88	5	4.0%	Inlet	10.68	0.0%	0.79
Oak Road	C	73.51	66	5.4%	Inlet	17.13	0.0%	0.94
Robinson Road	C	143.43	121	3.6%	Inlet	15.44	0.0%	0.88
Rotherwood Drive	C	326.69	275	3.4%	Inlet	11.735	4.0%	0.90
Ingersoll Avenue	C	6.98	14	7.5%	Inlet	8.17	8.9%	0.91
Silva Drive	C	25.58	35	2.8%	Inlet	9.31	10.9%	0.84
Camelia Road	C	177.03	217	2.1%	Outlet	10.22	13.2%	0.75
Woods-Smith Road	C	106.97	95	1.4%	Inlet	11.105	15.0%	0.81
W Red Bud Road 1	C	21.7	30	2.1%	Inlet	11.93	17.8%	0.80
Fruend Street	C	1.72	4	5.3%	Inlet	9.85	18.5%	0.89
Murray Drive 1	C	0.81	1	-0.9%	Outlet	0.33	19.2%	0.09
Hollywood Road/Hillview Road	C	3.78	11	3.9%	Inlet	10.54	20.2%	0.79
Cecil Johnson	M	5.79	3	13.2%	Outlet	2.44	20.7%	0.34
Pleasant Ridge Road	C	142.82	158	2.3%	Inlet	11.62	24.3%	0.88
Proctor Street	C	329.77	319	4.7%	Outlet	3.93	25.0%	0.46
Sparrow Drive	M	16.04	12	2.3%	Inlet	6.3	29.2%	0.57
Sullivan Road	M	199.61	154	2.2%	Outlet	6.43	29.2%	0.50
McKamey Road	C	787.7	473	2.6%	Inlet	9.04	29.5%	0.90
Valley Avenue	C	60.19	58	1.7%	Inlet	4.62	30.3%	0.62
Jacksboro Pike	C	2.77	3	3.9%	Inlet	6.44	30.8%	0.62
W Red Bud Road 2	C	2.48	4	4.3%	Inlet	2.26	34.1%	0.50
Lakewood Drive	C	5.93	9	3.9%	Inlet	9.26	35.7%	0.79
Westland Drive	C	266.25	195	1.1%	Inlet	9.29	40.0%	0.83
Lyle Avenue 2	C	0.81	2	4.3%	Inlet	1.63	42.4%	0.34
Lyle Avenue 3	M	0.79	2	7.4%	Inlet	2.11	49.5%	0.49
Piney Grove Church Road	M	33.88	20	5.2%	Outlet	6.41	49.9%	0.54
Plymouth Drive	C	38.91	30	2.0%	Inlet	9.94	50.0%	0.78
Thrall Drive	M	19.87	17	9.4%	Inlet	4.44	52.0%	0.50
North Hills Blvd	M	38.92	33	2.9%	Outlet	4.38	55.7%	0.28
Treemont Drive	M	10.12	27	0.2%	Outlet	4.68	68.5%	0.37
Boyd's Bridge Pike	C	47.91	35	2.1%	Outlet	5.35	74.8%	0.52
Toxaway Drive	C	5.9	7	4.1%	Outlet	5.36	75.2%	0.52
Lyle Avenue 1	C	0.81	2	3.8%	Inlet	2.55	95.6%	0.45
Jackson Road	M	3.02	4	-8.7%	Outlet	0	100.0%	0.02

The MI values for culverts with greater than 40 percent sediment deposition, met the criteria for frequent maintenance in over 83 percent of the locations.

As was seen throughout this project, there were often data that did not fit into an expected category or range, as was the case with several culvert locations in the MI. A pattern was identified that suggested some limitations for the use of the equation. Six of the seven large culverts had data points that did not seem to accurately fit into the expected category. The use of the MI for large culvert locations could provide misleading results. Table 5.6 displays the same information as Table 5.5 with the large culvert locations removed. In general, the large culverts category varied over a great range for some of the characteristics. The watershed areas range from 60 to 787 acres, the flow rates were from 58 to 473 cfs, and the culvert cross sectional areas ranged from 11.8 to 58.50 ft². These broad ranges may cause the culverts to act in a different manner with regard to sedimentation, than the smaller culverts used in the study. This could account for the high variability of the MI values for large culverts. Additionally, the MI equation does not take into consideration a time component. This could also account for some of the variation in the results found in Table 5.5 and 5.6. An interval of time, since a clean culvert condition existed, is rarely known and therefore was purposely not considered in the development of the MI.

Table 5.6. Maintenance index (MI) components and results, large culverts removed

Work Order Location Street	Material Type	WS Area acre	2-yr flow (cfs)	D/S Slope	Hydraulic Control	Velocity (ft/s)	% filled	Indices Value
Arrowhead Trail	M	1.83	2	15.9%	Inlet	8.35	0.0%	0.82
Cecil Avenue	C	12.95	19	14.5%	Inlet	10.43	0.0%	0.91
Crosby Drive	M	5.17	4	10.3%	Inlet	6.9	0.0%	0.82
Maple Drive	C	2.35	4	13.5%	Inlet	8.31	0.0%	0.89
Murray Drive 2	C	5.88	5	4.0%	Inlet	10.68	0.0%	0.79
Oak Road	C	73.51	66	5.4%	Inlet	17.13	0.0%	0.94
Robinson Road	C	143.43	121	3.6%	Inlet	15.44	0.0%	0.88
Rotherwood Drive	C	326.69	275	3.4%	Inlet	11.735	4.0%	0.90
Ingersoll Avenue	C	6.98	14	7.5%	Inlet	8.17	8.9%	0.91
Silva Drive	C	25.58	35	2.8%	Inlet	9.31	10.9%	0.84
Woods-Smith Road	C	106.97	95	1.4%	Inlet	11.105	15.0%	0.81
W Red Bud Road 1	C	21.7	30	2.1%	Inlet	11.93	17.8%	0.80
Fruend Street	C	1.72	4	5.3%	Inlet	9.85	18.5%	0.89
Murray Drive 1	C	0.81	1	-0.9%	Outlet	0.33	19.2%	0.09
Hollywood Road/Hillview Road	C	3.78	11	3.9%	Inlet	10.54	20.2%	0.79
Cecil Johnson	M	5.79	3	13.2%	Outlet	2.44	20.7%	0.34
Sparrow Drive	M	16.04	12	2.3%	Inlet	6.3	29.2%	0.57
Sullivan Road	M	199.61	154	2.2%	Outlet	6.43	29.2%	0.50
Jacksboro Pike	C	2.77	3	3.9%	Inlet	6.44	30.8%	0.62
W Red Bud Road 2	C	2.48	4	4.3%	Inlet	2.26	34.1%	0.50
Lakewood Drive	C	5.93	9	3.9%	Inlet	9.26	35.7%	0.79
Lyle Avenue 2	C	0.81	2	4.3%	Inlet	1.63	42.4%	0.34
Lyle Avenue 3	M	0.79	2	7.4%	Inlet	2.11	49.5%	0.49
Piney Grove Church Road	M	33.88	20	5.2%	Outlet	6.41	49.9%	0.54
Plymouth Drive	C	38.91	30	2.0%	Inlet	9.94	50.0%	0.78
Thrall Drive	M	19.87	17	9.4%	Inlet	4.44	52.0%	0.50
North Hills Blvd	M	38.92	33	2.9%	Outlet	4.38	55.7%	0.28
Treemont Drive	M	10.12	27	0.2%	Outlet	4.68	68.5%	0.37
Boyd's Bridge Pike	C	47.91	35	2.1%	Outlet	5.35	74.8%	0.52
Toxaway Drive	C	5.9	7	4.1%	Outlet	5.36	75.2%	0.52
Lyle Avenue 1	C	0.81	2	3.8%	Inlet	2.55	95.6%	0.45
Jackson Road	M	3.02	4	-8.7%	Outlet	0	100.0%	0.02

5.8 Proposed Use of the Maintenance Index

The intended use for the maintenance index (MI) is to aid municipalities in predicting the maintenance requirements for culverts. The locations for use of this method are primarily residential areas where the culvert size is between 12 and 36 inches. The information needed to evaluate a culvert under this method requires culvert geometry information as well as hydrologic and hydraulic analysis. Obtaining this level of information for all culverts would be quite cumbersome. However, the use of this MI could be appropriate for review of proposals for new installations (both developer and municipally installed), maintenance assessment of new installations, and for existing critical culvert locations.

Typically when a new culvert is proposed for installation, all of the culvert information needed for the MI equation is available. The use of the MI could be a requirement included as part of the plans approval process for new development. If the MI suggests the culvert will be low maintenance and all other design criteria are met, then the plan would be approved. If the MI did not predict a low maintenance culvert, then culvert or site changes could be made to improve the conditions. Improvements of this nature are typically possible in association with new development because the sites are significantly altered which allows for flexibility in design.

The municipality is typically responsible for the installation of existing culverts when the culverts have failed or require replacement. Design constraints can be more severe in existing locations because there is often little that can be done about existing grades. In cases of this nature, the MI could be used partly as a design tool but also as a planning tool. The goal is still to have a low maintenance culvert site, however, if the conditions are such that a low maintenance culvert is not practical, then appropriate maintenance scheduling can be considered.

Sediment blockages in culverts can result in flooding. Nuisance or yard flooding is typically not a serious problem. Roadway flooding can cause serious safety problems, but is also a concern when the roads are impassable. The designation of the road is also a factor. Collector and arterial roads or any road accessing a critical facility such as a police station, fire department or hospital, are considered critical location. Culverts that exist under these types of roadways are also called critical culverts. Additionally, culverts that have the potential to cause a backup of stormwater that could cause structural flooding of a house or business would also be considered a critical culvert. Determining a MI value for all culverts, as mentioned before, would require a tremendous amount of work. However, if only critical culverts were selected for review, the ability to assess these locations becomes more reasonable. This could provide a proactive approach for the culverts that are the most important.

5.9 Conclusions

While much work has been done to evaluate the relationships between culvert characteristics and sedimentation, future analysis would be beneficial to have a better understanding of culvert maintenance problems. Many additional topics were beyond the scope this project but would provide a more comprehensive evaluation of culvert maintenance. Future research should consider the following areas:

- More detailed statistical analysis of the data presented in this project could better isolate the factors influencing maintenance and better understand the degree of influence. The MI could be fine tuned for better accuracy.
- Sedimentation problems occur incrementally over time and are caused by a number of different factors. Debris problems at culverts can occur more sporadically, and can influence sedimentation. Further research is needed to better understand the relationship between sediment deposition and debris. Additionally research should also assess the magnitude of storm required for debris blockage problems to occur for a variety of watershed characteristics.
- Additional research that could assess the sediment yield of watersheds and correlate these values to culvert characteristics would be beneficial. This would determine the direct sources of erosion related to land use or cover conditions, which would provide an enhanced understanding of the sedimentation problems in culverts and could relate to improved maintenance programs.
- Sediment deposition is highly influenced by stormwater flows. The magnitude of each storm provides different flow rates and conditions. Further research to analyze how the patterns of rainfall affect the patterns of sediment deposition, from rainfall to rainfall, and from season to season would provide needed information about the cycles of sedimentation.

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Works Cited

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Vita

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